Water-filled ditches: Surface expressions of dead crevasses that are not connected to the bed

Kristin Poinar[1]

[1]University at Buffalo

November 23, 2022

Abstract

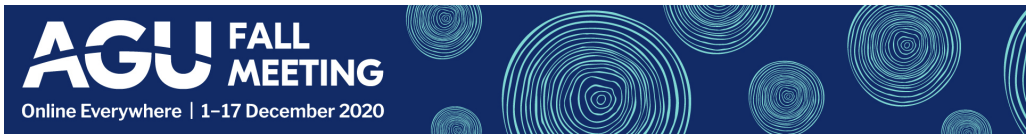
The increasing ubiquity of high-resolution imagery has yielded many observations of water-filled crevasses across the surfaces of glaciers and ice sheets (e.g., Figure 1a). The subsurface character of these features, however, is not apparent in imagery, nor can it be fully elucidated even through field geophysics. Thus, what visible surface water in crevasses indicates about englacial hydrology, including whether there is a surface-to-bed connection, is currently subjective and interpreted differently by different scientists. Application of a physically based crevasse model to this problem shows that if a crevasse visibly holds water, it likely does not connect to the bed. The crevasse model incorporates depth-dependent visco-elastic deformation and refreezing to evolve the size and shape of a water-filled crevasse over hourly to decadal timescales (Figure 1b). Seasonally, visco-elastic closure tends to form a neck at the water line of most crevasses. Over a year or more, this neck can pinch off, isolating a pod of water that can extend hundreds of meters beneath the surface. The area above the neck persists as a 1–5 meter wide, 10–40 meter deep "ditch": the surface expression of a dead crevasse that no longer receives surface melt. Accumulation of meltwater in these ditches is consistent with observations; the model results show that the ditches are not hydrologically connected to the crevasse or to the bed. These findings are consistent with recent observational work by Chudley et al. (2020), who concluded that visible water in crevasses sited in compressive stress settings was not connected to the bed. Observations of sudden drainage of these ditches show that reconnection to the englacial system, and potentially the bed, must be possible. The smooth bathymetry of the ditches, however, discourages formation of the starter crack needed to reactivate these hydrofractures. Thus, an external forcing, such as advection into a more-extensional stress setting, may be required to drain them. Overall, model results suggest that these water-filled ditches are shallow (<40 meters), overlie an englacial pod of liquid water that is in the process of refreezing, and are not connected to the bed.

Water-filled ditches: Surface expressions of dead crevasses that are not connected to the bed

Kristin Poinar, Univ. Buffalo

Visit my Zoom room (see link in lower right) anytime during the poster session (I will be there sometimes), or contact me with the AGU chat feature.

PRESENTED AT:

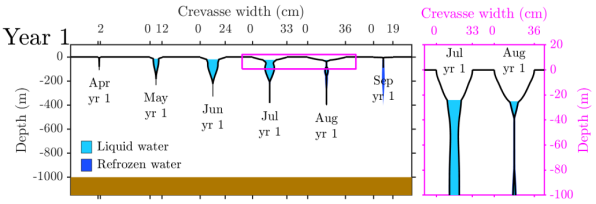


MOTIVATION

Observations of water-filled crevasses across the surfaces of glaciers are shown in the slide show below. Some of these crevasses are ditch-shaped, with wide openings and rounded bottoms. The visible water is sometimes interpreted as evidence that the crevasses connect to the subglacial hydrologic system, but this is not easily verified in the field.

This research uses a model for time-evolving crevasse shape, size, and depth to discover that these crevasse ditches are shallow (<40 meters), usually sit on top of a pod of liquid water inside the glacier (100+ meters deep), and probably do not connect all the way through to the bottom of the glacier.

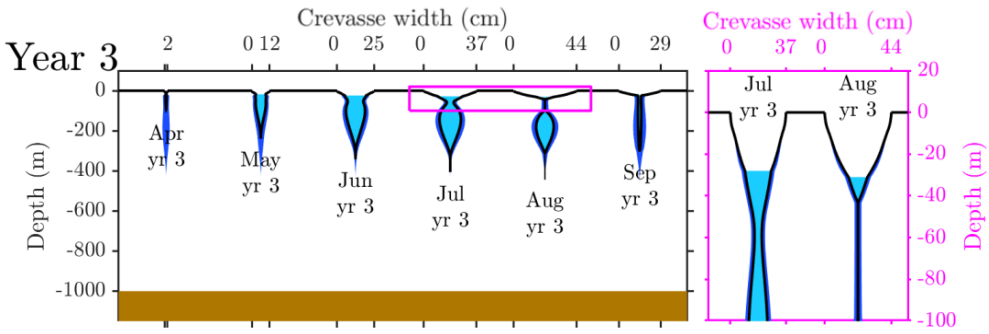
YEAR 1 OF CREVASSE LIFE



In Year 1, the crevasse penetrates a few hundred meters deep into the ice.

Towards the end of the melt season in July and August, the rate of refreezing inside the crevasse exceeds the rate of melt input, which causes the crevasse to narrow and become shallower. By September, **all water in the crevasse has refrozen**, closing the crevasse entirely at depth and leaving a **small, dry surface depression**.

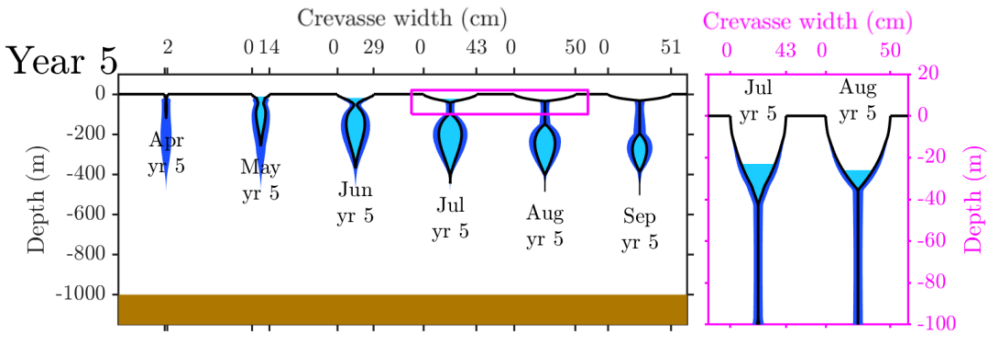
YEAR 3 OF CREVASSE LIFE



In Year 2 (not shown) and Year 3 (above), meltwater refills the crevasse and fractures it to ~500 meters depth, which is roughly half the local ice thickness. By mid-summer, visco-elastic closure at the water line causes **necking**, and the crevasse pinches off from the surface in August. This isolates a liquid water pod deep inside the glacier and leaves a small ditch, which can still collect meltwater, at the surface.

Whether new surface melt can reach the englacial water pod is unknown. I modeled both cases: a connected pod that receives surface melt, and a disconnected pod that does not. I'm presenting the former.

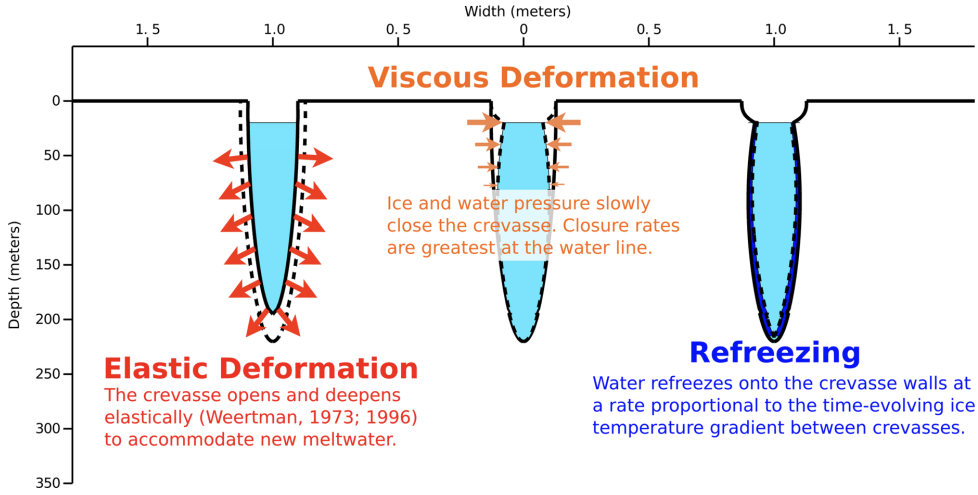
YEAR 5 OF CREVASSE LIFE



In Year 4 (not shown) and Year 5 (above), the vertical extent of the necking increases. By August of Year 5, the englacial water pod is separated from the surface ditch by ~200 meters of deformed and refrozen ice.

New meltwater continues to accumulate in the surface ditch, which has relief of ~40 meters and contains ~10-20 meters of water. These water-filled ditches are commonly observed from above (see air photos below).

MODEL FOR CREVASSE SHAPE AND DEPTH

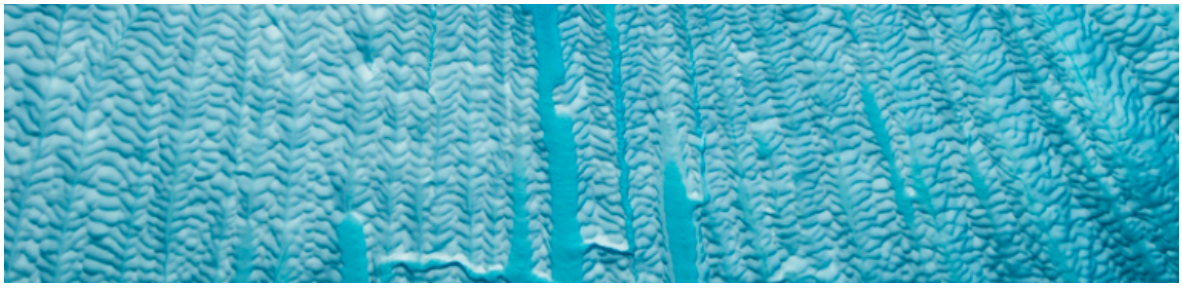


The crevasse shown in the plots above is one of many in a modeled crevasse field. Although I show the time evolution of a single crevasse, it is modeled in the stress setting appropriate for a crevasse field with a large number of crevasses that blunt the far-field stresses (Sassolas et al., 1996).

The model includes elastic deformation (following Weertman, 1973 and 1996), viscous deformation (Glen's Flow Law), and refreezing. The model is described completely in Poinar et al. (2017).

In the modeled crevasse field, the crevasses are spaced by 33 meters, ice thickness is 1000 meters, background stress is extensional at 120 kPa, ablation is 2 m/yr, and all meltwater flows directly into the nearest crevasse.

The model run shown here is in a lower stress setting (120 kPa) than many outlet glaciers (sometimes ~300 kPa or greater). The air photos shown to the right are probably more representative of the outlet-glacier settings. Thus, **I expect the modeled crevasses to be narrower** and perhaps deeper **than the crevasses shown in the photos**.



CONCLUSIONS

Model results show that water-filled ditches...

- are shallow (<40 meters)
- form within a year or two of crevasse birth
- **are not connected to the bed**
- overlie an englacial water pod that refreezes over many years

Observations by Chudley et al. (2020) found that "wet crevasses" are not connected to the bed. My model resuts agree with this finding.

Reach me on Zoom

Try me anytime during this poster session, December 16, in my Zoom room (https://buffalo.zoom.us/j/95201250157?pwd=bTh6UE9sYVdEMUh3UTN5ZkZkVzRlUT09).

REFERENCES

Chudley, T. R., P. Christoffersen, S. H. Doyle, T. Dowling, R. Law, C. Schoonman, M. Bougamont, and B. Hubbard (2020), Structural controls on the hydrology of crevasses on the Greenland ice sheet, doi:10.1002/essoar.10502979.1 (http://doi.org/10.1002/essoar.10502979.1).

Poinar, K., I. Joughin, D. Lilien, L. Brucker, L. Kehrl, and S. Nowicki (2017), Drainage of Southeast Greenland Firn Aquifer Water through Crevasses to the Bed, Front. Earth Sci., 5, 8–15, doi:10.3389/feart.2017.00005 (http://doi.org/10.3389/feart.2017.00005).

Sassolas, C., T. Pfeffer, and B. Amadei (1996), Stress interaction between multiple crevasses in glacier ice, Cold Regions Science and Technology, 24(2), 107–116.

Weertman, J. (1973), Can a water-filled crevasse reach the bottom surface of a glacier? IASH Publ, 95, 139–145.

Weertman, J. (1996), Dislocation based fracture mechanics, World Scientific, London.