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Modeling Outburst Flooding as a Turbulent Hydraulic Fracture Parallel to a Nearby Free Surface

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Meltwater generated at the surface and base of glaciers and ice sheets is known to have a large impact on how ice masses behave dynamically, but much is still unknown about the physical processes responsible for how this meltwater drains out of the glacier. For example, little attention has been paid to short-timescale processes like turbulent hydraulic fracture, which is likely an important mechanism by which drainage channels initially form when water pressures are high. In recent work (Tsai and Rice [Fall AGU, 2008; JGR subm., 2009]), we have constructed a model of this turbulent hydraulic fracture process in which over-pressurized water is assumed to flow turbulently through a crack, leading to crack growth. However, one important limitation of this prior work is that it only strictly applies in the limit of short crack length, 2L, compared to glacier height, H, whereas relevant observations of supraglacial lake drainage, jokulhlaups and sub-glacial lake-to-lake transport episodes do not fall in this regime. Here, we improve somewhat upon this model by explicitly accounting for a nearby free surface. We accomplish this by applying the approach of Erdogan et al. [Meth. Anal. Sol. Crack Prob., 1973] to numerically calculate elastic displacements consistent with crack pressure distribution for a crack near a free surface, and use these results as before to simultaneously satisfy the governing fluid, elastic and fracture equations. Our results are analogous to the zero fracture toughness results of Zhang et al. [Int. J. Numer. Anal. Meth. Geomech., 2005], but applied to the case of turbulent flow rather than laminar flow of a Newtonian viscous fluid. Our new results clarify the importance of the free surface and potentially explain discrepancies between our previous modeling results and observations of supraglacial lake drainage by Das et al. [Science, 2008]. However, the numerical challenges increase as 2L becomes comparable to or much larger than H. We hope to ultimately develop simpler analyses for that range which make use of (visco)elastic plate theory at positions along the uplifted ice sheet that are remote from the fracturing front. This approach may also be of interest for tidal interactions with the ice-shelf grounding line location.