A New Model for Subglacial Flooding During the Rapid Drainage of Supraglacial Lakes

Surendra Adhikari[1,2]

Victor C. Tsai[1]

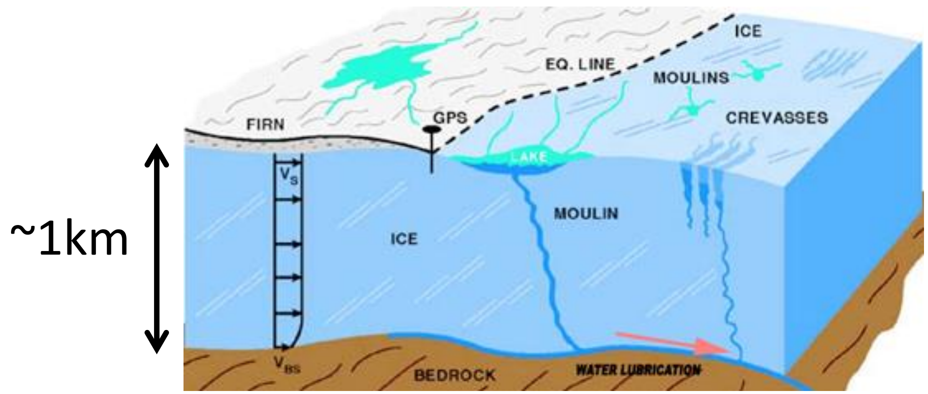
[1]Seismological Laboratory | [2]Jet Propulsion Laboratory

California Institute of Technology

This model is applied to the present-day GrIS. It will also be applicable to the WAIS, when climate warming eventually leads to the formation of supraglacial lakes in the future!

The Zwally effect

- Short-term acceleration of land-terminating portions of the GrIS is linked to surface melting.



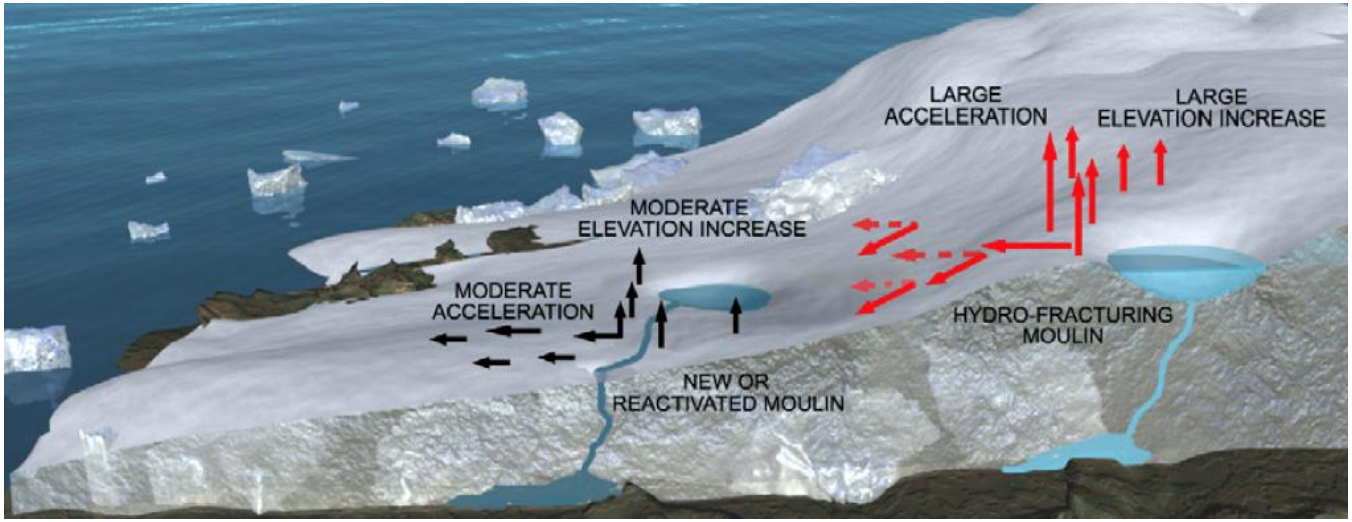
Zwally et al., *Science*, 2002

- It is not simply the “mean melt supply”, but the “melt supply variability” that is responsible!

Supraglacial lakes and rapid drainage events

- The formation and the nature of drainage of supraglacial lakes strongly control the melt supply variability.

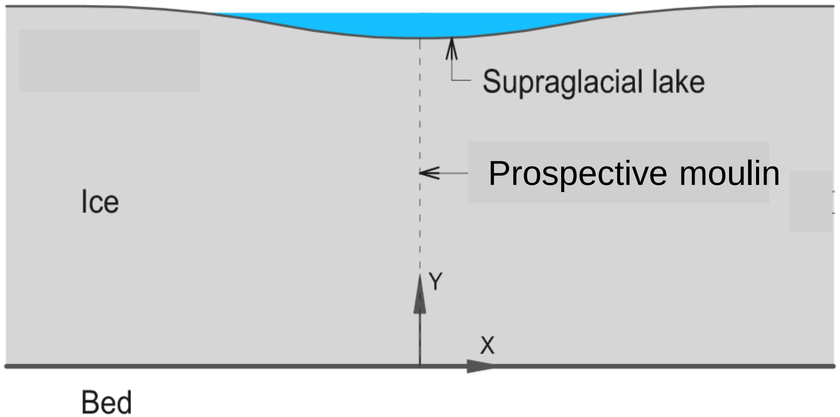
- Presently, about 15% of supraglacial lakes on the GrIS drain rapidly within the timescale of a few hours.

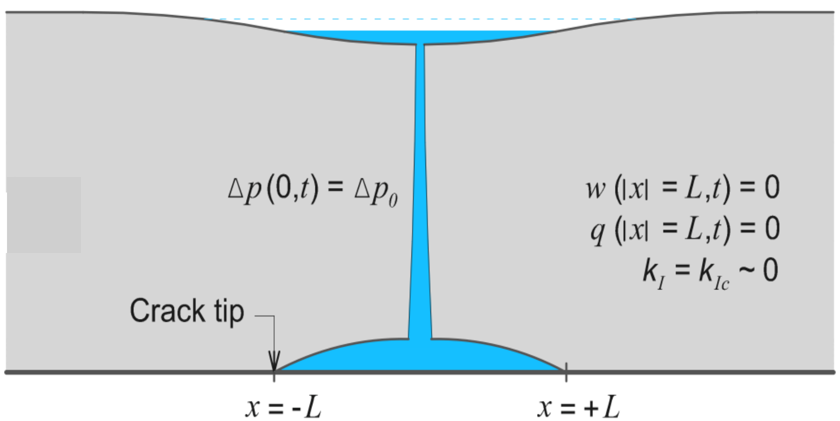


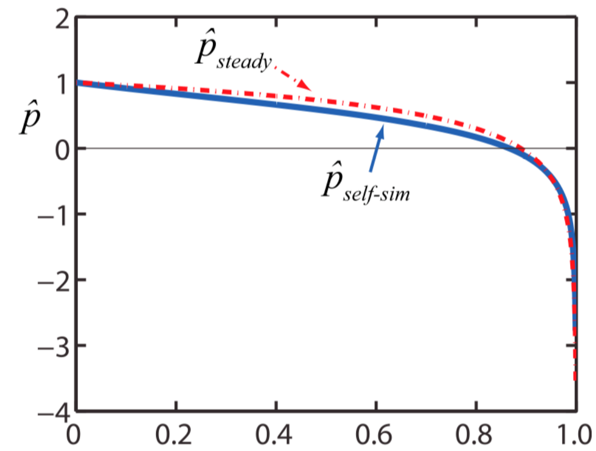
Tedesco et al., ERL, 2013

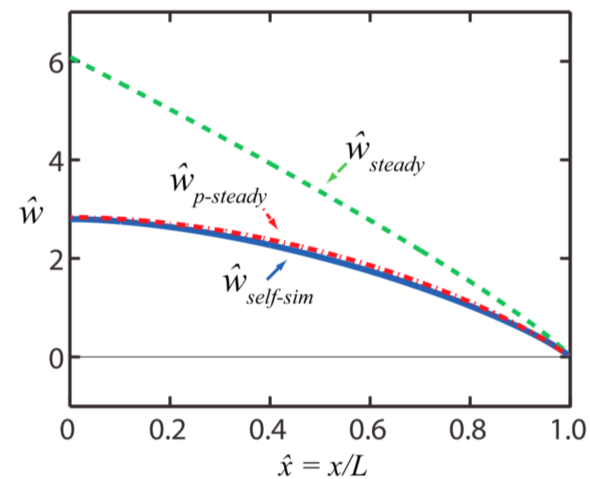
Rapid drainage

Hydrofracture model (based on an LEFM approach)



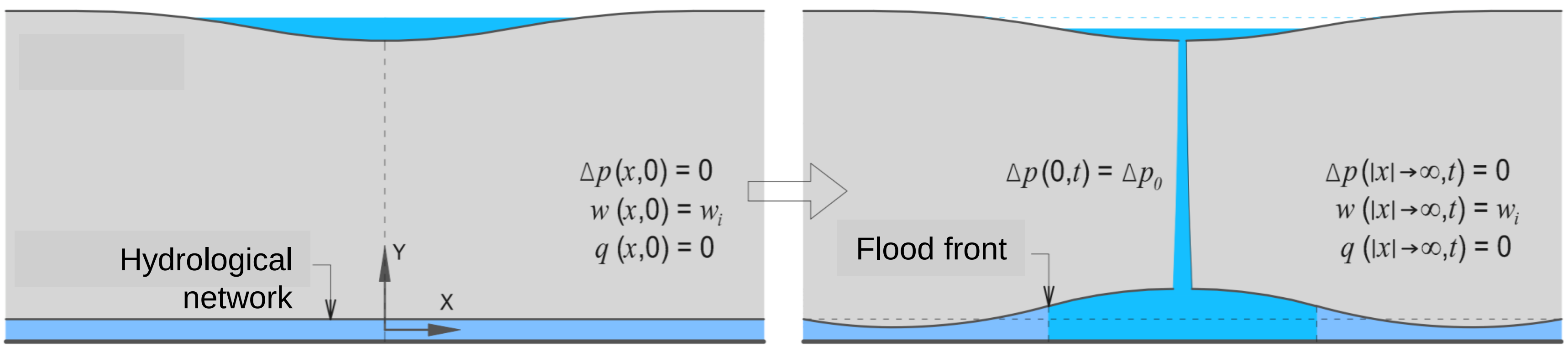






Tsai and Rice, JGR, 2010

Subglacial flooding through a hydrological network



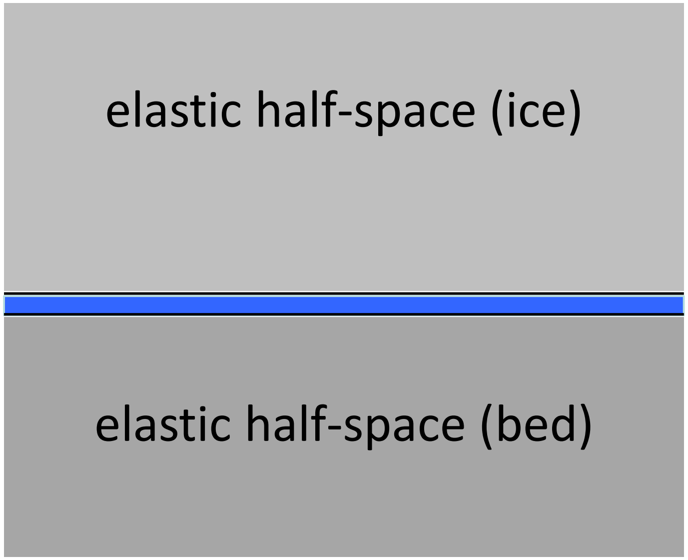
Adhikari and Tsai, JGR, in review

- The hypothesized initial opening can be interpreted as an average height of distributed system of linked cavities.

Governing equations

$$\frac{\partial \Delta w(x,t)}{\partial x} = \frac{2}{\pi E'} \left\{ \text{v.p.} \int_{-\infty}^{\infty} \frac{\Delta p(s,t)}{s-x}\, ds \right\}$$

Plane-elasticity

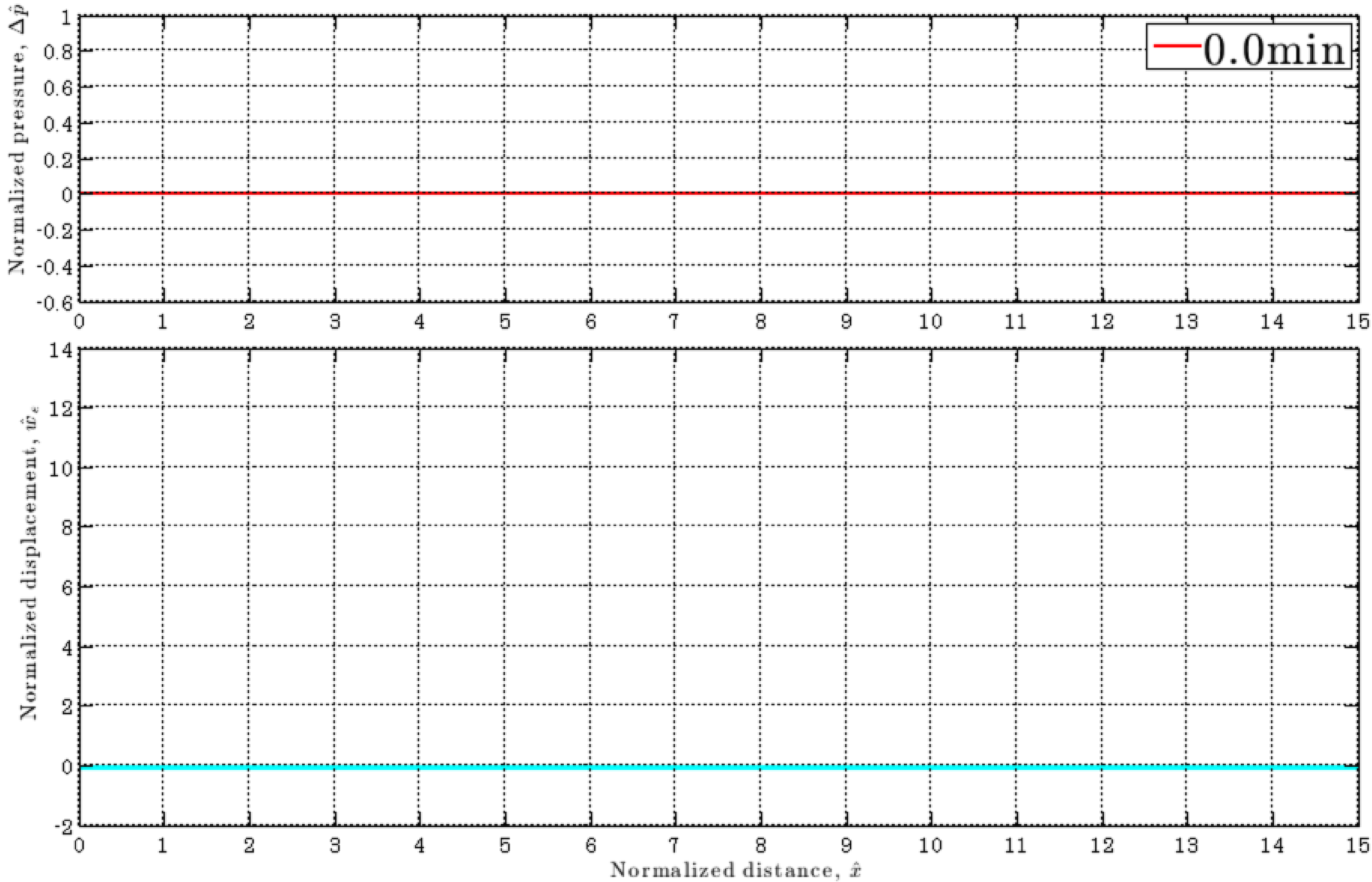


$$E' = E/(1-\nu^2) \qquad \xi = 1 + \frac{E'}{E'_{bed}} \approx 1.104$$

$$\xi \frac{\partial}{\partial t} \int_x^{\infty} \Delta w(x,t)\, \mathrm{d}x = \pm 2 \left[w_i + \xi \Delta w(x,t) \right]^{5/3} \left[\frac{1}{f_0 \rho k^{1/3}} \right]^{1/2} \left[\mp \frac{\partial \Delta p(x,t)}{\partial x} \right]^{1/2}$$

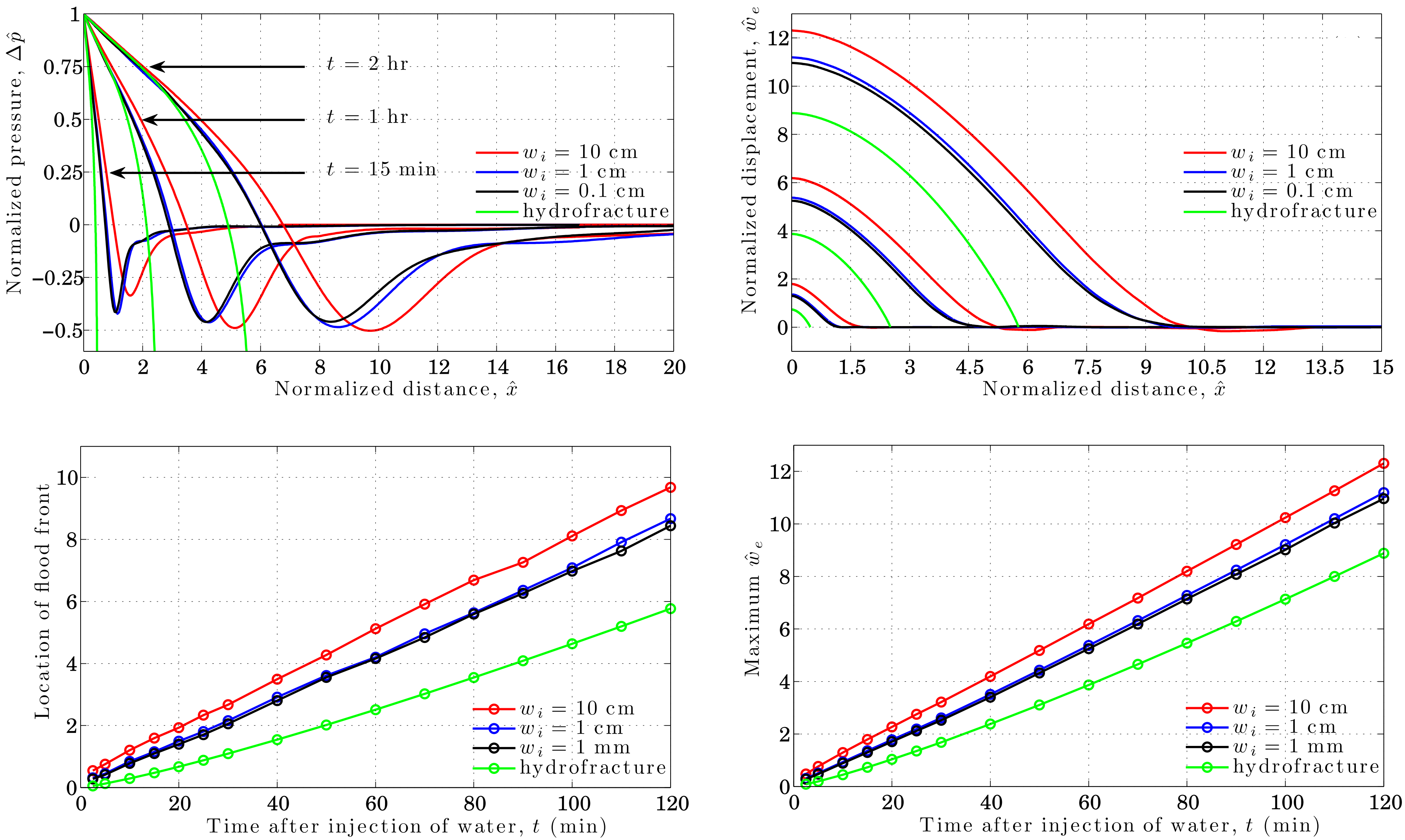
Local continuity

Manning-Strickler turbulent flow

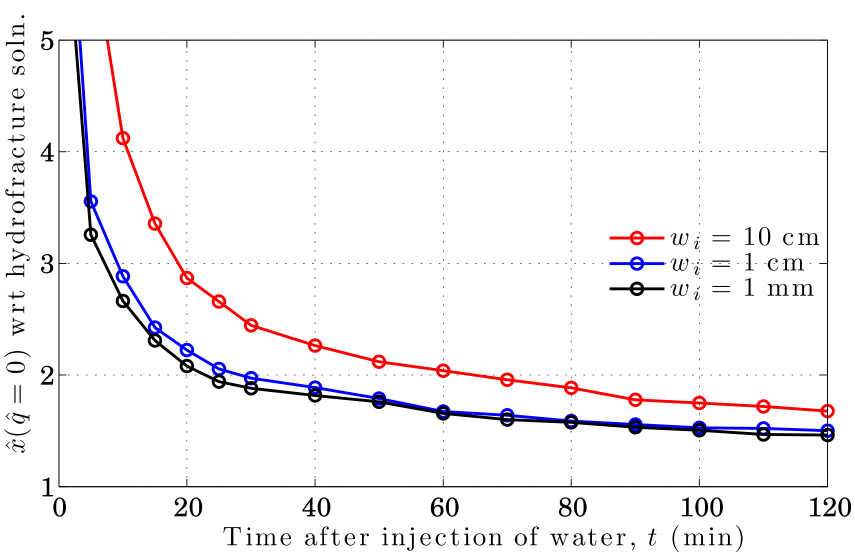


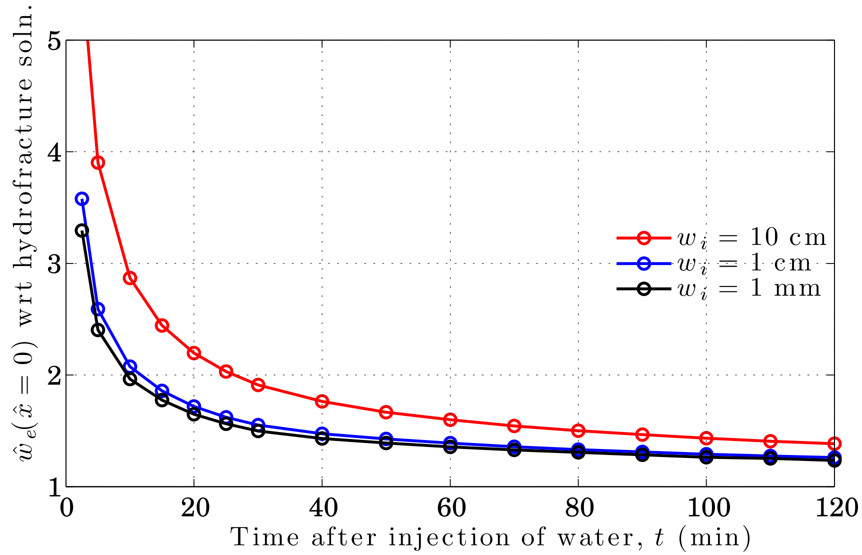
Normalized pressure, $\Delta\hat{p}$
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
0.0min
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Normalized displacement, $\hat{w}_e$
14
12
10
8
6
4
2
0
-2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Normalized distance, $\hat{x}$

Effects of initial opening

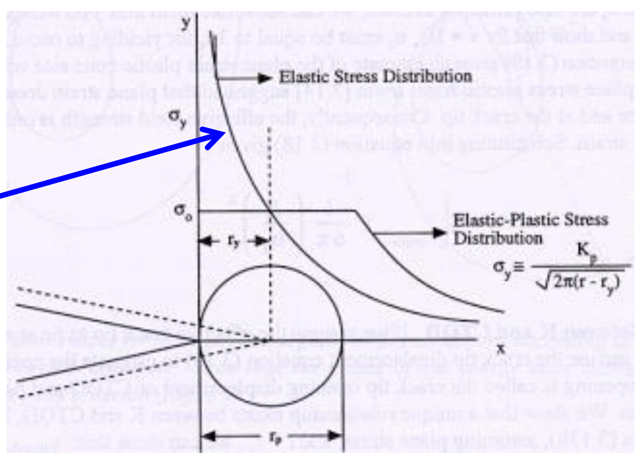


Our model versus hydrofracture model





Infinite (unrealistic) stress concentration in front of the crack tip!



Results: Summary

- There exists a region of positive pressure gradient beyond flood front. (Note: Pressure singularities exist at the crack tips in the hydrofracture model.)
- Greater perturbations in the subglacial system are found for larger initial openings. Floods propagate much faster and displacements are much greater!
- The hydrofracture model should not be mistaken as a special case of our model (with zero initial opening).

Implications

- Our model is compatible with contemporary continuum subglacial hydrological models. No solution singularities!

- We may infer subglacial hydrological conditions from surface observables. To constrain hydrological models, sliding laws!

- Apart from its application to contemporary ice sheets, our model is also relevant to paleo ice sheets. To simulate the rapid collapse of the Laurentide Ice Sheet!