Coupling a subglacial hydrologic model for distributed water flow to the Community Ice Sheet Model

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With much help from:
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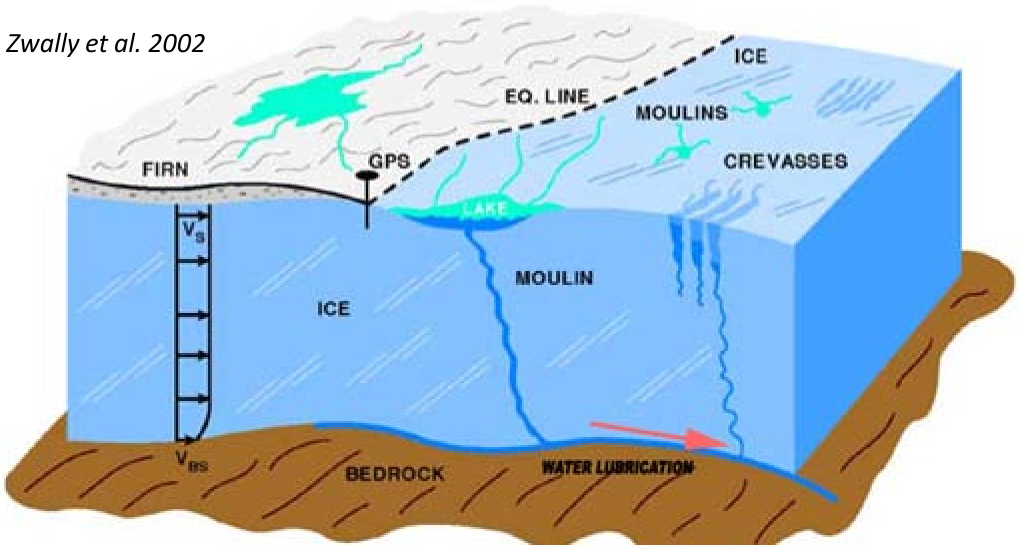
Greenland Ice Sheet contribution to sea level rise depends on “dynamical processes related to ice flow”

- Outlet glacier acceleration after disappearance of buttressing ice tongues
- Lubrication of the bed by surface meltwater draining through kilometer-thick ice
- Increased ice discharge after steepening of ice surface

In summer, surface melt water drains to the bottom of the Greenland Ice Sheet and lubricates the bed, increasing sliding.

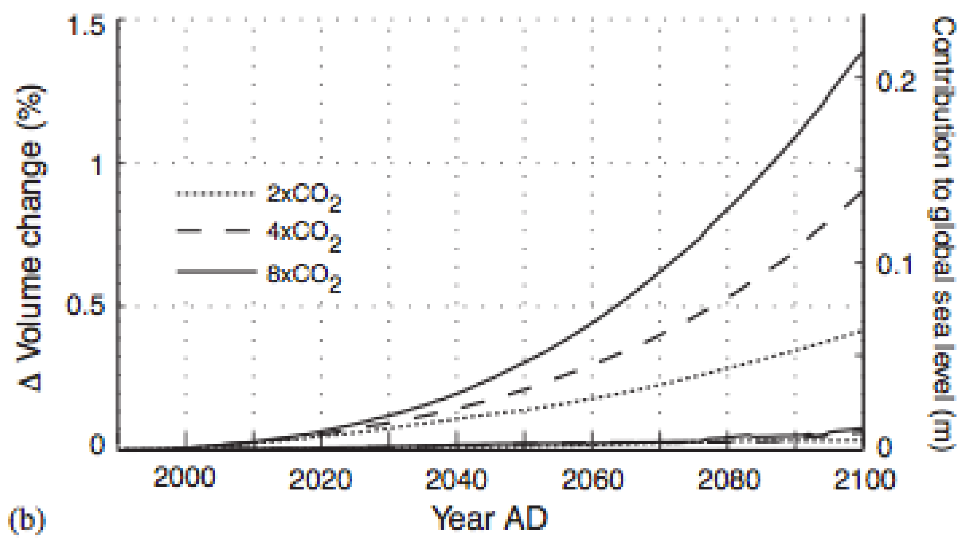
Zwally et al. 2002



Summer velocity is faster than winter by 15-100%

(Depends on location, year, and how you define summer.)

Parizek & Alley 2004

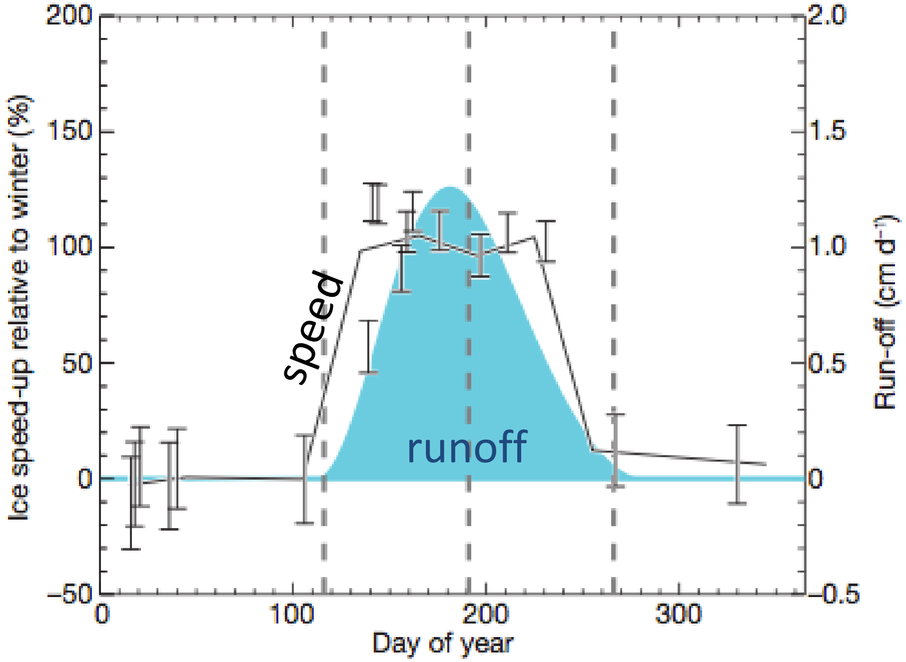


If **sliding** is **proportional** to **melting**, meltwater induced acceleration may contribute an extra ~10 cm to SLR.

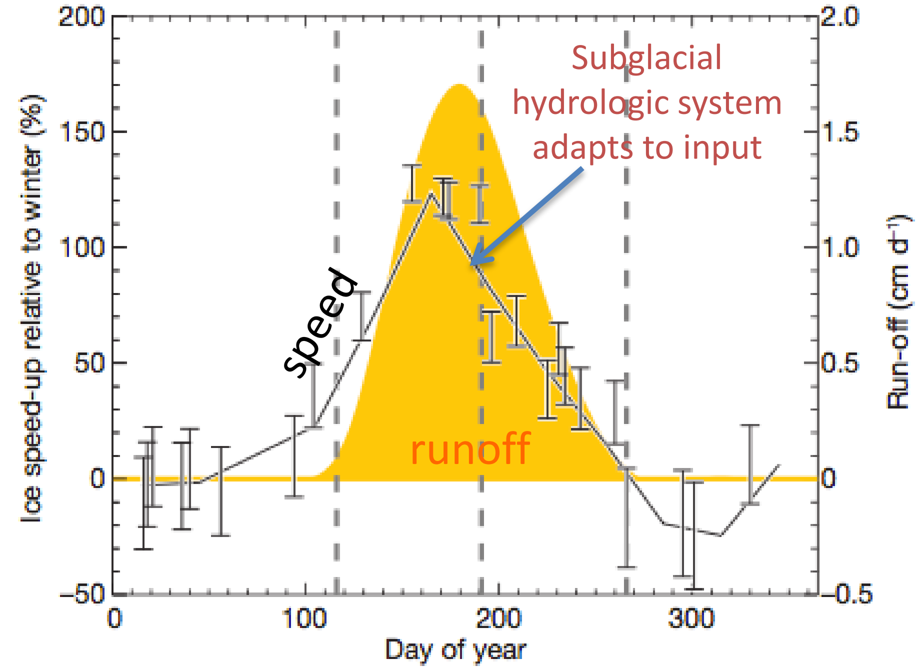
The Reality is More Complicated

e.g., van de Wal et al. 2008; Bartholomew et al. 2010; Schoof 2010; Sundal et al. 2011; Hoffman et al. 2011 (plus countless papers on alpine glacier hydrology…)

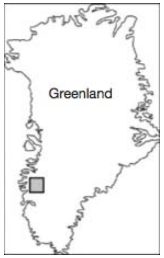
Low Melt Years



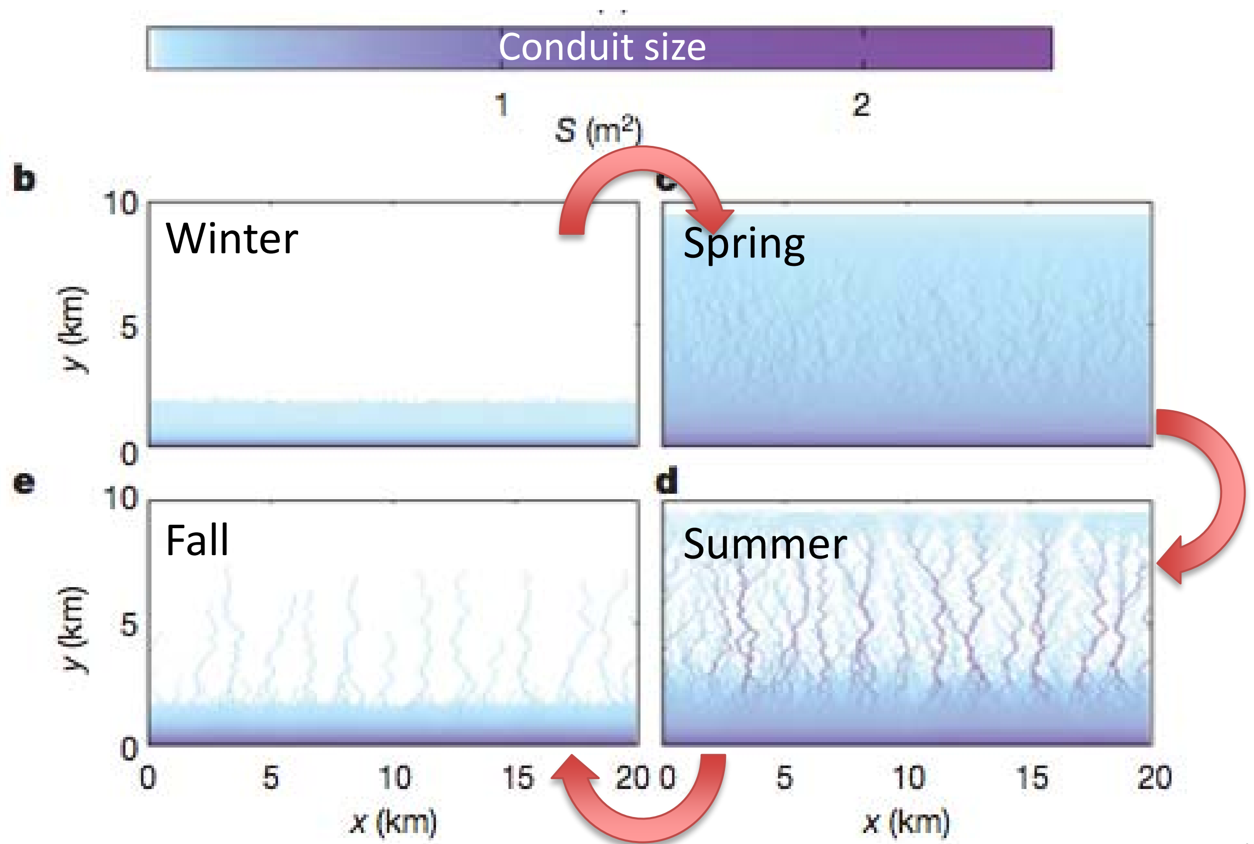
High Melt Years



Sundal, et al. 2011



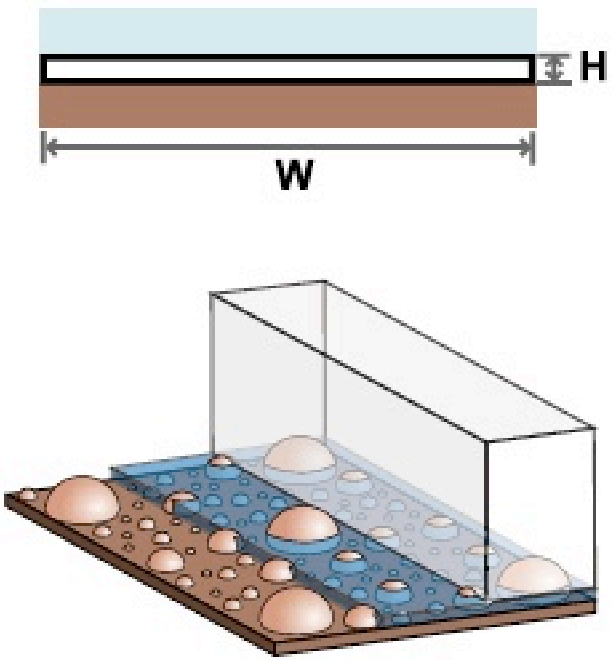
Seasonal Cycle involves a switch from Distributed to Channelized drainage



Schoof 2010

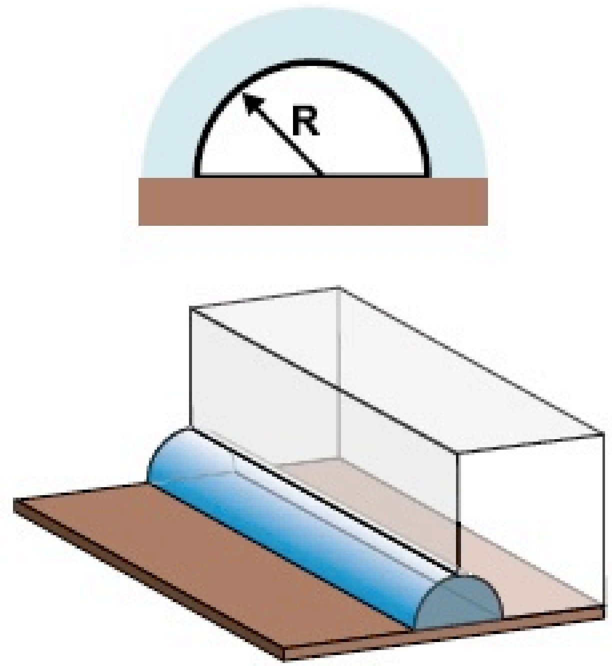
Subglacial Hydrologic Systems

Distributed System



macroporous water sheet
low capacity
low efficiency
typical of winter

Channelized System



ice-walled conduit
high capacity
high efficiency
typical of summer

Creyts & Clarke 2010!

Distributed Flow Model

- Based on Hewitt 2011 (similar to Creyts & Schoof 2009, Schoof 2010, Werder this session)
- Generalized porous medium flow (may represent e.g. linked cavities, till canals, patchy films)

1) Mass conservation of water

(e.g. surface meltwater)

$$dh/dt + \nabla \bullet \text{flux} = \text{local melt} + \text{source}$$

2) Sheet thickness evolution

(melting, sliding over bumps) (creep closure)

$$dh/dt = \text{sheet opening} - \text{sheet closing}$$

3) Darcy style flow law

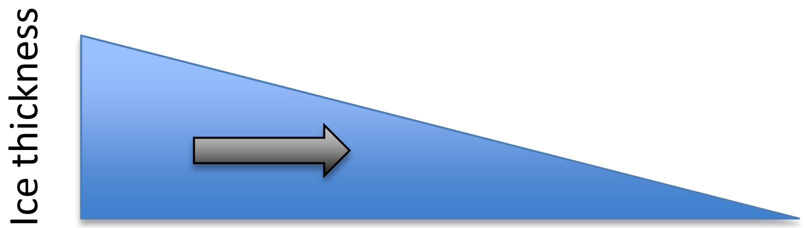
$$\text{flux} = T(h)\,\nabla\phi$$

Output: sheet thickness, effective pressure

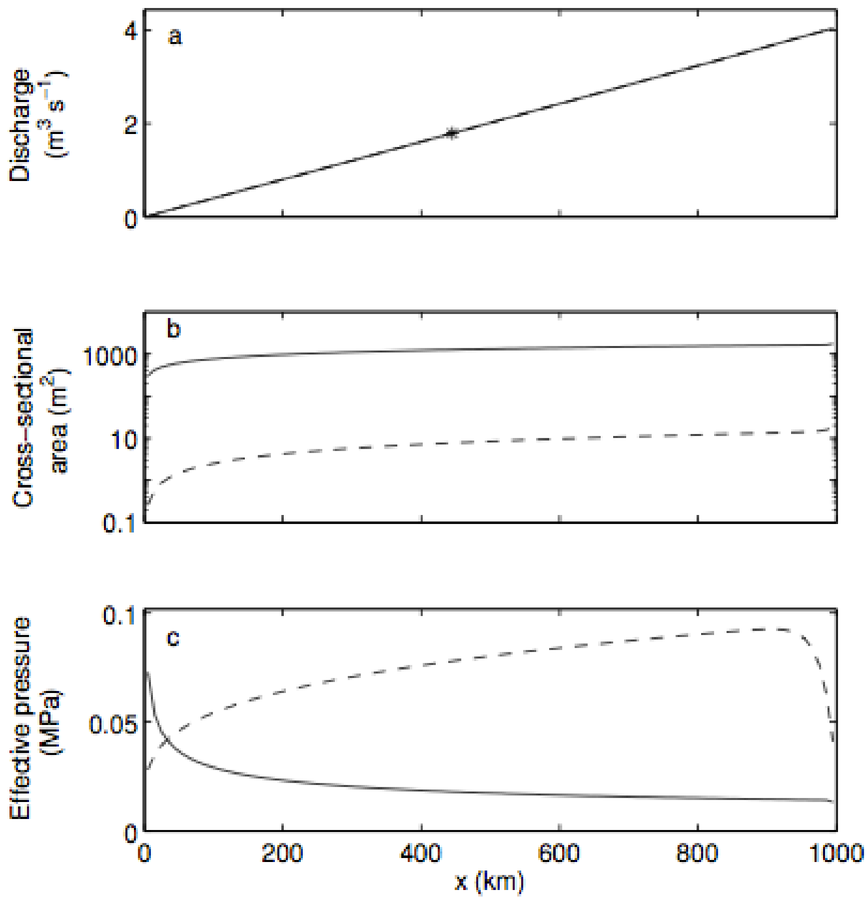
(ice overburden – water pressure)

Implemented in a branch of CISM as a basal water option.

Simple Ramp Test Case, Steady-state



Hewitt 2011, Figure 2



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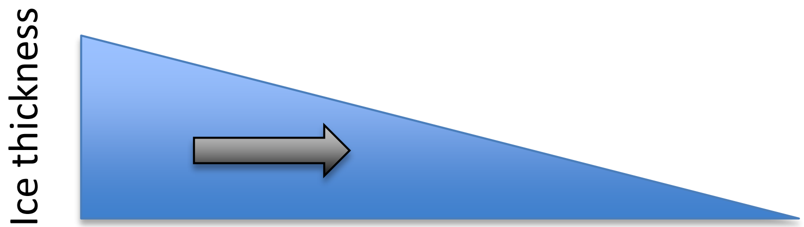
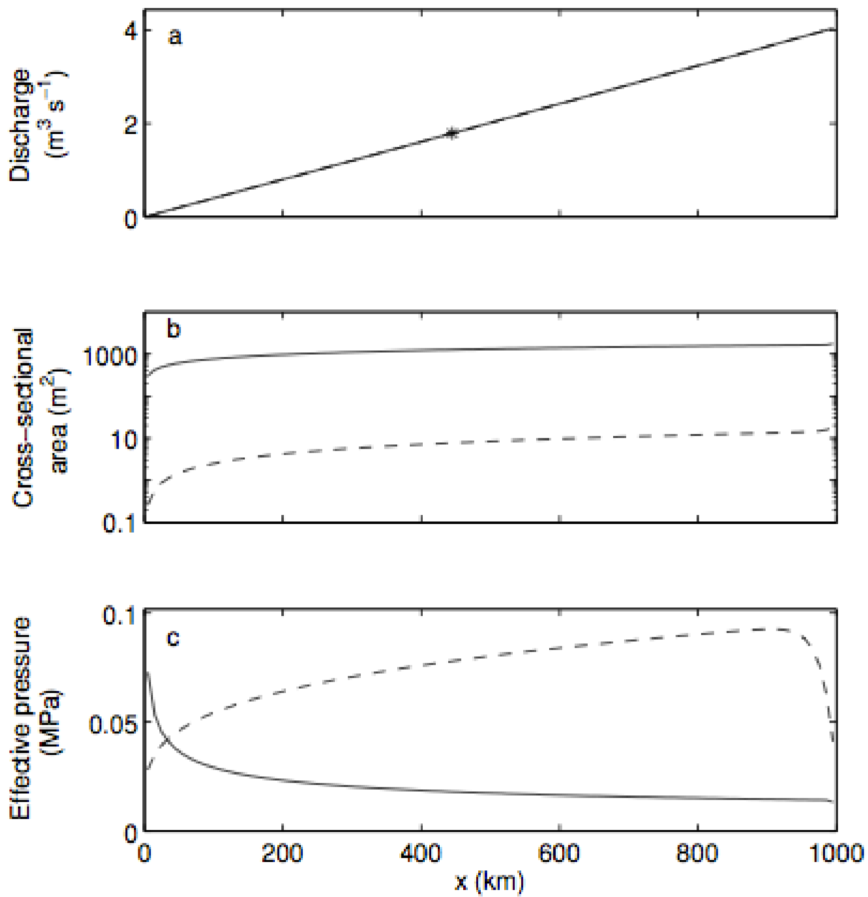
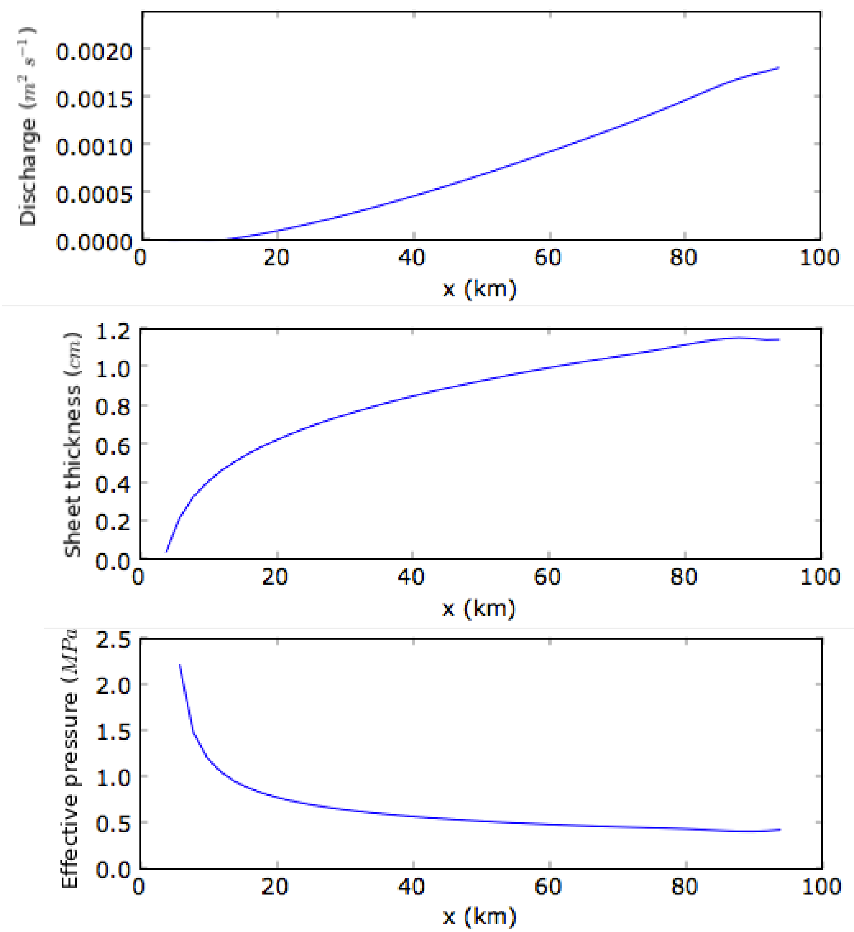


Hewitt 2011, Figure 2



CISM Sheet Model output



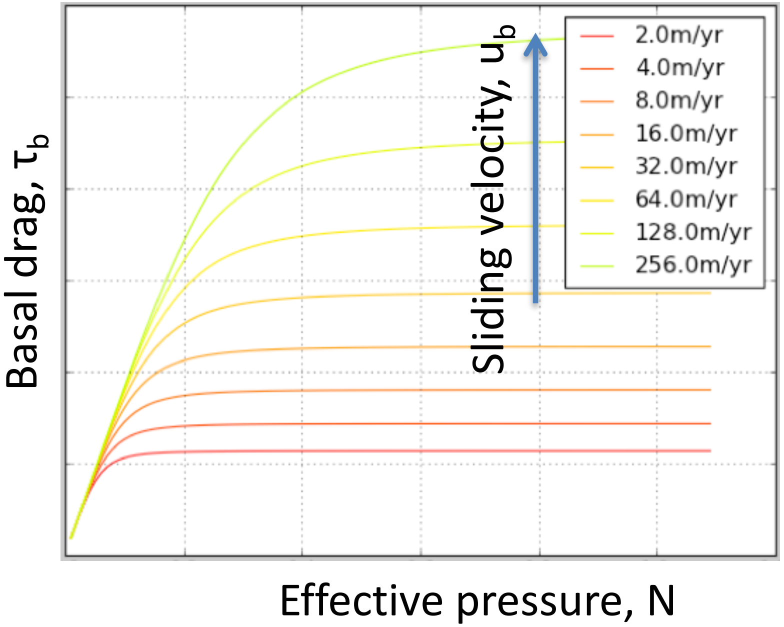
Coulomb friction sliding rule

- Schoof 2005, bounded basal drag, cavitation
- Couples hydrology (N) to dynamics (τ_b)

$$\tau_b = C\left(\frac{u_b}{u_b + N^n \Lambda}\right)^{1/n} N$$

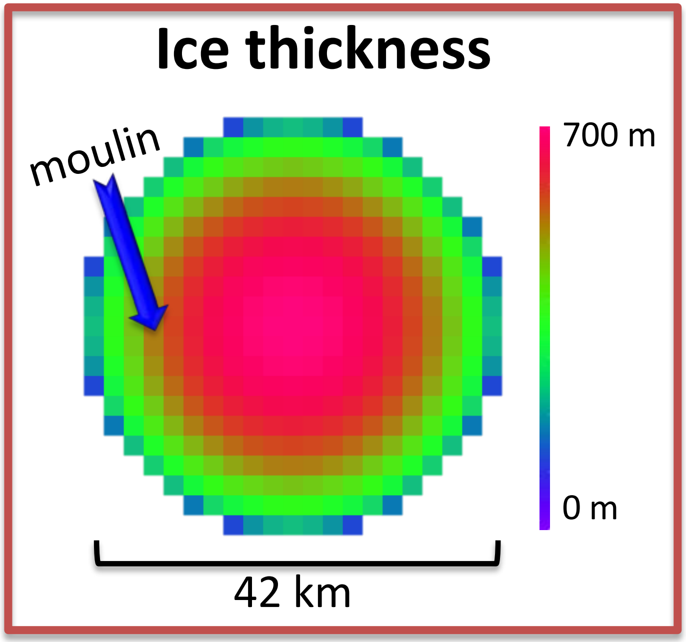
Bedrock geometry

- $\tau_b \propto u_b^{1/n}$ at high N
- $\tau_b \propto N$ at low N

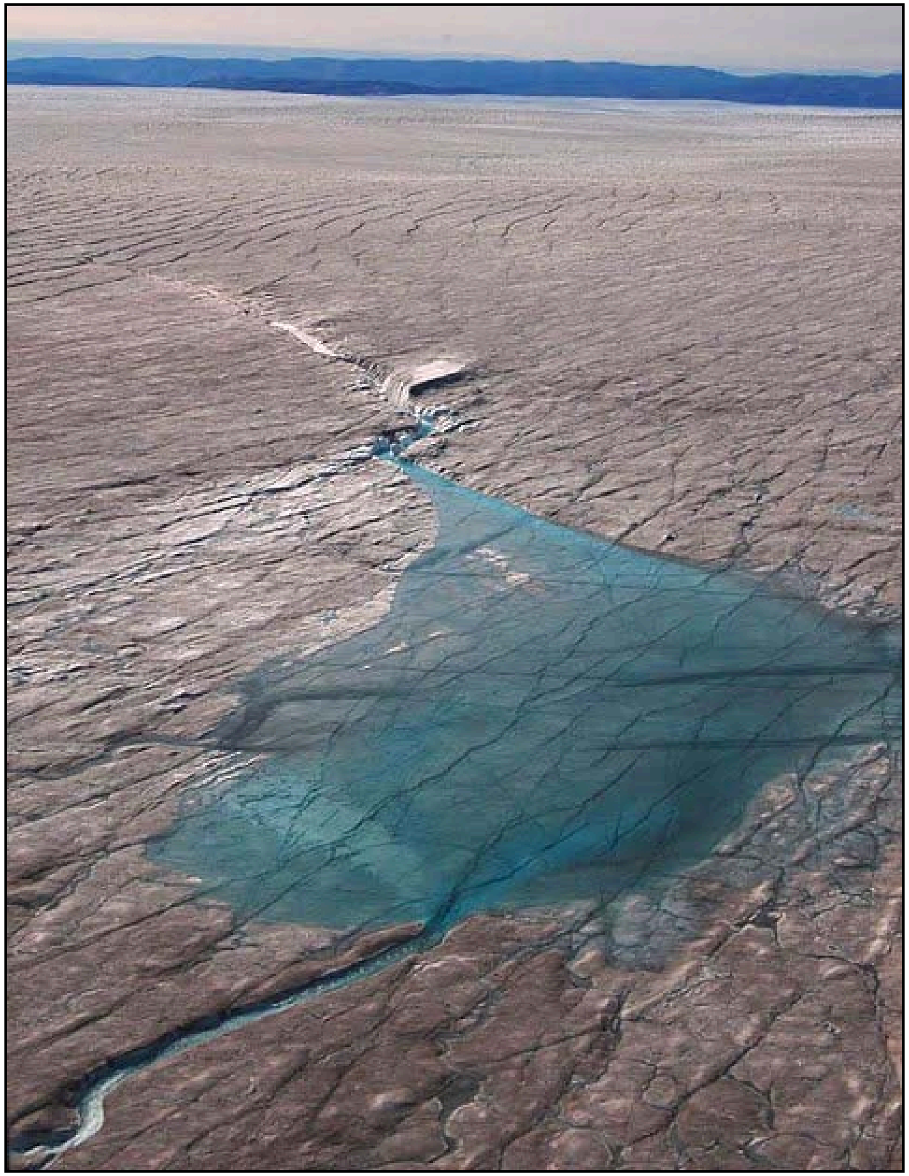


Implemented in a branch of CISM as a HO basal boundary condition option.

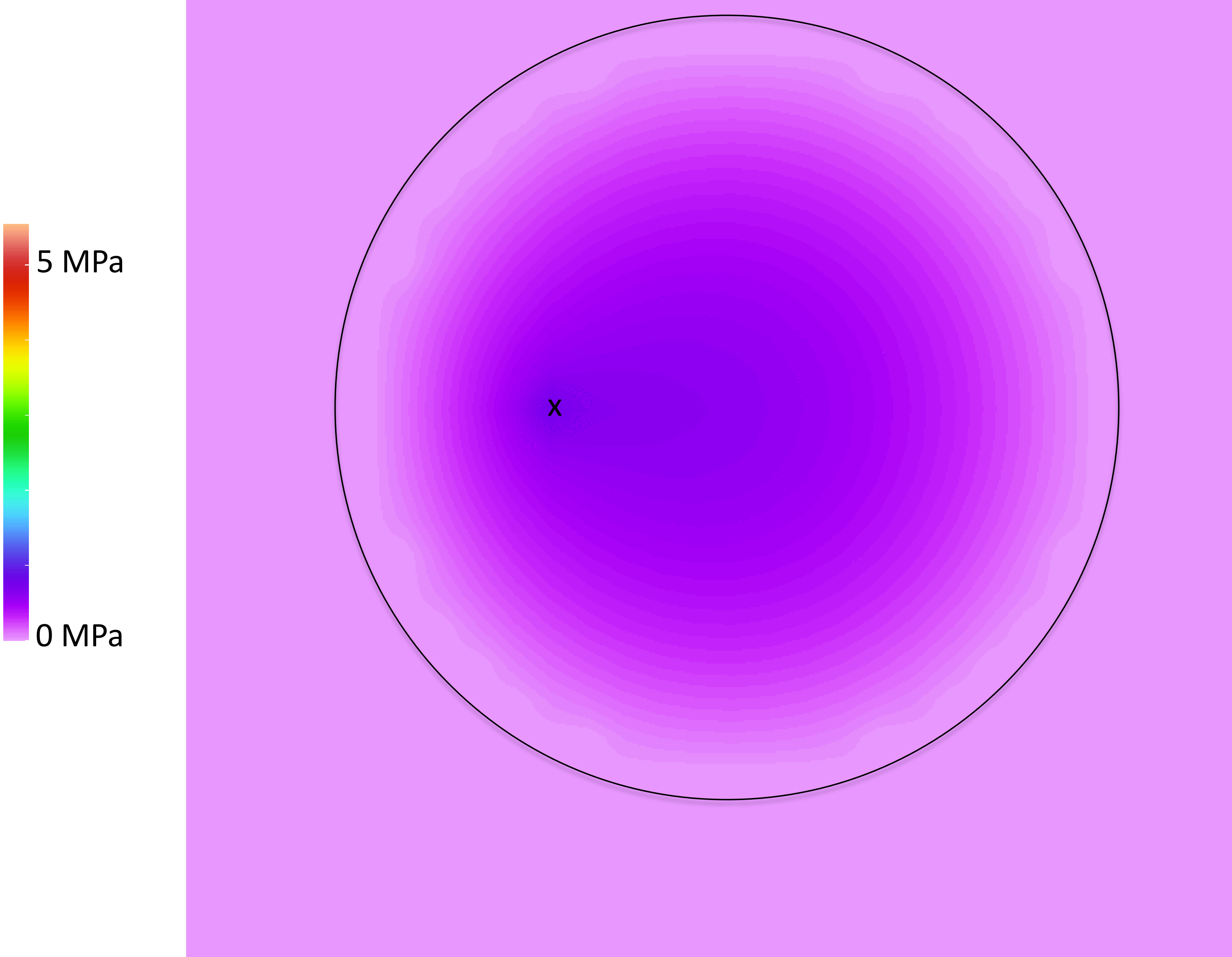
Dome test case with a “moulin”



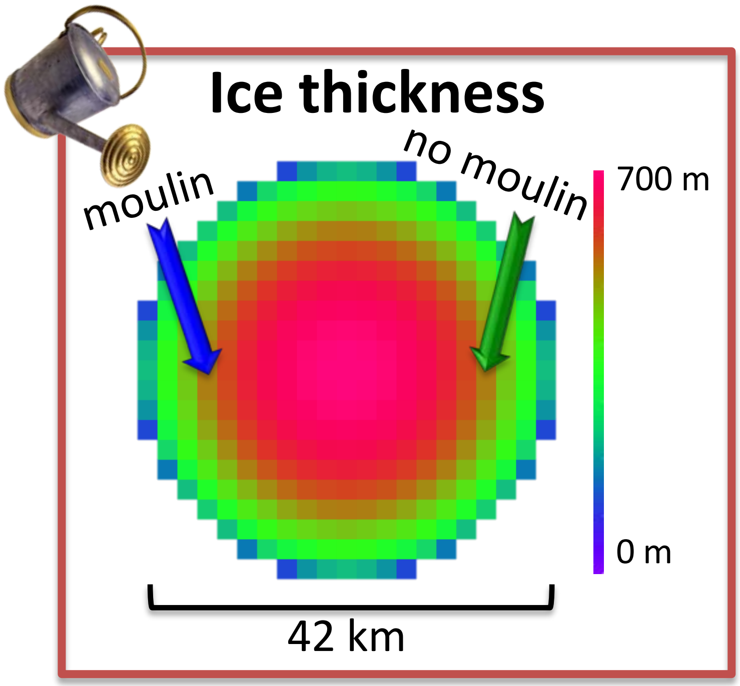
Constant water input of 0.4 m^3/s.



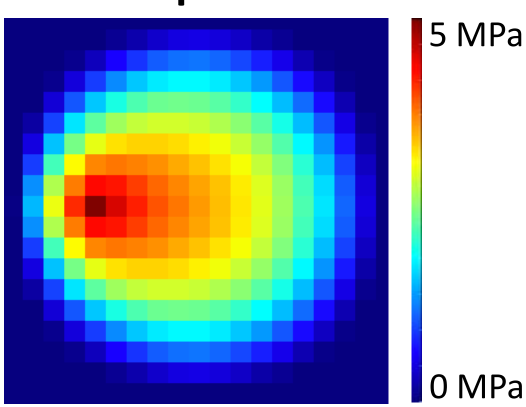
Water pressure



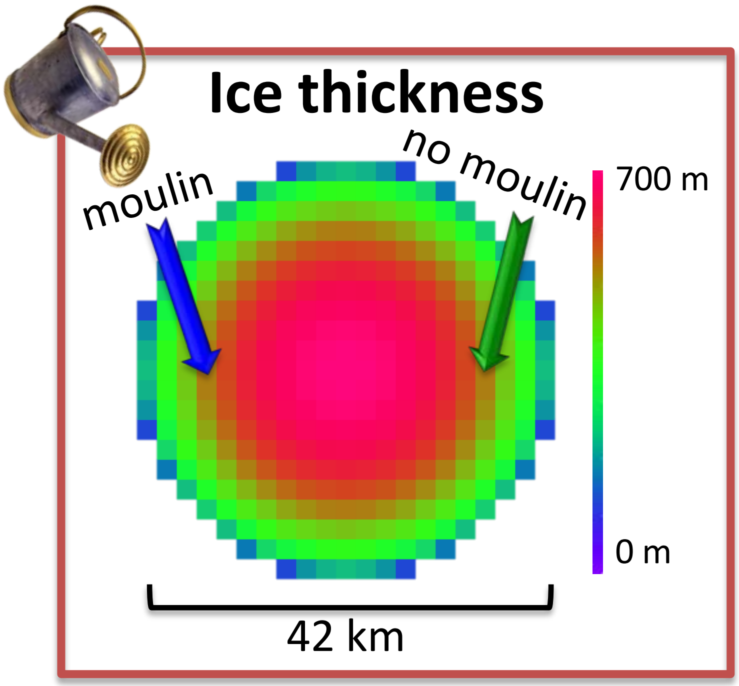
Dome test case with a "moulin"



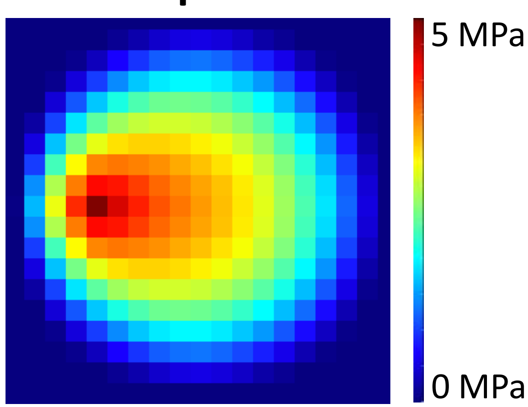
Steady state water pressure

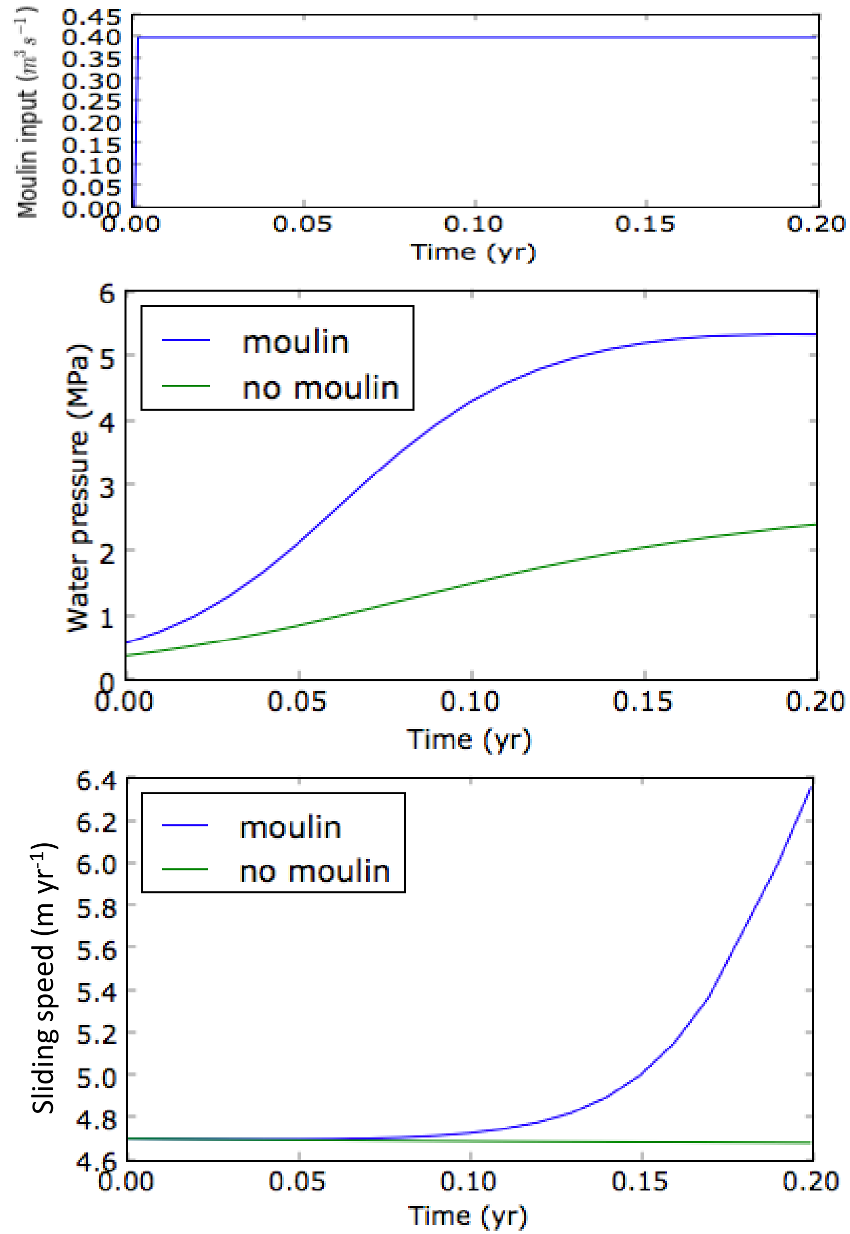


Dome test case with a “moulin” – effect on sliding

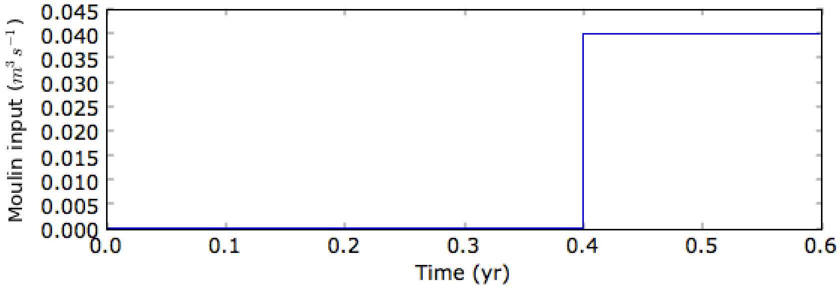


Steady state water pressure





Sheet Perturbation Experiment



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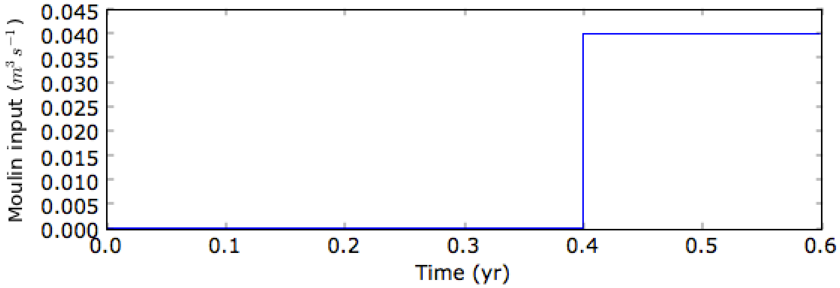

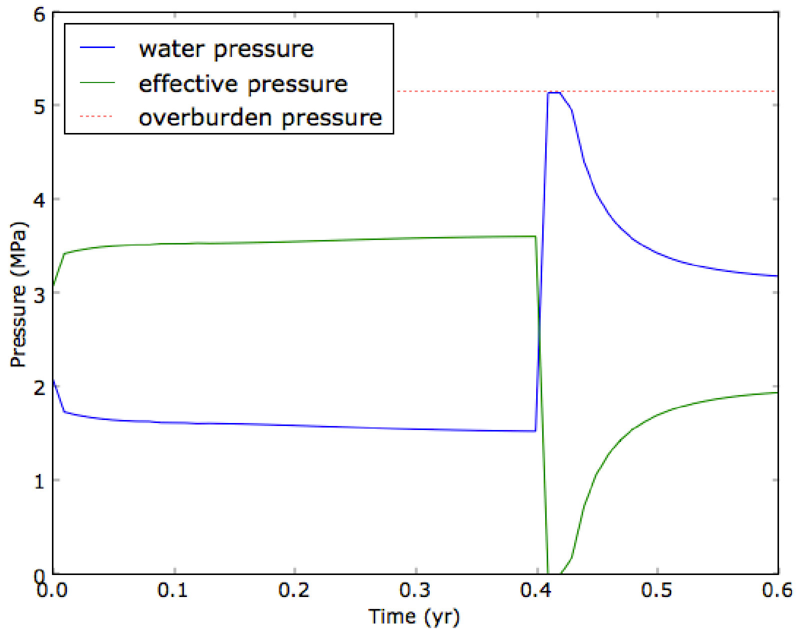

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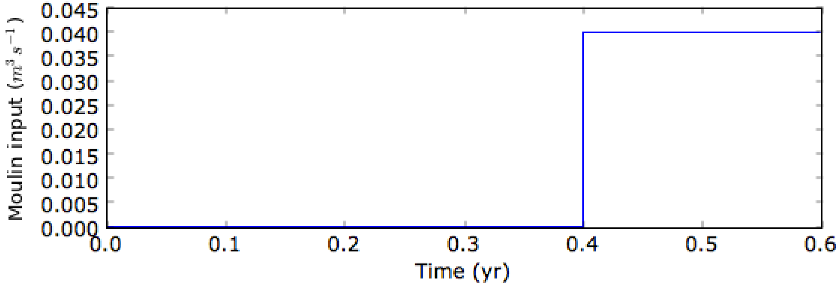

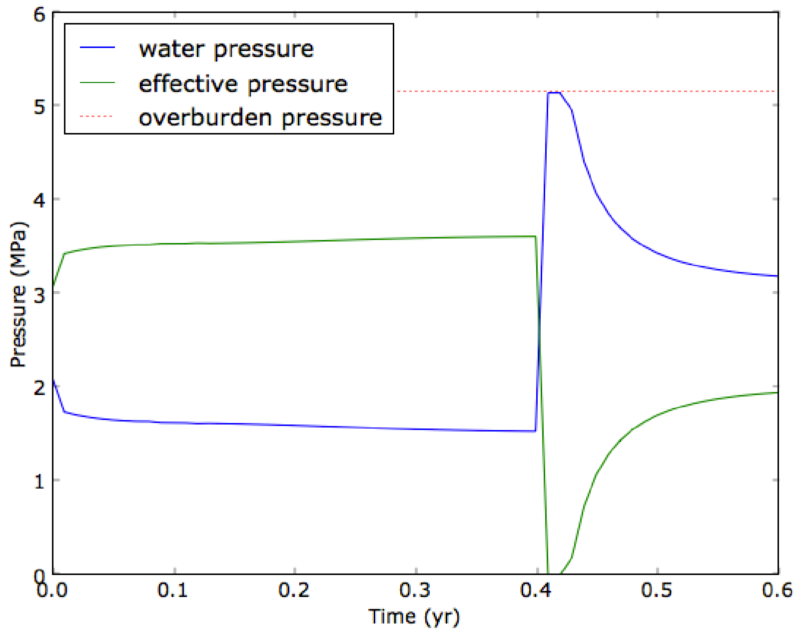

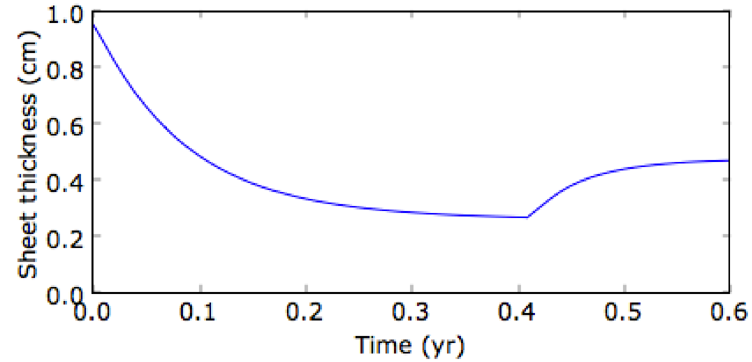

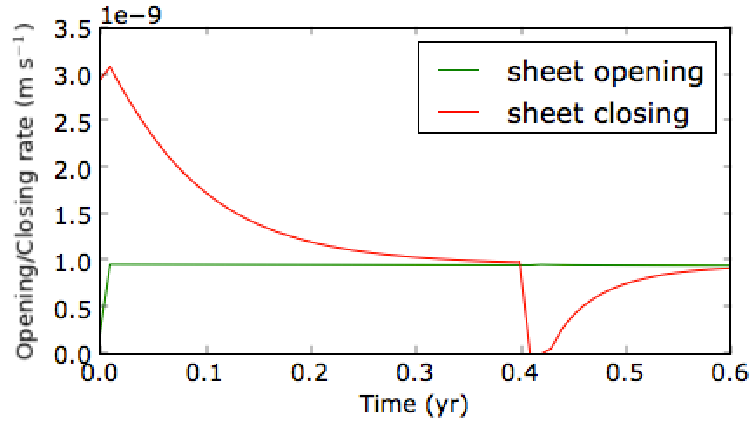

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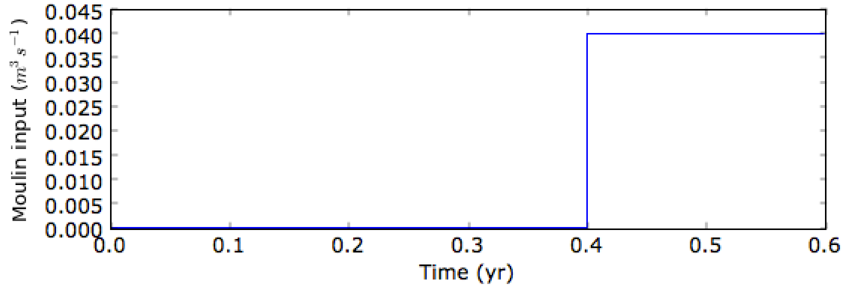

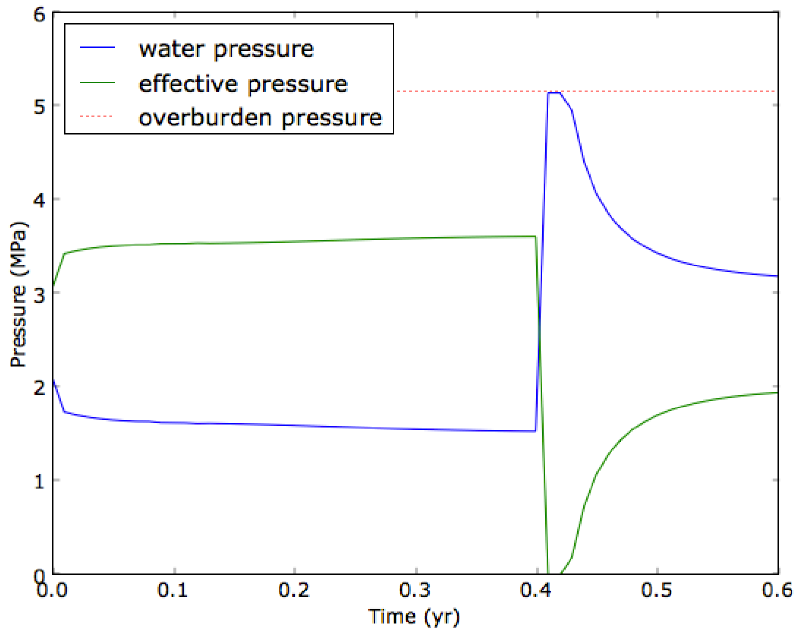

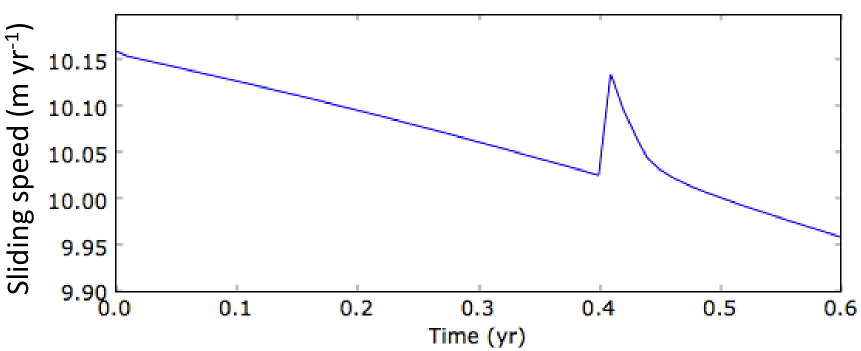

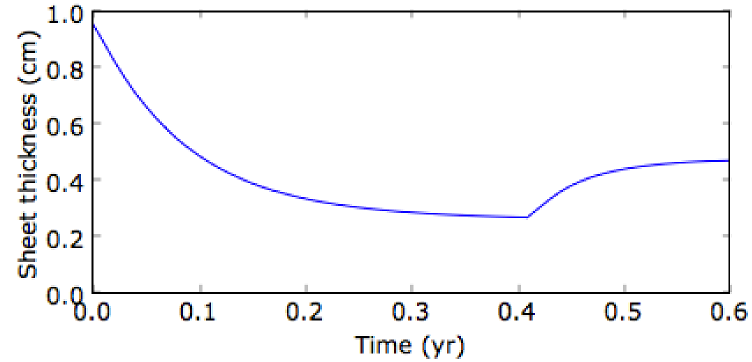

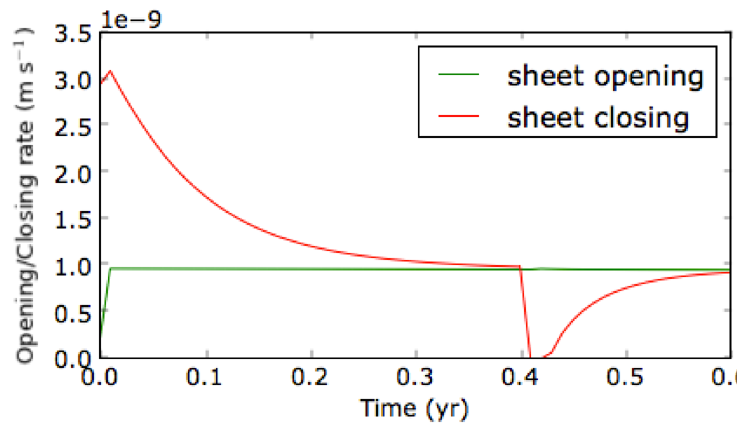

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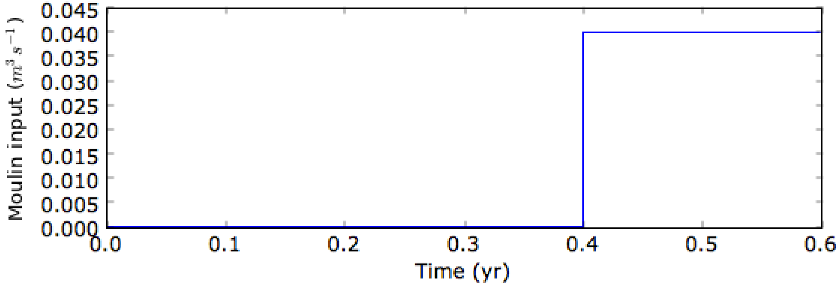

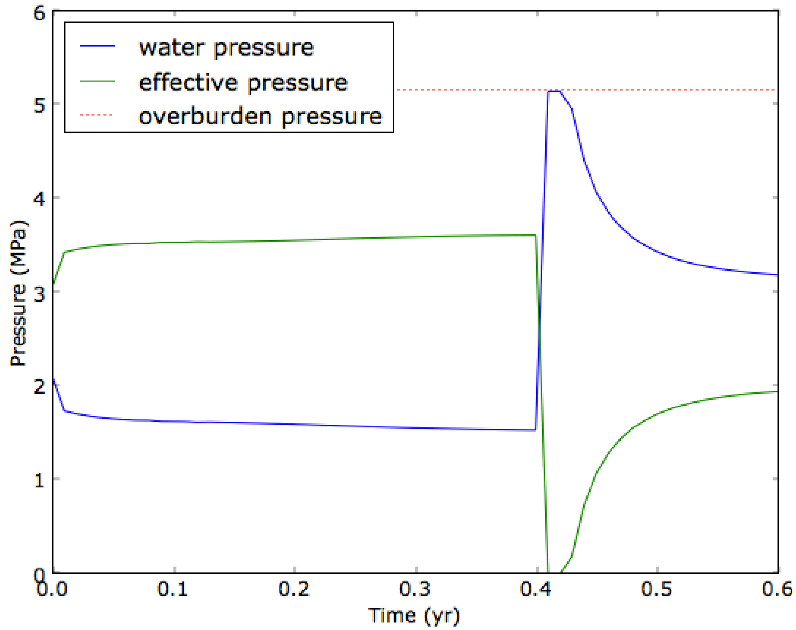

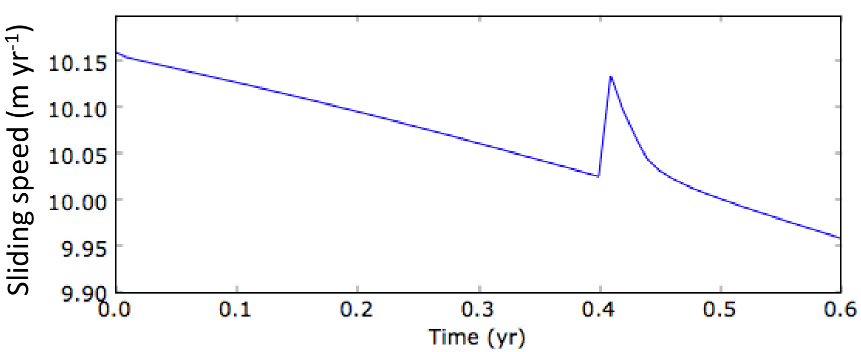

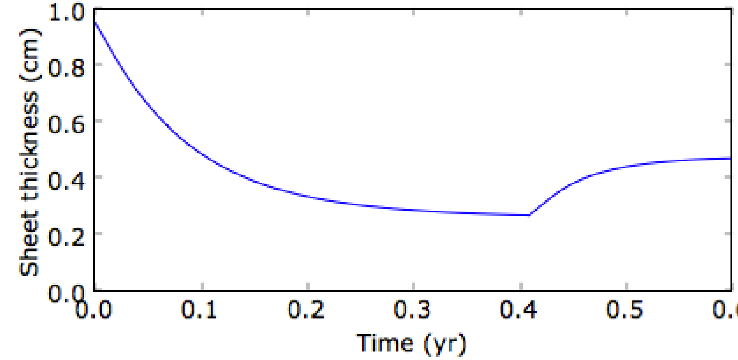

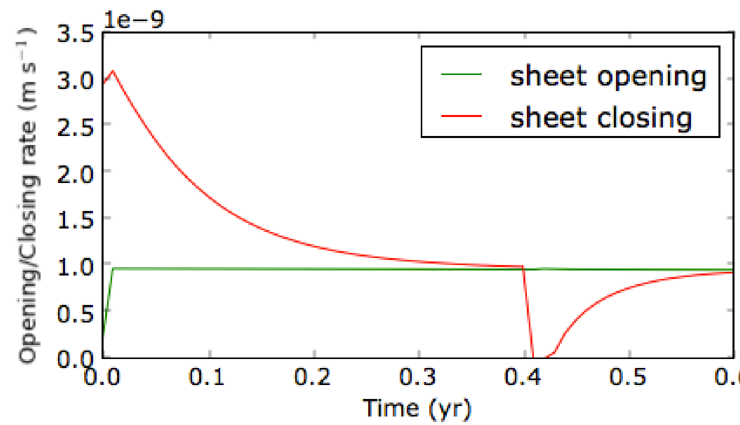

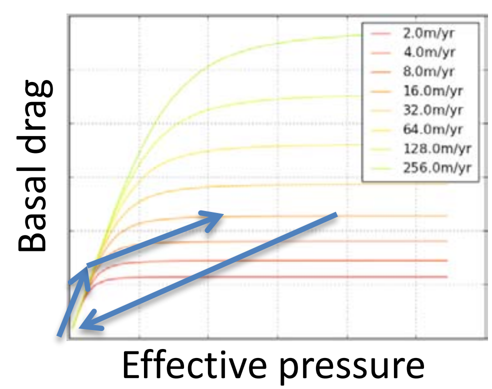

Tentative insights from coupled hydrology/dynamics

- Sheet dynamics can cause temporary speedup from steady water input.
  - High water pressure is transient while system adapts to input.
  - The Coulomb friction sliding rule is insensitive to a certain range of new steady state effective pressures (if they are high enough).
- Termination of a speedup event may not **require** channelization (?)
  - Do these conditions exist in real world?
  - Would this process be interrupted by channelization?

Much Future Work

- Bells & Whistles: viscous dissipation, turbulent flow, nonlinear creep closure, explore sliding feedbacks
- Channel model, coupling, switching
- Englacial, groundwater storage
- Overpressure & underpressure
- Supraglacial, englacial components – melt production and routing
- Time scale issues – Dynamics: ~yr; Hydrology: <day
- Space scale issues – Dynamics: ~km; Hydrology: ~10m
- Move to unstructured mesh? e.g. MPAS
- Parameter estimation – hydrology model & sliding law