

# Modeling glacial hydrology & implications for submarine meltwater discharge

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- Brief summary of (sub)glacial hydrology
- Basal lubrication
- Subglacial discharge to the ocean

Surface mass balance + surface water routing

- Temperature index models
- Energy balance models
- Refreezing / routing

Englacial drainage / storage

- Moulins
- Storage / refreezing

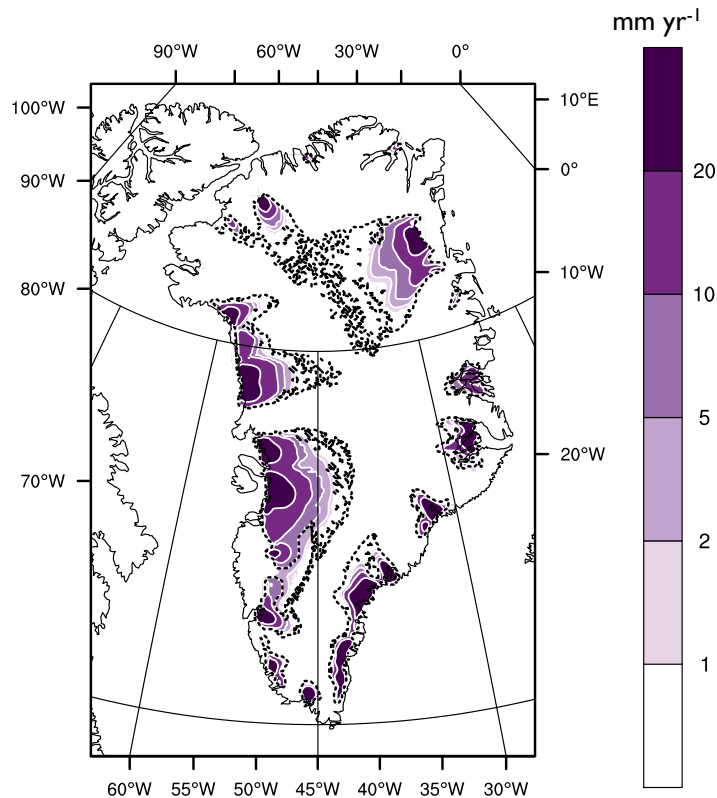
Subglacial drainage

- Basal melting / refreezing
- Storage
- Transport

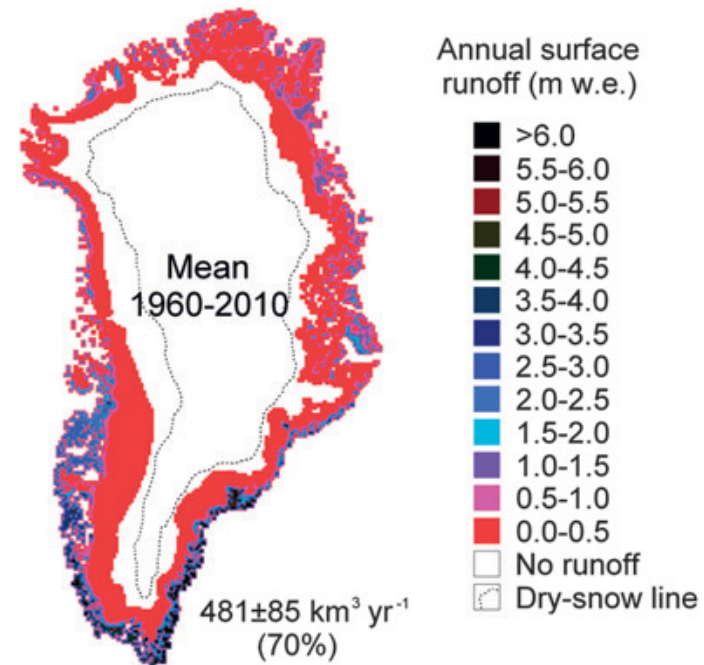
# Water sources

- Basal melting  $\sim 5 \text{ mm yr}^{-1}$

- Surface runoff  $\sim 1000 \text{ mm yr}^{-1}$



Aschwanden et al 2012



Mernild & Liston 2012



Discharge  $\sim 3 \text{ m}^3\text{s}^{-1}$  per kilometre of margin

Individual drainage basins have summer meltwater discharge  $1 \text{ m}^3\text{s}^{-1} - 1000 \text{ m}^3\text{s}^{-1}$

# Two key concepts

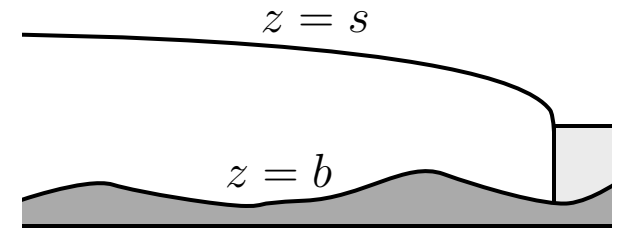
- Hydraulic potential

$$q \propto -\nabla\phi$$

- Surface water flows down surface gradient
- Basal water flows down surface gradient
  - + small influence of bed gradient
  - + small influence of effective pressure

- Effective pressure

$$N = p_i - p_w$$



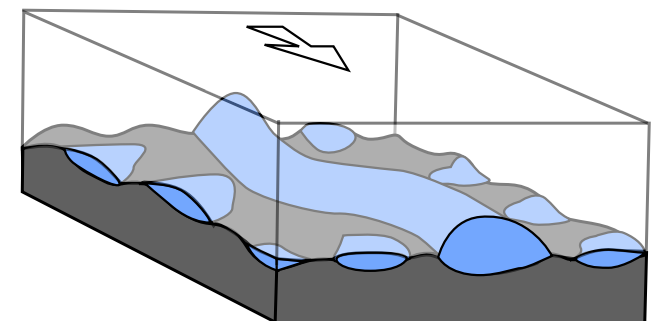
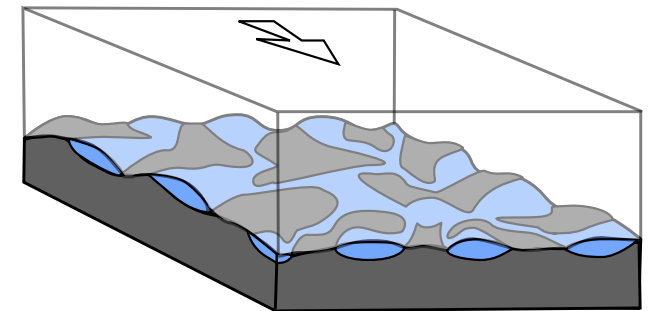
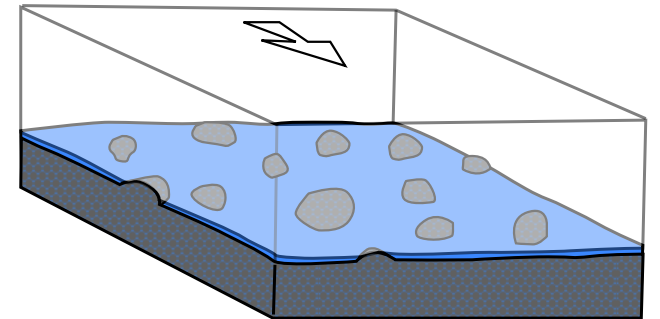
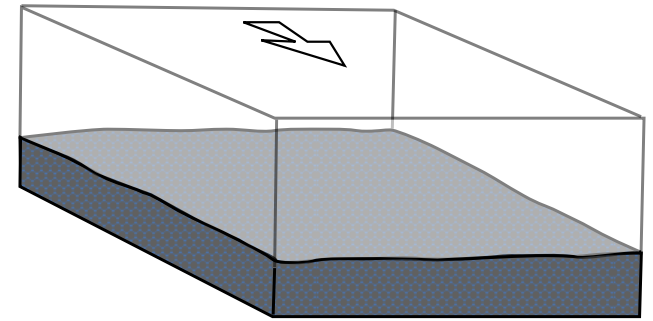
$$\phi = \rho_w g s$$

$$\phi = \rho_i g s + (\rho_w - \rho_i) g b + N$$

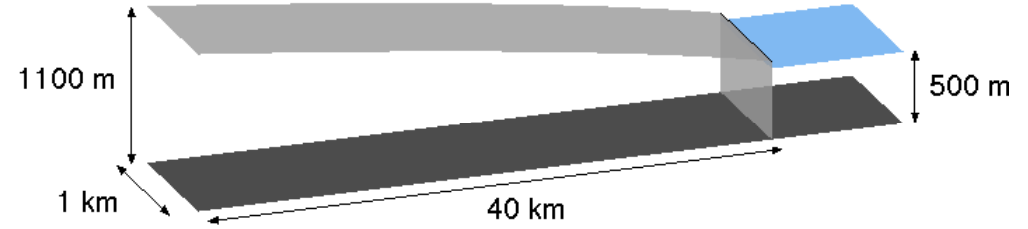
(pressures taken to be suitable local averages)

# Subglacial drainage

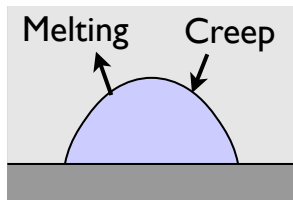
- Saturated sediments
  - not capable of carrying required discharge
- 'Distributed' systems
  - uneven water films
    - Weertman 1972, Walder 1982, Alley 1989, Creyts & Schoof 2009
  - micro-cavity networks
    - Fountain & Walder 1998, Flowers & Clarke 2002
  - canals
    - Walder & Fowler 1994
  - linked cavities
    - Lliboutry 1976, Walder 1986, Fowler 1986, Kamb 1987
  - Nye channels
    - Nye 1973
- 'Channel' systems
  - Röthlisberger 1972, Nye 1976, Hooke et al 1990



# Steady state theory

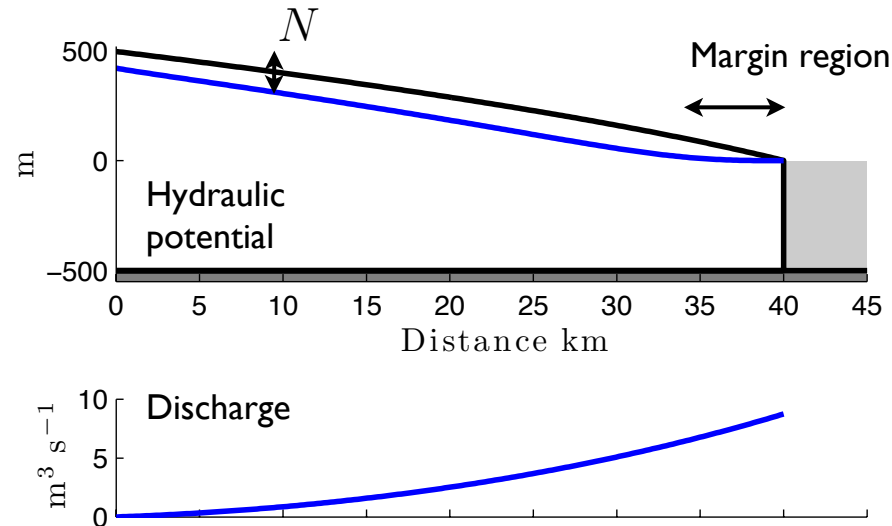


## Channel theory

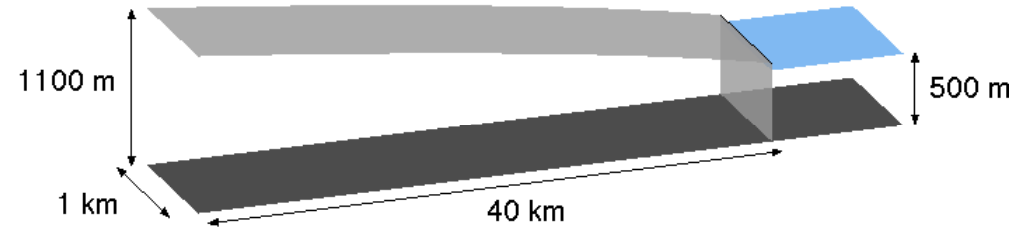


$$N \propto |\nabla\phi|^{11/24} Q^{1/12}$$

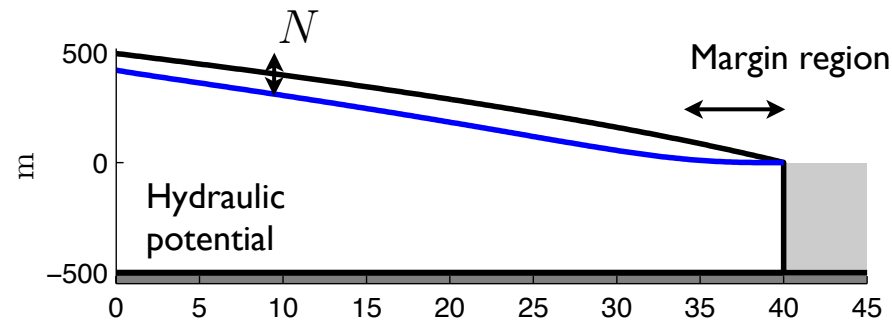
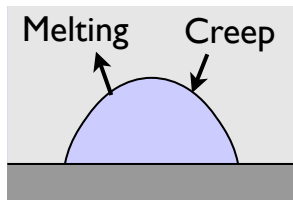
$$t \propto \frac{1}{|\nabla\phi|^{11/8} Q^{1/4}}$$



# Steady state theory



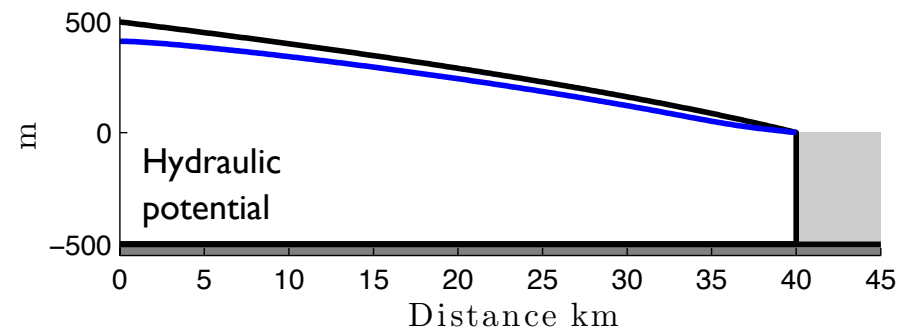
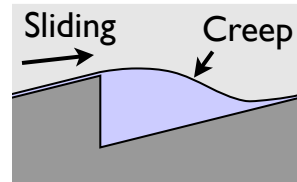
## Channel theory



$$N \propto |\nabla\phi|^{11/24} Q^{1/12}$$

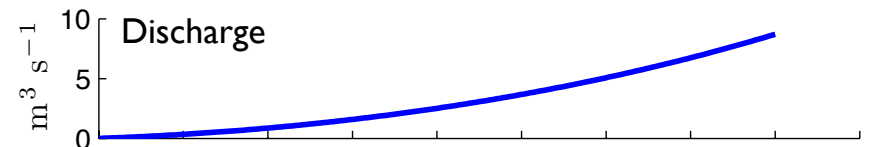
$$t \propto \frac{1}{|\nabla\phi|^{11/8} Q^{1/4}}$$

## Cavity theory

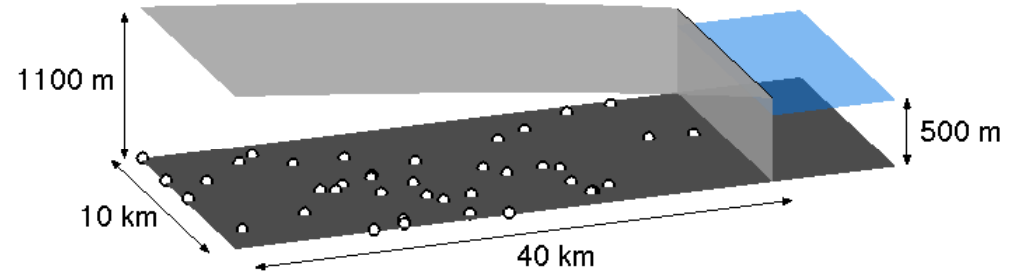


$$N \propto \frac{u_b^{1/3} |\nabla\phi|^{1/9}}{Q^{1/9}}$$

$$t \propto \frac{Q^{1/3}}{u_b |\nabla\phi|^{1/3}}$$

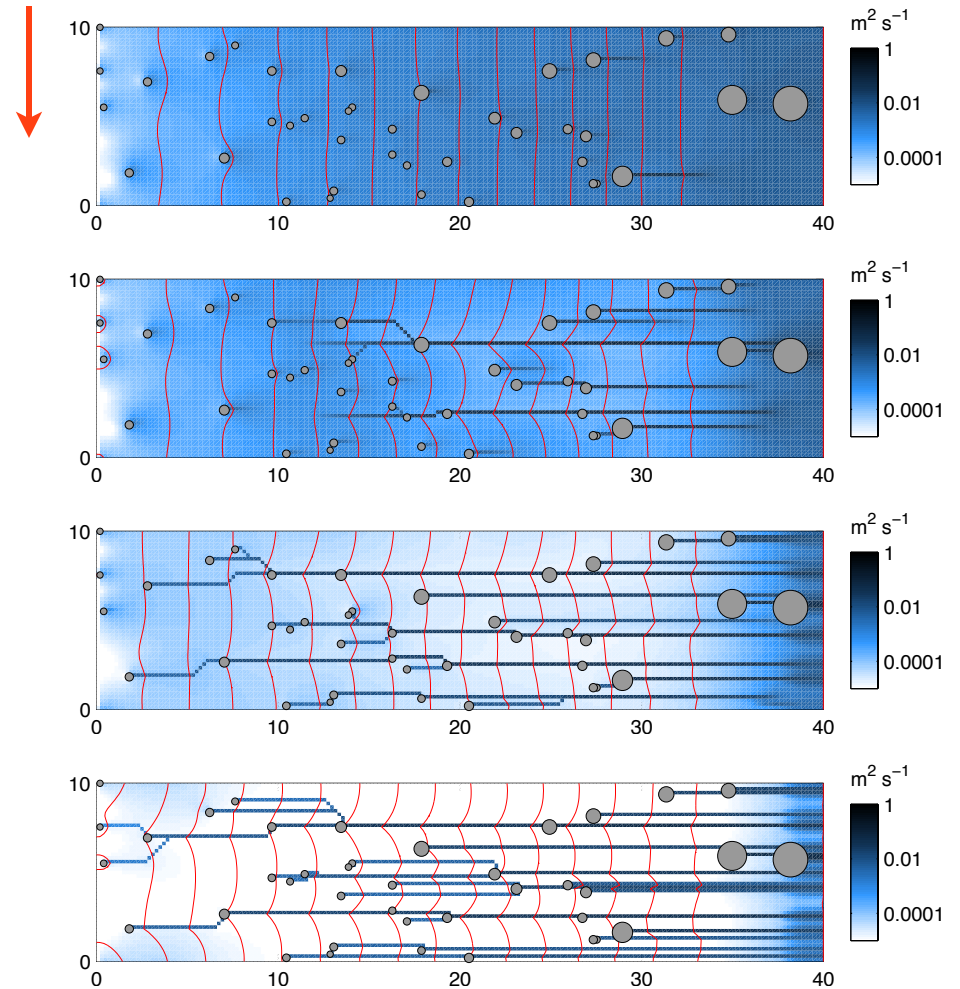


# Channel spacing



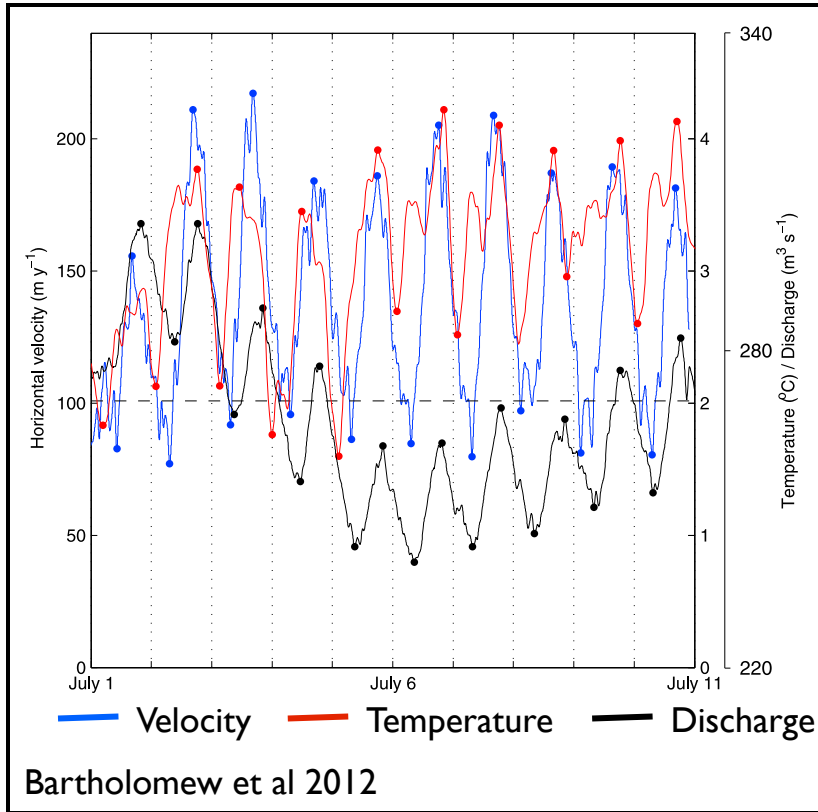
- More densely spaced smaller channels likely if
  - slope is large
  - distributed system is poorly connected
- Steady state may never occur in practice.
- Continuum of scales, from orifices to channels.
- Modelled channels tend to coarsen over time.

## More poorly connected cavities

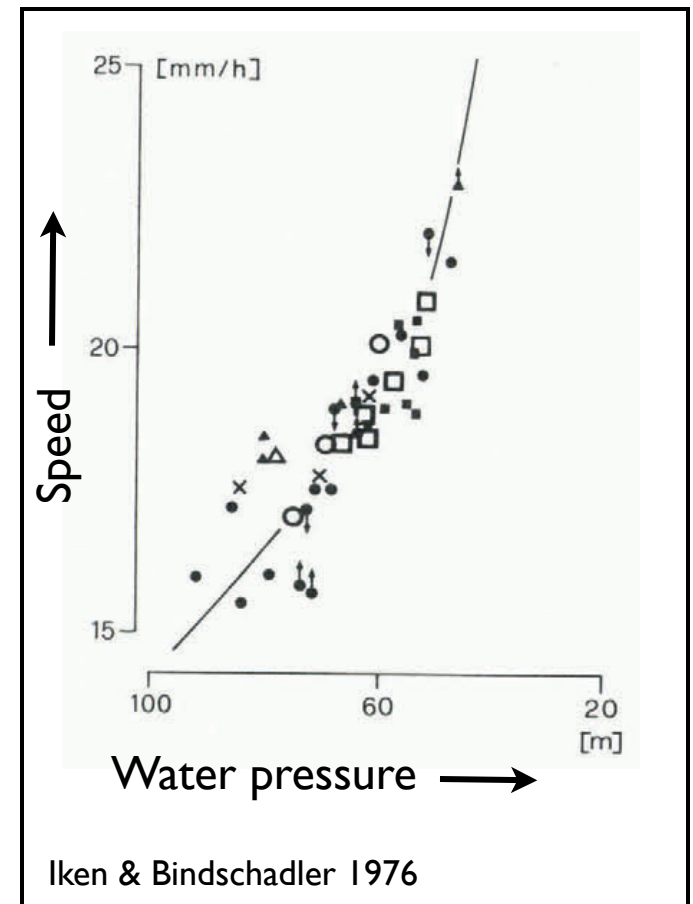


# Basal sliding

- Frequently observed that ice speed varies diurnally

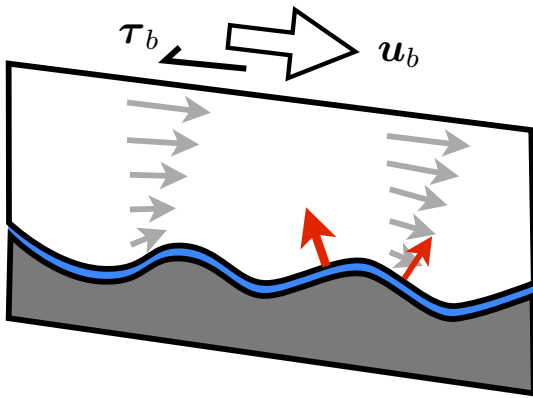


- Correlations between speed and borehole water pressure



# Basal sliding

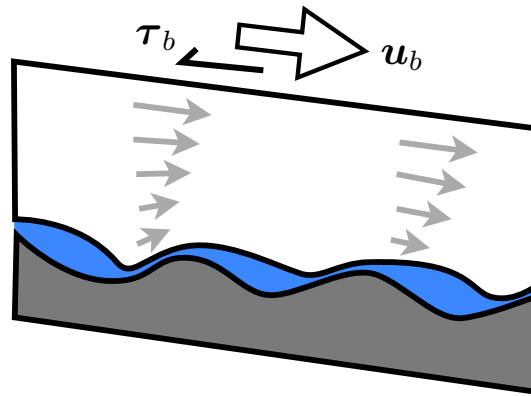
$$\tau_b \approx -\rho_i g H \nabla s$$



Hard bedrock

$$\tau_b = R U_b^{1/m}$$

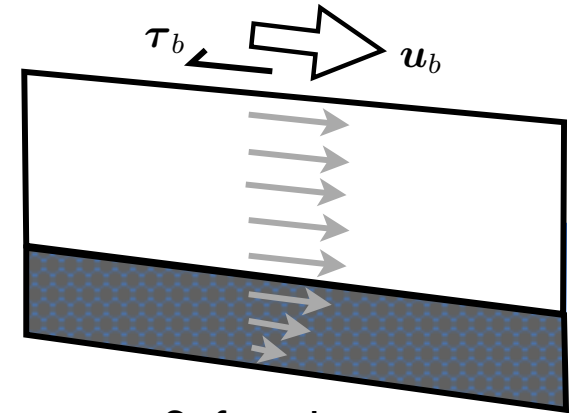
Water film facilitates sliding



Cavities

$$\tau_b = C U_b^p N^q$$

Lower effective pressure  
Larger cavities  
Less friction



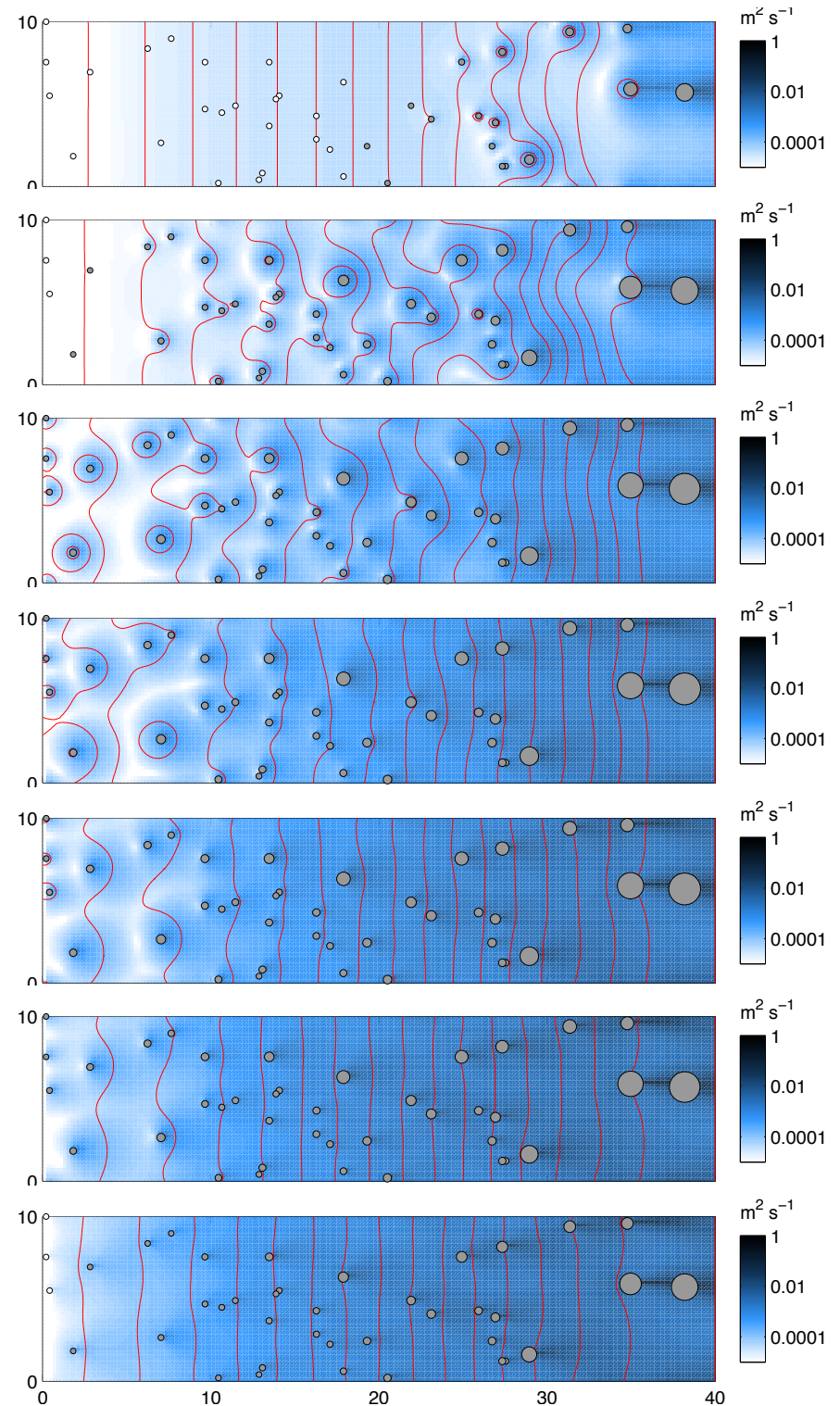
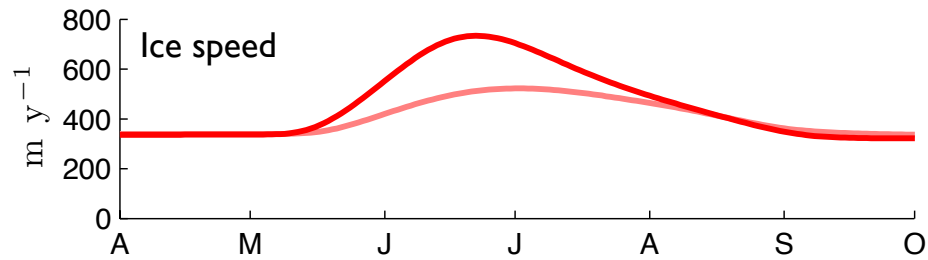
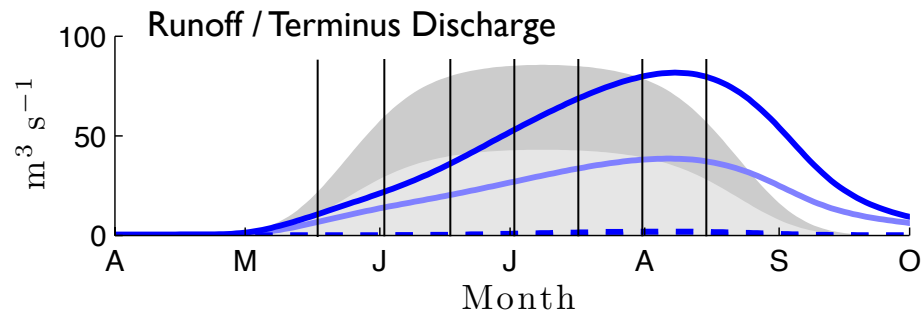
Soft sediments

$$\tau_b = \mu N$$

Lower effective pressure  
Lower yield stress

# Modelled sliding variations

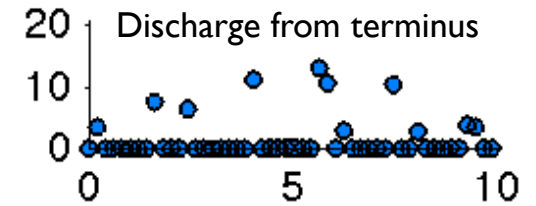
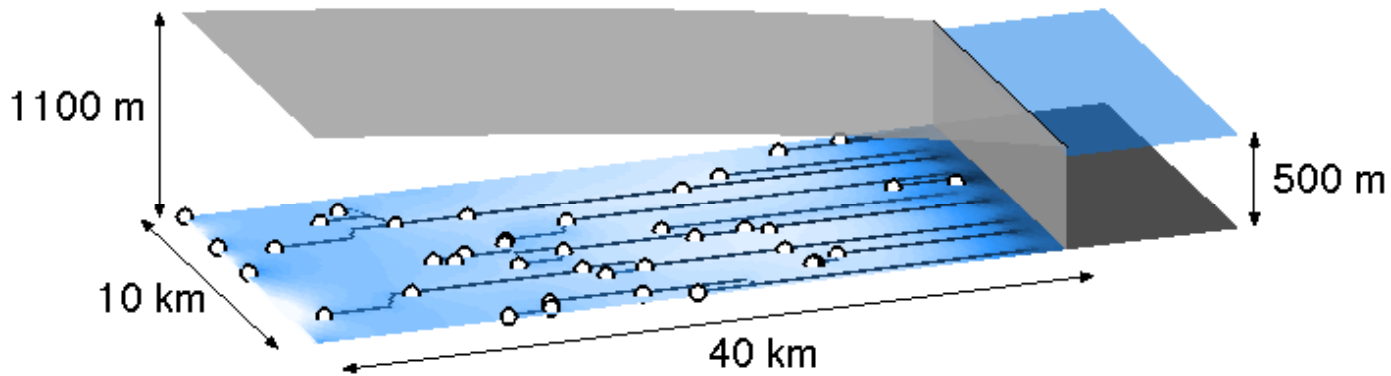
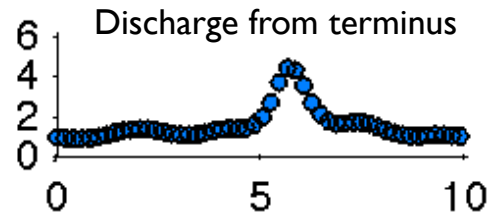
- Sliding law  $\tau_b = CU_b^{1/3}N^{1/3}$
- Ice flow due to sliding only



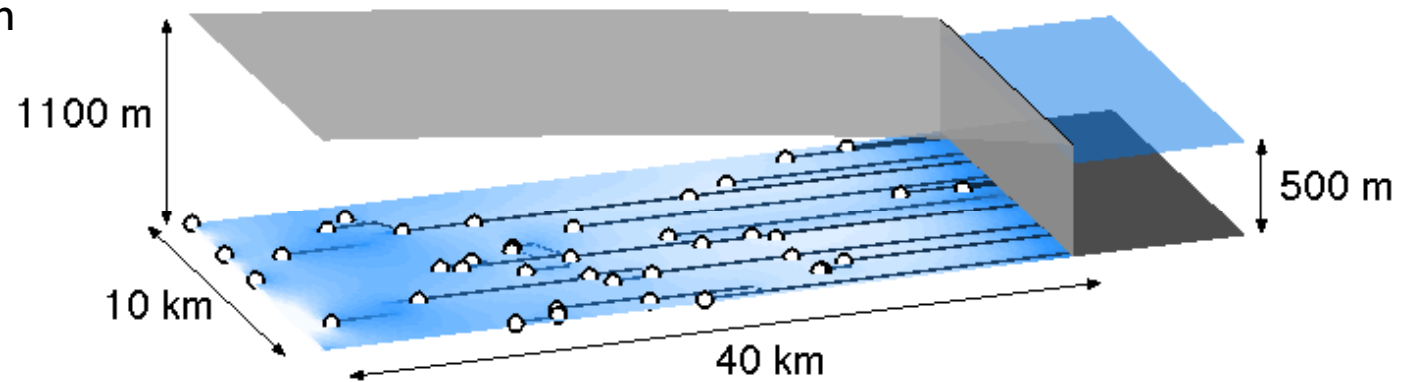
# Discharge to the ocean

- How is discharge to the ocean distributed?

- Terminus at flotation



- Terminus above flotation



# Summary

- Increased quantity of surface runoff in recent years.
  - Little data on subglacial hydrology. Simple first order approaches required for modelling.
  - Evolution of the drainage system is important.
  - Any channelized flow may fan out near a terminus.
- 
- How appropriate are effective pressure-dependent sliding laws?
  - What is basal water pressure?
  - Ice dynamics; may be better to use statistical links between surface melting and sliding speed.