

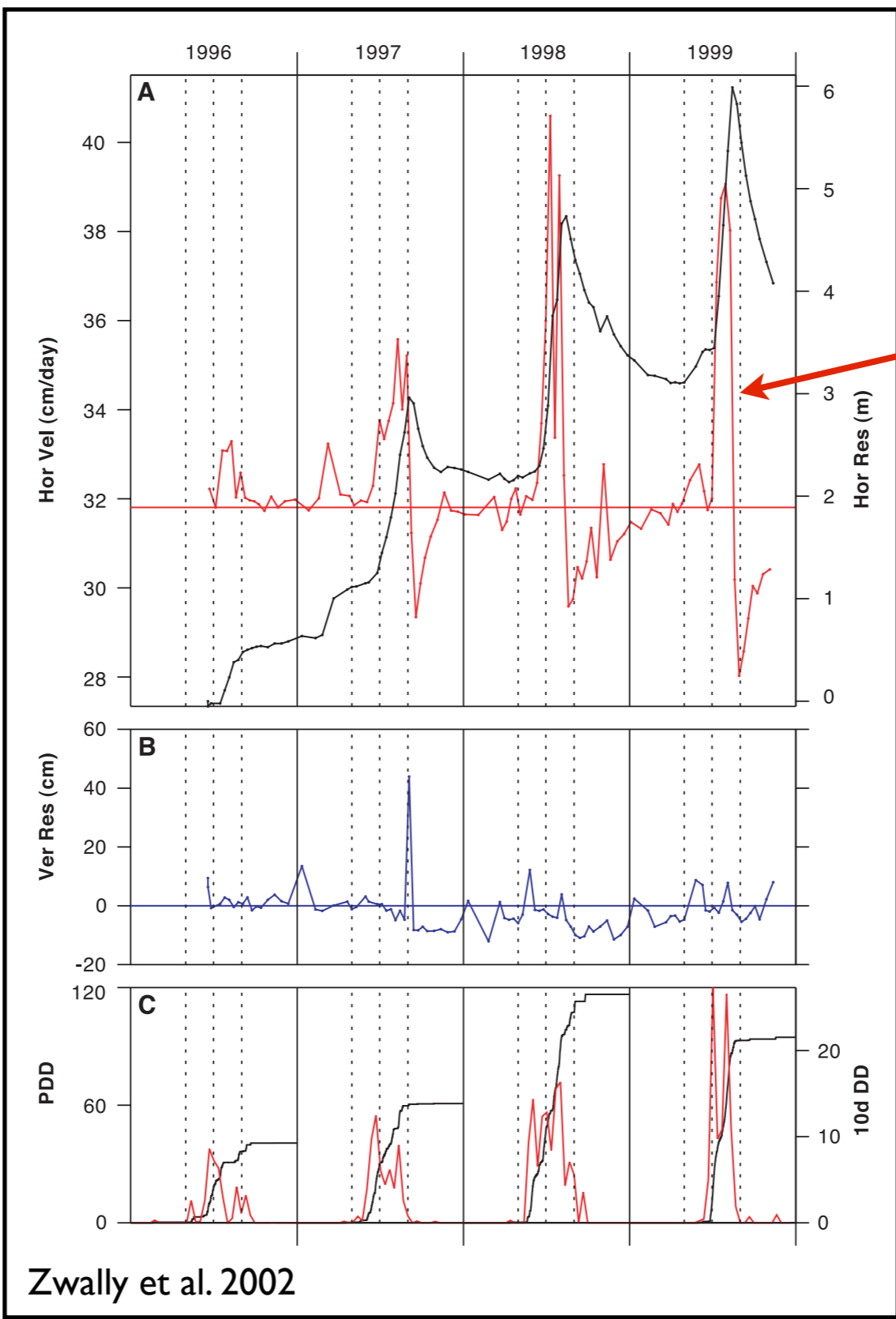
(In)consistent modelling of subglacial drainage and sliding

Ian Hewitt, University of Oxford



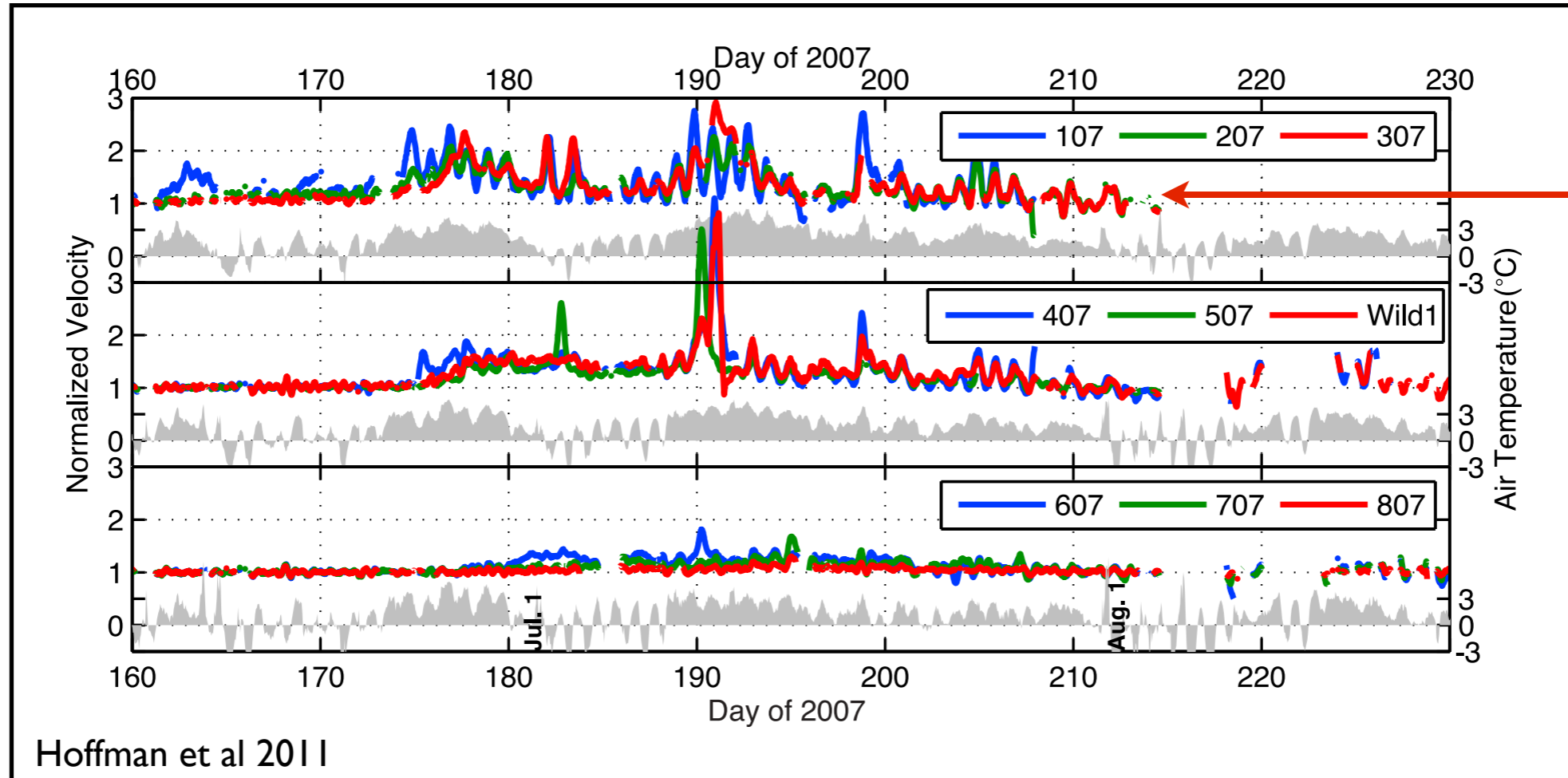
Ice acceleration and deceleration due to surface melting

Greenland surface velocities (GPS)

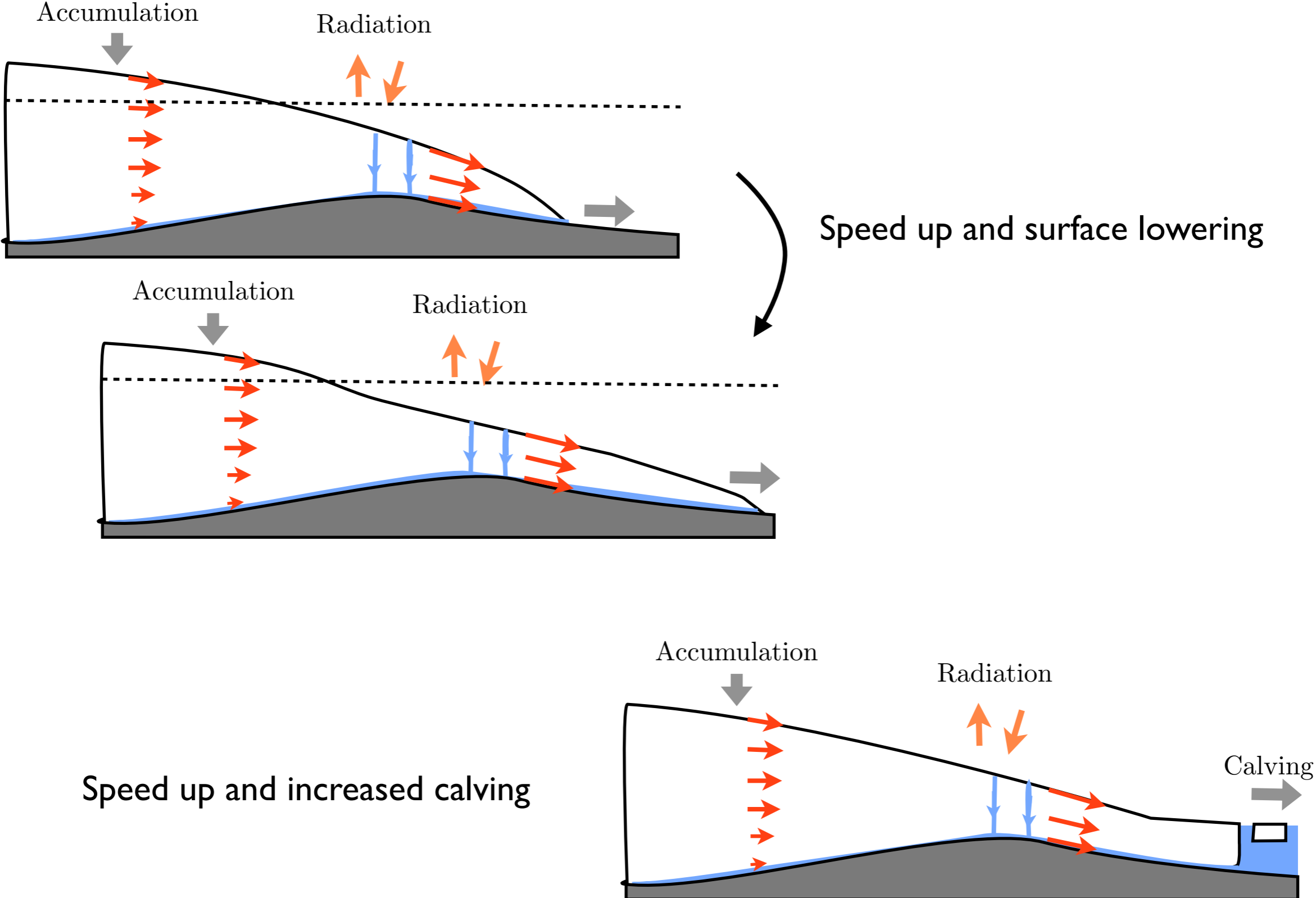


Zwally et al. 2002

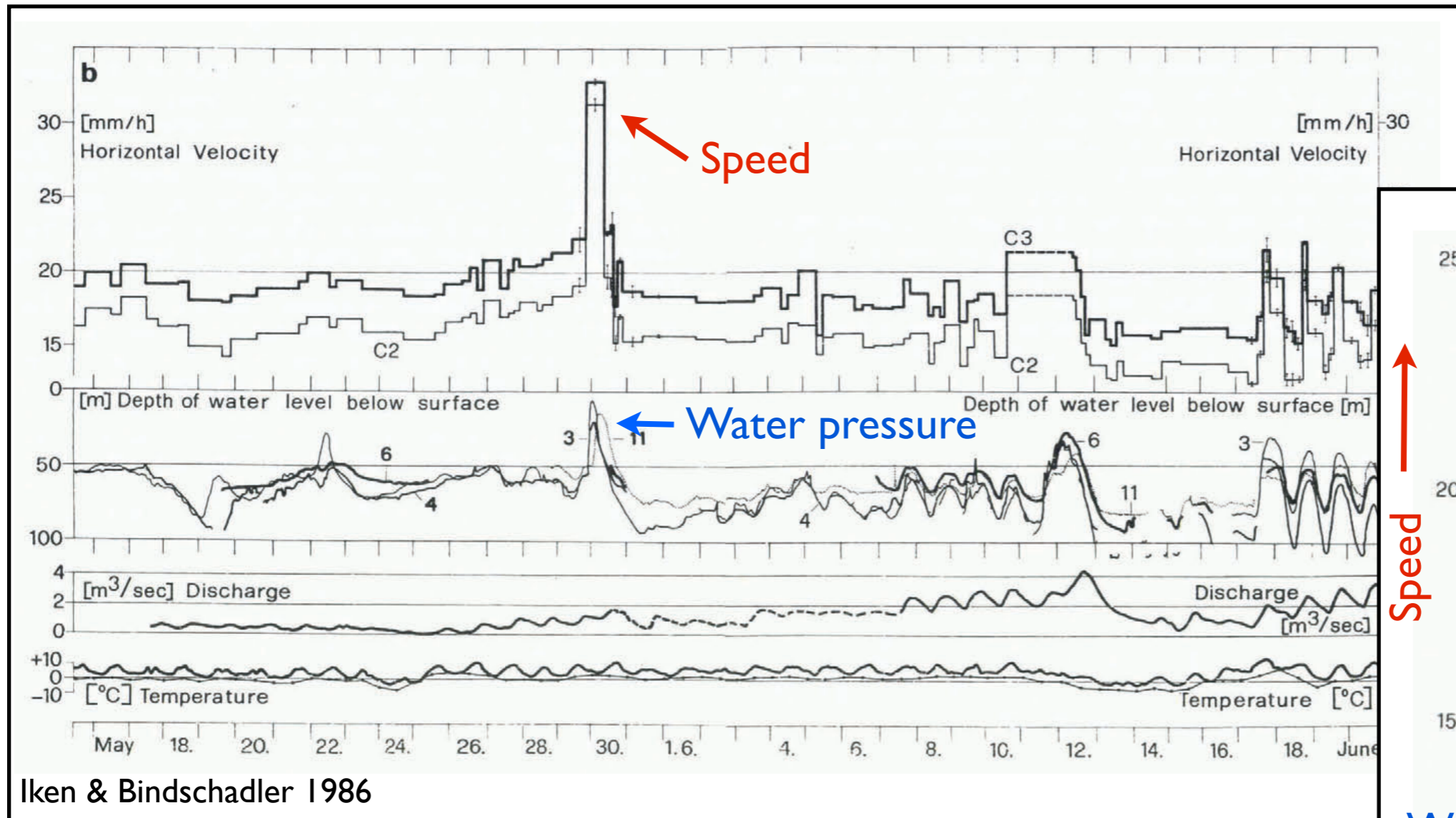
Ice speed varies diurnally



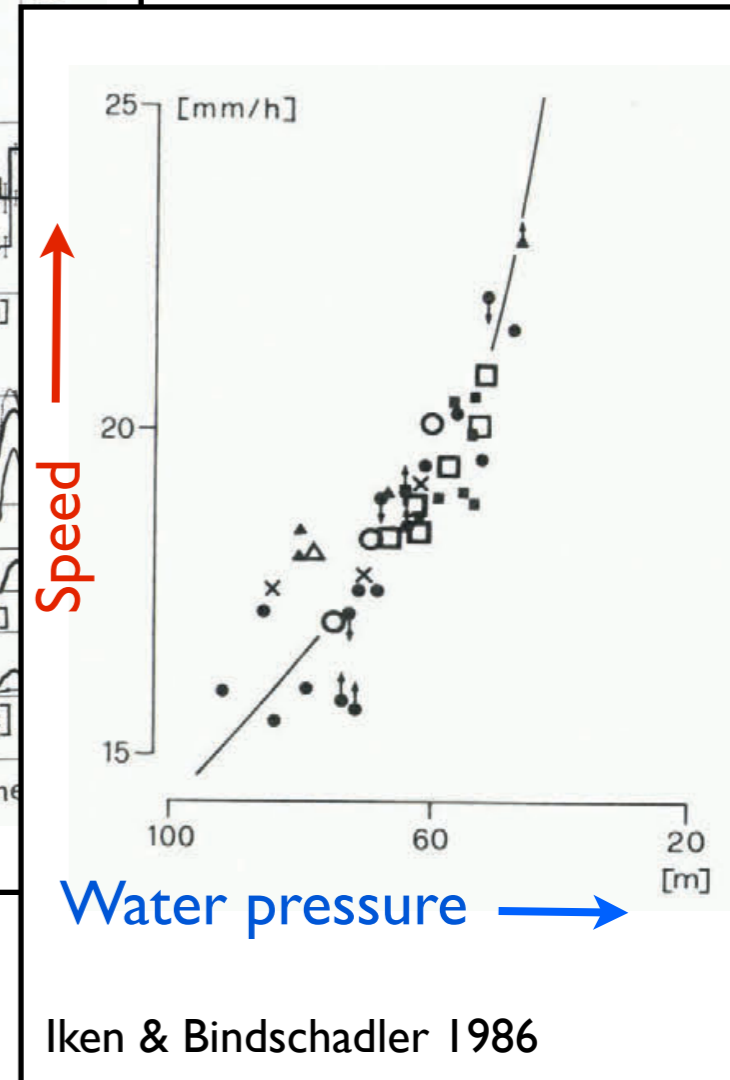
Ice-dynamic influences on ice-sheet mass balance



Sliding and water pressure



Iken & Bindshadler 1986



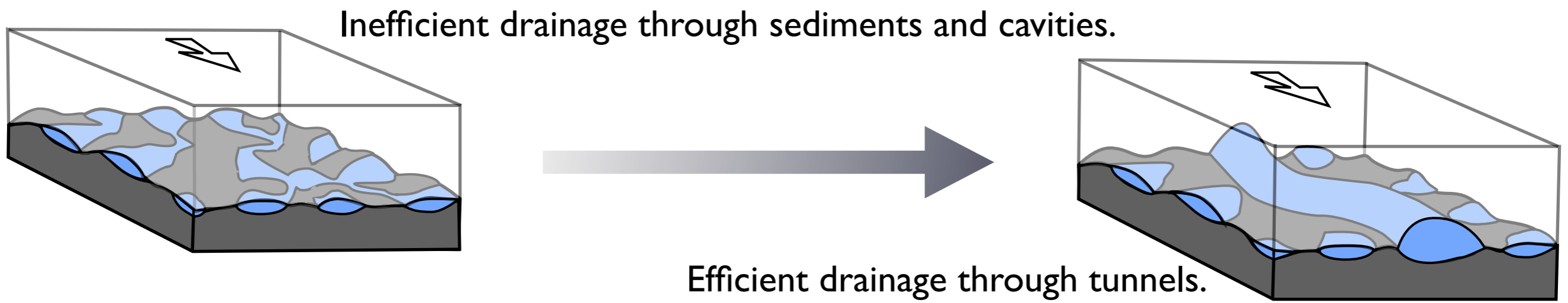
Correlation between surface velocity and borehole water pressure

BUT this relationship is not always consistent

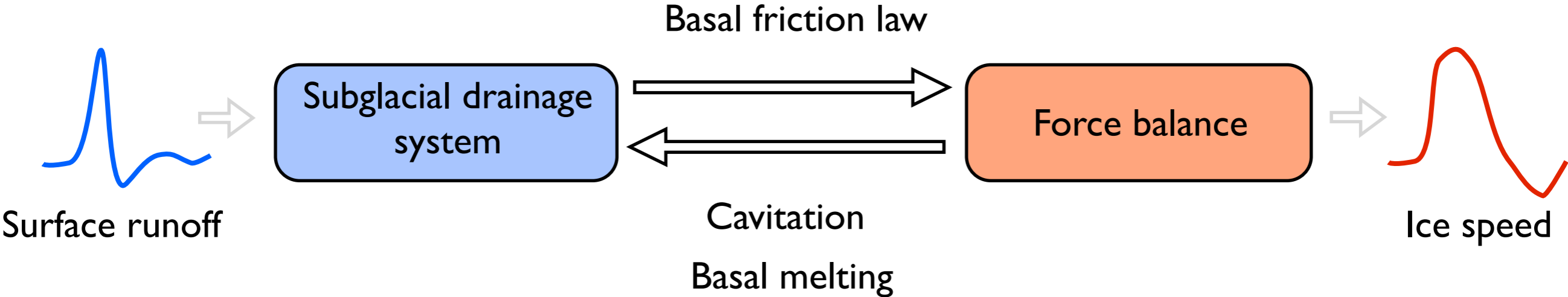
Sugiyama & Gudmundson 2004, Harper et al 2007, Howat et al 2008, Fudge et al 2009

Subglacial drainage system

Lots of evidence suggests subglacial drainage systems are constantly evolving.



Modelling coupled hydrology and sliding



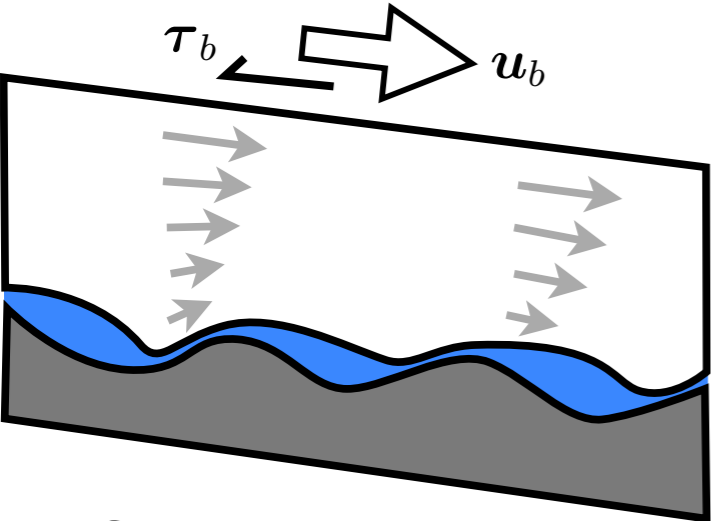
Isothermal ice-sheet model (2d vertically integrated approximation incorporating longitudinal stresses and internal shear).

Fixed ice-sheet geometry.

Basal friction law

Assume sliding depends on *effective pressure* $N = p_i - p_w$

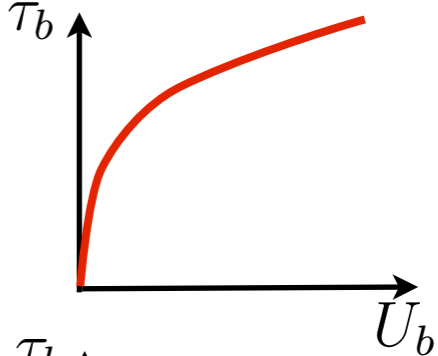
$$\tau_b = f(U_b, N)$$



Cavities

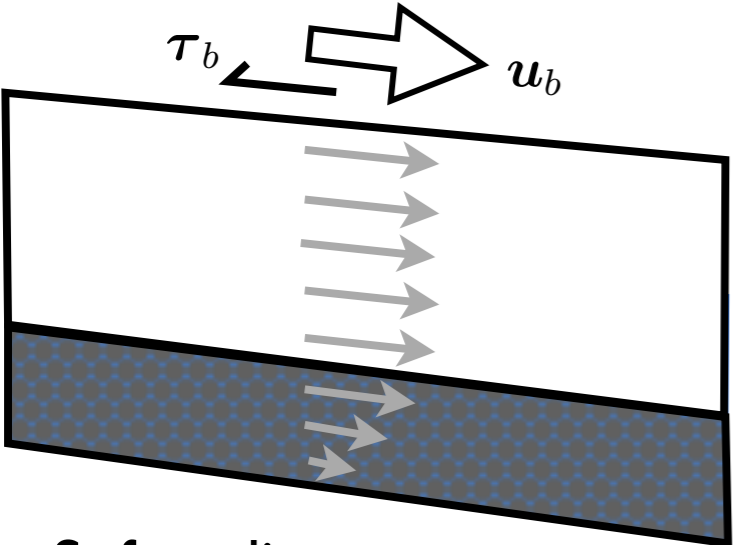
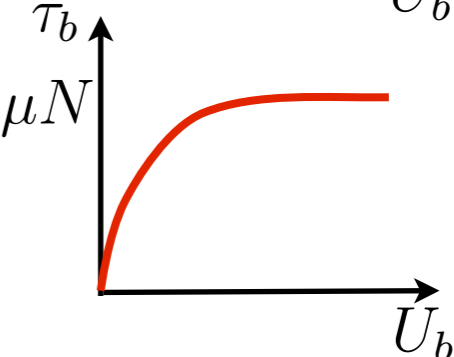
$$\tau_b = CU_b^p N^q$$

Lliboutry 1979, Budd et al 1979, Fowler 1986



$$\tau_b = \mu N \left(\frac{U_b}{U_b + \lambda AN^n} \right)^{1/n}$$

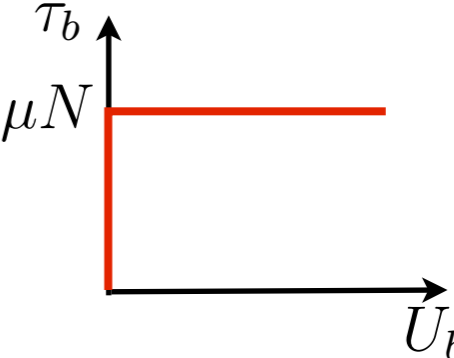
Schoof 2005, Gagliardini et al 2007



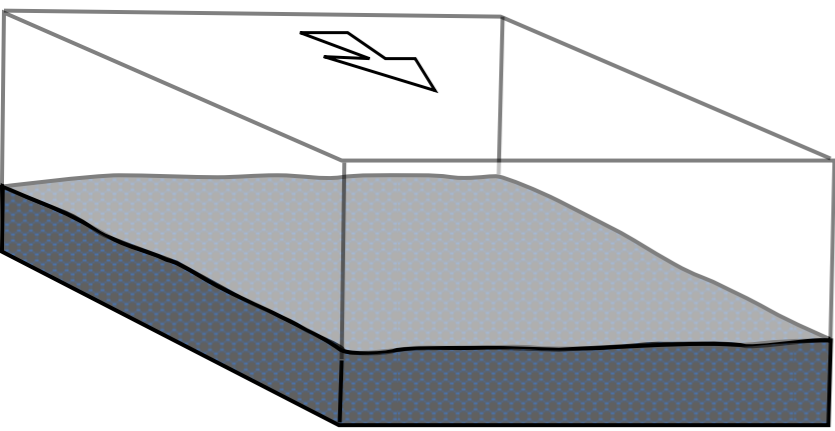
Soft sediments

$$\tau_b = \mu N$$

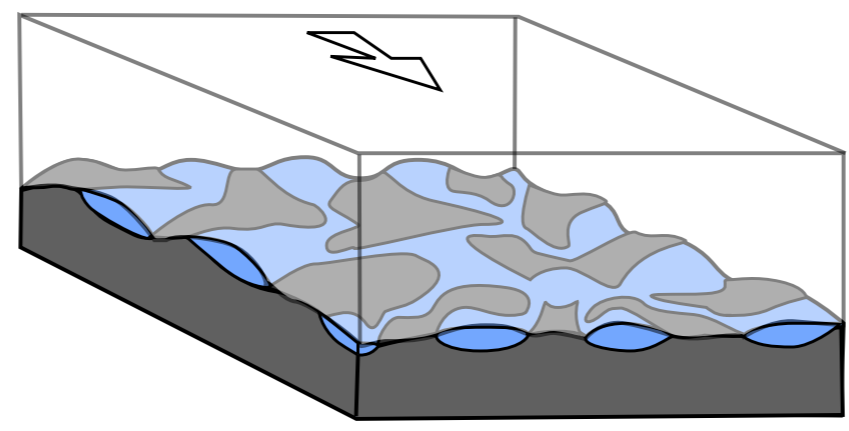
Kamb 1991, Tulaczyk 2000



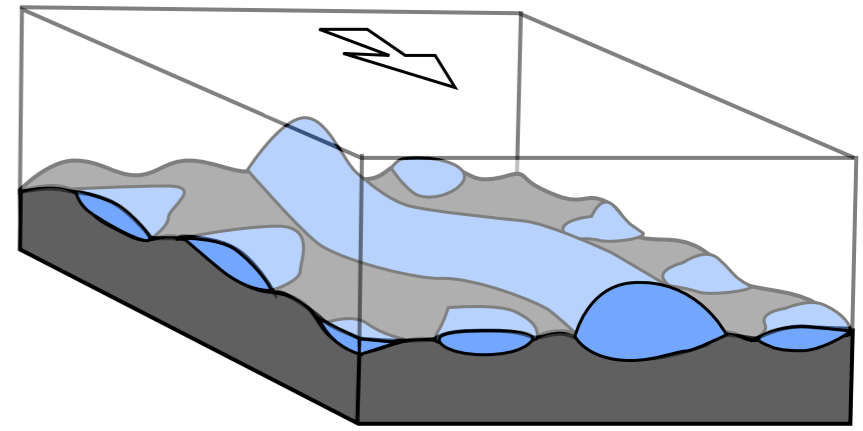
Subglacial drainage model



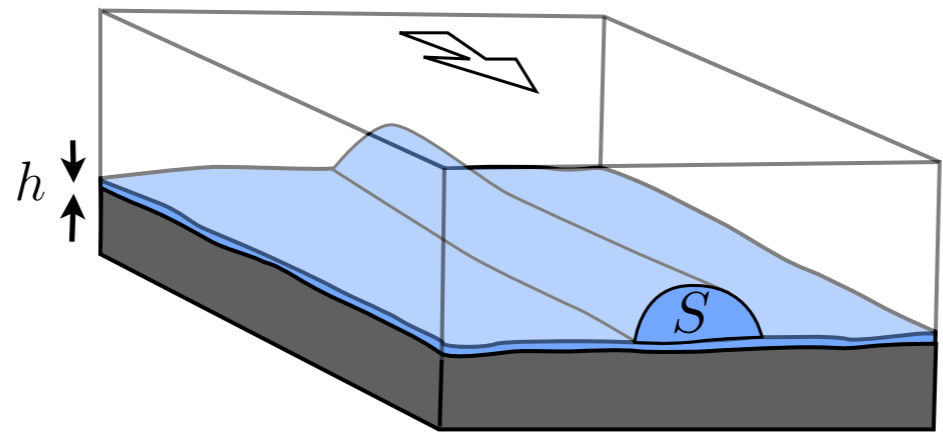
Saturated sediments



'Distributed' systems



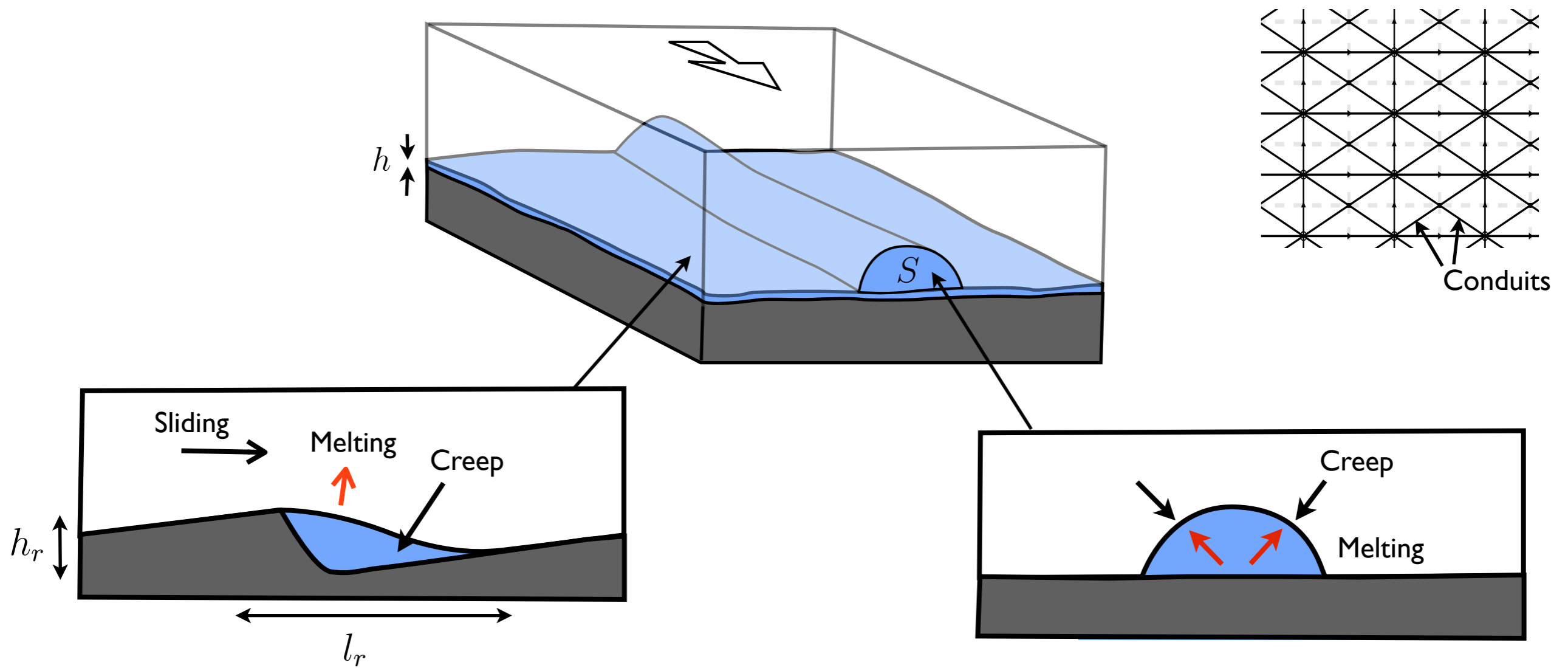
'Channel' systems



h

S

Subglacial drainage model



$$\frac{\partial h}{\partial t} = \frac{\rho_w}{\rho_i} m + U_b \frac{h_r - h}{l_r} - \frac{2A}{n^n} h N^n$$

$$\frac{\partial h}{\partial t} + \nabla \cdot \mathbf{q} = m + r$$

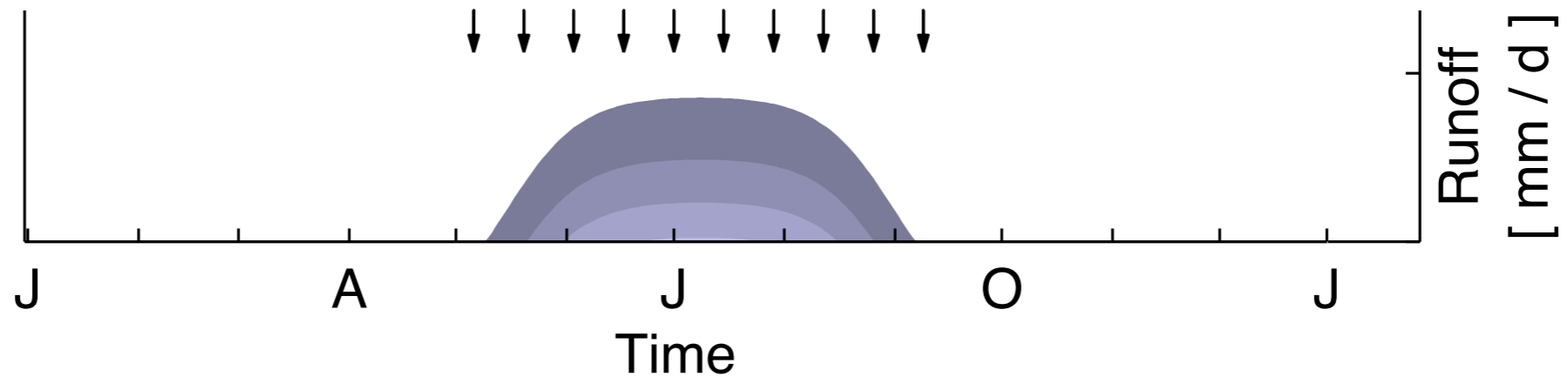
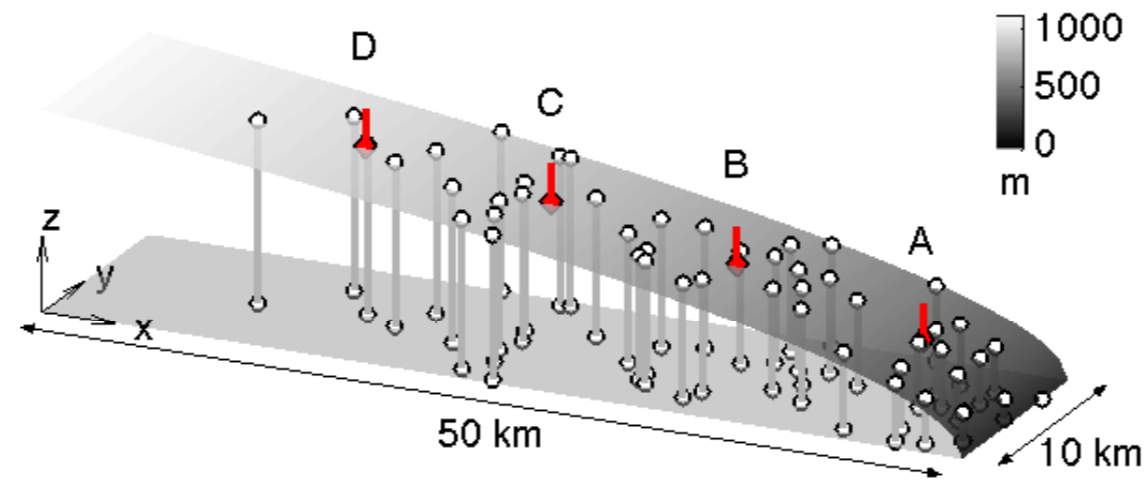
$$m = \frac{G + \boldsymbol{\tau}_b \cdot \mathbf{u}_b}{\rho_w L}$$

$$\frac{\partial S}{\partial t} = \frac{\rho_w}{\rho_i} M - \frac{2A}{n^n} S |N|^{n-1} N$$

$$\frac{\partial S}{\partial t} + \frac{\partial Q}{\partial s} = M + \left[\mathbf{q} \cdot \mathbf{n} \right]_{-}^{+}$$

$$M = \frac{|Q \partial \phi / \partial s| + \lambda_c |\mathbf{q} \cdot \nabla \phi|}{\rho_w L}$$

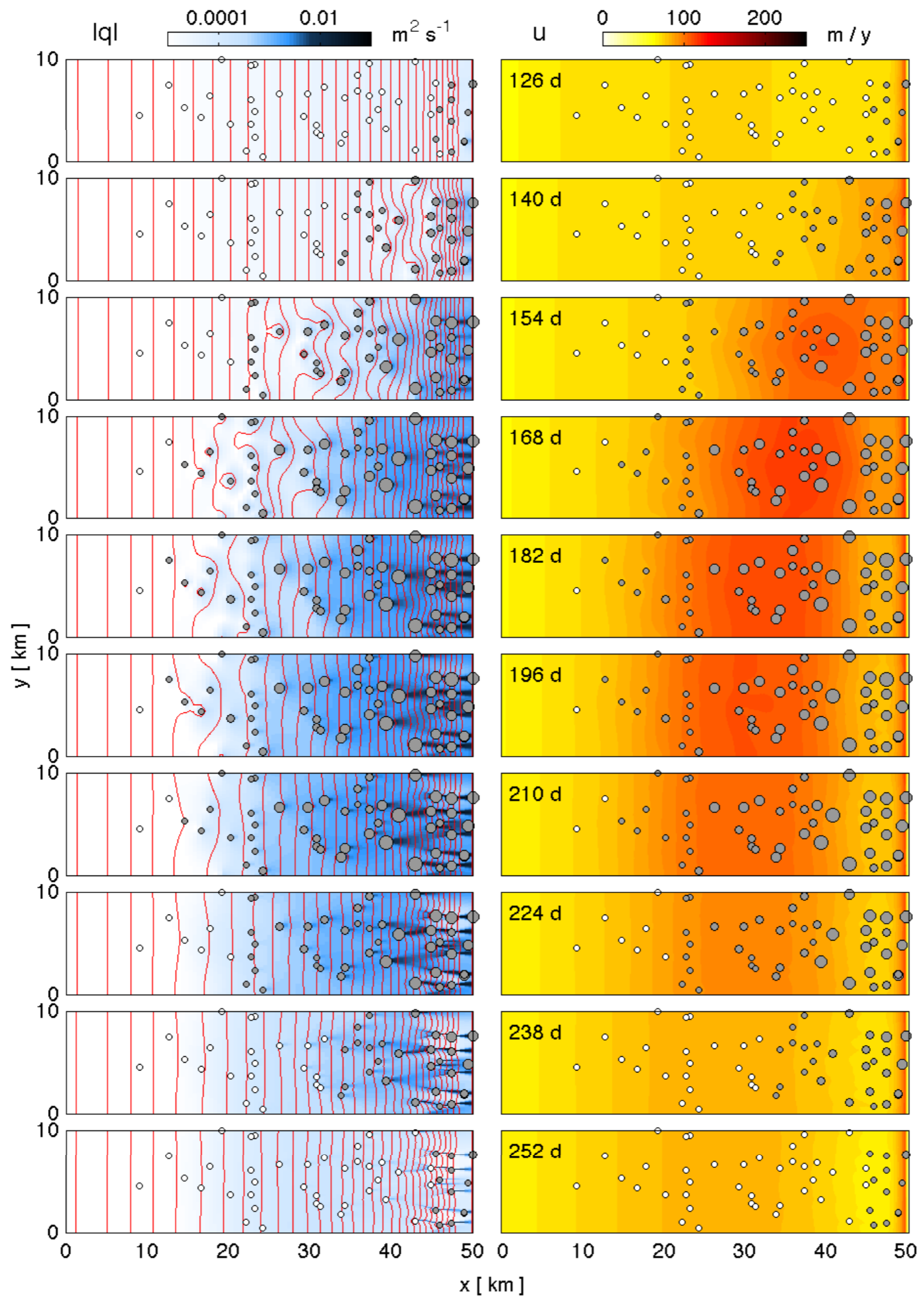
Annual cycle for a synthetic ice-sheet margin



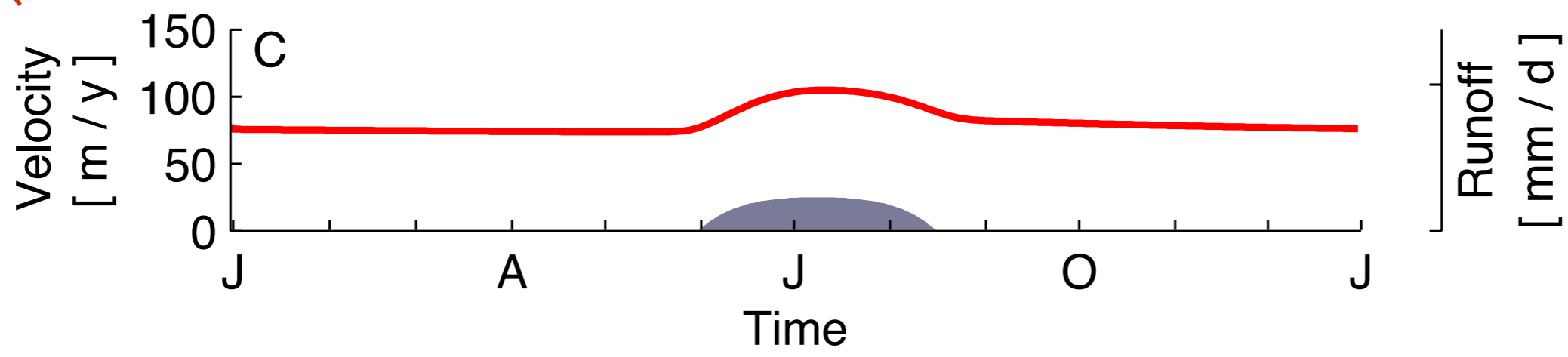
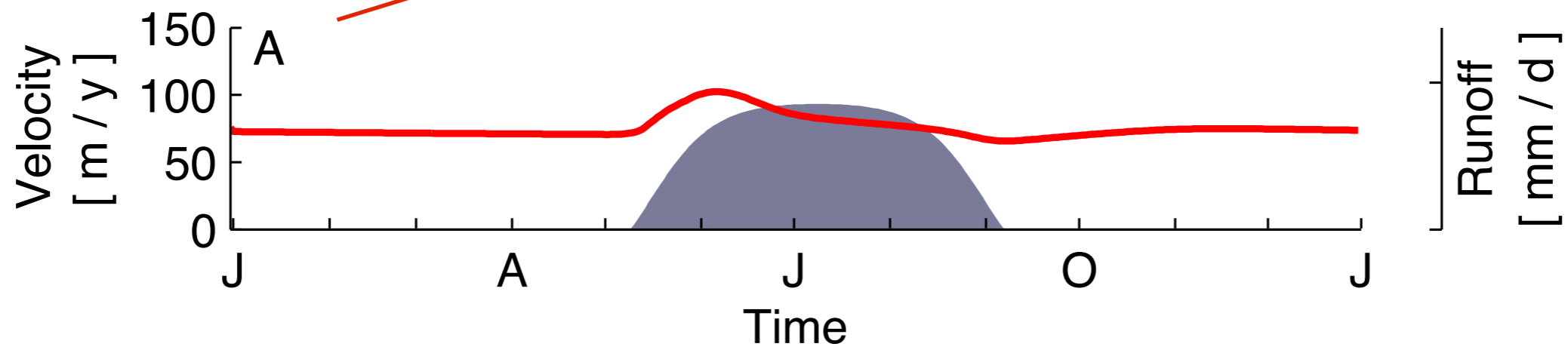
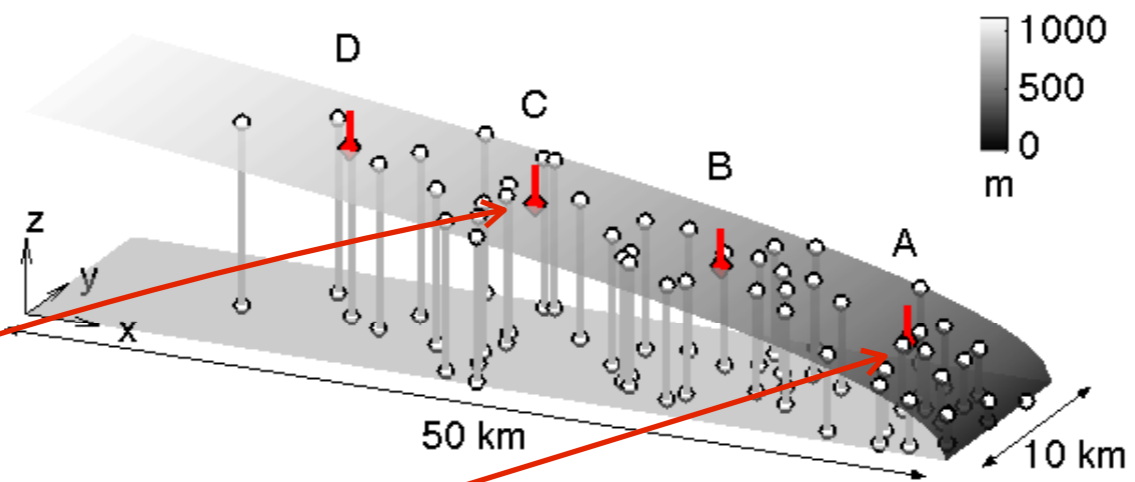
Surface runoff (rain + melt - retention) decreases linearly with elevation.

Runoff is collected from catchments and input to randomly distributed moulins.

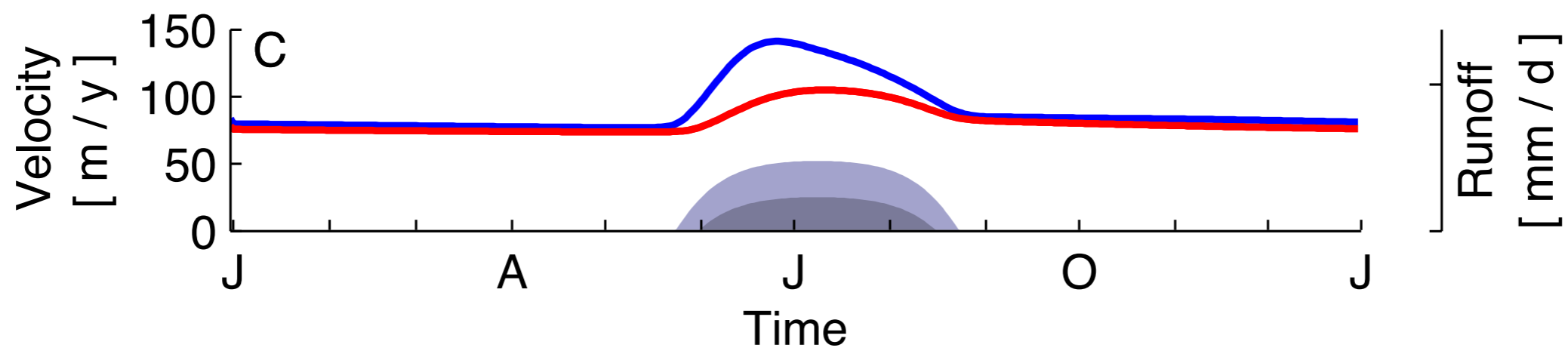
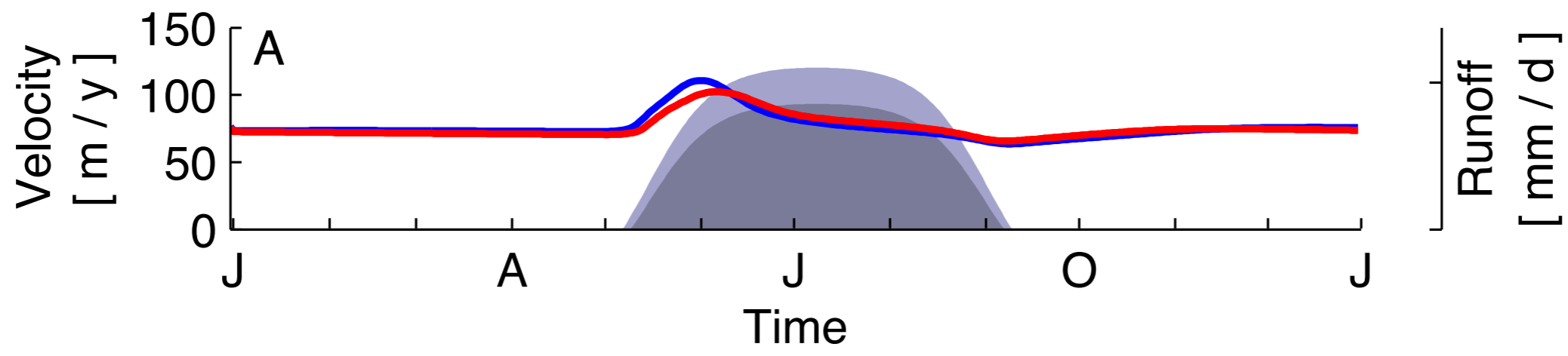
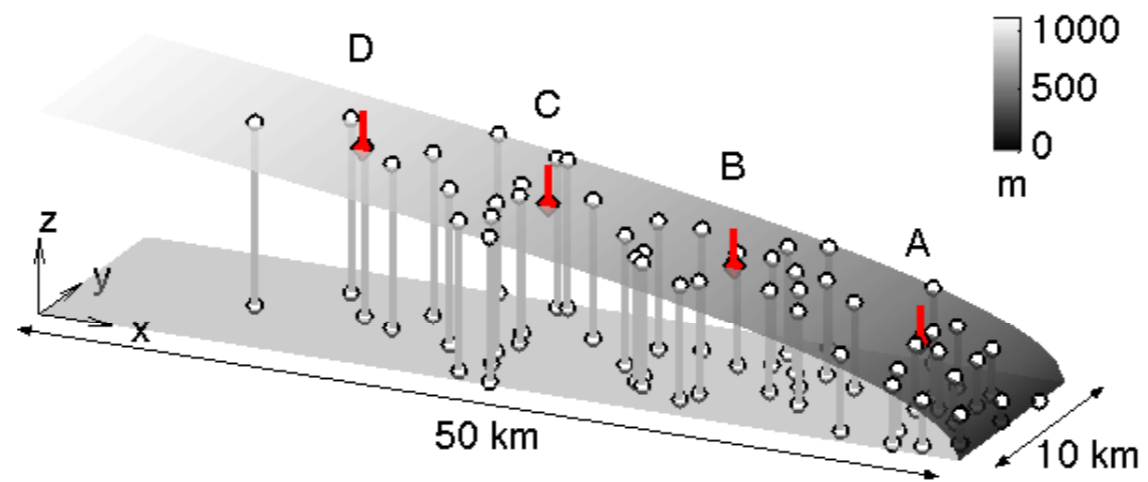
$$\text{Friction law } \tau_b = \mu U_b N$$



Surface velocity response

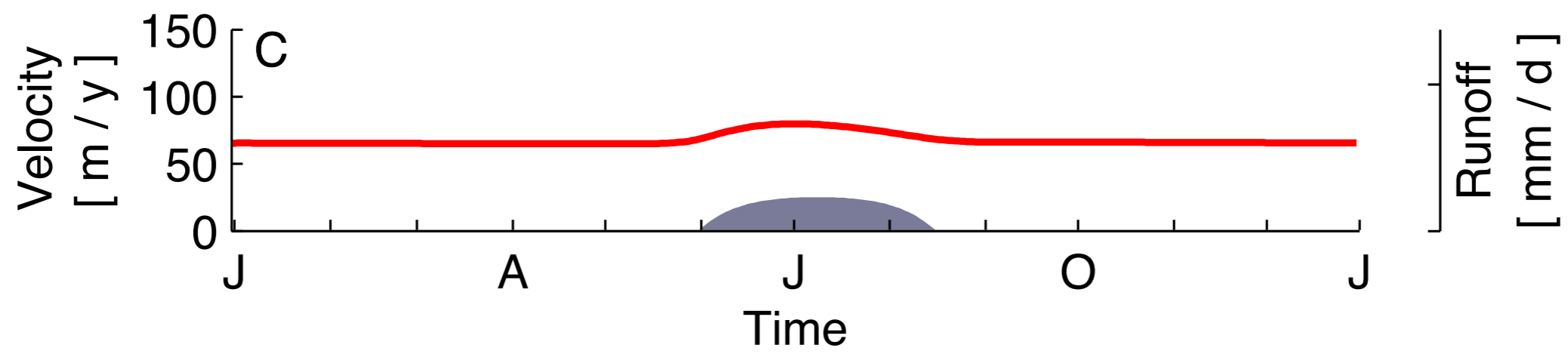
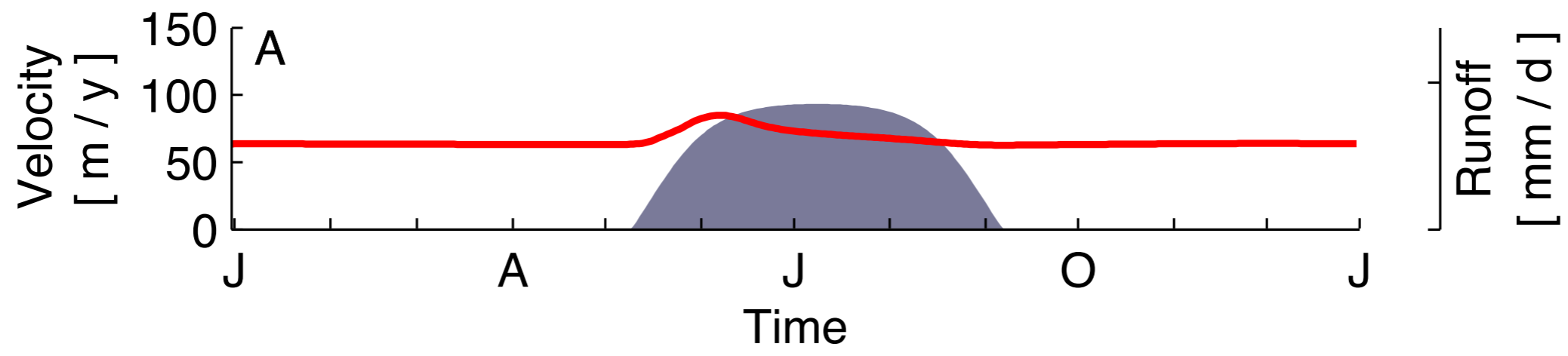
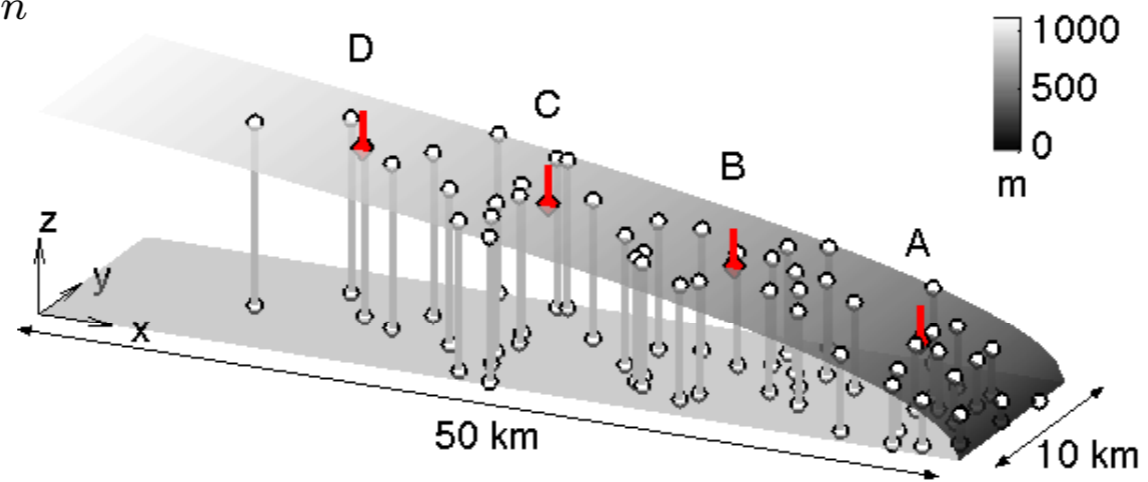


Increased surface melt

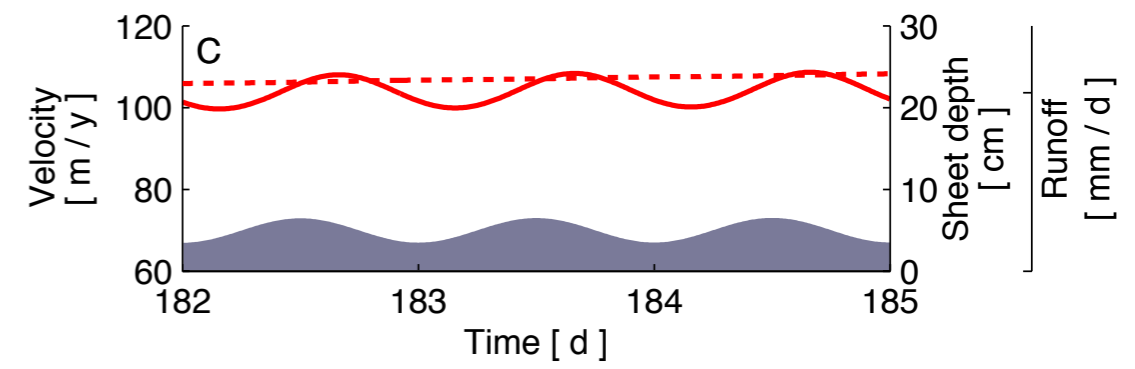
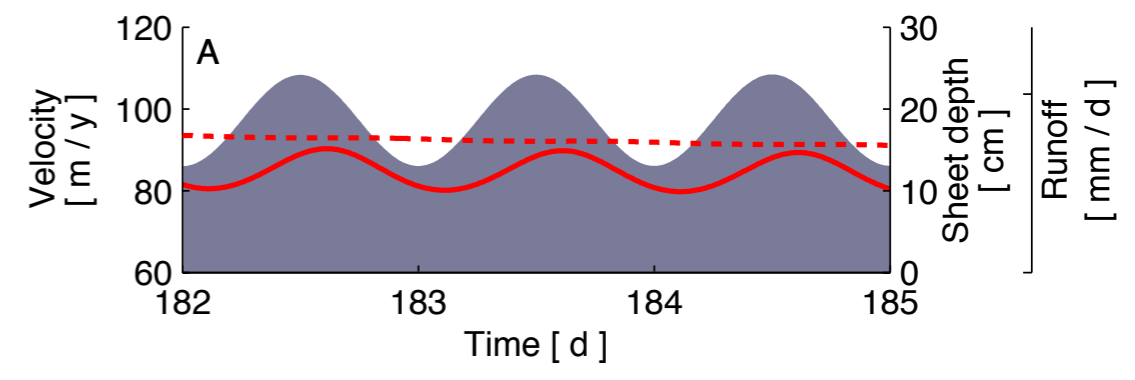
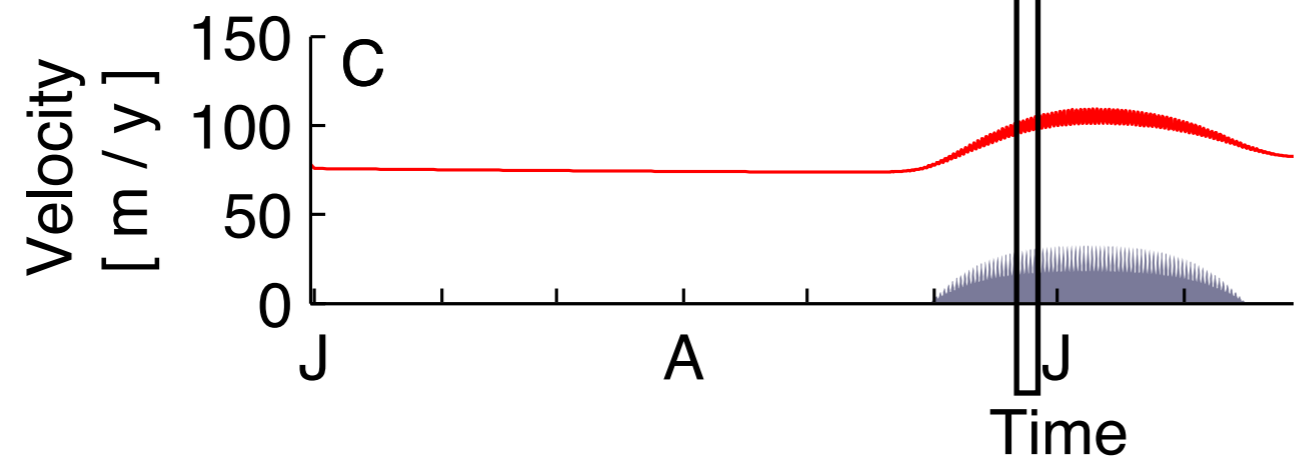
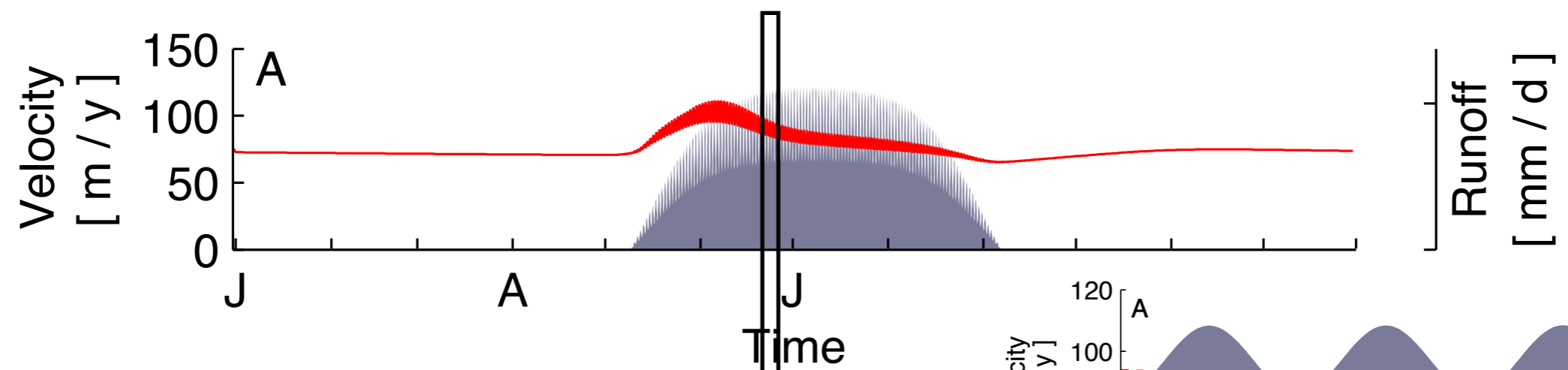
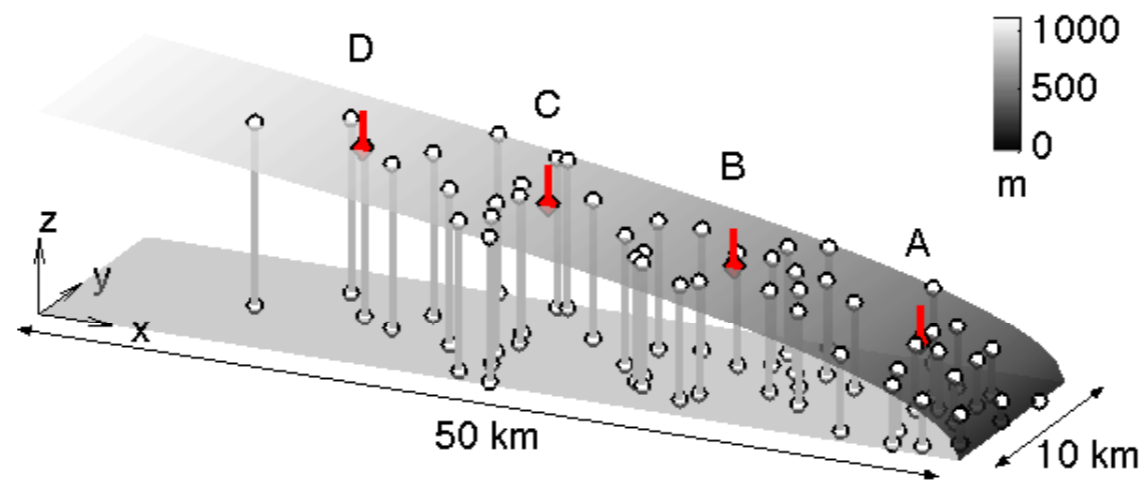


Cavity friction law

$$\tau_b = \mu N \left(\frac{U_b}{U_b + \lambda AN^n} \right)^{1/n}$$

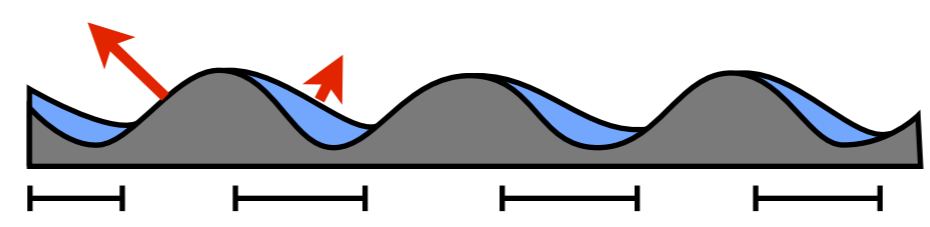


Diurnal modulation of runoff

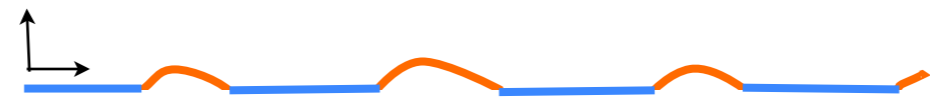


Cavitation

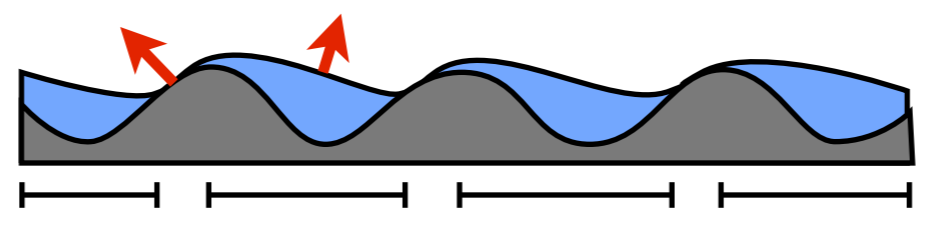
τ_b U_b



Normal stress



Increase water pressure



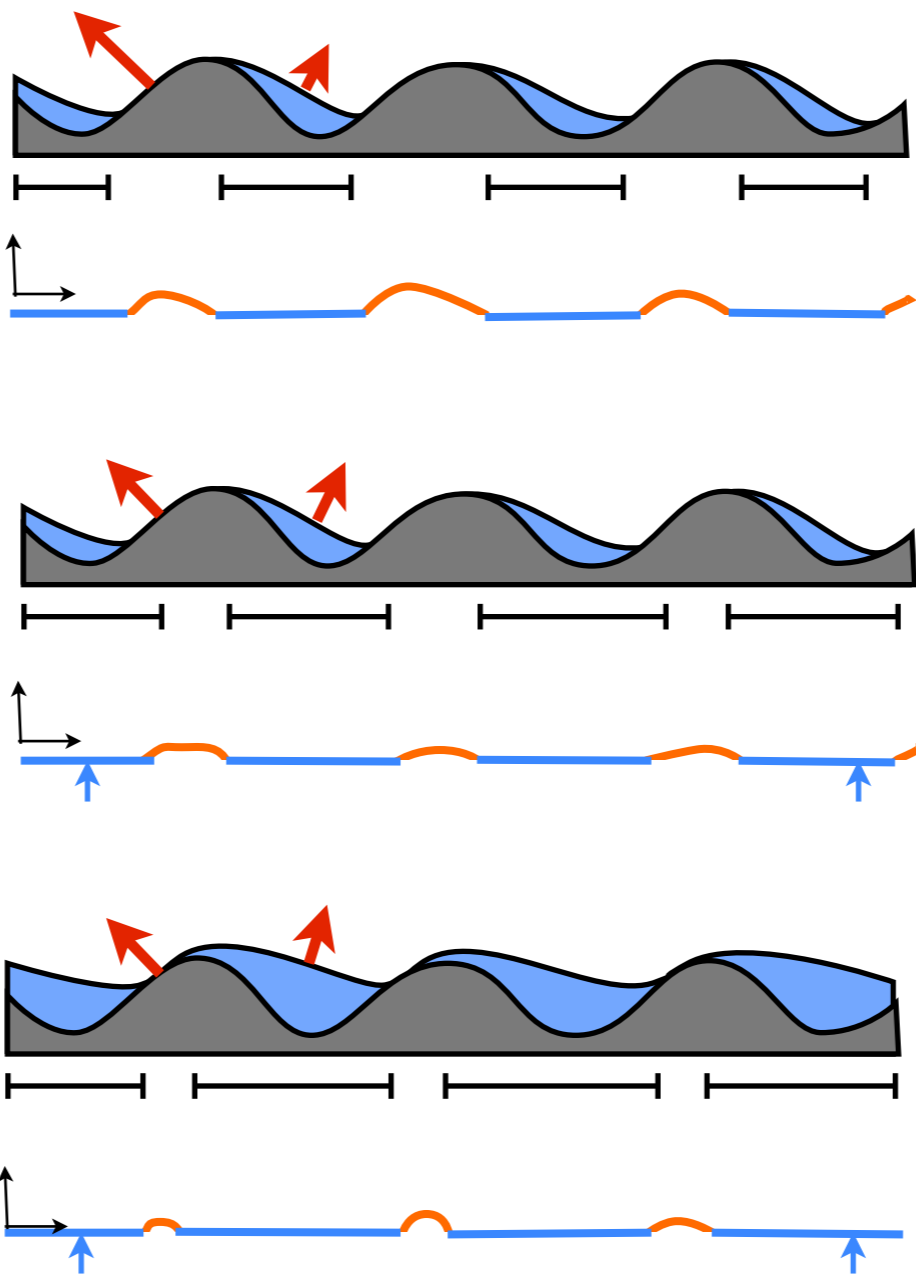
Cavitation

τ_b U_b

Normal stress

Increase water pressure

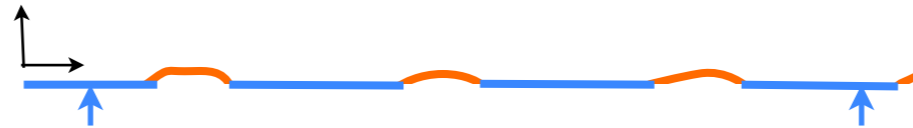
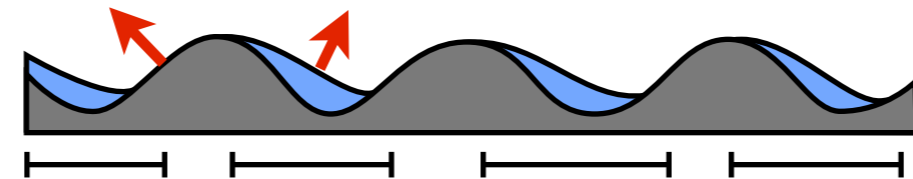
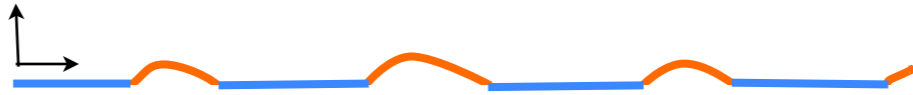
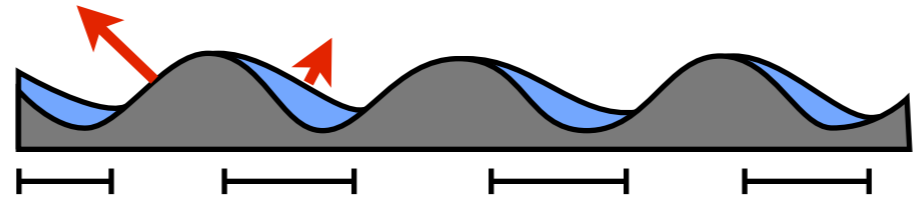
Growing cavities
Iken 1981



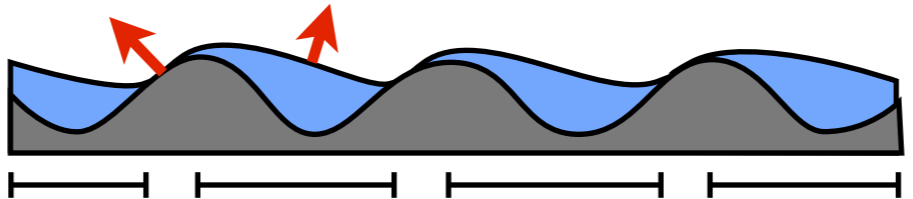
Cavitation

τ_b U_b

Normal stress



Increase water pressure



Growing cavities

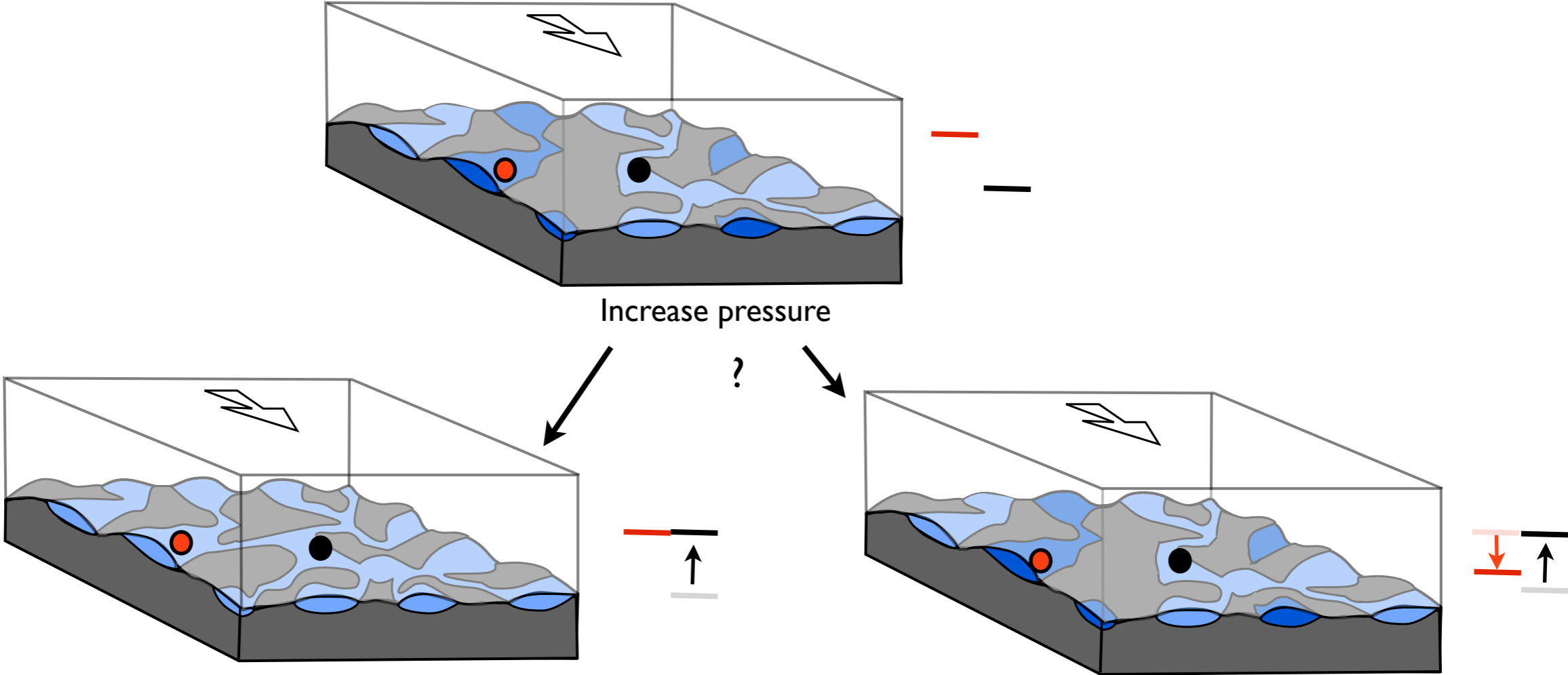
Iken 1981

$$\tau_b = f(U_b, N, \chi)$$

χ fractional cavitated area

Connectedness of the drainage system

Water pressure in the hydrology model is really an average over a **connected** drainage system. It cannot be expected to be the same as pressure in unconnected regions.



Comparison with borehole measurements is very difficult!

Summary

- Model combines an effective pressure-dependent friction law with calculation of water pressure in the subglacial drainage system. It can reproduce a range of observed ice behaviour. Quantitative evaluation is still needed.
- Important aspects of the model
 - evolution of the subglacial drainage system
 - feedback of sliding speed on the drainage system
- The assumption of local connectivity of the drainage system is almost certainly wrong. Observations suggest we should consider
 - transient cavitation
 - unconnected regions of the bed
- Understanding the coupling of meltwater and ice dynamics is also important for erosion and long term landscape evolution.

