Evolution of subglacial meltwater channels near ocean termini

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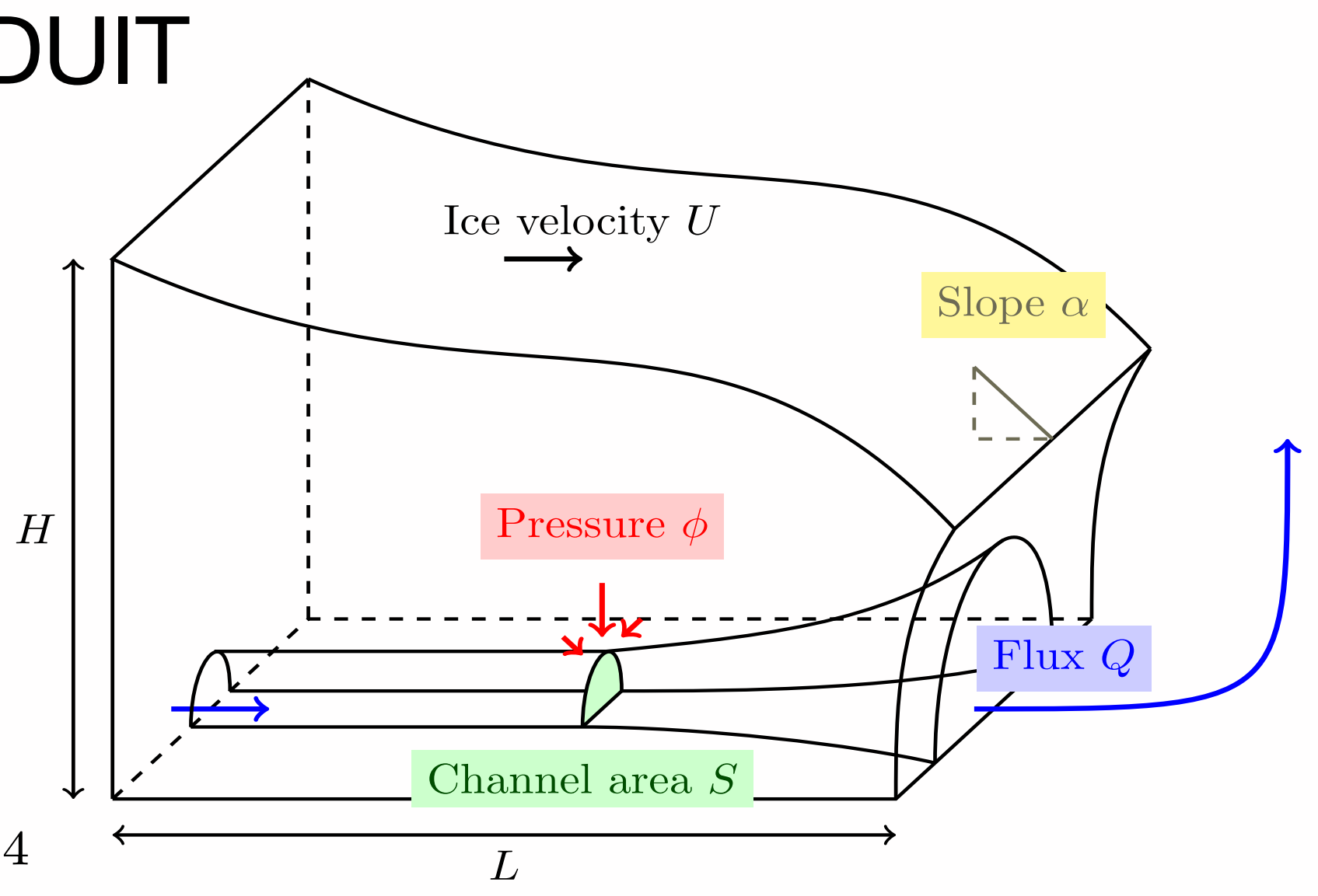
MOTIVATION

- ▷ Meltwater discharge from beneath glacier termini exerts a strong control on ocean dynamics and melting rates at the ice front.
- ▷ To explore the nature of this meltwater discharge, we model how subglacial conduits behave as they approach the margin.

BEHAVIOUR OF A SINGLE CONDUIT



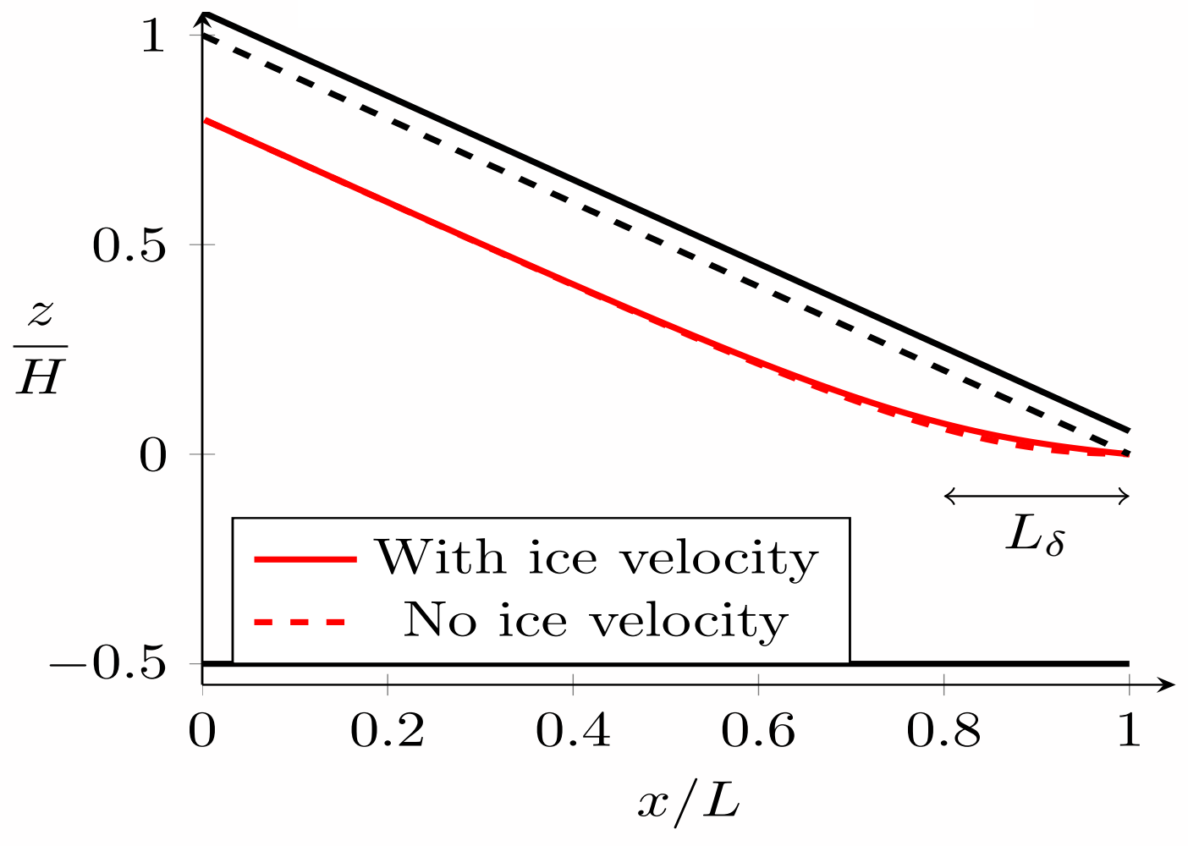
Creep closure is weak near the margin.

Cross-sectional area becomes large.
Mean water speed is reduced.

Conduits are advected with rapid ice flow.
Cross-sectional area at margin:

$$S = C(\alpha U)^{-9/44} Q^{9/11}, \quad C \approx 0.3\,\mathrm{m}^{-1/4}\mathrm{s}^{27/44}$$

Hydraulic potential

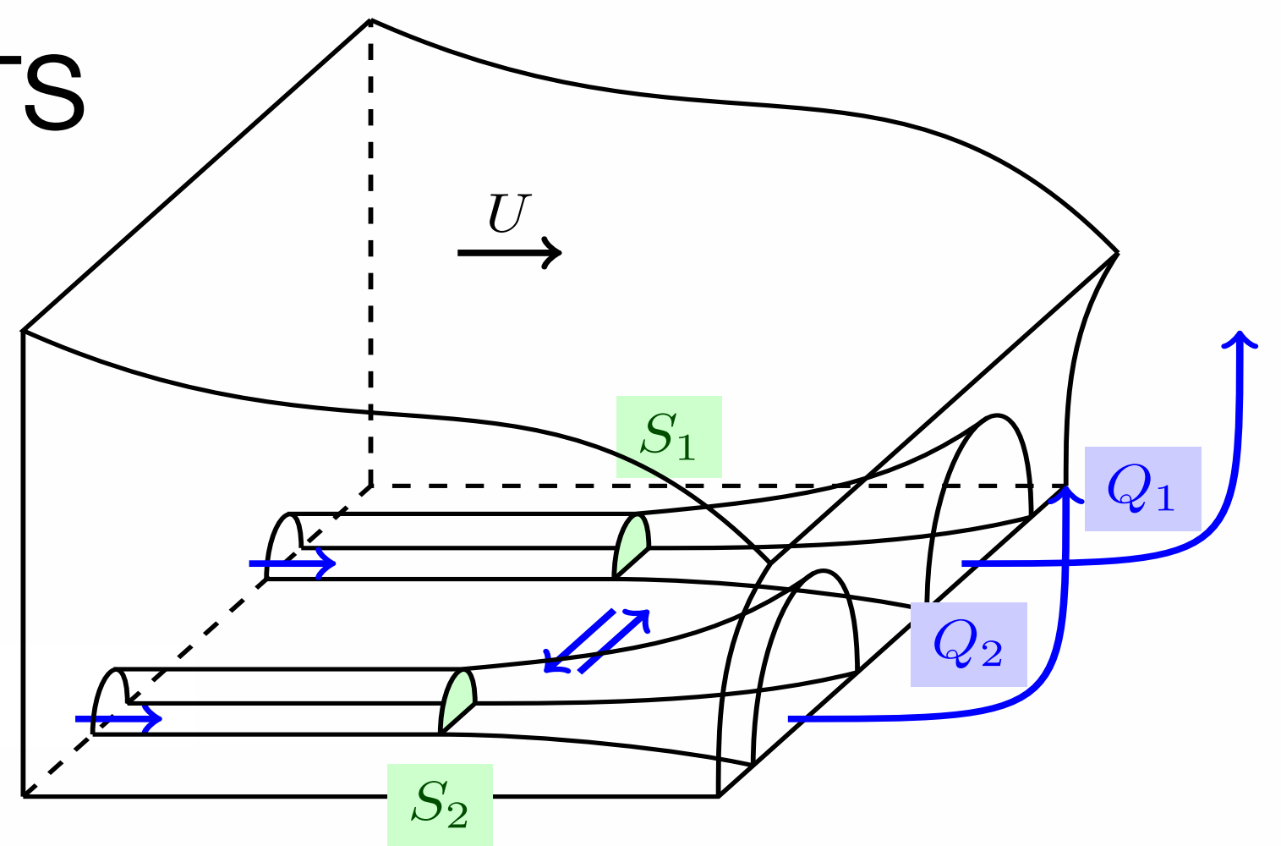


Representative values

	Q ($\mathrm{m^3\,s^{-1}}$)	S ($\mathrm{m^2}$)	Q/S ($\mathrm{m\,s^{-1}}$)
HELHEIM	1	4	0.2
$\alpha = 0.01$	10	27	0.4
$U = 8\mathrm{km\,yr^{-1}}$	100	179	0.6
JAKOBSHAVN	1	3	0.3
$\alpha = 0.02$	10	22	0.5
$U = 11\mathrm{km\,yr^{-1}}$	100	146	0.7

- ▷ Behaviour is very similar to land-terminating conduits. Primary difference is that marine terminating conduits must remain water-filled.

COMPETITION BETWEEN CONDUITS

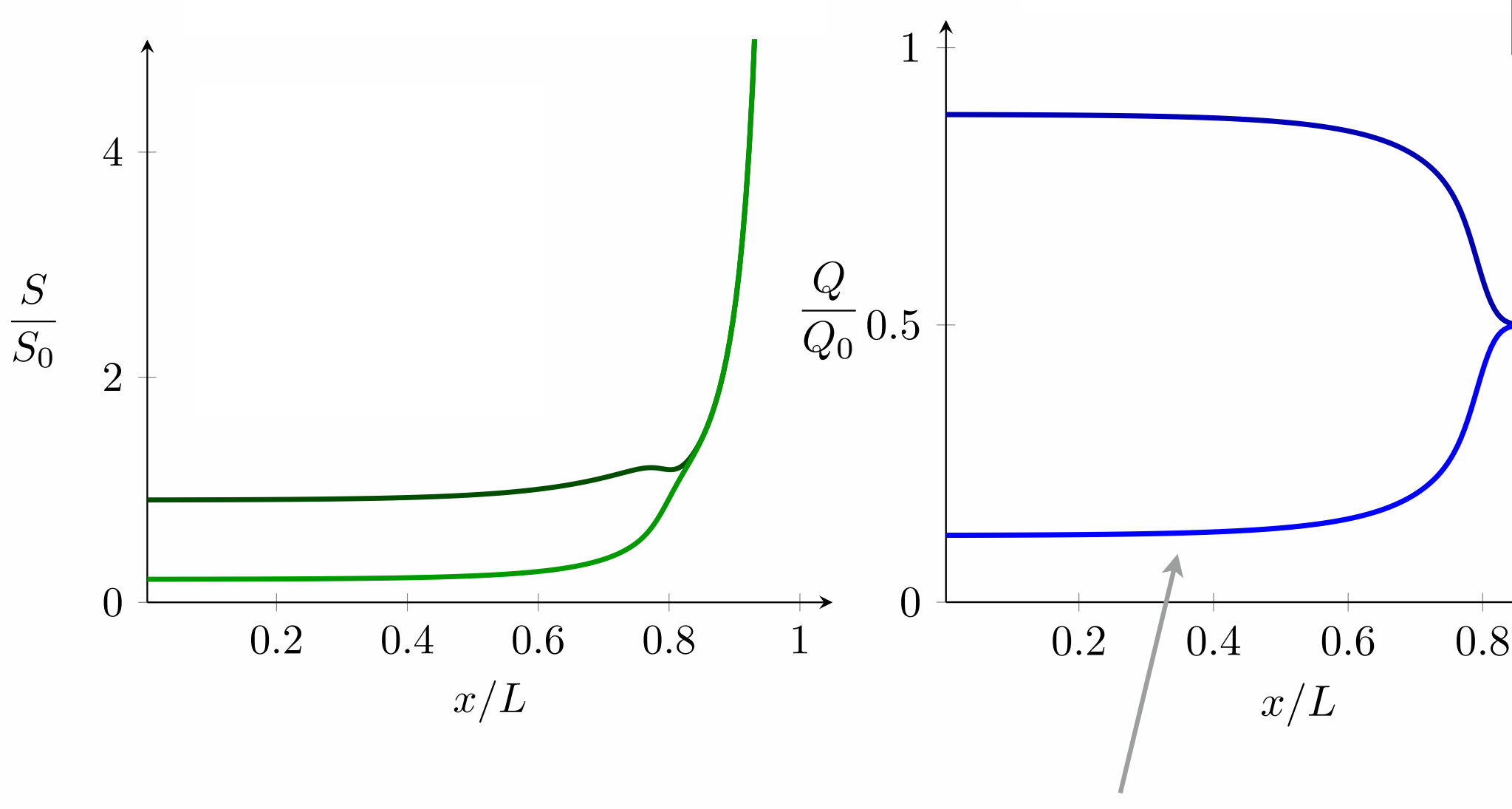


Consider discharge partitioned between two parallel conduits with efficient connection.

$$Q_1 + Q_2 = Q \qquad \phi_1 = \phi_2$$

Cross-sectional area

Discharge



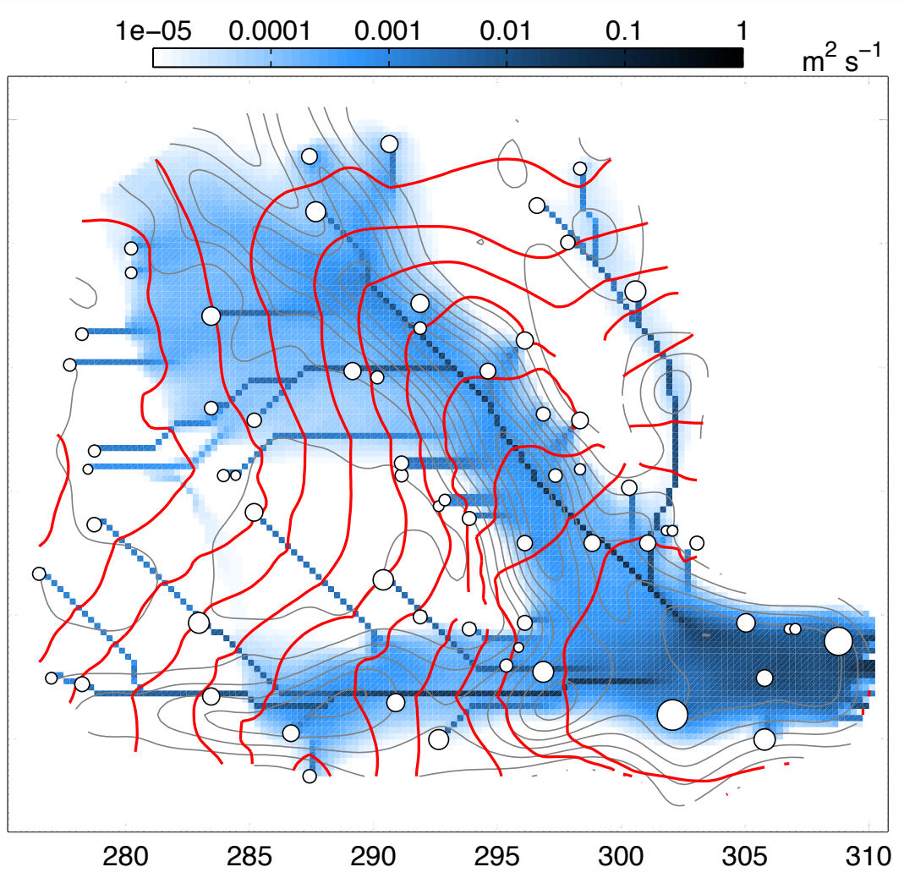
Dissipative heating reduced. Conduits become the same size and share the discharge.

Channelization due to dissipative heating. One conduit carries most of discharge.

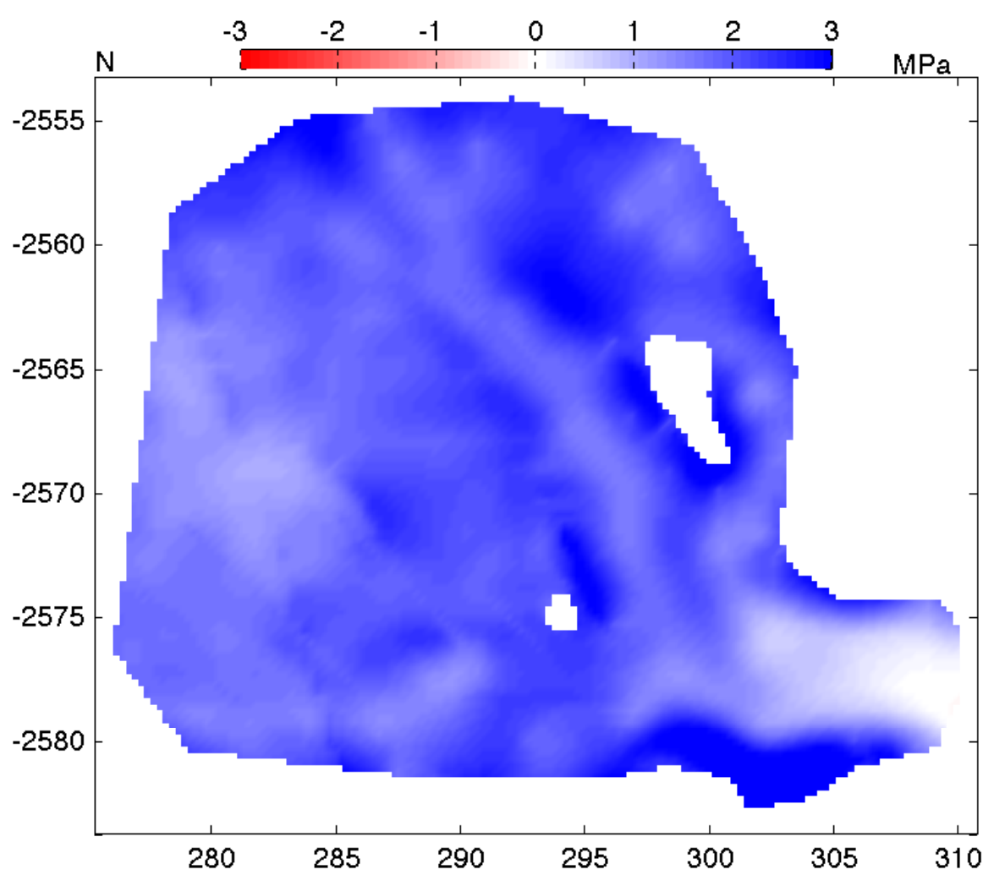
APPLICATION TO HELHEIM GLACIER

Prescribed ice and basal topography, sliding speed, and meltwater source. Calculated subglacial water flow and effective pressure.

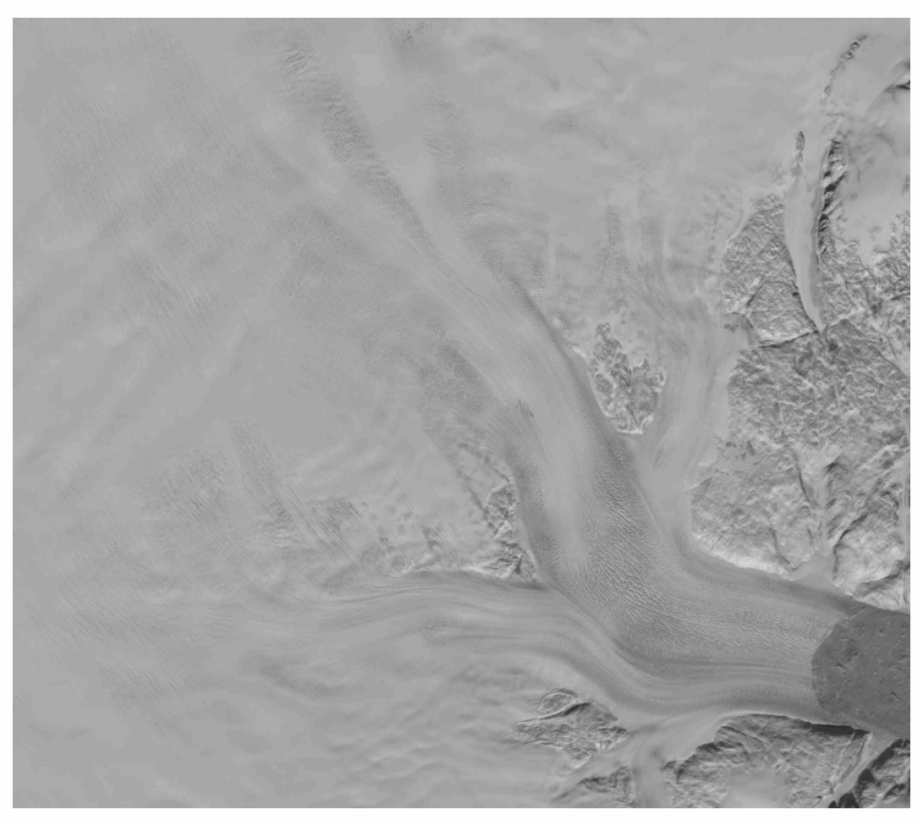
Discharge



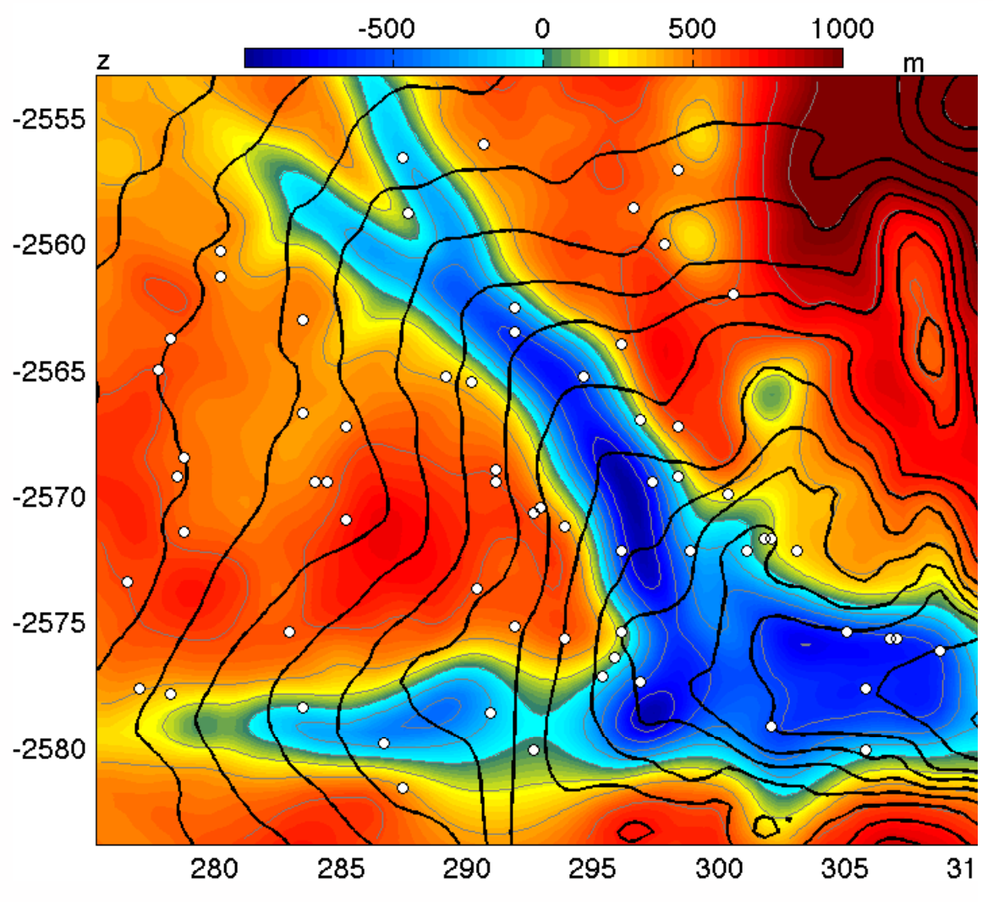
Effective pressure



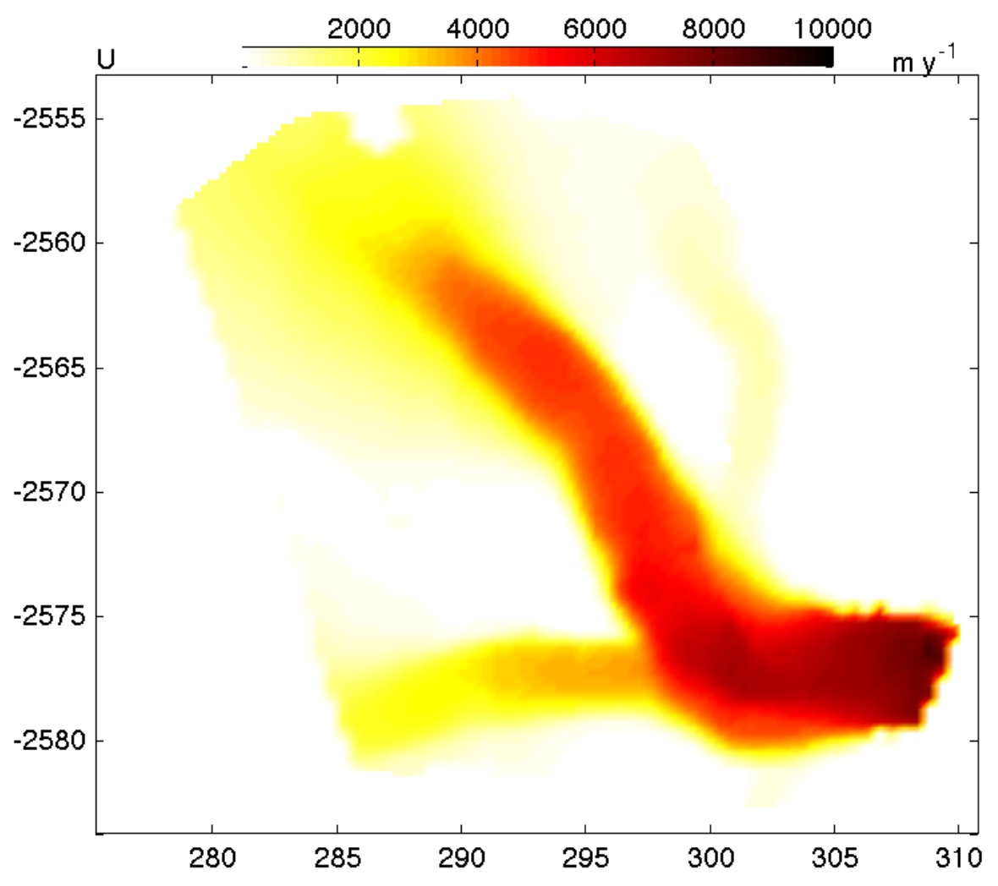
Satellite



Bed & surface elevation



Ice speed



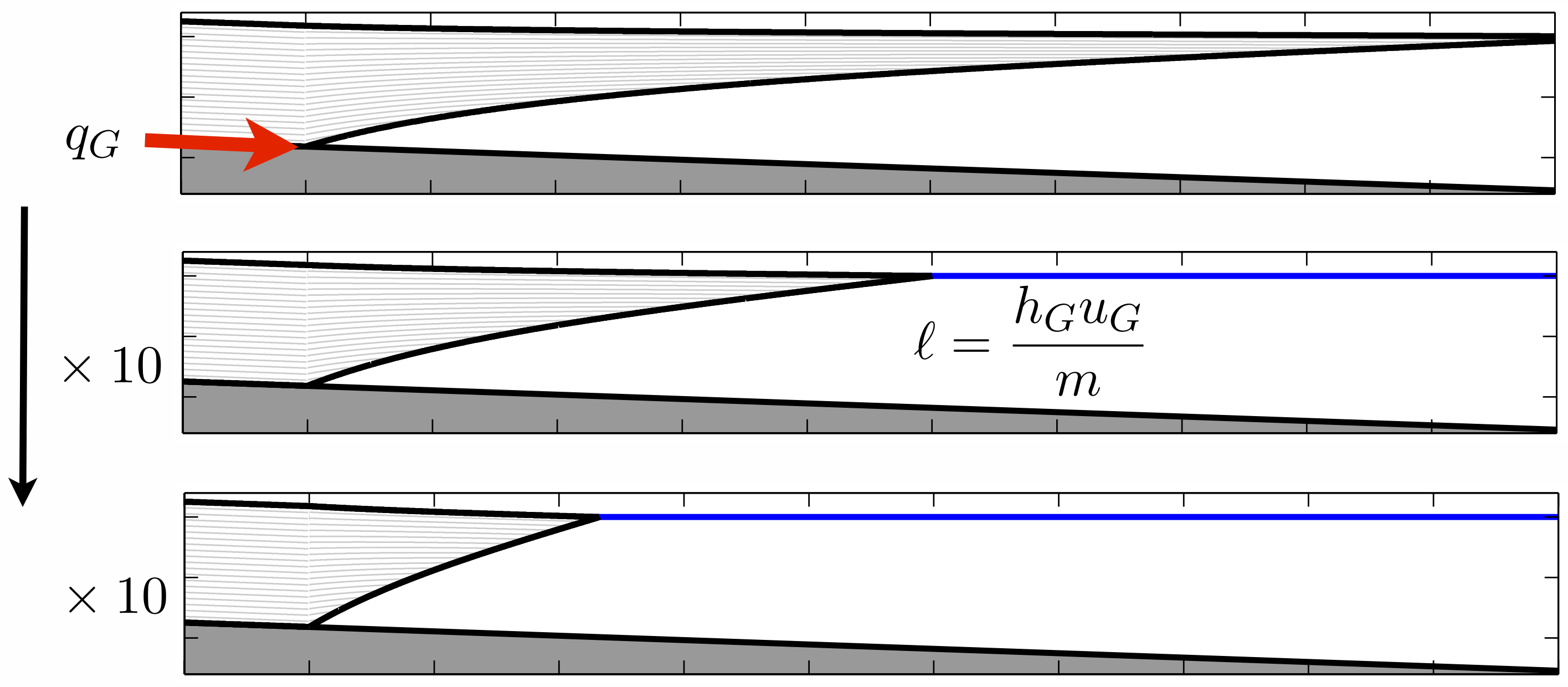
CONCLUSIONS

- ▷ Supraglacial runoff to moulins provides dominant subglacial outflow.
- ▷ Conduits grow near the margin due to low effective pressure. Ice advection prevents them becoming too large.
- ▷ Rapid sliding typical of outlet glaciers may inhibit channelization.
- ▷ Topography likely to be the primary control on spatial distribution of outflow.

MELTING OF THE ICE FRONT

A simple plume model suggests melting of the ice front scales with subglacial discharge:

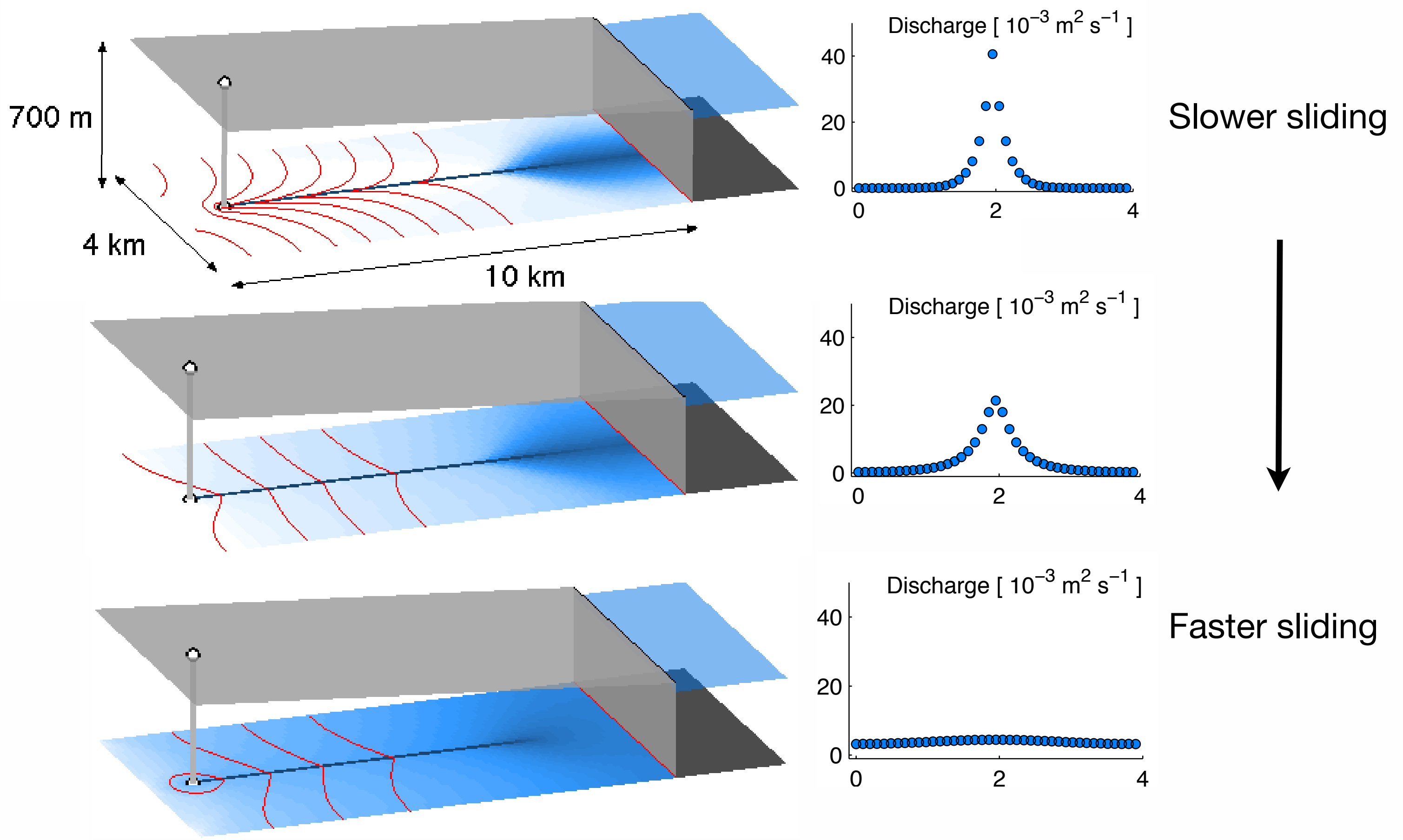
$$m = \frac{\gamma_T c T_a}{L}\left(\frac{\beta_S S_a g}{E_0}\right)^{1/3} q_G^{1/3}$$



- ▷ Lateral distribution of subglacial discharge is key. Melting is largest for widely dispersed discharge.

BEHAVIOUR OF A CONDUIT NETWORK

Faster sliding promotes opening of drainage pathways and results in more distributed outflow.



CONDUIT MODEL

Water conservation $\quad \dfrac{\partial S}{\partial t} + \dfrac{\partial Q}{\partial x} = M$

Turbulent flow $\quad Q = K_c S^{4/3} \left|\dfrac{\partial \phi}{\partial x}\right|^{1/2}$

Advection Melting Sliding Creep closure

$$\frac{\partial S}{\partial t} + U_b \frac{\partial S}{\partial x} = \frac{\rho_w}{\rho_i} M + U_b h_r - A S N^n$$

Melting $\quad M = \dfrac{1}{\rho_w L}\left|Q \dfrac{\partial \phi}{\partial x}\right|$

Effective pressure $\quad N = \rho_i g Z_s - \phi$

METHODS

The conduit network models are based on that of Hewitt (2013), with conduits arranged to connect nodes on a square lattice along 8 compass points. Each conduit incorporates the potential for both cavity-like and channel-like behaviour as described by Schoof (2010). Effective pressure is prescribed to be zero at the ocean margin, no-flux is prescribed on other boundaries, a small basal melting rate is prescribed everywhere, and steady point sources are prescribed for moulins.

The simplified plume model is similar to that discussed by Jenkins (2011); it assumes uniform salinity and temperature of ocean water. Melting is limited by the turbulent transfer of heat from the plume to the ice interface, which is assumed to be proportional to the mean water speed. That speed is governed by a balance between buoyancy and entrainment and is approximately constant, determined by the buoyancy source provided by the subglacial discharge. Given the uniform melt rate, a reduced ice flow model allows a steady ice shelf shape to be found (e.g. MacAyeal & Barcilon, 1988).

REFERENCES

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