Coupling Glacial Hydrology into a High-order Numerical Ice Model

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Introduction

A new high-order flow-band model with coupled subglacial hydrology is used to explore the drainage of supraglacially-stored water through englacial fractures and assess the influence of this water on glacier dynamics.

Model

Flow-band

One horizontal dimension (in the direction of the ice flow), one vertical dimension, and a parameterization of the width across the flowline.

High-order Stress Components

The model incoporates a multilayer longitudinal stress scheme following [1] and [2]. The vertical normal stress is assumed to be hydrostatic $\frac{\partial \sigma_{zz}}{\partial z} = \rho_i g$ with the pressure (the sum of the normal stresses) departing from the hydrostatic pressure by the longitudinal deviatoric stress

$$P_i = \sigma'_{xx} + \sigma'_{yy} - \rho_i g(s - z).$$

Basal Sliding Rule

$$u_b = A_s \tau_d^3 (P_i - P_w)^{-3.5}$$

Coupled Hydrology

Solve coupled nonlinear partial differential equation for subglacial water drainage [3].

$$\frac{\partial h^s}{\partial t} + \frac{\partial Q}{\partial x} = \frac{Q_G + u_b \tau_b}{\rho L} + M_b,$$

h^s denotes the subglacial water sheet thickness, the water flux is given by

$$Q = -\frac{K h^s}{\rho_w g}\frac{\partial \phi}{\partial x},$$

with fluid potential $\phi = P_w + \rho_w g b$ and hydraulic conductivity $K = K(h^s)$. The water pressure, P_w, is calculated by

$$P_w = P_i \left(\frac{h^s}{h^s_c}\right)^{7/2},$$

where h^s_c is the critical water sheet thickness.

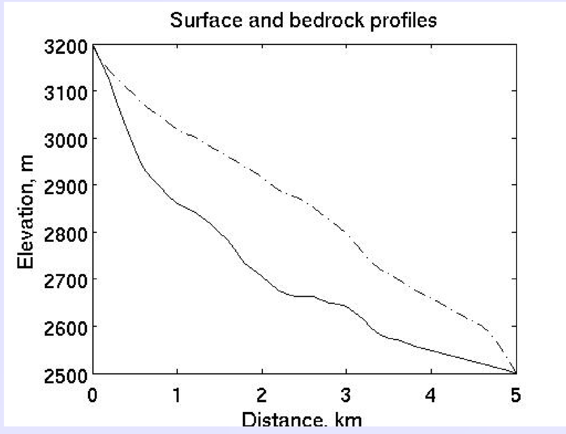
We model vertical fracture propagation using linear elastic fracture mechanics [4].

Intercomparison

Intercomparison exercises have been used to examine model performance together with analytical solutions under simplifying assumptions.

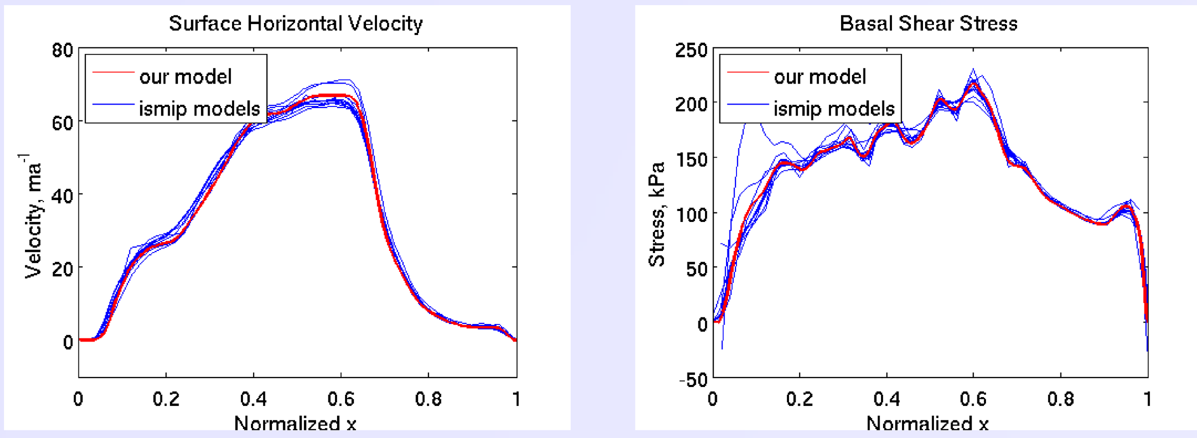
ISMIP-HOM Experiment E: Haut Glacier d'Arolla

Comparison with Ice Sheet Model Intercomparison Project - High Order Models (ISMIP-HOM) [5].

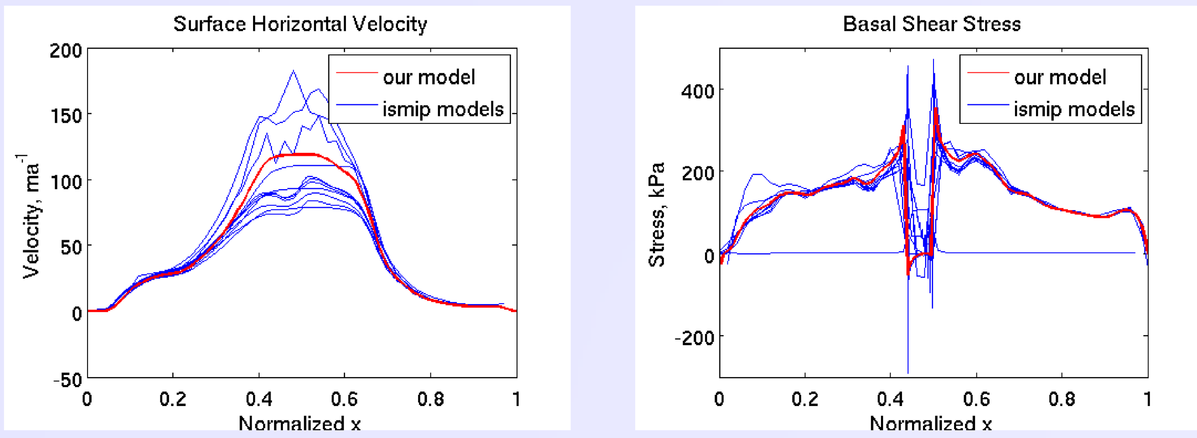


Solve the velocity/stress solution of the non-linear force-balance equations using a fixed geometry and isothermal conditions.

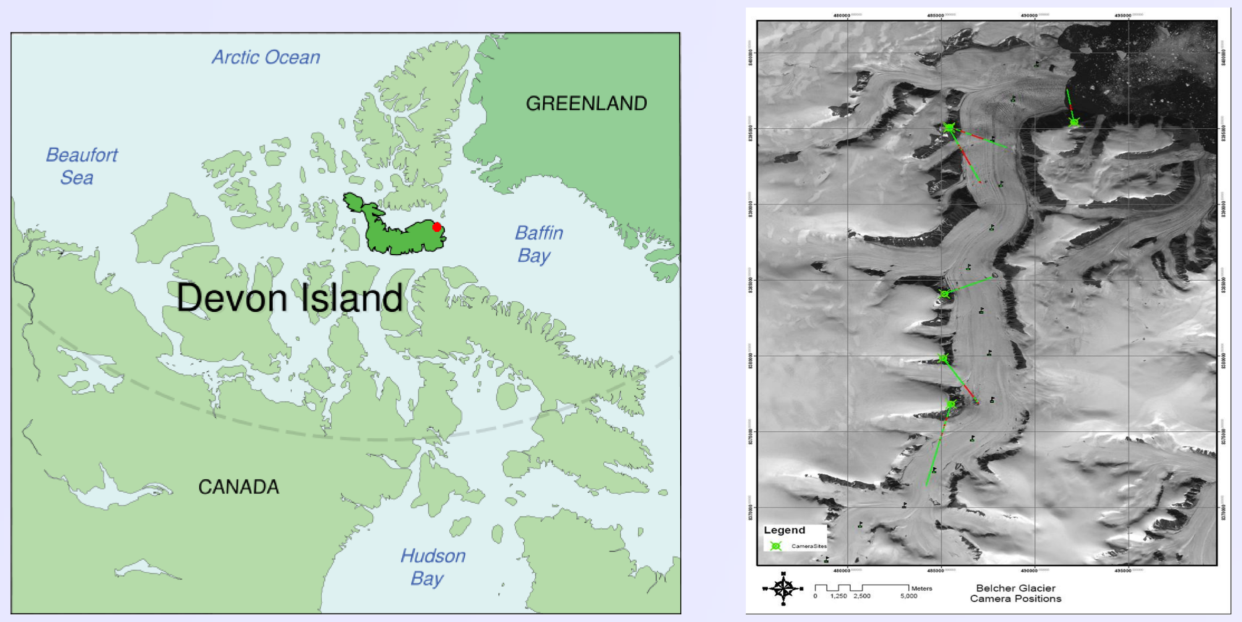
a) No Sliding



b) Sliding



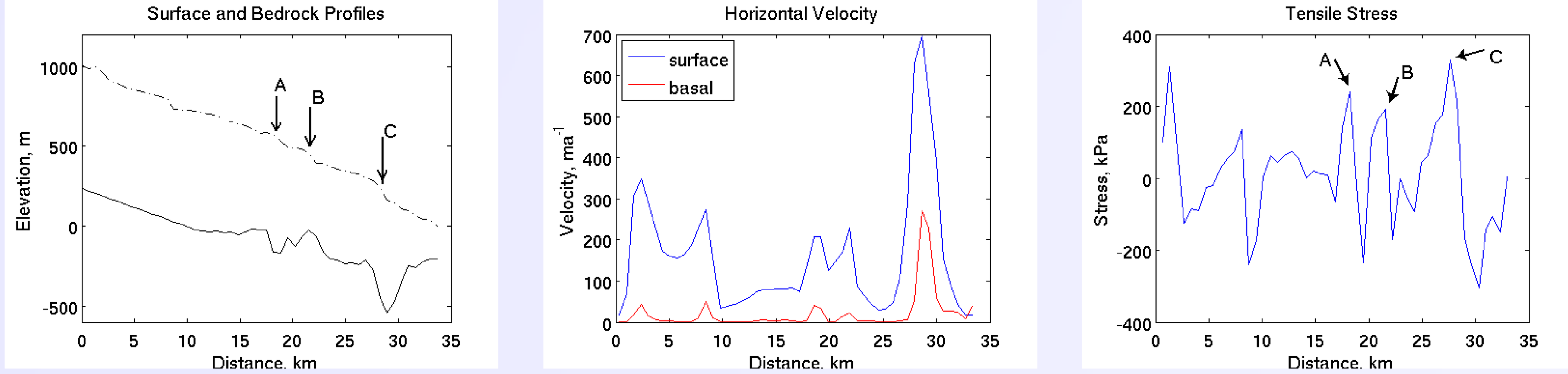
Belcher Glacier on Devon Island



The Belcher Glacier is the largest outlet glacier of the Devon Island Ice Cap in the Canadian Arctic. This is a large, fast-flowing, tidewater glacier that shares similarities with many Greenland outlet glaciers.

Results

A preliminary Belcher bedrock and surface profile is used as a basis for investigating fracture propagation and the effects of subglacial drainage on glacier velocities.



Englacial fracture occurs when the stress intensity factor at the crevasse tip equals the fracture toughness of the glacier ice. The injection of supraglacially-stored meltwater into this fracture causes downward propagation to occur and can lead to the fracture reaching the bed.

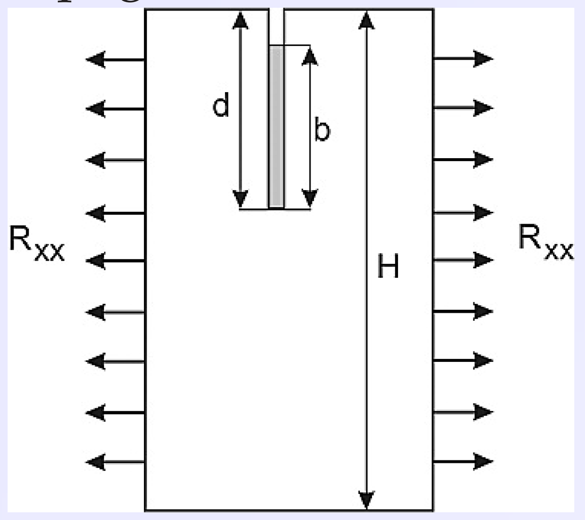
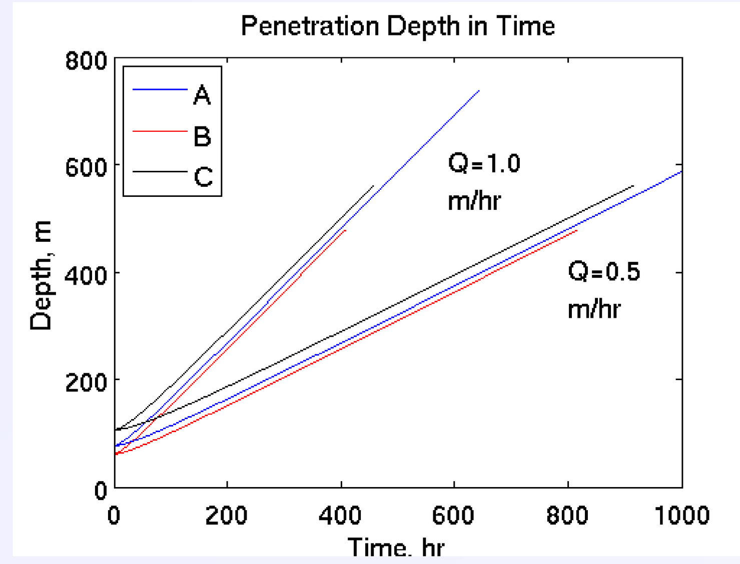


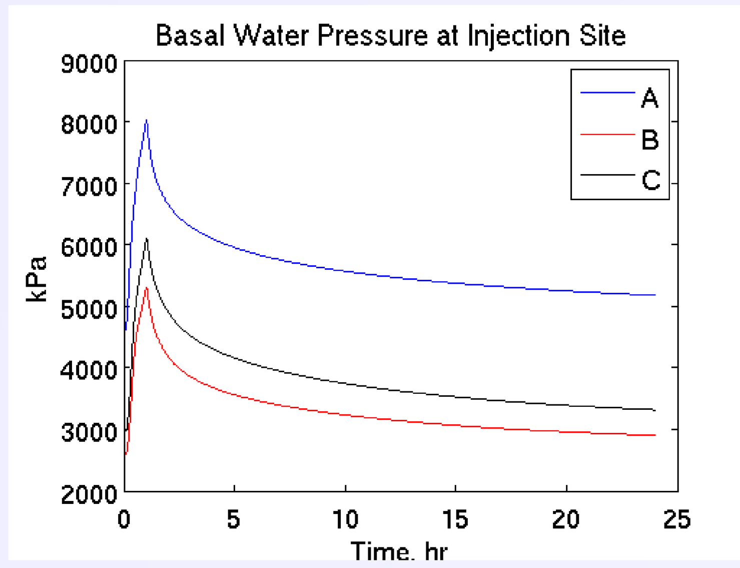
Diagram reproduced from [4]

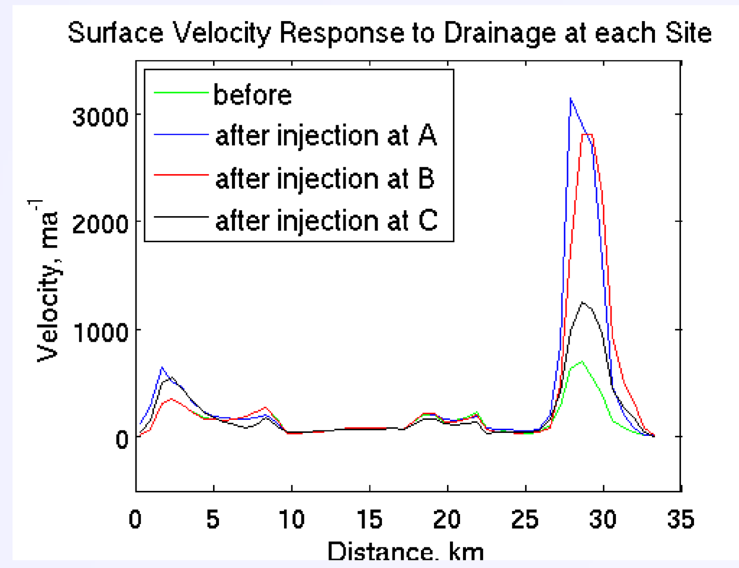
R_{xx} tensile stress
H = ice thickness
d = fracture depth
$b = Q \times t$ = water level in crevasse
Q = constant water inflow
t = time
$R_{xx} = 240, 193, 328$ kPa at A, B, and C
$H = 737, 477, 561$ m at A, B, and C



Once connection to the bed is made the meltwater lake drains rapidly, lubricating the sole of the glacier, causing horizontal acceleration.

We allow a rapid drainage of $126\,m^3s^{-1}$ for an hour. This amounts to the emptying of a meltwater lake of $453600\,m^3$. The model is run for a further 23 hours to monitor transient effects.





With the input of this subglacial water at locations A, B, and C the surface velocities after 24 hours have increased by 130%, 112%, and 37% respectively.

Future Directions

We will explore theoretically possibilities of modeling surface uplift effects resultant from hydrological drainage. A new improved DEM for the Belcher Glacier together with GPS data of short-term vertical and horizontal accelerations will be used to initialize and validate our model and gain a greater understanding of Belcher's dynamics.

References

[1] Blatter, *J. Glaciol.*, 41:333-344, 1995; [2] Pattyn, *J. Glaciol.*, 48:467-477, 2002; [3] Flowers et al., *J. Glaciol.*, 49:257-270, 2003; [4] van der Veen, *Geophys. Res. Lett.*, 34:L01501, 2007; [5] Pattyn et al., *The Cryosphere*, 2, 2008.

Acknowledgements

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