A Hydrologically coupled high-order flow-band model of ice dynamics

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Aims

GLACIODYN

A new high-order flow-band model with coupled subglacial hydrology has been developed and will be used to explore the drainage of supraglacially-stored water through englacial fractures and assess the influence of this water on glacier dynamics including at the Belcher glacier system.

Model Description

High-order stress components

- The model incoporates a multilayer longitudinal stress scheme following (Blatter, 1995) and (Pattyn, 2002)
- This provides a good description of glacier flows that experience slow and fast sliding (Schoof & Hindmarsh, 2009)
- Longitudinal stretching plays a leading order role when basal sliding and bed topographic variations are considerable, e.g. at the Belcher

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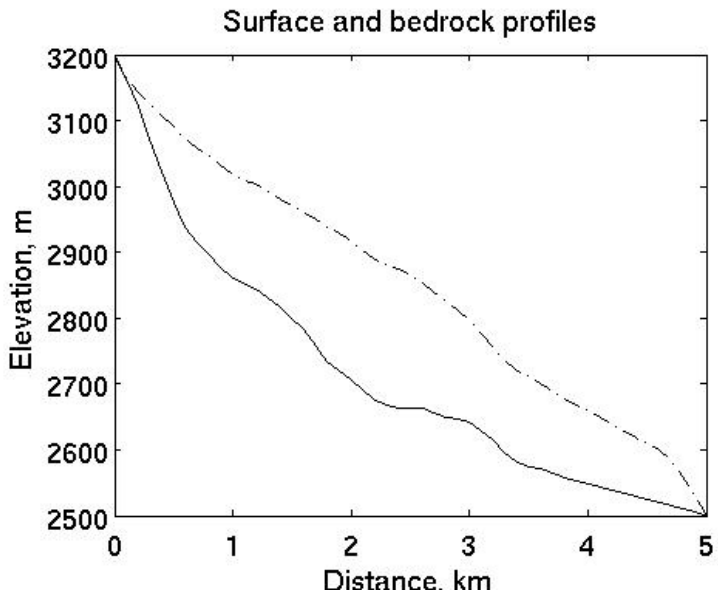
Model Comparison

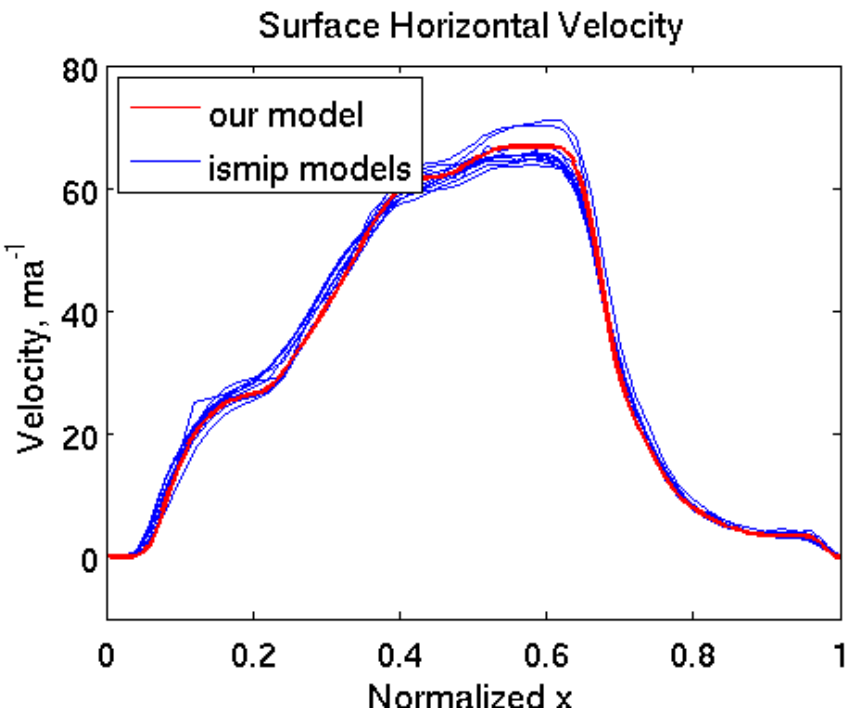
ISMIP-HOM Experiment E: Haut Glacier d'Arolla

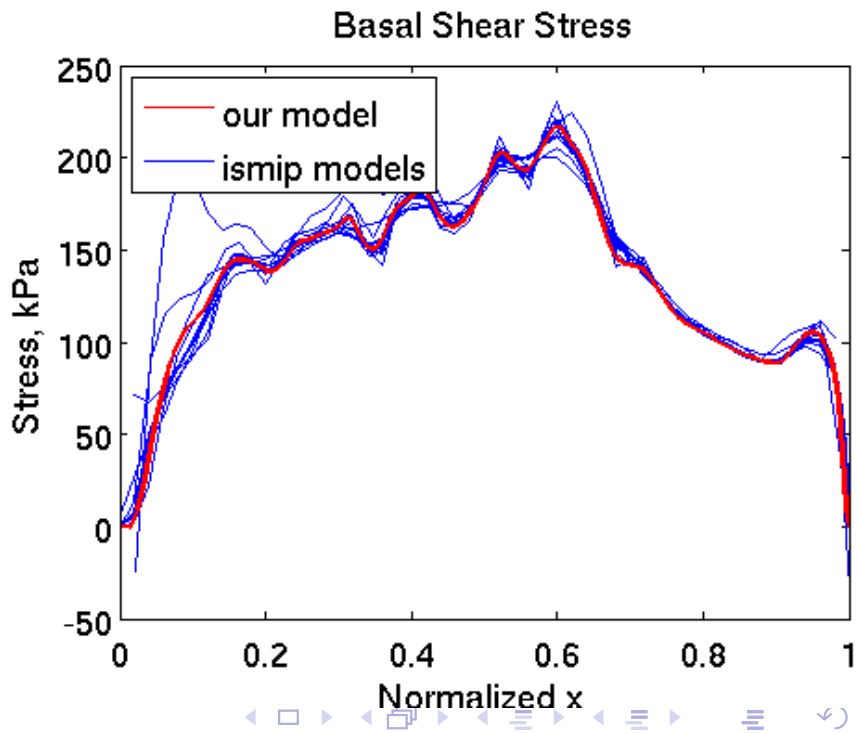


- test the velocity/stress solution of the non-linear force-balance equations
- use fixed geometry
- no-slip basal b.c.
- isothermal

ISMIP-HOM results taken from (Pattyn et al., 2008)

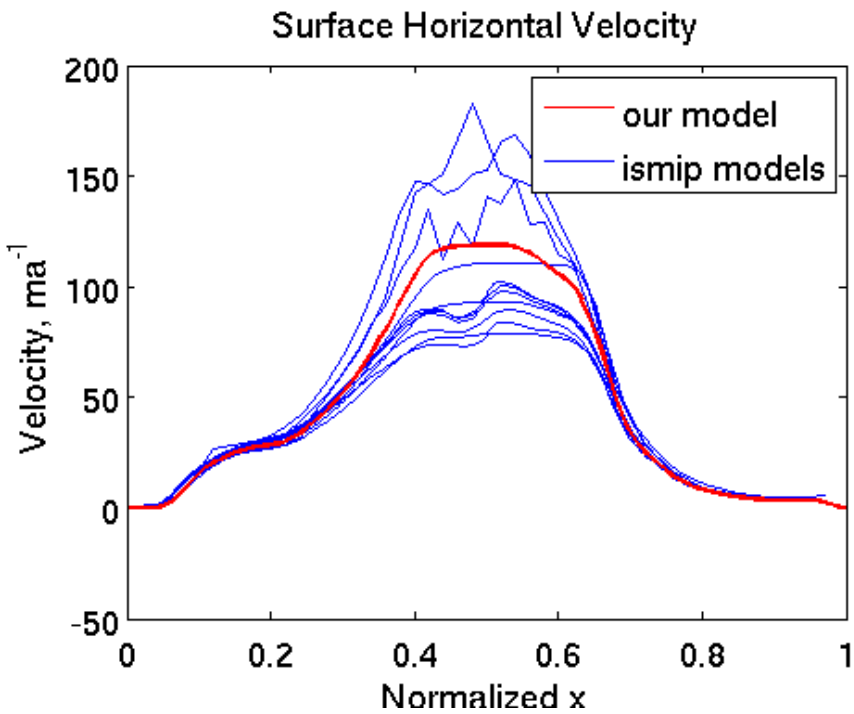
Without Basal Sliding

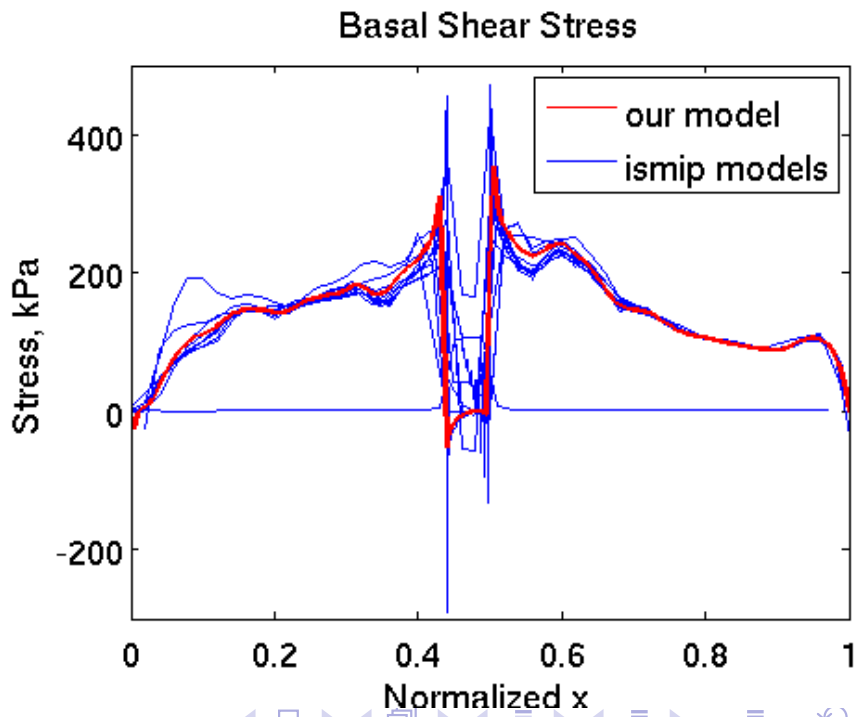




ISMIP-HOM results taken from (Pattyn et al., 2008)

With Local Basal Sliding





Subglacial hydrology

An interacting “fast” and “slow” subglacial drainage system is implemented (Flowers, 2008)

- **Fast drainage:** Comprises ice-walled conduits, characteristic of summer
- **Slow drainage:** Consists of a macroporous water sheet, characteristic of winter

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Sliding law

- The hydrology is coupled to the ice mechanics by use of a Coulomb friction law (Schoof, 2005)
- This is a pressure dependent sliding rule utilizing the spatial and temporal variations in basal water pressure from the hydrology sub-model
- Overcomes problem of standard sliding laws that allow arbitrarily large basal shear stresses regardless of effective pressure
- Implemented as a non-linear Robin-type boundary condition which cannot be solved independently but forms part of the solution to the ice-flow problem

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Lateral drag parameterization

- This is a 2-D model, but incorporate the effects of three dimensional geometry
- Vertically resolved lateral shear stress is incorporated into the force-balance equations by use of a new parameterisation
- Lateral shear stress in the model is influenced by:
  - Vertically resolved sliding along the glacier wall which is described by the Coulomb friction law
  - Basin shape

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Additional features

- **Englacial fracture:** Linear elastic fracture mechanics (van der Veen, 2007) used for crevasse propagation
- **Uplift**
  - When large amounts of water impinge on the glacier bed high water pressures are generated and cause flexure of the overlying ice
  - This uplift effect is modelled by treating the glacier as a uniform static beam
- **Surface evolution:** Mass balance equation
- **Thermomechanical coupling:** Advective-Diffusive heat equation

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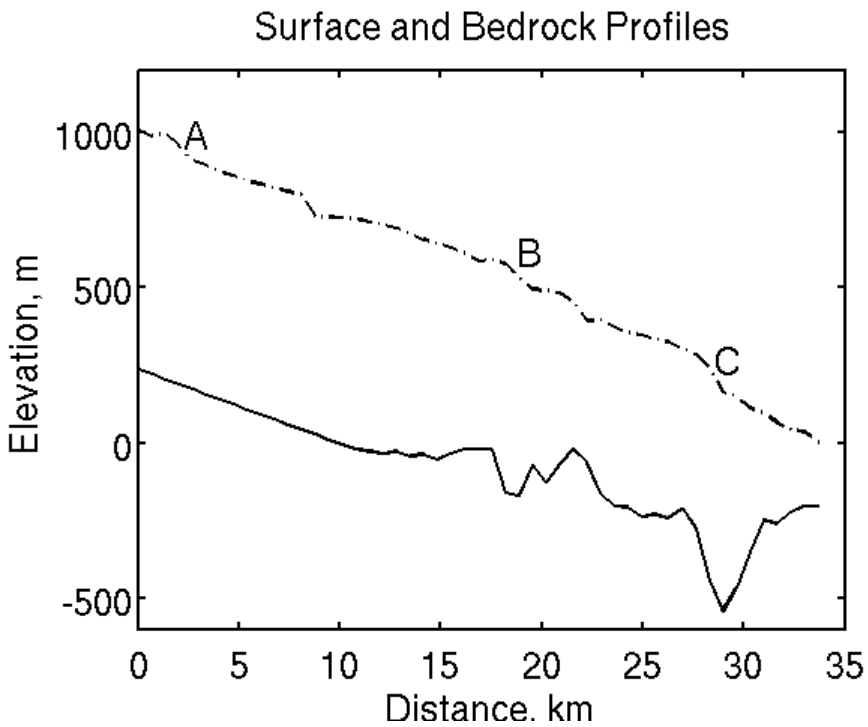
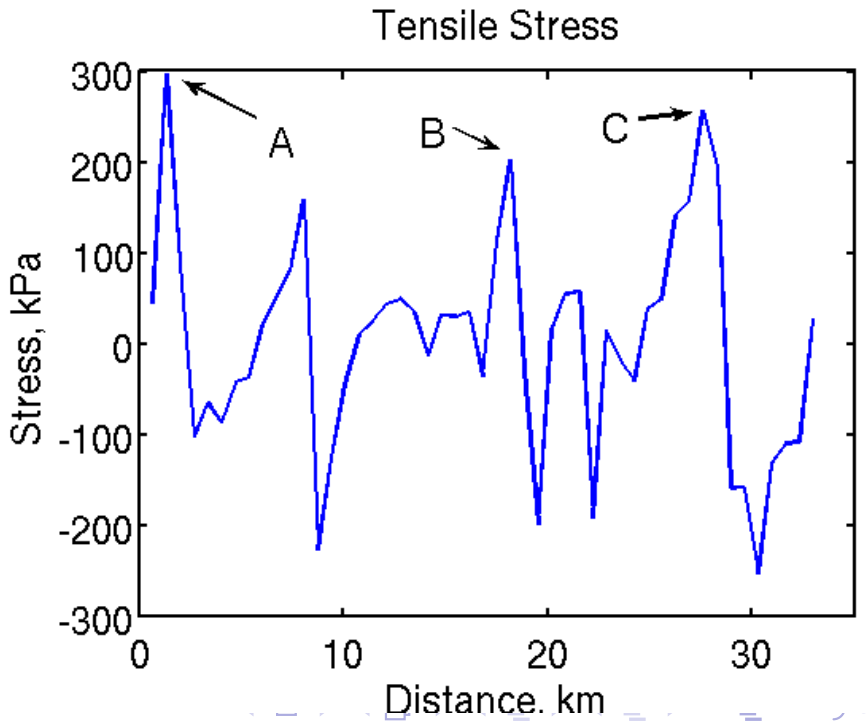
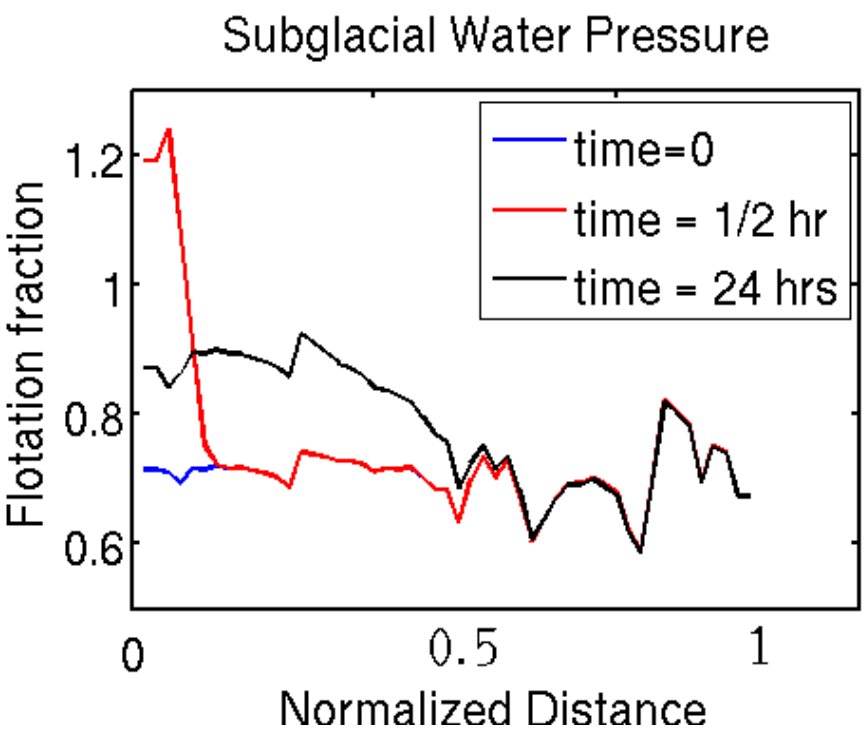
A sample flood

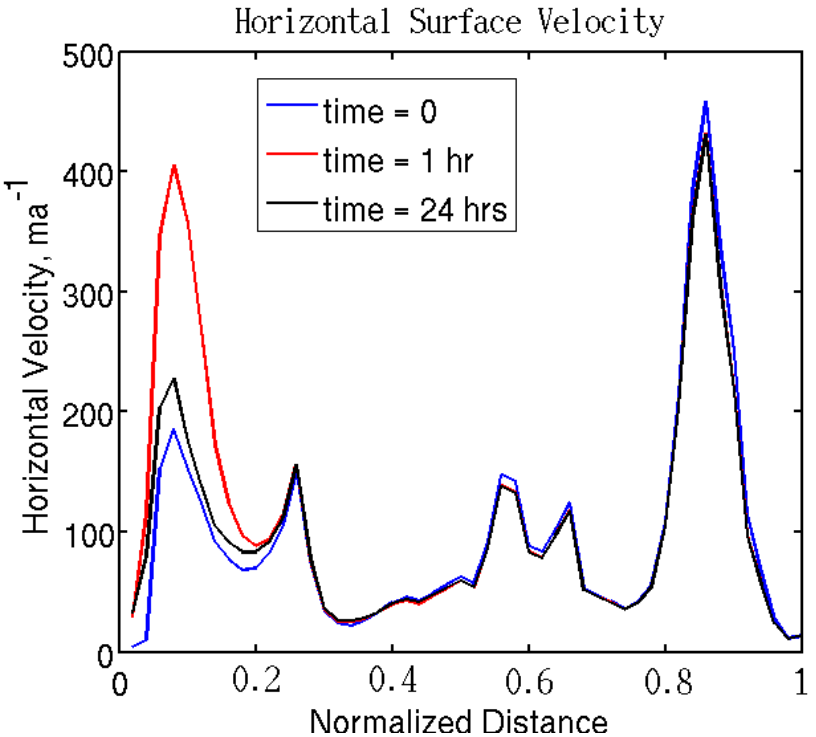
An experiment to mimic the drainage of a supraglacial lake at site A on the Belcher flowline of the Dowdeswell et al. (2004) radar survey



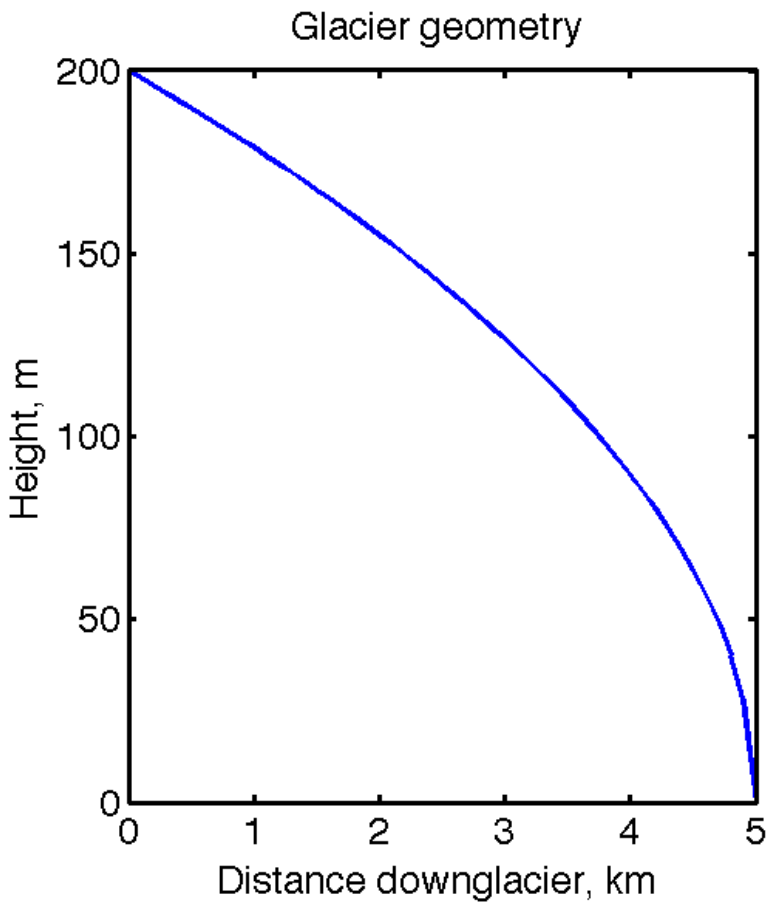


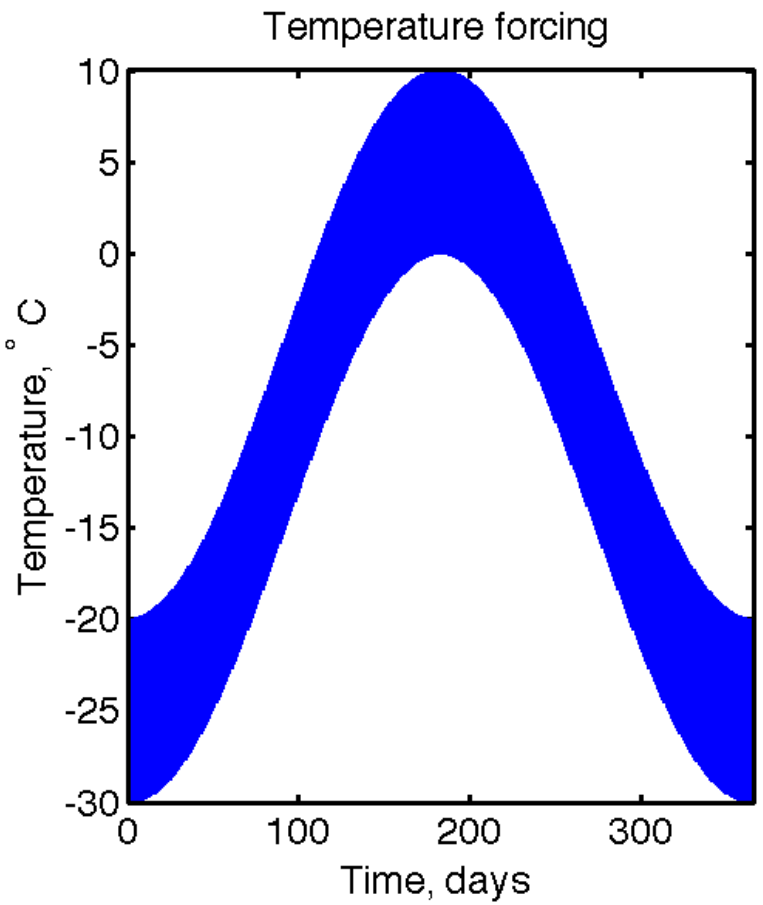
The transient response of water pressure and glacier flow speed to a sample flood at site A

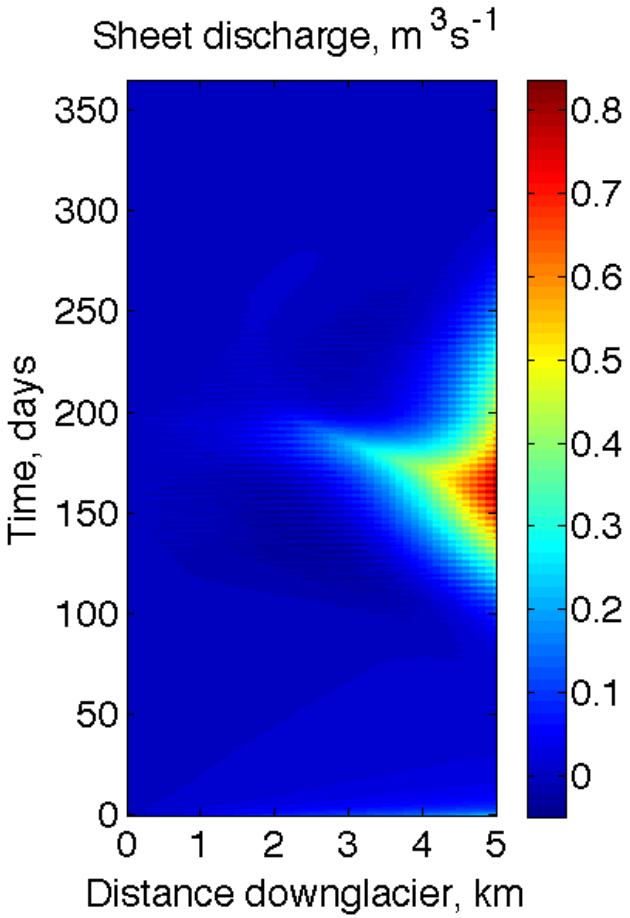


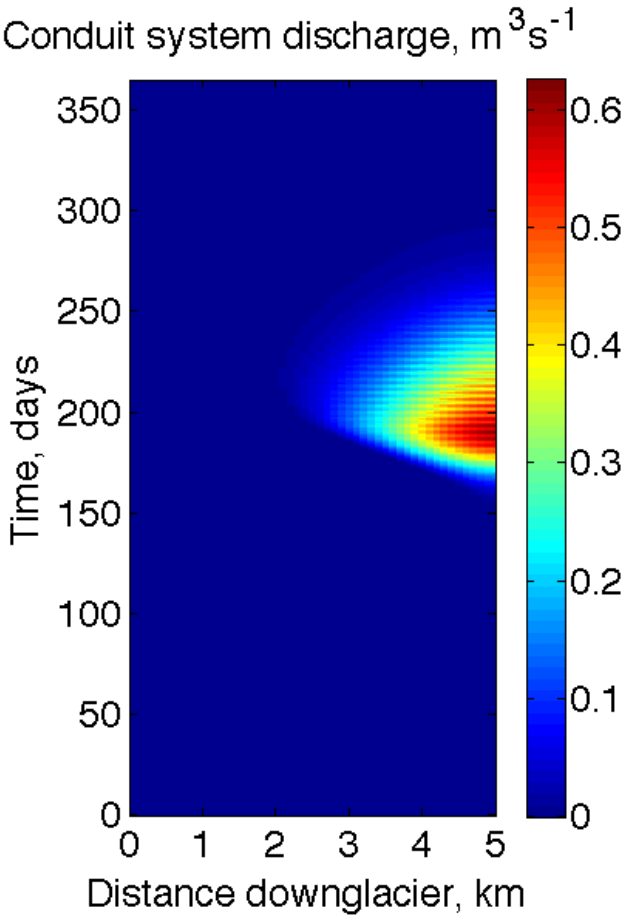


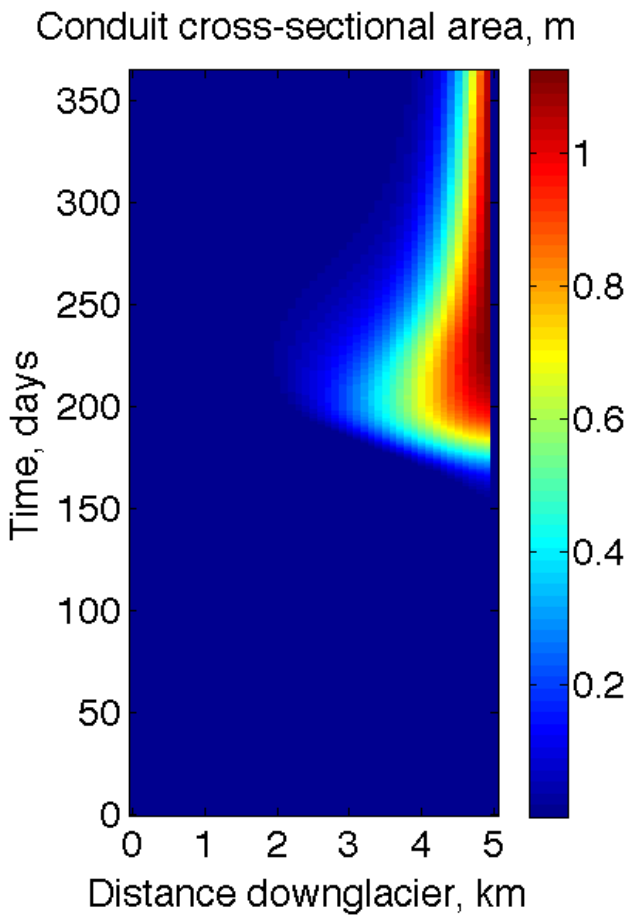
An idealised test case

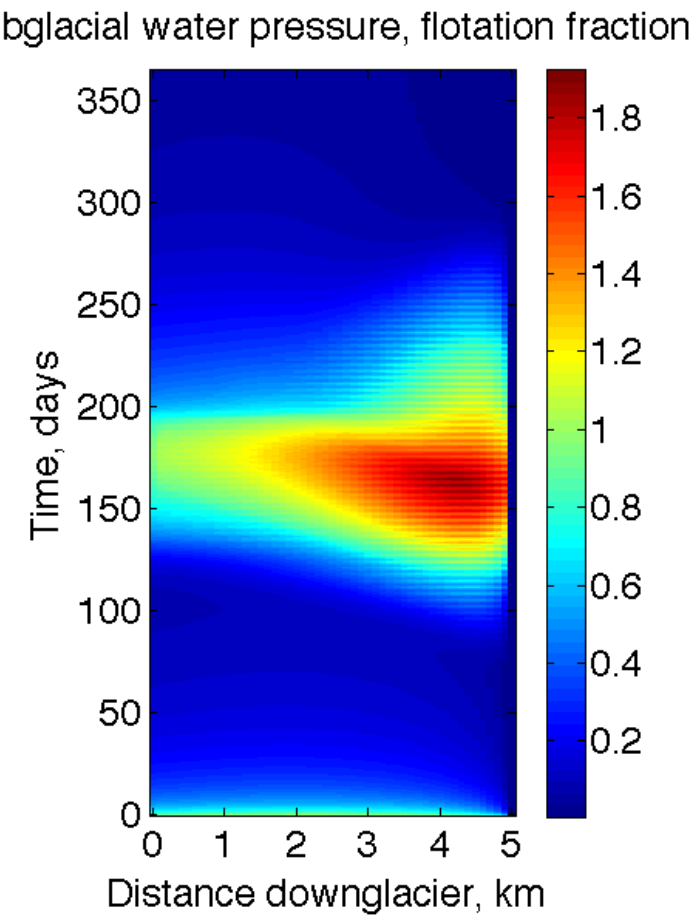


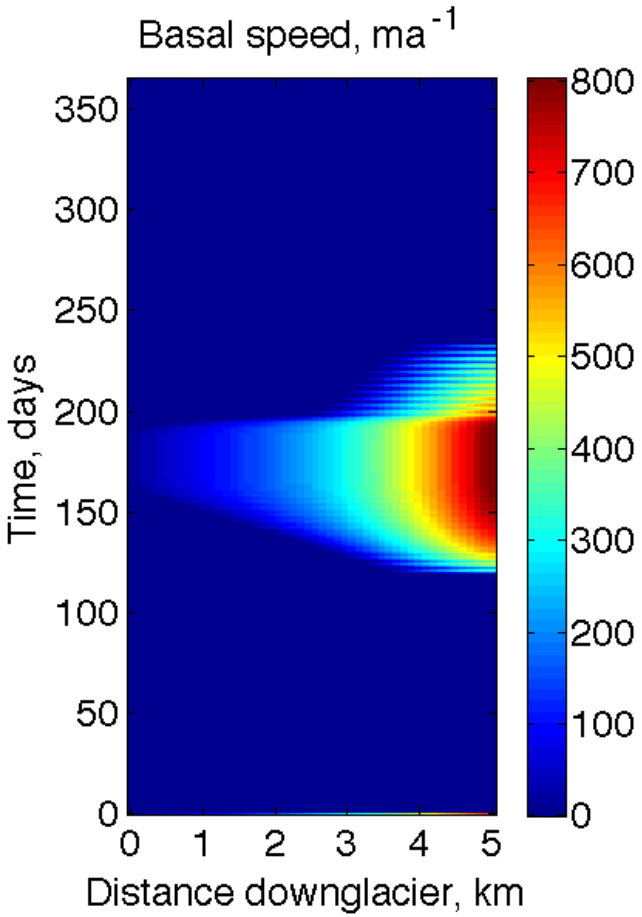


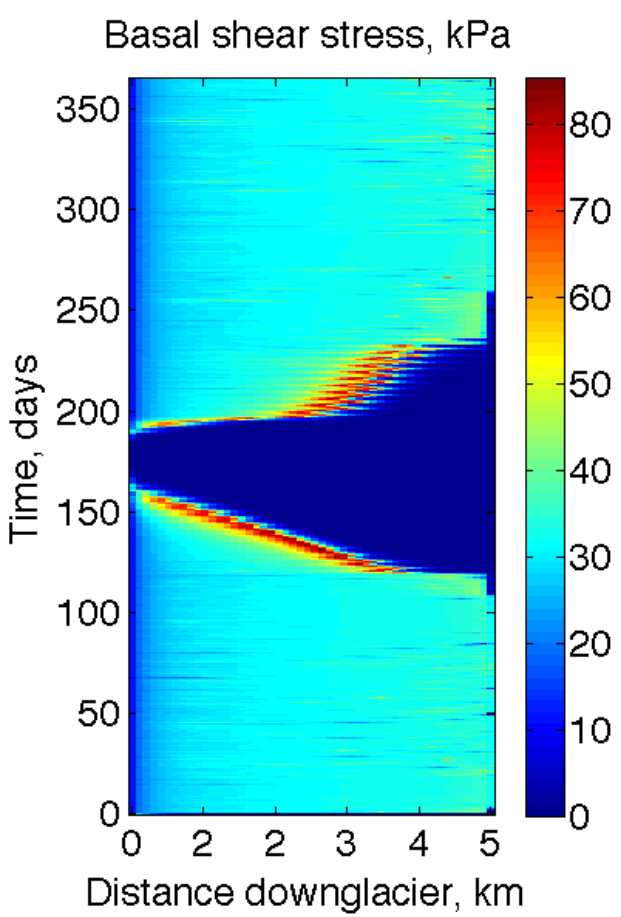

Sheet discharge, m 3s-1
Time, days
Distance downglacier, km
0
50
100
150
200
250
300
350
0
1
2
3
4
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

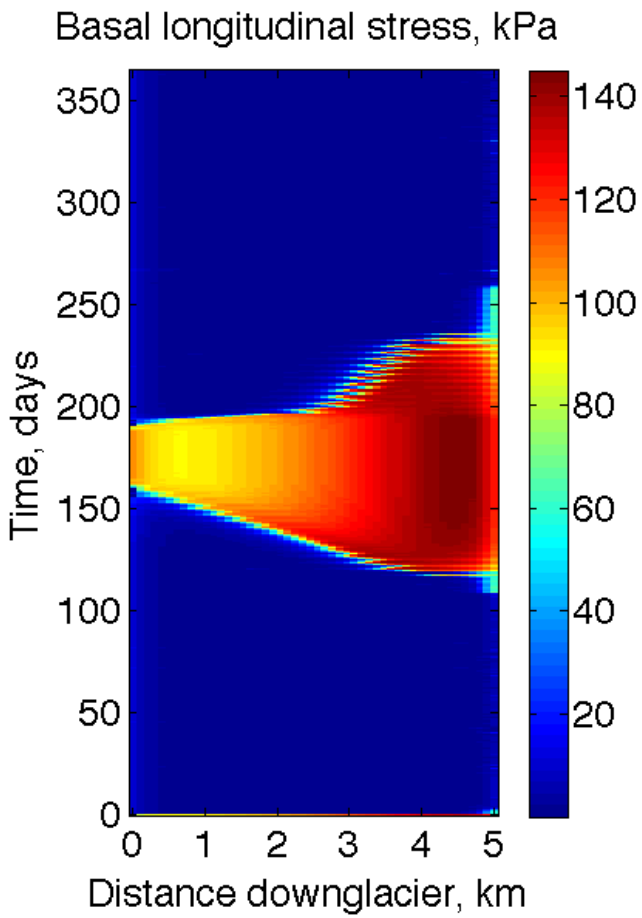

Conduit system discharge, m 3s-1
Time, days
Distance downglacier, km
0
50
100
150
200
250
300
350
0
1
2
3
4
5
0
0.1
0.2
0.3
0.4
0.5
0.6

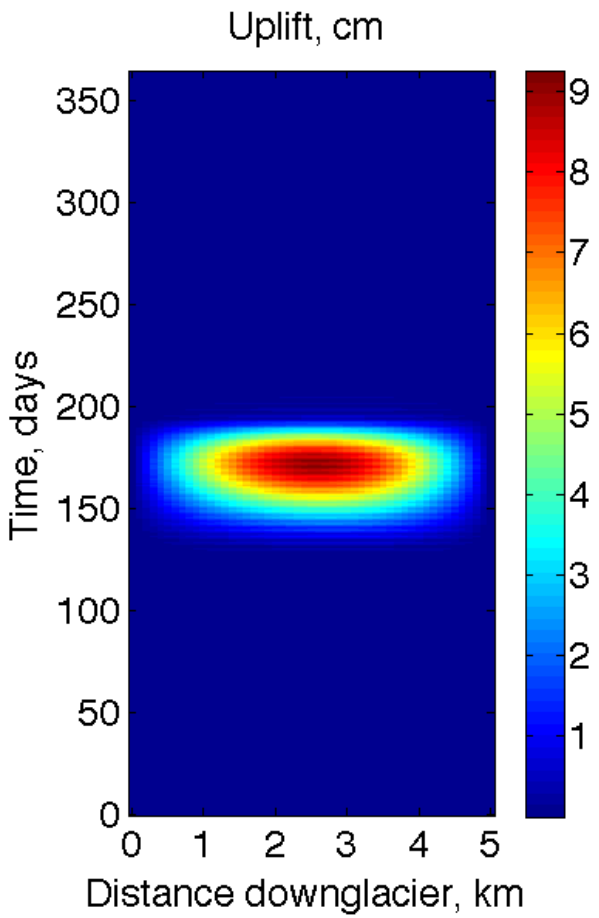

Conduit cross-sectional area, m
Time, days
Distance downglacier, km
0
50
100
150
200
250
300
350
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1


Subglacial water pressure, flotation fraction
Time, days
Distance downglacier, km
0
50
100
150
200
250
300
350
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8


Basal speed, ma -1
Time, days
Distance downglacier, km
0
50
100
150
200
250
300
350
0
1
2
3
4
5
0
100
200
300
400
500
600
700
800


Basal shear stress, kPa
Time, days
Distance downglacier, km
0
50
100
150
200
250
300
350
0
2
2
3
4
5
0
10
20
30
40
50
60
70
80


Basal longitudinal stress, kPa
Time, days
Distance downglacier, km
0
50
100
150
200
250
300
350
0
1
2
3
4
5
20
40
60
80
100
120
140


Uplift, cm
Time, days
Distance downglacier, km
0
50
100
150
200
250
300
350
0
1
2
3
4
5
1
2
3
4
5
6
7
8
9

Future plans

A numerical study of the major drainage events on the Belcher making use of available field data

- Numerical estimates of flowline velocities
- Model supraglacial lake drainage
- How does the diurnal and seasonal influx of meltwater to the bed effect glacier dynamics?

Use of Belcher data

- Topography:
  - Surface and bed elevations of main trunk + major tributaries
  - Flow band widths
  - Basin shape
- Water inputs:
  - Meltwater lake volumes
  - Supraglacial lake drainage times
  - Drainage locations
- Surface flow velocites:
  - Vertical and horizontal accelerations

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