Role of subglacial hydrology and basal topography in driving Greenland outlet glaciers flow

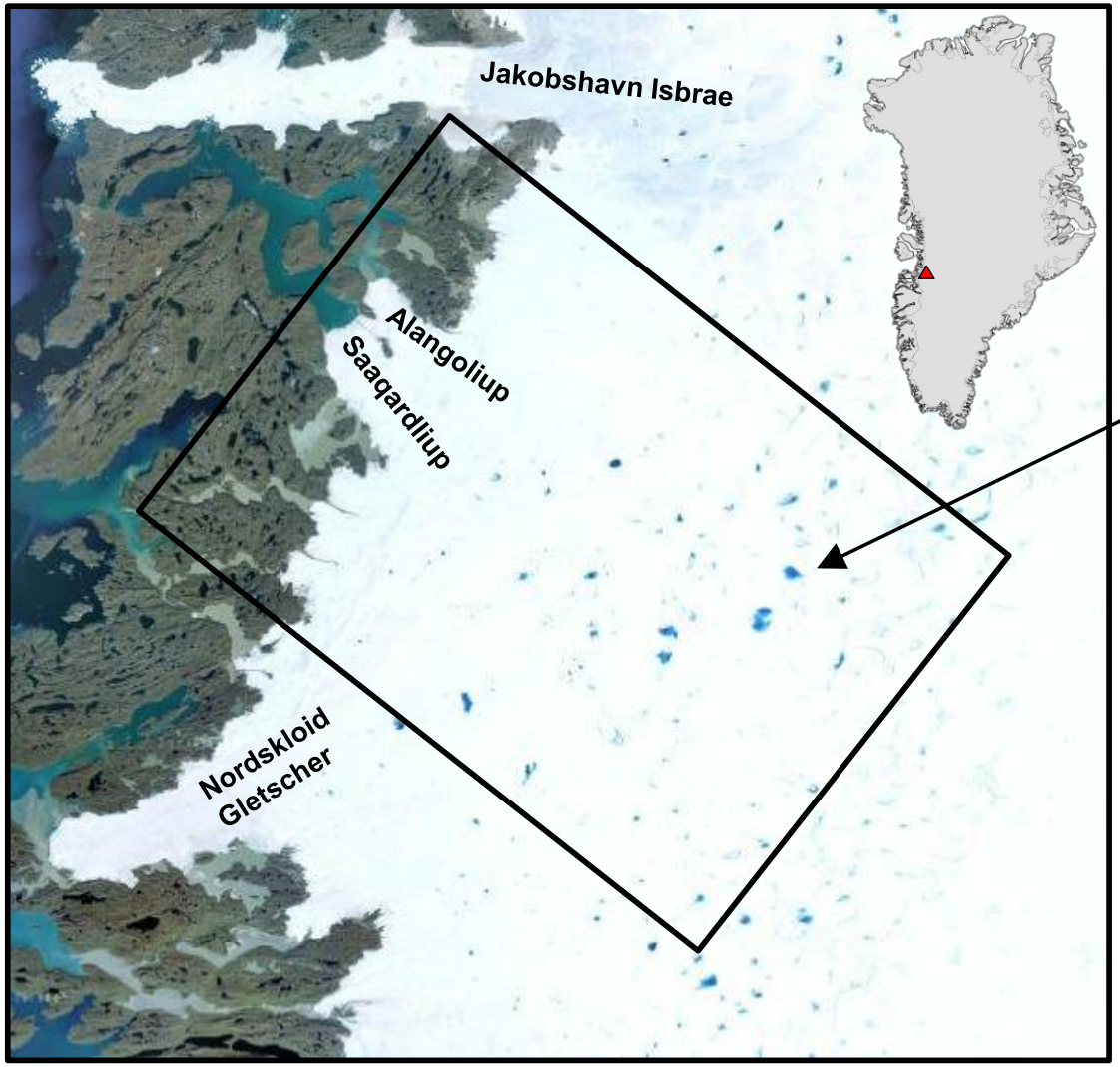

Photo from Sarah Das

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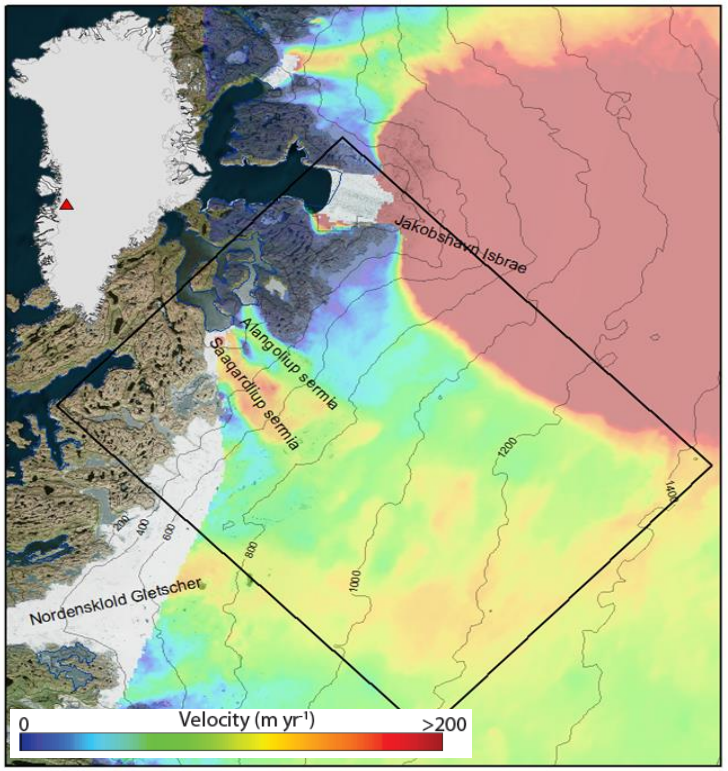
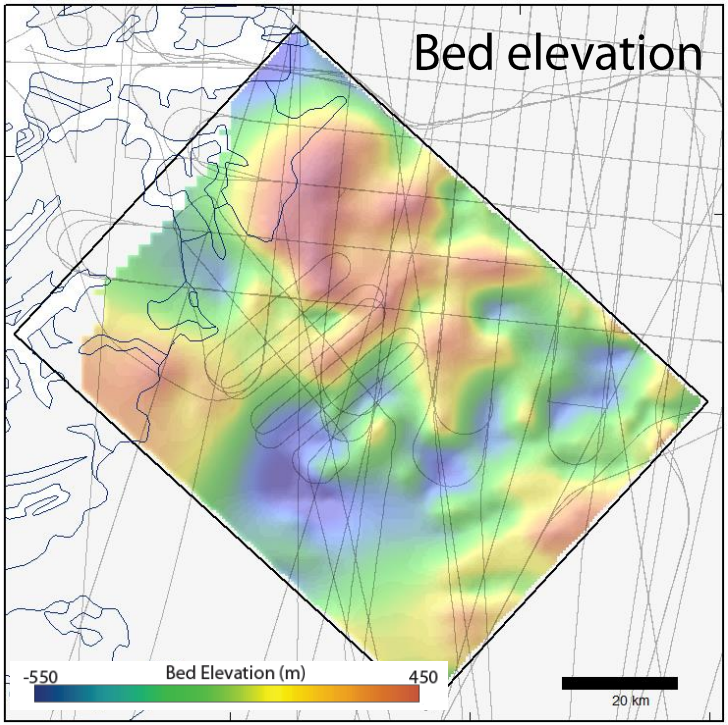
Scientific questions

- How drainages of surface melt water influence subglacial discharges on a seasonal timescale?
- How pattern of subglacial water flow influences ice flow?

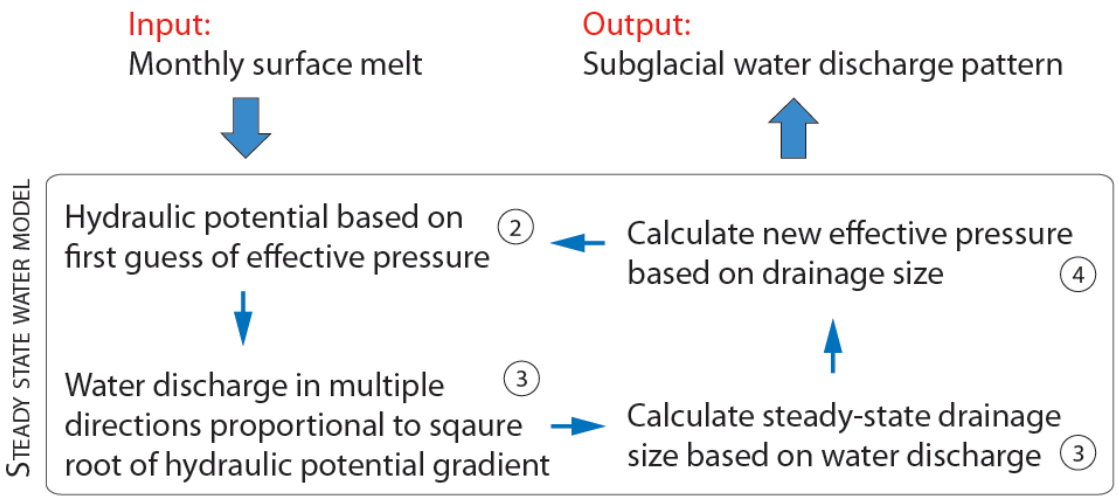


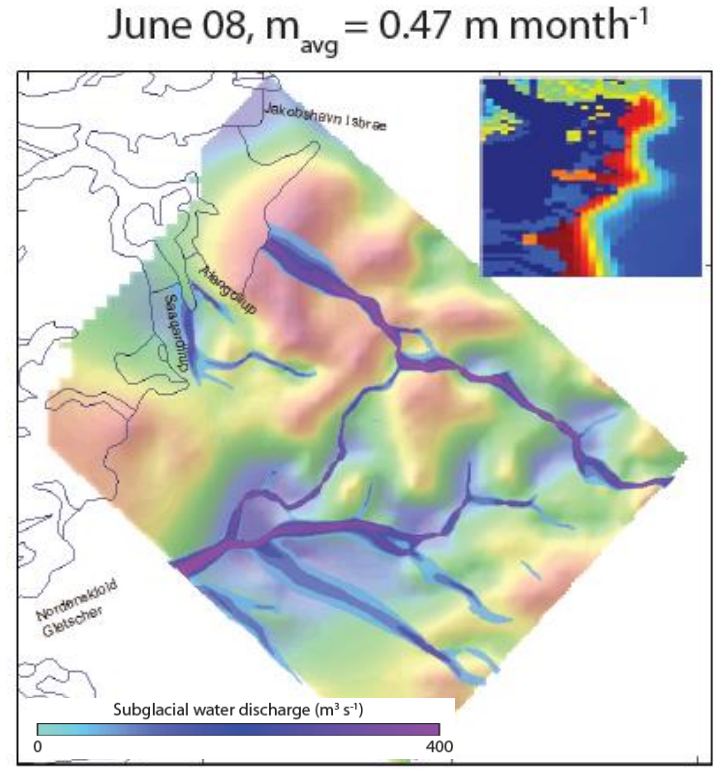
Methods

- We use geophysical observations and a simplified water flow model.
- Geophysical data:
  1. Radar ice thickness
  2. NASA IceBridge AIRGRav
  3. NASA ATM laser



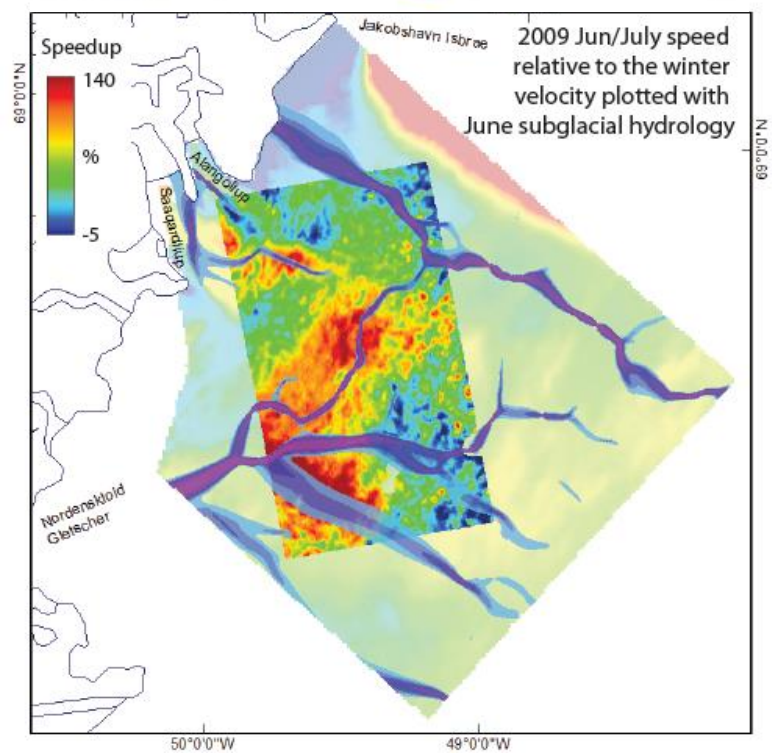
Water flow model





What we learnt

- Spatial pattern of summer ice flow speedup is broadly consistent with the subglacial flow pattern.
- Seasonal surface melting has a minimal impact on the pattern of subglacial water flow.
- **Detail knowledge of basal topography close to the ice margin is very important.**



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Summary

- We use geophysical observations and a simplifed numerical model to examine how subglacial drainage of surface melt water affects ice flow.
- Seasonal surface melting has a miminal impact on the pattern of subglacial water. Surface drainage events on shorter timescales (e.g. lake drainages) may influence subglacial flow pattern.
- Spatial pattern of summer ice flow speedup is broadly consistent with the subglacial summer water flow distribution.
- Basal topography is important to subglacial water flow: subglacial water does not always follow surface flow.

Methods

- Geophysical data from AGAP and NASA IceBridge campaigns include radar ice thickness and AIRGRav used to generate bed map, and ATM laser for surface map.
- 2D steady-state finite difference model for water flow. Water flow is routed through a hydraulic potential surface dervied from ice surface and bedrock topography.
- Model input is monthly surface melt estimates determined using the Polar MM5 modeled positive degree-days (Box et al., 2009).

Model

Input:
Monthly surface melt

Output:
Subglacial water discharge pattern

STEADY STATE WATER MODEL

Hydraulic potential based on first guess of effective pressure ②

Calculate new effective pressure based on drainage size ④

Water discharge in multiple directions proportional to sqaure root of hydraulic potential gradient ③

Calculate steady-state drainage size based on water discharge ③

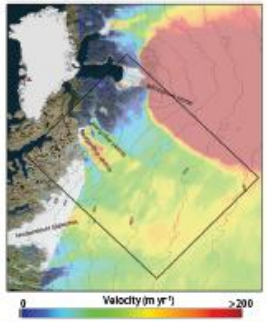
① Effective pressure $N = P_i - P_w = P_i - f_w P_i$

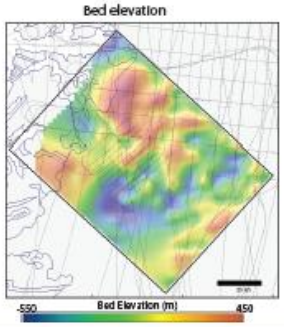
② Hydraulic potential gradient $\nabla\phi = -\rho_i g \nabla h - (\rho_w - \rho_i) g \nabla b + \nabla N$

③ Water discharge $Q = -K S^{5/4} |\nabla\phi|^{-1/2} \nabla\phi \propto \nabla\phi^{1/2}$

④ Drainage mass balance $\frac{Q \nabla\phi}{\rho_i L} = \frac{2A}{n} S |N|^{n-1} N$

Study region



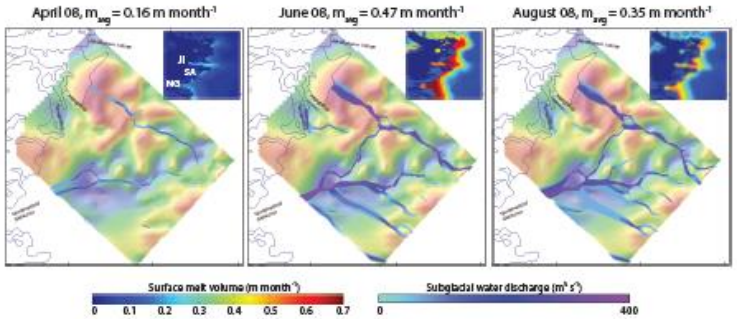


Geophysical observations

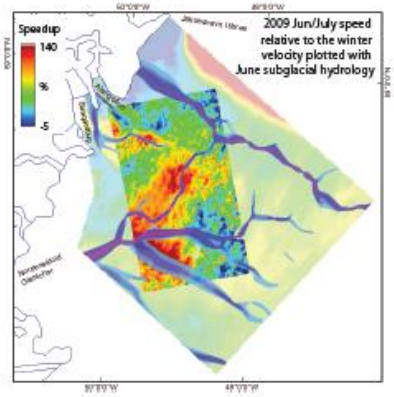
- Catchment is characterized by a series of SW-NE trending basal ridges and troughs.
- A prominent 300 m high basal ridge bisectes the catchment.
- Asymmetric bed underneath Saaqardliup sermia and Alangoliup sermia.
- Saqarquiliup sermia lies over a broad low-lying bed of 90 m below sea level, Alangoliup sermia lies over higher bed bounded by steep sloping ridges to the North.

Seasonal melt influence

Basal topography plotted with subglacial water drainage.
Inset shows monthly surface melt water estimates.



Summer speedup comparison



Model observations

- Enhanced surface melting from April to June increases subglacial discharge.
- Pattern of subglacial drainage is similar throughout the melt season.
- Large portion of drainage discharge is diverted away from the outlet glaciers margin to neigboring Nordenskloid gletscher.
- Subglacial discharge is topographically limited by the basal ridge that bisected the catchment.

Future work

- Incorporate an ice sliding law that depends on effective pressure.
- Implement the water drainage model on a staggered grid with prescribed boundary conditions.
- Incorporate multiple flow types in the water model.