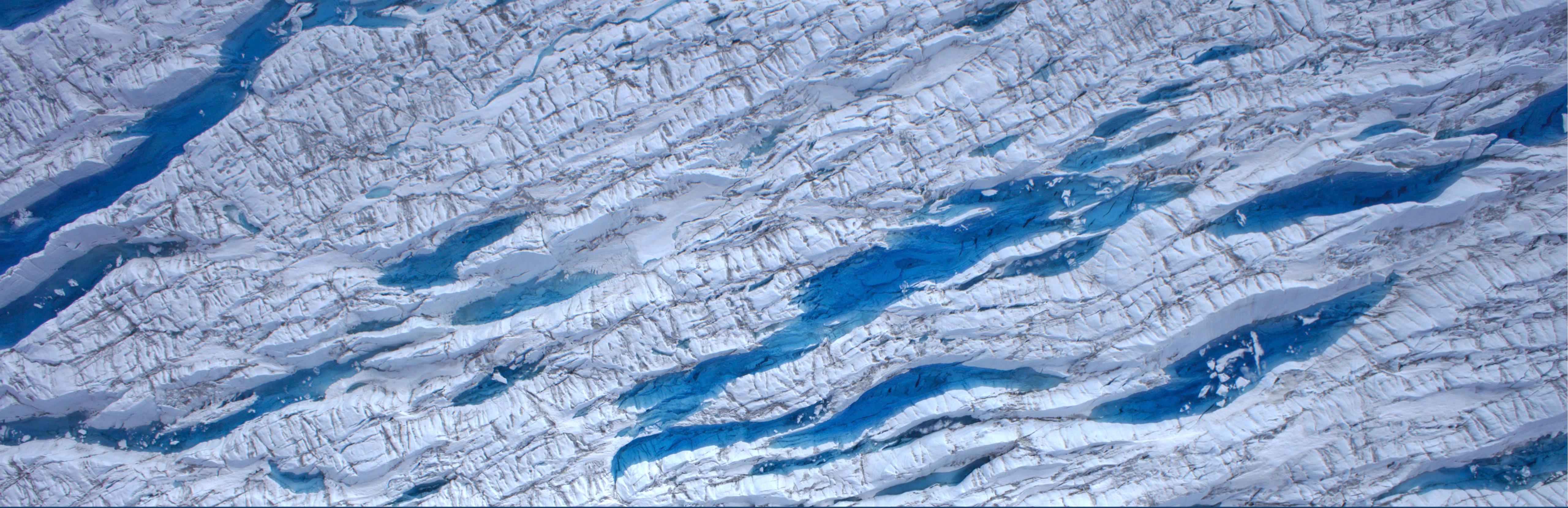

Controls on crevasse water transmission to the bed of an ice sheet

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Natural Environment Research Council

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This work has recently been submitted for review – a preprint should be [available on ESSOAr](#) by the end of the week!

How do crevasses transfer meltwater to the bed of ice sheets?

Episodic hydrofracture?

Evidence:

Shear zone drainage (Lampkin *et al.* 2013)

Supraglacial lake drainage (Doyle *et al.* 2013)

Continuous englacial drainage?

Evidence:

Störglaciaren observations (Fountain *et al.* 2005).

Models (McGrath *et al.* 2011; Colgan *et al.* 2011)

Crevasses capture as much as half of seasonal runoff (Koziol *et al.* 2017), but no studies have attempted to account for the diversity of ways in which crevasses have been thought to transfer water to the bed of ice sheets...

Implementations in regional hydrological models

Episodic hydrofracture?

Clason et al. 2015:

Crevasse fields identified with σ_v threshold.

Crevasses fields allowed to fill and then fracture following van der Veen (2007).

Continuous englacial drainage?

Koziol et al. 2017:

Crevasse fields identified with σ_v threshold.

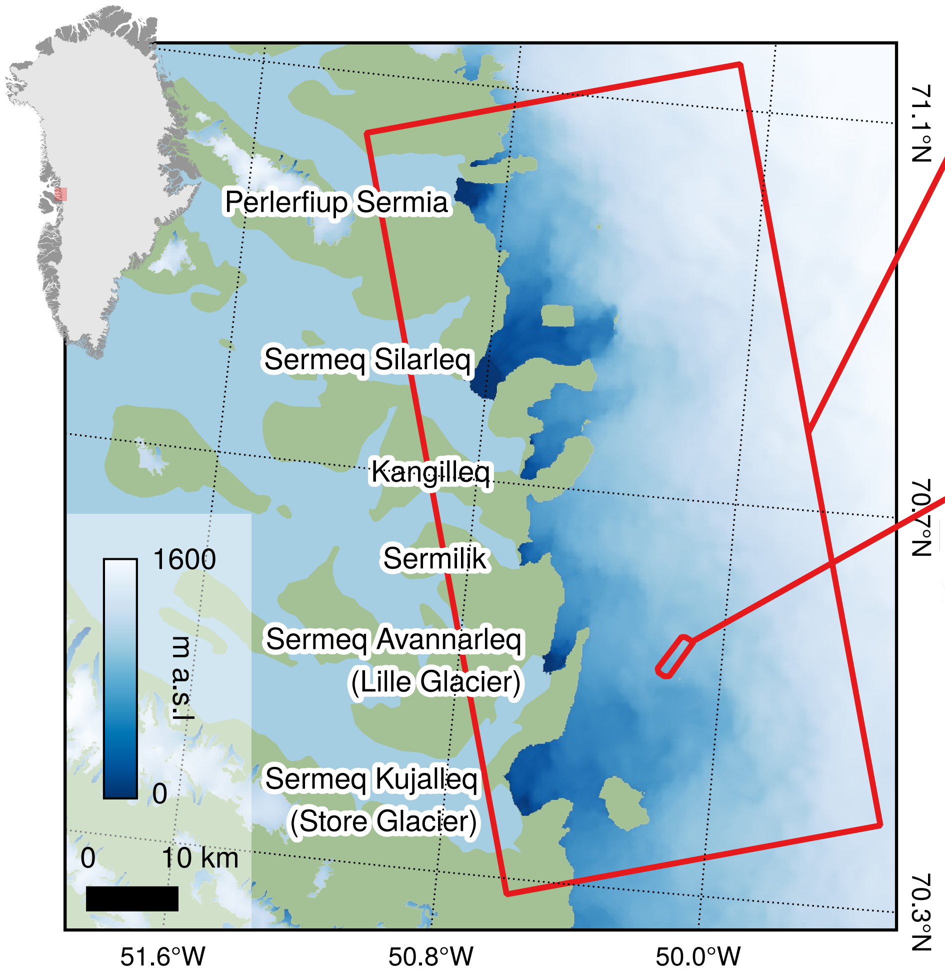
Meltwater can drain through crevasse fields immediately without requiring hydrofracture.

Models assume uniform style of drainage, distribution based on threshold *von Mises stress* (σ_v). But von Mises found to predict crevasse *presence*, not *hydrology* (Vaughan, 1993).

Is this the best way to predict crevasse behaviour?

Research questions

- What evidence is there for episodic/continuous crevasse drainage modes?
- Do controls on crevasse hydrology differ from controls on crevasse presence?
- Is there a way that these controls can be better represented in models?



Satellite evidence

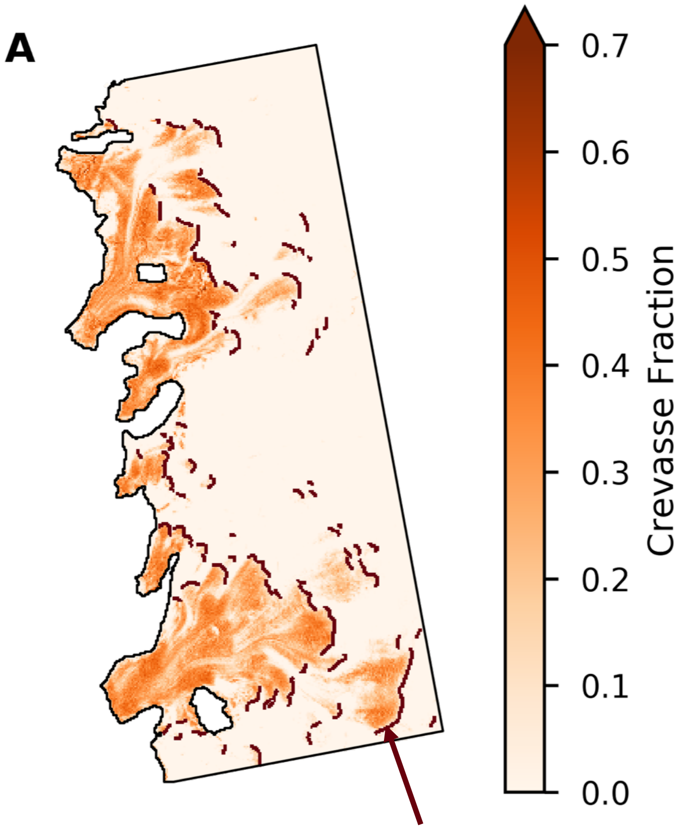
- Water: Sentinel-2
- Crevasses: ArcticDEM
- Stress: MEaSUREs

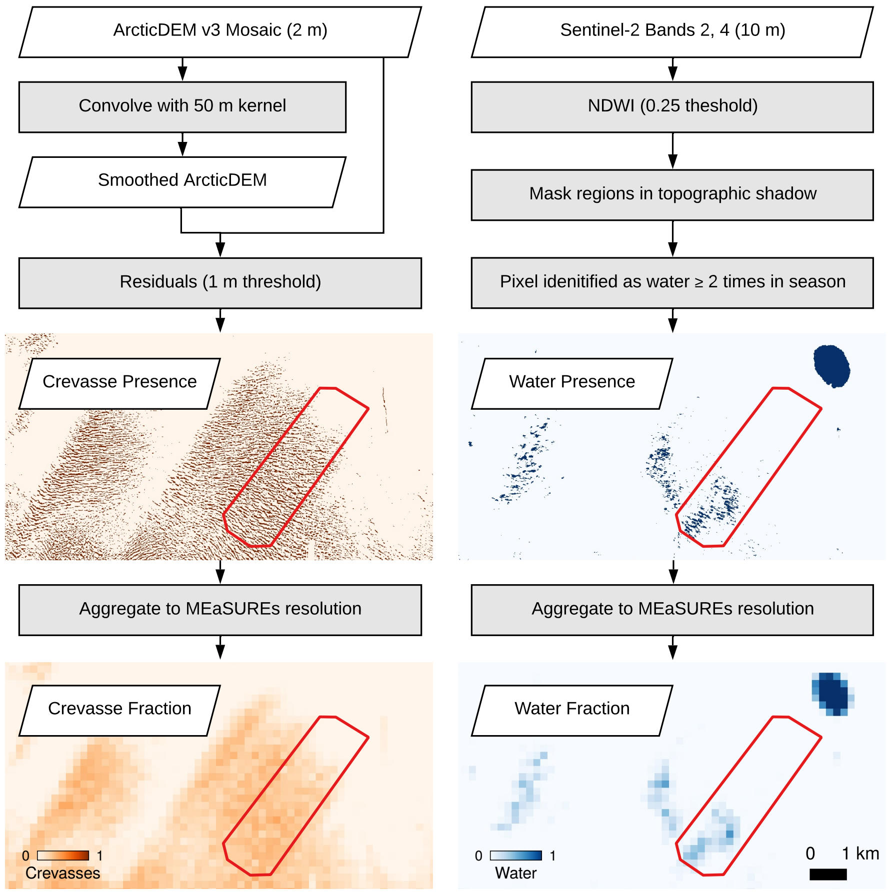
UAV Evidence

- Water/crevasses: Machine learning
- Stress: feature tracking
- See preprint for full analysis

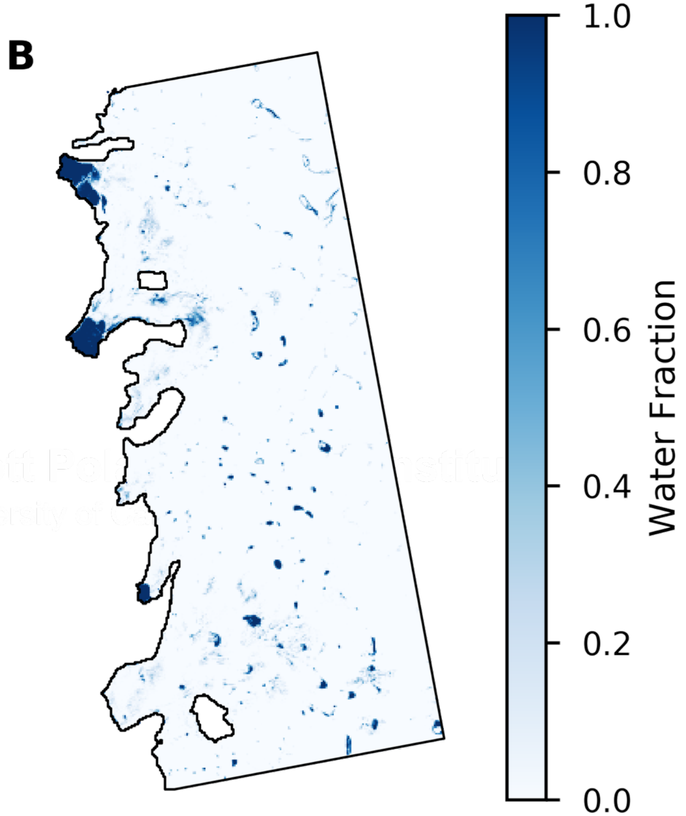
Satellite Data Analysis

Crevasse Distribution





Water Distribution



Manually identified crevasse initiation zones

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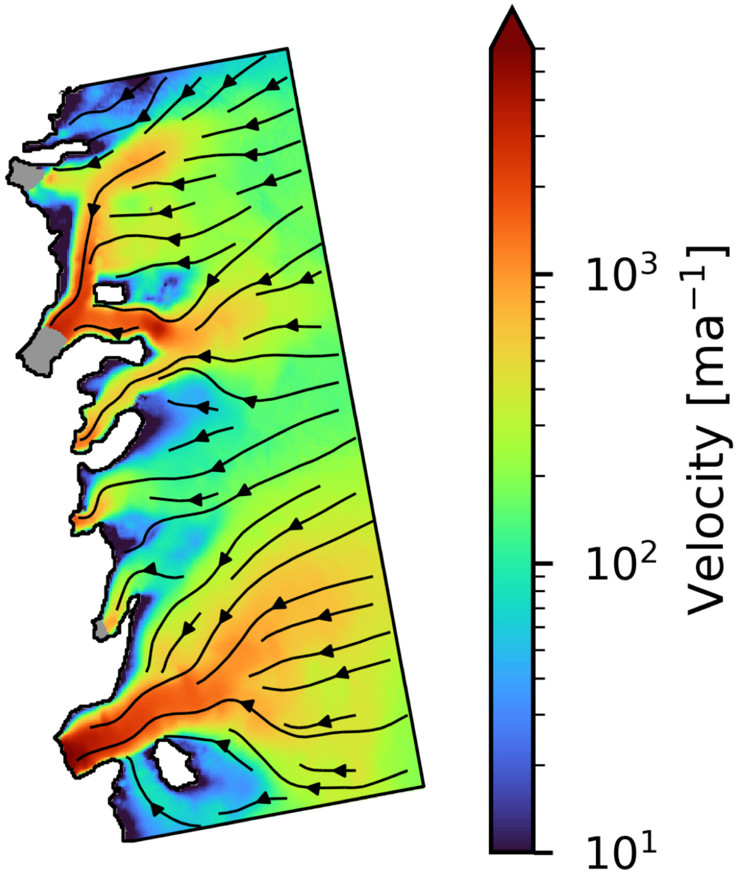
Satellite Data Analysis



From MEaSUREs 2018 annual velocity field, estimate stresses with Glen's flow law as constitutive equation

First (σ_1) and second (σ_2) principal stress

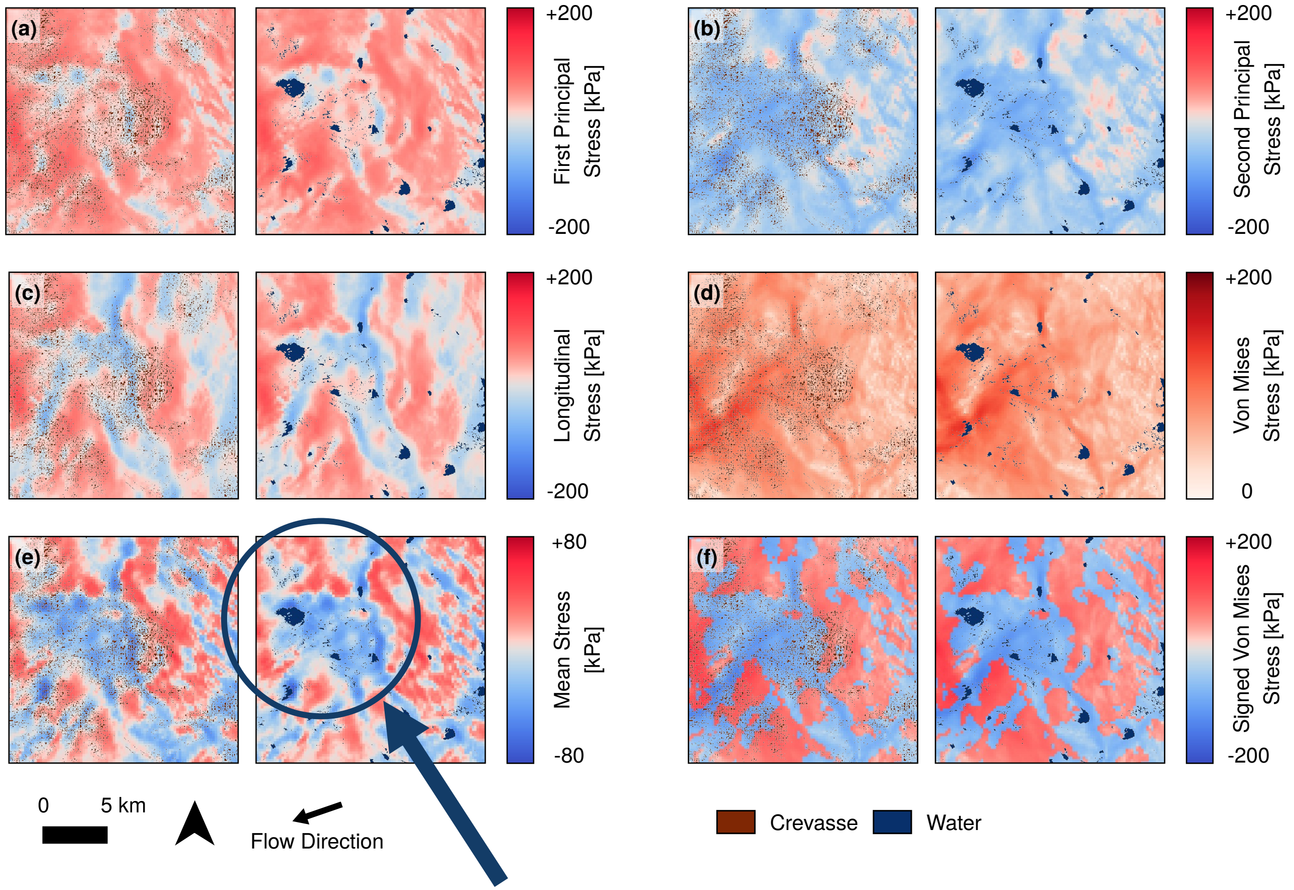
Longitudinal stress (σ_l)

von Mises (σ_v) $\quad \sigma_v^2 = \sigma_1^2 + \sigma_2^2 + \sigma_1\sigma_2$

Mean Stress (σ_m) $\quad \sigma_m = ½ [\sigma_1 + \sigma_2]$

Signed σ_v (σ_{sv}) $\quad \sigma_{sv} = \text{sgn}(\sigma_m) * \sigma_v$

Crevasses, Water, and Stress



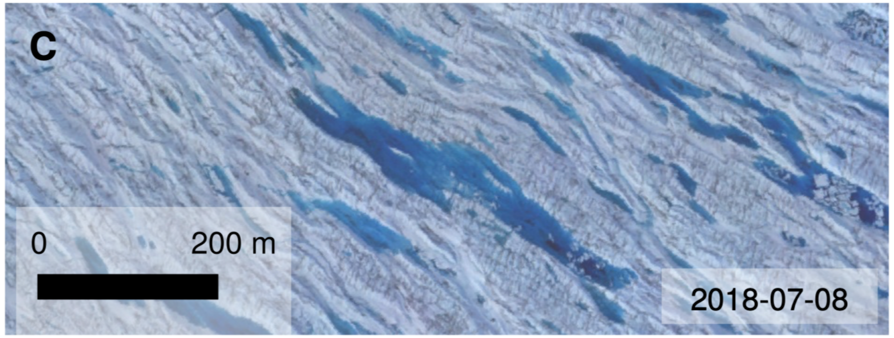
Crevasses pond in compressive regimes

Stress estimates good at predicting crevasse distribution are not the same as those predicting crevasse hydrology!

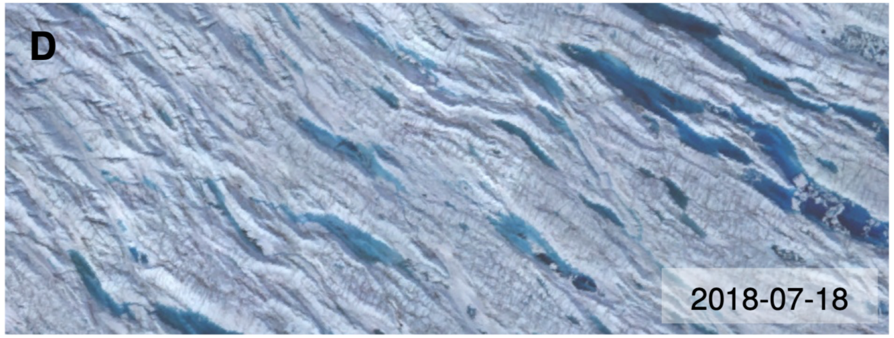
Crevasses observed to be water-filled through the 2018 melt season occur in regions of compressive mean stress (panels e, f).

Crevasses, Water, and Stress

- Crevasses initiate at high **positive** von Mises Stress
  - Median ~60 kPa, in line with van der Veen (1998) estimate of 30-90 kPa.
- Once formed, crevasses exist over the full range of stress regimes.
  - Crevasses can be advected through compressive stress regimes without healing entirely (Mottram and Benn, 2009).
- Water is more likely to pond in crevasses in a compressive stress regime.
  - Because compressive regimes can close pathways to the bed? ('pinch-off' – Irvinne-Fynne *et al.* 2011).
  - Convincing evidence from UAV data that rapid hydrofracture is a property of ponded crevasses in compressive regimes – see more from the UAV data in the full preprint!



Crevasse ponding leads to hydrofracture in compressive regimes



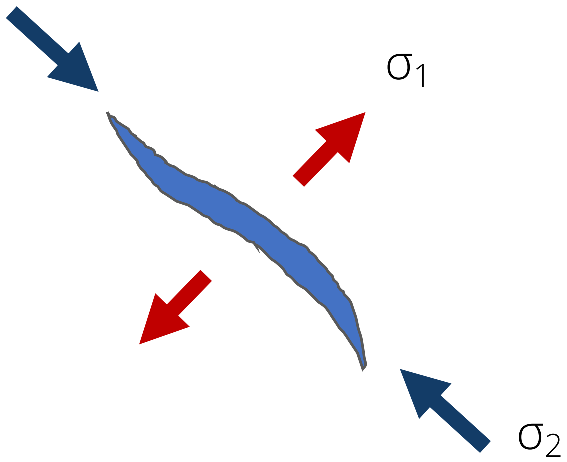
Relating stress observations to crevasse drainage modes

Episodic hydrofracture

Compressive mean stress regime.

Pathways to englacial system closed.

Water ponding leads to hydrofracture, opens pathways to bed.

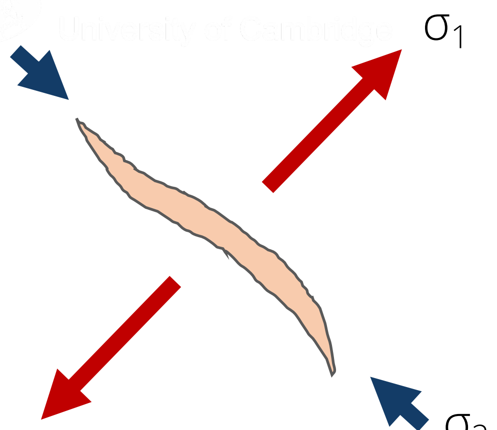


Continuous englacial drainage

Extensional mean stress regime.

Englacial system remains accessible.

Water can drain continuously, hence no water presence observed at the surface.



Varying drainage modes have glaciological consequences

Episodic hydrofracture

Infrequent but rapid delivery of larger quantities of meltwater to the bed.

- Dynamic impacts analogous to lake drainages –meltwater pulses lead to channelization (Andrews *et al.* 2018).
- Unlike lakes, crevasses observed to drain multiple times a season (Cavanagh *et al.* 2017). Consequences unknown?

Continuous englacial drainage

Continuous and inefficient delivery of meltwater via englacial system.

- Inefficient delivery damps pulses of input such as diurnal cycles: dynamic impact lessened (McGrath *et al.* 2011).
- Enhanced refreezing potential leads to greater cryo-hydrologic warming (Colgan *et al.* (2011).

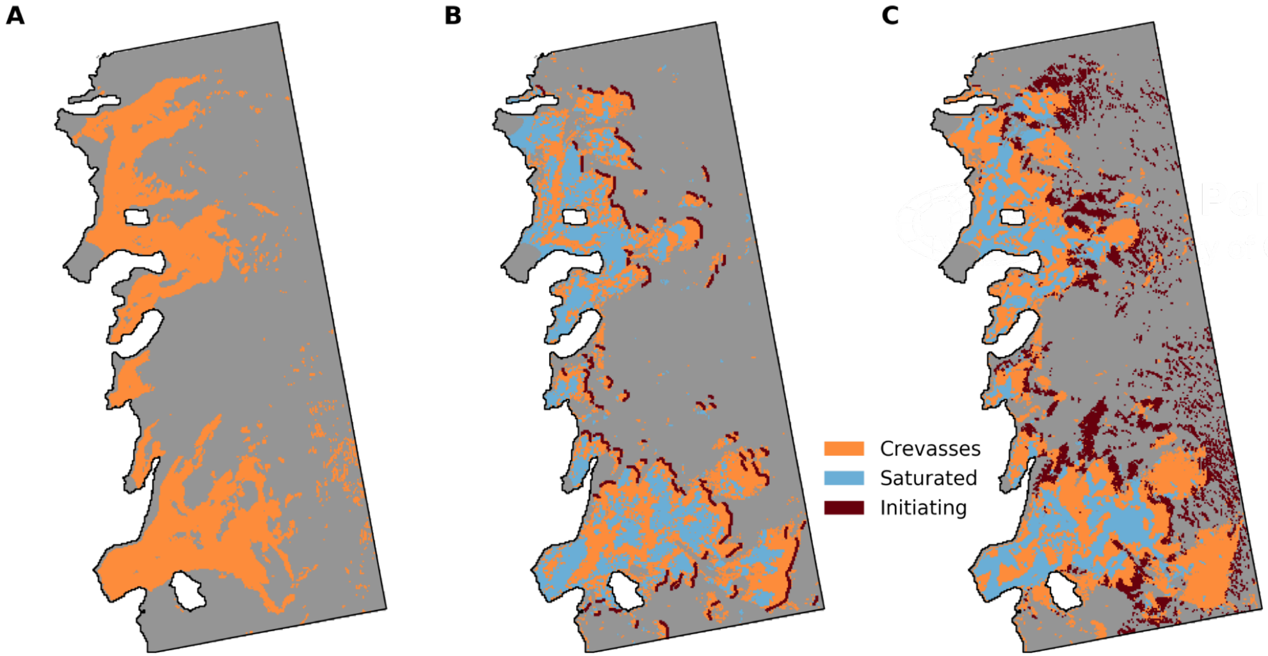
Applications for regional hydrological modelling

We can begin to account for heterogenous crevasse drainage style in models using simple thresholds. Using this, spatially variable dynamic/thermal effects could be quantified.

A. Prior method

- Clason *et al.* (2015); Koziol *et al.* (2017).
- Crevasse presence based upon σ_V threshold.
- No ability to differentiate drainage style.

B. Observations.



C. New method?

- Crevasse presence from observations.
- Crevasse initiation and drainage style from σ_{SV} threshold.
- Crevasse drainage styles can be differentiated.

Thank you

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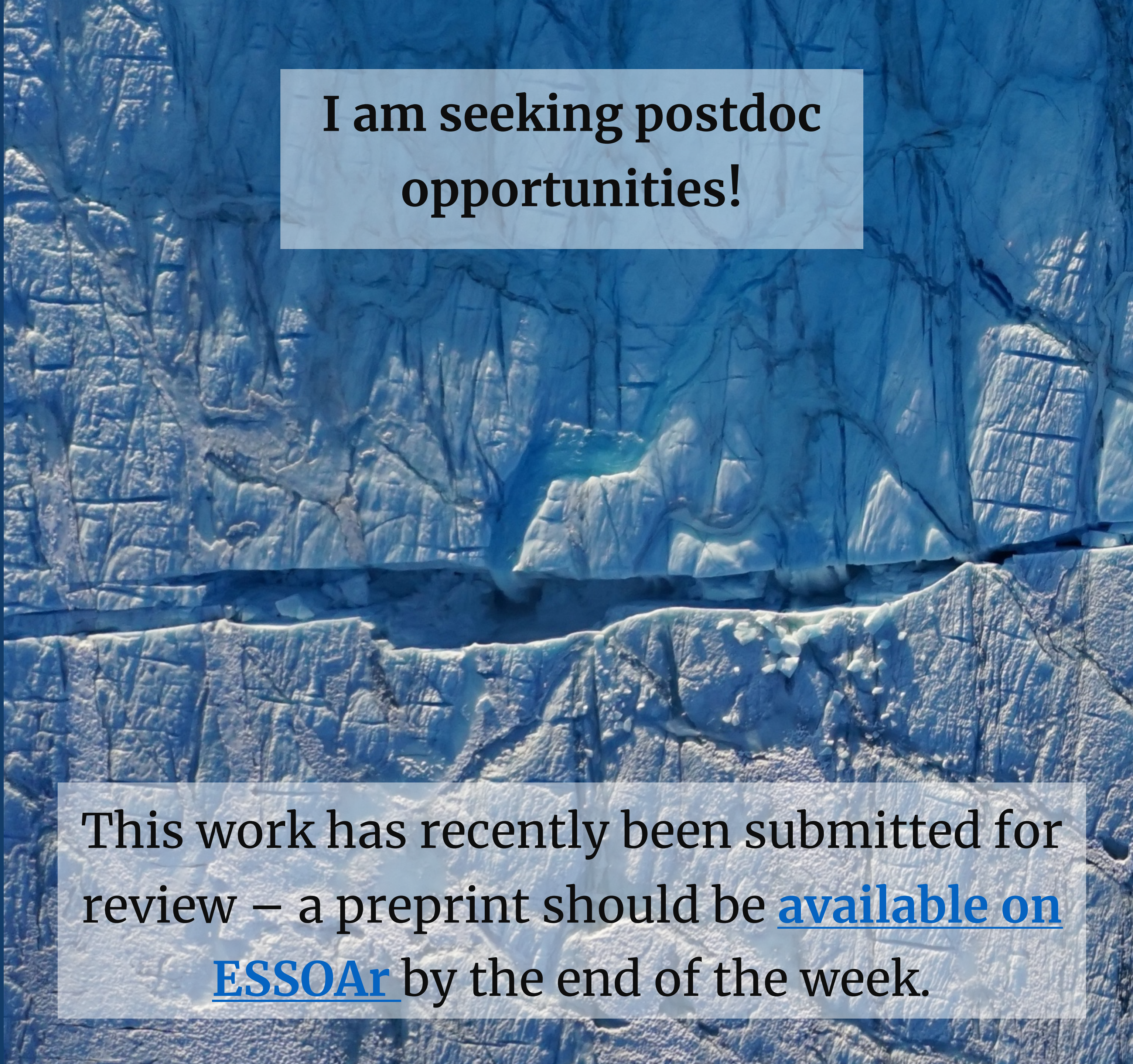

I am seeking postdoc opportunities!

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