GPS measurements during two major calving events at Bowdoin Glacier

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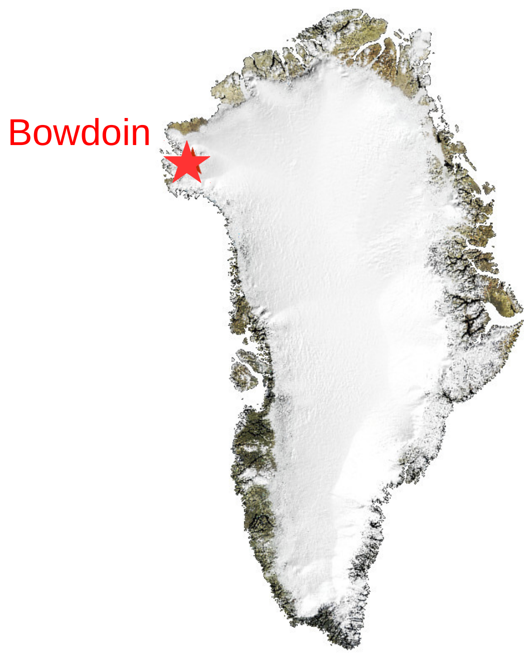
Bowdoin Glacier

Kangerluarsuup Sermia in Greenlandic

a unique opportunity to conduct
in-situ measurements at the calving front
due to a crevasse-free moraine



Source: MODIS

Sentinel2A image, 2017-07-25, processed using SentinelFlow

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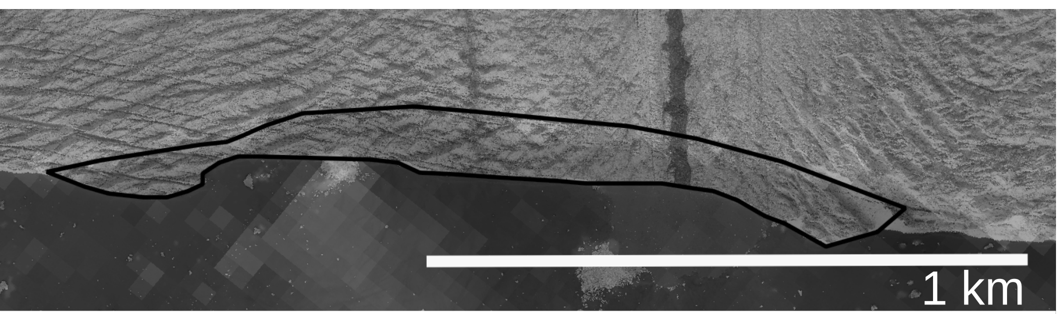
Previously observed major calving events

2015

2017



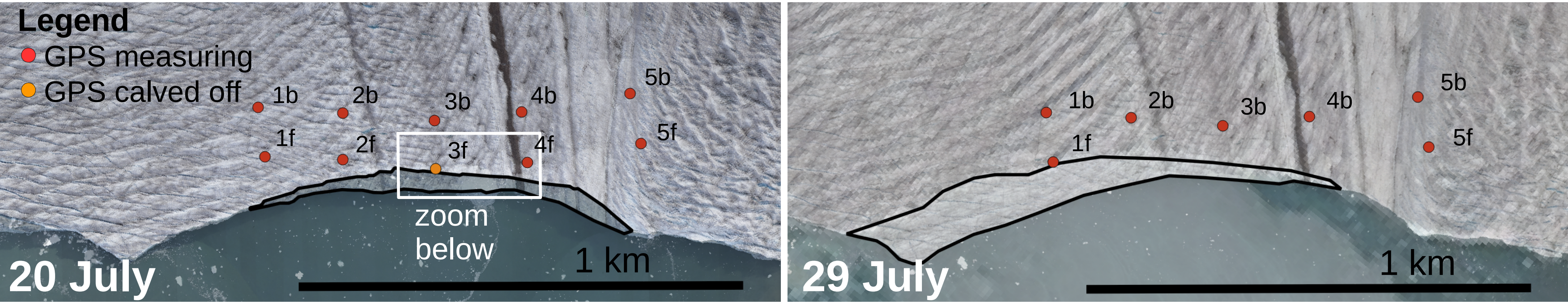
2015:
~ 1km x 100m
crevasse opened during field campaign
2 weeks from crevasse seen in field → calving after leaving the glacier, 27 July

2017:
~ 650 x 80m
crevasse present when field campaign started, at least 5 days from crevasse → calving 8 July during field campaign

Fieldwork July 2019

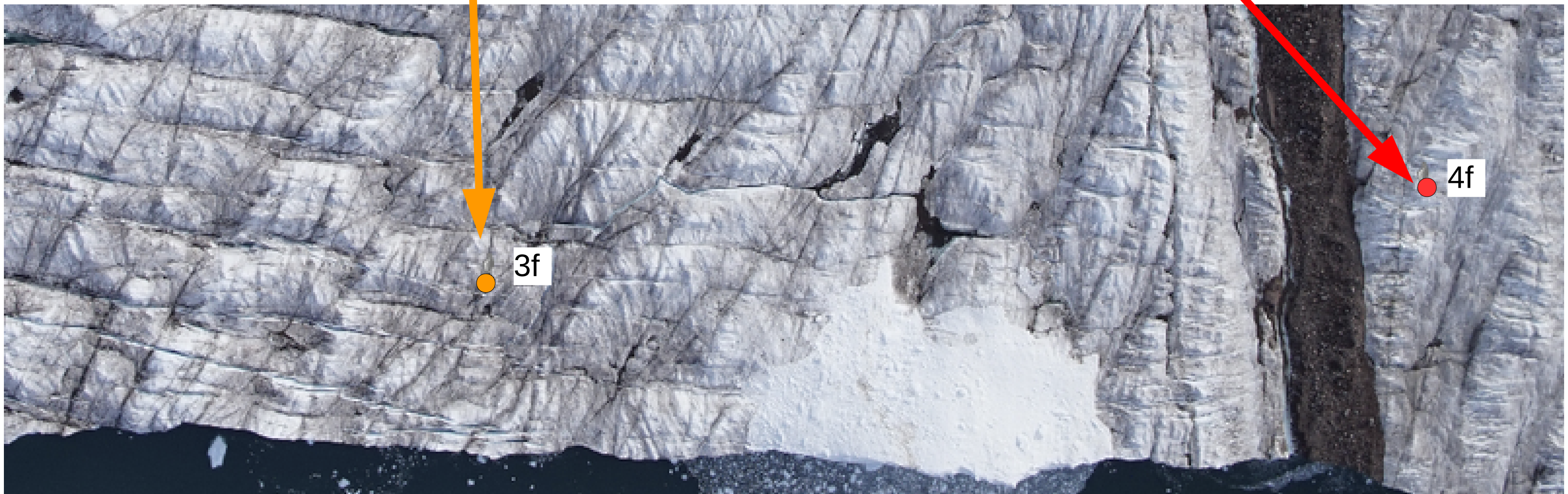
- 4 weeks at Bowdoin Glacier
- maintained network of 10 differential GPS
- daily mapping of calving front by drone flights
- two major calvings observed during field work

Two large-scale calvings during 2019 fieldwork



In contrast to previous years, **no major surface crevasses were observed prior to calving**, neither in the field nor from aerial imagery.

For example, on this 19 July drone image, no precursor crevasse is visible, although GPS 3f calved 1 day later and 4f did not.

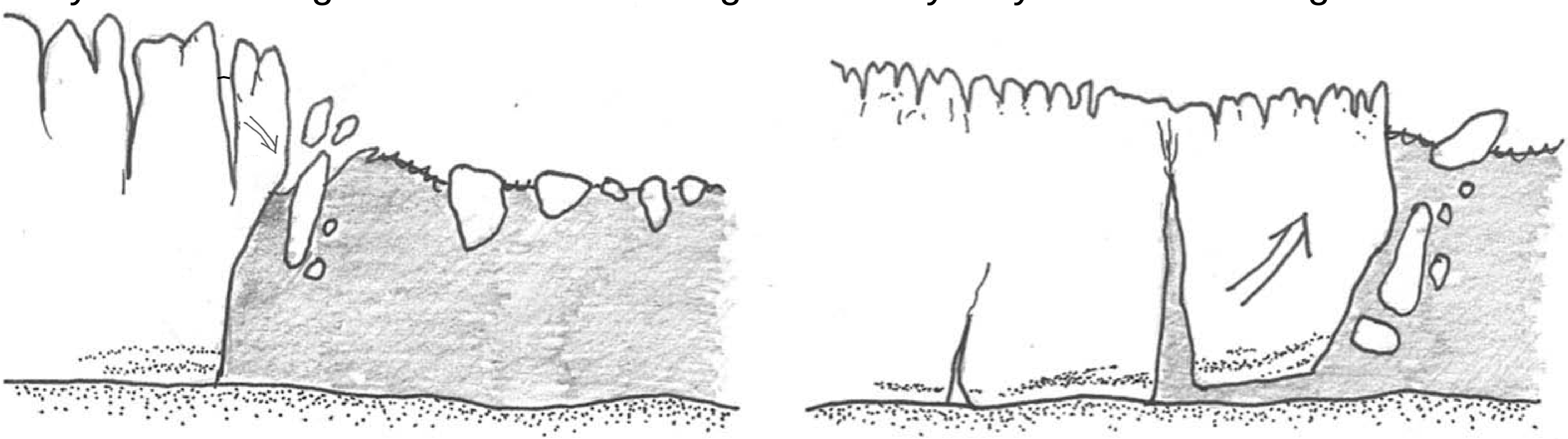


see figure above for calving extent

Changing calving behaviour?

The **absence of a precursor** surface crevasse suggests the calving mechanism at Bowdoin Glacier has changed **from surface crevasses** due to **hydro-fracturing and melt-undercutting** (Jouvet et al., 2017, Van Dongen et al., 2020) to **basal crevasse formation** due to **buoyancy.**

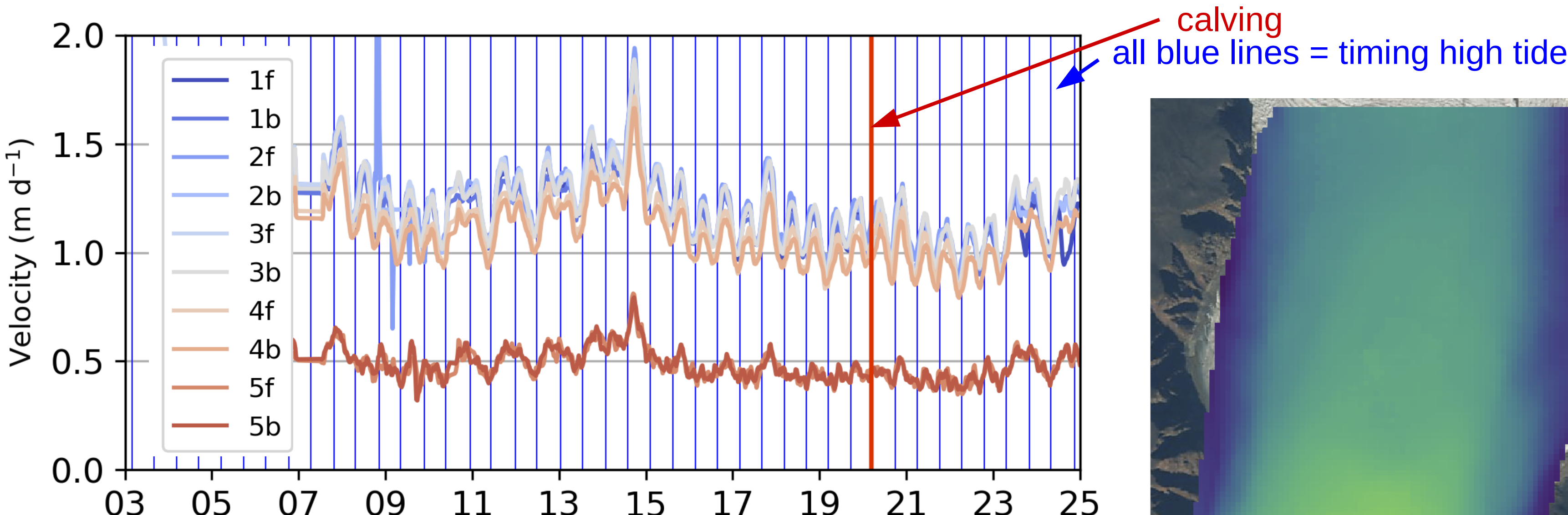
hydro-fracturing and melt-undercutting → buoyancy-induced calving



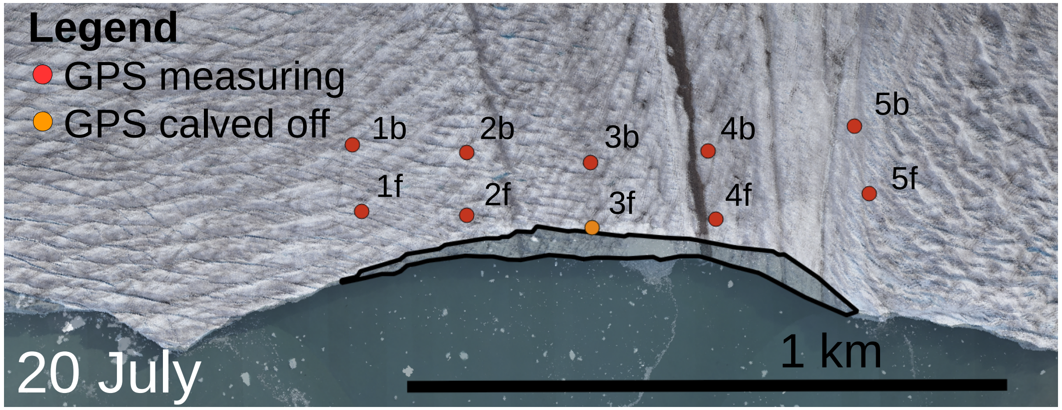
Adapted from Benn and Åström (2018)

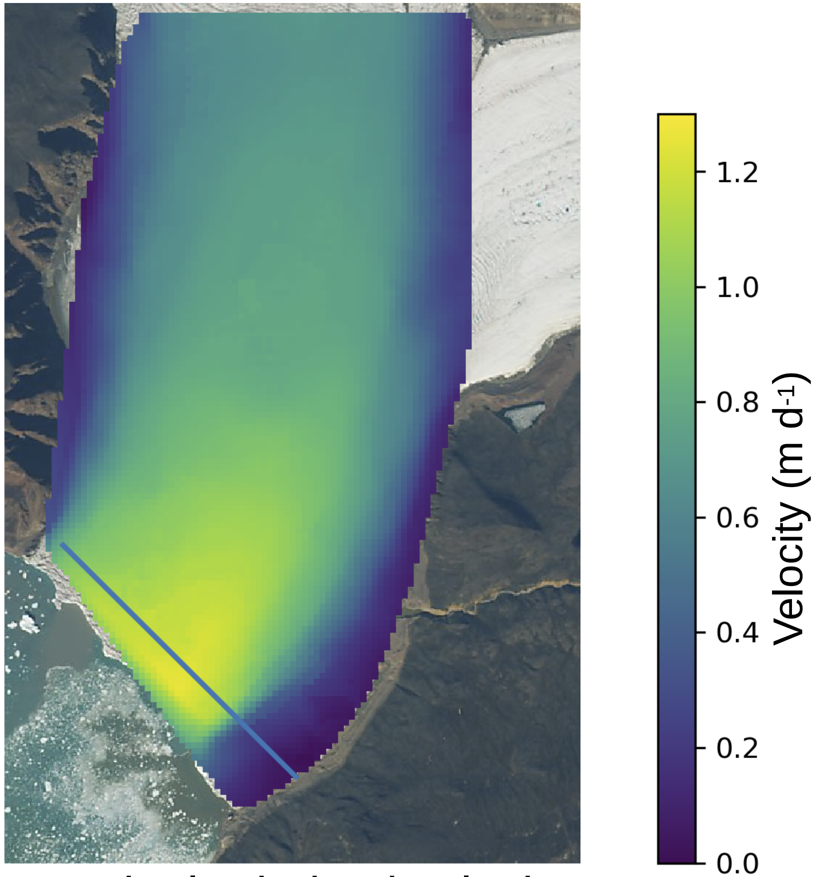
Horizontal velocity

Characterized by almost **stagnant zone east of moraine** (station 5b-f), highest velocity in central region (1b-f) and **low tide speed-ups**. **Calving** on 20 July has **no detectable effect on velocity**.



Day in July, 4 hr averaged GPS-derived velocity





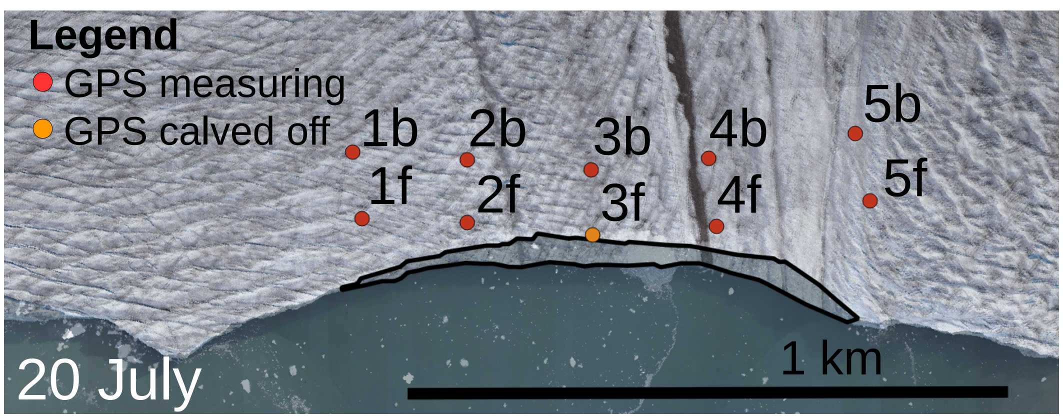
Sentinel2-derived velocity,
12 March – 28 September 2019

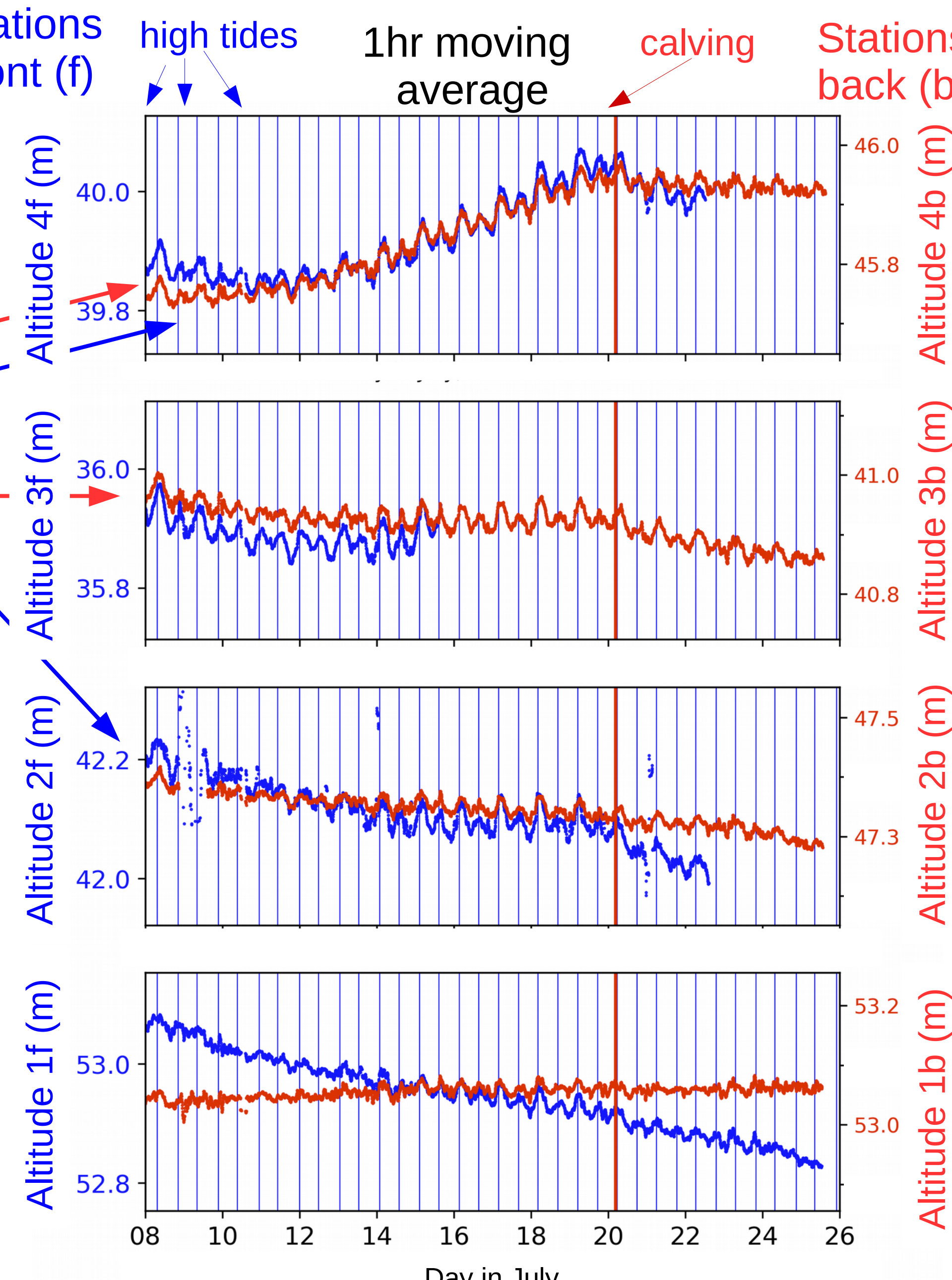
Elevation change from GPS

Semi-diurnal uplift at stations 1-4 of **~2 cm** in response to ~1 m tidal height.

20 July **calving affects vertical motion**:

- ~20 cm uplift prior to calving stops (4b),
- turns into downward motion (4f) or
- downward motion increases (3b and 2f).





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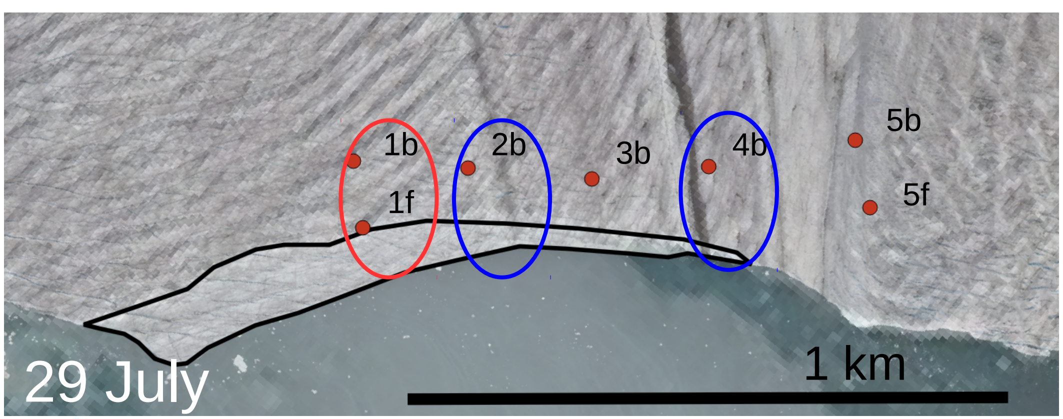
Along flow strain from GPS

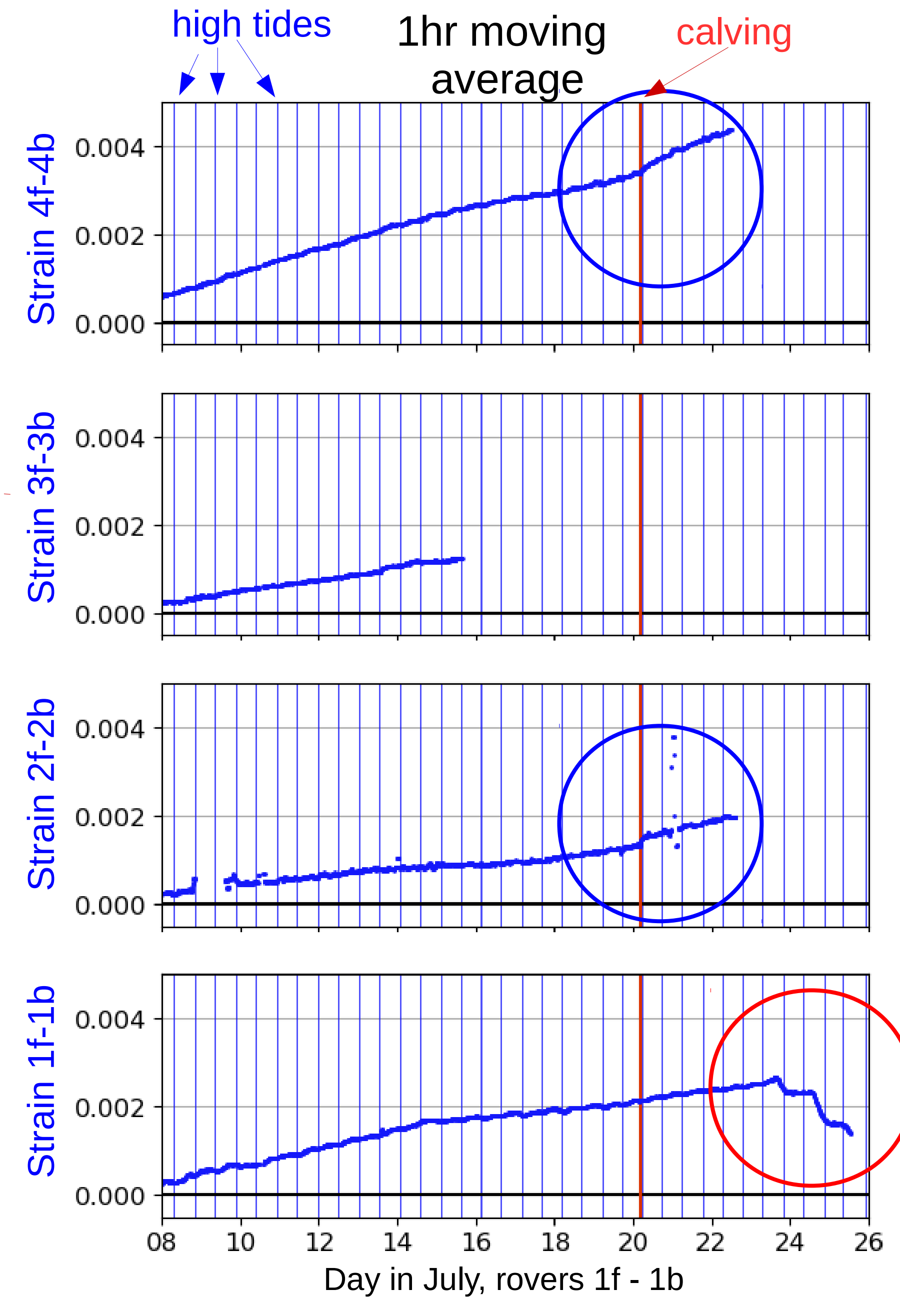
As measure of strain, the distance change between each pair of aligned stations is calculated:

$$\frac{d(t) - d(0)}{d(0)}$$

Changes in strain are observed closely to when two large-scale calving events occurred:

- 4b-f and 2b-f show **increased extension after** the 20 July calving: come closer to the new calving front.
- 1b-f show **strong horizontal compression** from 24 July onward, **prior to major calving** at 29 July.





Discussion

Bowdoin Glacier had a stable terminus position since 2013, but has been observed to thin ~5.5 m yr^{-1} at the calving front (Tsutaki et al., 2016).
Therefore a **change towards buoyancy-driven calving** is expected.

Our observations indicate that Bowdoin's **terminus was at/close to flotation** in July 2019:
- Vertical **tidal modulation,**
- Changes in vertical motion observed at stations 2f, 3b, 4b and 4f after 20 July calving can be explained by the **loss of floating area due to calving.**

Murray et al. (2015) describe buoyancy-driven calving: if the front of the glacier is out of buoyant equilibrium, **buoyancy forces** can cause the **front to lift and rotate**, creating **bottom crevasses**, and forming a **depression at the surface** of the glacier.

Several observations indicate **buoyancy-induced calving** at Bowdoin in 2019:
- **Downward motion at 1f and 2f**, on the edge of the 29 July calving event.
- **Horizontal compression at 1b-f prior to calving** at 29 July, since stretching at the glacier base could induce compression at the surface.
- **Uplift at 4b-f prior** to the 20 July calving is not consistent with observations by Murray et al. (2015) at Helheim Glacier, where the entire zone that lifted up subsequently calved off. However, the 20 July event was substantially smaller than calving at Helheim which could explain different behaviour.

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Thanks for looking at our display!

Acknowledgements

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