School of Earth and Environment
INSTITUTE FOR CLIMATE & ATMOSPHERIC SCIENCE

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A new methodology for ice shelf and glacier grounding line delineation with synthetic aperture radar in low coherence regions using tidal motion correlation

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The Antarctic Peninsula – an important and dynamic region of Antarctica

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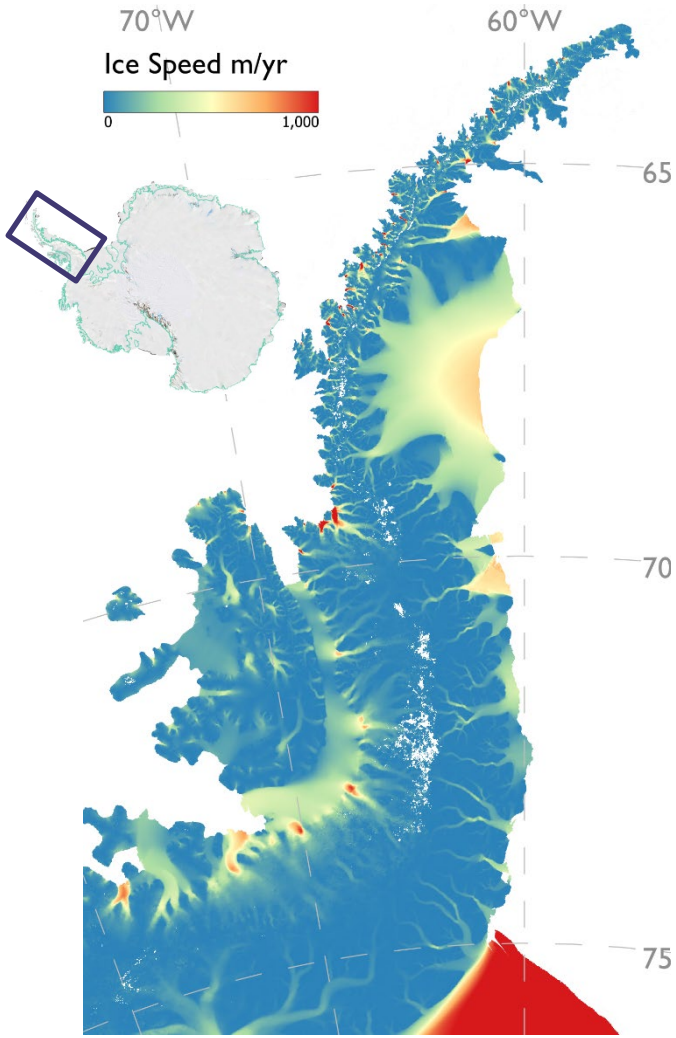
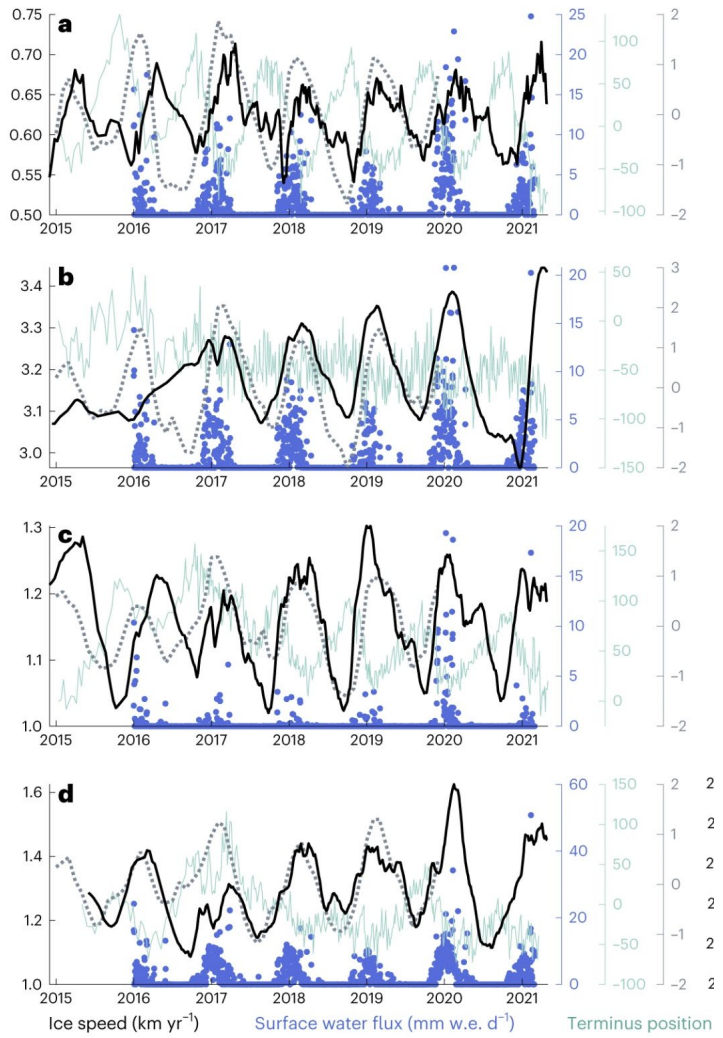
- From 1992 to 2017 the Antarctic Peninsula accounted for **19%** of Antarctica's ice mass loss[1].
- In the remote sensing era: major ice shelf collapses[2,3], ice flow acceleration[4,5] and glacier retreat[6].
- Recent observations of seasonal ice speed variability show sensitivity to climate on short timescales[7,8].





[1]Shepherd et al., 2018, [2]Rott et al., 1996, [3]Rack & Rott, 2004, [4]Rignot et al., 2004, [5]Wuite et al. 2015, [6]Cook et al. 2016, [7]Boxall et al., 2022, [8]Wallis et al., 2023

Grounding lines – a quick recap

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What?

- The grounding line is where glaciers and ice shelves begin floating.

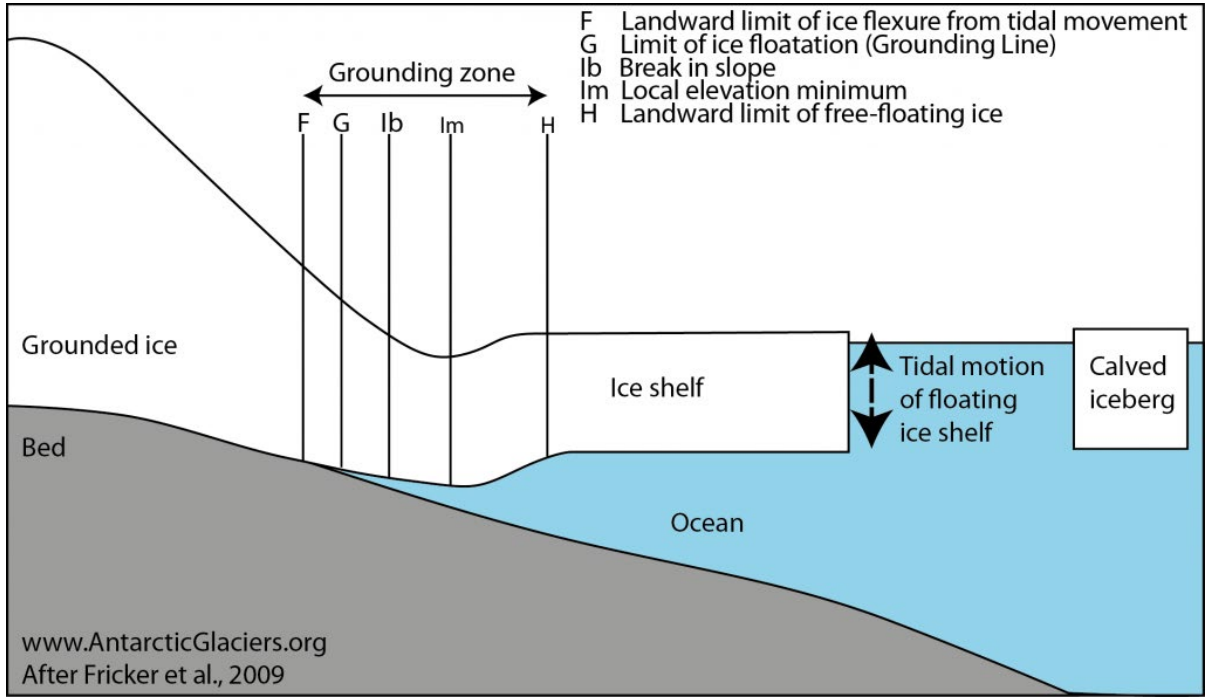
- There's actually a grounding zone – because the ice flexes with the tide.

Why?

- We need to know where the ice is floating to work out the ice sheet's contribution to sea-level rise.

- Ice sheet modelers need accurate grounding lines to initialise and run their models.

- The position of the grounding line on the bed can tell us about the glacier's stability.



Grounding lines on the AP are unknown or outdated

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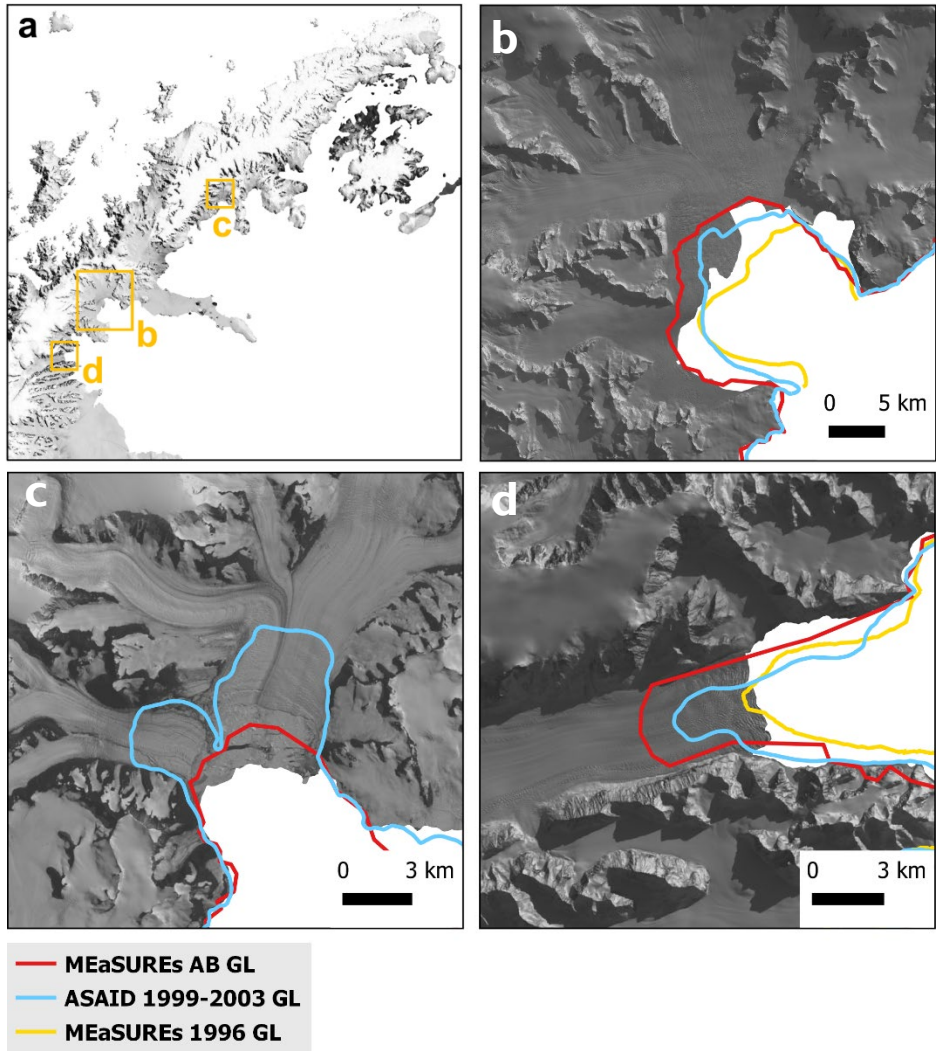
- The AP has high accumulation, fast ice flow, extreme topography and lots of small glaciers.
- In other words: **a difficult place to maintain InSAR coherence!**
- In many locations the most recent available grounding lines are from the tandem phase of ERS-1&2 (1996).
- This creates difficulty when interpreting observations.



Existing methods to cope with low DInSAR coherence have limitations

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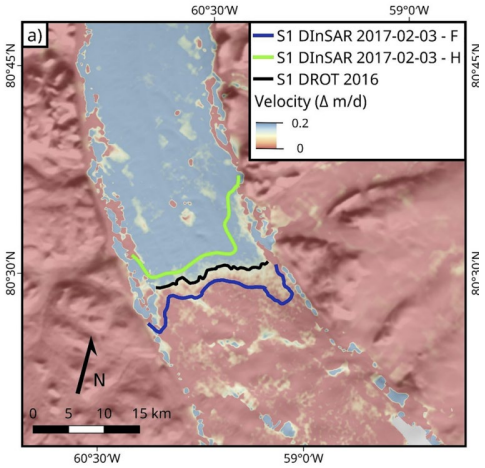
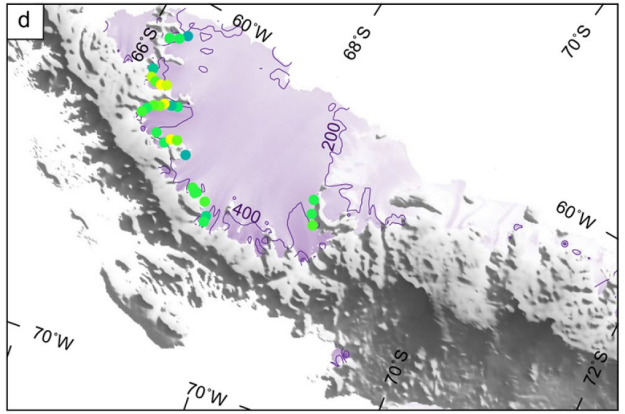
Differential range offset tracking (DROT):



- Far less sensitive than DInSAR
- Requires manual delineation

Image: Nagler et al. 2017

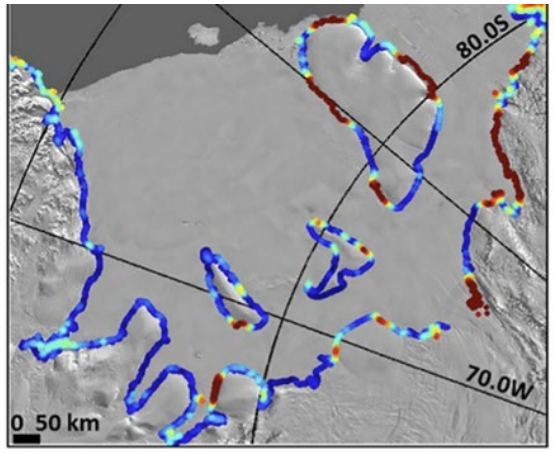
Repeat altimetry methods:



- Altimeter track spacing is greatest at lower latitudes

Image: Dawson & Bamber, 2020

Static methods, e.g. surface slope:



- Not a dynamic measurement
- Hard to interpret at ice planes

Image: Hogg et al., 2017

We actually have a lot of useful data already!

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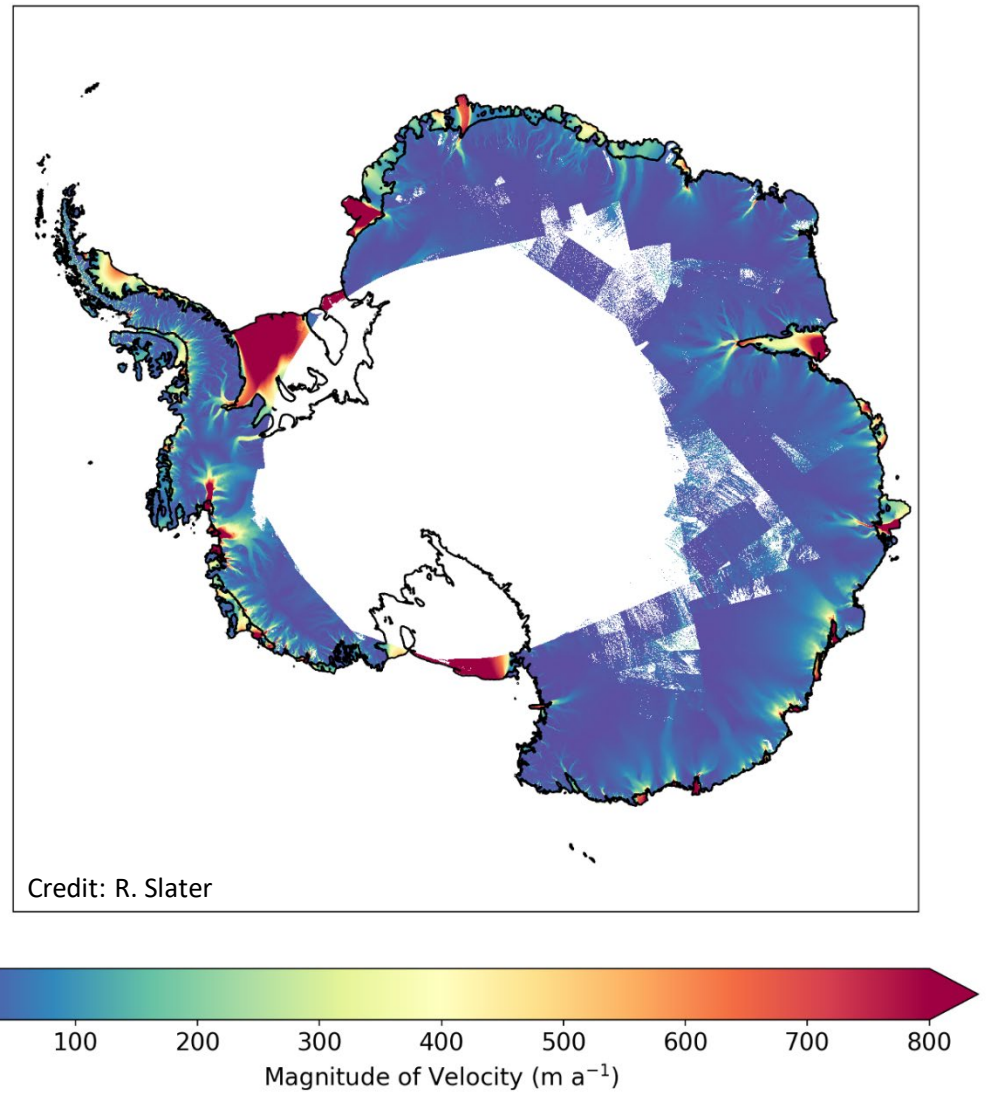
We already routinely process large volumes of ice velocity data



Tidal motion in velocity tracking - noise or useful information?

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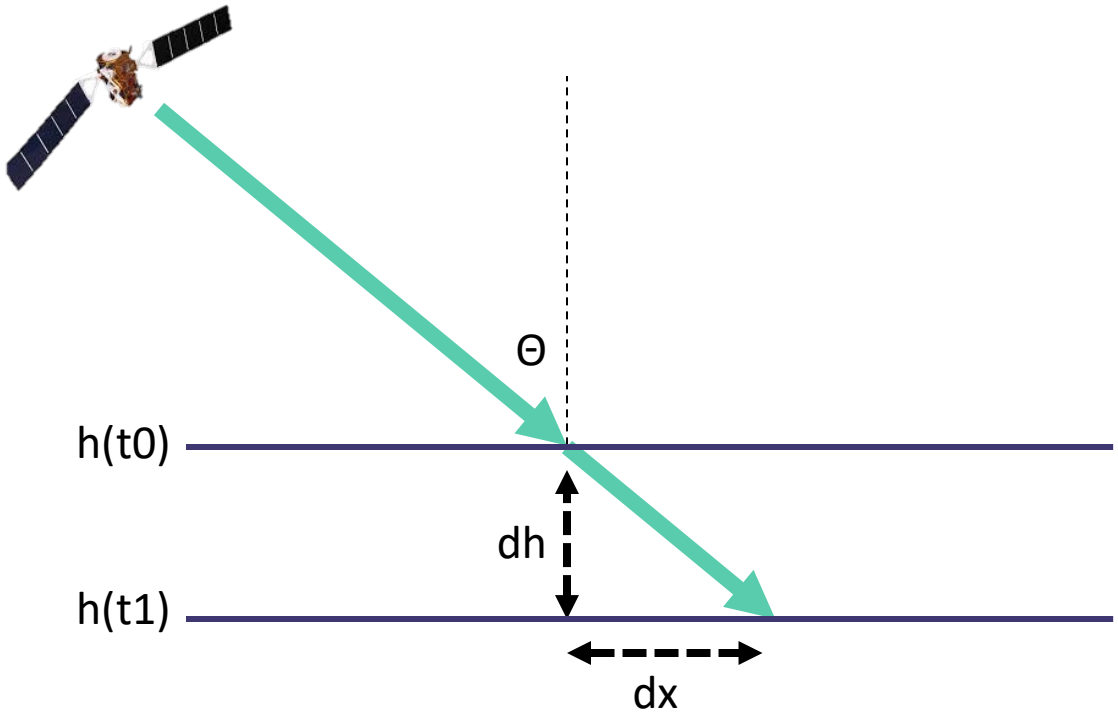
- Vertical tidal displacement creates an apparent range velocity component in feature tracking.
- This creates a noisy signal where the ice is floating.
- This is usually considered a source of error to be corrected.
- But, the presence of these signals could tell us if the ice is floating.

Real vertical motion

=

Apparent horizontal motion



Tidal motion offset correlation (TMOC) algorithm description & physical basis

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Feature track SAR images as normal

Extract just the range direction speed

Filter out any long-term speed signals

Model (CATS2008) tide heights at each acquisition

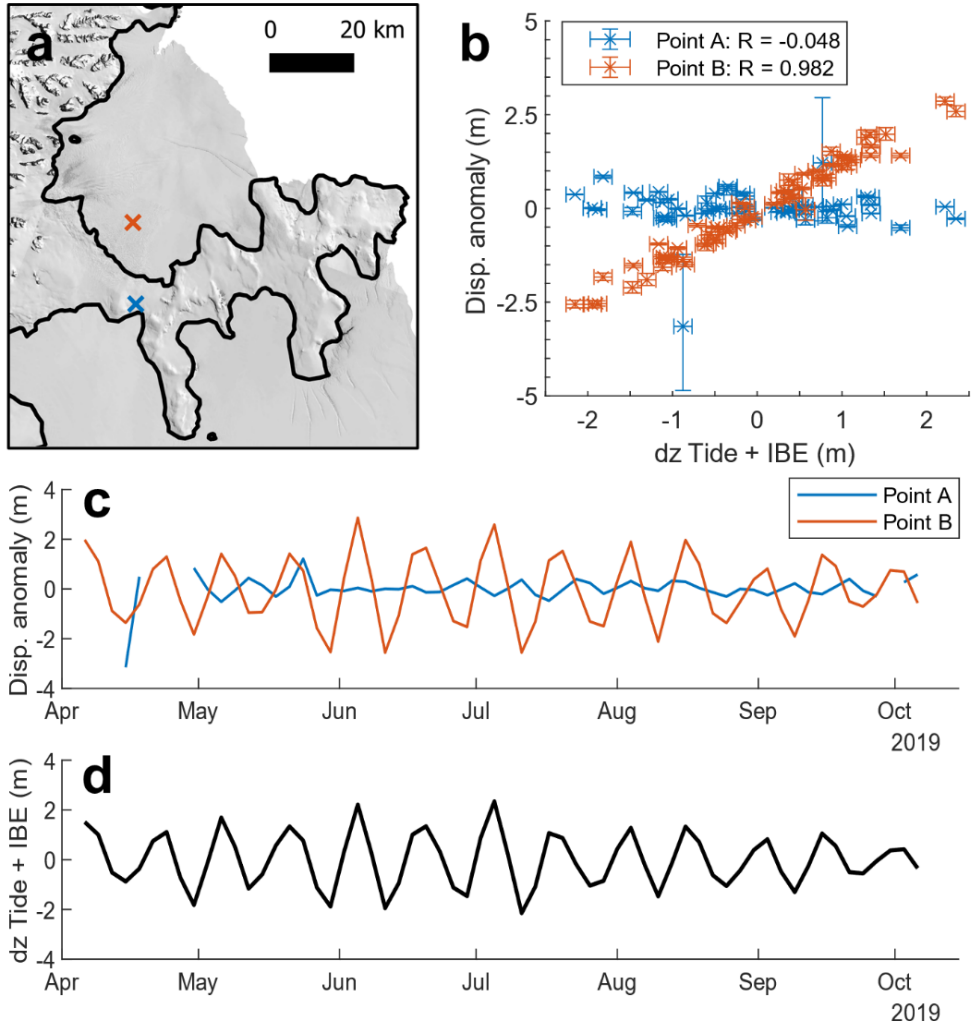
Calculate vertical displacement for each pair

Exclude pairs with tide displacements < 0.2 m

ERA5 sea-level atmospheric pressure data

Calculate the correlation between tide displacement and range velocity

Post process and contour to extract the grounding line



Results using Sentinel-1 ice velocity data from 2019-2020

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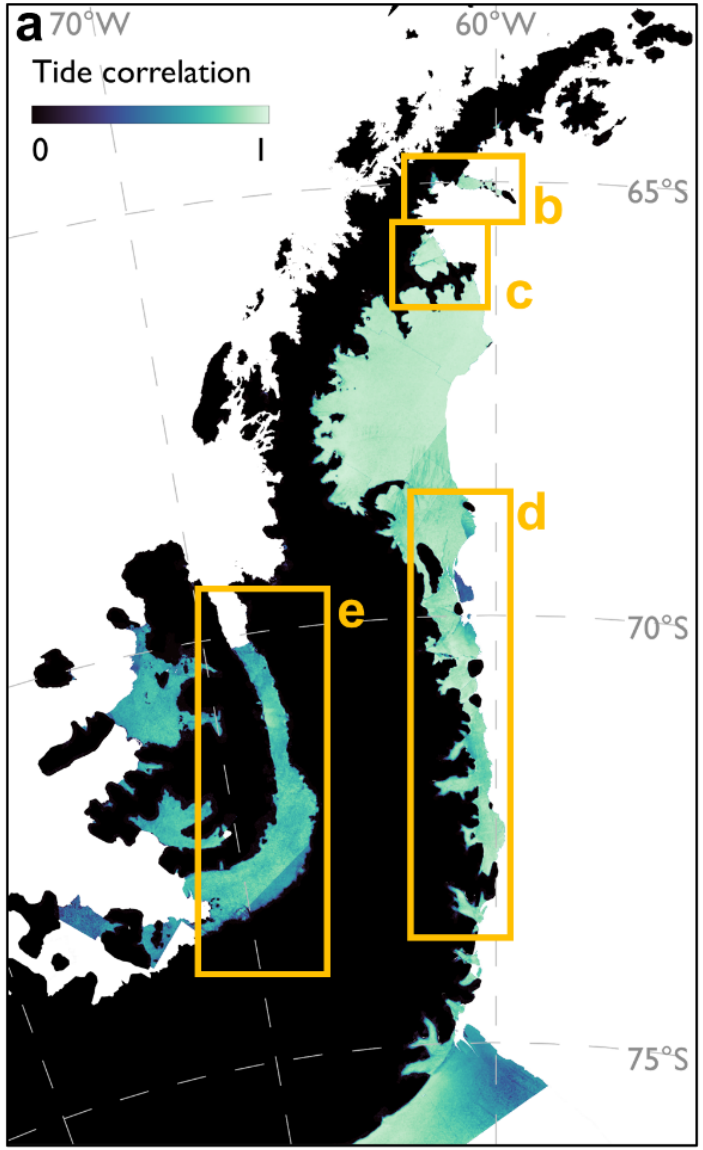

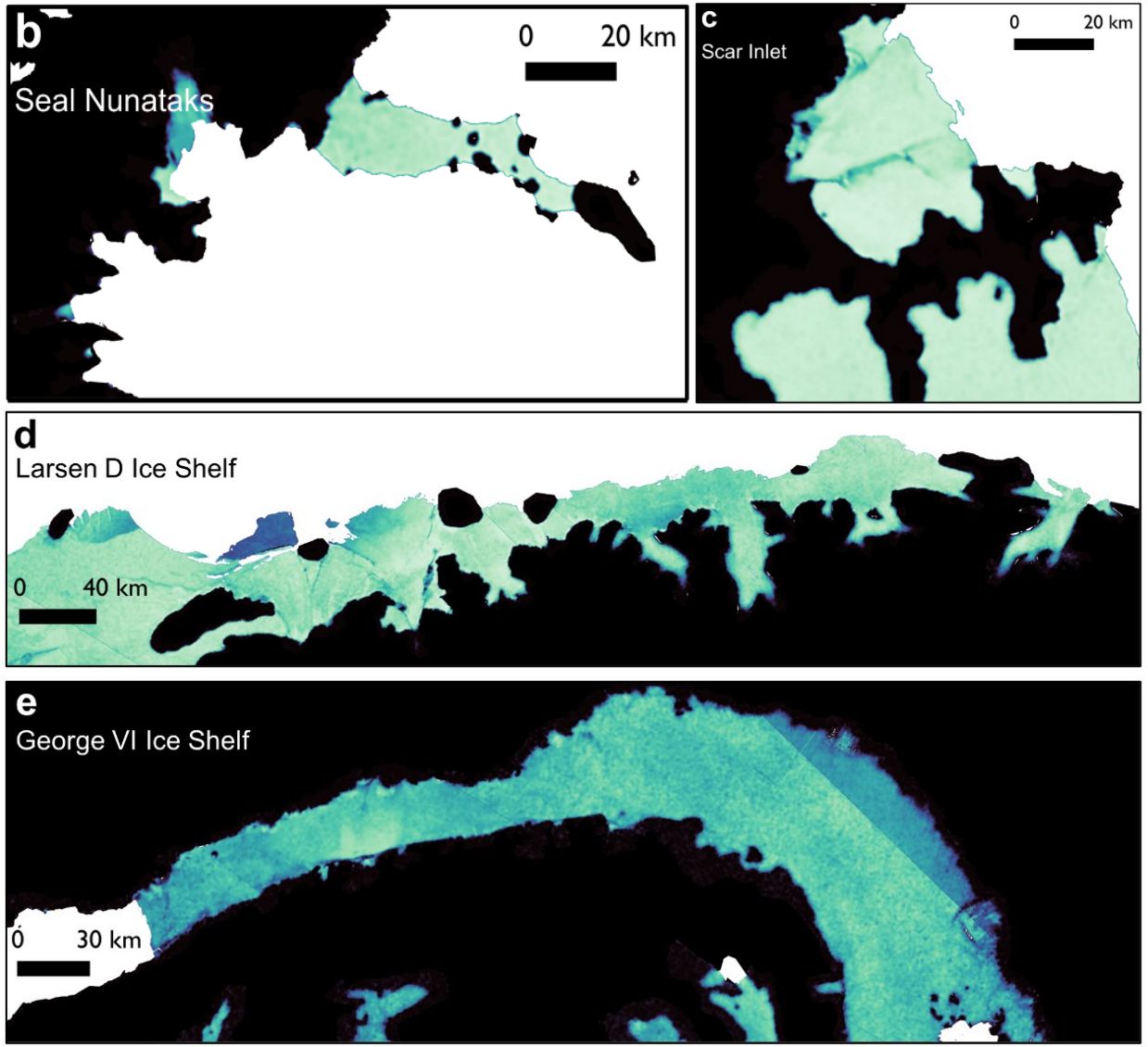

Taking a closer look – InSAR vs TMOC

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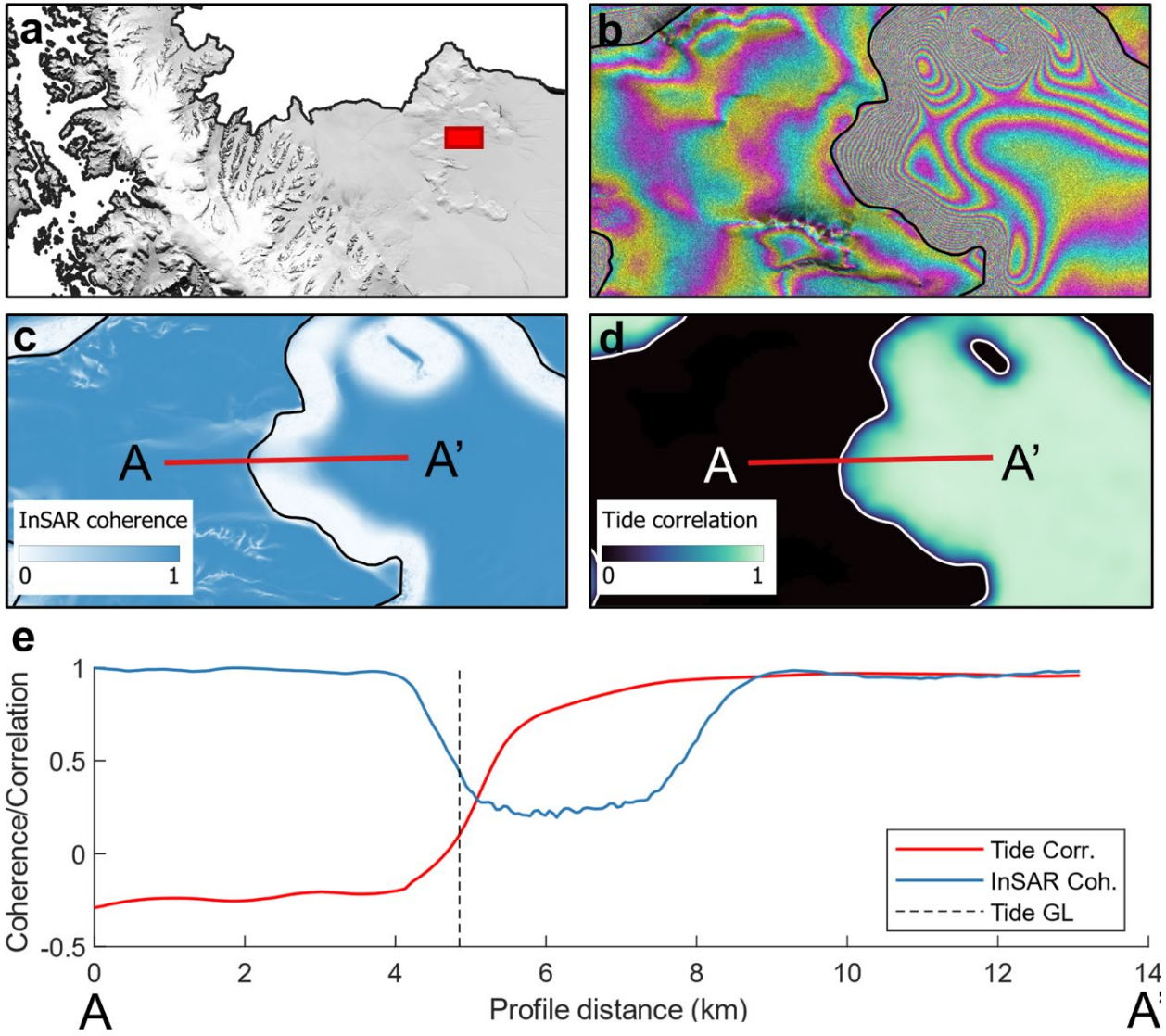

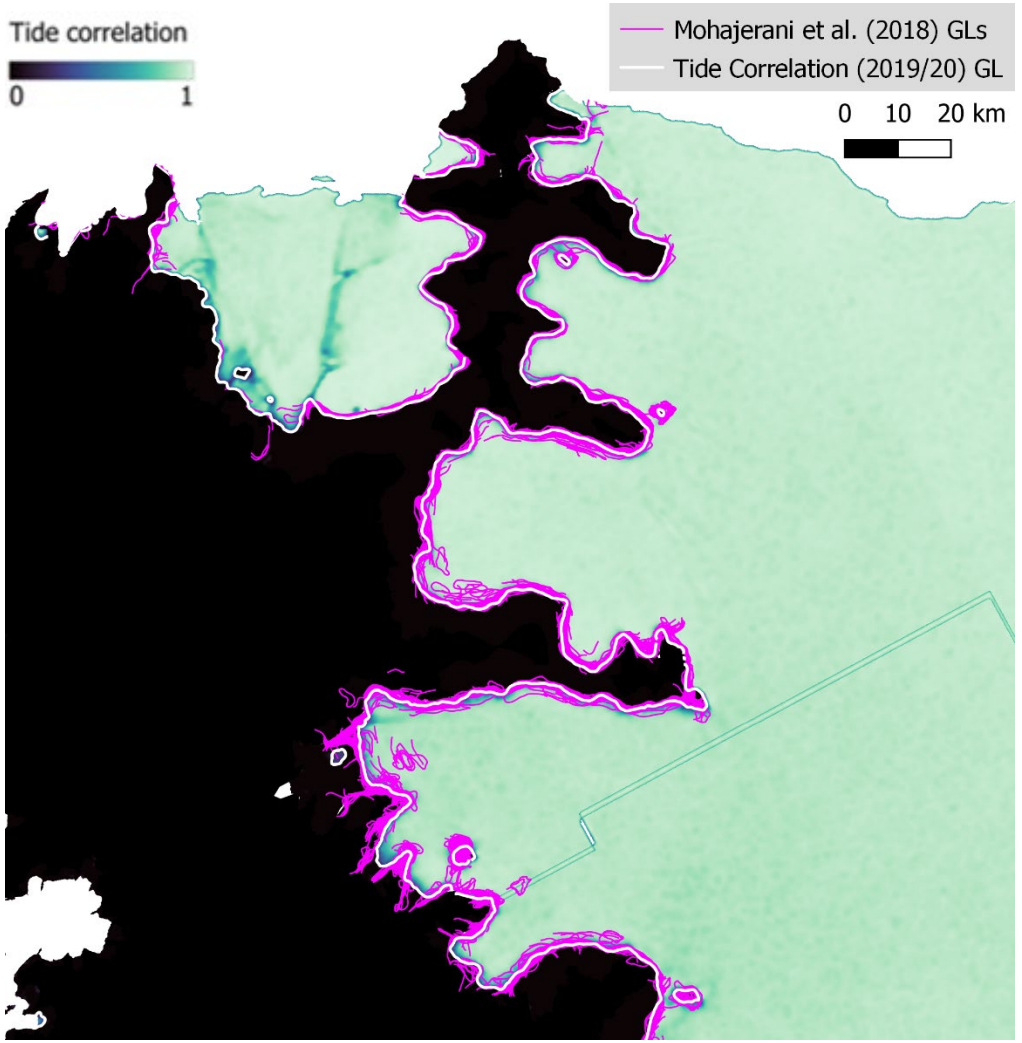

Taking a closer look – InSAR vs TMOC

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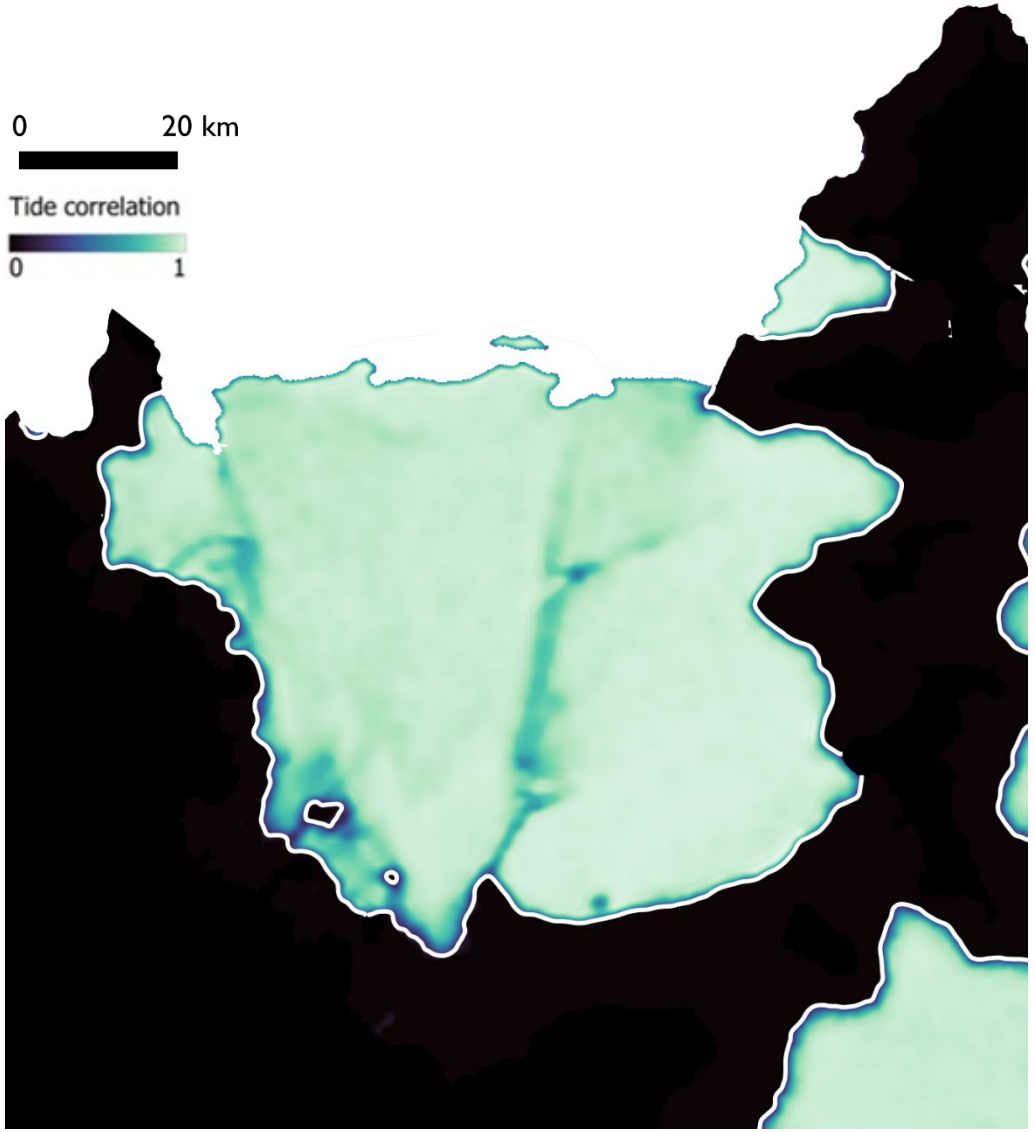
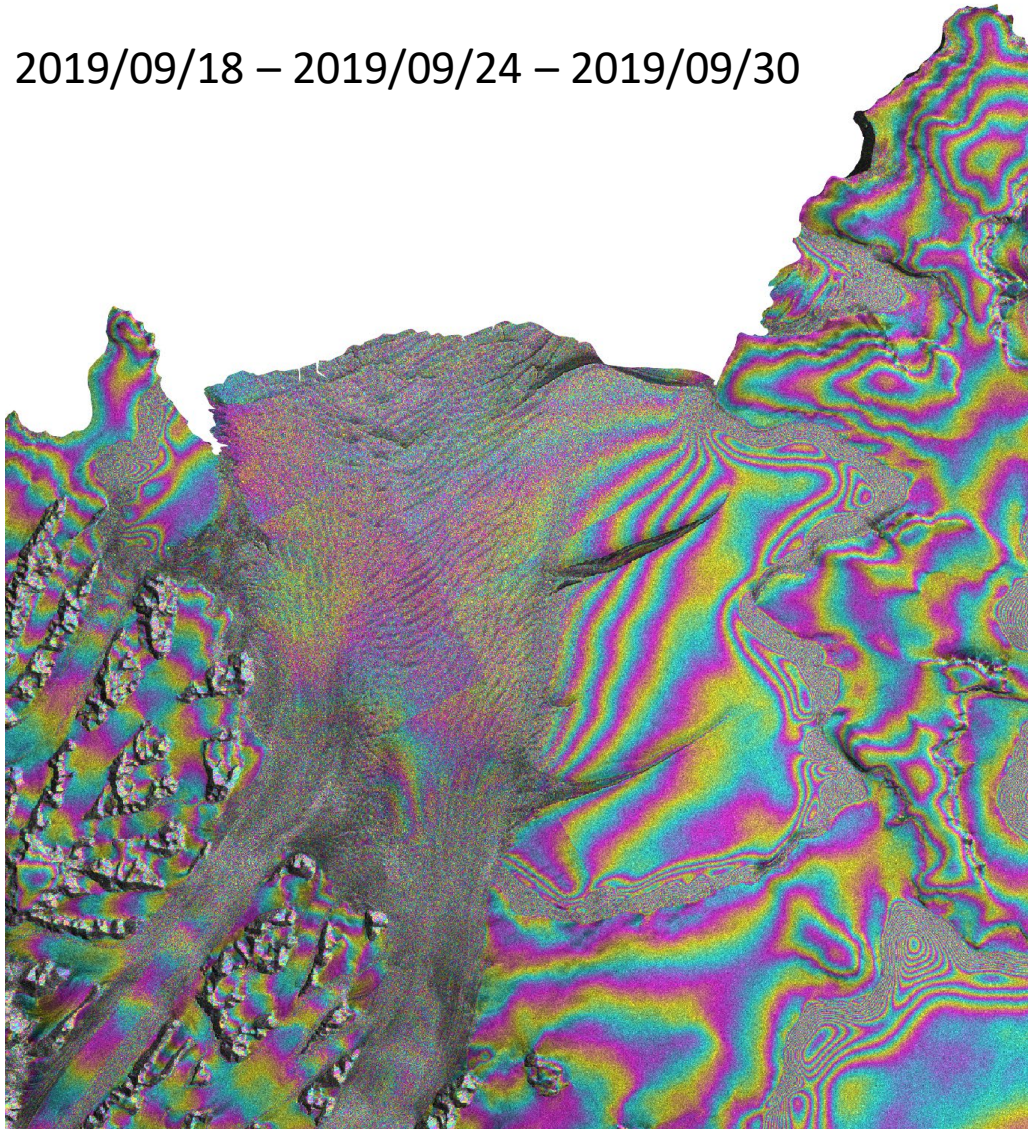


2019/09/18 – 2019/09/24 – 2019/09/30



So how good is it? - Large scale performance

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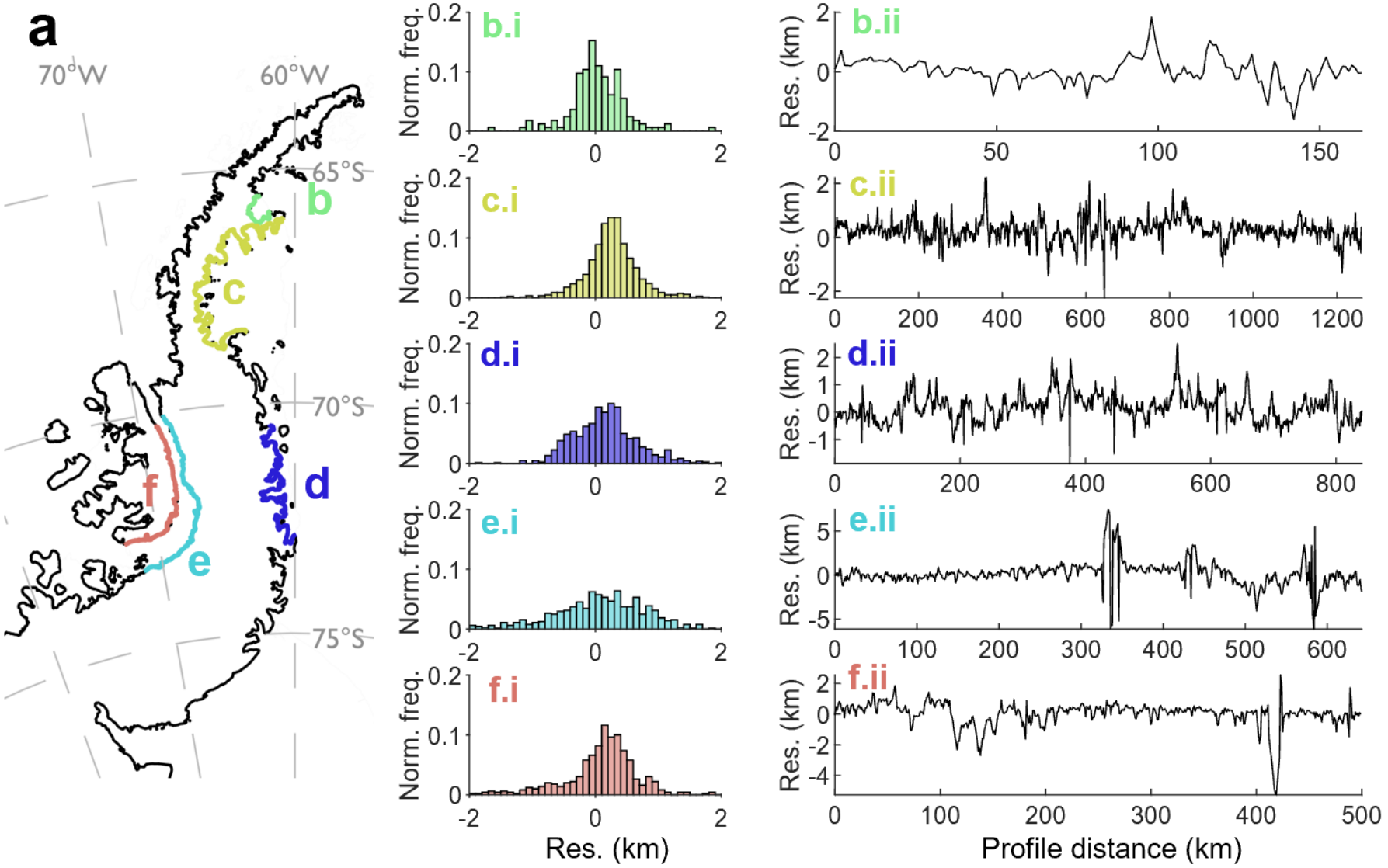

Region	Tide vs MEaSUREs Antarctic Boundaries (2019) v2	
	Mean seaward offset (m)	Std. (m)
Larsen B remnant	136.4	473.6
Larsen C	208.2	316.4
Larsen D	162.1	546.2
George VI East	138.3	1449.3
George VI West	166.1	266.0
Total	164.6	293.9

Now let's use it! – pinning points

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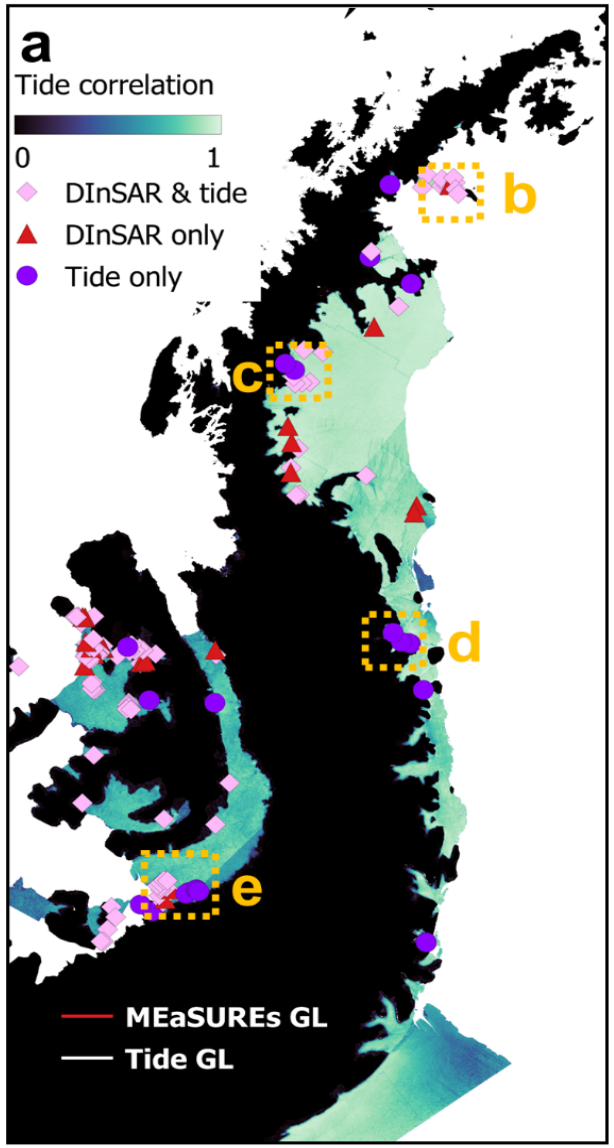
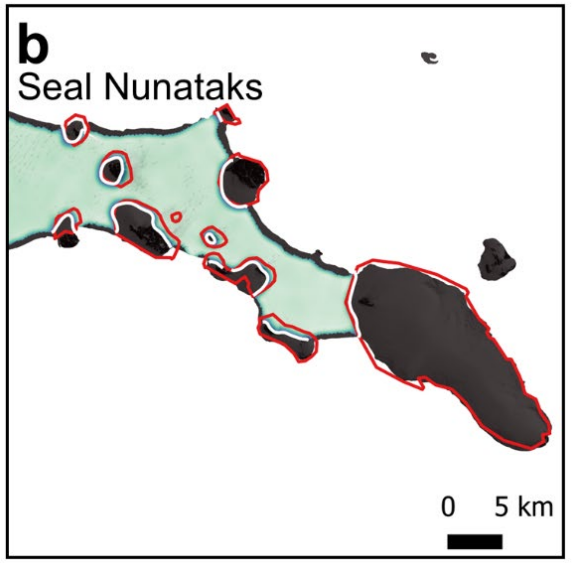
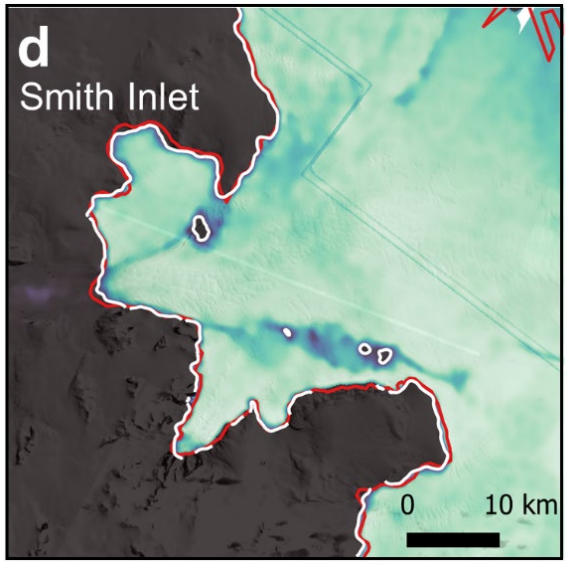
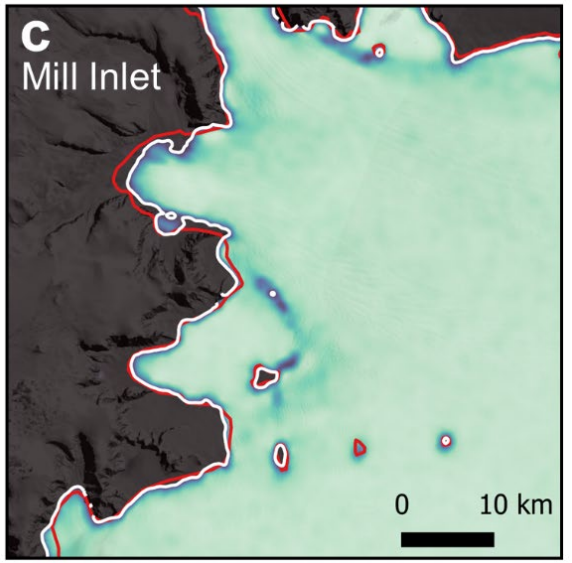
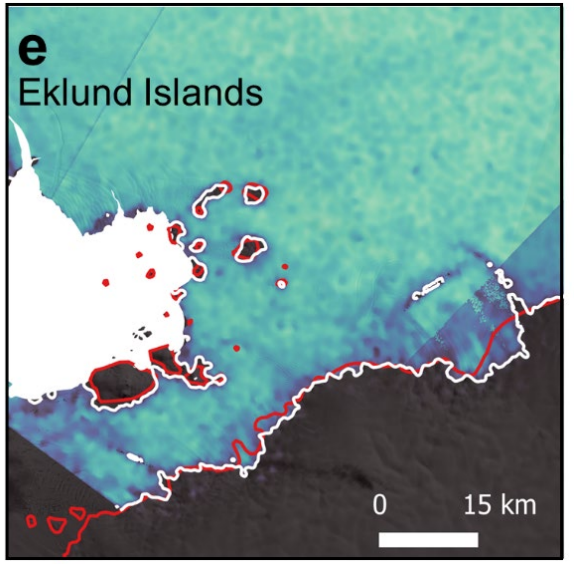
- We can use our new method to study pinning points
- Changes to pinning points can indicate ice shelf thickness change
- We identified 22 unmapped pinning points











Using TMOC we have observed grounding line retreat in the Antarctic Peninsula region

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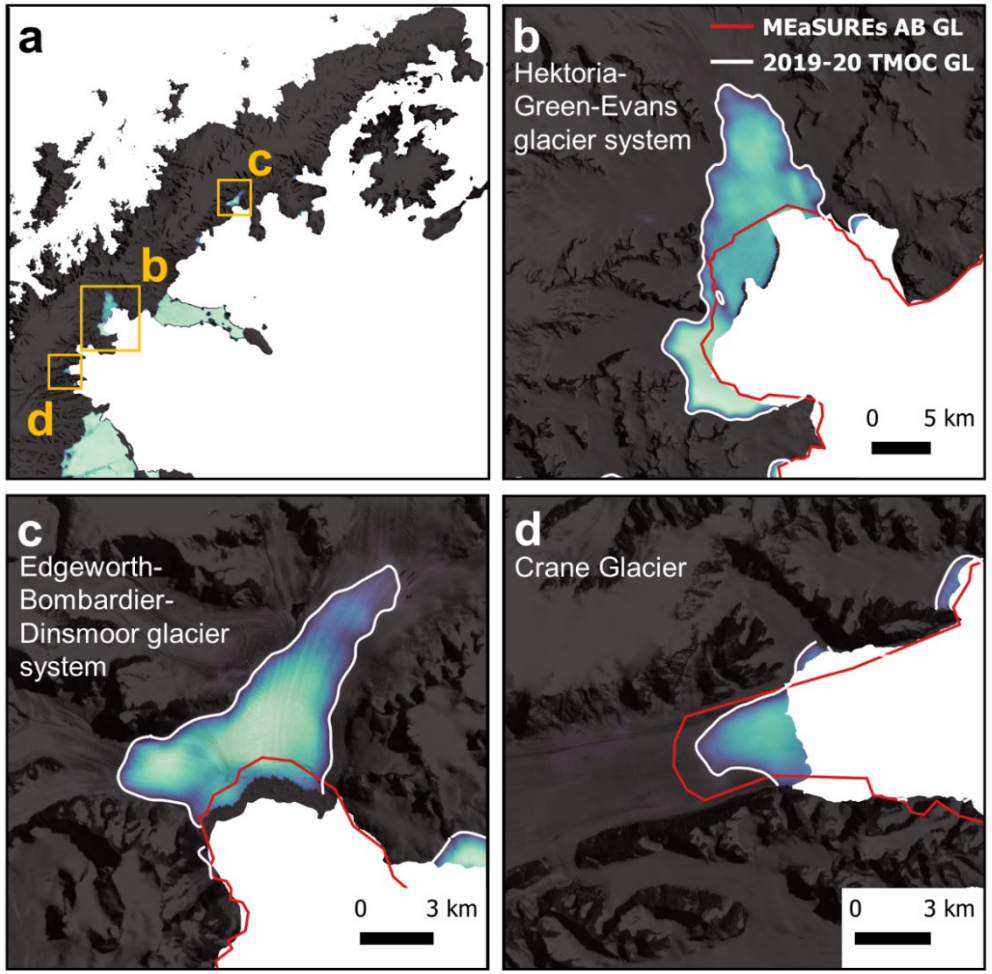

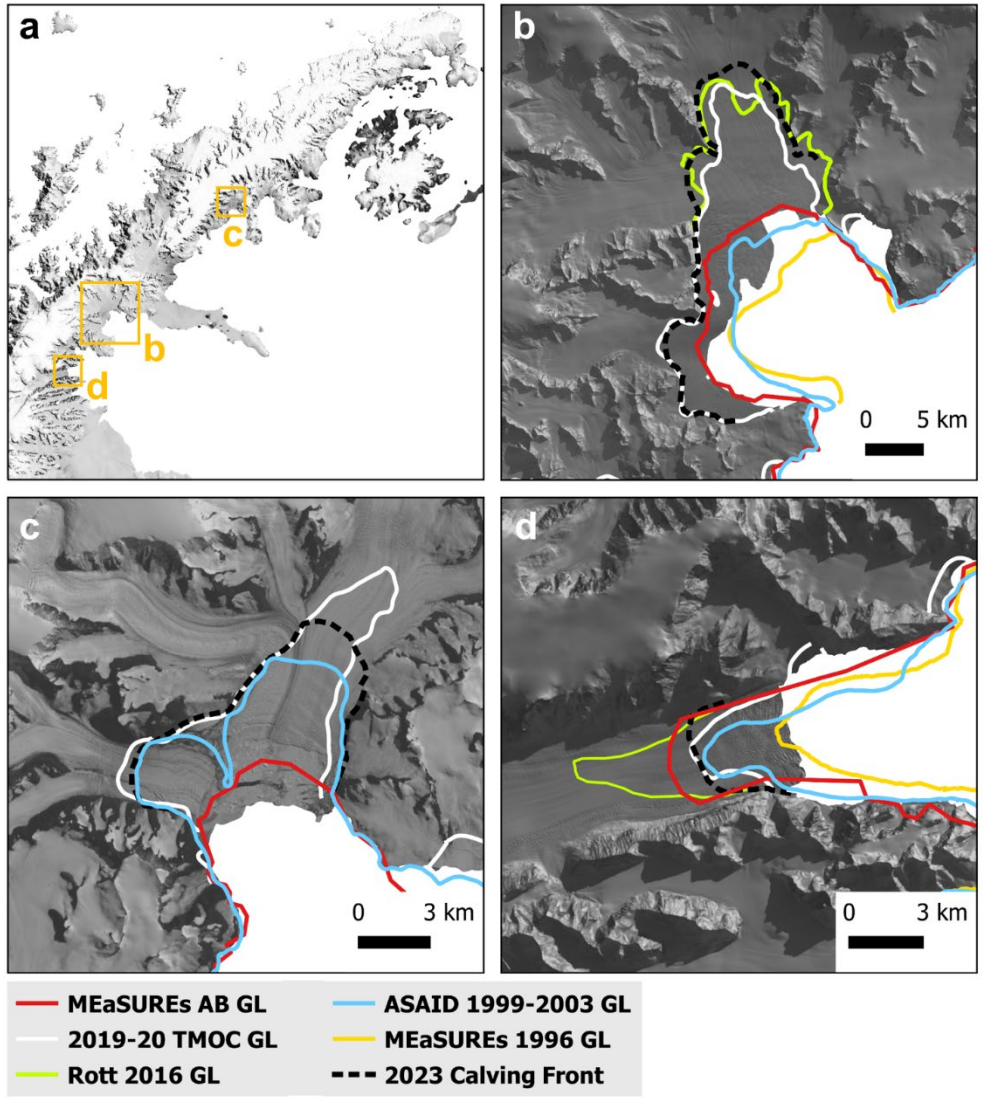

Towards persistent monitoring of grounding lines

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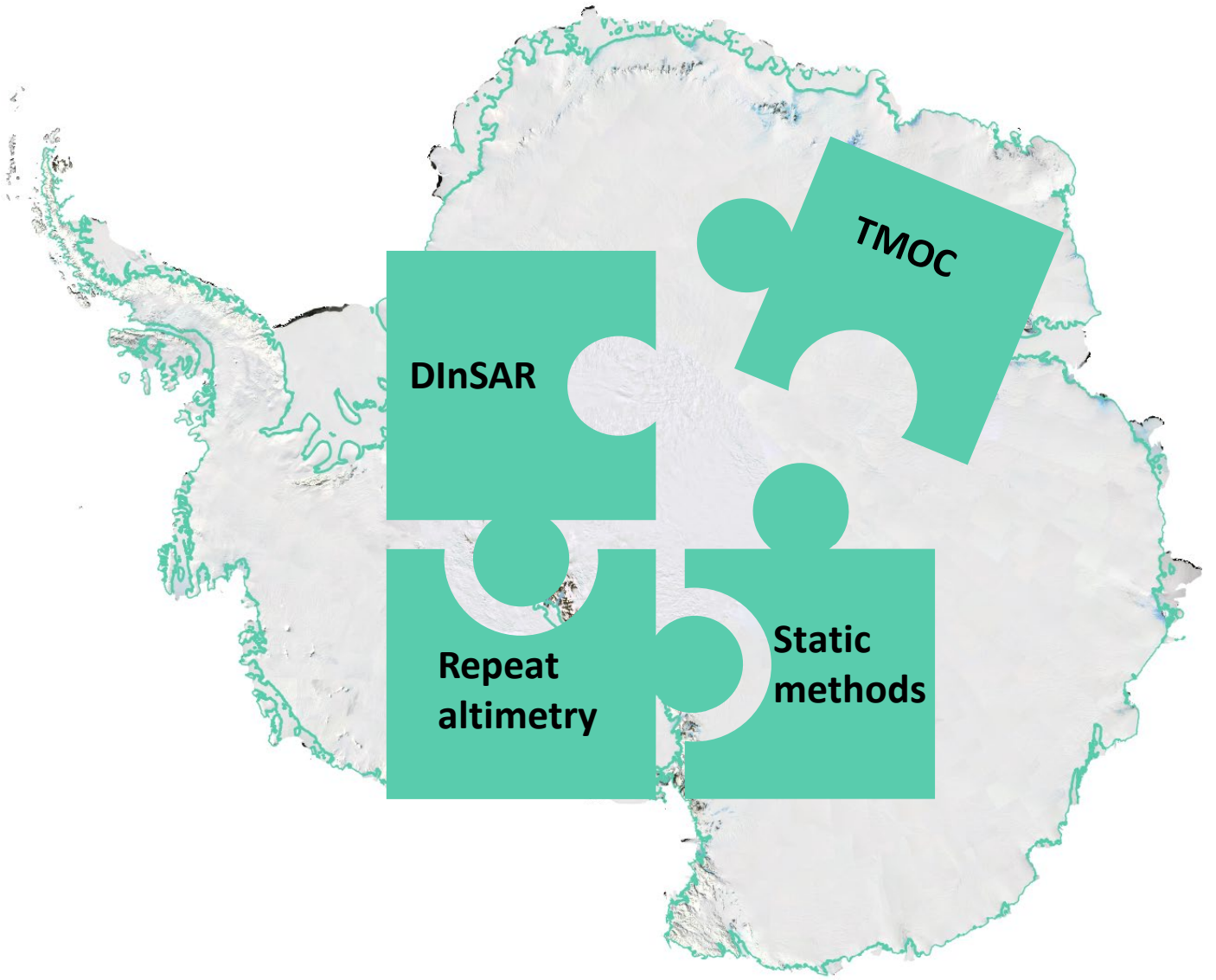
- Grounding lines are an essential parameter which should be persistently monitored.
- Existing methods already do a great job in most parts of Antarctica, but challenges remain (e.g. the Peninsula)
- We have produced a comprehensive Antarctic Peninsula grounding line dataset for 2019-20.
- Our grounding lines have already been used in modelling of Larsen B (Surawy-Stepney et al. 2023)



Summary & Recommendations

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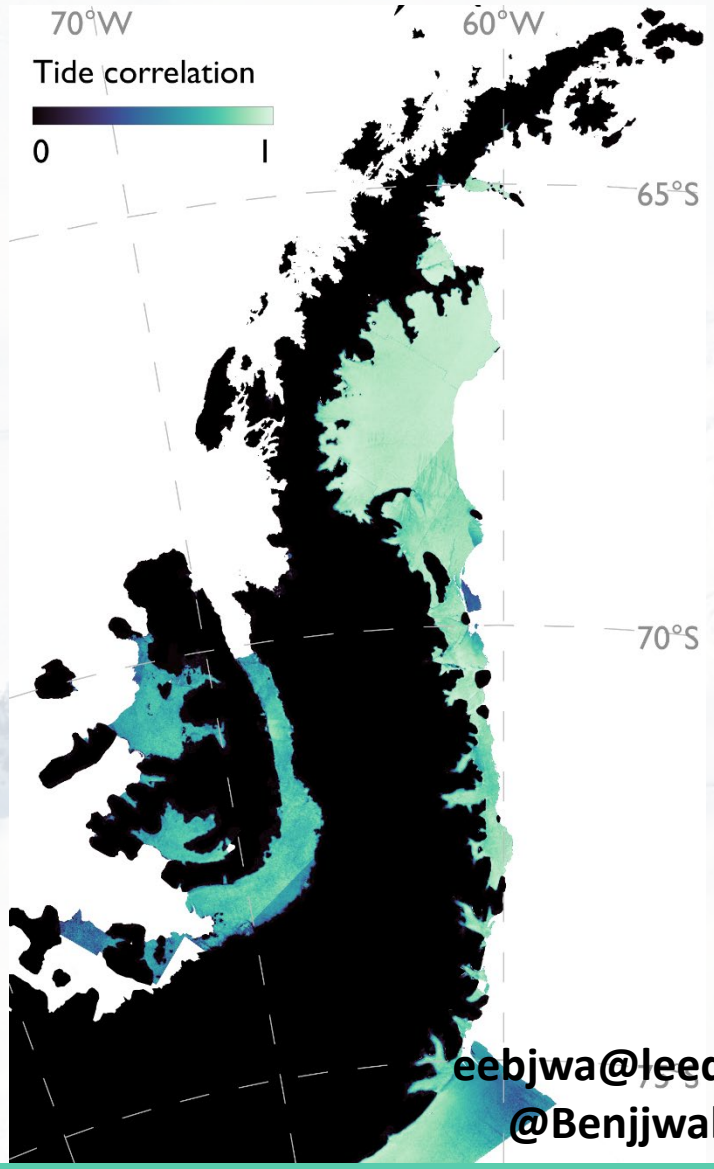
Summary:

- We describe a new method to measure grounding line position where there is a lack of InSAR coherence.
- This method provides near total coverage in the Antarctic Peninsula.
- This method performs well in comparison to DInSAR with an average deviation of < 200 m.
- We use this method to produce an up-to-date Antarctic Peninsula grounding line.
- We find examples of grounding line retreat (up to 16.5 km since 1996) in the north-east Peninsula.

Recommendations:

- Developing complete and persistent monitoring of the Antarctic Ice Sheet grounding line must remain a priority.
- This is best achieved through combining methods to improve coverage and reduce uncertainty.
- The resumption of 6-day repeats is essential to monitoring grounding line change in Antarctica.



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