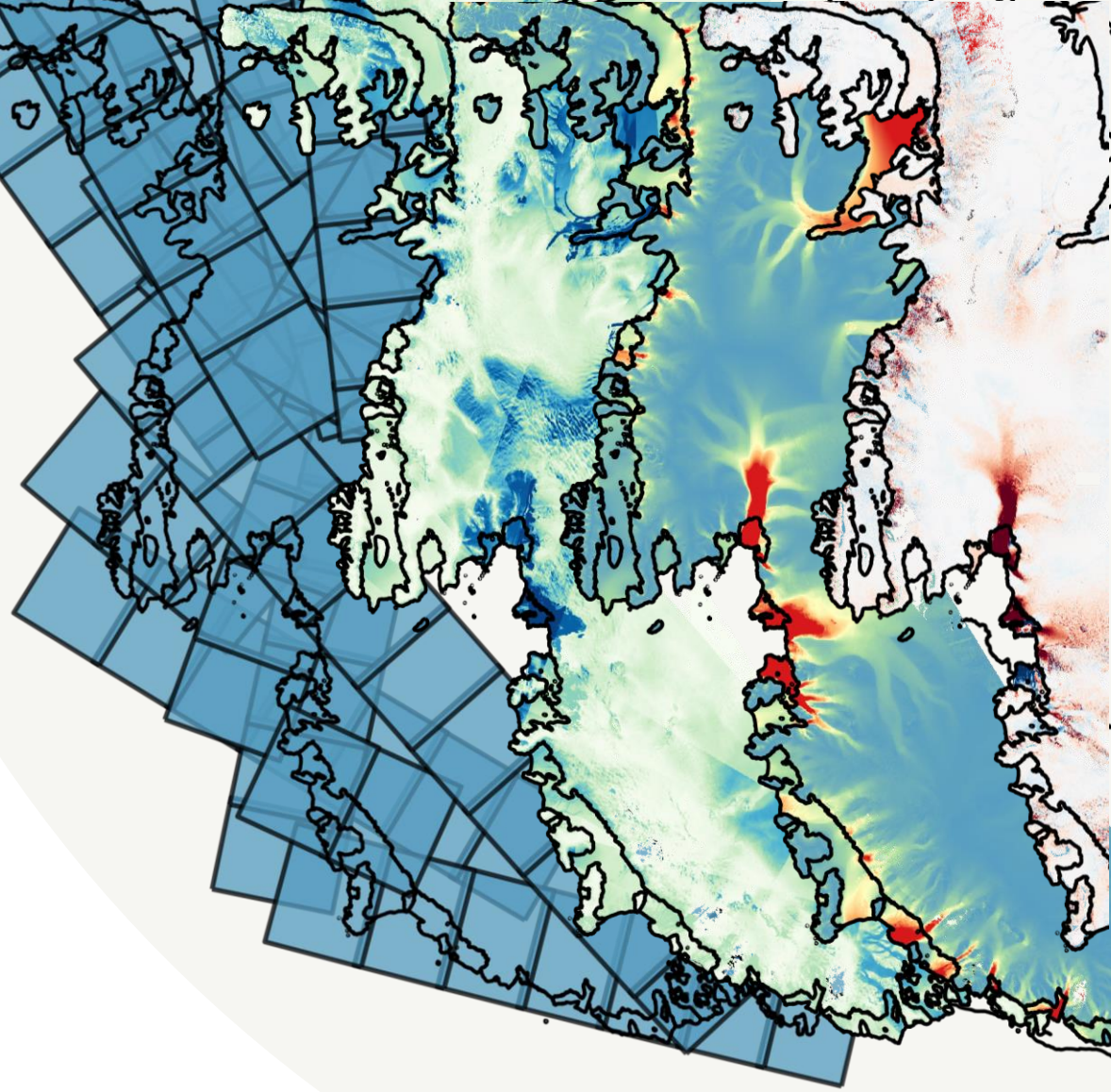
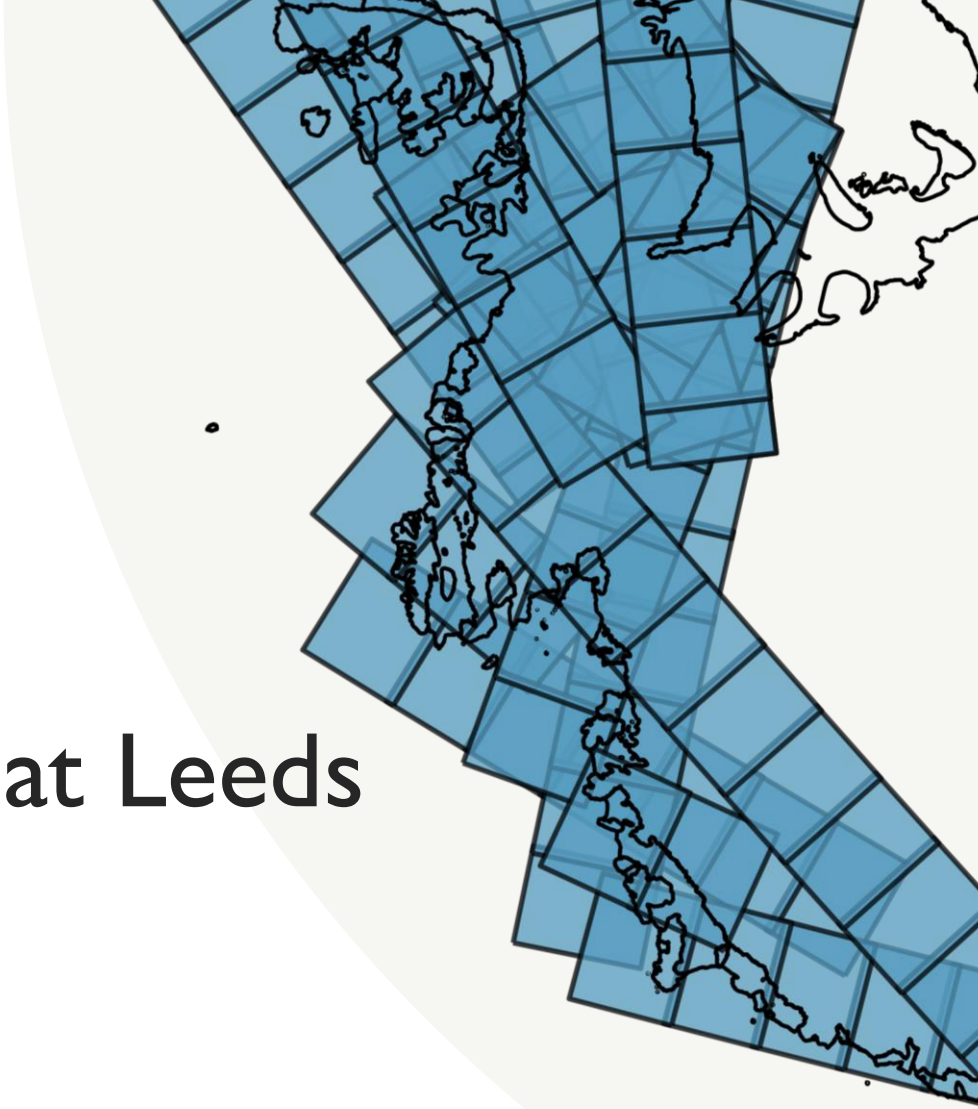
Large-scale ice velocity mapping in Antarctica: status, advances and opportunities



Benjamin J. Wallis, Anna E. Hogg, Ross A.W. Slater
Institute for Climate and Atmospheric Science
University of Leeds, UK

04/09/2024

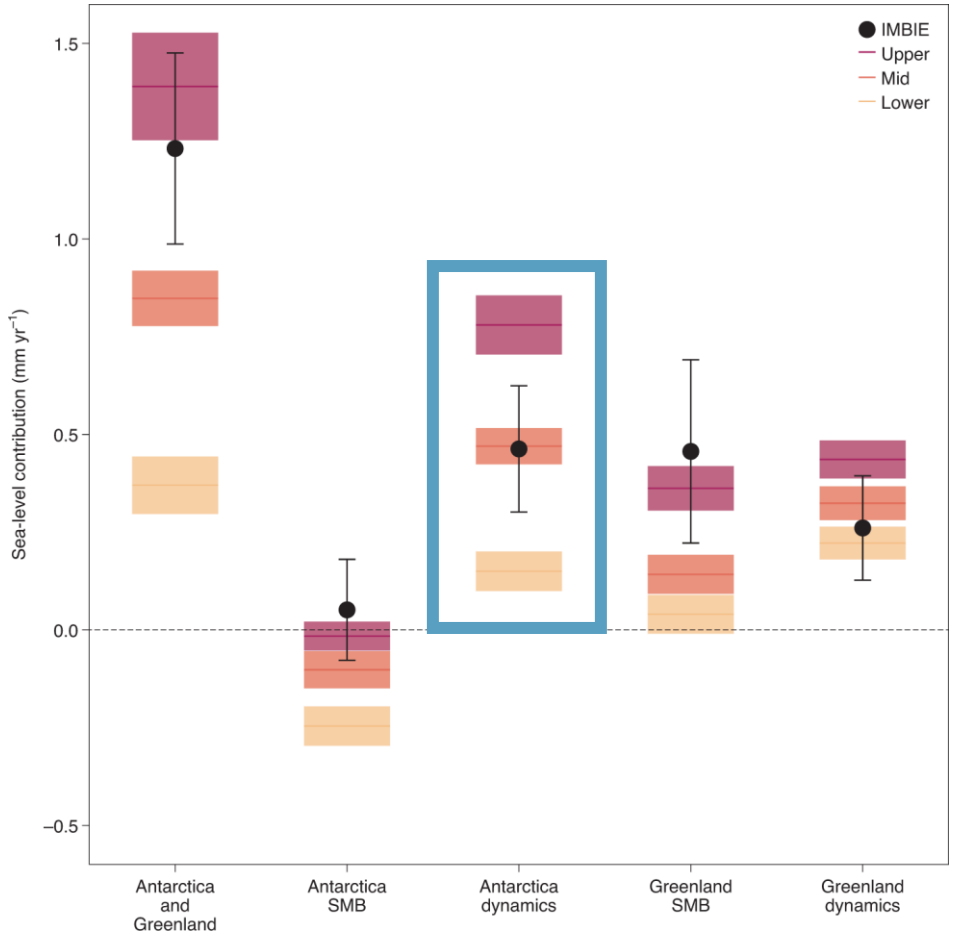
UNIVERSITY OF LEEDS



Part 1
Satellite Ice Dynamics at Leeds

Why monitor Antarctic Ice Sheet dynamics?

- Ice sheet mass loss is a major contributor to global sea-level rise.
- Ice dynamics constitute 90% of Antarctica's sea-level rise contribution[1].
- Knowledge of ice dynamics is crucial to developing our understanding of ice-sheet processes, including tipping elements.
- Satellite data is the only way to achieve monitoring on the scale our challenges demand.

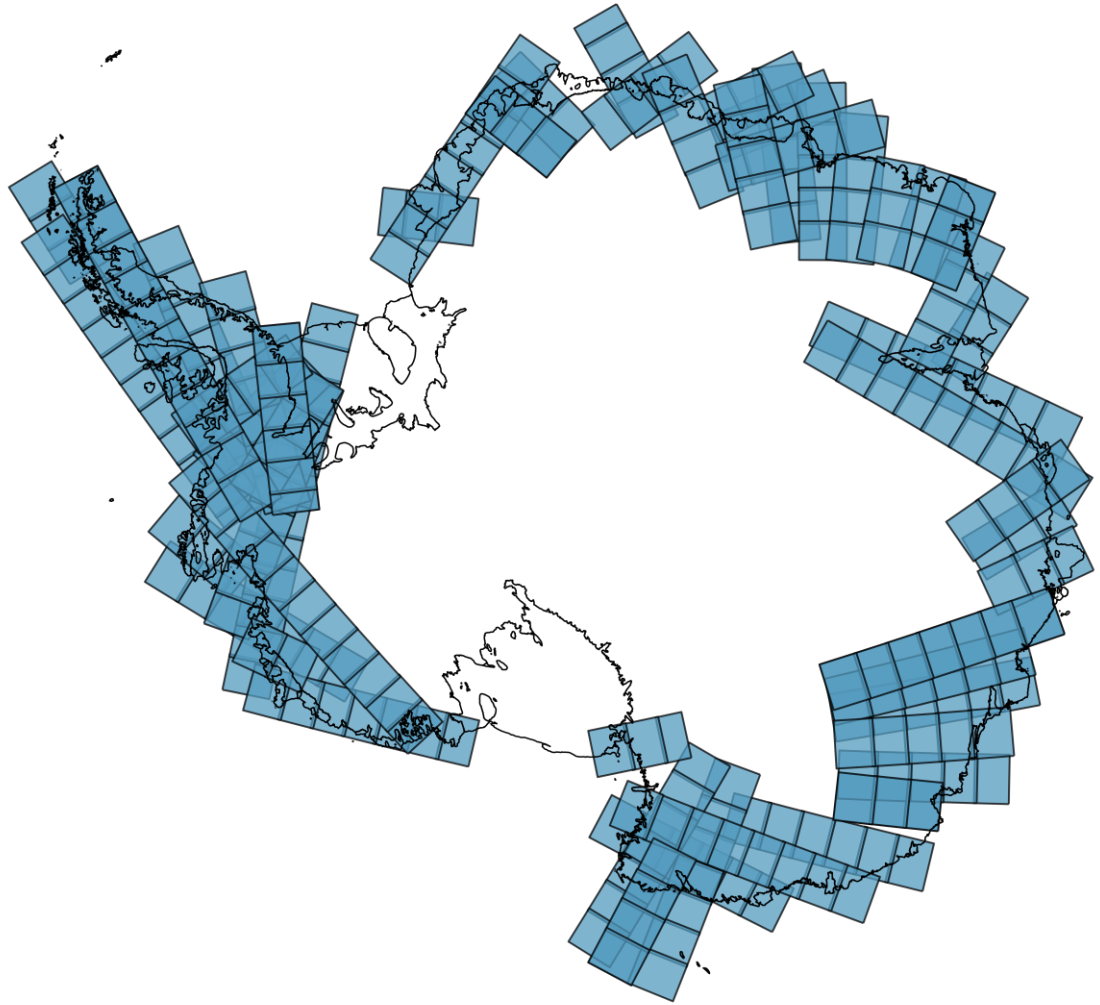


(Reproduced from Slater et al. 2020)

[1]Slater et al. 2020

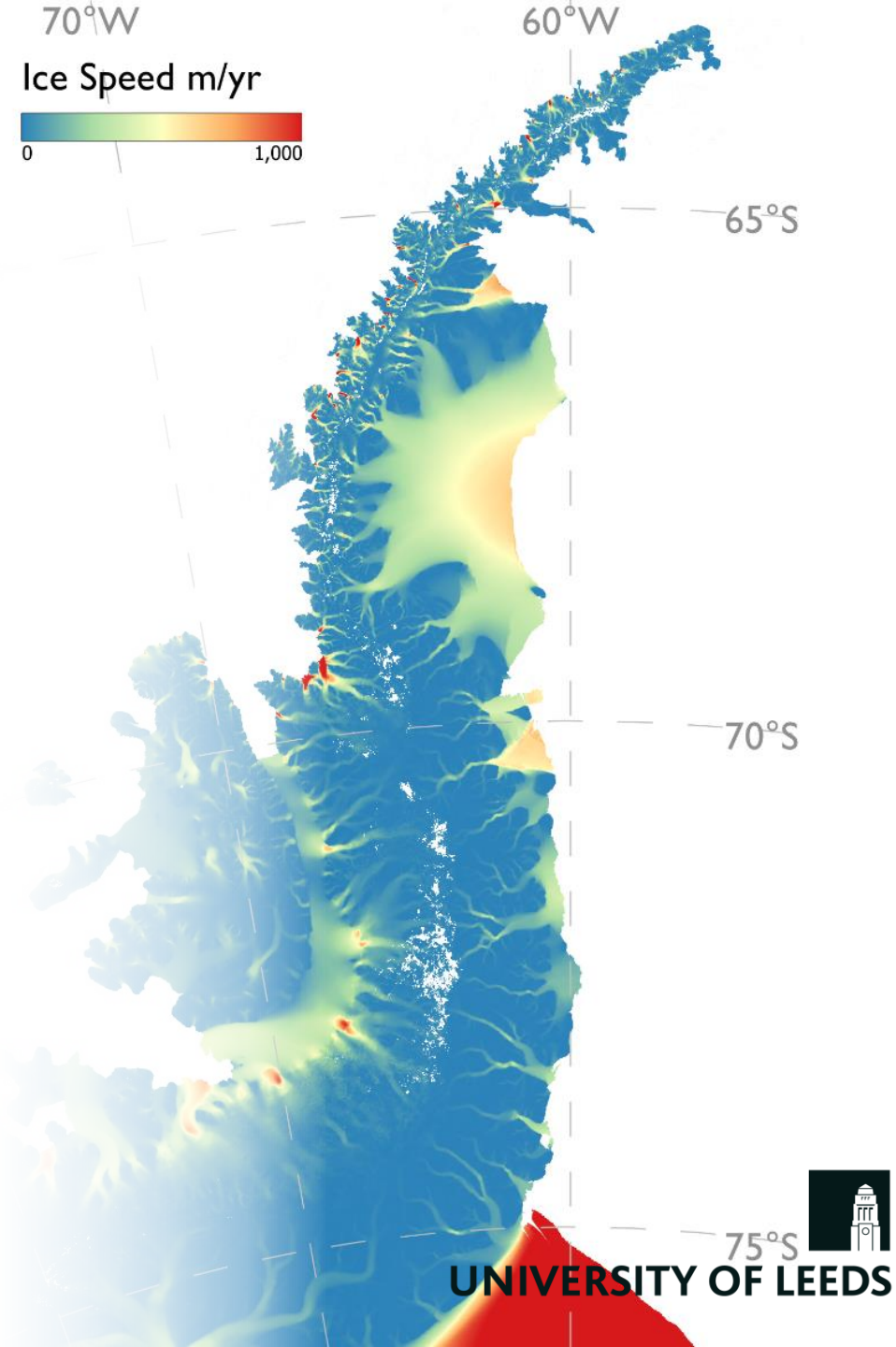
Routine ice velocity processing for Antarctica

- Sentinel-1 now offers a decade of regular SAR acquisitions for Antarctica.
- At Leeds we process all available frames to measure ice velocity.
- We implement our processing chain using ***GAMMA*** – see Davison et al. 2023.
- Currently, we process 322 new scenes every 12 days, totaling 114,075 pairs of 6- & 12-day separated images.



My work – The Antarctic Peninsula

- From 1992 to 2020 the Antarctic Peninsula accounted for **14%** 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].
- The AP is a unique venue to study ice dynamics in Antarctica.
- Observations from the AP have been influential to how we think about Antarctica's future.

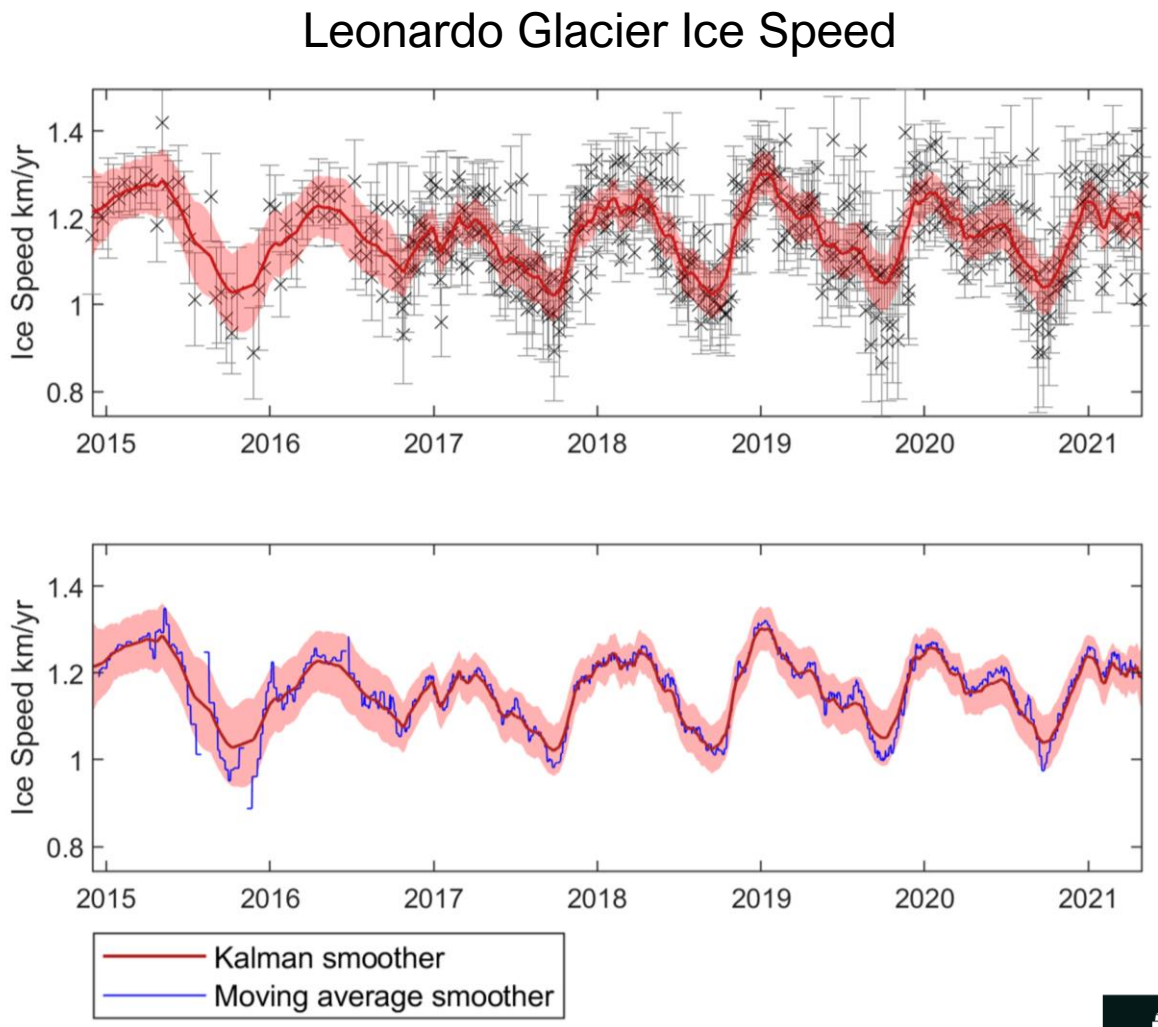


[1]Otosaka et al., 2023, [2]Rott et al., 1996, [3]Rack & Rott, 2004, [4]Rignot et al., 2004, [5]Wuite et al. 2015, [6]Cook et al. 2016

UNIVERSITY OF LEEDS

Finding seasonal ice speed variations on the AP

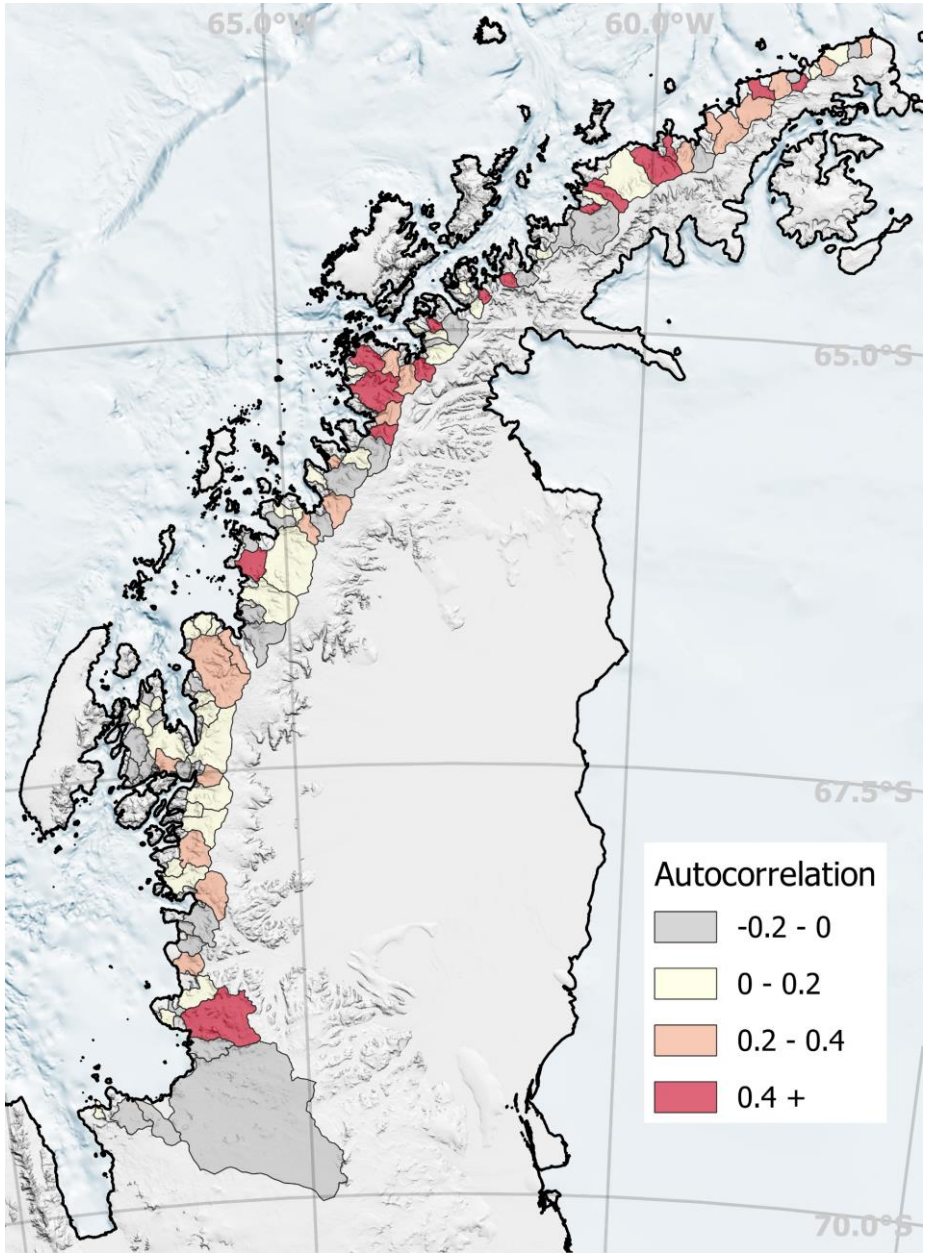
- Observations of ice speed on the west AP coast showed seasonal speed-up in the summer.
- A long and dense time-series of measurements was essential to observing these variations.
- We used a Bayesian recursive smoother to filter our ice speed measurements.
- We find that these patterns are widespread on the AP's west coast, with an average speed-up of **12.4 ± 4.2 %** up to a maximum of **22.3 ± 3.2 %.**



UNIVERSITY OF LEEDS

Finding seasonal ice speed variations on the AP

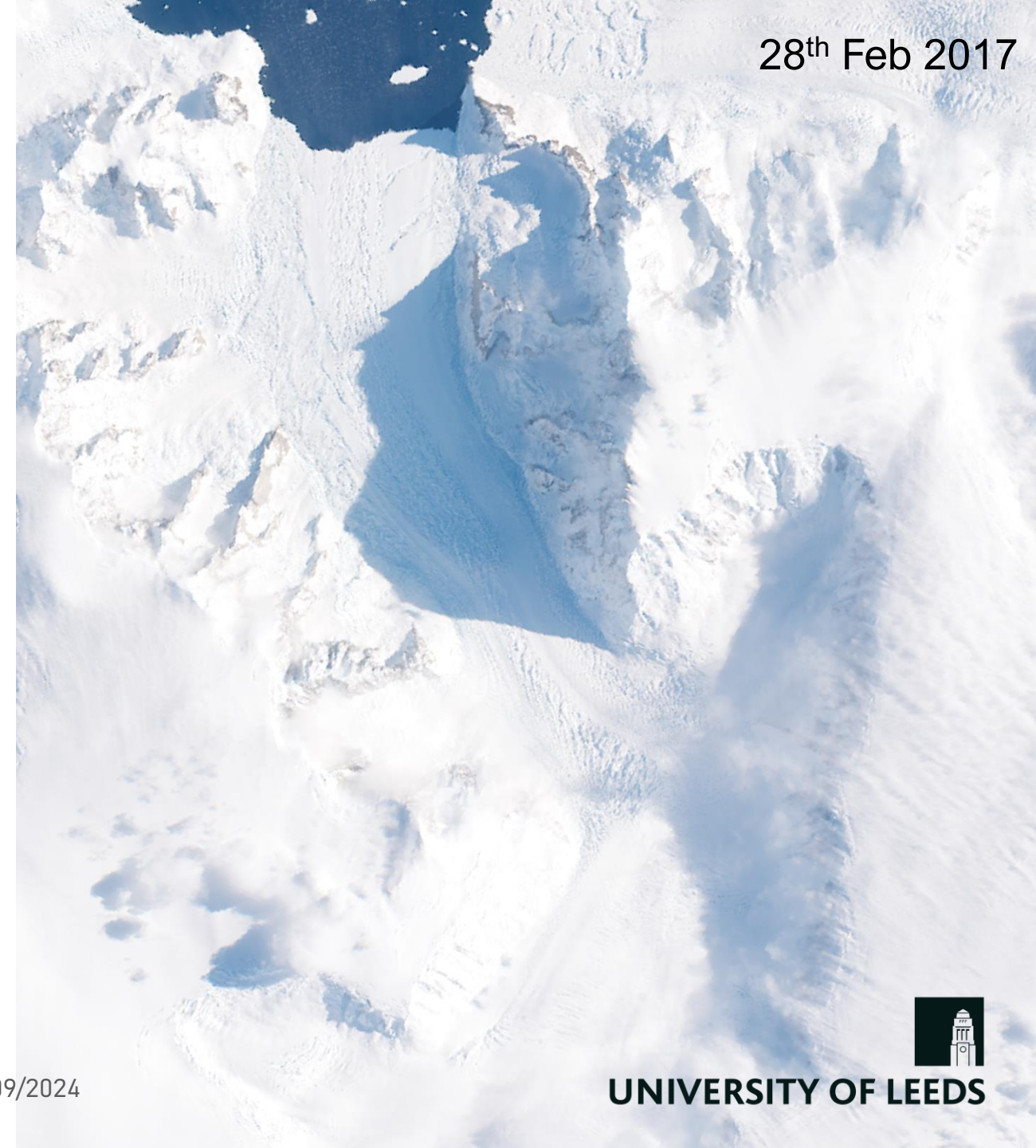
- Observations of ice speed on the west AP coast showed seasonal speed-up in the summer.
- A long and dense time-series of measurements was essential to observing these variations.
- We used a Bayesian recursive smoother to filter our ice speed measurements.
- We find that these patterns are widespread on the AP's west coast, with an average speed-up of **12.4 ± 4.2 %** up to a maximum of **22.3 ± 3.2 %.**



Increased Antarctic Peninsula ice discharge

- A case-study of Cadman Glacier showed an acceleration of 1.47 km/yr, retreat of 8 km and ice discharge increase of 28 %[1].
- We followed this up with a study of ice discharge across the whole west AP and found an increase of 7.4 % since 2017[2].
- These changes coincided with a period of anonymously warm ocean temperature.

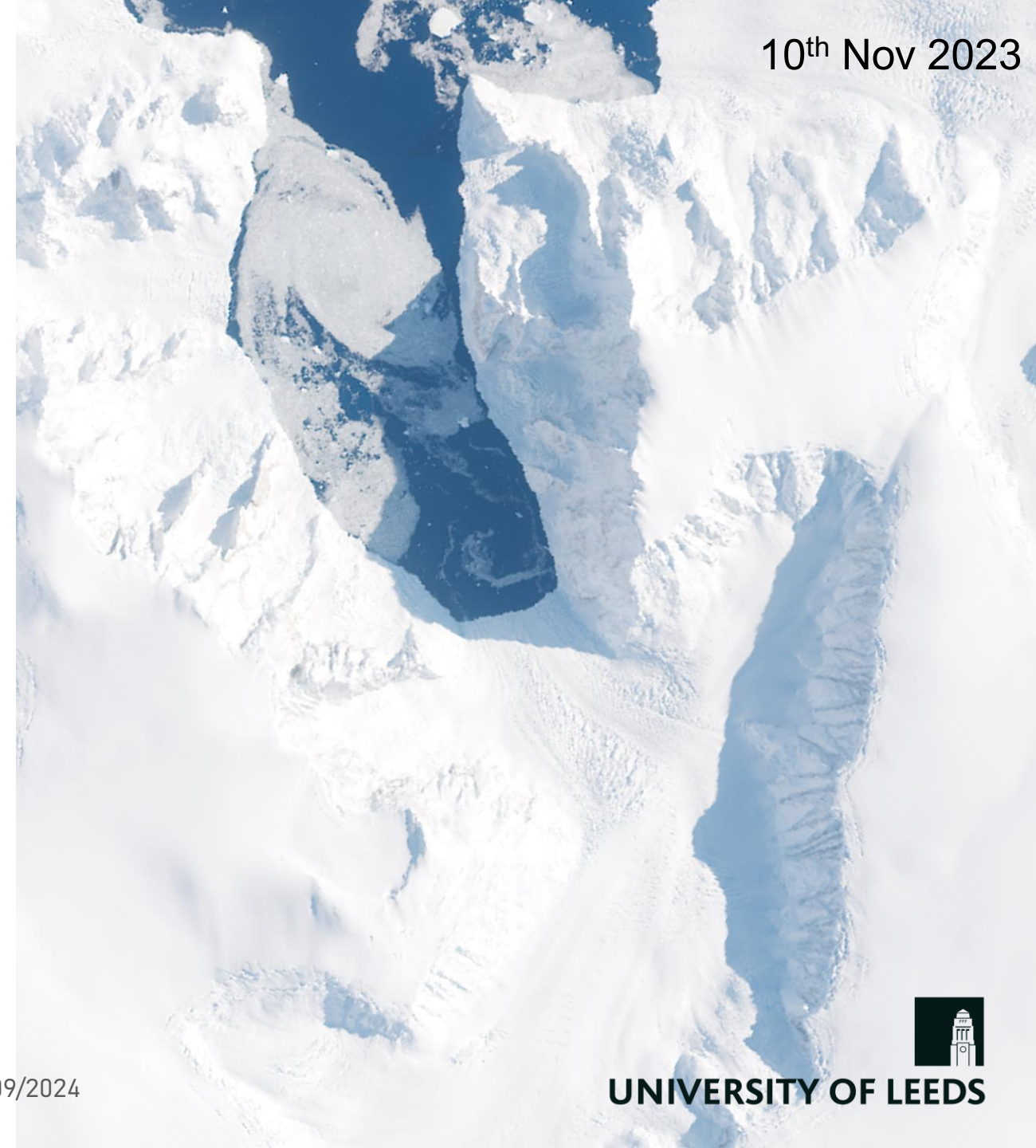
[1]Wallis et al. 2023b, [2]Davison et al. 2024.



Increased Antarctic Peninsula ice discharge

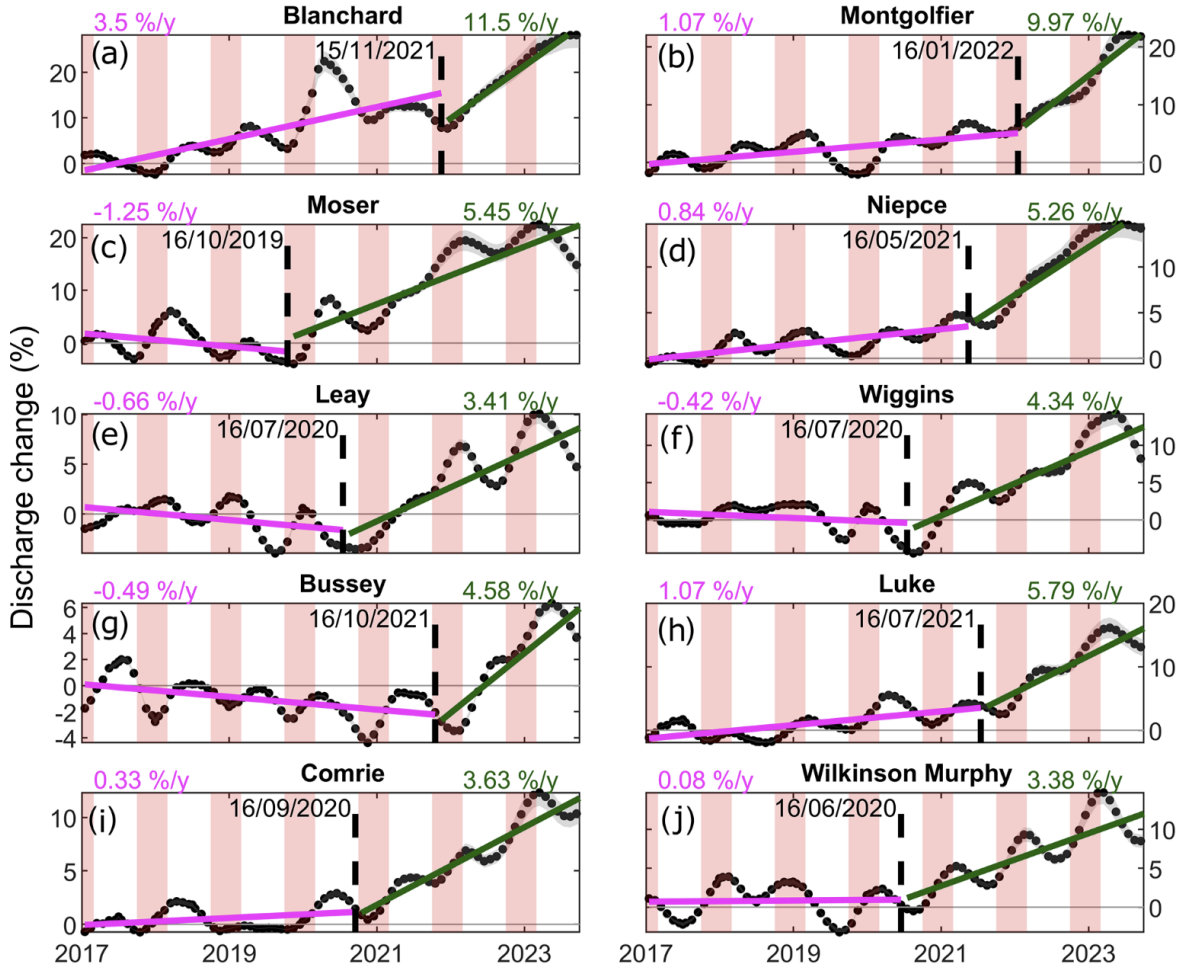
- A case-study of Cadman Glacier showed an acceleration of 1.47 km/yr, retreat of 8 km and ice discharge increase of 28 %[1].
- We followed this up with a study of ice discharge across the whole west AP and found an increase of 7.4 % since 2017[2].
- These changes coincided with a period of anonymously warm ocean temperature.

[1]Wallis et al. 2023b, [2]Davison et al. 2024.



Increased Antarctic Peninsula ice discharge

- A case-study of Cadman Glacier showed an acceleration of 1.47 km/yr, retreat of 8 km and ice discharge increase of 28 %[1].
- We followed this up with a study of ice discharge across the whole west AP and found an increase of 7.4 % since 2017[2].
- These changes coincided with a period of anonymously warm ocean temperature.

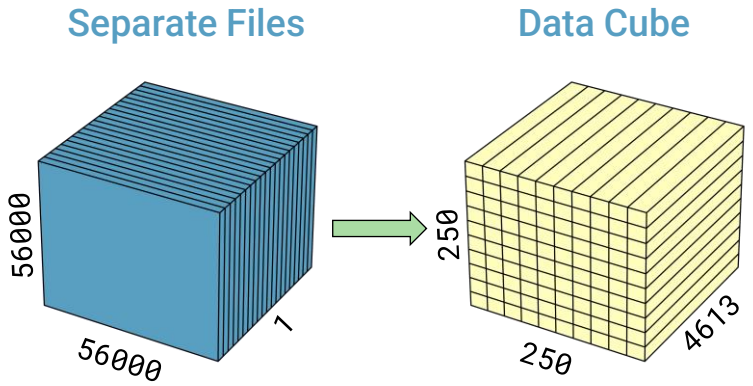


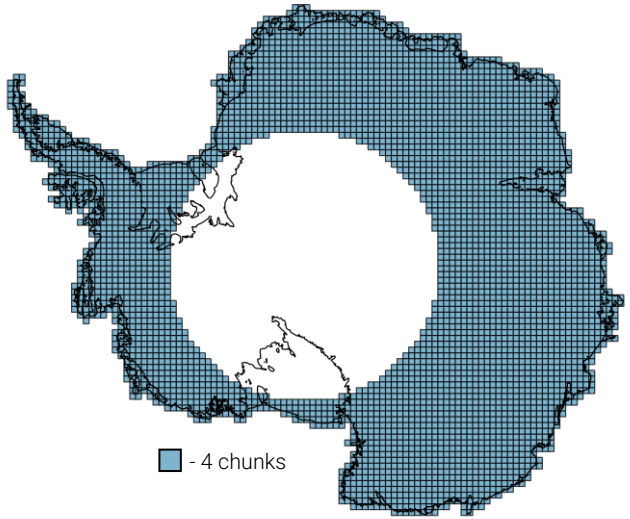
[1]Wallis et al. 2023b, [2]Davison et al. 2024.

UNIVERSITY OF LEEDS

Not just the AP – Getting clever with big data

- Routine SAR acquisitions and ice velocity processing create vast volumes of data – **this is a challenge!**
- Smart curation allows us to make our data as useable and easy to work with as possible.
- Organising our data using **Zarr** data cubes allows fast read/write in the time dimension.
- Parallelising processing using **dask** maximises our HPC resources.

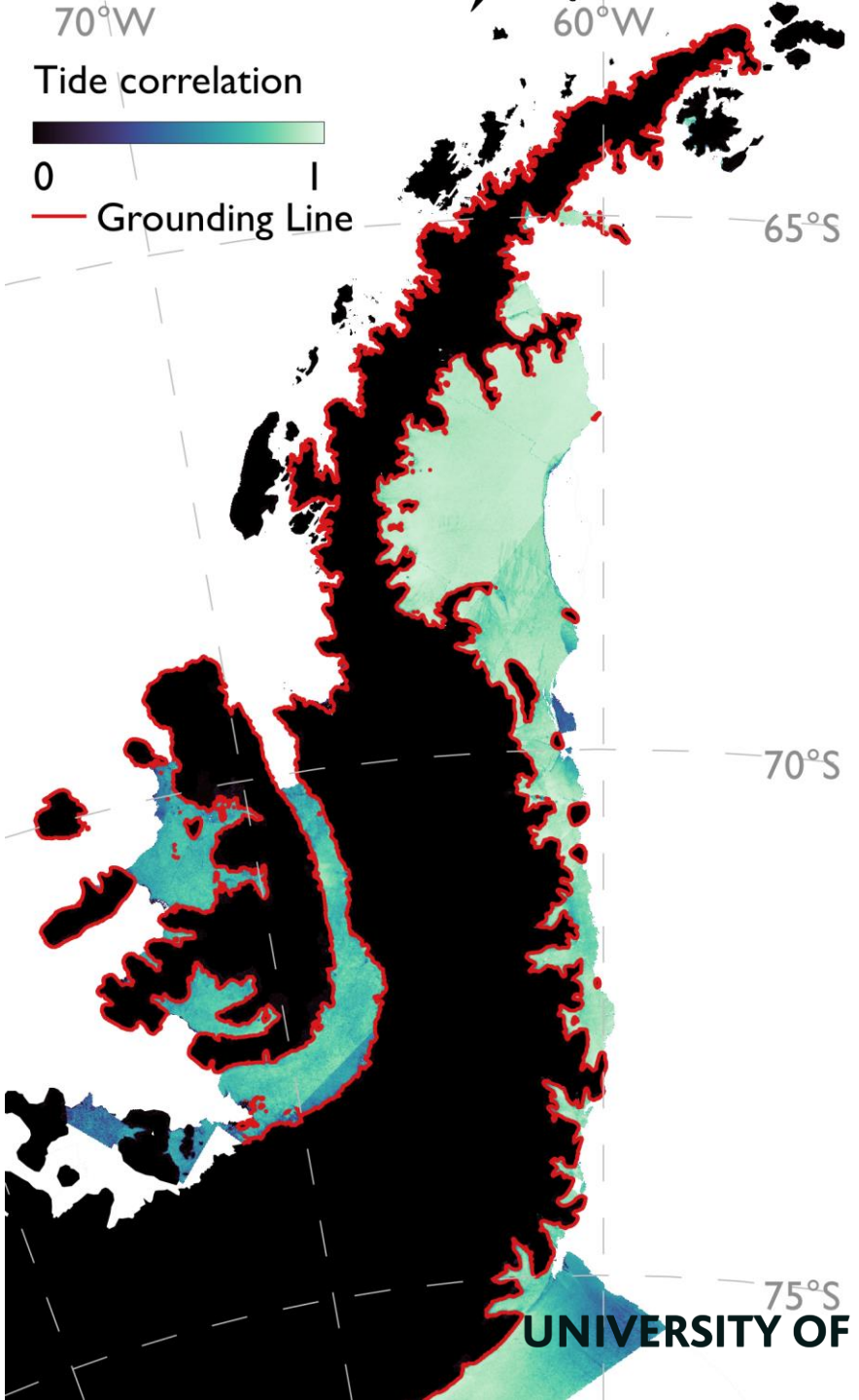




Big data processing facilitates more science

- Having pre-processed ice velocity data has enabled us to do exciting side-projects, such as:
- Producing an updated grounding line dataset for the Antarctic Peninsula[1].
- Supporting modelling studies, like a recent study of the Larsen-B embayment[2].
- Routine ice velocity processing is a resource for innovation – it allows low input trials and faster science.

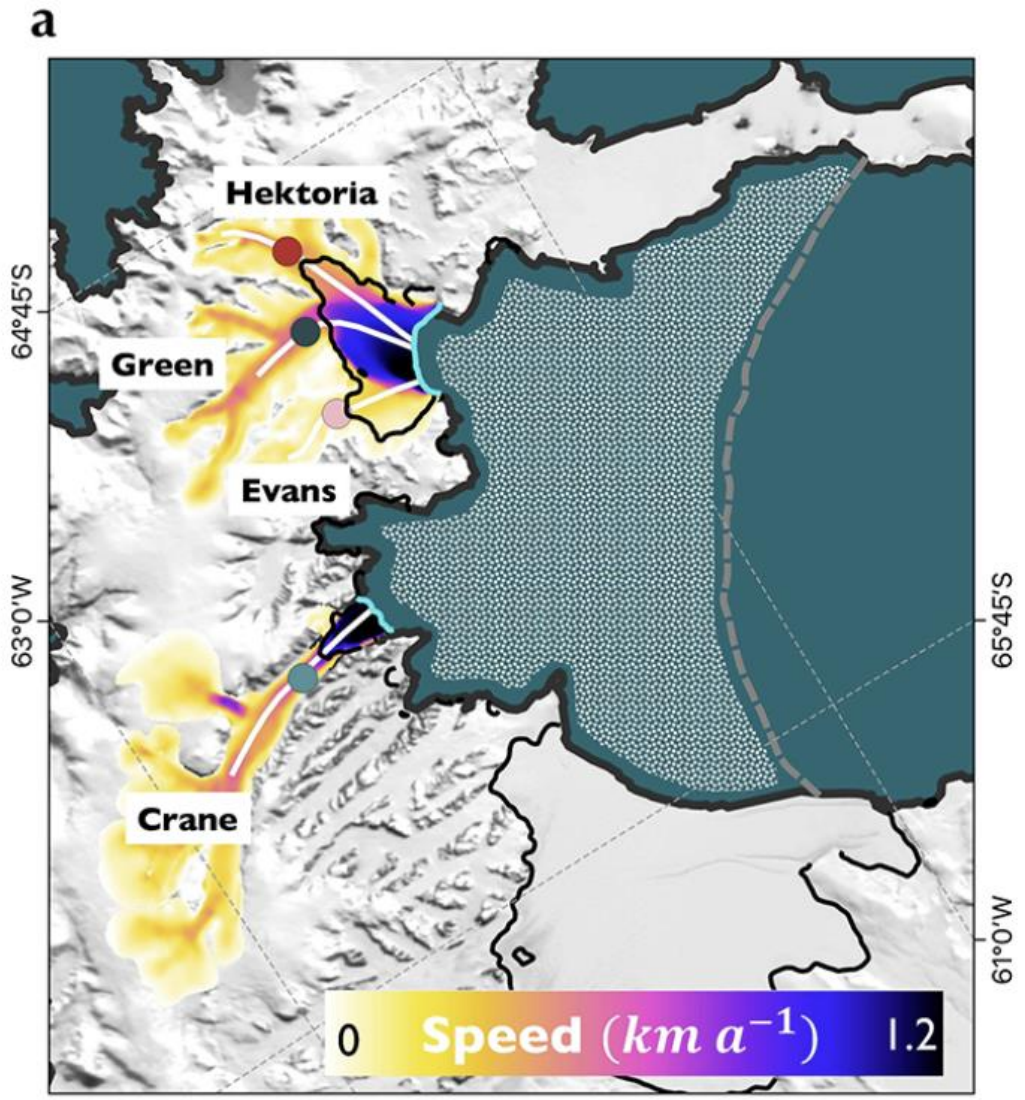
[1]Wallis et al. 2024, [2]Surawy-Stepney et al. 2024.



UNIVERSITY OF LEEDS

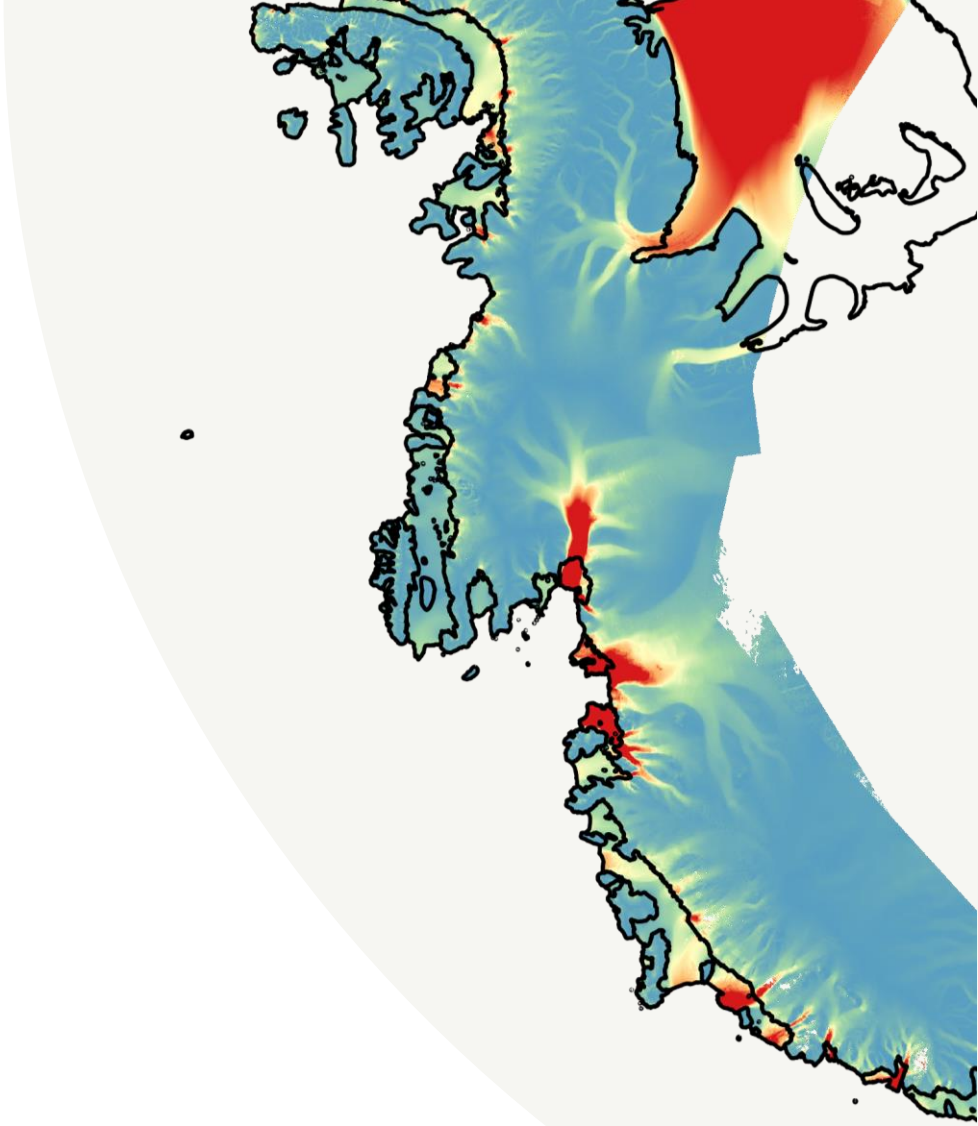
Big data processing facilitates more science

- Having pre-processed ice velocity data has enabled us to do exciting side-projects, such as:
- Producing an updated grounding line dataset for the Antarctic Peninsula[1].
- Supporting modelling studies, like a recent study of the Larsen-B embayment[2].
- Routine ice velocity processing is a resource for innovation – it allows low input trials and faster science.



[1]Wallis et al. 2024, [2]Surawy-Stepney et al. 2024.

Part 2
Challenges



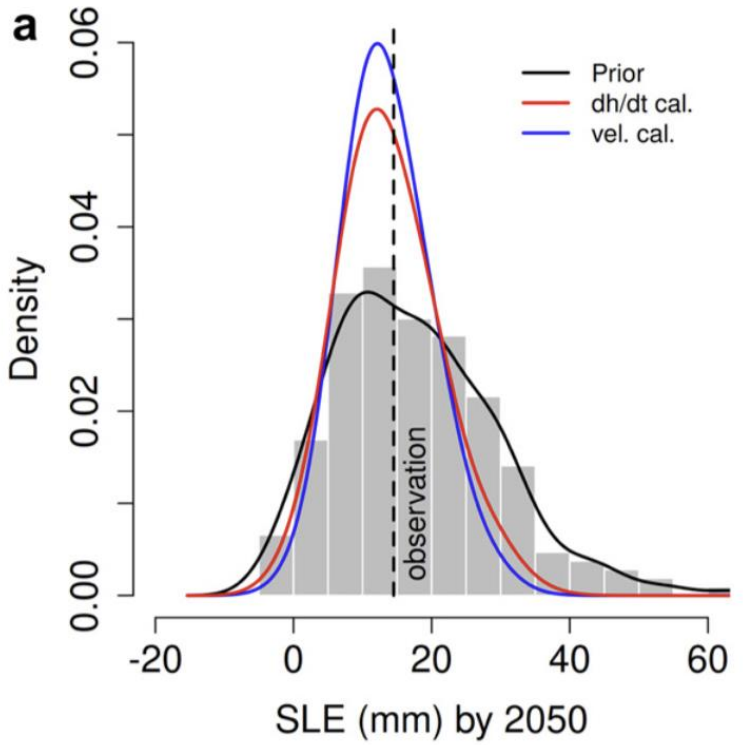
Improving ice-velocity errors and uncertainties

- A range approaches are used to provide an uncertainty for ice velocity measurements.
- The many sources of error in velocity measurements are complex: geolocation, co-registration, out of date DEMs, tidal motion, offset tracking, surface melt, etc.
- Few GPS measurements to validate against, particularly in Antarctica.
- **Is there scope to perform an IV intercomparison exercise between independent satellite datasets and all accessible GPS measurements?**

Uncertainties matter – they'll be used for important things

- New generations of global sea-level rise projections will use calibrations from observational data.
- The most powerful statistical techniques require an uncertainty associated with observations.
- **There's a chain of uncertainties directly from our observations to projections of SLR used by policymakers.**

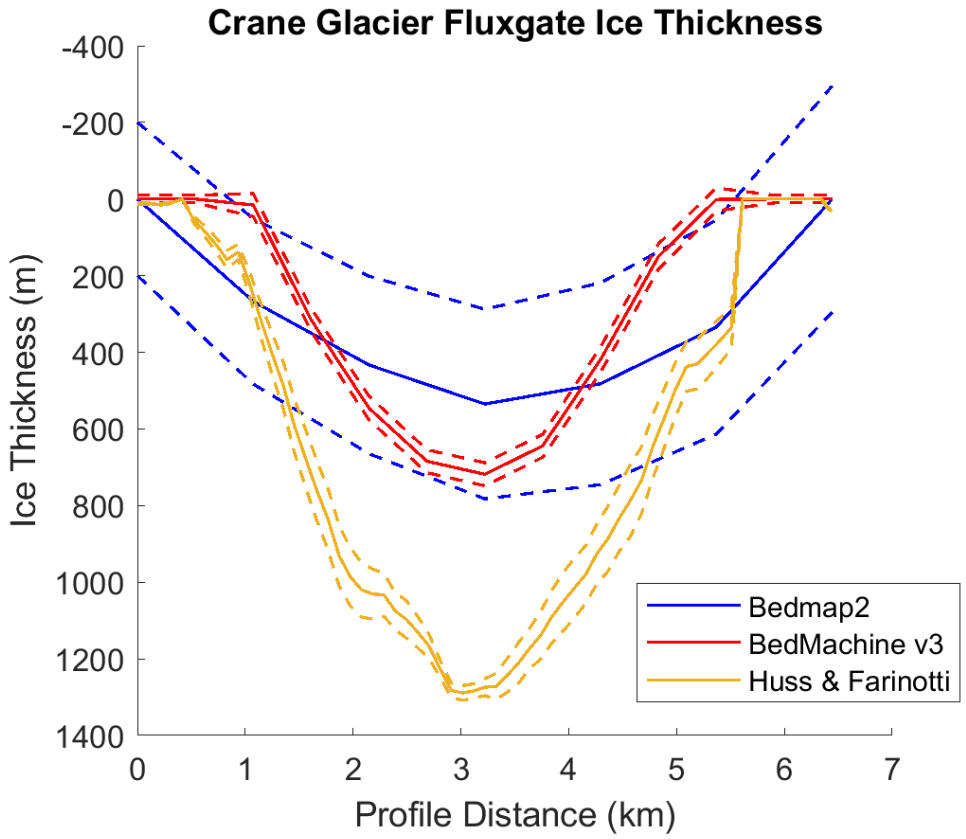
$$P(SLR|Obvs) \propto P(SLR)P(Obvs|SLR)$$



(Reproduced from Bevan et al. 2023)

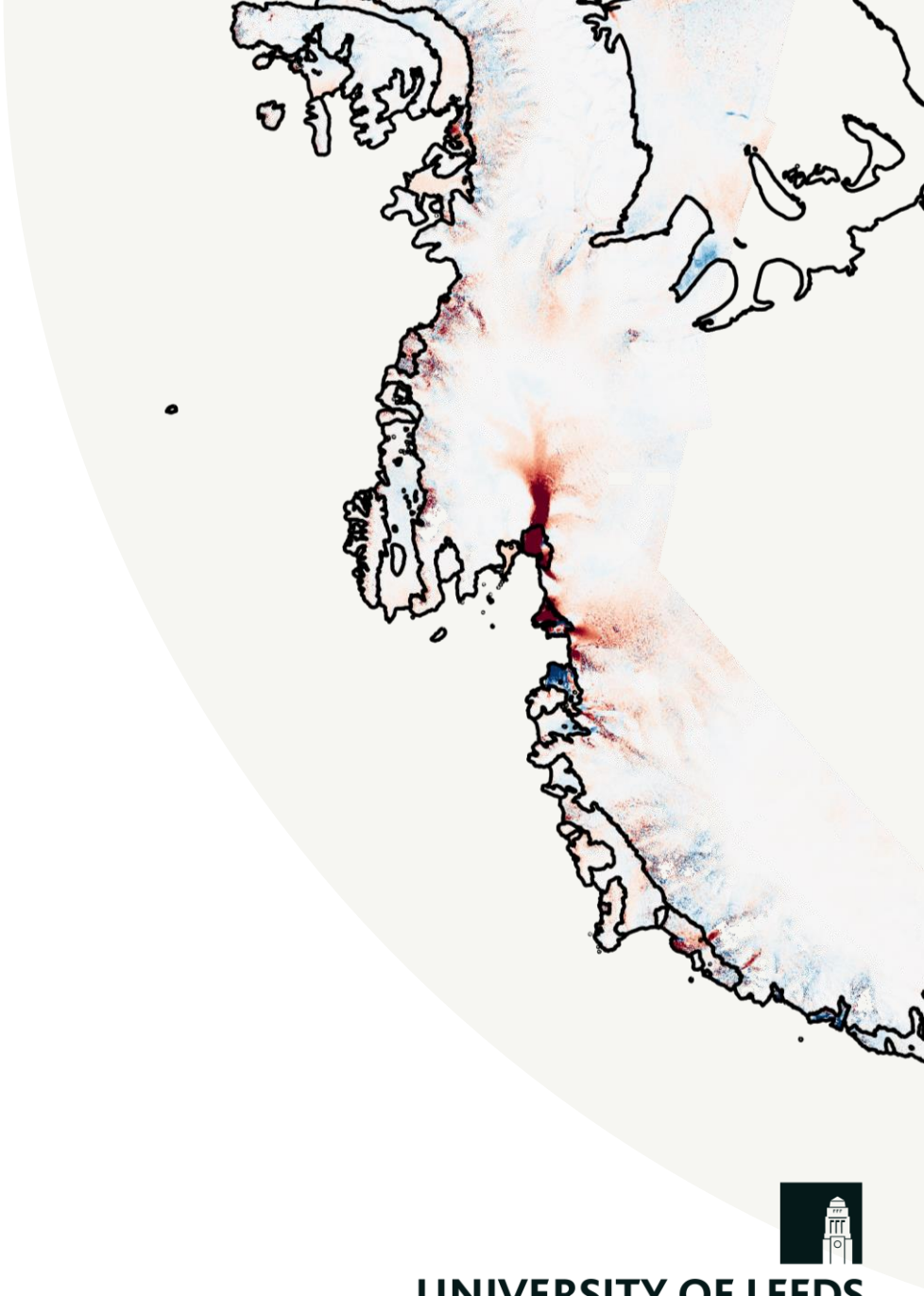
Other datasets contribute to mass balance uncertainties:

- **Ice thickness** – in the AP this is by far the biggest source of error in any calculations of mass balance[1,2].
- **GL position** – varying flux-gate location changes discharge by 4.5 %[2]. Also significant for historic GL measurements which may not have accounted for tidal migration[3,4].
- **SMB models** – we know there are significant differences in these over Antarctica[5].



[1]Shahateet et al. 2023, [2]Davison et al. 2024, [3]Freer et al. 2023, [4]Rignot et al. 2024, [5]Mottram et al. 2021.

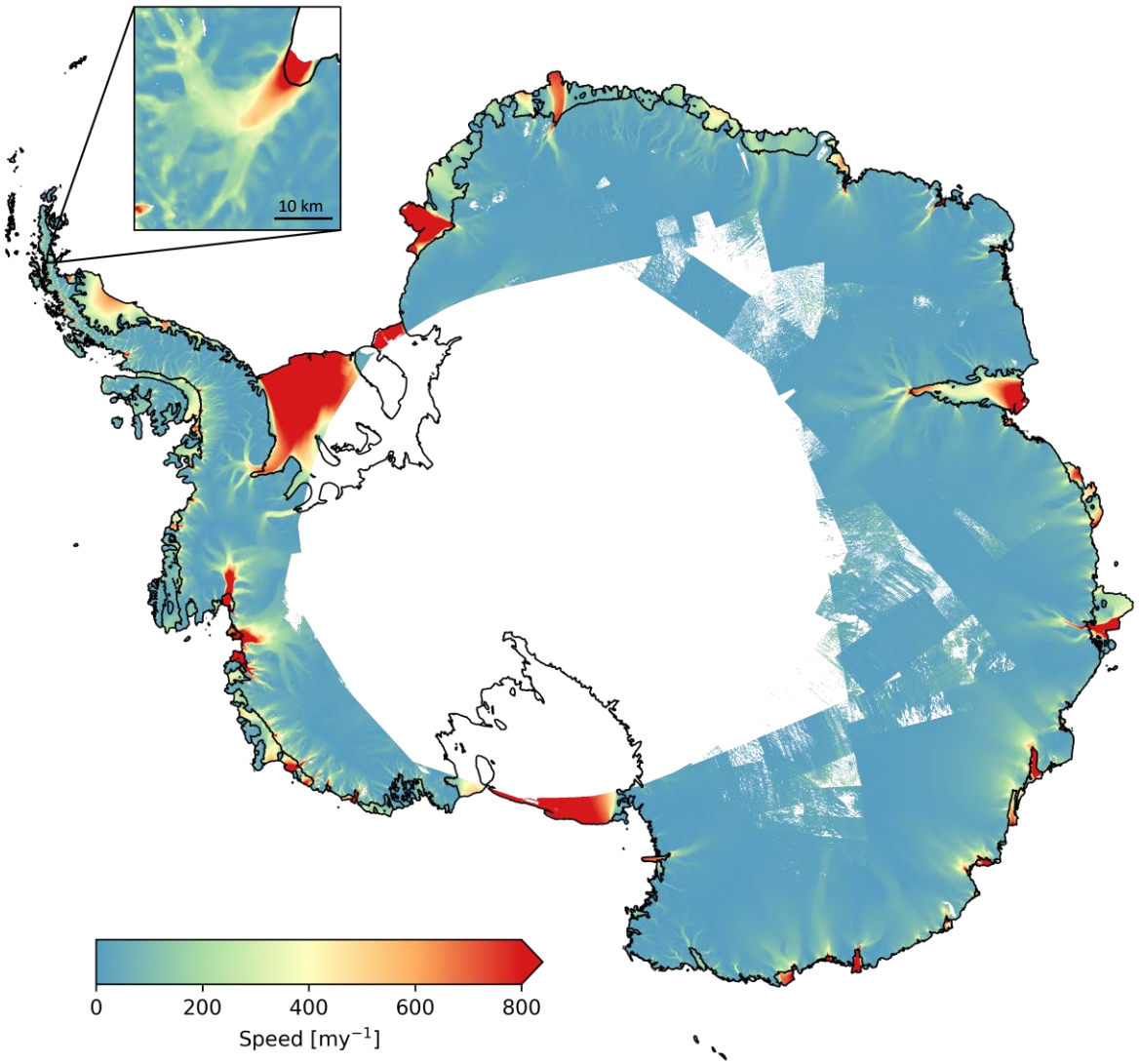
UNIVERSITY OF LEEDS



Part 3
Outlook

The Importance of Sentinel-1

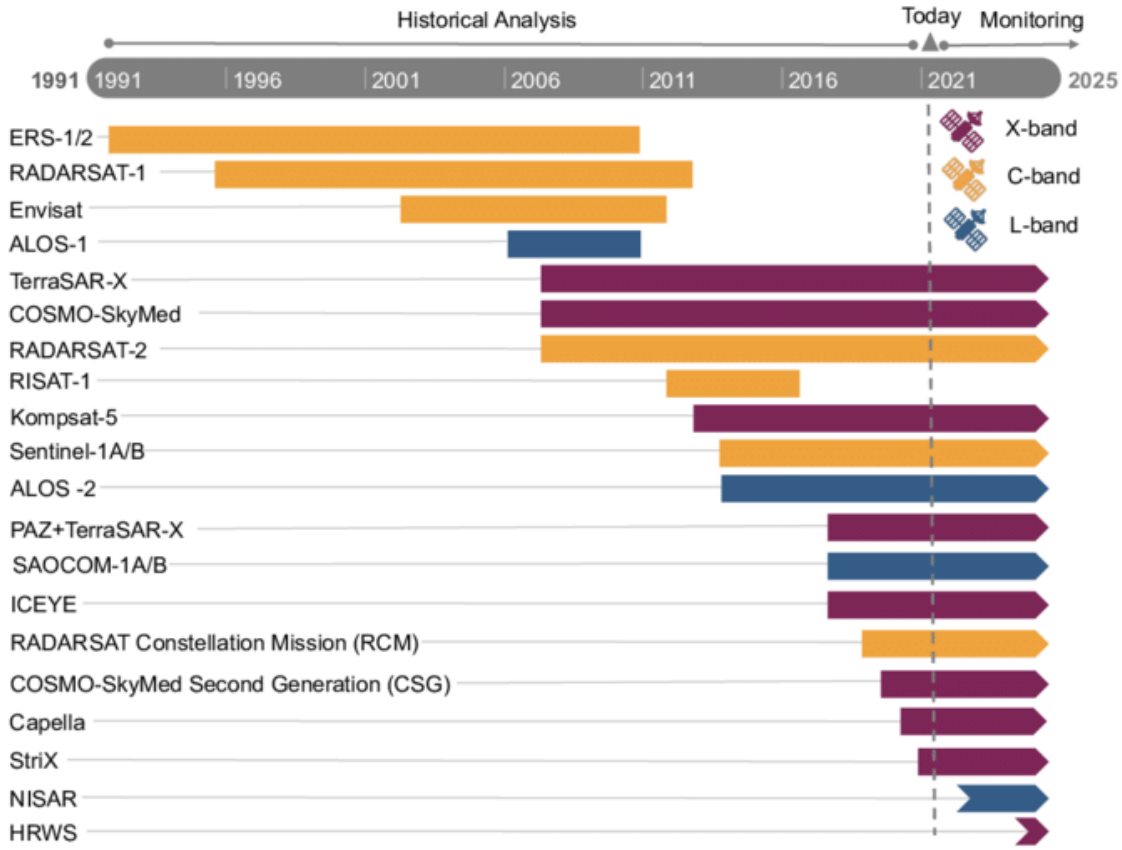
- Sentinel-1 remains the workhorse of ice dynamics monitoring in Antarctica.
- We have a decade of continuous measurements of the Antarctic margin.
- Maintaining this unparalleled continuous record is **essential.**
- Capability was reduced with the loss of 1B. E.g., grounding line position measurements.
- Resuming 6-day repeats should be a priority.



UNIVERSITY OF LEEDS

The possibilities of multi-frequency SAR

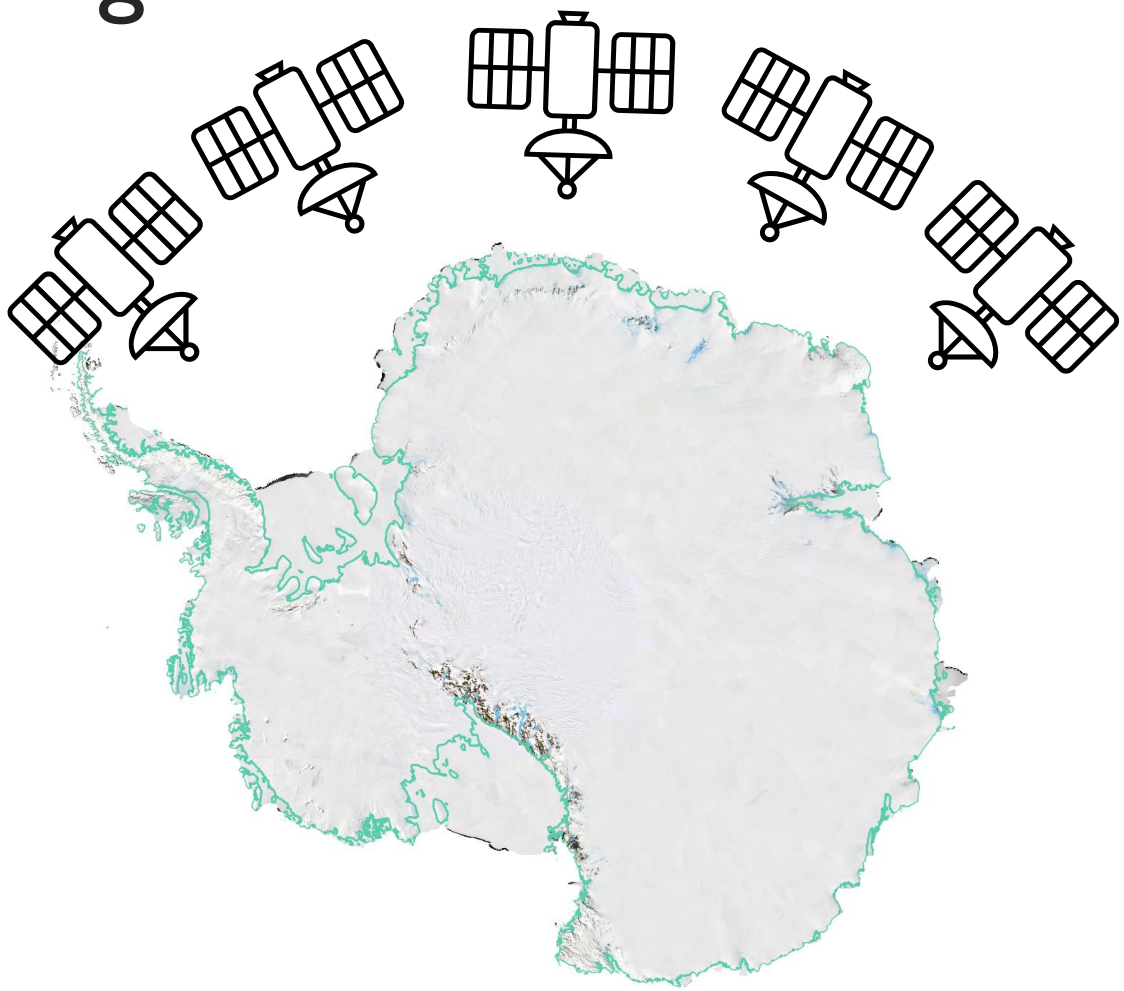
- Upcoming missions will enhance ice sheet dynamics observations.
- Commercial X-band offers the opportunity for targeted studies in high-impact areas – e.g. The Amundsen Sea.
- NISAR, ROSE-L and Biomass will add routine, L, S and P band measurements in Antarctica.
- Combining frequencies can address measurement uncertainties, like the impact of surface melt on the scattering horizon.



(Reproduced from Macchiarulo et al, 2023)

Towards persistent monitoring of ice-sheet dynamics

- Modern satellite observations provide unprecedented capability to monitor the Earth's ice sheets.
- With Sentinel-1 we are generating a continuous record of ice sheet velocity and discharge at 12-day resolution.
- **Other key parameters are joining**, enabled by the power of AI: grounding lines, calving fronts, crevassing and damage.



Summary and Recommendations

- Sentinel-1 has given us an unprecedented observational record.
- This has enabled important science, but there's still more to be done.
- Our observations and uncertainties directly impact future sea-level rise projections – so let's keep improving these.
- Multi-frequency SAR observations should be closely coordinated to improve observations of ice dynamics.
- Efforts to address other data gaps, like ice thickness, are also essential.