Ice shelf basal melt rates from in-situ phase sensitive radar

Keith Nicholls, British Antarctic Survey

- Preamble: why measure basal melt rates?
- ApRES – a phase sensitive radar
- Limitations of ApRES?
- "Representativeness"?
- Satellite-derived melt rate products
- Summary

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British Antarctic Survey

Why measure basal melt rates?

- Help improve model physics – teach models to diagnose melt rates from their simulated fields of U, S & T: parameterizations.

  → Requires contemporaneous ocean forcing data

- Provide alternative to sub-ice moorings: Data for model validation and data assimilation: alternative to moored instruments

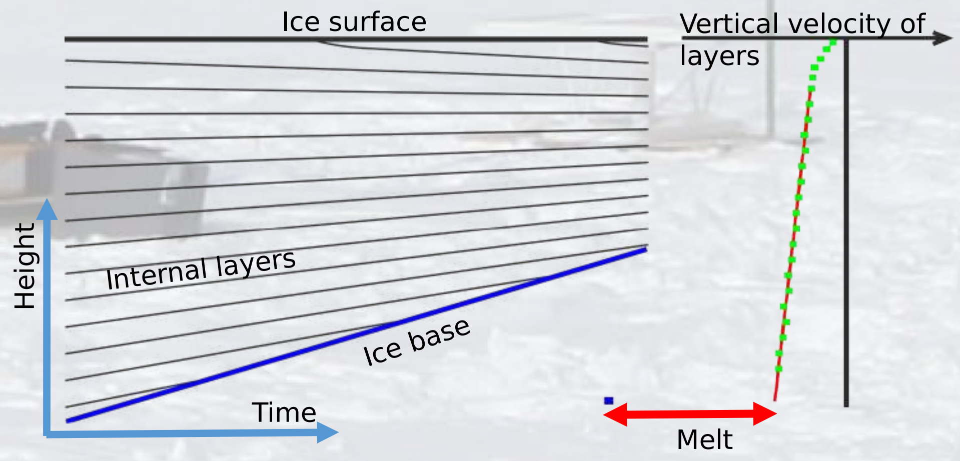
These are two different tasks that generally need different experiments.

ApRES – a phase sensitive radar

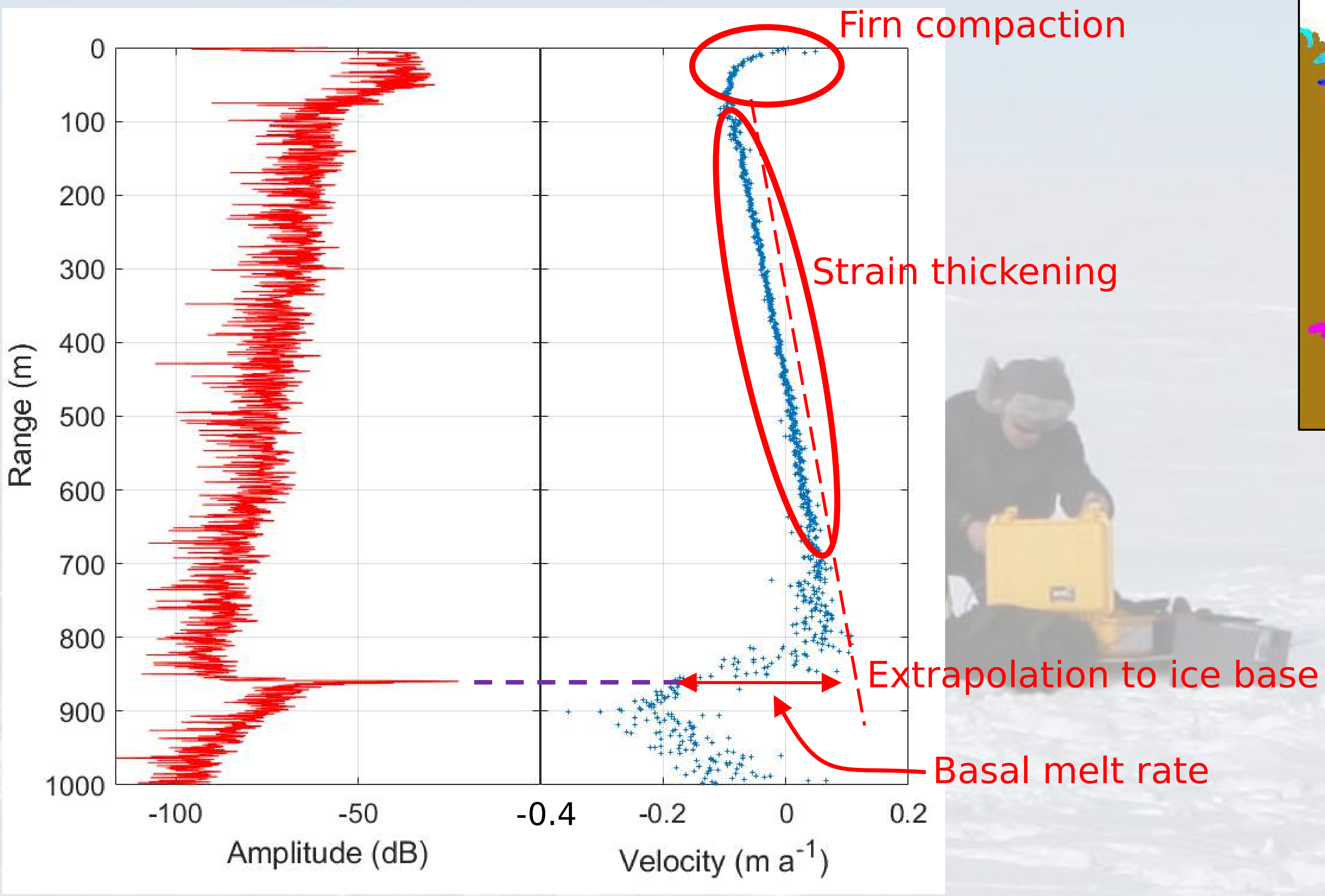
(*Autonomous phase-sensitive Radio Echo Sounder*)

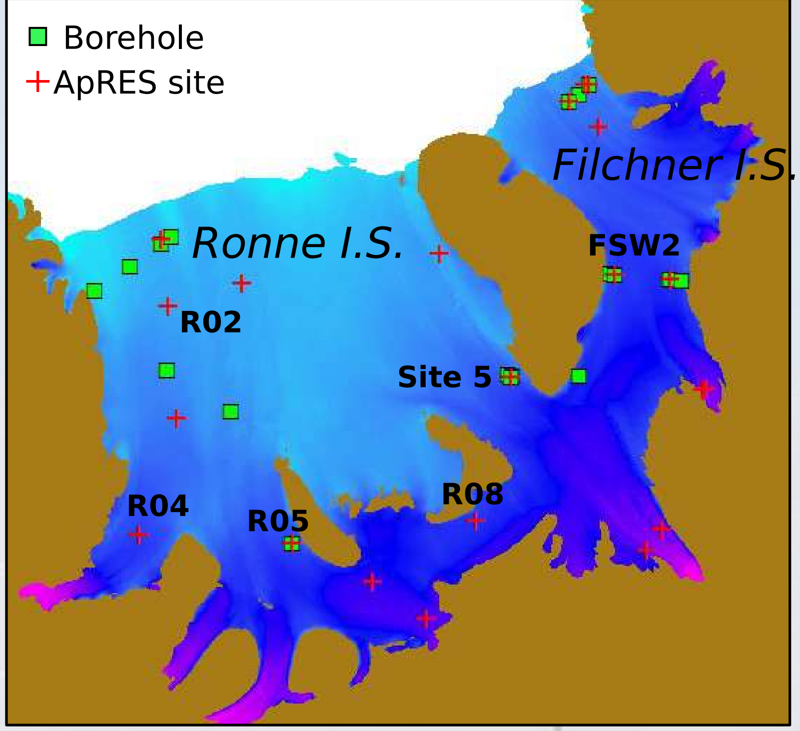
- Downward-looking FMCW radar
- Small logistical footprint
- Low weight, power & cost (relatively…)
- Typically ~1 hour to install

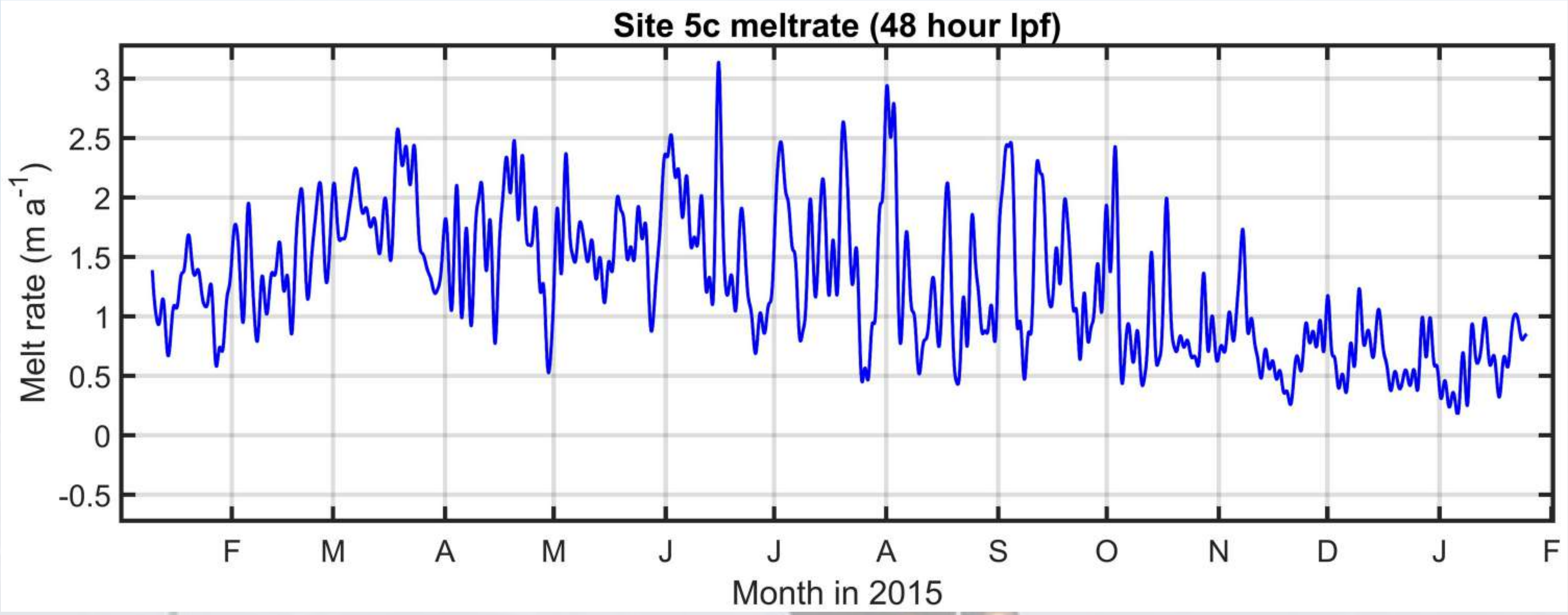
- Monitors “internal reflections” and ice base in a Lagrangian experiment
- Calculates vertical velocities relative to antennas
- Can calculate total ice thinning and subtract effect of ice deformation to yield melt rate



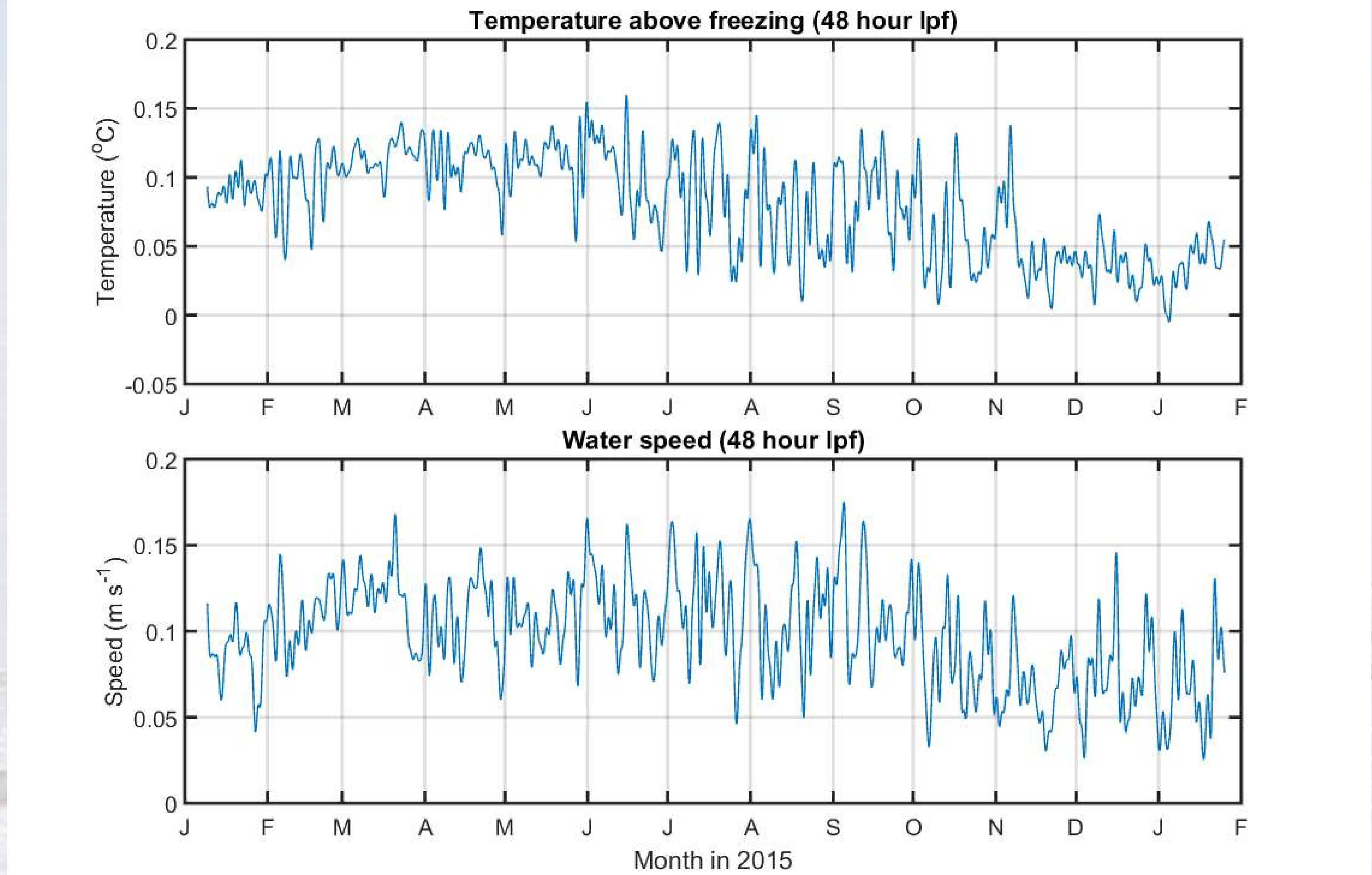
Example from FSW2, southern Filchner Ice Shelf







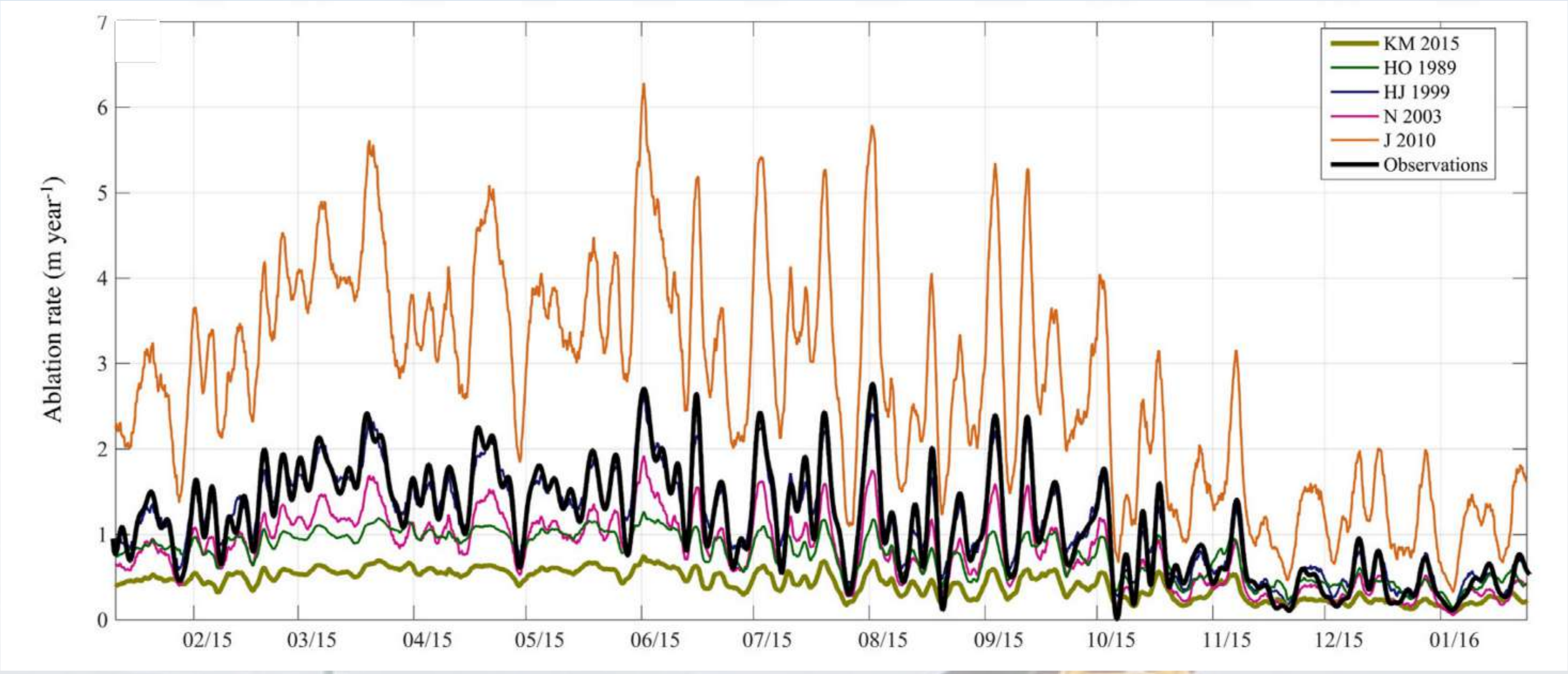
Time series data shows ocean-style variability
To improve parameterizations of melting, require ocean data from the boundary layer.
A sub-ice shelf mooring was installed at the same site:



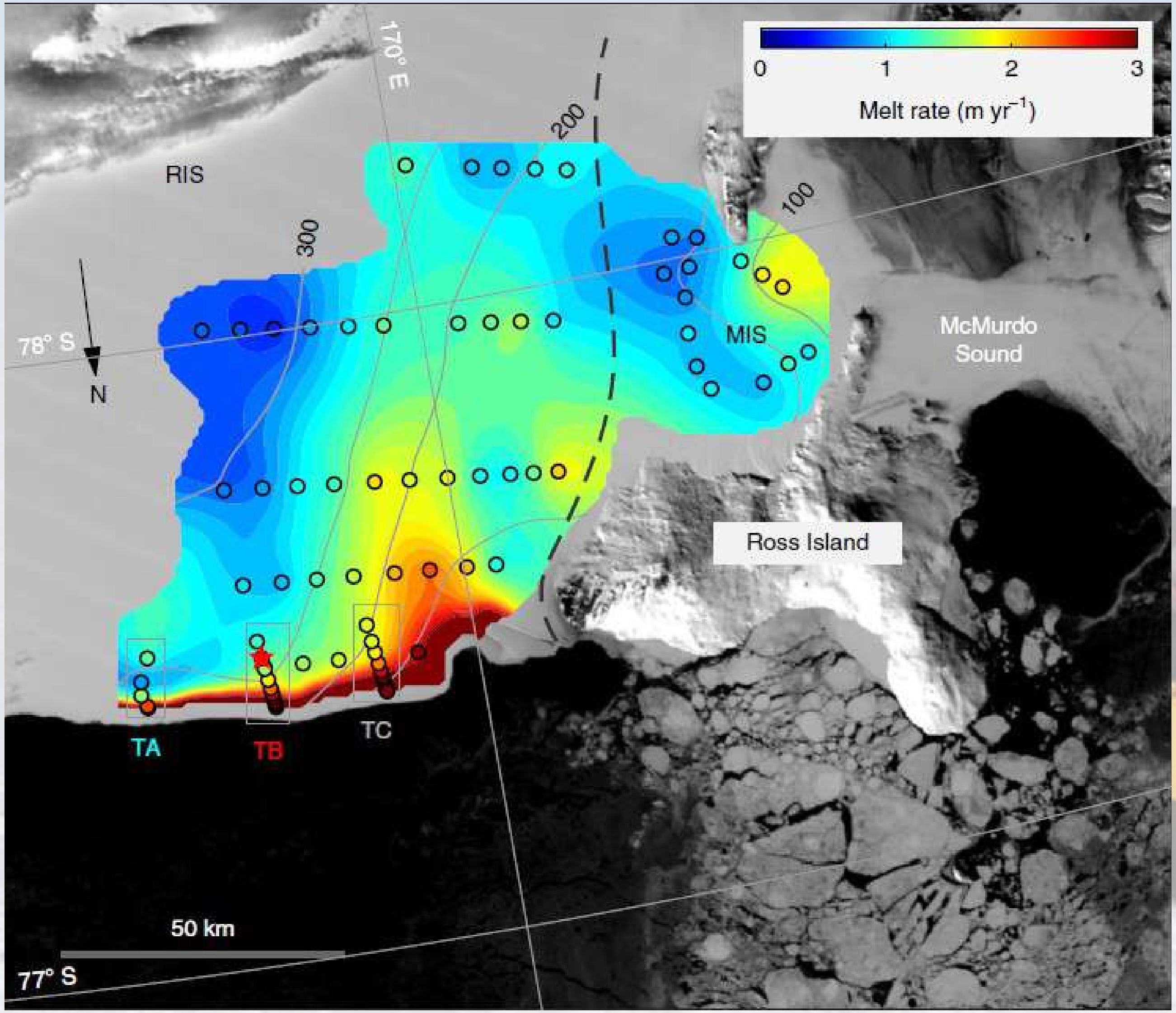
Temperature above freezing (48 hour lpf)
Temperature (°C)
0.2
0.15
0.1
0.05
0
-0.05
J F M A M J J A S O N D J F
Water speed (48 hour lpf)
Speed (m s-1)
0.2
0.15
0.1
0.05
0
J F M A M J J A S O N D J F
Month in 2015

Ronne Ice Shelf (Site 5c)

Malyarenko et al 2020



Site 5c. Year of data with observed melt rate (heavy black line), and a variety of parameterizations using temperature and current data from co-located instruments beneath ice shelf.



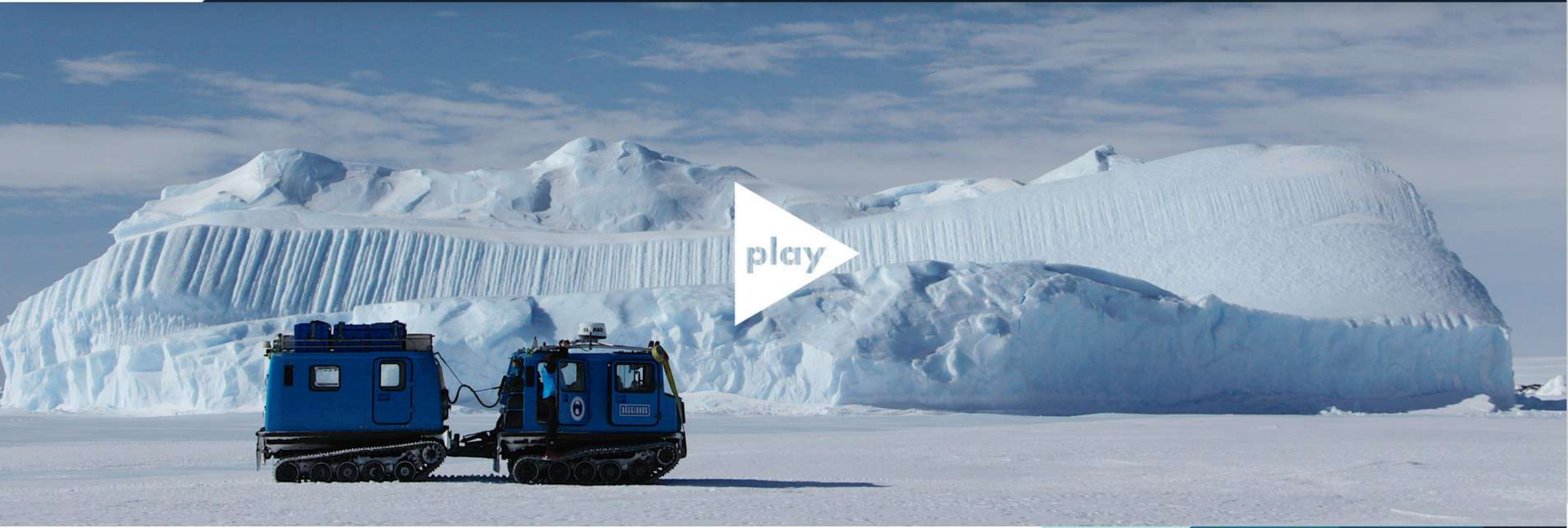
Stewart et al 2019
Survey of NW Ross Ice Shelf

Revisit mode of operation

- Make spatially-extensive measurements
- Revisit flagged sites after an interval (e.g. 1 yr)
- Measure mean melt rate at each site.

The NECKLACE project: a SOOS-endorsed initiative to collect and collate time series of in situ observations of basal melt rates from Antarctic ice shelves

Groups from 10 nations
1 month to several years



Melting underneath the floating ice shelves around Antarctica is one of the most important but hardest to observe processes driving mass loss from the ice sheet. Measuring this melt is key to understanding and predicting the continent's future.

The NECKLACE project seeks to collate data on ice shelf melt, gathered by research teams around the world. Results are standardised and collated into a single data product that can be used by glaciologists, oceanographers, and ice sheet modellers to compare with their own results. By building on each team's individual effort, we aim to create a continent-wide, open-access data product.

Limitations of ApRES

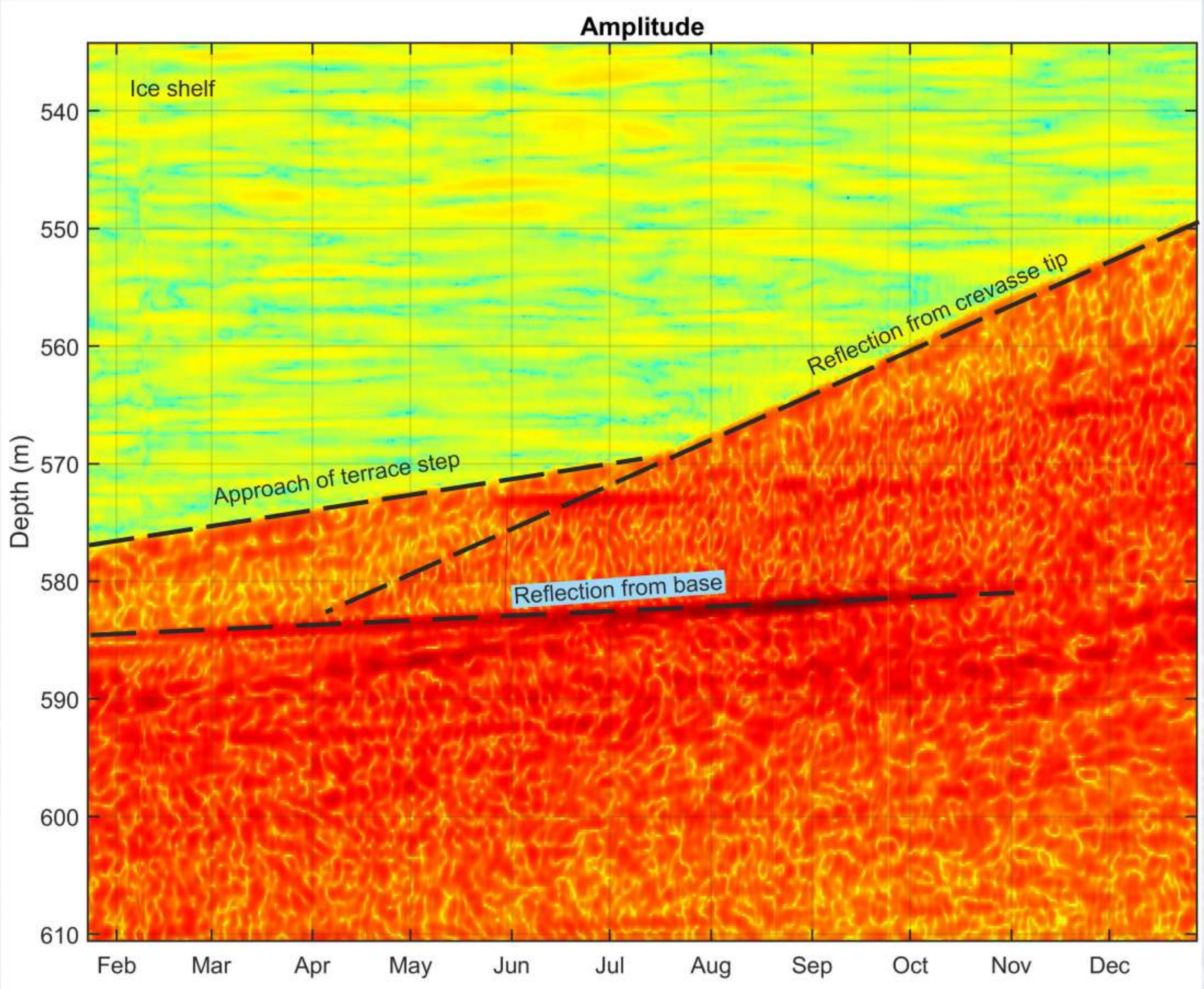
- Footprint is small (10s to 100s metre). But useful for comparison with ocean data.
- Struggles in areas with significant (>10s metres) marine ice (even if melting)
- Struggles in areas with a lot of surface ponding
- Thick firn aquifers *might* prevent use of the technique

- Surface crevassing is less of a problem (for the technique, at least)
- Complex basal topography (esp. basal crevassing): returns from crevasse tips can obscure true base.

Amplitude profiles plotted against time

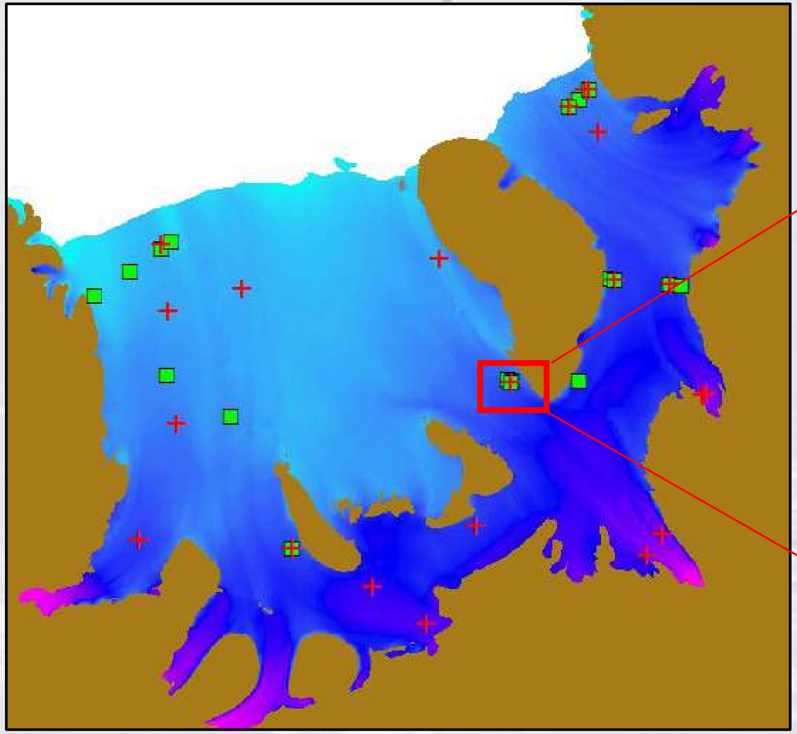
- Thwaites East grounding zone
- A terrace step is approaching the site
- A basal crevasse opens nearby
- This can be confusing

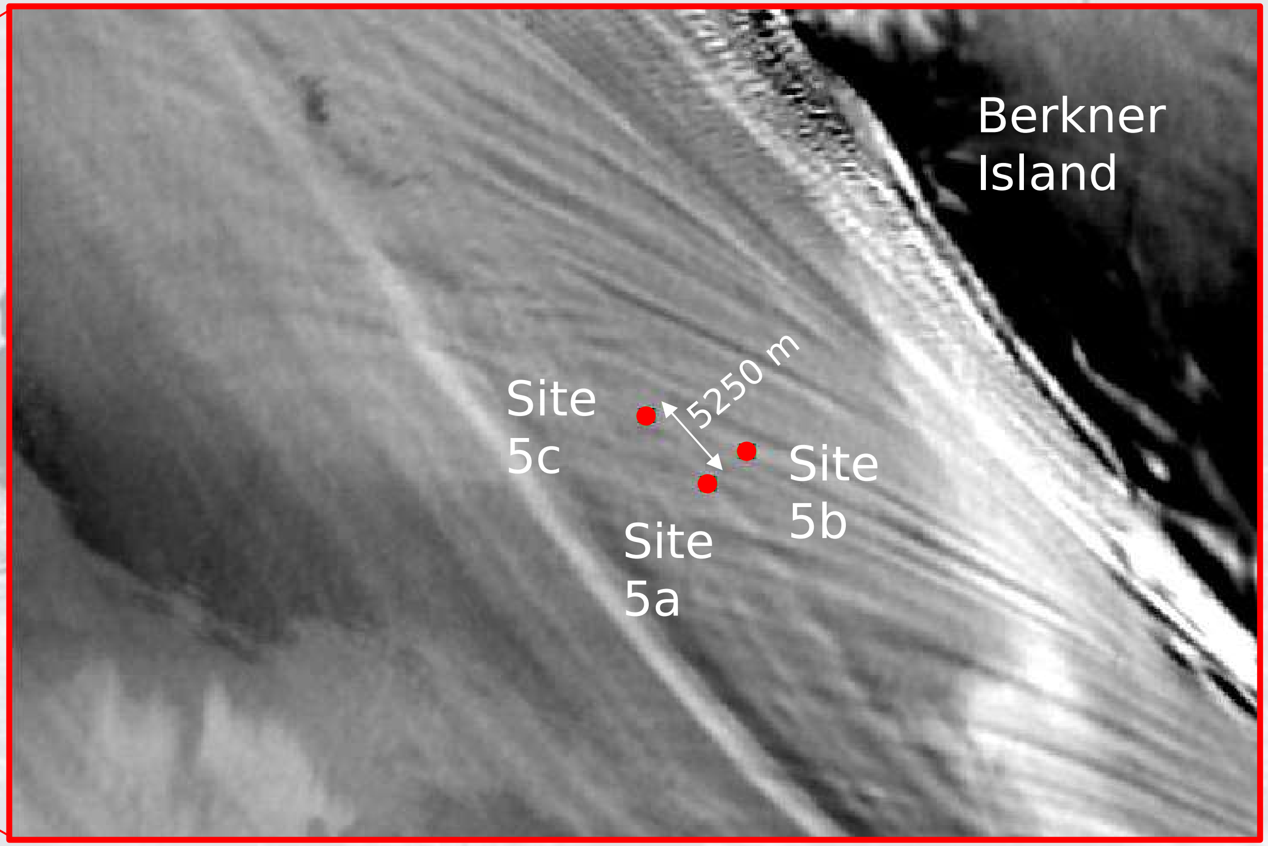
  → requires spatial context of observed geometry

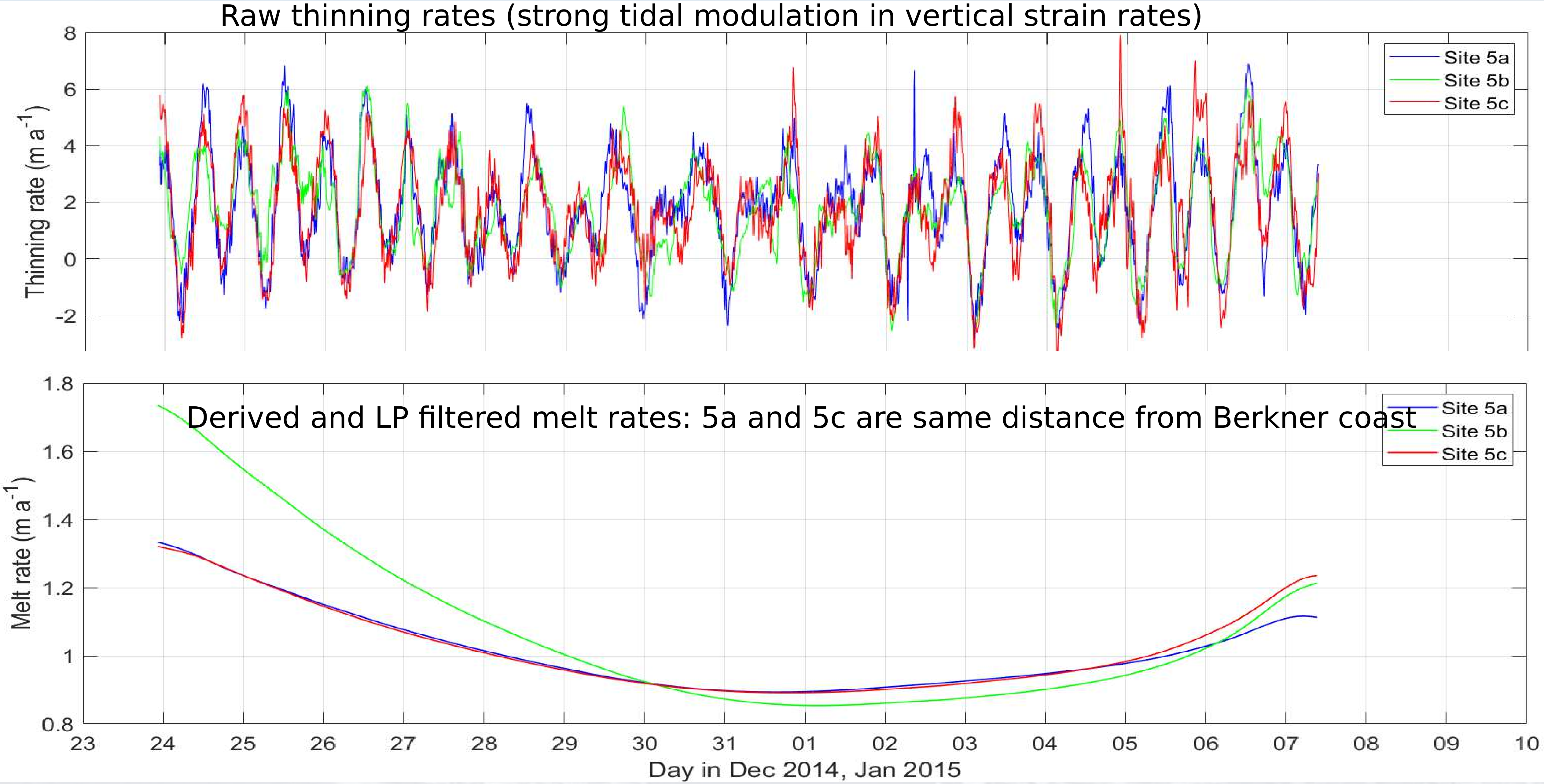


How representative are meltrates from phase-sensitive radars?

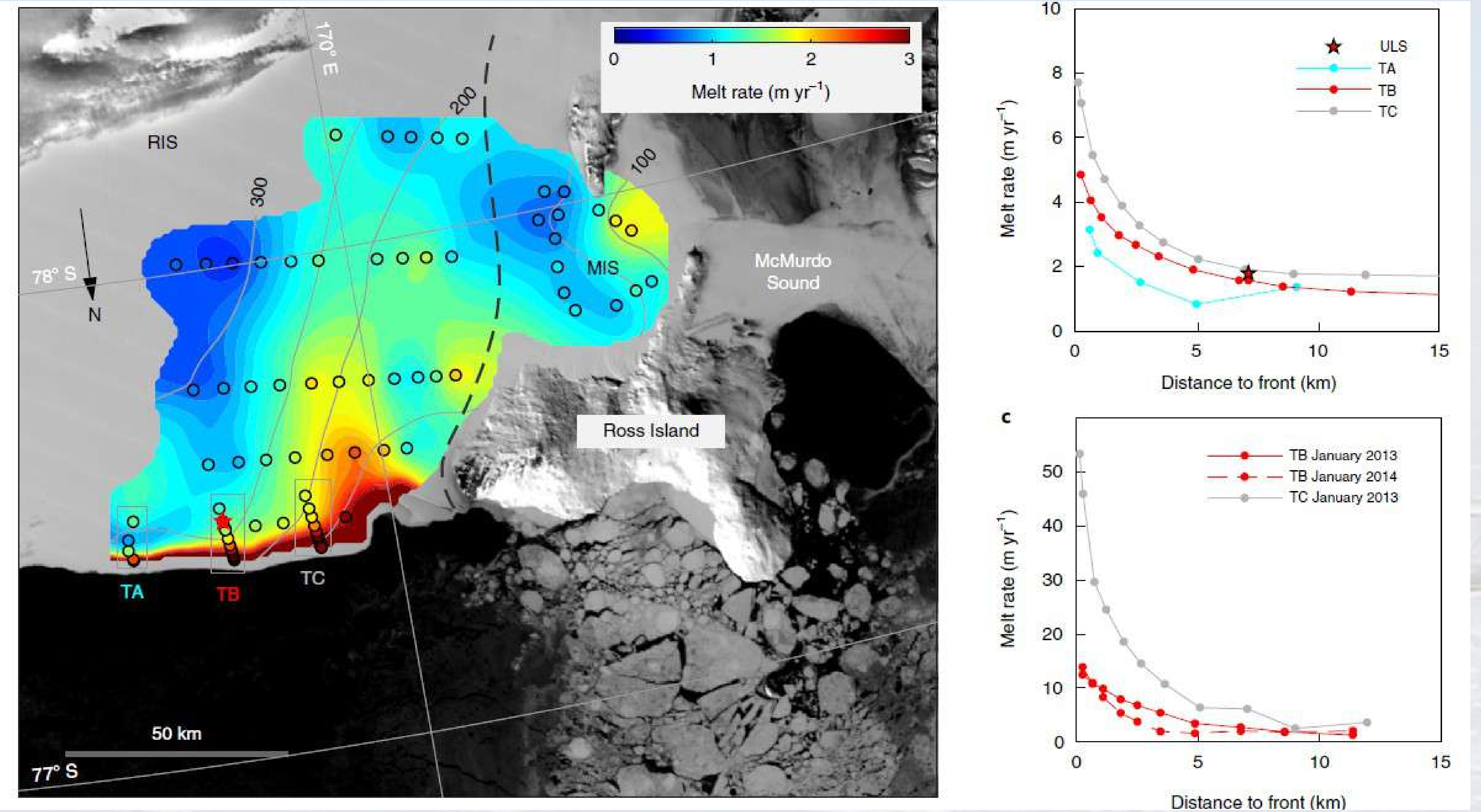
- If melt rates vary due to oceanography, radar will reflect that
- Three sites occupied within a few km on Ronne Ice Shelf
- Contemporaneous data for two-three weeks






Raw thinning rates (strong tidal modulation in vertical strain rates)
Thinning rate (m a-1)
8
6
4
2
0
-2
Site 5a
Site 5b
Site 5c
Derived and LP filtered melt rates: 5a and 5c are same distance from Berkner coast
Melt rate (m a-1)
1.8
1.6
1.4
1.2
1
0.8
Site 5a
Site 5b
Site 5c
23 24 25 26 27 28 29 30 31 01 02 03 04 05 06 07 08 09 10
Day in Dec 2014, Jan 2015

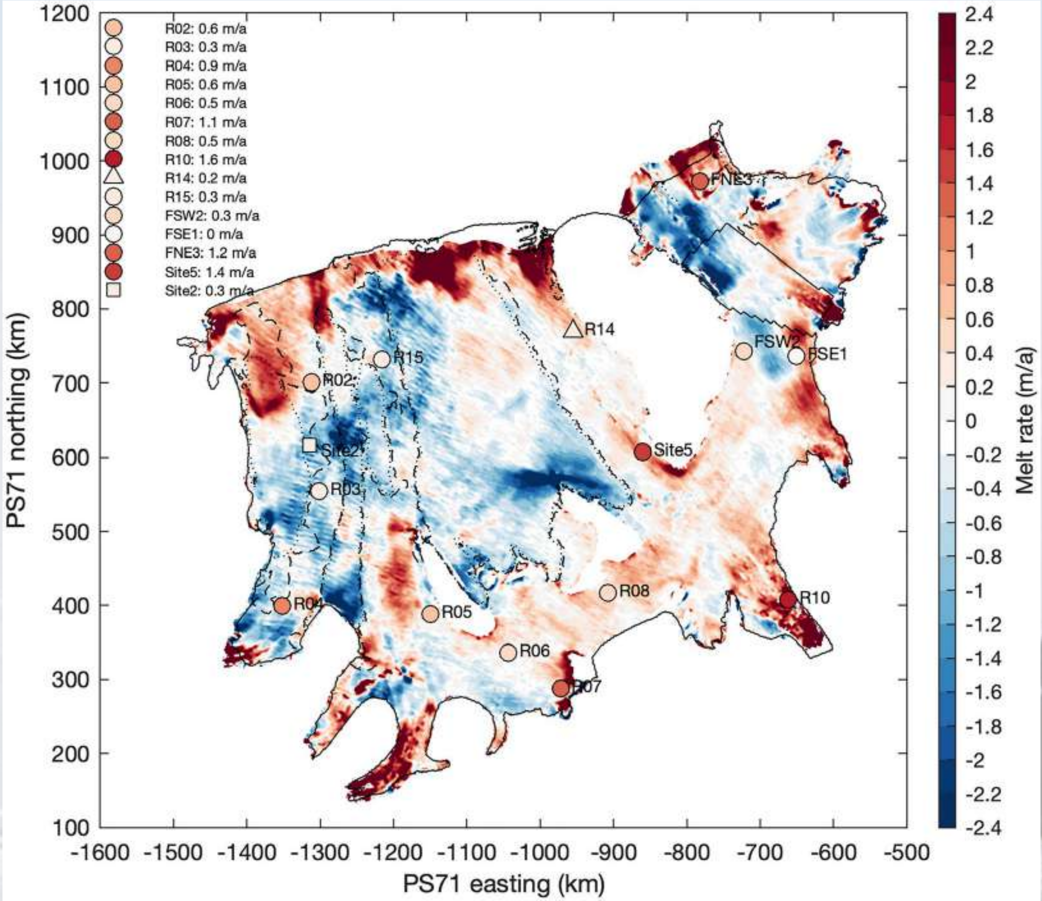
Spatial “smoothness” of derived melt rates



Stewart et al 2019

Satellite-derived melt rate products

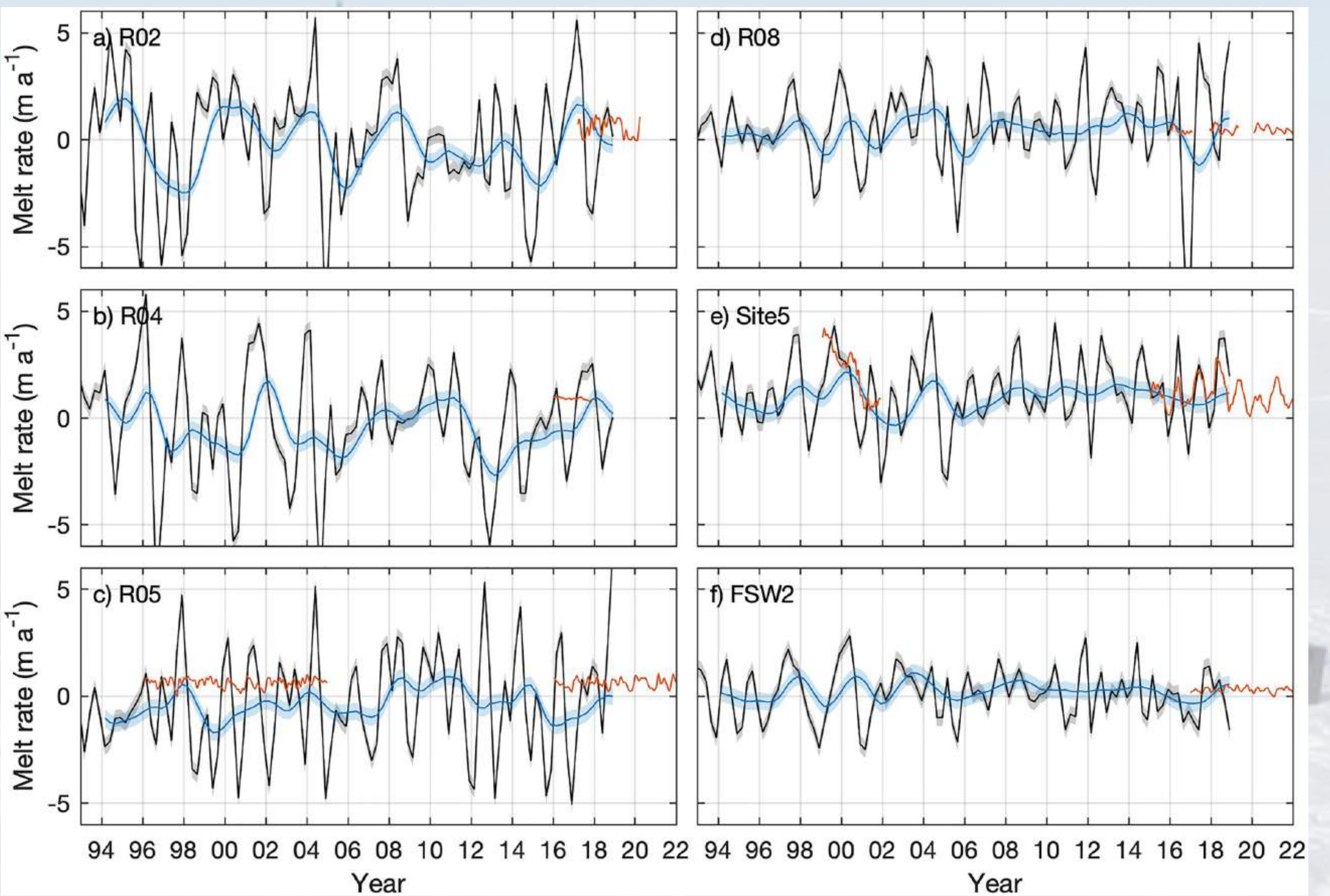
- ApRES data can be used to validate satellite-derived products
- Products are very refined, and utilise precipitation data from models
- Spatial distribution of melting and freezing averaged over several years look reliable
- Absolute averaged values are more challenging, but looking ok
- Time series at resolution ~<1 year need a lot of work

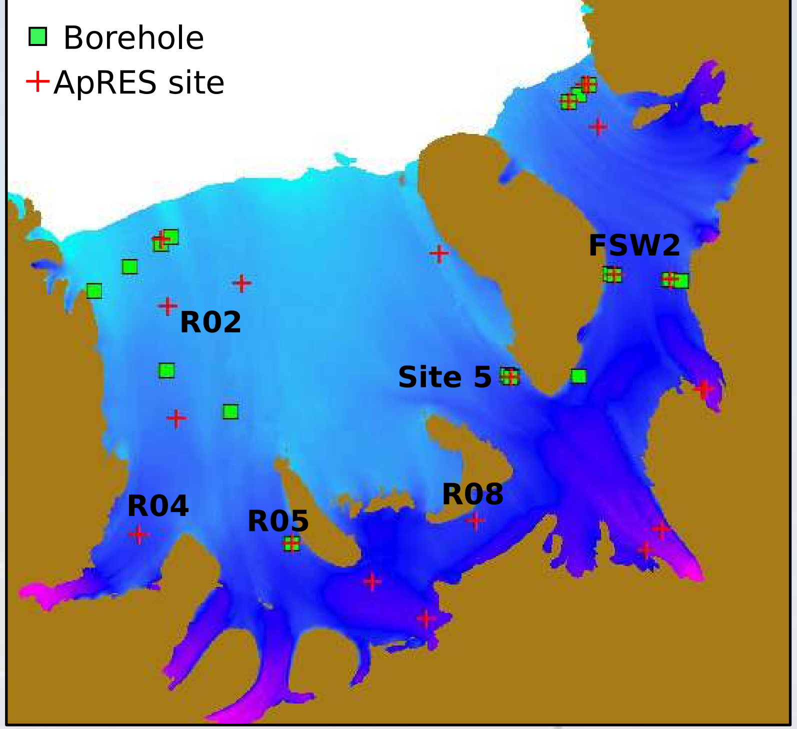


Note that averaging time periods of ApRES and sat-derived melt rates differ

Vaňková and Nicholls 2022
(Satellite derived meltrates from Adusumilli et al 2020)

Comparison of time series data





Black: 3-monthly SDM
Blue: 3-yearly SDM
Red: “Direct” (ApRES) observation

Vaňková and Nicholls 2022

Summary

- Deployed, phase-sensitive radars can give multi-year time series of melt rates at temporal resolution down to days or less;
- With mooring data, basal melt time series directly improve parameterizations used in models;
- Melt rate time series can be used to validate models and, suggest data assimilation
- Holy Grail: reliable sat-derived melt rate time series at res. down to a few months, everywhere. This would be an exceptional dataset for model validation and data assimilation. Requires work, and ground-based methods (e.g. ApRES) can help.