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Remote sensing of Larsen C Ice Shelf: Surface melt, rifting, and A-68 calving

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Dan McGrath *University of Colorado*
Michiel van den Broeke *University of Utrecht*

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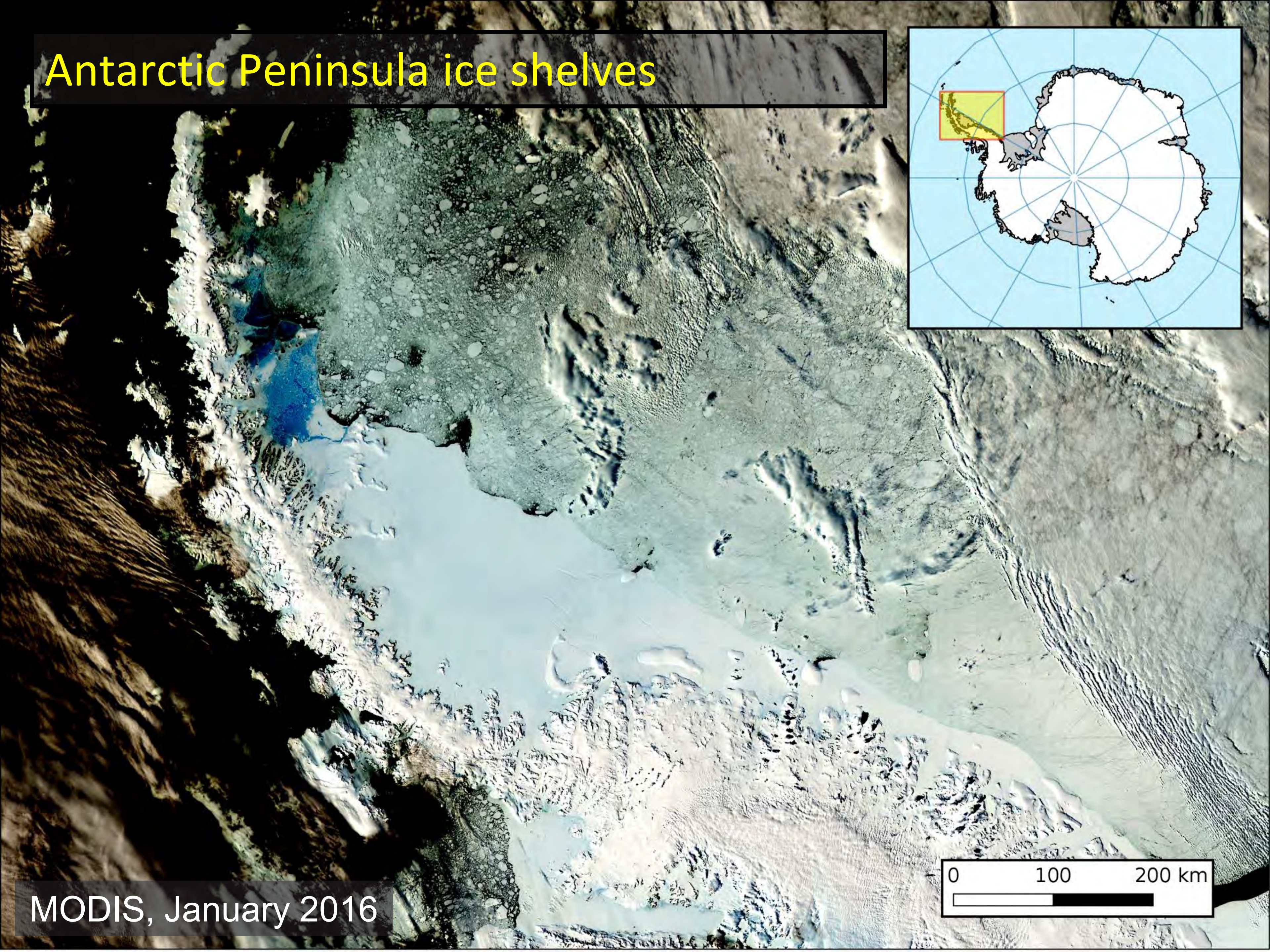
Previous related grants

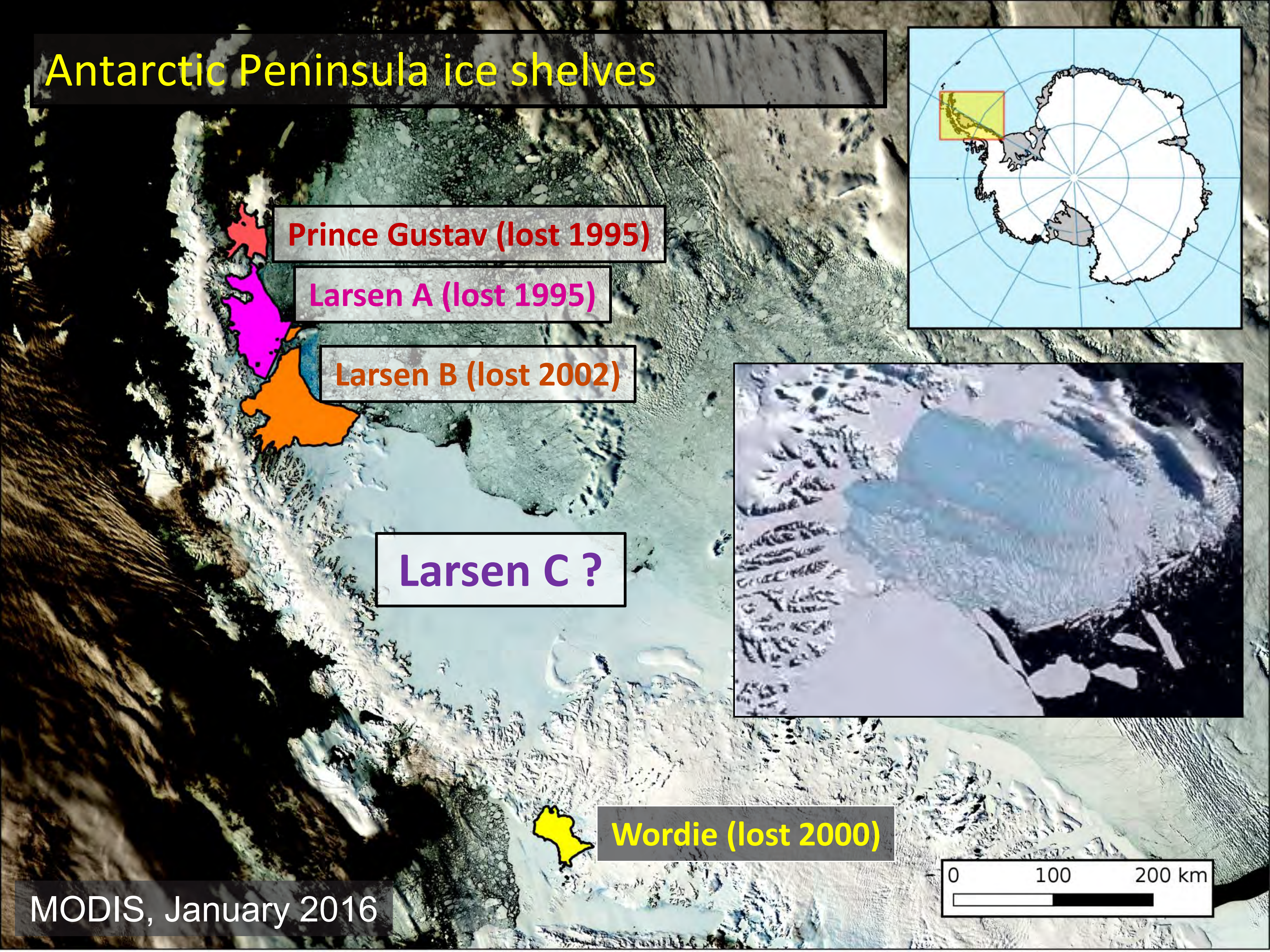
AFI Grant NE/E012914/1: *Stability of Larsen Ice Shelf (SOLIS): 2008 - 2011*
Small Grant NE/I016678/1: *Quantifying the role of marine ice in Larsen C Ice Shelf dynamics: 2011 – 2012*
Geophysical Equipment Facility (GEF): *Loans 863 & 890, GPR and GPS (SOLIS)*
GEF: *Loan 1028, GPR and GPS (MIDAS)*

Project MIDAS

NERC
SCIENCE OF THE ENVIRONMENT

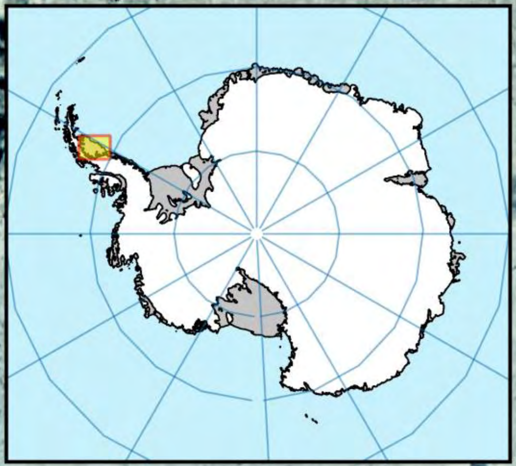


Antarctic Peninsula ice shelves
MODIS, January 2016
0
100
200 km

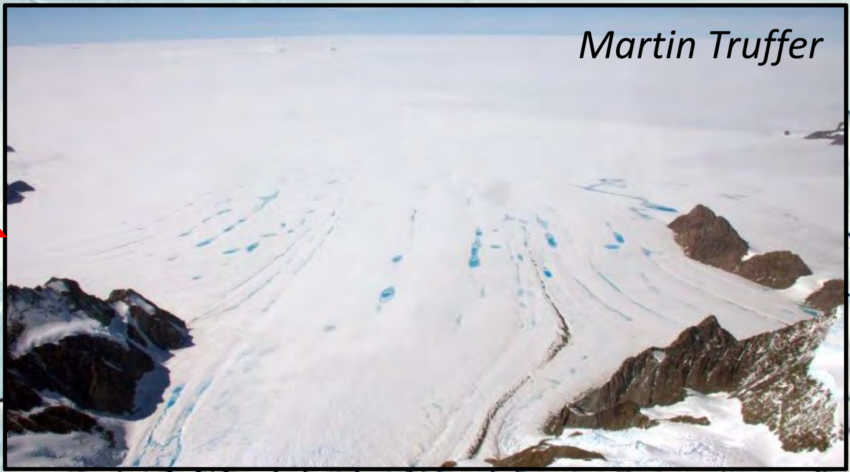


Antarctic Peninsula ice shelves
Prince Gustav (lost 1995)
Larsen A (lost 1995)
Larsen B (lost 2002)
Larsen C ?
Wordie (lost 2000)
0
100
200 km
MODIS, January 2016

Larsen C:
Melt ponds



- Larsen B had ponds prior to collapse
- On Larsen C:
  - Where and why?
  - How long have they been forming?
  - What effect do they have?



Martin Truffer

MODIS Aqua, January 2016

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Project MIDAS

MIDAS

- Impact of **M**elt on **I**ce shelf **D**ynamics **A**nd **S**tability
  - NERC Standard Grant, 2014 to 2017
- Original aims
  - Investigate surface melt patterns and trends from satellite data
  - Examine history of ponding from virtual ice cores and surface radar
  - Satellite and weather station data to explore föhn event timing
  - Ice dynamic modelling to consider future impacts
- Rift and calving
  - Previous Larsen C calving and rift origin
  - Rift propagation from Sentinel-1 SAR interferometry
  - Surface velocity evolution from Sentinel-1 feature tracking
  - Post-calving impact model and observations
  - A68 iceberg and its likely fate

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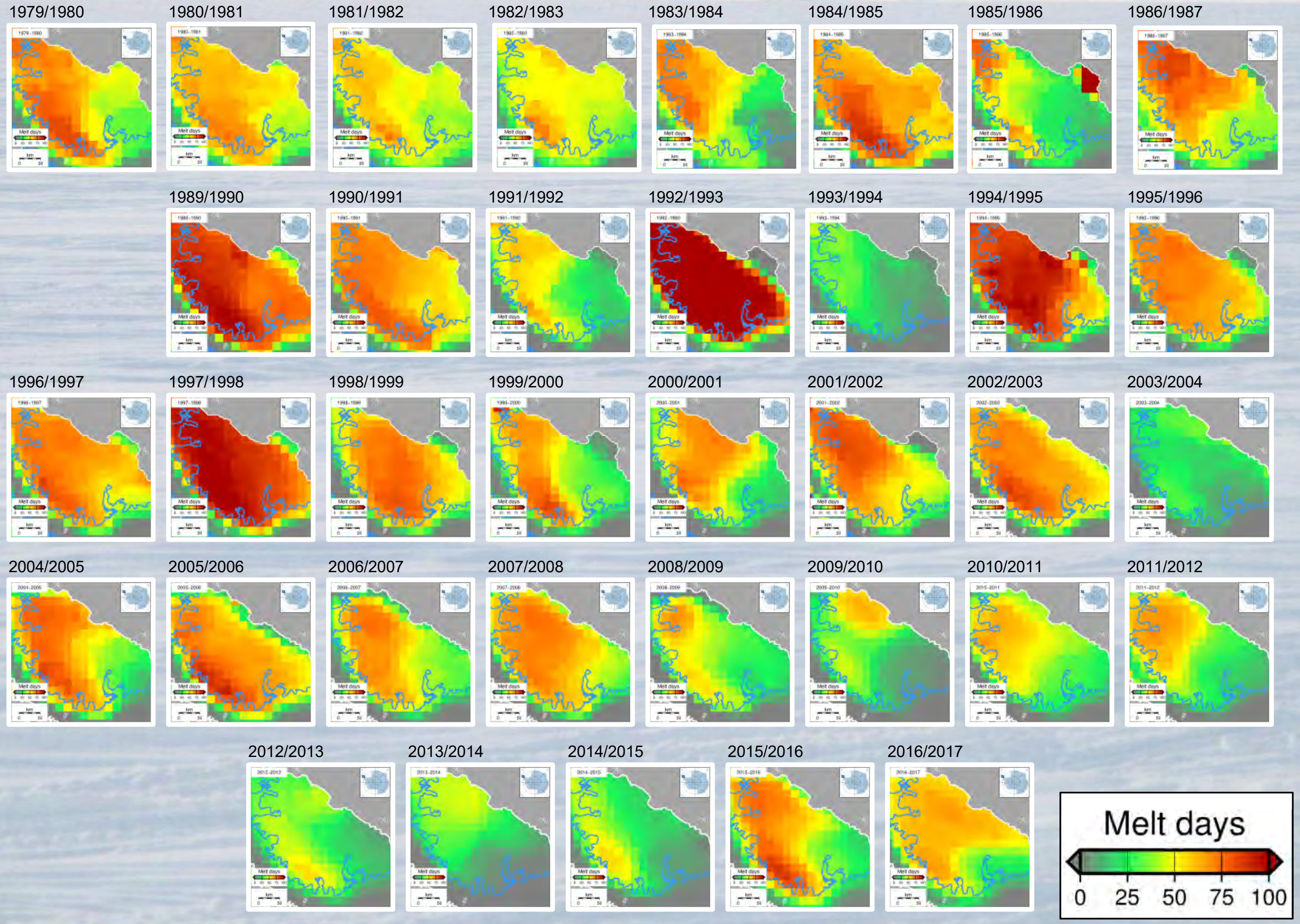
Melt and ponding:

Passive microwave melt detection, 1979-present



- SMMR and SSMI, ~25km Resolution, Data from NSIDC
  – Considerable variability in surface melt duration

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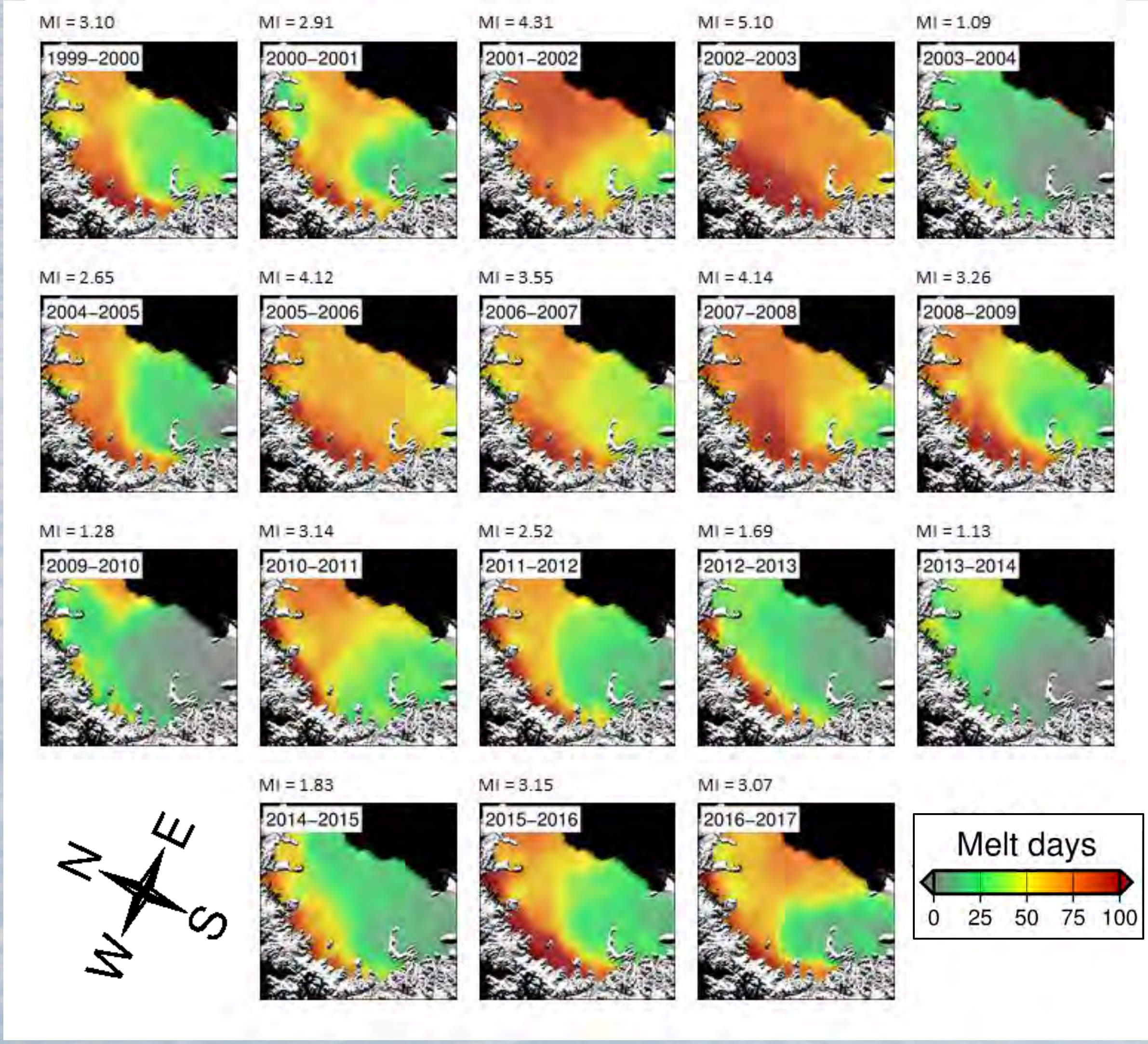
Melt and ponding:
Active microwave melt detection, 1999-present



- Scatterometer
  - Enhanced resolution products from Brigham Young University:
  - QuikSCAT (SeaWinds)
    - 1999 to 2009, 5km
  - ASCAT (Eumetsat)
    - 2009 to 2017, 4.45 km
- Melt pattern:
  - Variability confirmed
  - South-North trend
  - Plus warmer inlets

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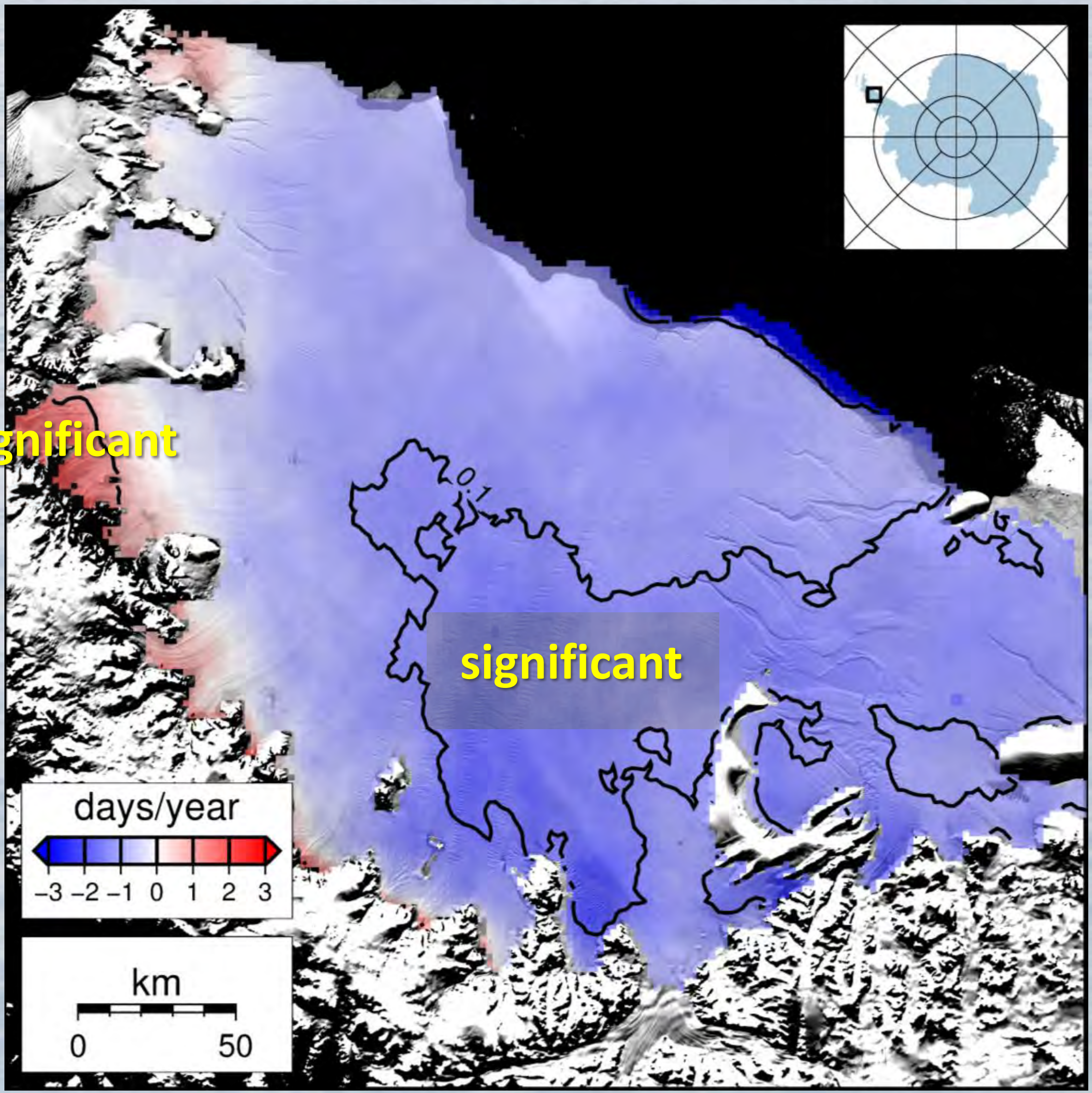
Melt and ponding:

Melt duration trend 1999-2017

- Melt duration on Larsen C ice shelf has been decreasing since 1999
  - In line with mean annual air temperatures
- Except in the inlets where where föhn winds bring warm dry air to the surface



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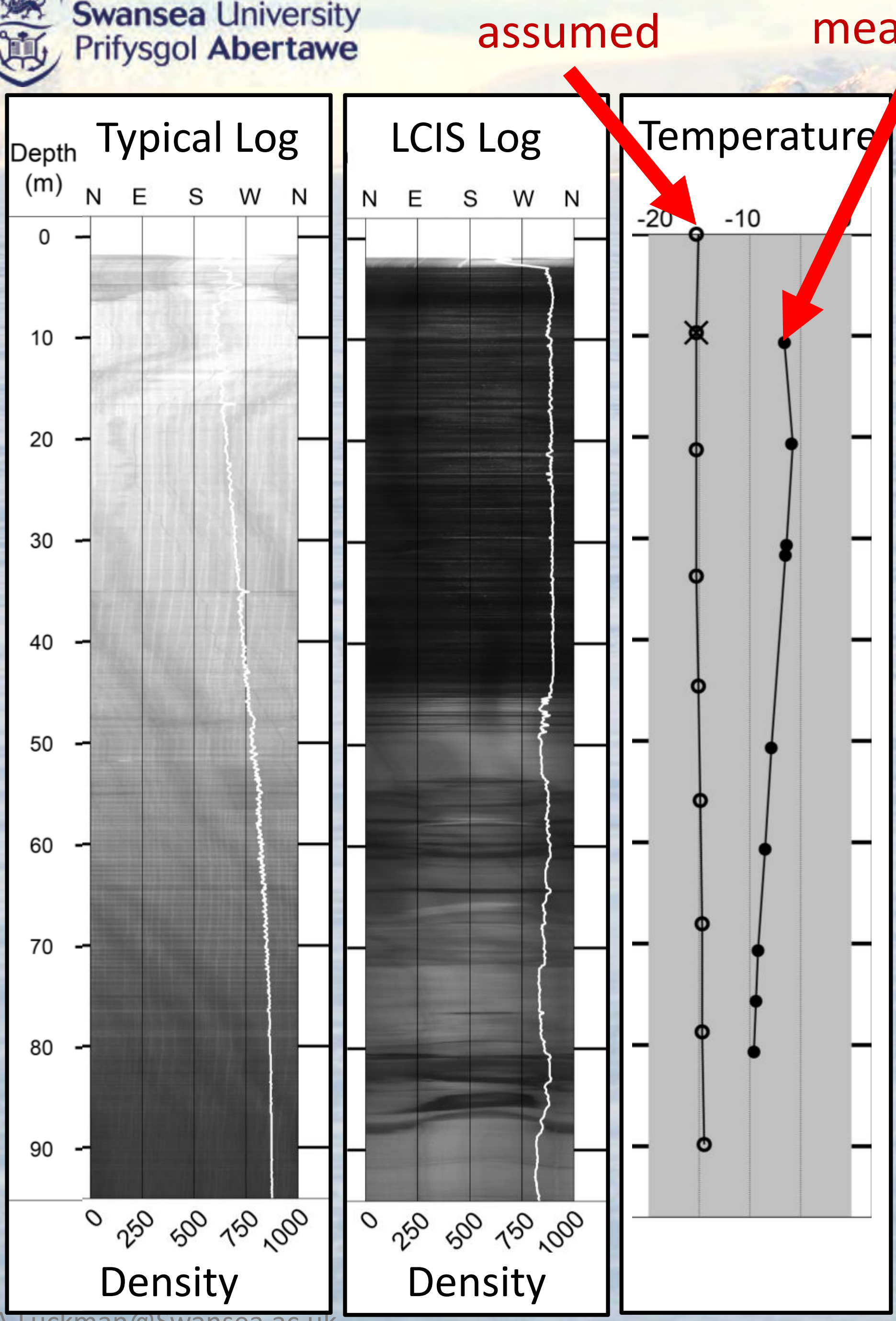
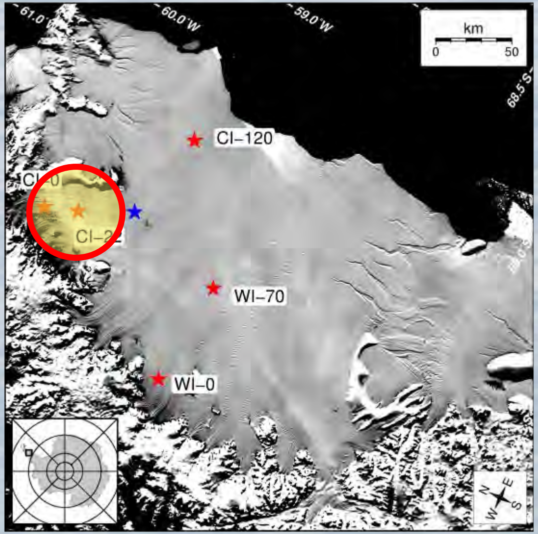
Melt and ponding: *Borehole survey*



- 5 boreholes, 2014 & 2015
  - Optical televiewer & thermistor strings
- Findings
  - Refrozen melt ponds in inlets accumulate substantial layers of solid ice overlying infiltrated firn
  - Ice is up to 10°C warmer than expected
  - But how widespread is this?



Hubbard, B., Luckman, A., Ashmore, D. W., Bevan, S., Kulessa, B., Kuipers Munneke, P., Philippe, M., Jansen, D., Booth, A., Sevestre, H., Tison, J.-L., O'Leary, M., Rutt, I., Jun. 2016. Massive subsurface ice formed by refreezing of ice-shelf melt ponds. *Nature Communications* 7, 11897+.

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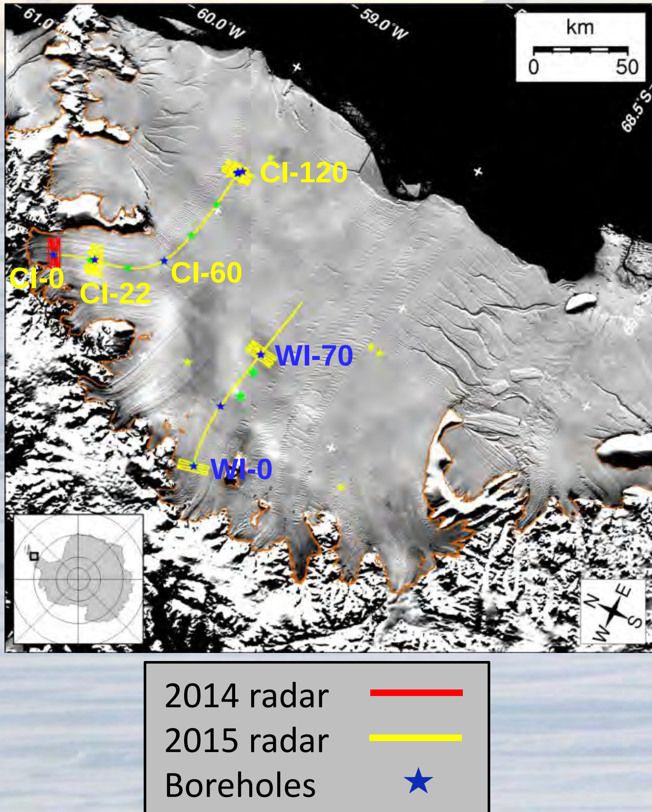
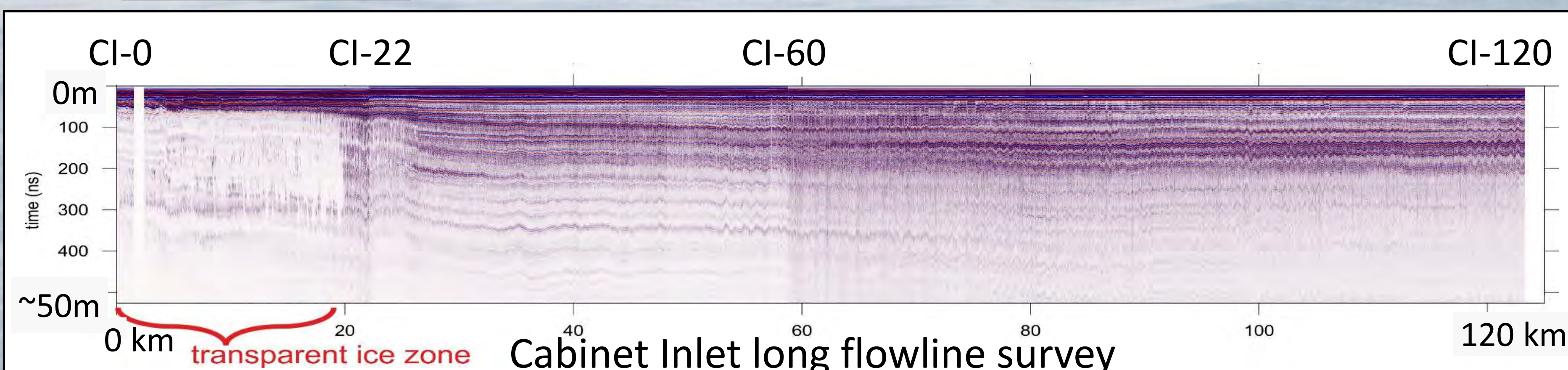
Melt and ponding:
Radar survey



- Snowscooter survey along flowlines and in grids
  - 200 MHz common-offset
- Interpretation
  - Horizontal radargram features are melt/accumulation layers
  - These features are supressed by meltwater infiltration and refreezing
    - Transparent ice zone
- Conclusion
  - Massive melt layer in Cabinet Inlet (CI-0) borehole data is longitudinally extensive



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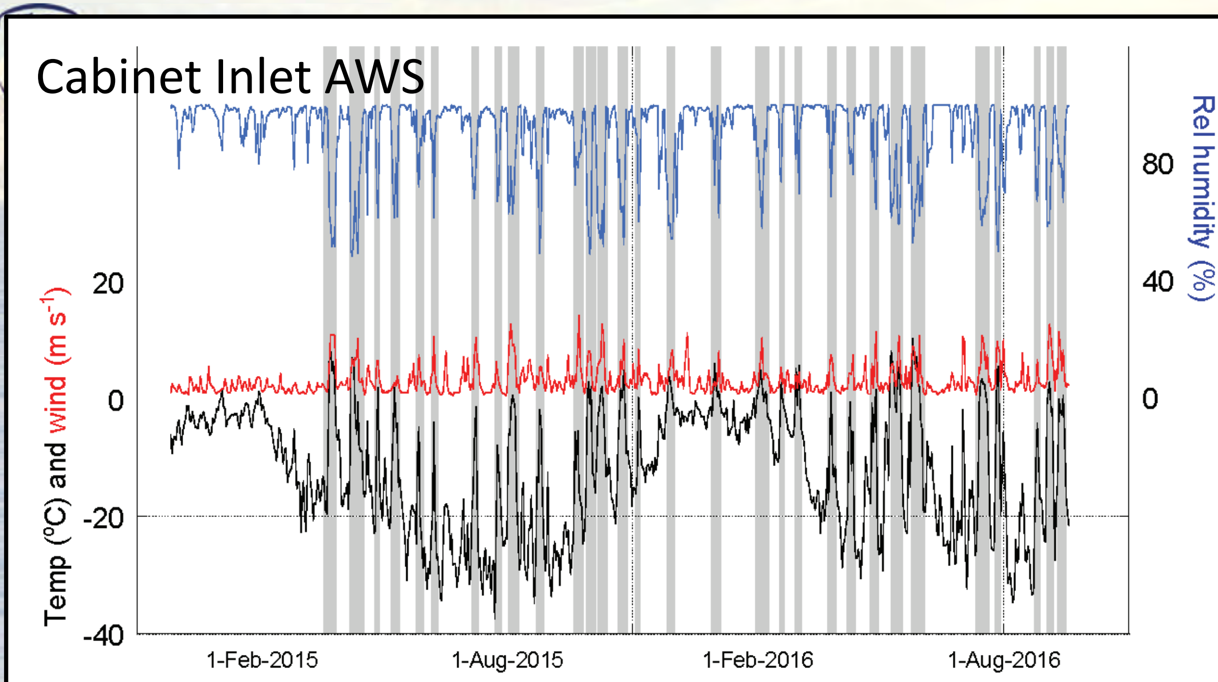
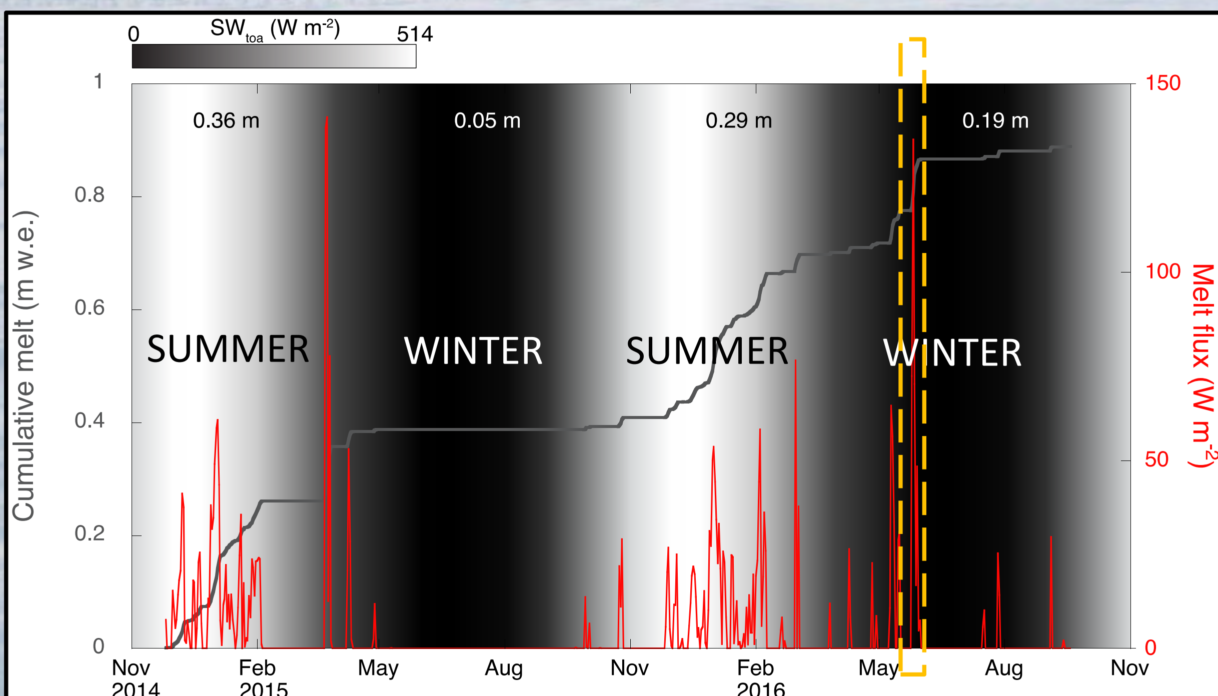


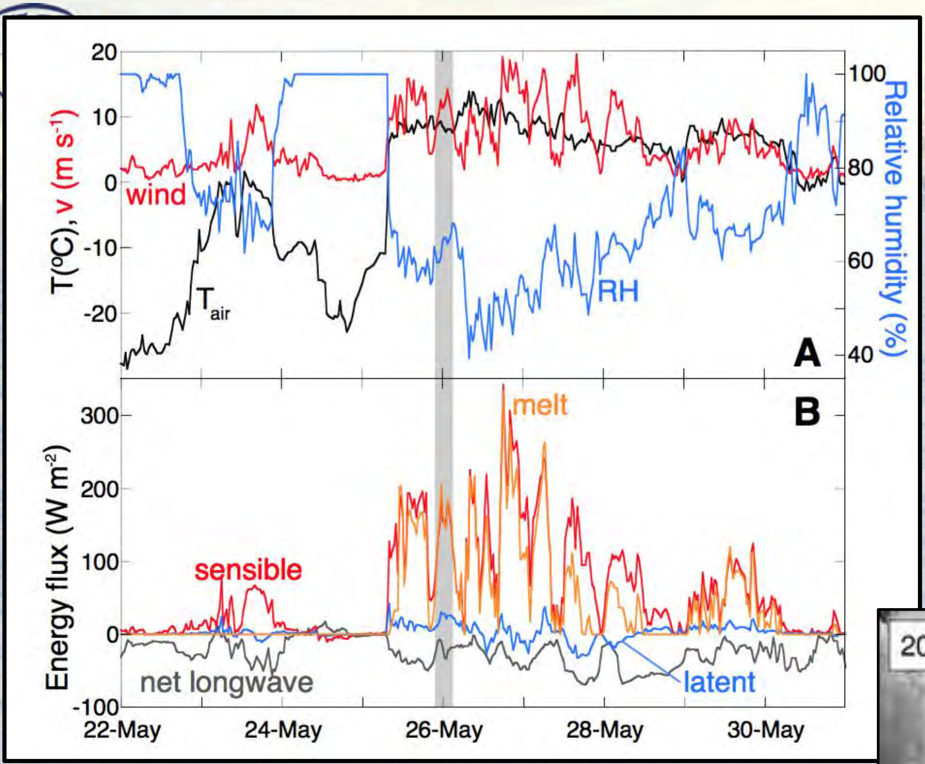


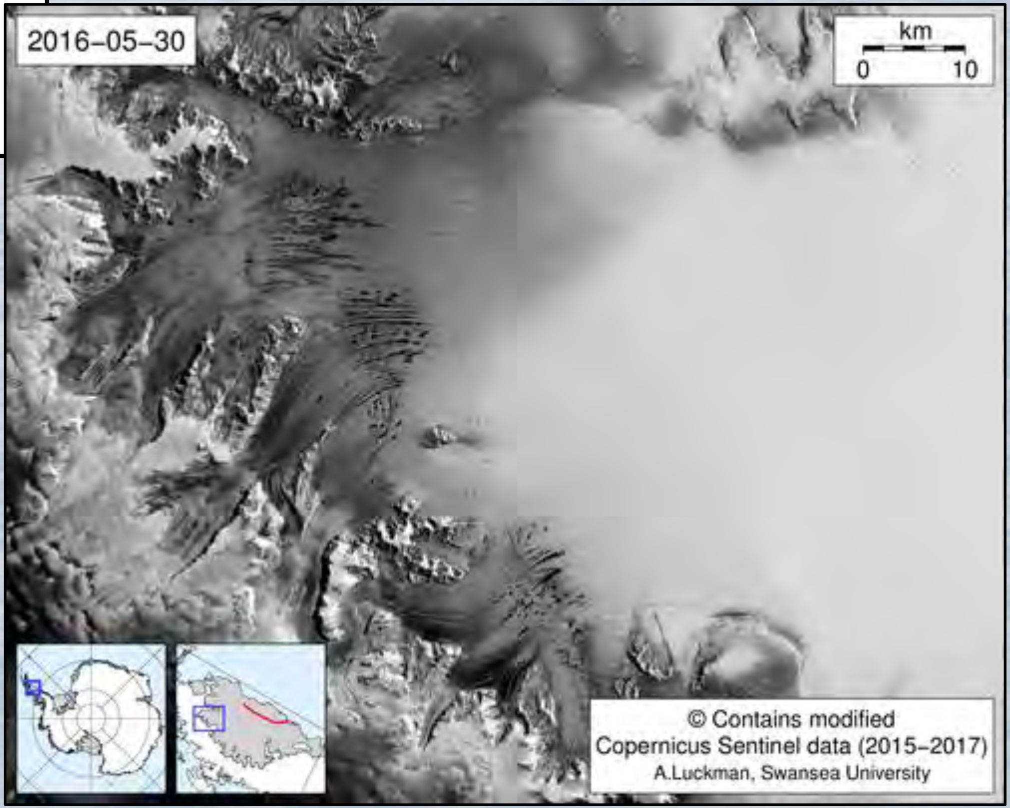
Melt and ponding: *Timing*

- Summer mean temperature occasionally gets above freezing
  - Sometimes producing enough melt flux for ponds to form
- Winter föhn winds also frequently give rise to surface melt
  - Westerly wind
  - Low humidity
  - Air warms as it descends onto the ice shelf
- In 2016, 40% of melt occurred in the winter!
  - Compacting firn
  - Significantly raising firn temperature
  - And sometimes producing ponds

Kuipers Munneke, P., Luckman, A. J., Bevan, S. L., Smeets, C. J. P. P., Gilbert, E., van den Broeke, M. R., Wang, W., Zender, C., Hubbard, B., Ashmore, D., Orr, A., King, J. C., Kulessa, B., May 2018. Intense winter surface melt on an Antarctic ice shelf. Geophysical Research Letters.

Melt and ponding:
Winter-time events





- End of May 2016
  - Melt ponds clearly visible in Sentinel-1 SAR

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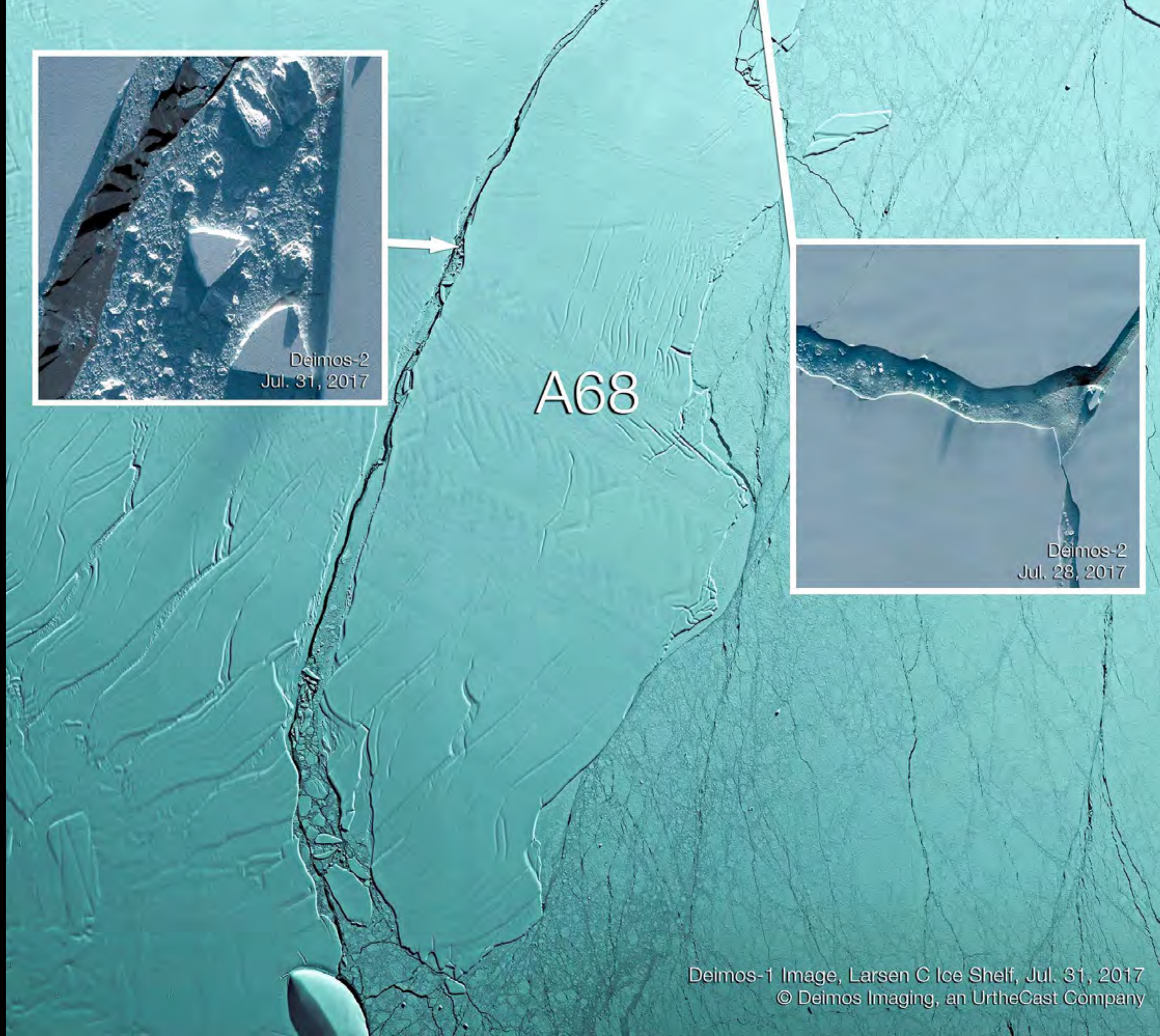
Then along came a rift…

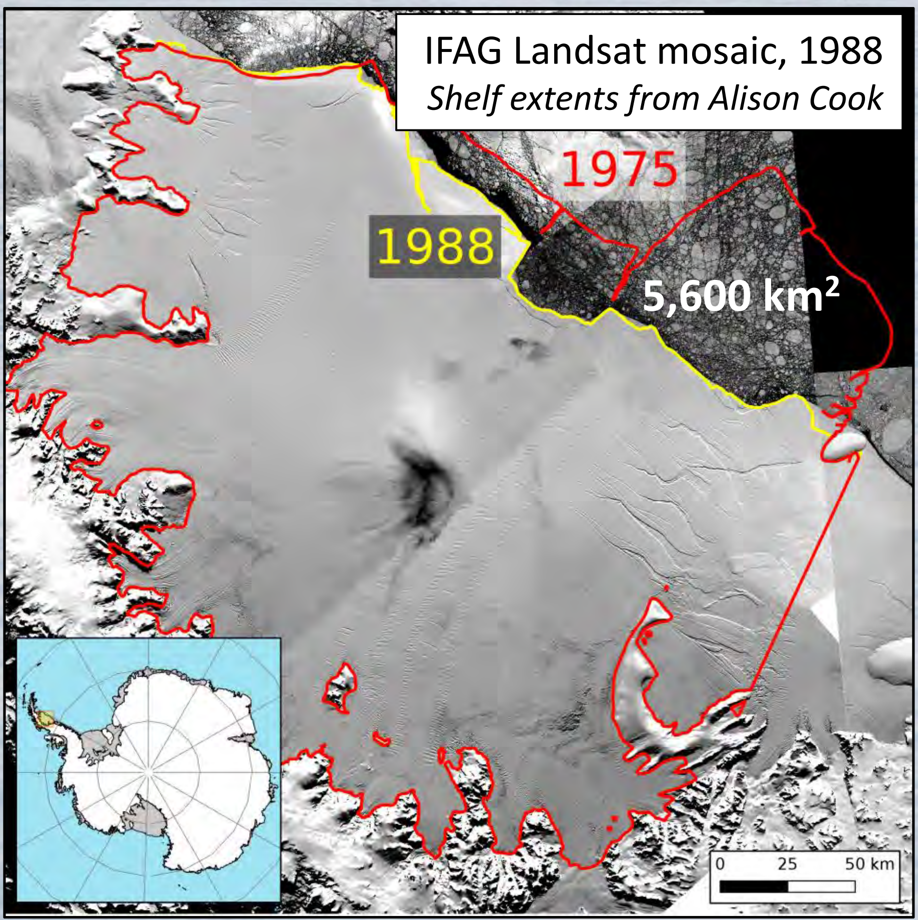
John Sontag, NASA, November 10th 2016

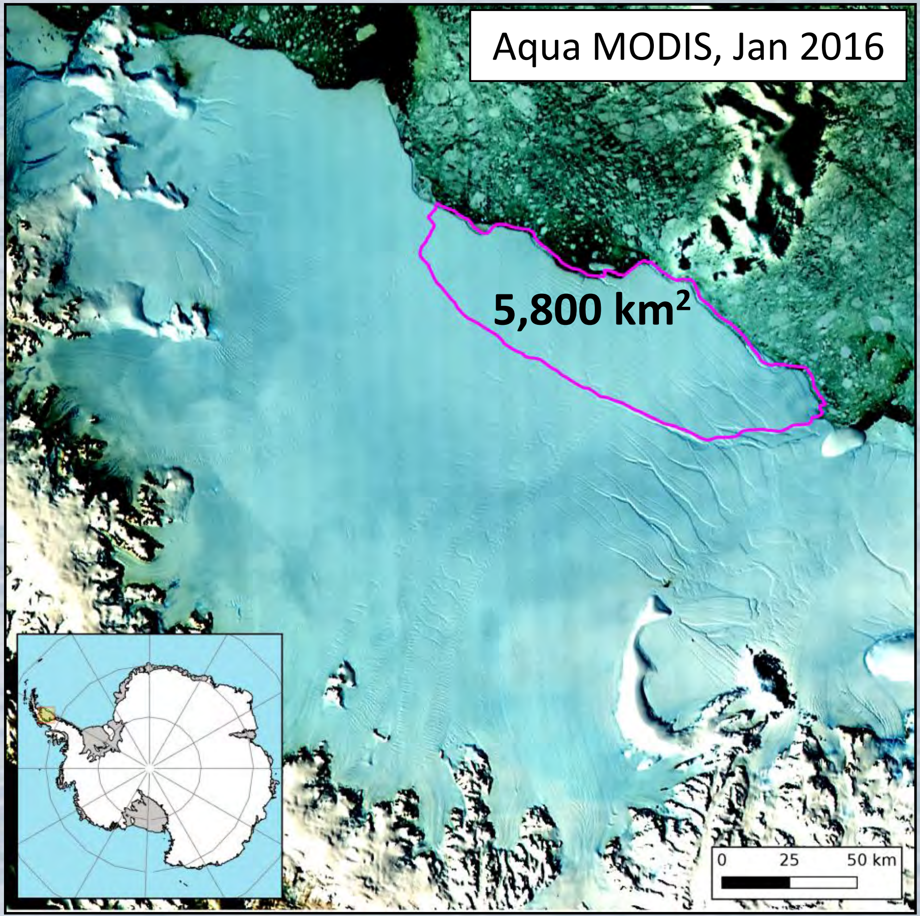
Rift and calving



Rift and calving:

Calving history





- Larsen C calved Iceberg A20 in 1986
  - A20 was probably bigger than A68
- Larsen C area trend has generally been negative

Phillips (now Fricker), H. A., Laxon, S. W., Jan. 1995. Tracking of Antarctic tabular icebergs using passive microwave radiometry. *International Journal of Remote Sensing* 16 (2), 399-405.

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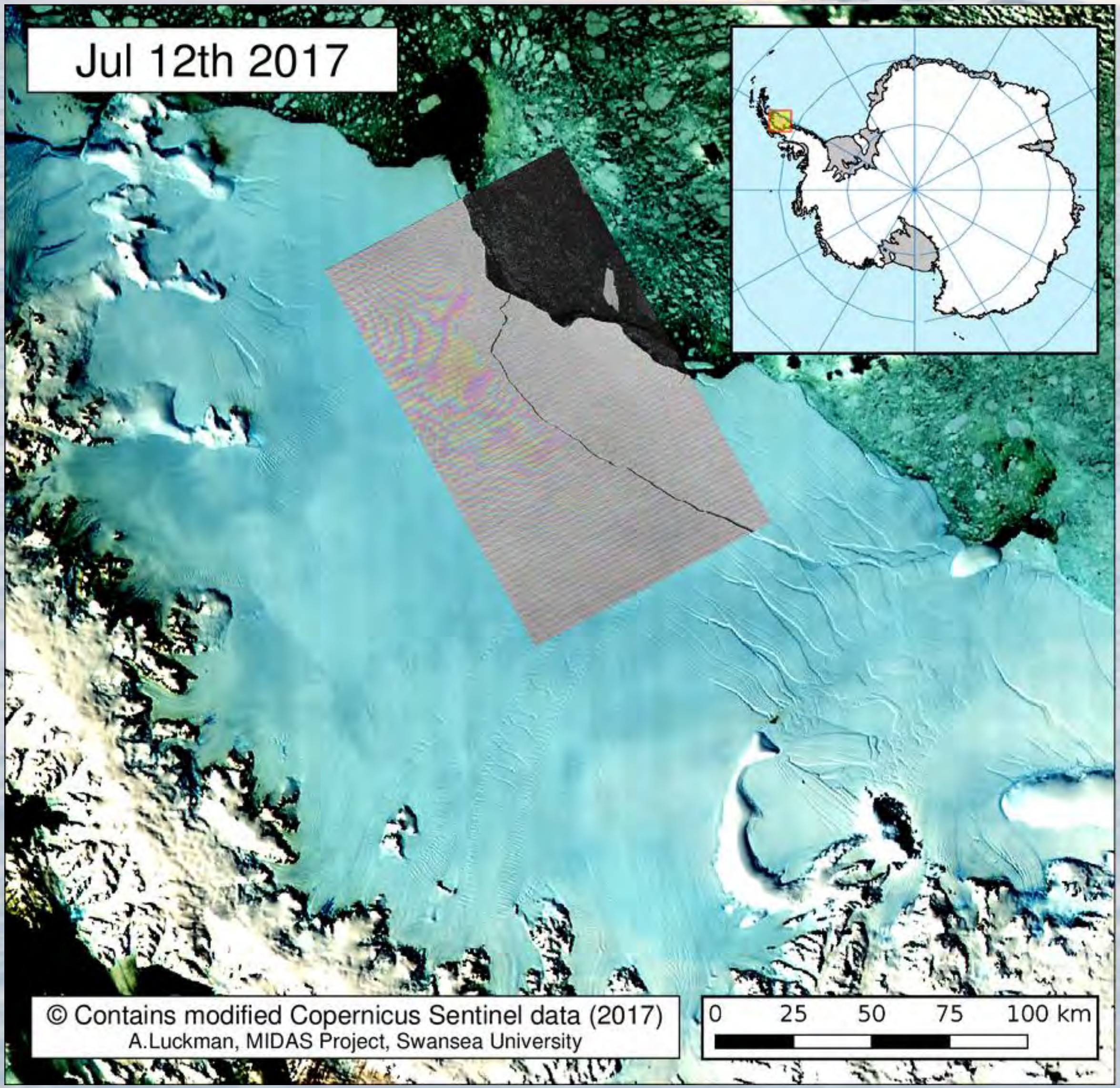
Rift and calving:

Rift propagation



- We first spotted the rift that had progressed beyond its neighbours in 2014
  - Landsat data
  - Rare cloud-free images
- Sentinel-1 repeat-pass InSAR coherence is sensitive to very small geometric changes
  - Wavelength 5.6 cm
  - The rift caused phase-changing vertical and/or horizontal shifts even before it was visible at the surface

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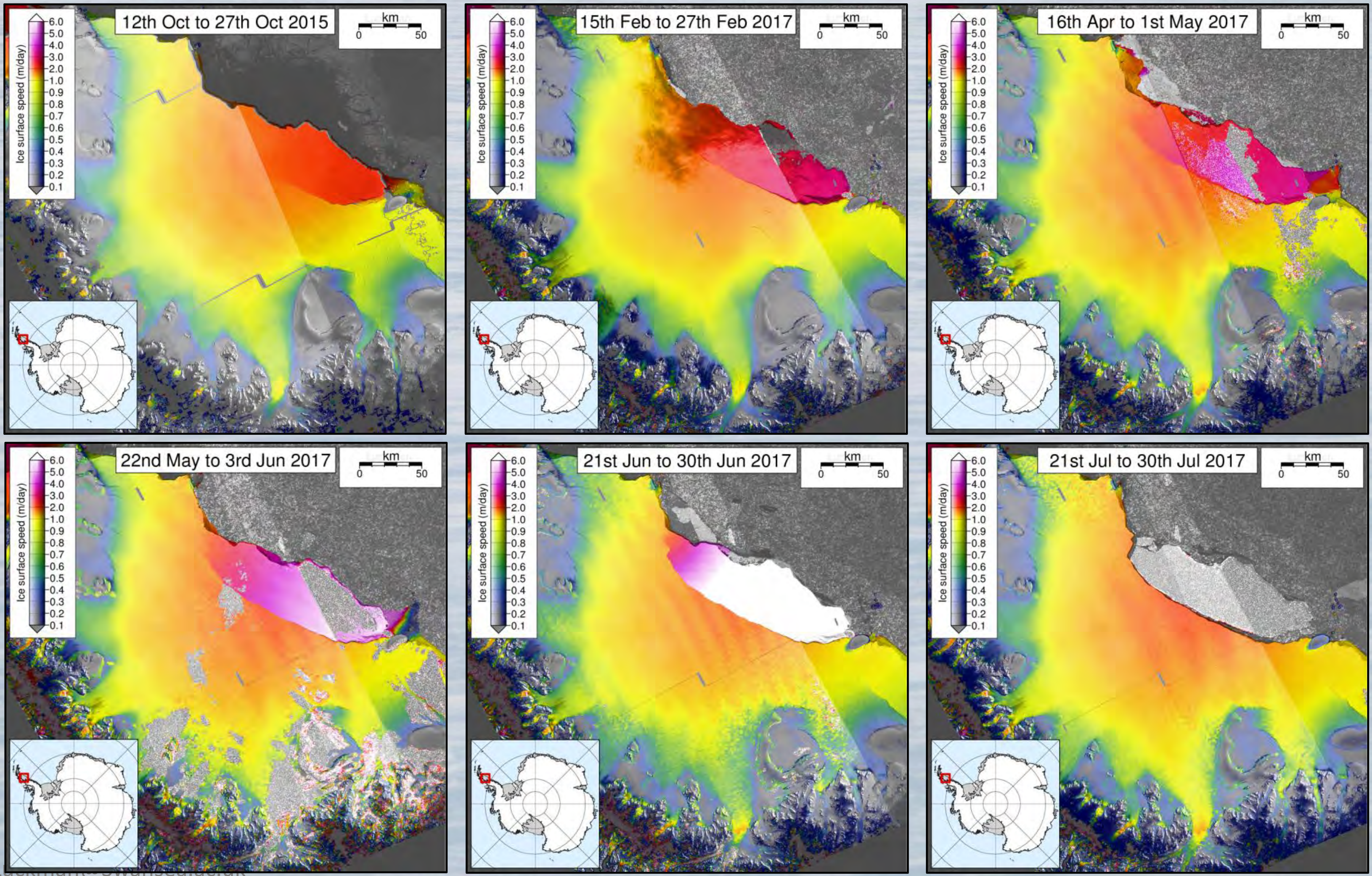
Rift and calving:
surface velocity evolution

Sentinel-1 SAR feature/speckle tracking



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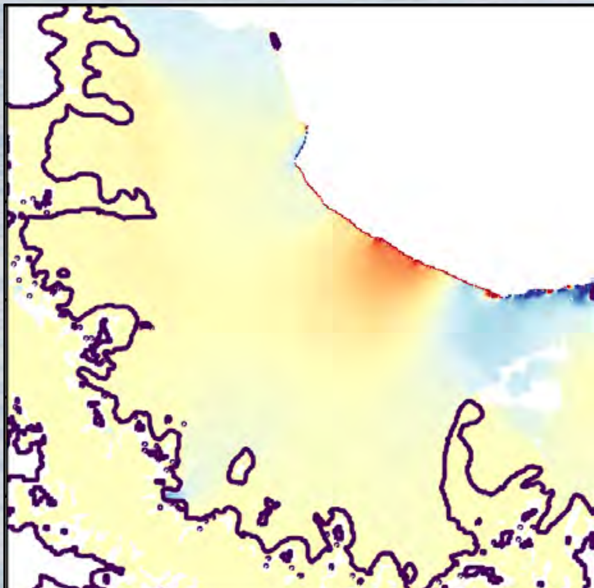
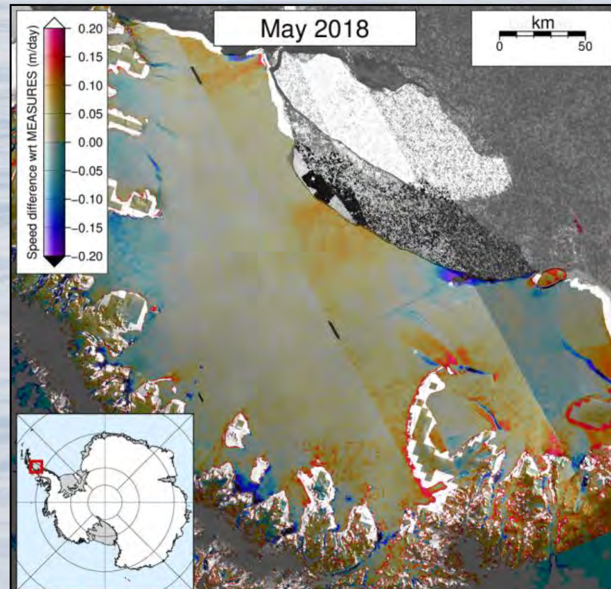
Rift and calving:
Post-calving model



Expected ice speed-up following iceberg calving



Observed ice speed-up from 2009 to 2018

- Bisicles model assumes instantaneous rift progression
  - In reality, shelf has had months to begin to adapt
- Velocity increases at centre of ice-front and decreases either side
  - A68 provided some back-stress
- Change magnitude
  - Comparable to observation/model error
  - On the same scale as Sentinel-1 feature tracking uncertainty

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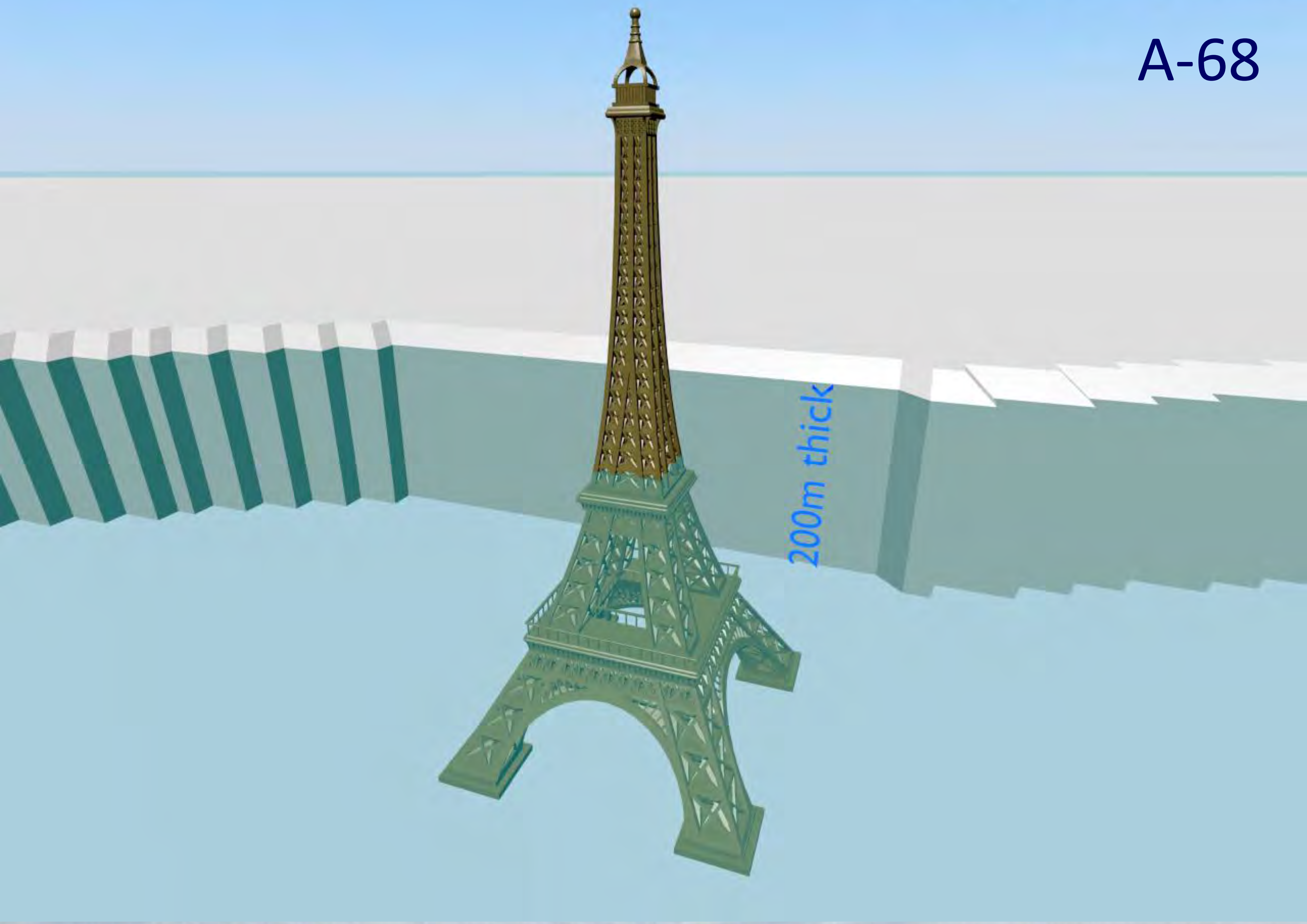
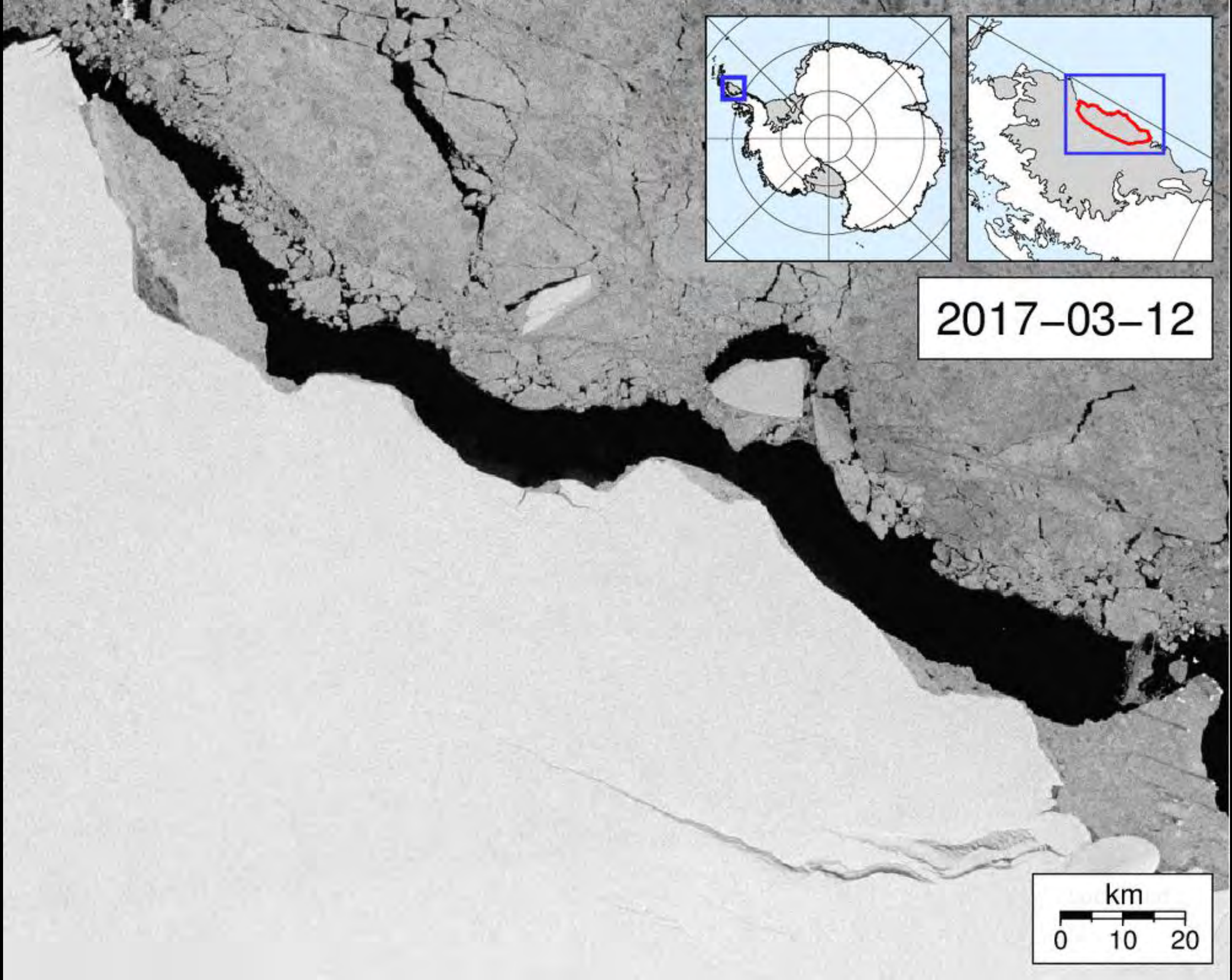
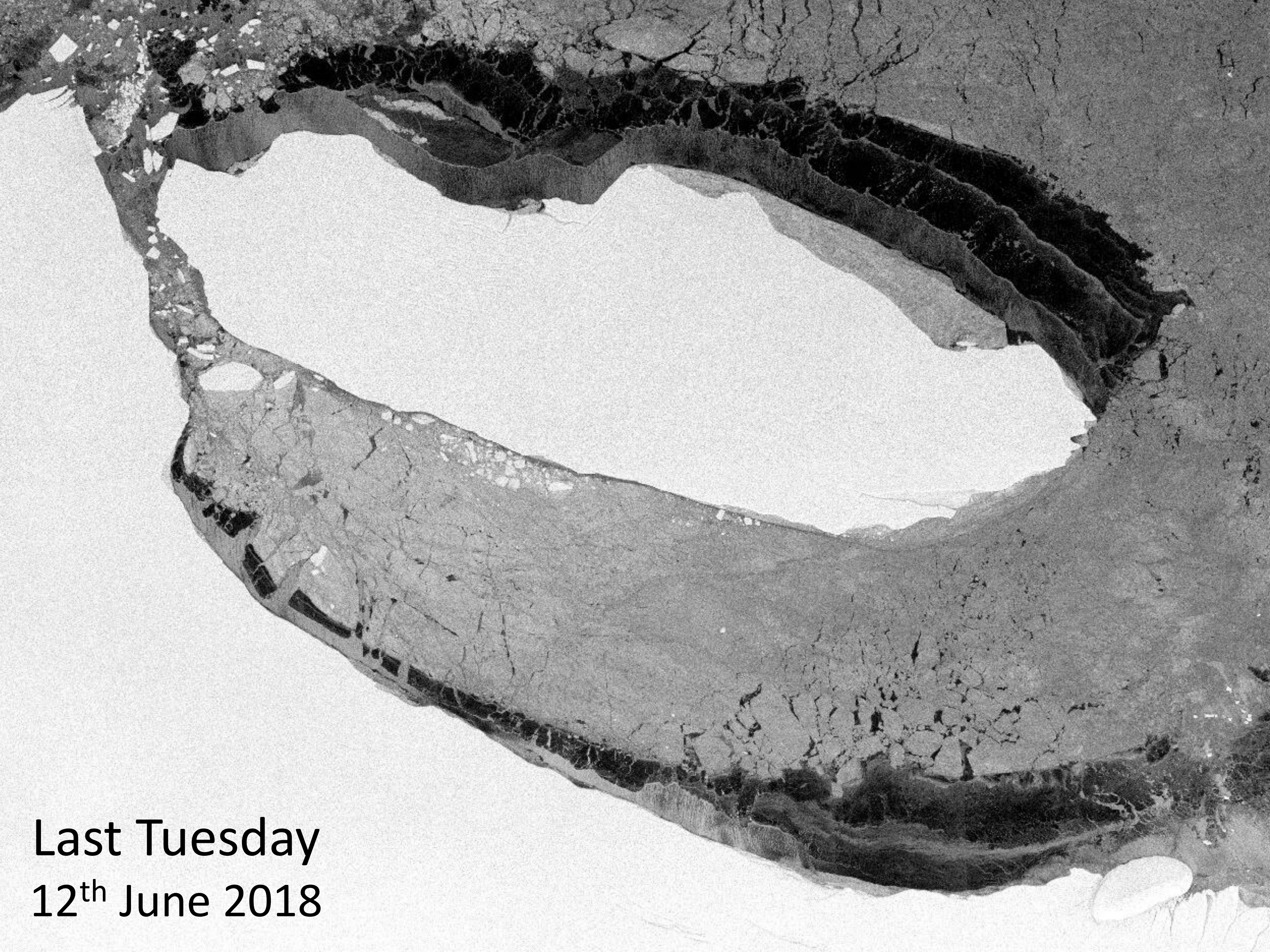
A-68

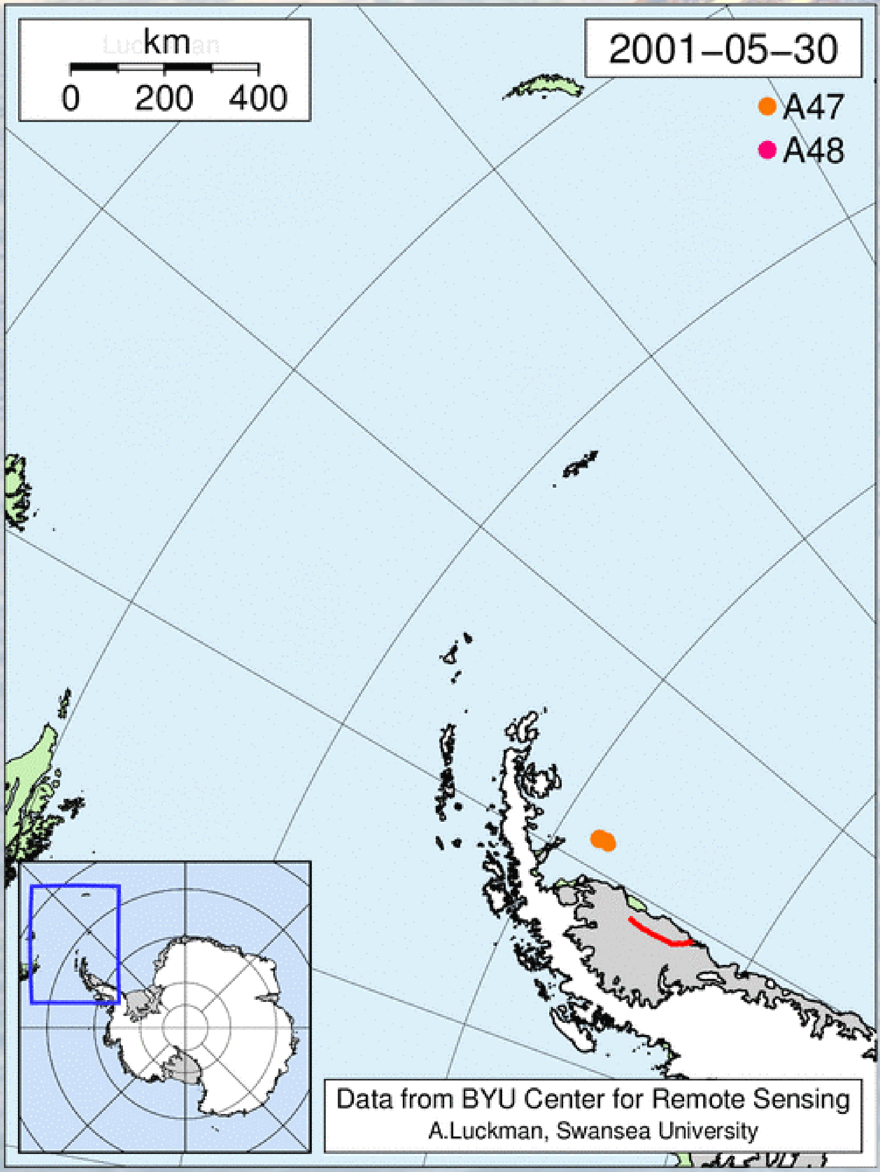



2017−03−12
km
0
10
20



Last Tuesday
12th June 2018

Possible A-68 Iceberg fate



- Data from two previous large icebergs from the same vicinity suggest possible trajectories
  - Scatterometer climate record pathfinder
  - http://www.scp.byu.edu/data/iceberg/

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Conclusion

- Larsen C rift and calving
  - Sentinel-1 was instrumental in tracking rift propagation
  - But many other satellite instruments contribute to ice shelf and iceberg science
  - The remaining ice shelf is behaving as expected
- Remote sensing of the cryosphere
  - Change signals much bigger than the noise
  - Many more sources of data coming on line
  - The future of cryosphere remote sensing science is looking good
- Thanks to ESA for a great training course!

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Friday 6 January 2017 by Dan Sweryt

Iceberg insists it can thrive on its own after winning referendum to leave Antarctica

Thanks!

One of the ten biggest icebergs ever recorded is planning to leave Antarctica immediately after comprehensively winning a referendum on the matter.

After the vote, a rift in the Larsen C ice shelf grew suddenly, and there is now little hope of the iceberg retaining strong links to Antartica.

A number penguins have raised funds to appeal the case to the Southern Hemisphere