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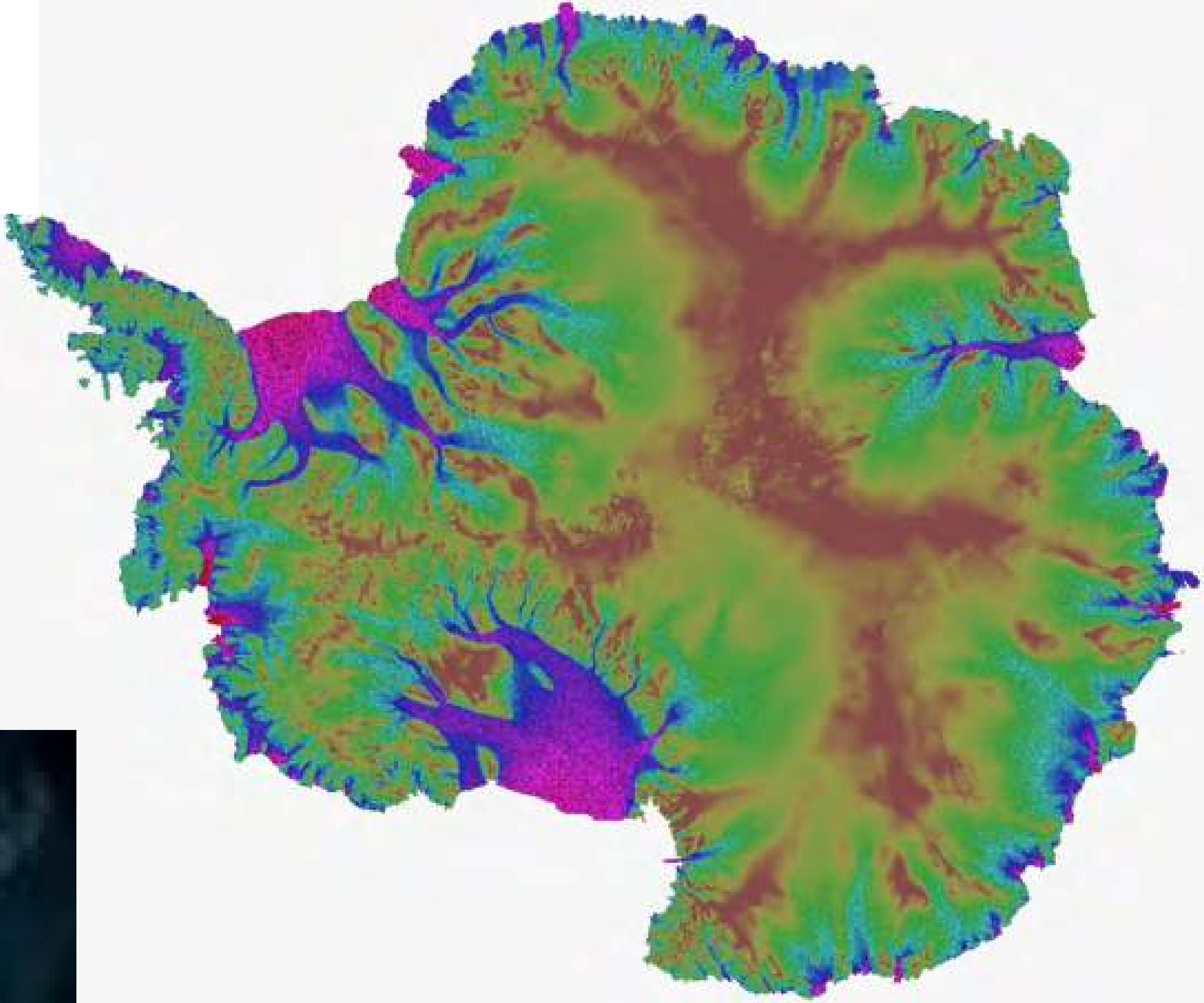
Future applications of SAR missions in Cryosphere Science

Eric Rignot

Earth System Science

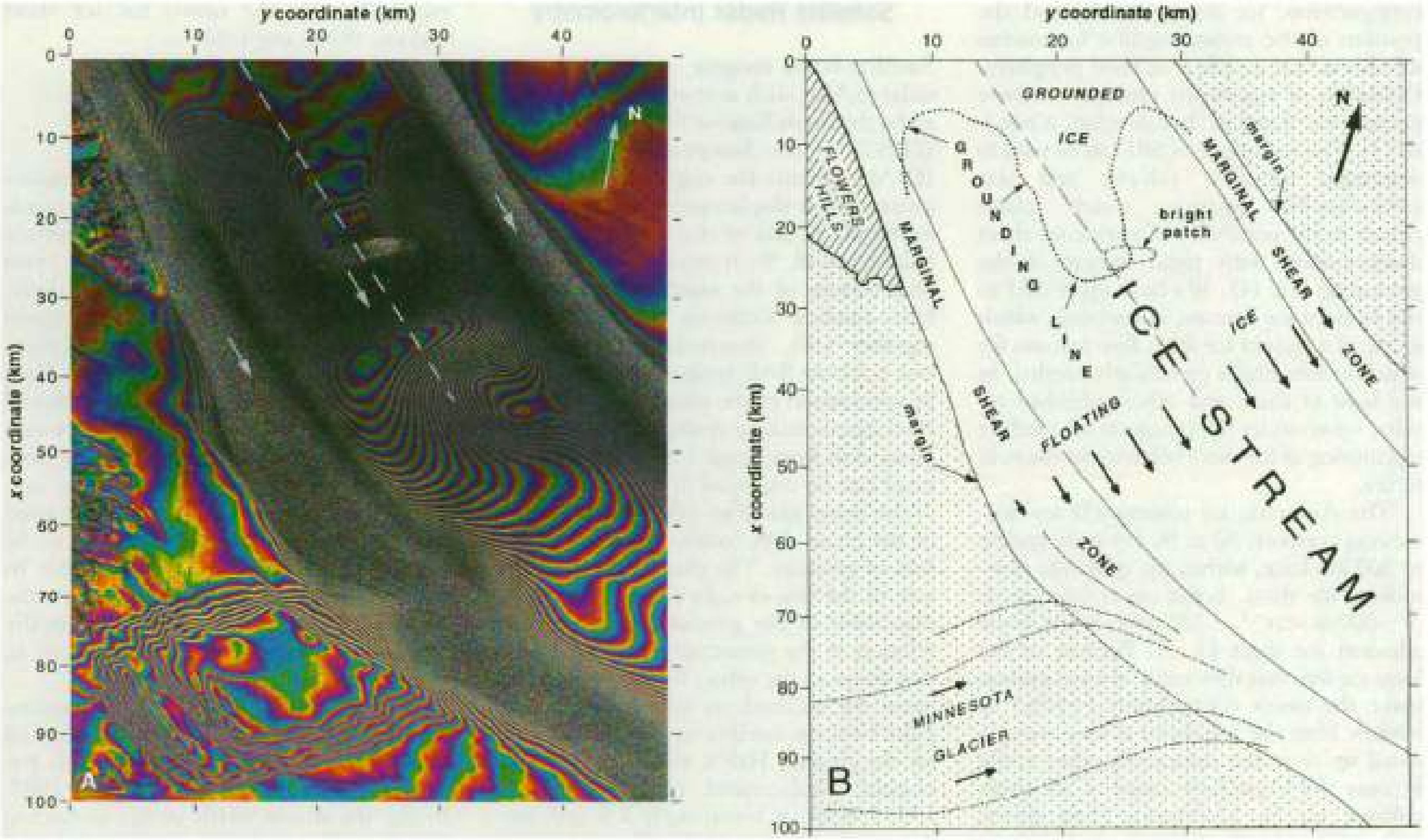


1993

Satellite Radar Interferometry for Monitoring Ice Sheet Motion: Application to an Antarctic Ice Stream

Richard M. Goldstein, Hermann Engelhardt, Barclay Kamb, Richard M. Frolich

When it all began ..



R. Goldstein, JPL

ERS-1, ESA

1993

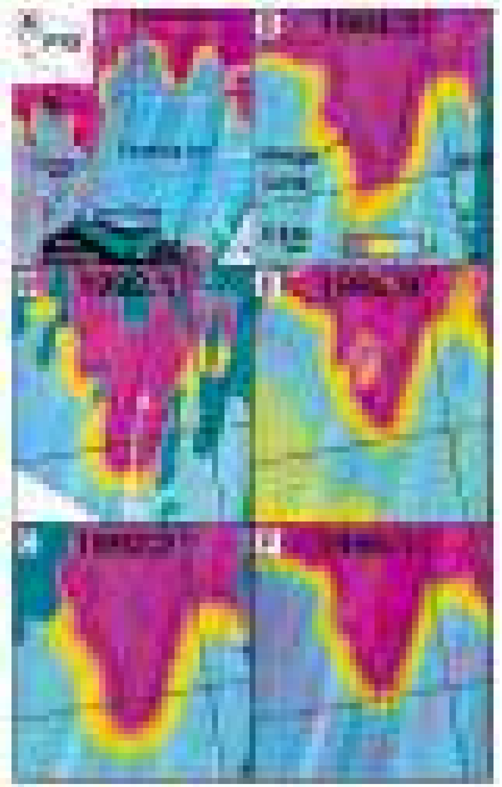
ERS-1/2 tandem mission

1998

ESA flies ERS-1/2 in tandem (1-day) for 9 months.

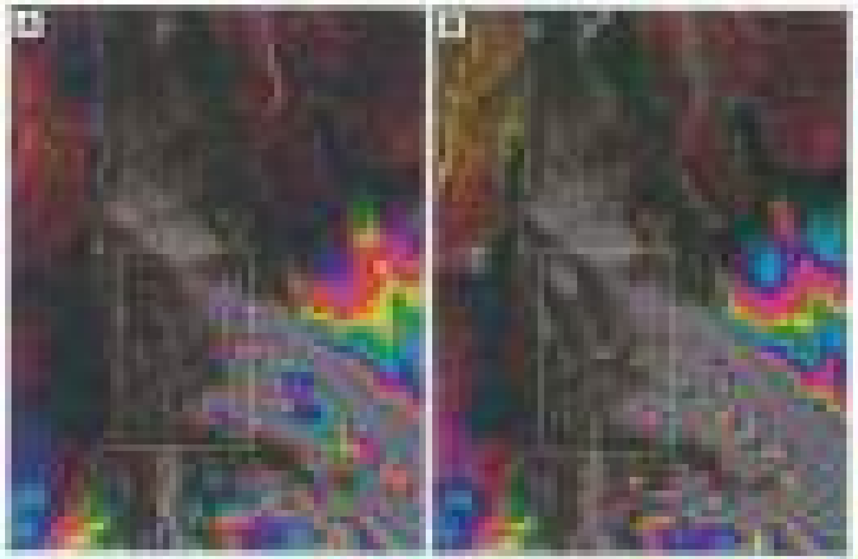
Fast Recession of a West Antarctic Glacier

E. J. Rignot



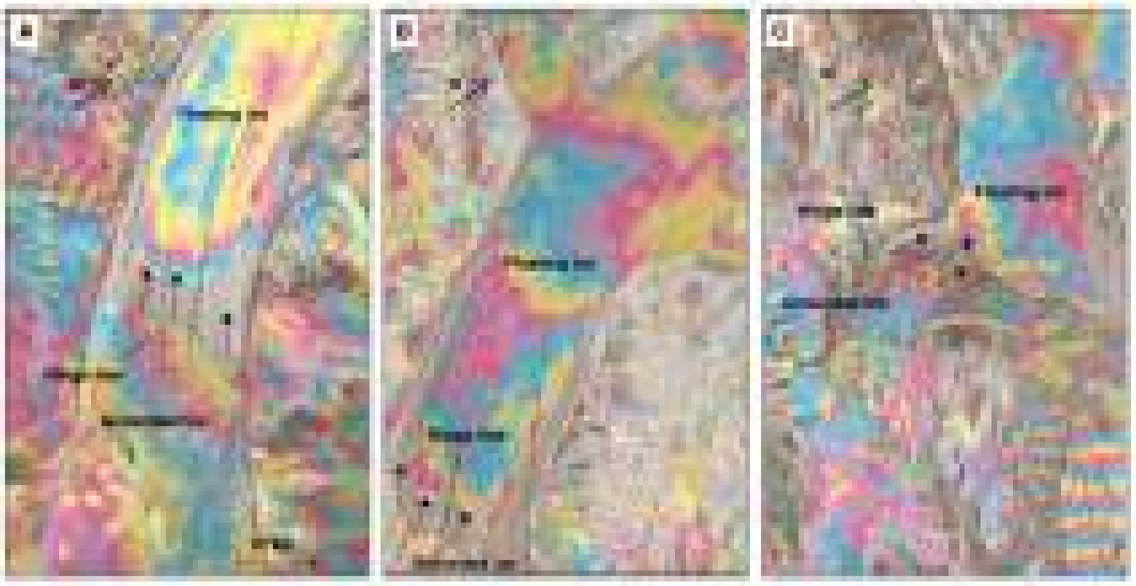
A Mini-Surge on the Ryder Glacier, Greenland, Observed by Satellite Radar Interferometry

Ian Joughin, Slawek Tulaczyk, Mark Fahnestock, Ron Kwok



North and Northeast Greenland Ice Discharge from Satellite Radar Interferometry

E. J. Rignot,* S. P. Gogineni, W. B. Krabill, S. Ekholm



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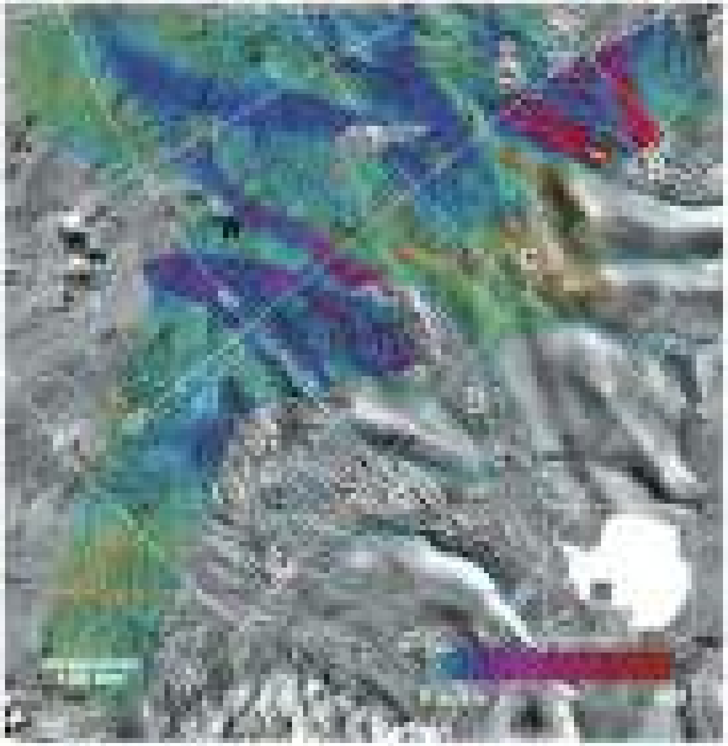
2006

RADARSAT-1 AMM-1, 2 (1997, 2000)

CSA flies the Antarctic Mapping Mission(s).

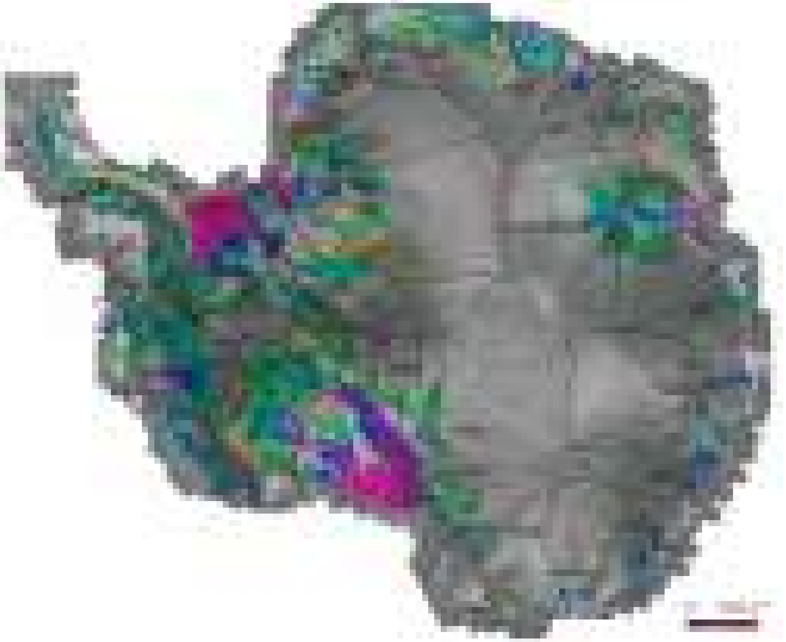
Tributaries of West Antarctic Ice Streams Revealed by RADARSAT Interferometry



Changes in the Velocity Structure of the Greenland Ice Sheet

Changes in ice dynamics and mass balance of the Antarctic ice sheet

By Eric Rignot*



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Ice Flow of the Antarctic Ice Sheet

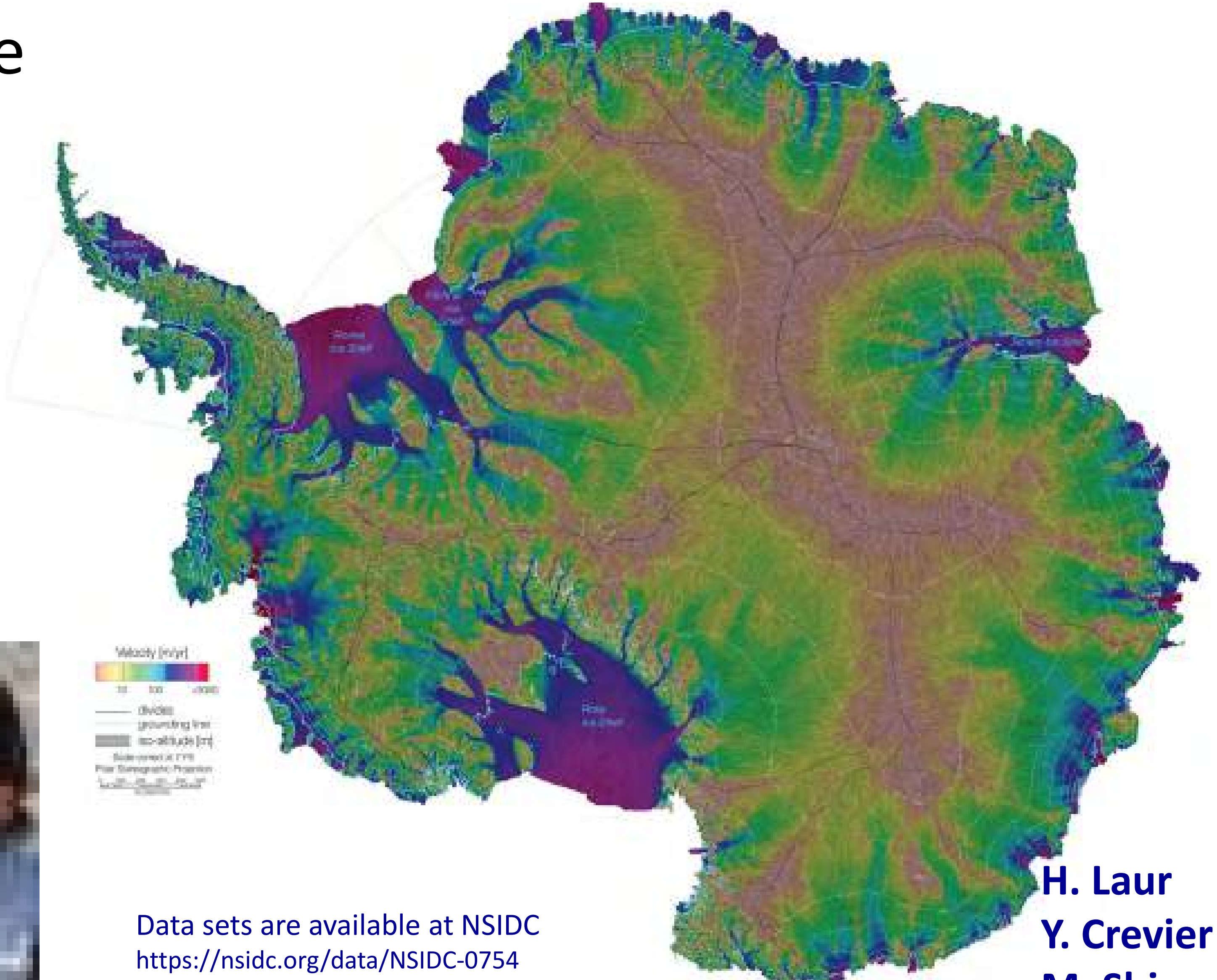
E. Rignot,[1,2]* J. Mouginot,[1] B. Scheuchl[1]

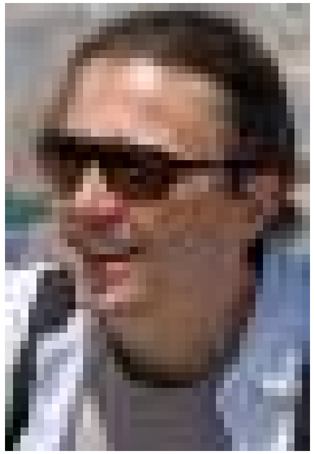
2011

Continental scale

Data Sources:

Copernicus Sentinel-1,
ERS-1 & ERS-2,
ENVISAT-ASAR,
RADARSAT-1 & -2,
COSMO SkyMED,
ALOS PALSAR
ALOS-2 PALSAR-2,
TerraSAR-X & TanDEM-X,
Landsat-8





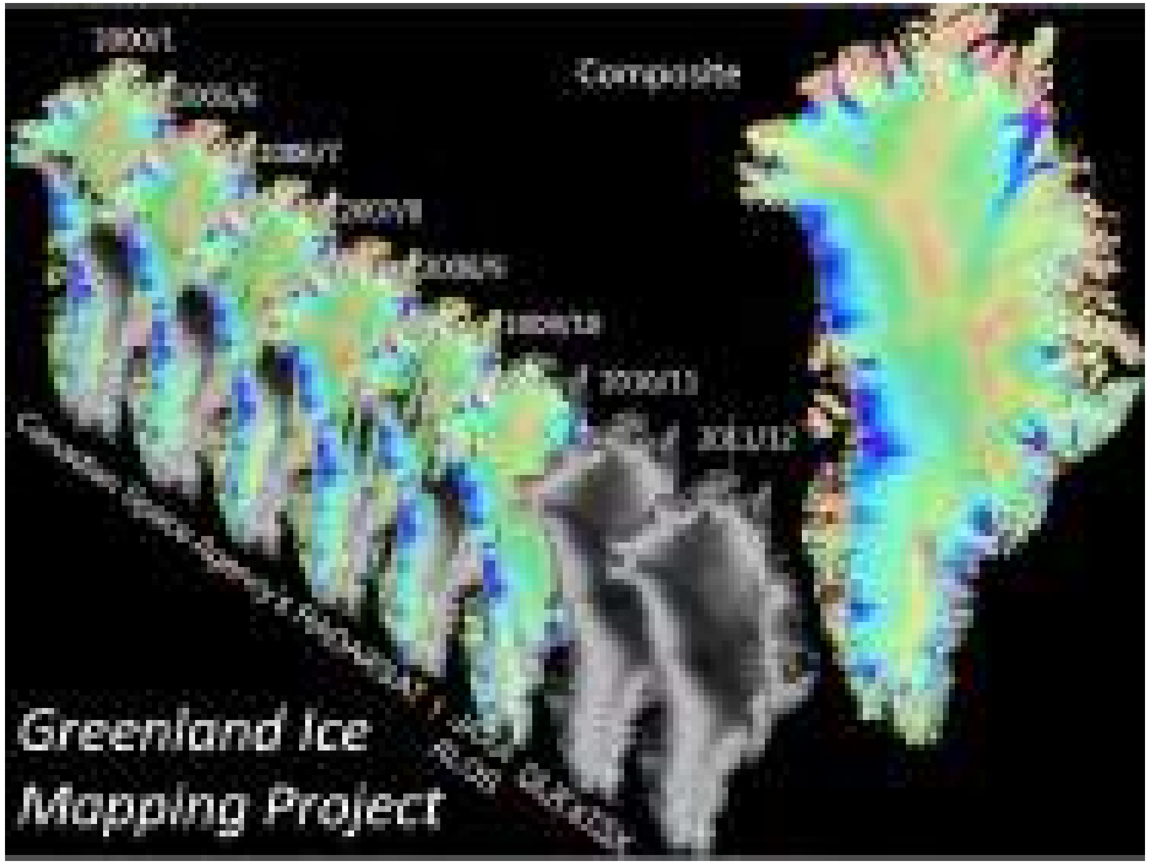
Data sets are available at NSIDC
https://nsidc.org/data/NSIDC-0754
https://nsidc.org/data/NSIDC-0498

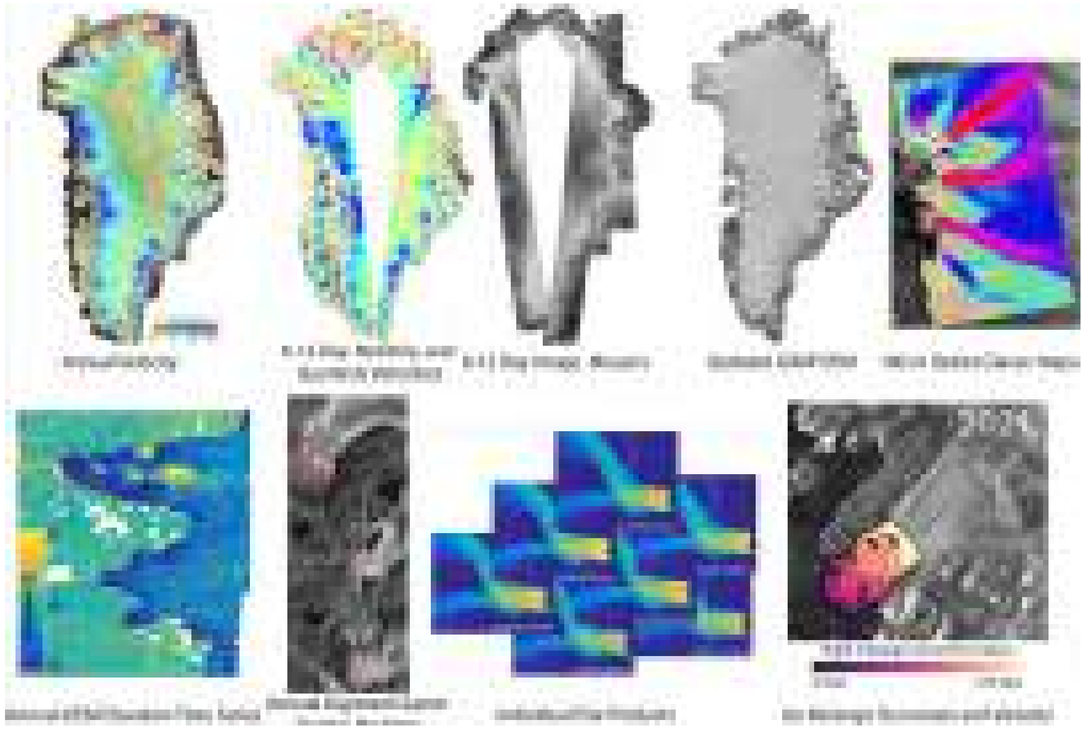
H. Laur
Y. Crevier
M. Shimada

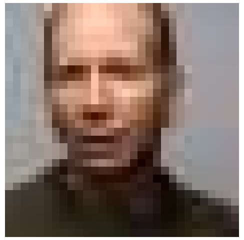
2015

WMO’s Polar Space Task Group

Shifted from campaign style to continuous mapping at the continental scale

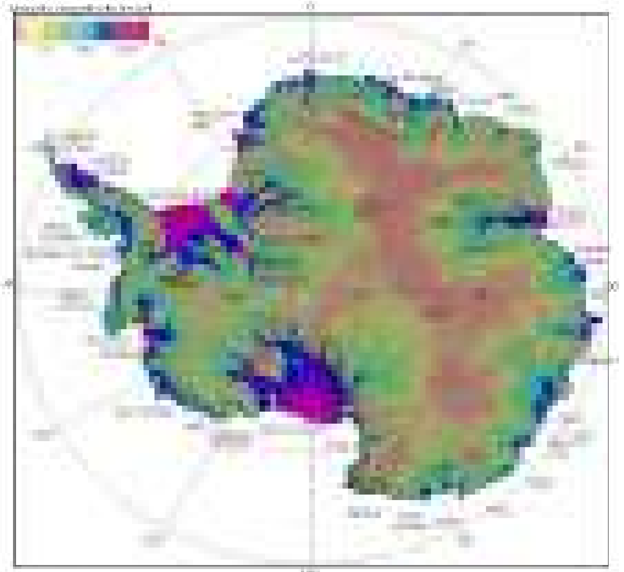


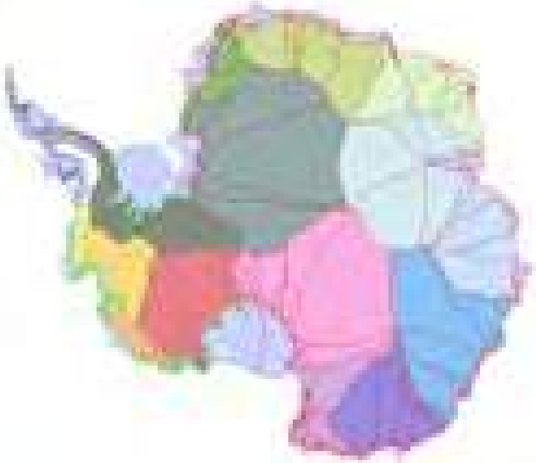


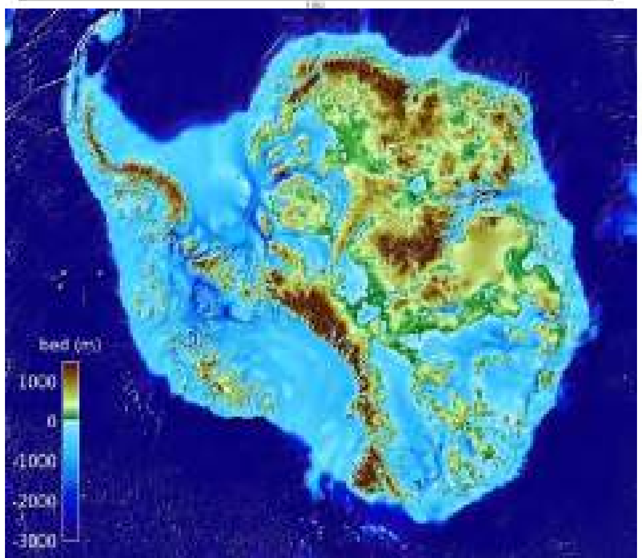


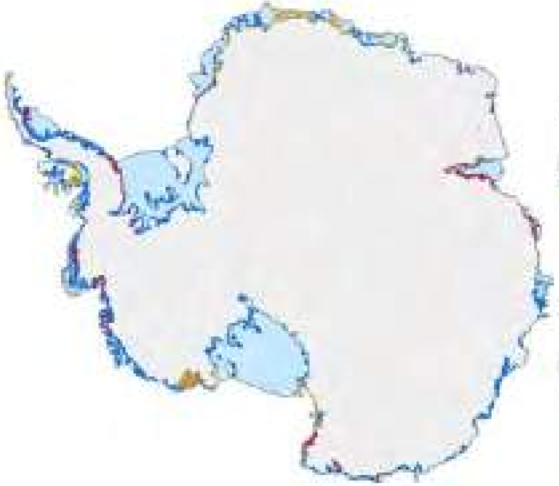
2017

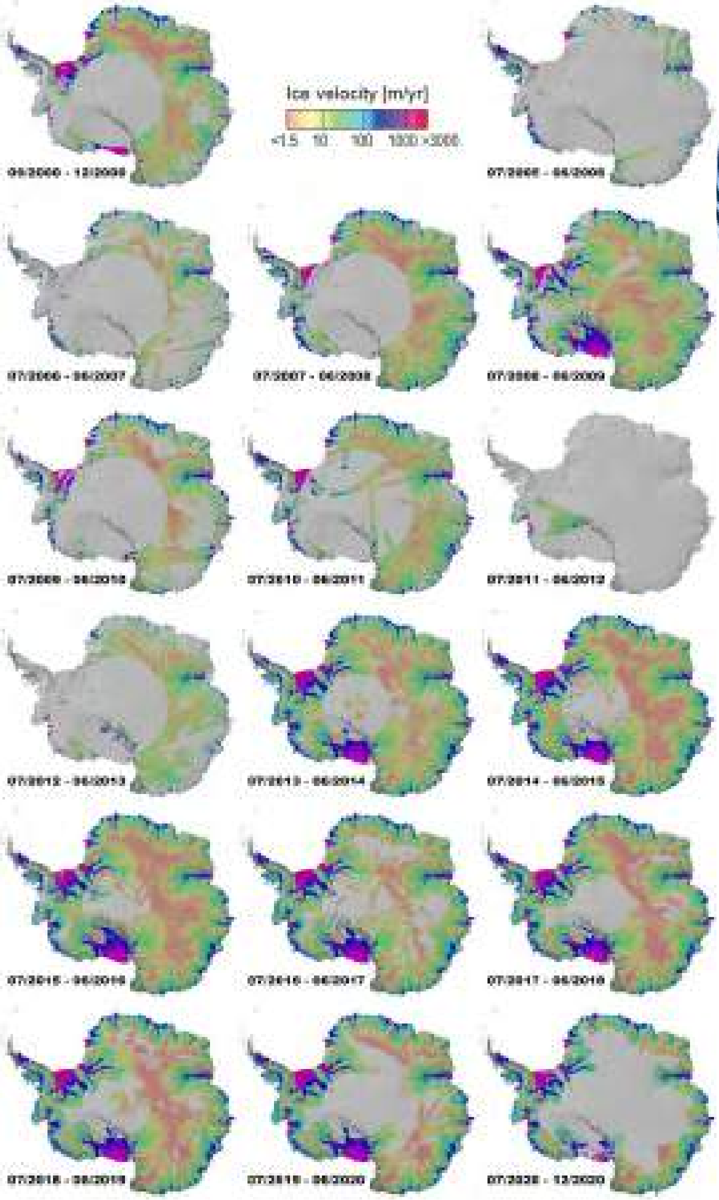
WMO’s Polar Space Task Group











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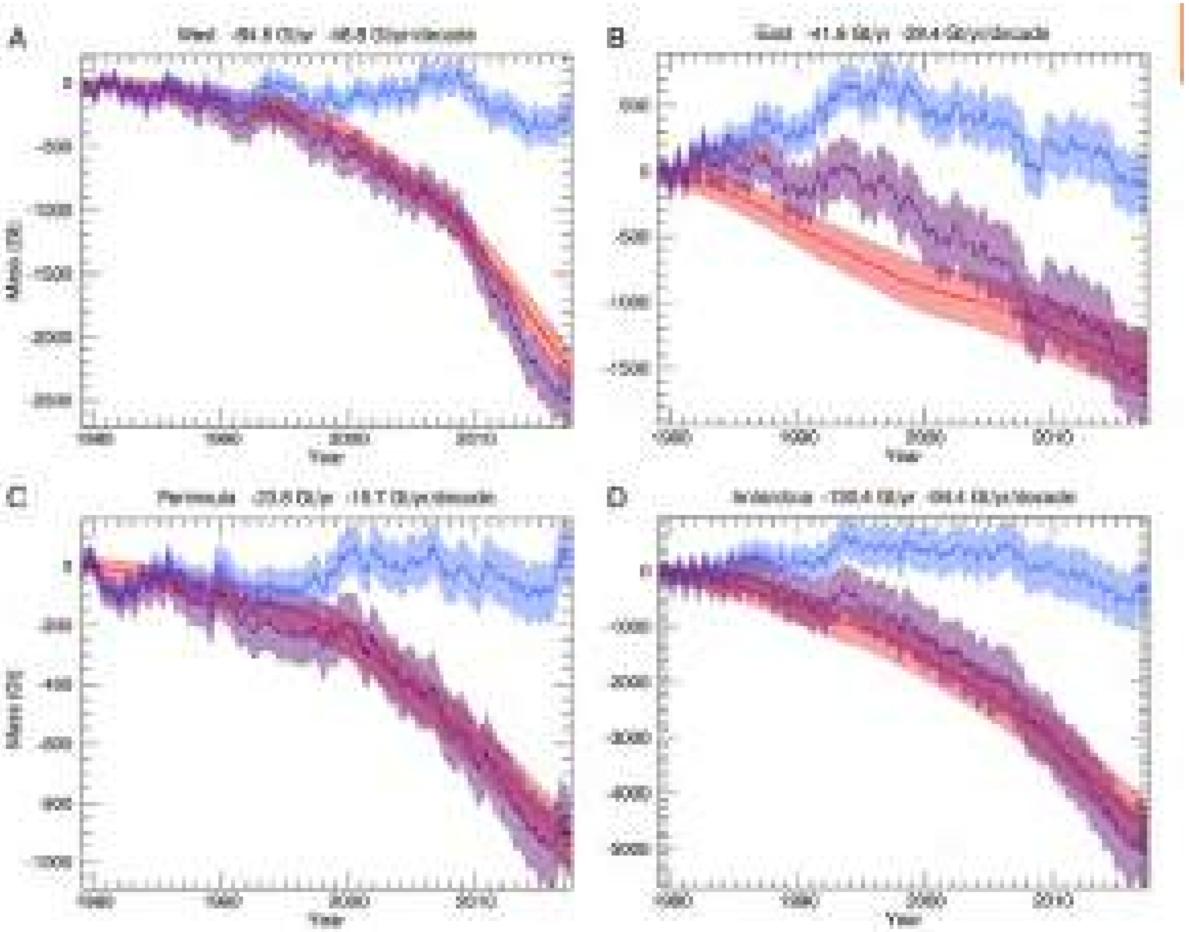
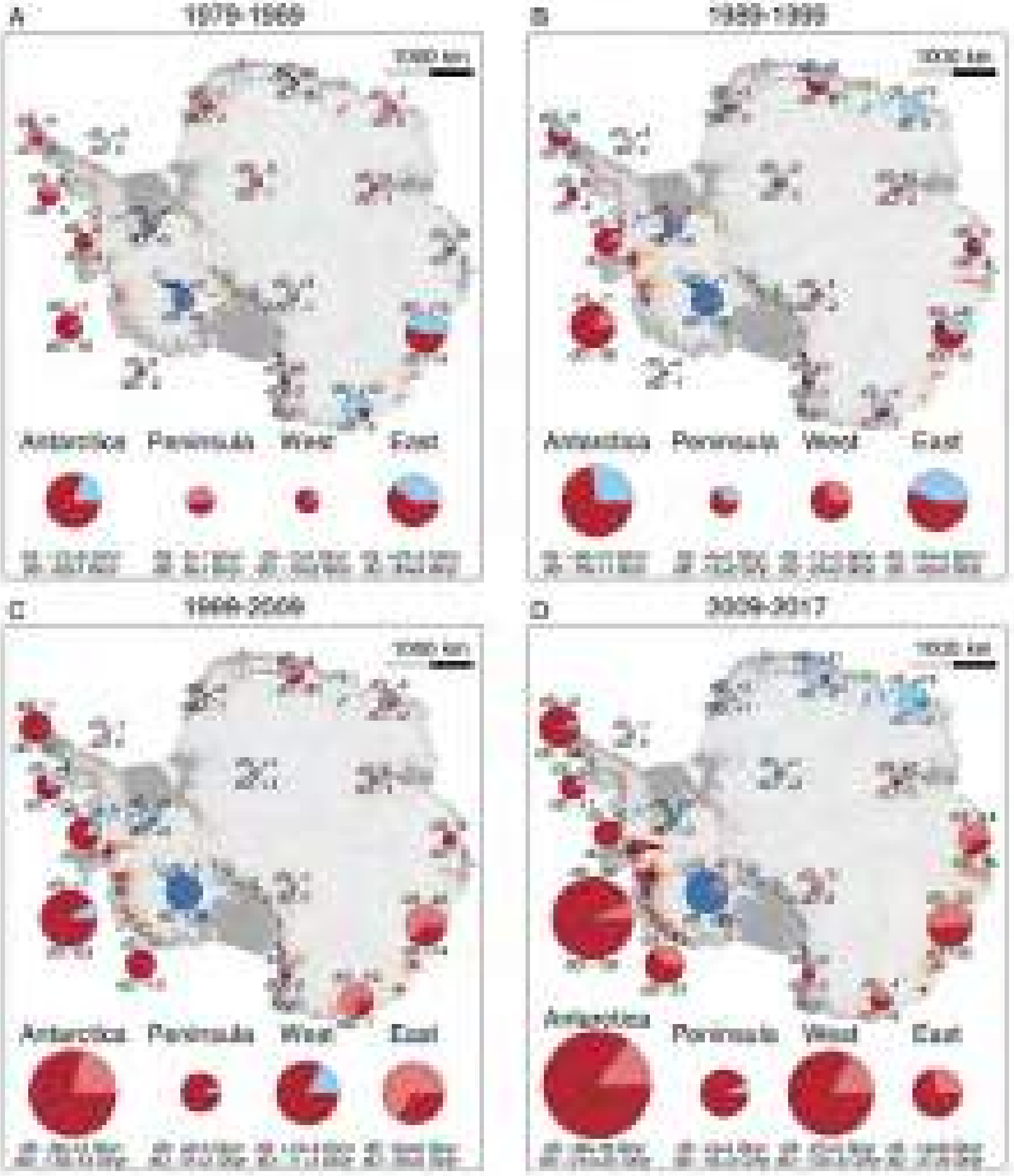
Four decades of Antarctic Ice Sheet mass balance from 1979–2017

Eric Rignot, Jérémie Mouginot, Bernd Scheuchl, Michiel van den Broeke, Melchior J. van Wessem, and Mathieu Morlighem

2019

NASA JPL





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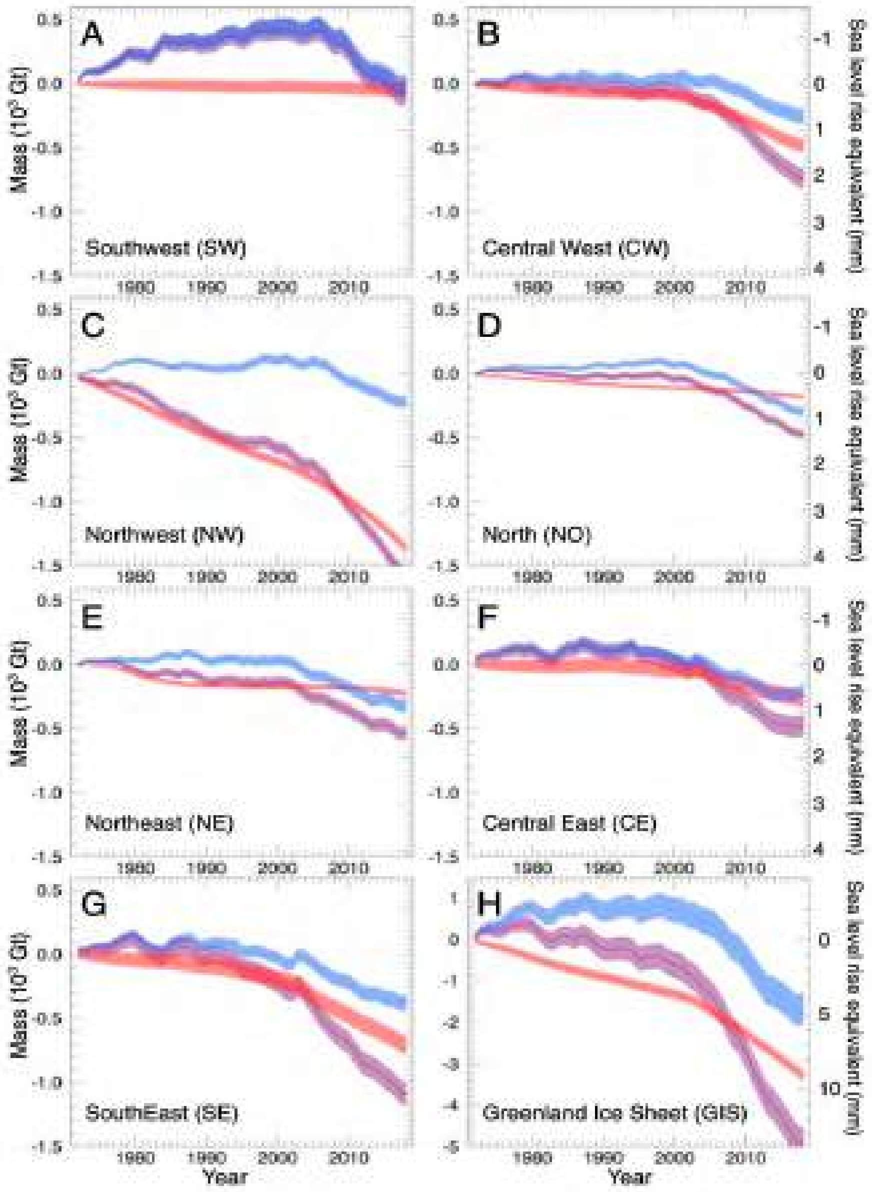
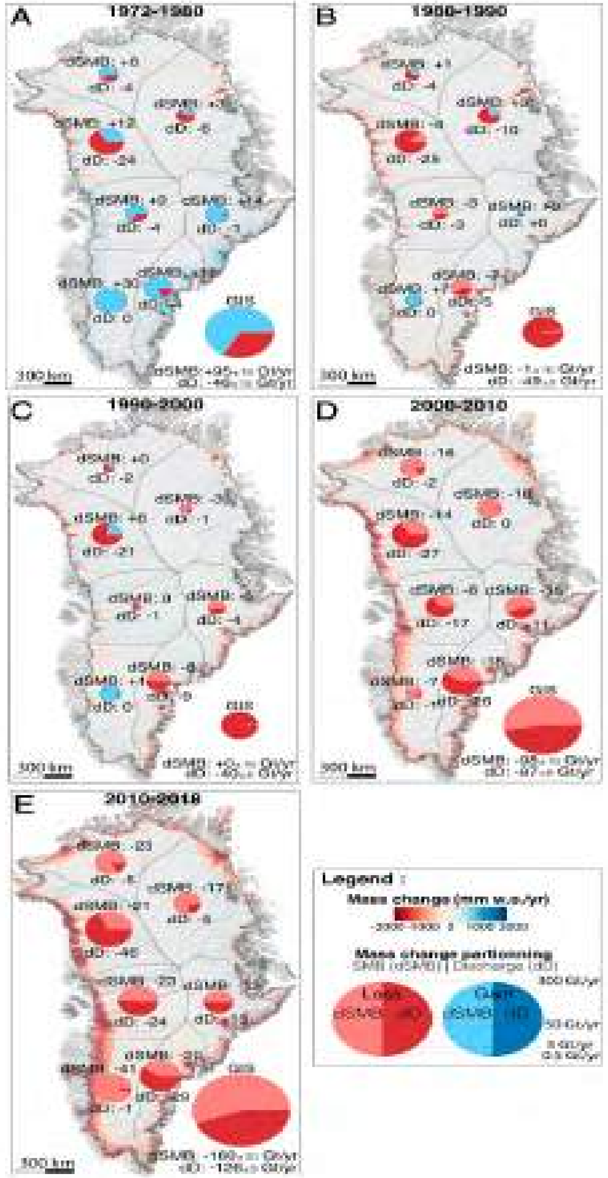
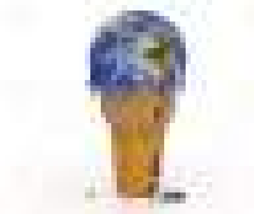
Forty-six years of Greenland Ice Sheet mass balance from 1972 to 2018

Jérémie Mouginot[a,b,1,2], Eric Rignot[a,c,1,2], Anders A. Bjørk[a,d], Michiel van den Broeke[e], Romain Millan[a], Mathieu Morlighem[a], Brice Noël[e], Bernd Scheuchl[a], and Michael Wood[a]

2019







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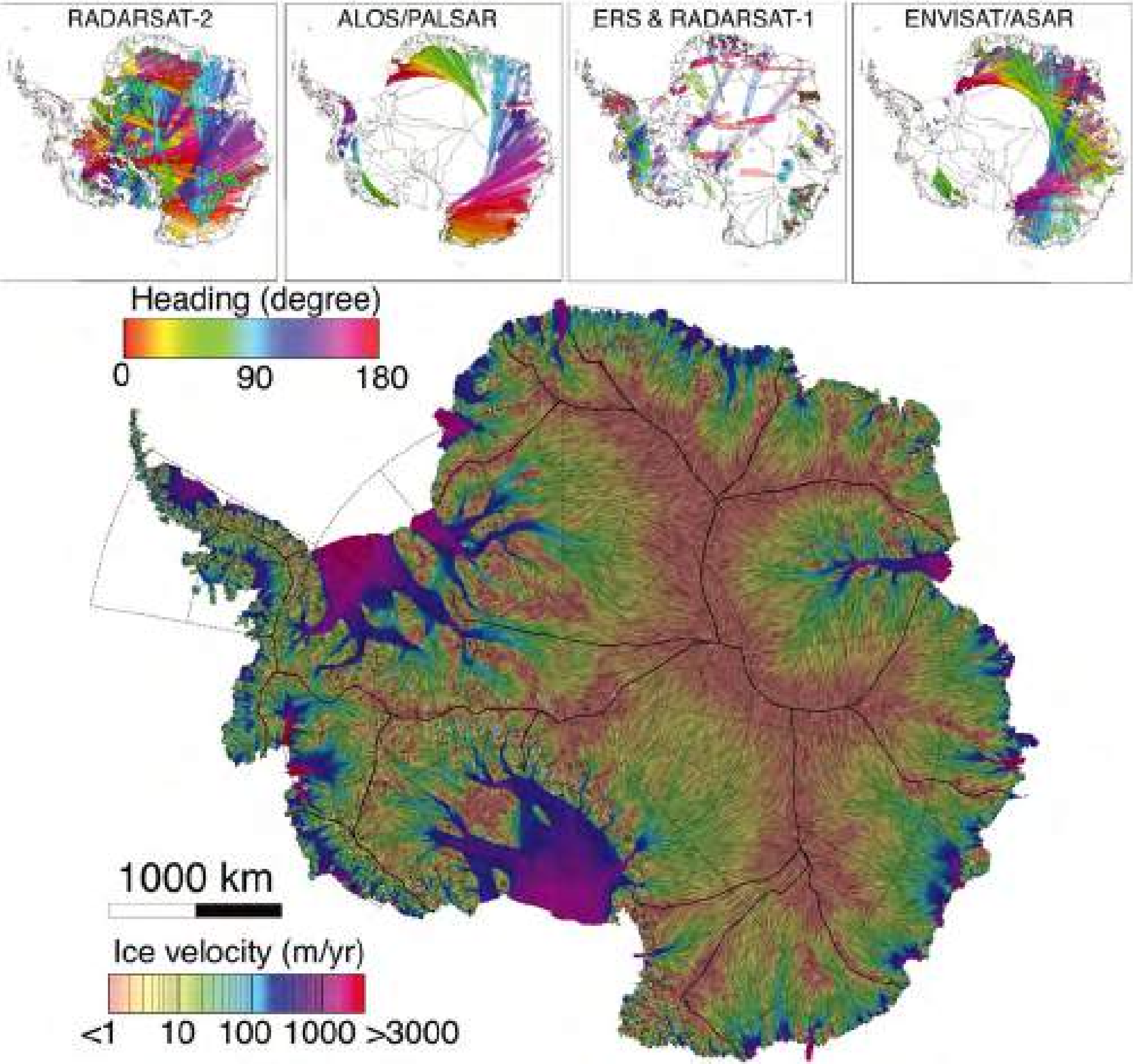
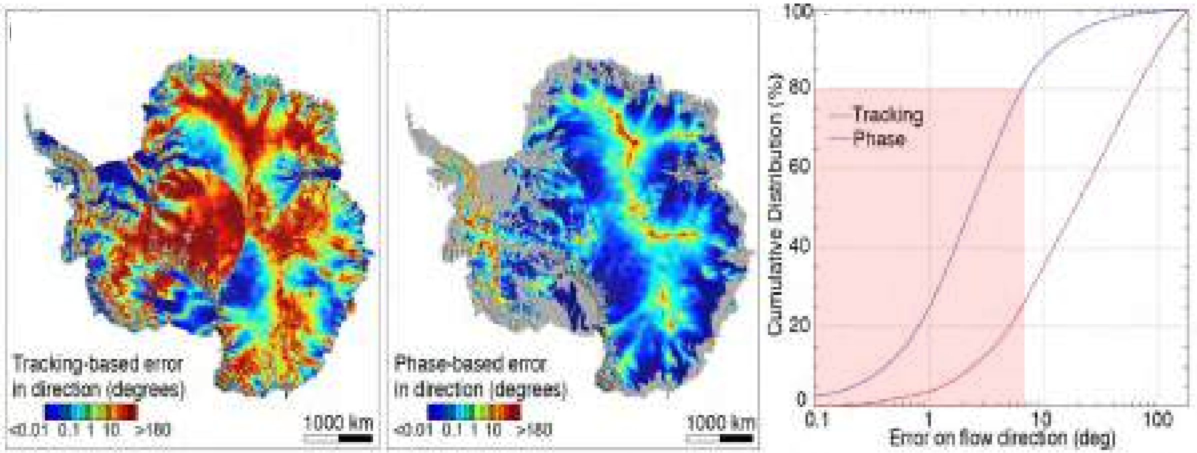
Continent-Wide, Interferometric SAR Phase, Mapping of Antarctic Ice Velocity

J. Mouginot, E. Rignot, and B. Scheuchl

2019





Speckle tracking ~ 2 m/yr

SAR phase ~ 20 cm/yr, 5°

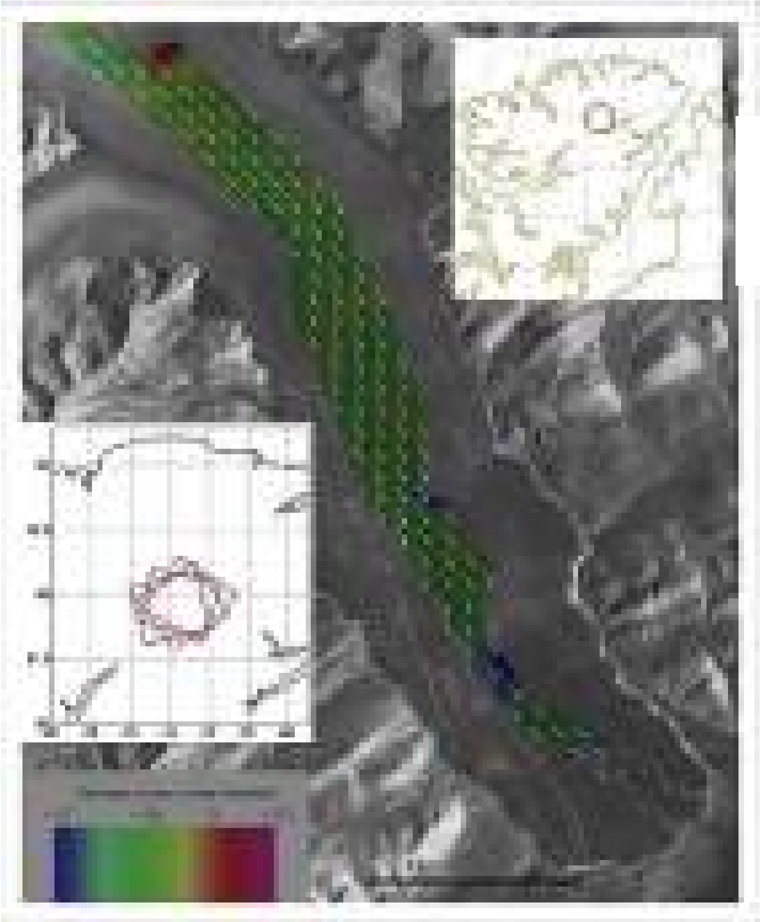
Still in "surface parallel flow"

3D to 4D radar interferometry

Using multiple RADARSAT InSAR pairs to estimate a full three-dimensional solution for glacial ice movement

Laurence Gray[1,2]

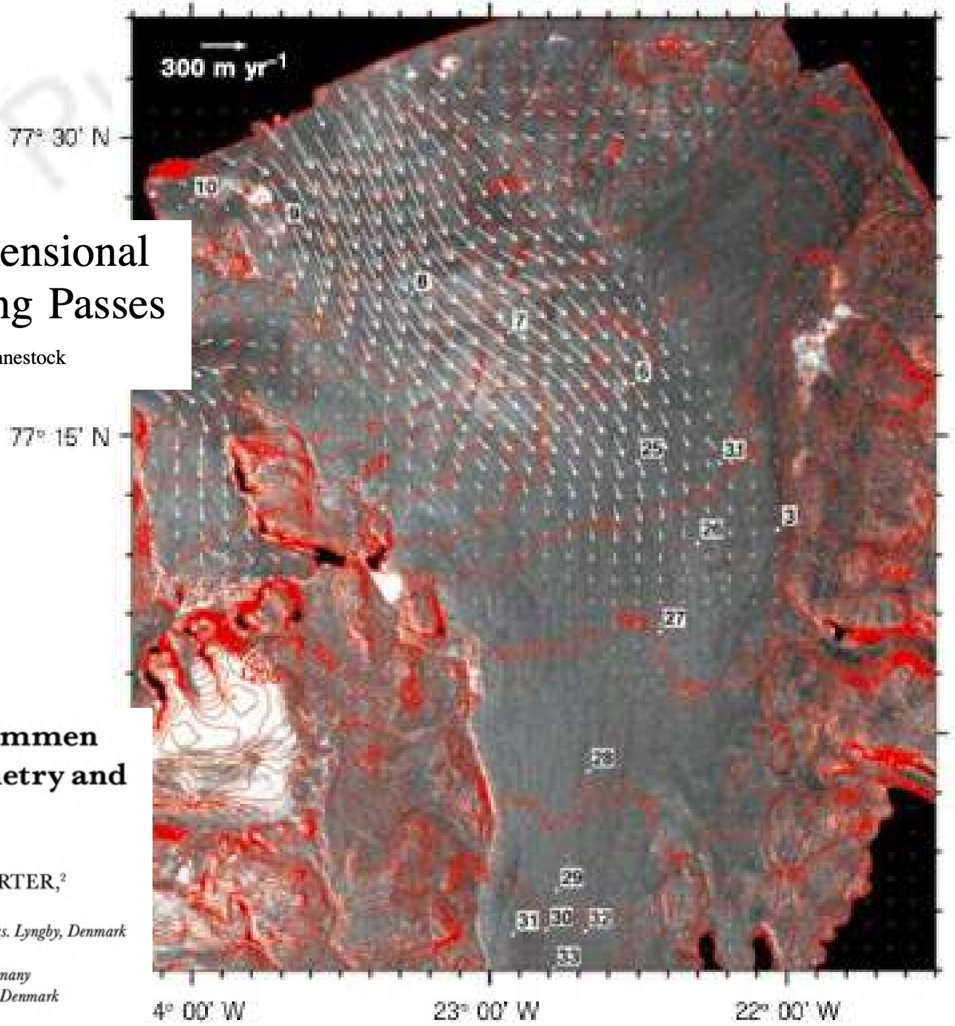
Received 12 December 2010; revised 18 January 2011; accepted 28 January 2011; published 4 March 2011.



Three-dimensional glacial flow and surface elevation measured with radar interferometry

Johan J. Mohr, Niels Reeh & Søren N. Madsen

Danish Center for Remote Sensing, Department of Electromagnetic Systems, Technical University of Denmark, DK-2800 Lyngby, Denmark



Interferometric Estimation of Three-Dimensional Ice-Flow Using Ascending and Descending Passes

Ian R. Joughin, *Member, IEEE,* Ronald Kwok, *Member, IEEE,* and Mark A. Fahnestock

$$\frac{\partial S}{\partial t} - b_S(t) = \vec{n}_s \cdot \vec{v} \,,$$

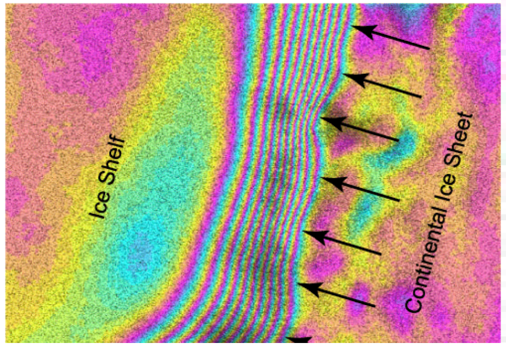
Three-dimensional surface velocities of Storstrømmen glacier, Greenland, derived from radar interferometry and ice-sounding radar measurements

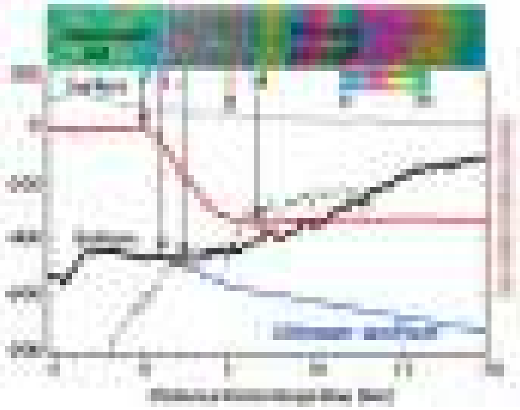
Niels Reeh,[1*] Johan Jacob Mohr,[1] Søren Nørvang Madsen,[1] Hans Oerter,[2] Niels S. Gundestrup[3†]

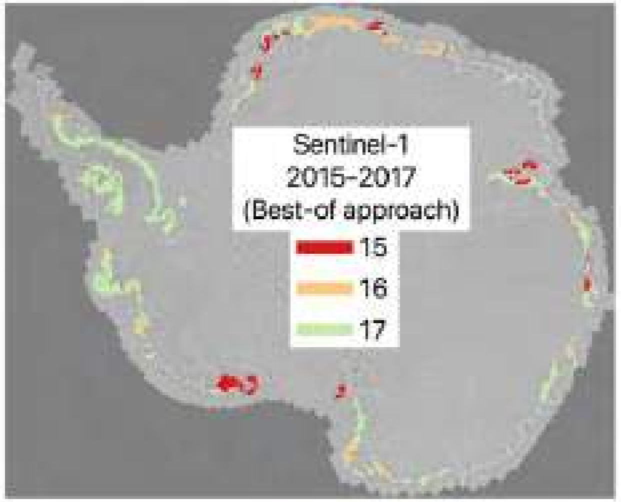
[1] *Ørsted•DTU, Electromagnetic Systems, Technical University of Denmark, Building 348, Ørsteds plads, DK-2800 Kgs. Lyngby, Denmark*
E-mail: nr@oersted.dtu.dk
[2] *Alfred-Wegener-Institut für Polar und Meeresforschung, Columbusstrasse, D-27568 Bremerhaven, Germany*
[3] *Niels Bohr Institute for Astronomy, Physics and Geophysics, Juliane Maries Vej 30, DK-2100 Copenhagen, Denmark*

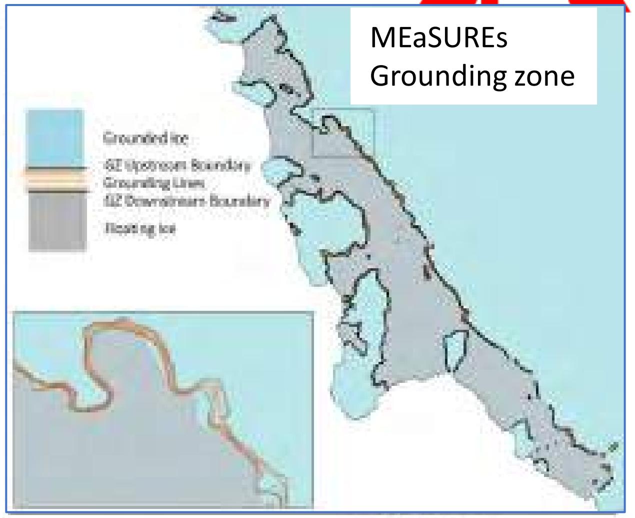
Antarctic Grounding Zone

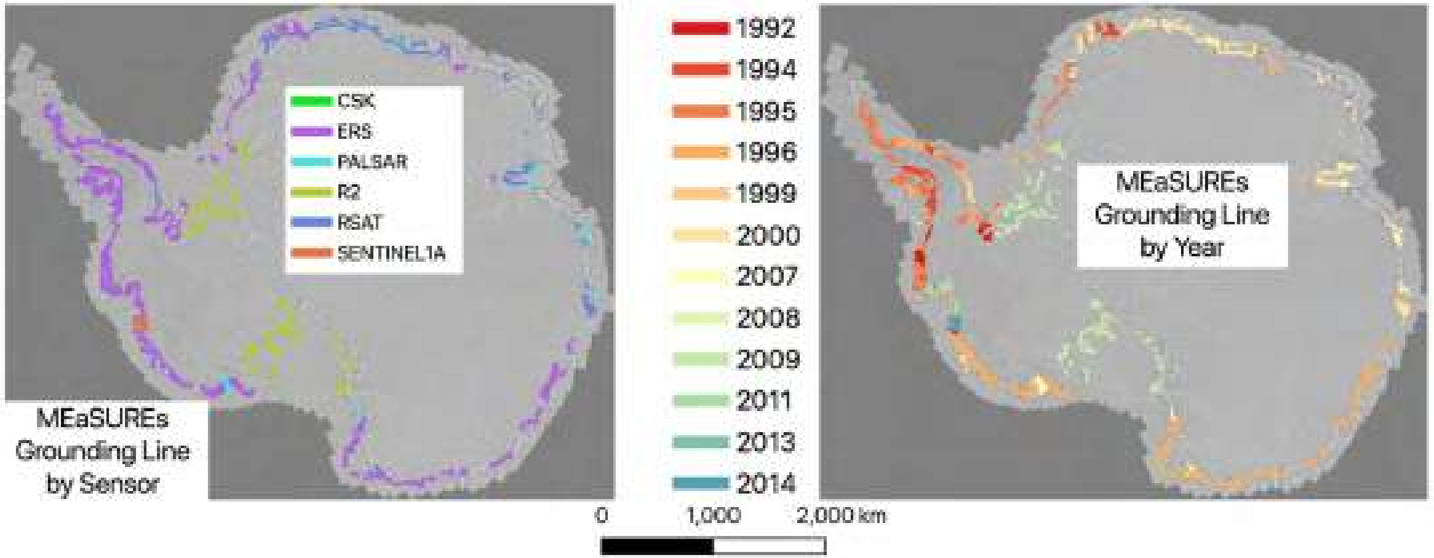
DInSAR reveals *grounding lines*.
Tidal migration reveals *grounding zones*.
Data sources: S1, RADARSAT-2, CSK-2G











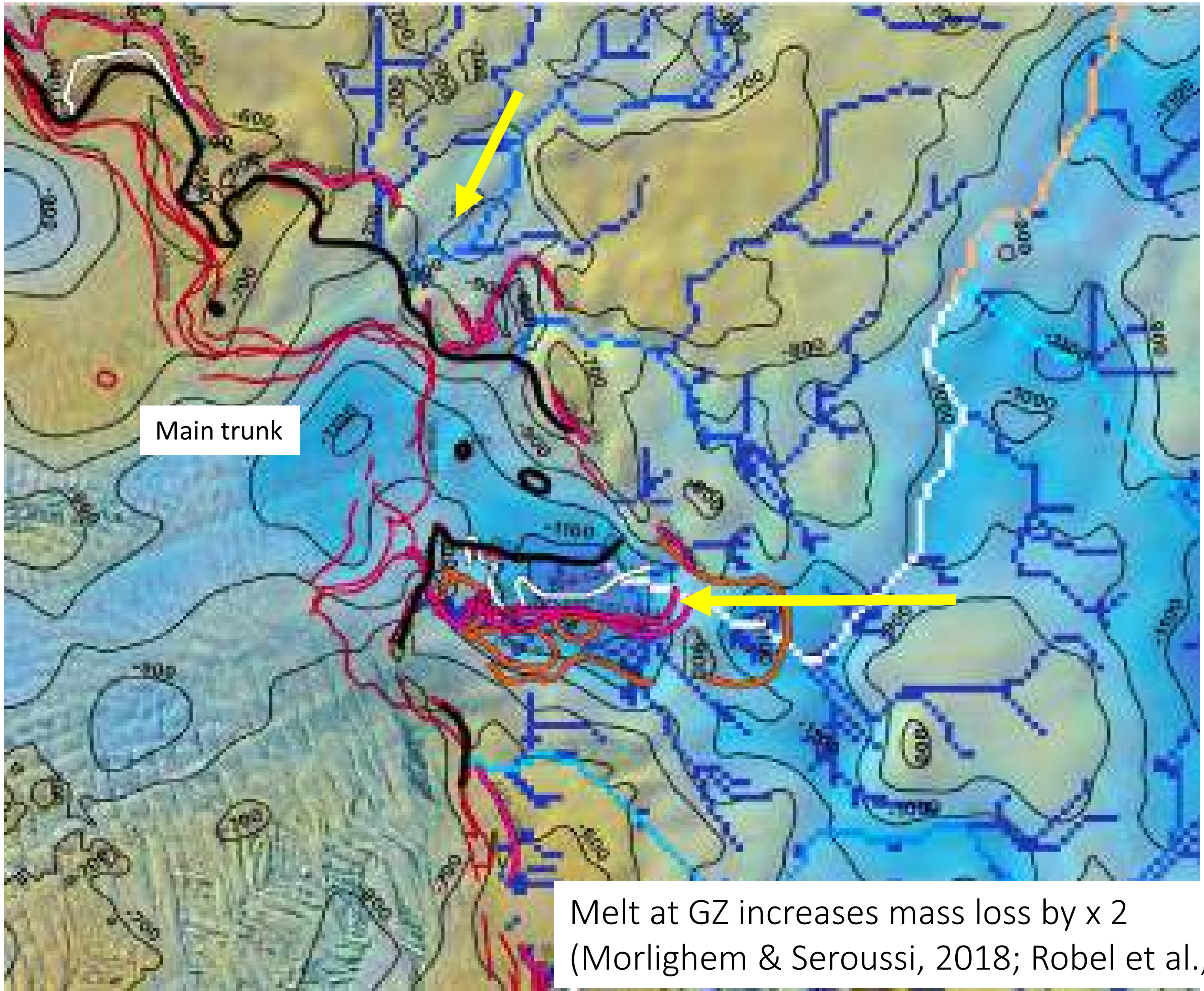
Automatic delineation of glacier grounding lines in differential interferometric synthetic-aperture radar data using deep learning

Yara Mohajerani[1,2✉], Seongsu Jeong[1], Bernd Scheuchl[1], Isabella Velicogna[1,3], Eric Rignot[1,3] & Pietro Milillo[1]

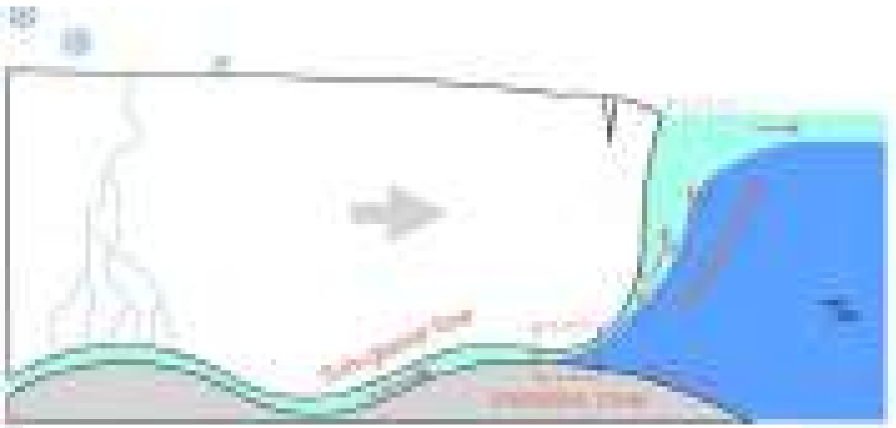
https://nsidc.org/data/NSIDC-0498/
https://nsidc.org/data/NSIDC-0778/

Thwaites Glacier: the factor x 2

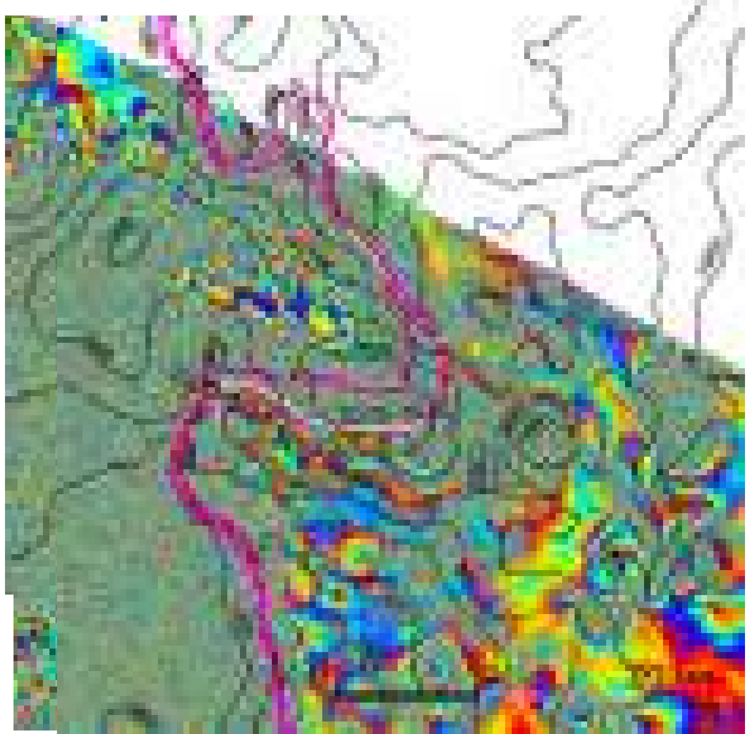
10-km seawater intrusions



Melt at GZ increases mass loss by x 2
(Morlighem & Seroussi, 2018; Robel et al., 2022



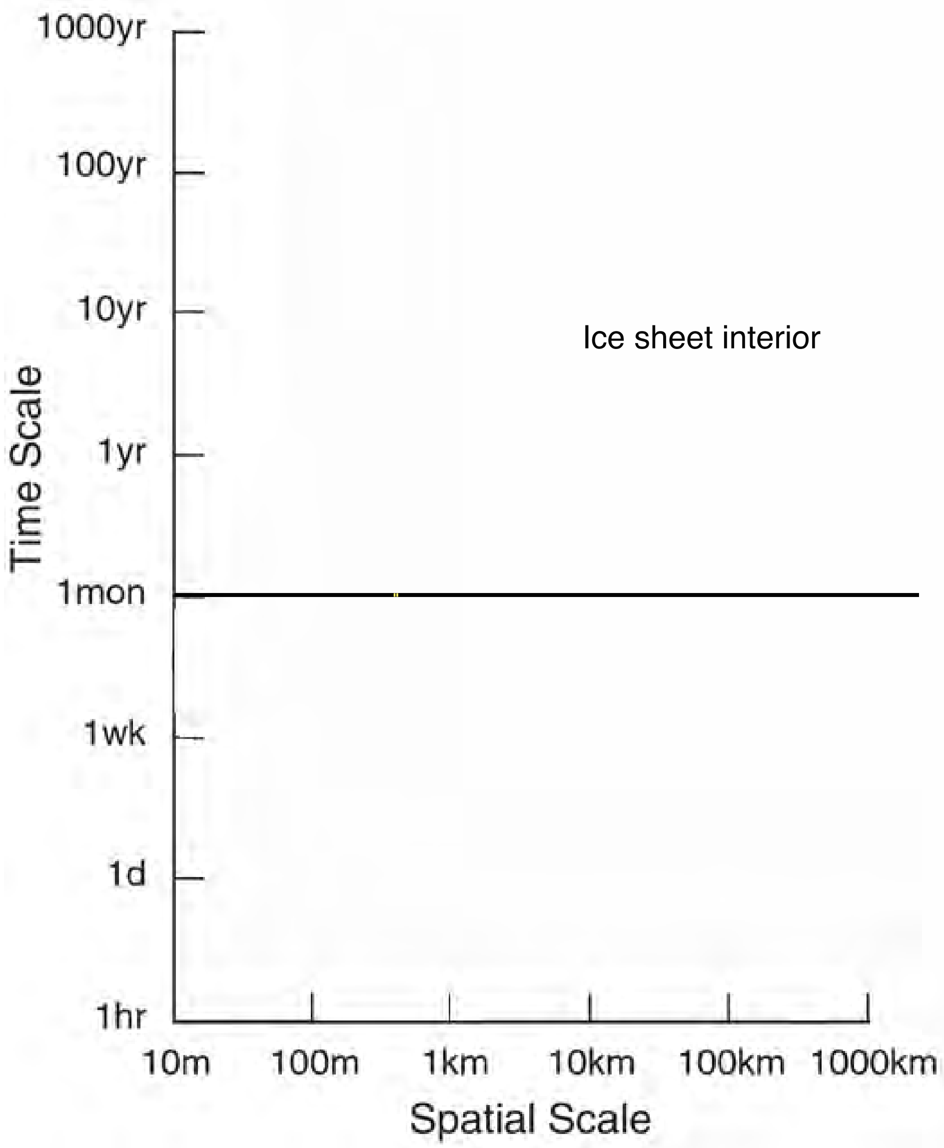
Robel et al., 2022; Wilson et al., 2022



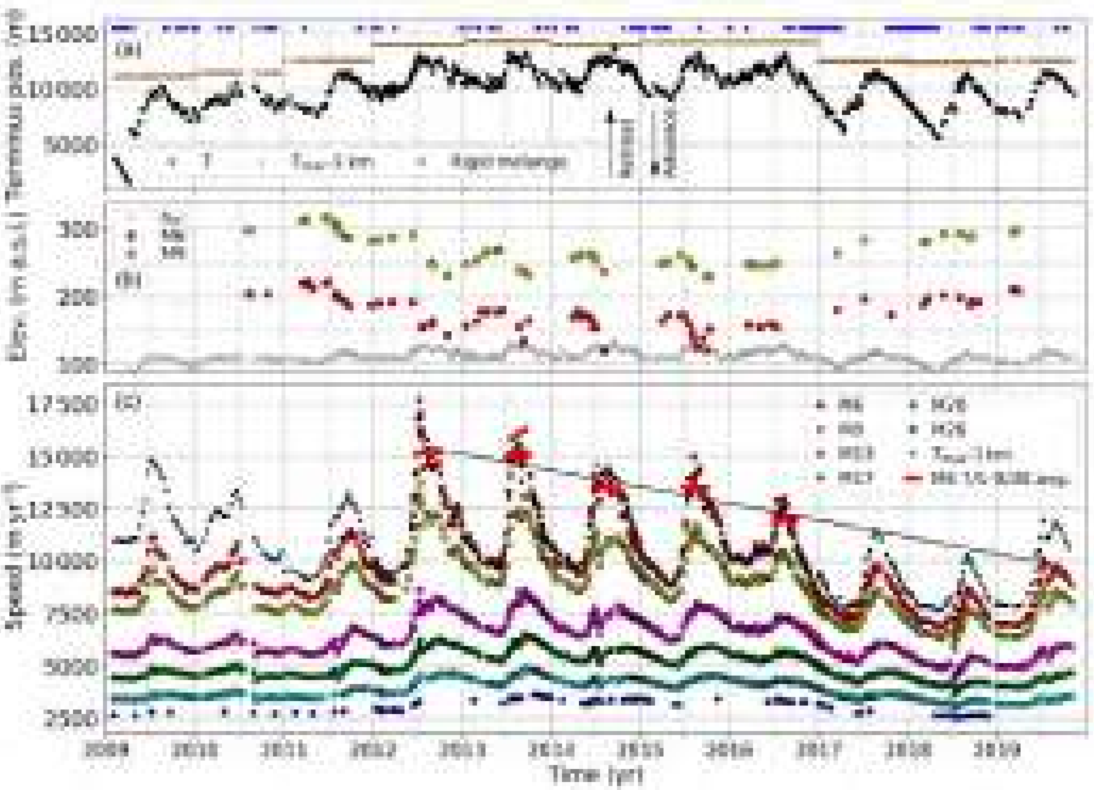
Enabling new science

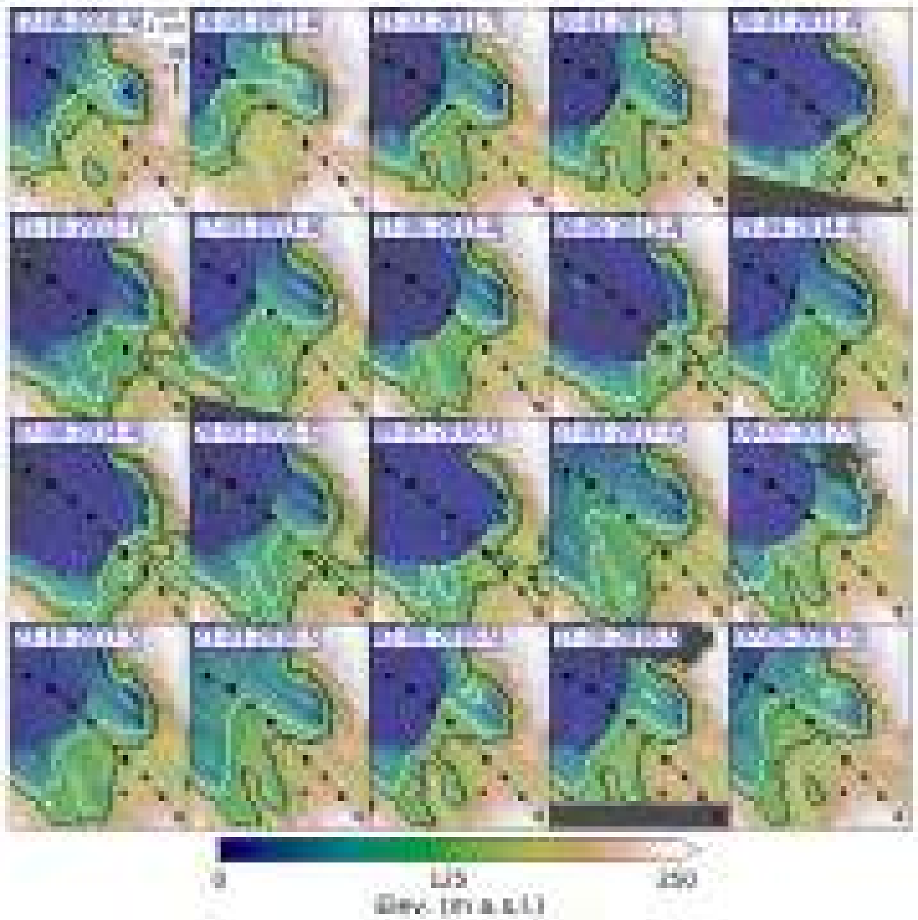
Temporal and spatial scales of physical processes driving ice sheet mass balance and sea level rise (Stommel diagram)

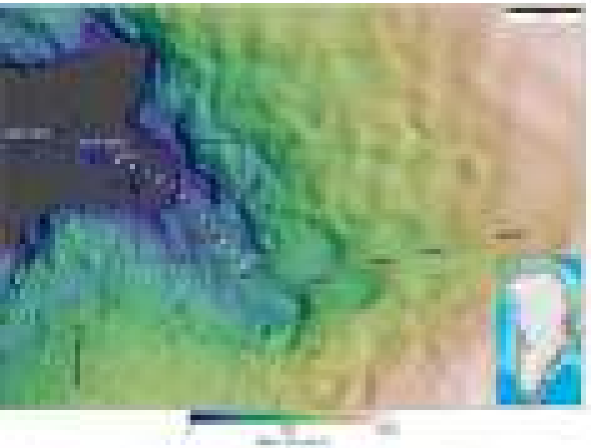
- Early missions: annual/1 km.
- NISAR/S1: weekly/30 m.
- Future: **sub-daily/higher res** (5 m) for fast processes: calving, rifting, fracturing, tidal dynamics, which are **vectors of rapid change**.



3D velocity and time-tagged DEMs







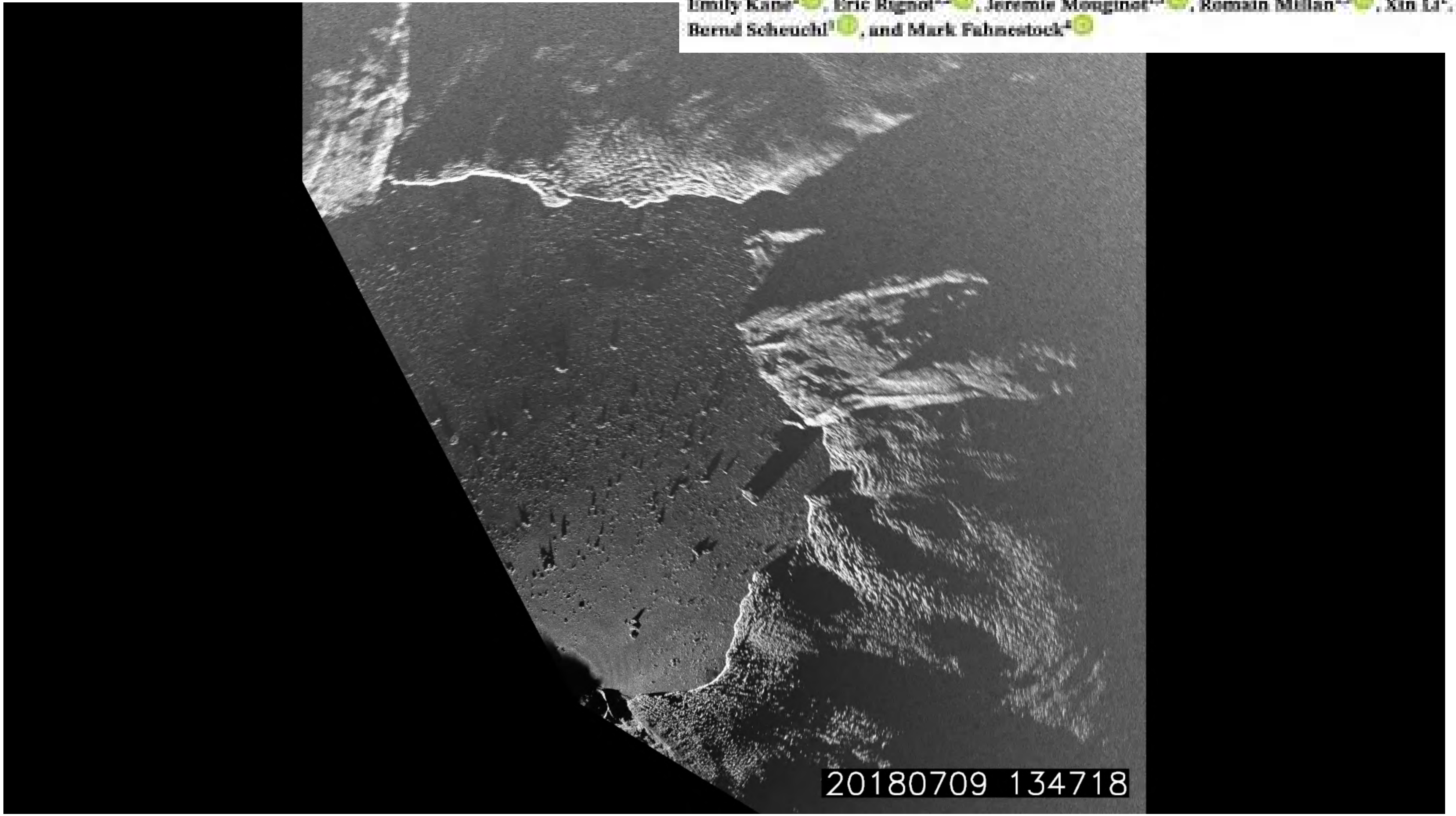
A decade of variability on Jakobshavn Isbræ: ocean temperatures pace speed through influence on mélange rigidity

Ian Joughin[1], David E. Shean[2], Benjamin E. Smith[1], and Dana Floricioiu[3]

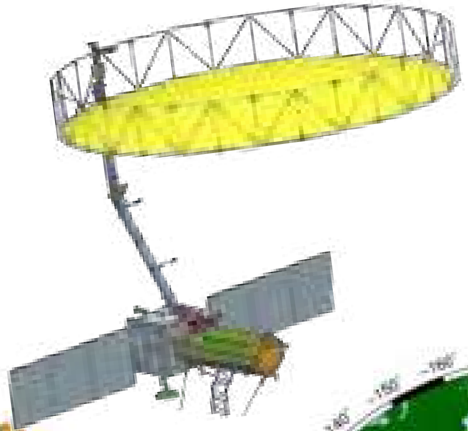
The future ..

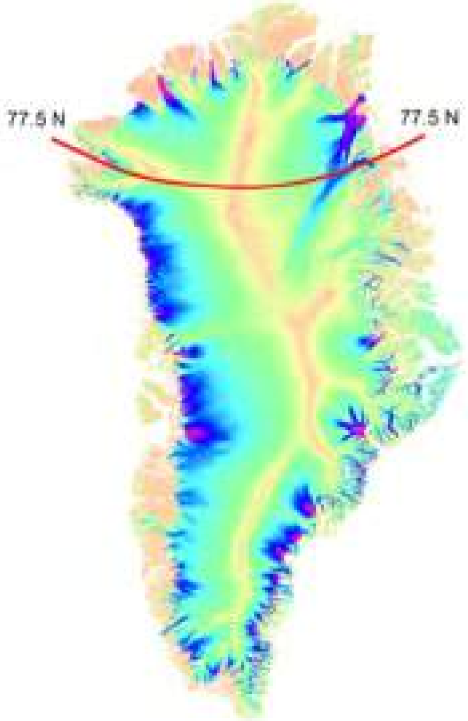
Impact of Calving Dynamics on Kangilernata Sermia, Greenland

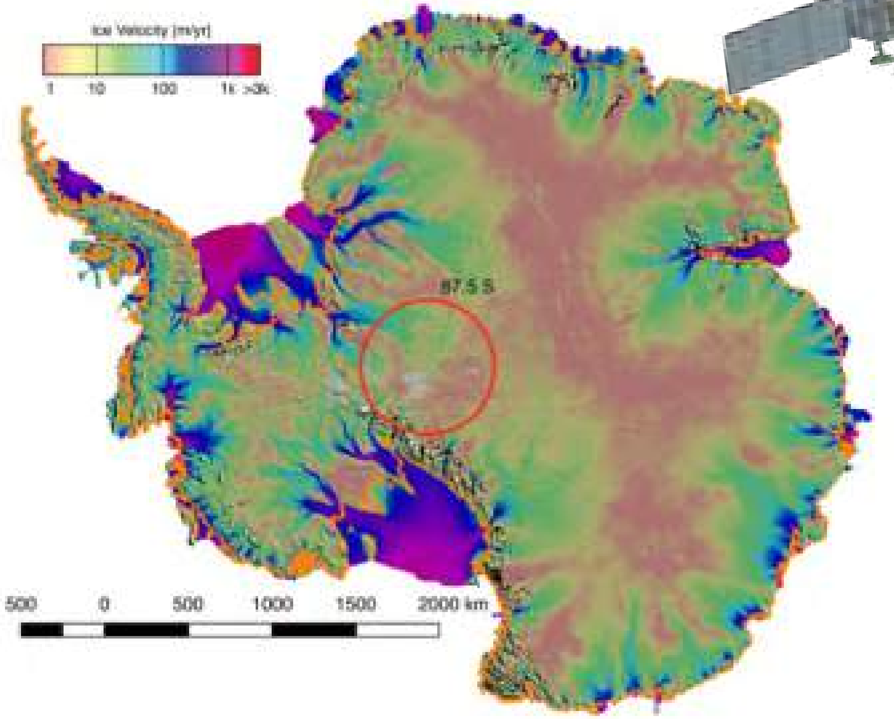
Emily Kane[1], Eric Rignot[1,2], Jeremie Mouginot[1,3], Romain Millan[1,3], Xin Li[1], Bernd Scheuchl[1], and Mark Fahnestock[4]

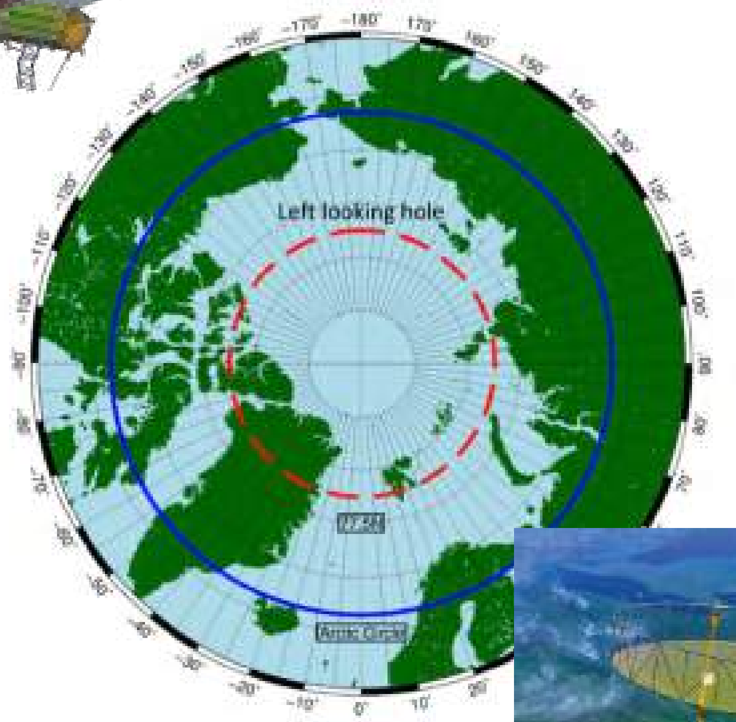


NISAR







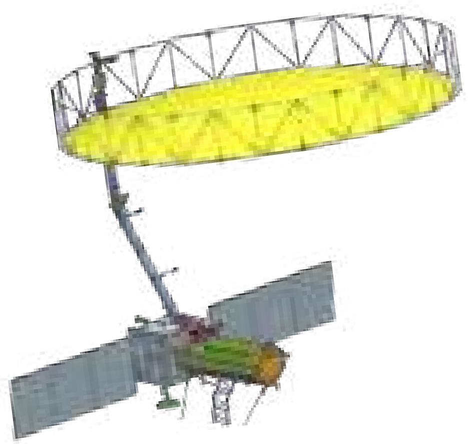


- Measure annual fast (slow) ice sheet horizontal velocity with 250 (100)-m resolution over 90% of the ice-covered areas with errors less than 3% plus 5(1) m/yr.
- Measure ice sheet velocity in fast moving regions at 12-day intervals with 500-m resolution and errors of less than 3% plus 10 m/yr.
- Measure the vertical differential displacement of all floating ice shelves and ice tongues with vertical accuracy of 100 mm at 100-m resolution annually (> 95% coverage) and monthly (>50% coverage).

Measure point to point horizontal displacements with accuracy of 100 m/day on a 5-km grid using data with 3-day sampling for 70% of the sea ice covered areas of both polar regions.

Future of InSAR for Cryosphere Applications

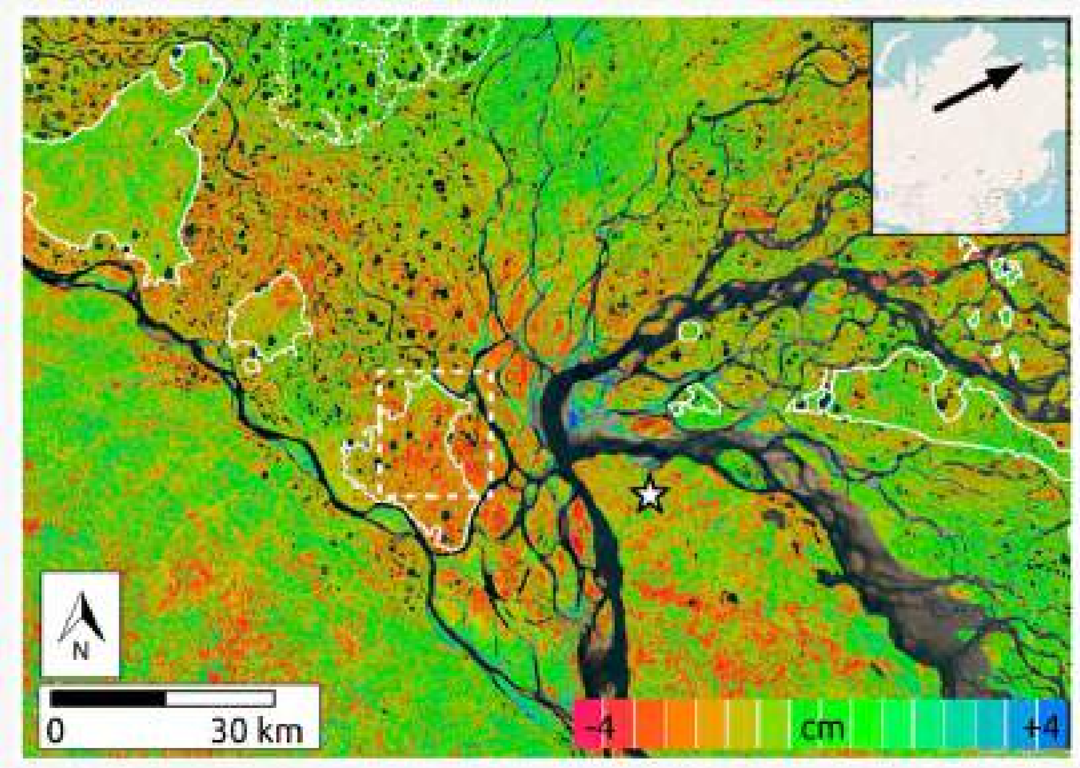
- Grounding lines: S1/Harmony, NISAR/SDC (CSK-2G, Iceye).
- 3D Ice velocity: S1/Harmony, NISAR, (ROSE-L, SAOCOM-1/2, PALSAR-3, CSK-2G, Iceye).
- Elevation change (ice melt): TDX, Harmony.
- Fast processes (Ice fracturing, tidal dynamics)



Future of InSAR for Cryosphere Applications

Permafrost: Problem is decorrelation, then mixture of processes: dynamic thawing/freezing, temperature, soil type, land cover, precipitation. Goal is ALT and permafrost layer thickness (Strozzi et al., 2018).

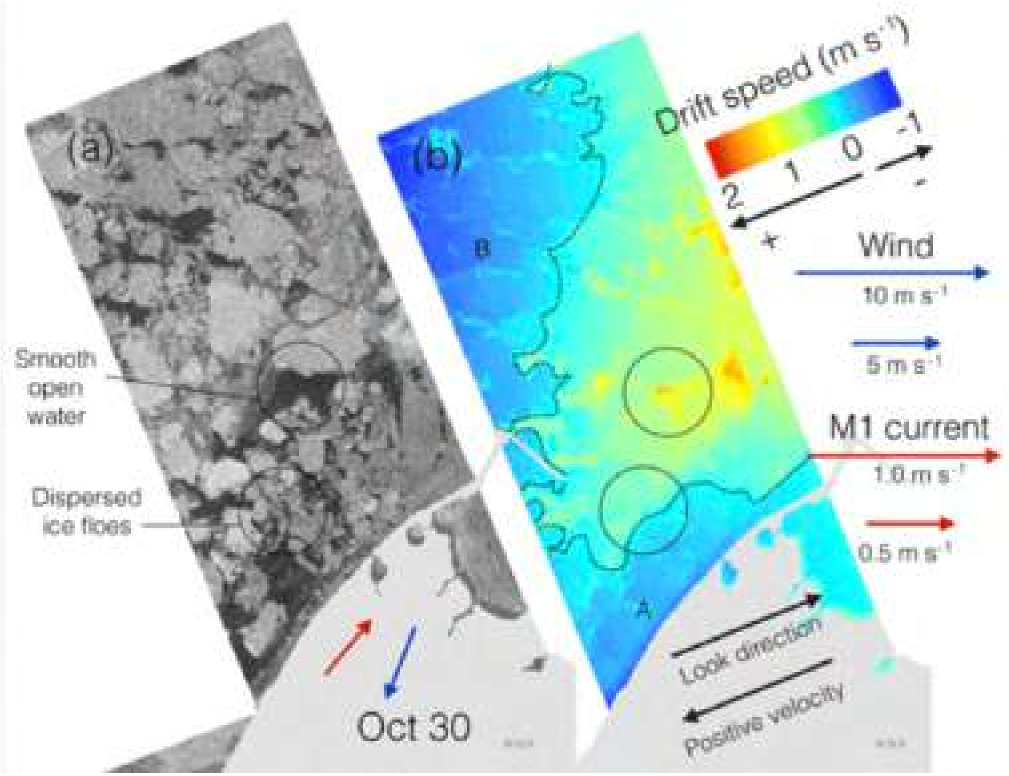
Progress will be significant w. L-band radars and w. radar sounders (DEBRIS, STRATUS)

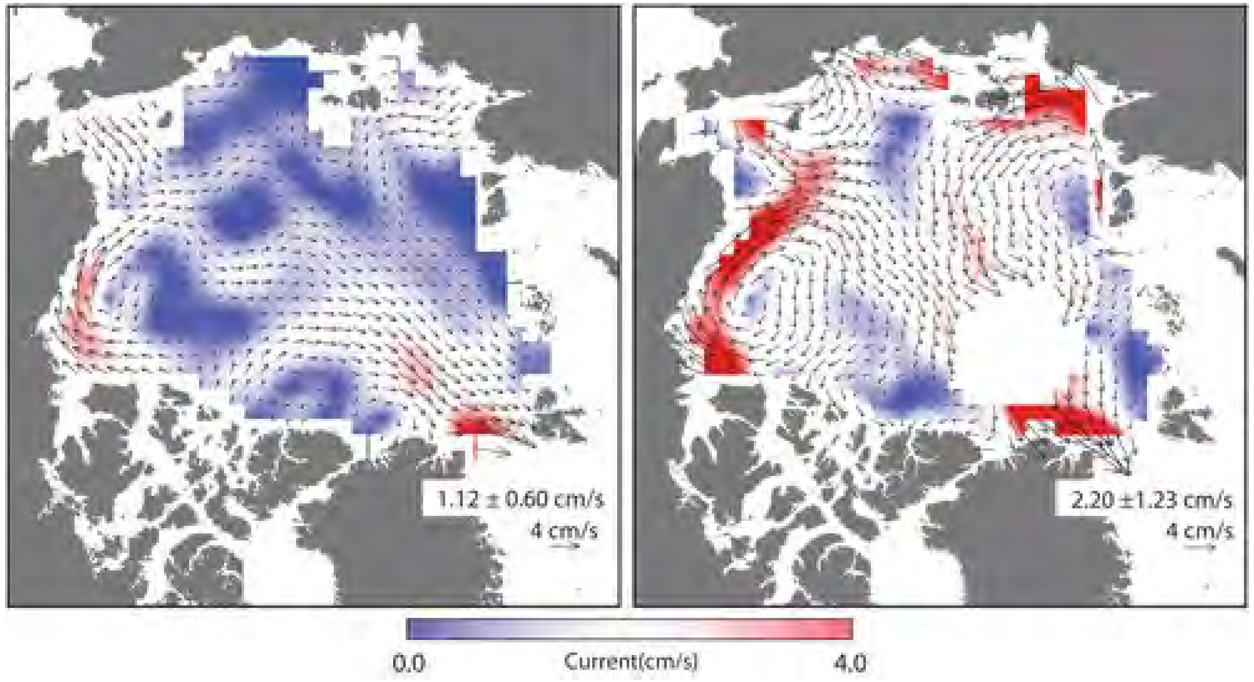


Future of InSAR for Cryosphere Applications

Sea ice: Horizontal motion complete with feature tracking but does not include leads and fractures. 3D motion is complicated by block rotation, tilting, fracture. Requires fast (ATI) repeat pass (Damman et al., 2019)

Snow Water Equivalent: density + depth + electric path length, remains difficult.





Conclusions

Future requires interferometric-phase systems, high coherence, fast repeat, high resolution to resolve physical processes that matter most to ice dynamics: grounding line dynamics, 3D flow, fracturing, ice melting.

Need data from multiple platforms to achieve observation objectives (e.g. DEM and 3D).

Need radar sounding mission and ocean temperature observation network as (missing) complement.

Other cryosphere applications will benefit from more experience interpreting radar signals at long wavelengths in complex environments in terms of physical processes.