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An international science collaboration led by JAXA

K&C Phase 4 – Final Report

Ice Sheet Monitoring using ALOS-2

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UCI DEPARTMENT OF EARTH SYSTEM SCIENCE

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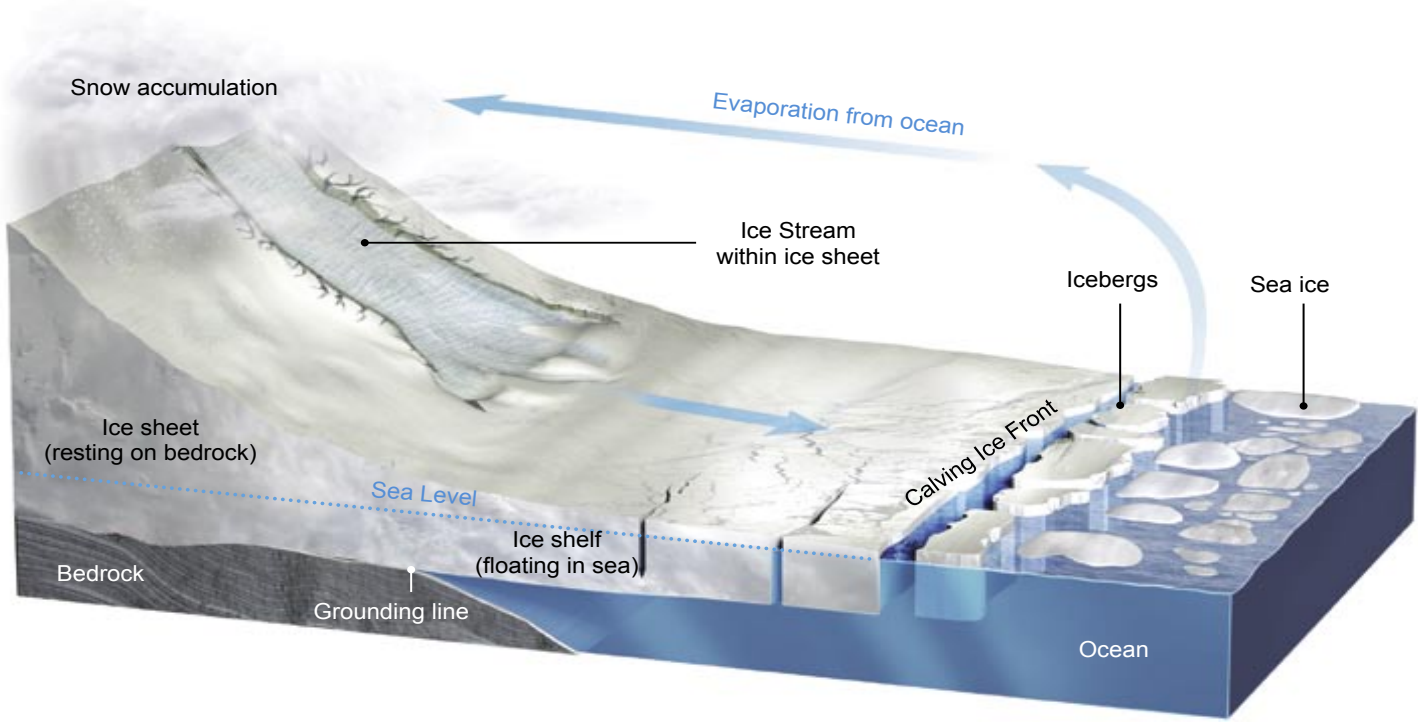
Ice Sheets

An ice sheet is a mass of glacial land ice extending more than 50,000 square kilometers (20,000 square miles).

Over thousands of years, layers of snow pile up into thick masses of ice.

Ice sheets are constantly in motion, slowly flowing downhill under their own weight.



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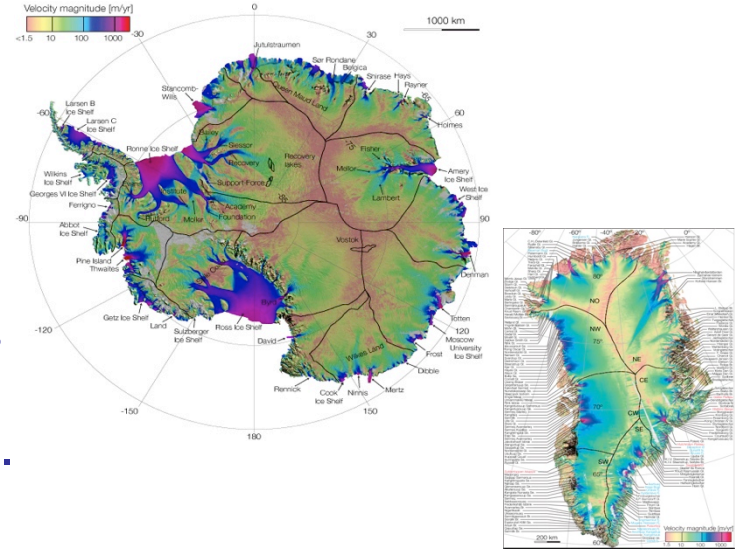
Climate Change, International Conventions

Motivation for this work

Ice sheets are acknowledged by WMO and UNFCCC as Essential Climate Variable (ECV) needed to make significant progress in the generation of global climate products and derived information. The 2011 update for the GCOS Systematic observation requirements for satellite- based data products for climate specifically mentions the need to monitor the great ice sheets.



Background

As contribution to the International Polar Year (IPY, 2007-2009) the Space Task Group coordinated large scale SAR data acquisitions in Antarctica and Greenland. The campaign was a spectacular success and the science community responded by producing continent wide ice velocity maps and related products.

Current situation

Post IPY: The Polar Space Task Group (**PSTG**) was established to succeed STG and build on the IPY success.

CSA ASC Canadian Space Agency / Agence spatiale canadienne

esa

DLR

agenzia spaziale italiana

JAXA Japan Aerospace Exploration Agency

NASA

Norsk Romsenter NORWEGIAN SPACE CENTRE

Key Questions

Is the ice sheet losing mass?

- **Mass balance**
  (need input information to calculate it)

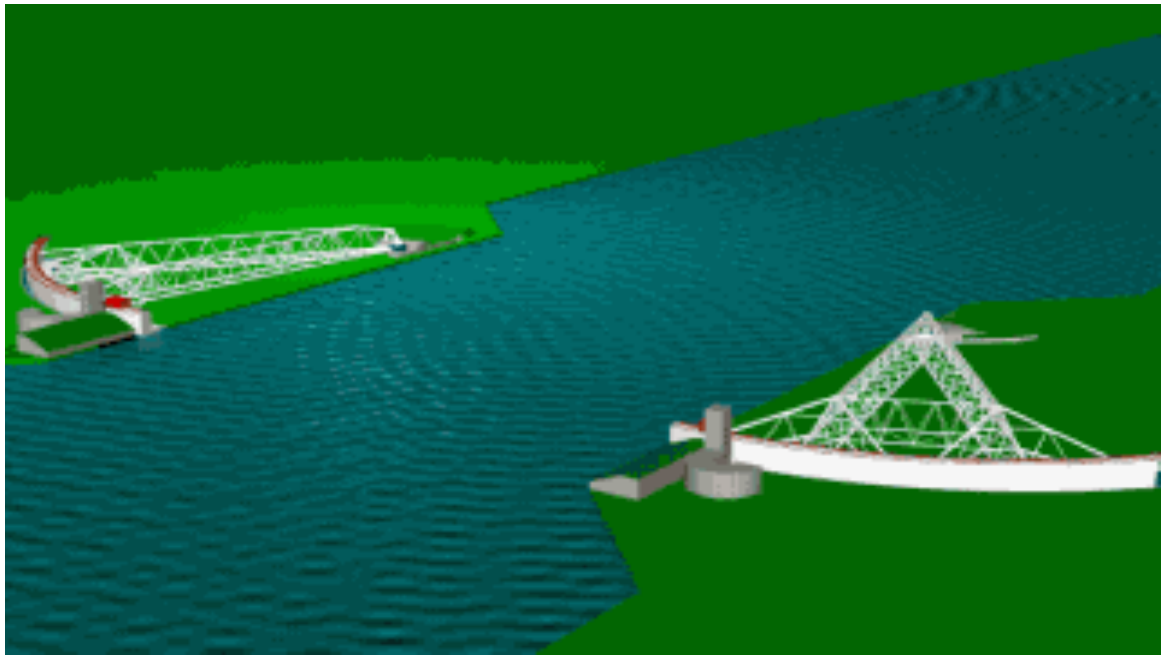
How does the ice sheet react to a changing climate
(e.g. what are the possible scenarios in 2100)?

- **Monitoring**
  - **evaluating the “now” (nowcast)**
  - **build up an archive of observations (hindcast)**
- **Modeling (forecast)**

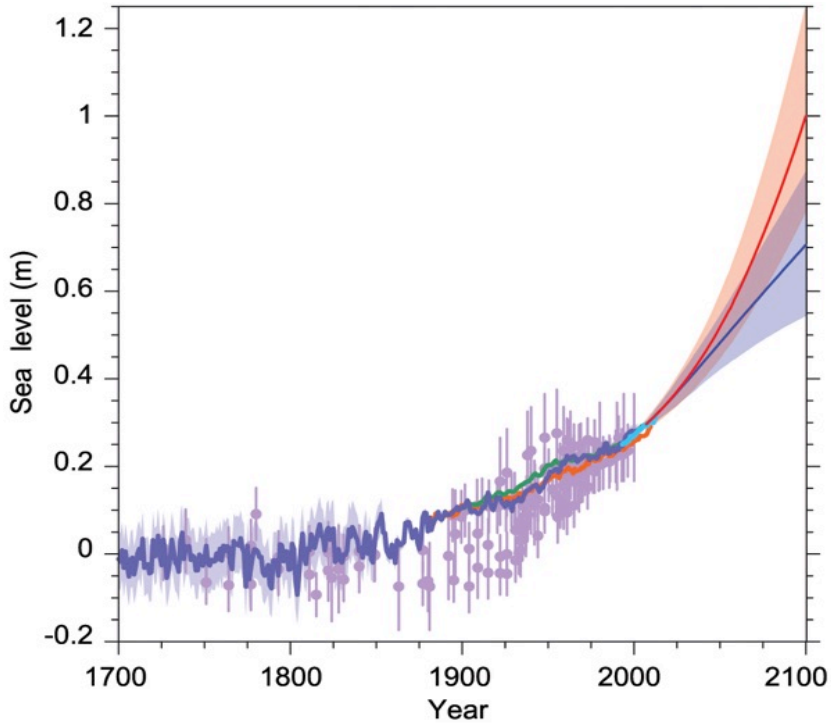
Why should we care?

Global mean sea level rise

- increased ocean warming
- increased mass loss from glaciers and ice sheets



Maeslantkering, NL



Source: IPCC AR5

2013 Danube Flood

- 500 year flood in Passau
- 100 year flood in Vienna
- 25 souls lost
- 10 Billion Euro Damage

My point here:

Human Engineering provided some level of protection.

Height of that flood wall?

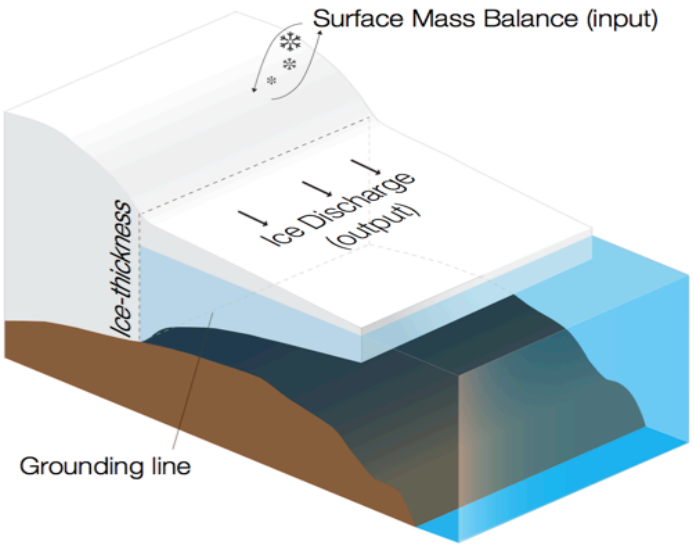
Project outline and objectives

The main objective of our project is to generate ice sheet relevant earth system data records (ESDR) based on ALOS-2. The basic observation plan for ALOS-2 includes systematic InSAR data acquisitions over the ice sheets in **Antarctica** and **Greenland**. We propose to utilize a portion of these BOS acquisitions to produce ice velocity and grounding line maps.

A secondary objective of our project is the documentation of the impact of CO2-induced warming on glacier retreat.

The ESDRs produced will contribute to a *reduction of uncertainties related to the climate system*. They will also be useful in developing strategies to prepare for the *adverse impacts of climate change*.

Ice Sheet Science Requirements & Component Method



Key ice sheet science issues

Surface Elevation & Elevation Change

Ice Velocity

Grounding Line Location

Calving Front Location

Bed Elevation

Surface Mass Balance – INPUT

Ice Discharge – OUTPUT

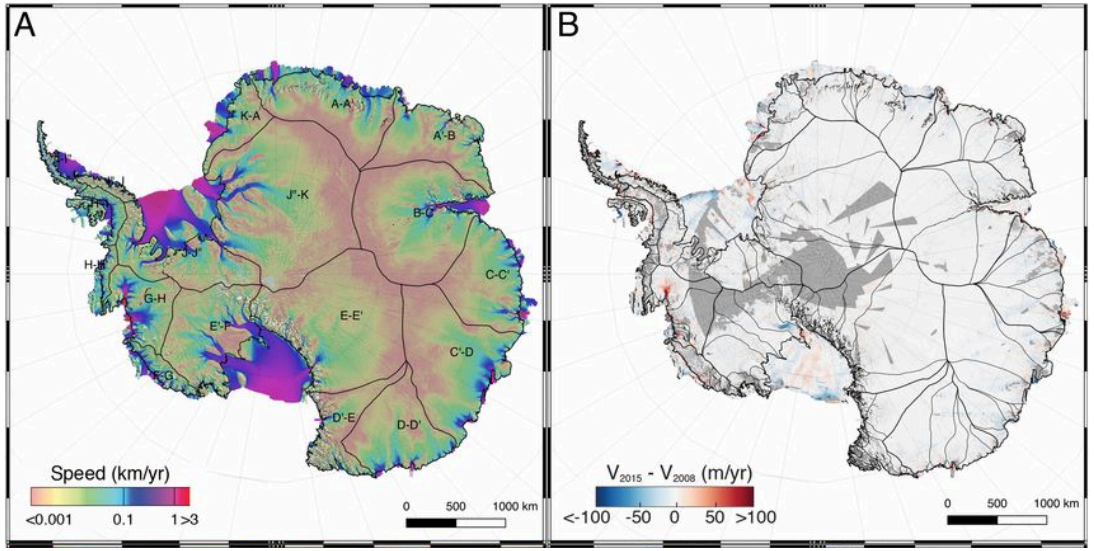
Component Method

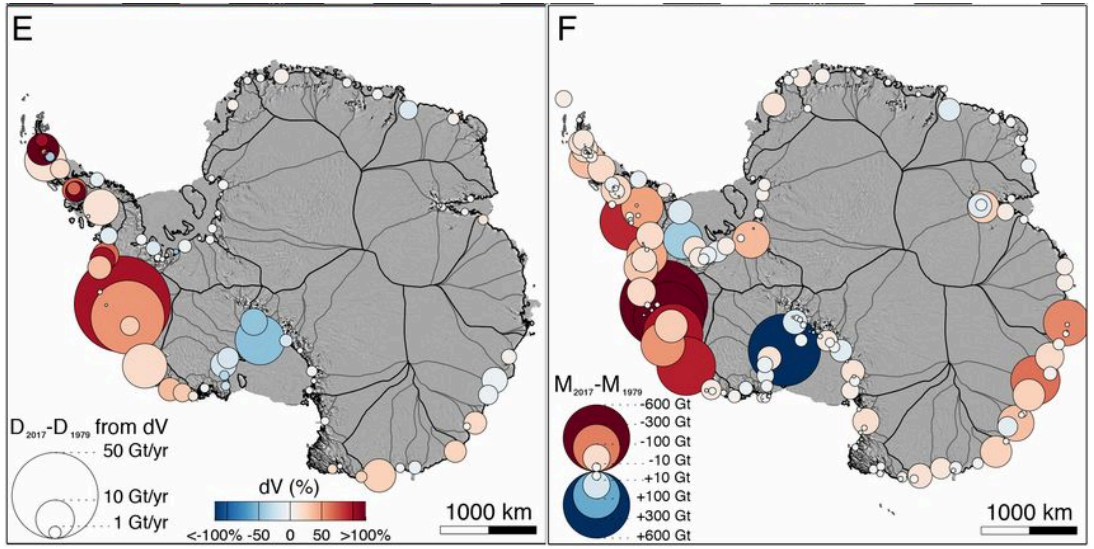
(A) Ice speed of the Antarctic Ice Sheet derived from multisensor data for the time period 2014–2016 with 18 basins.

(B) Change in flow speed from the time period 2007–2008 to 2014–2015
blue (deceleration) to red (acceleration).

(*E*) Change in grounding line ice discharge, D, for 1979–2017 with percentage change in speed color-coded from red (acceleration) to blue (deceleration) and circle radius proportional to change.

(*F*) Total change in mass of major basins color-coded from blue (gain) to red (loss) for 1979–2017 with circle radius proportional to the absolute mass balance.





Eric Rignot et al. PNAS 2019;116:4:1095-1103

IMBIE

The ice sheet mass balance inter-comparison exercise (IMBIE)
http://imbie.org/

First round 2012: results published in Science
Second round 2018: Antarctica results published in Nature.

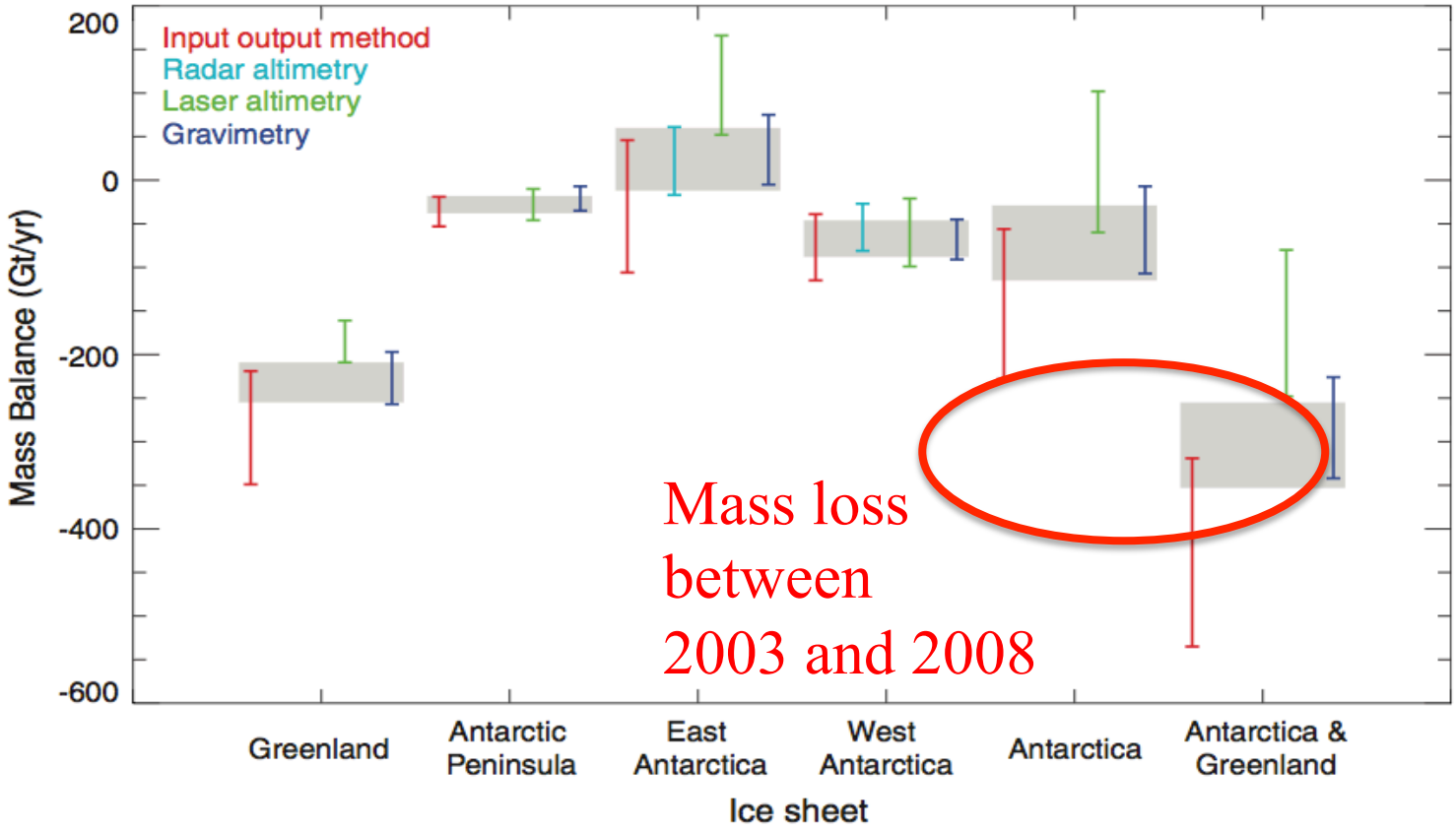
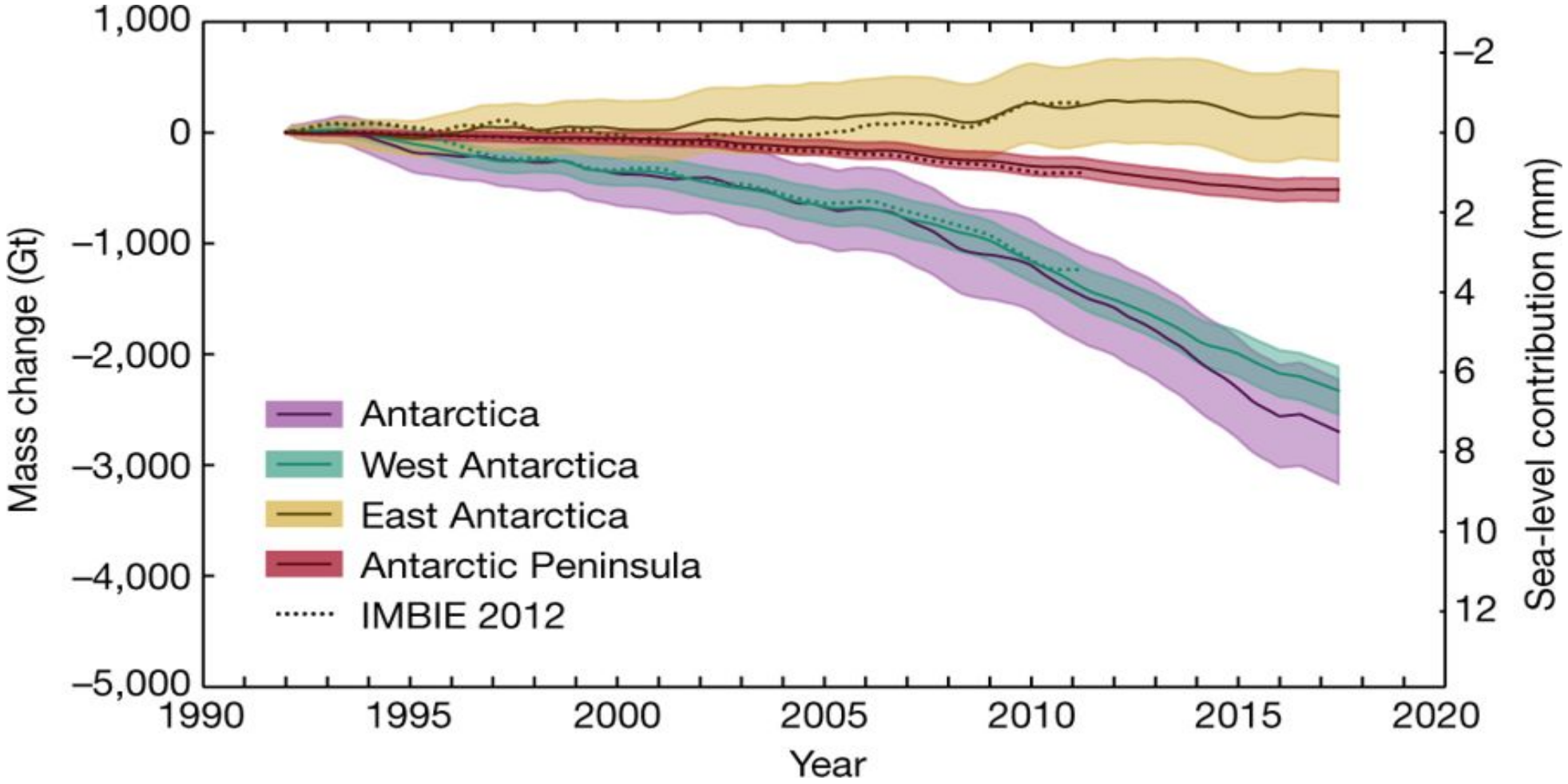


Fig. 3. Intercomparison of mass balance estimates of the GrIS, APIS, EAIS, WAIS, AIS, and the AIS plus GrIS, derived from the four independent geodetic techniques of RA (cyan), IOM (red), LA (green), and gravimetry (blue) over the period 2003 to 2008. Also shown is the reconciled result (gray).

Andrew Shepherd and 46 others.
A Reconciled Estimate of Ice-Sheet Mass Balance,
Science **338**, 1183 (2012); DOI: 10.1126/science.1228102

IMBIE



The IMBIE Team.
Mass balance of the Antarctic Ice Sheet from 1992 to 2017
Nature 556 (2018): pages219-222. DOI: 10.1038/s41586-018-0179-y

Project milestones & Data sharing

For each year we envision the production of the aforementioned ESDRs.

After year 3, we will also assemble time series products that will be published once the final year (year 4) data can be integrated.

Finally, we plan to integrate the ALOS based ESDRs with ESDRs from other spaceborne SAR data to achieve an ice sheet wide, post IPY reference map.

We will publish our findings in the scientific literature.

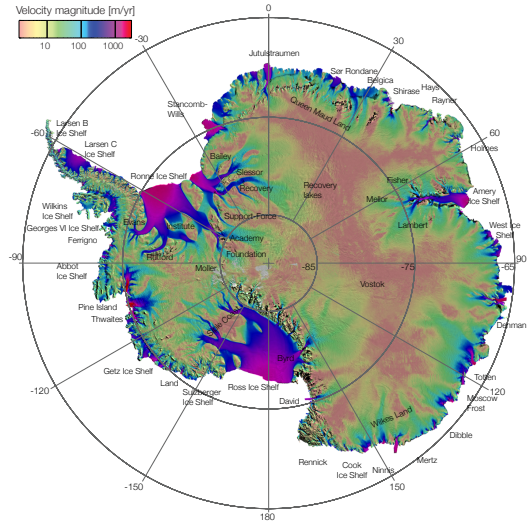
We do not collect ground truth data for this project but we have shared with JAXA all ice sheet ESDRs that were generated using data from multiple SAR satellites

Deliverables

- Annual ice velocity maps over selected regions in Antarctica and Greenland
- Grounding line maps for selected regions in Antarctica where data proves suitable to generate this information (delivery at project end)
- Ice front maps for selected ice shelves and glaciers in Antarctica and Greenland
- Publications

We do not collect ground truth data for this project but we have shared with JAXA all ice sheet ESDRs that were generated using data from multiple SAR satellites

MEaSUREs Antarctica



http://nsidc.org/data/measures/data_summaries

MEaSUREs Annual Antarctic Ice Velocity Maps 2005-2017, V1
http://nsidc.org/data/NSIDC-0720

MEaSUREs Antarctic Boundaries for IPY 2007-2009 from Satellite Radar, V2
http://nsidc.org/data/NSIDC-0709

MEaSUREs InSAR-Based Antarctica Ice Velocity Map, V2
http://nsidc.org/data/NSIDC-0484

MEaSUREs Antarctic Grounding Line from Differential Satellite Radar Interferometry, V2
http://nsidc.org/data/NSIDC-0498

MEaSUREs InSAR-Based Ice Velocity of the Amundsen Sea Embayment, Antarctica, V1
http://nsidc.org/data/NSIDC-0545

MEaSUREs InSAR-Based Ice Velocity Maps of Central Antarctica: 1997 and 2009, V1
http://nsidc.org/data/NSIDC-0525

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Antarctic Grounding Line

Product
MEaSUREs Antarctic Grounding Line from Differential Satellite Radar Interferometry, V 2

Link
http://nsidc.org/data/NSIDC-0498/

Funding Program:
NASA MEaSUREs

Data Sources:
ERS-1, ERS-2, RADARSAT-1, RADARSAT-2, ENVISAT ASAR, ALOS PALSAR, Copernicus SENTINEL-1, and Cosmo-Skymed

The WMO Polar Space Task Group is gratefully acknowledged for its role in coordinating data acquisition plans.

Rignot et al 2011
Rignot et al. 2014
Li et al. 2015
Scheuchl et al. 2016
Milillo et al 2017

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Antarctic Boundaries

Product
MEaSUREs Antarctic Boundaries for IPY 2007-2009 from Satellite Radar, Version 2

Link
https://nsidc.org/data/nsidc-0709/

Funding Program:
NASA MEaSUREs

Data Sources:
ERS-1, ERS-2, RADARSAT-1, RADARSAT-2, ENVISAT ASAR, ALOS PALSAR, Copernicus SENTINEL-1, and Cosmo-Skymed

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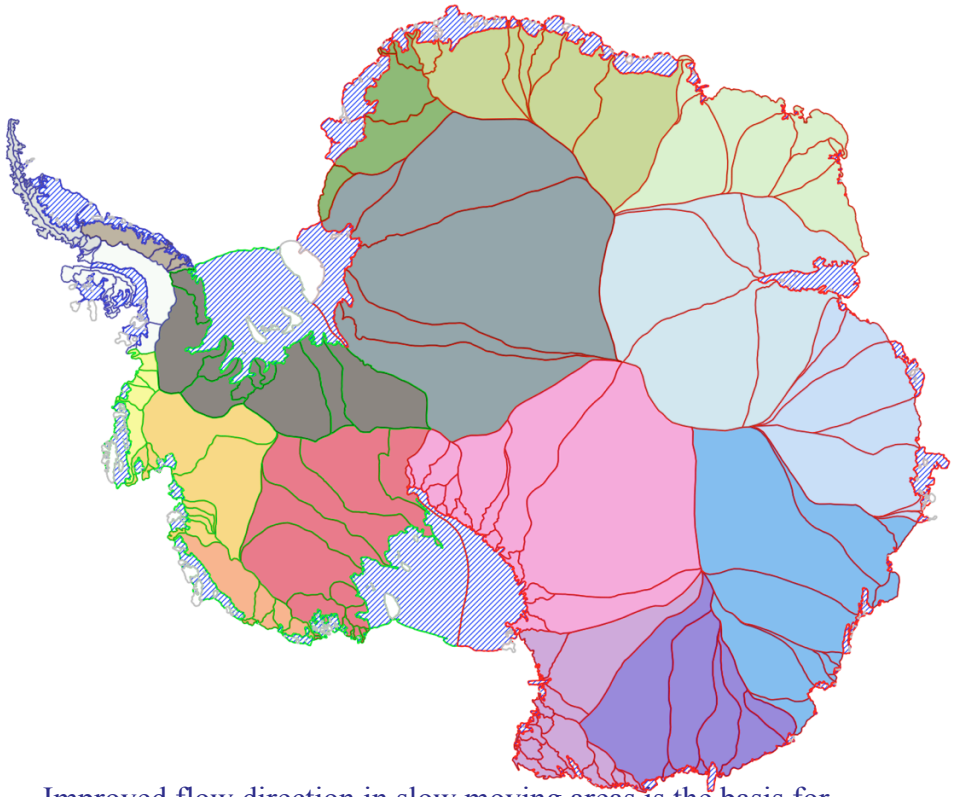

- Improved flow direction in slow moving areas is the basis for improved glacier basins, which are crucial for mass balance studies
- IMBIE-2 basins + a refined version
- Ice shelf mask (IPY, Rignot et al. 2013)
- Coast line and grounding line (continuous product based on InSAR GL and other available products)

Rignot, E., S. S. Jacobs, J. Mouginot, and B. Scheuchl. 2013. Ice-shelf melting around Antarctica, *Science*. 341. 266-270. http://dx.doi.org/10.1126/science.1235798

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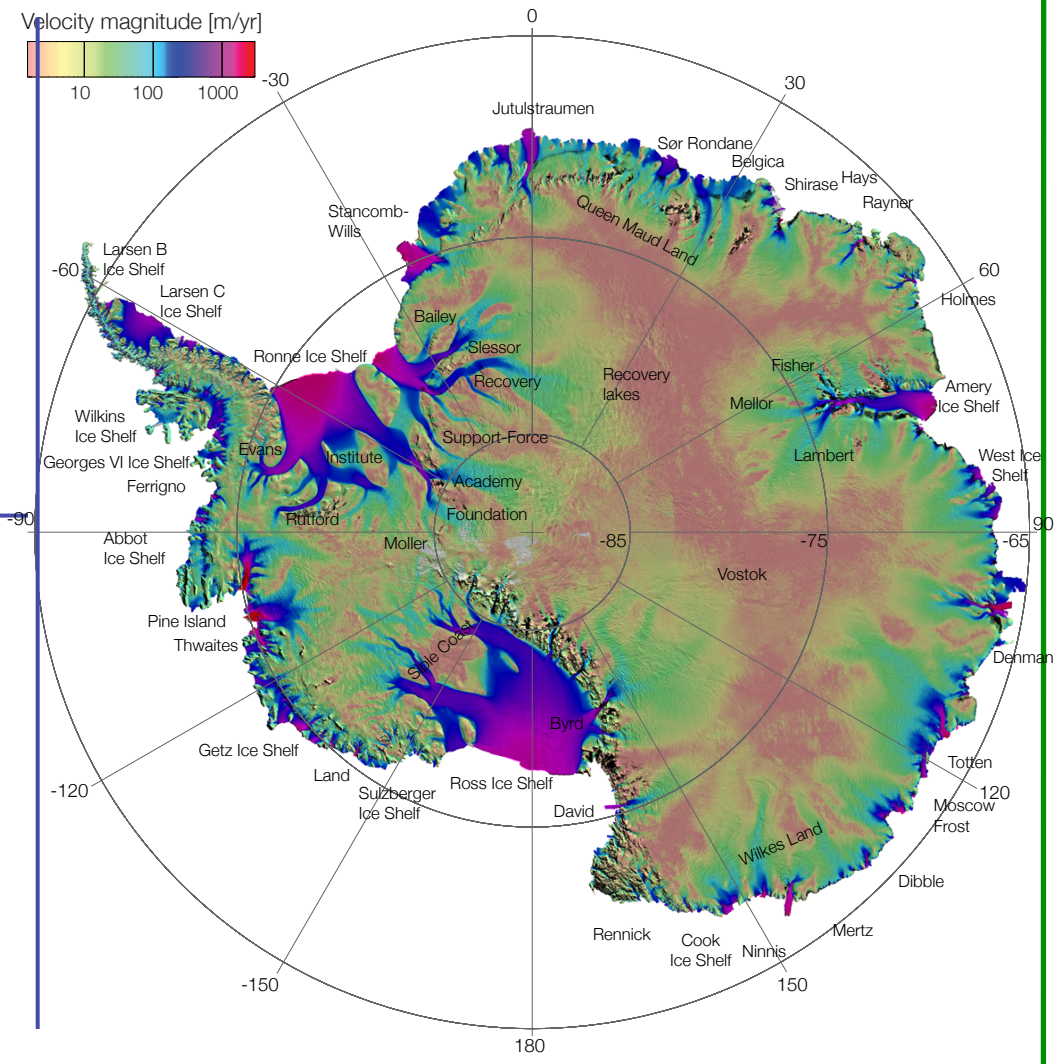
Continent-Wide Ice Velocity Map

Product
MEaSUREs InSAR-Based
Antarctica Ice Velocity Map V2 .

Link
https://nsidc.org/data/NSIDC-0484/

Funding Program:
NASA MEaSUREs



Data Sources:
ERS-1, ERS-2, RADARSAT-1, RADARSAT-2, ENVISAT ASAR, ALOS PALSAR, ALOS-2 PALSAR-2, Copernicus SENTINEL-1, LANDSAT-8

The WMO Polar Space Task Group is gratefully acknowledged for its role in coordinating data acquisition plans.

Mouginot, J., Rignot, E., Scheuchl, B., Millan, R. 2017. Comprehensive Annual Ice Sheet Velocity Mapping Using Landsat-8, Sentinel-1, and RADARSAT-2 Data. *Remote Sensing* 9(4): Art. #364. doi: http://dx.doi.org/10.3390/rs9040364

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Annual Ice Velocity Maps

Product
MEaSUREs Annual Ice Velocity Maps of Antarctica.

Link
https://nsidc.org/data/NSIDC-0720/

Funding Program:
NASA MEaSUREs

Data Sources:
ERS-1, ERS-2, RADARSAT-1, RADARSAT-2, ENVISAT ASAR, ALOS PALSAR, ALOS-2 PALSAR-2, Copernicus SENTINEL-1, LANDSAT-8

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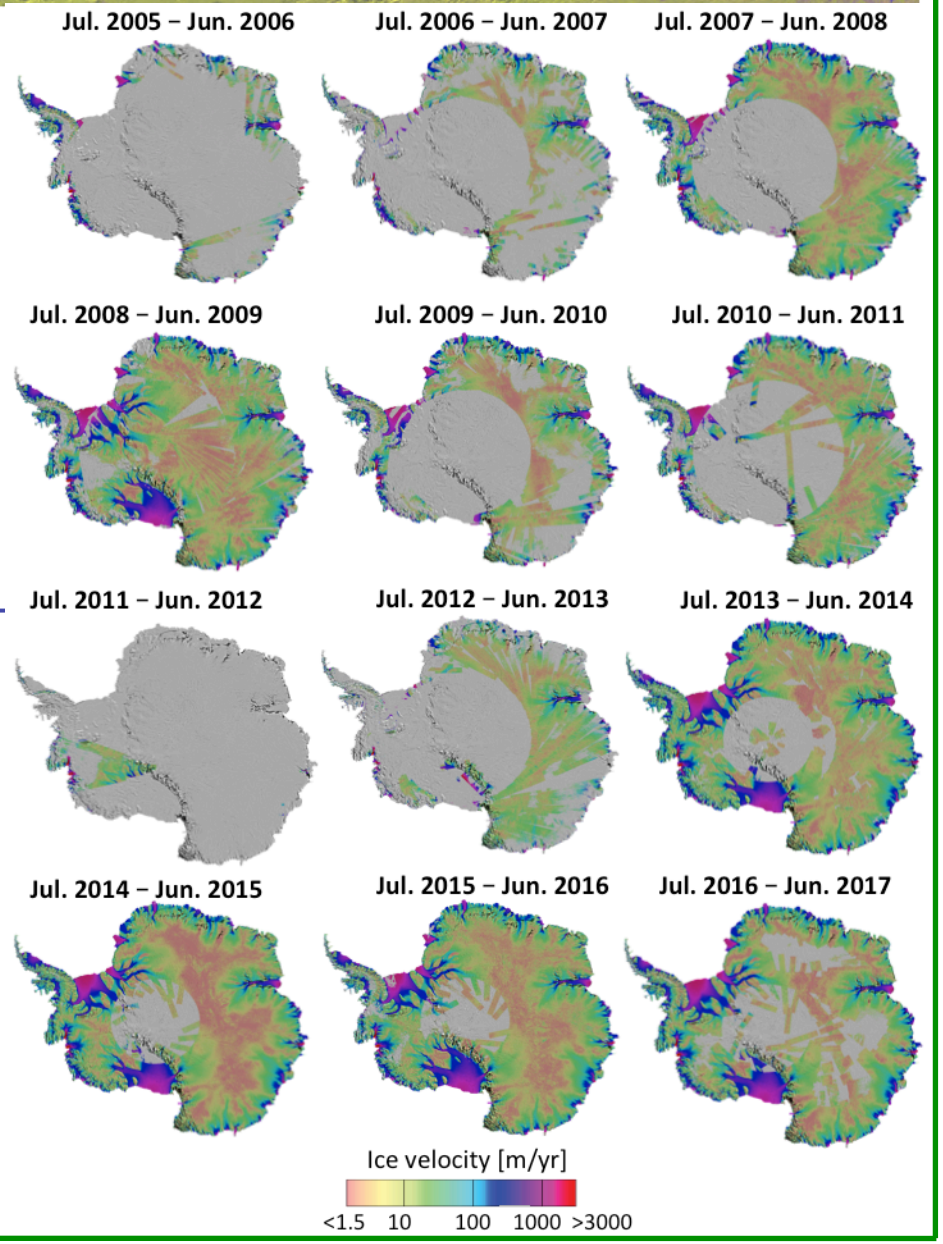
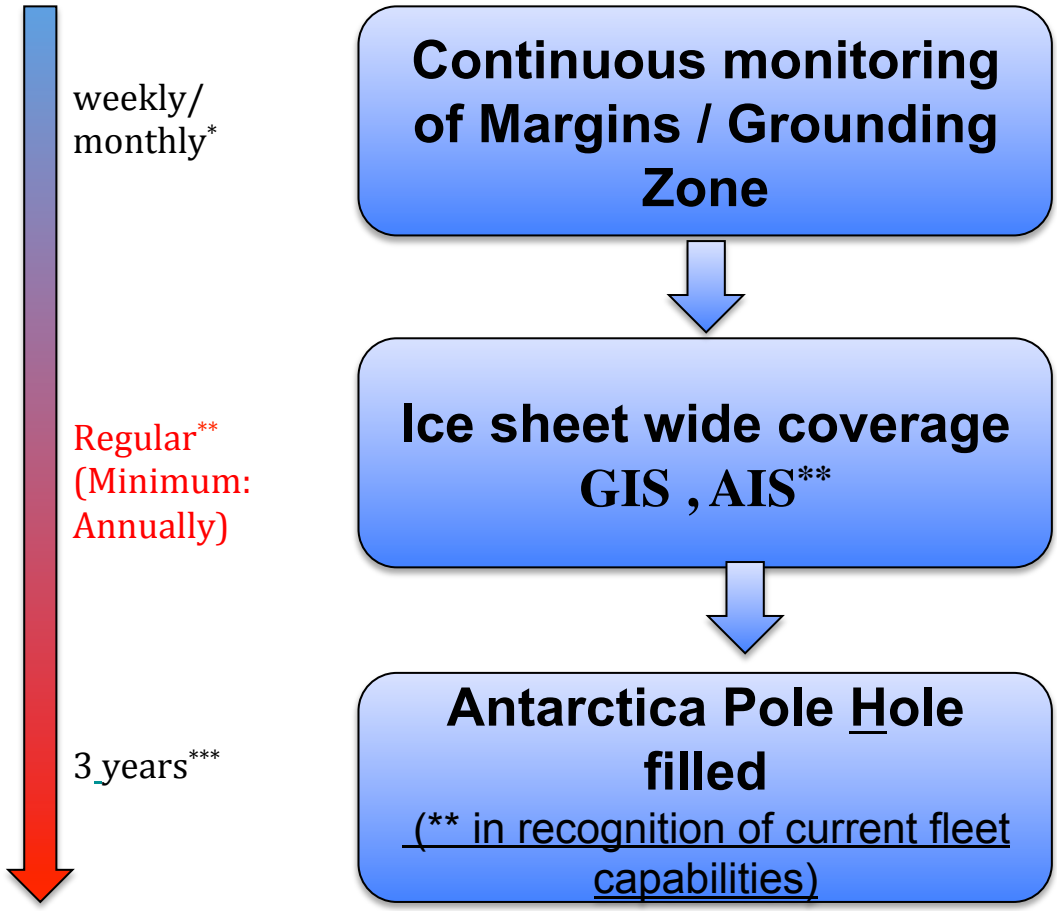


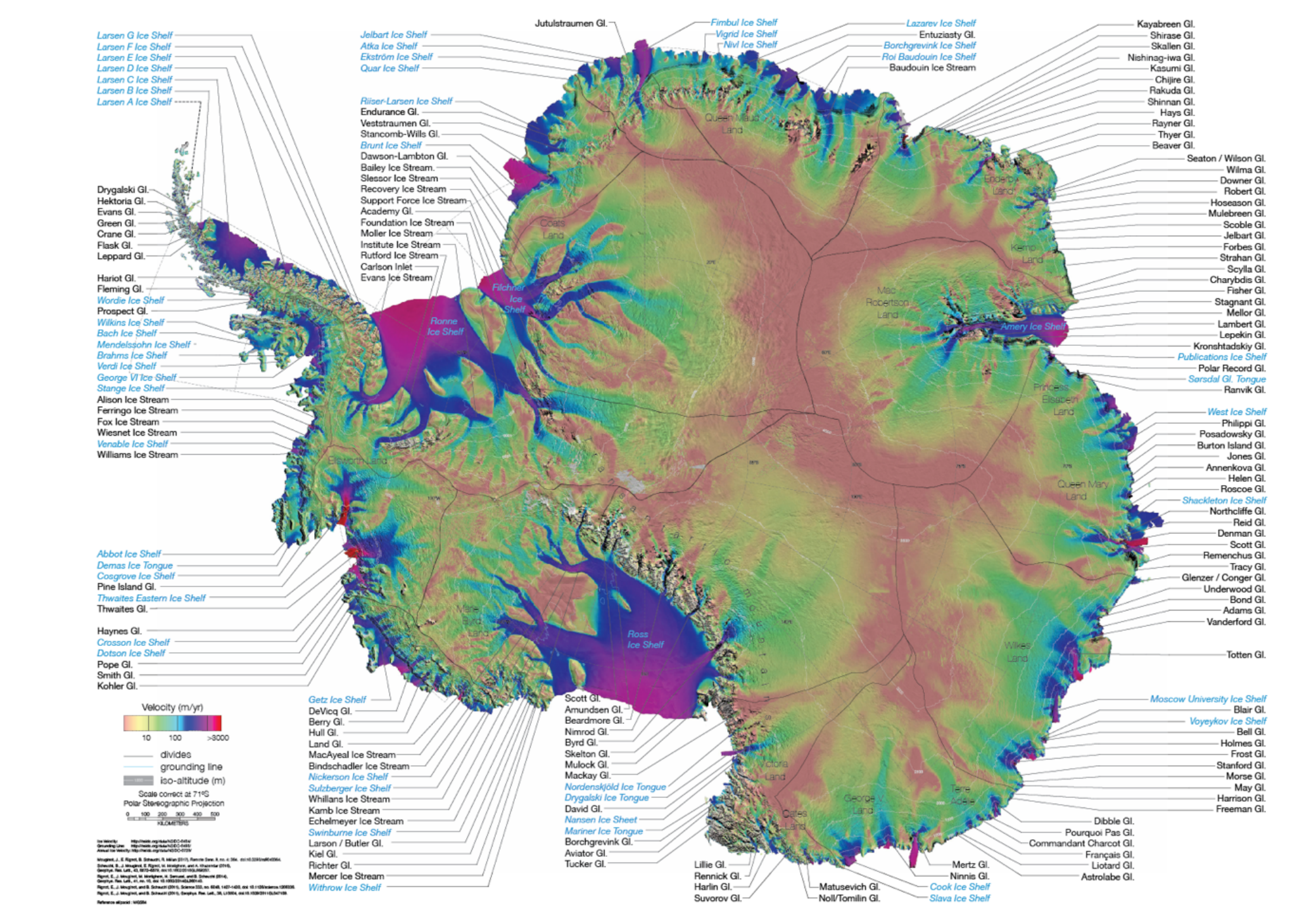
Acquisition Requirements (PSTG)



* Weekly → need for ongoing acquisitions using every available repeat. For missions with 1 day interval multiple 1 day repeats in the grounding zone of glaciers would be an asset.

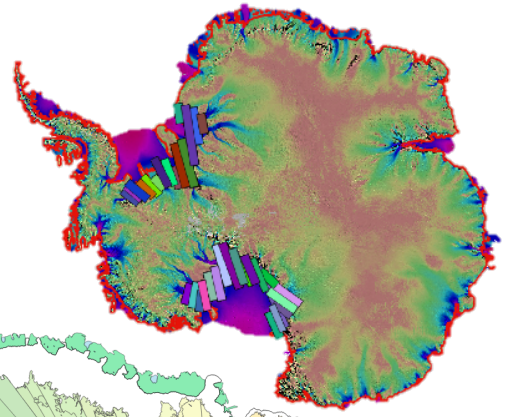
** Regular ice sheet wide reflects the desire to have more frequent full coverages.

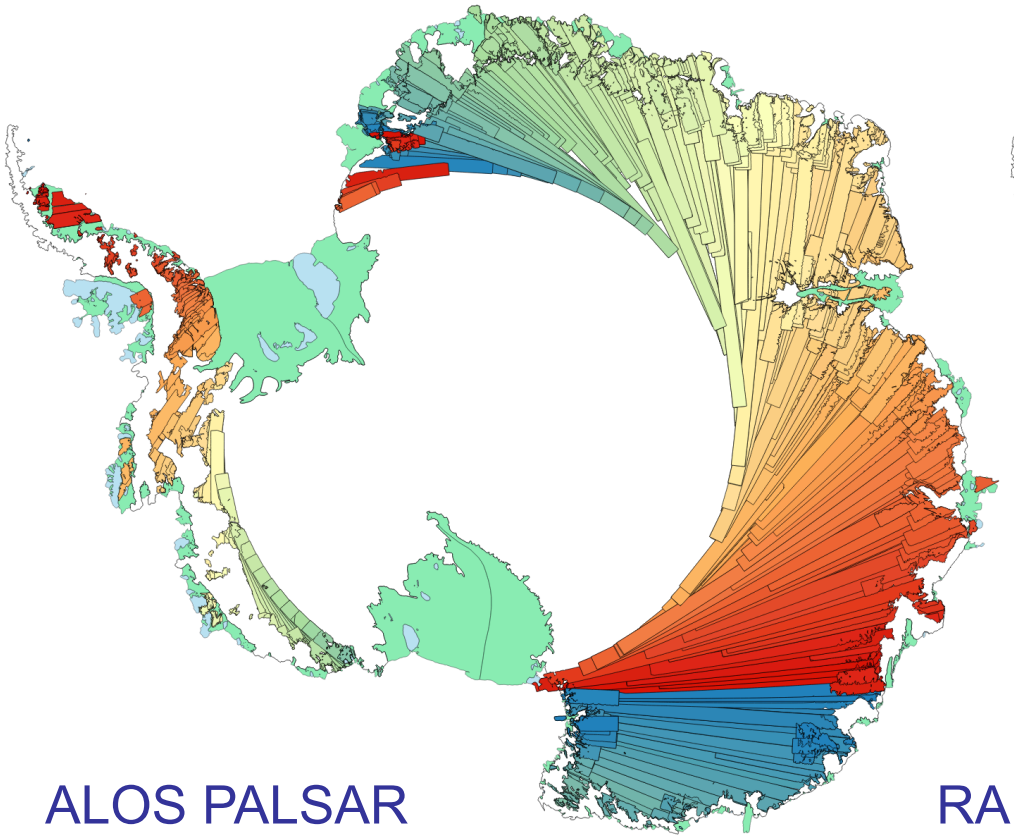
*** 3 year box is in recognition of current fleet capabilities. With more left looking capabilities available, this changes to regular.


Larsen G Ice Shelf
Larsen F Ice Shelf
Larsen E Ice Shelf
Larsen D Ice Shelf
Larsen C Ice Shelf
Larsen B Ice Shelf
Larsen A Ice Shelf
Drygalski Gl.
Hektoria Gl.
Evans Gl.
Green Gl.
Crane Gl.
Flask Gl.
Leppard Gl.
Hariot Gl.
Fleming Gl.
Wordie Ice Shelf
Prospect Gl.
Wilkins Ice Shelf
Bach Ice Shelf
Mendelssohn Ice Shelf
Brahms Ice Shelf
Verdi Ice Shelf
George VI Ice Shelf
Stange Ice Shelf
Alison Ice Stream
Ferringo Ice Stream
Fox Ice Stream
Wiesnet Ice Stream
Venable Ice Shelf
Williams Ice Stream
Abbot Ice Shelf
Demas Ice Tongue
Cosgrove Ice Shelf
Pine Island Gl.
Thwaites Eastern Ice Shelf
Thwaites Gl.
Haynes Gl.
Crosson Ice Shelf
Dotson Ice Shelf
Pope Gl.
Smith Gl.
Kohler Gl.
Getz Ice Shelf
DeVicq Gl.
Berry Gl.
Hull Gl.
Land Gl.
MacAyeal Ice Stream
Bindschadler Ice Stream
Nickerson Ice Shelf
Sulzberger Ice Shelf
Whillans Ice Stream
Kamb Ice Stream
Echelmeyer Ice Stream
Swinburne Ice Shelf
Larson / Butler Gl.
Kiel Gl.
Richter Gl.
Mercer Ice Stream
Withrow Ice Shelf
Jutulstraumen Gl.
Jelbart Ice Shelf
Atka Ice Shelf
Ekström Ice Shelf
Quar Ice Shelf
Riiser-Larsen Ice Shelf
Endurance Gl.
Veststraumen Gl.
Stancomb-Wills Gl.
Brunt Ice Shelf
Dawson-Lambton Gl.
Bailey Ice Stream.
Slessor Ice Stream
Recovery Ice Stream
Support Force Ice Stream
Academy Gl.
Foundation Ice Stream
Moller Ice Stream
Institute Ice Stream
Rutford Ice Stream
Carlson Inlet
Evans Ice Stream
Filchner Ice Shelf
Ronne Ice Shelf
Fimbul Ice Shelf
Vigrid Ice Shelf
Nivl Ice Shelf
Lazarev Ice Shelf
Entuziasty Gl.
Borchgrevink Ice Shelf
Roi Baudouin Ice Shelf
Baudouin Ice Stream
Queen Maud Land
Coats Land
Ellsworth Land
Ross Ice Shelf
Marie Byrd Land
Scott Gl.
Amundsen Gl.
Beardmore Gl.
Nimrod Gl.
Byrd Gl.
Skelton Gl.
Mulock Gl.
Mackay Gl.
Nordenskjöld Ice Tongue
Drygalski Ice Tongue
David Gl.
Nansen Ice Sheet
Mariner Ice Tongue
Borchgrevink Gl.
Aviator Gl.
Tucker Gl.
Victoria Land
Oates Land
George V Land
Lillie Gl.
Rennick Gl.
Harlin Gl.
Suvorov Gl.
Matusevich Gl.
Noll/Tomilin Gl.
Cook Ice Shelf
Slava Ice Shelf
Mertz Gl.
Ninnis Gl.
Dibble Gl.
Pourquoi Pas Gl.
Commandant Charcot Gl.
Français Gl.
Liotard Gl.
Astrolabe Gl.
Terre Adélie
Wilkes Land
Totten Gl.
Moscow University Ice Shelf
Blair Gl.
Voyeykov Ice Shelf
Bell Gl.
Holmes Gl.
Frost Gl.
Stanford Gl.
Morse Gl.
May Gl.
Harrison Gl.
Freeman Gl.
Princess Elisabeth Land
Queen Mary Land
West Ice Shelf
Philippi Gl.
Posadowsky Gl.
Burton Island Gl.
Jones Gl.
Annenkova Gl.
Helen Gl.
Roscoe Gl.
Shackleton Ice Shelf
Northcliffe Gl.
Reid Gl.
Denman Gl.
Scott Gl.
Remenchus Gl.
Tracy Gl.
Glenzer / Conger Gl.
Underwood Gl.
Bond Gl.
Adams Gl.
Vanderford Gl.
Mac Robertson Land
Amery Ice Shelf
Kemp Land
Edden Land
Kayabreen Gl.
Shirase Gl.
Skallen Gl.
Nishinag-iwa Gl.
Kasumi Gl.
Chijire Gl.
Rakuda Gl.
Shinnan Gl.
Hays Gl.
Rayner Gl.
Thyer Gl.
Beaver Gl.
Seaton / Wilson Gl.
Wilma Gl.
Downer Gl.
Robert Gl.
Hoseason Gl.
Mulebreen Gl.
Scoble Gl.
Jelbart Gl.
Forbes Gl.
Strahan Gl.
Scylla Gl.
Charybdis Gl.
Fisher Gl.
Stagnant Gl.
Mellor Gl.
Lambert Gl.
Lepekin Gl.
Kronshtadskiy Gl.
Publications Ice Shelf
Polar Record Gl.
Sørsdal Gl. Tongue
Ranvik Gl.
Velocity (m/yr)
10
100
>3000
divides
grounding line
iso-altitude (m)
Scale correct at 71°S
Polar Stereographic Projection
0 100 200 300 400 500
KILOMETERS

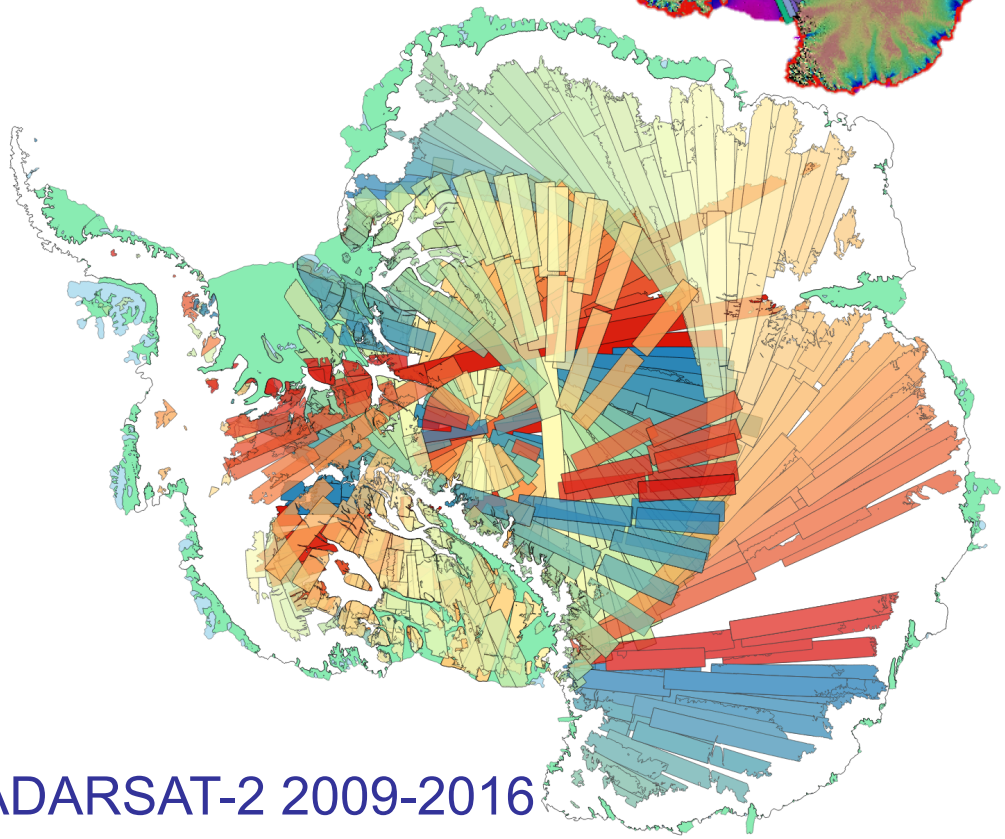
On the importance of left looking capability

Only few sensors can acquire data in left looking mode.
Right looking sensors leave a big gap in Antarctica





ALOS PALSAR
2006-2010



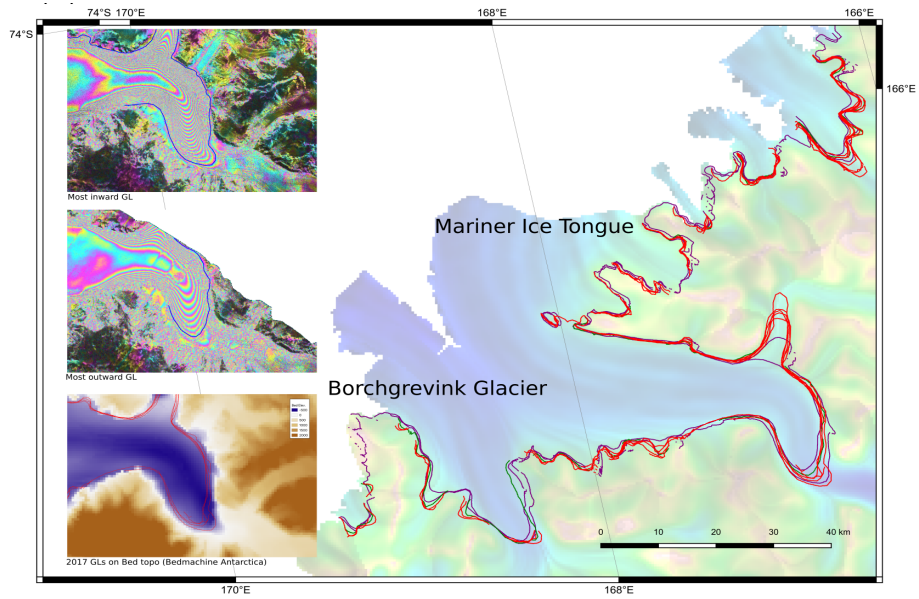
RADARSAT-2 2009-2016
(2 large scale left looking campaigns to date)

Developments Grounding Line

Data needs:
2 independent interferograms (3-4 acquisitions)
of the grounding line region.
Double difference interferometry

Multiple measurements per year.
Different tide constellations are
→ Grounding Zone

High resolution DEM information is
now available (REMA, TanDEM-X)



Thank You

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