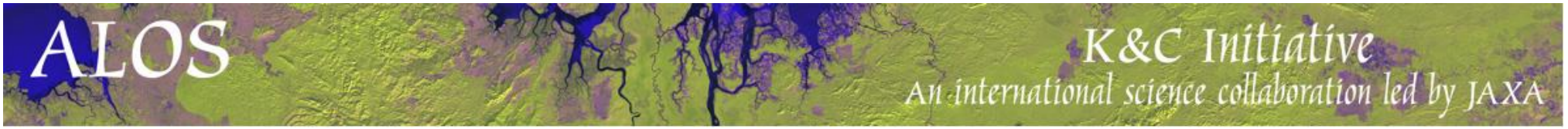

K&C Phase 4 – Status report

Ice Sheet Monitoring using ALOS-2

Bernd Scheuchl[1], Jeremie Mouginot[1], Eric Rignot[1,2]

[1]University of California, Irvine
[2]JPL

Science Team meeting #24
Tokyo, Japan, January 29-31, 2018

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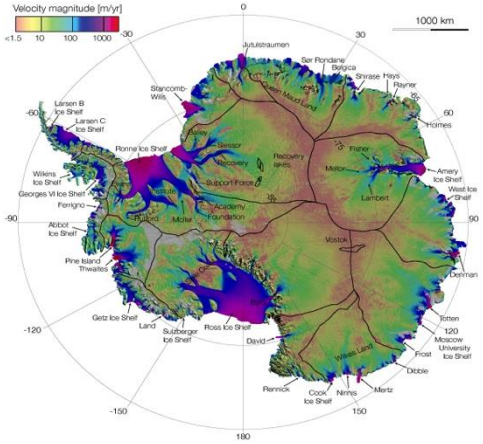
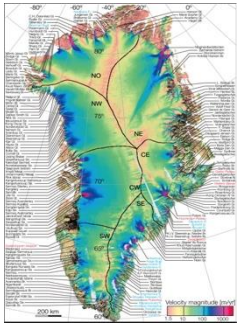
Climate Change, International Conventions

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

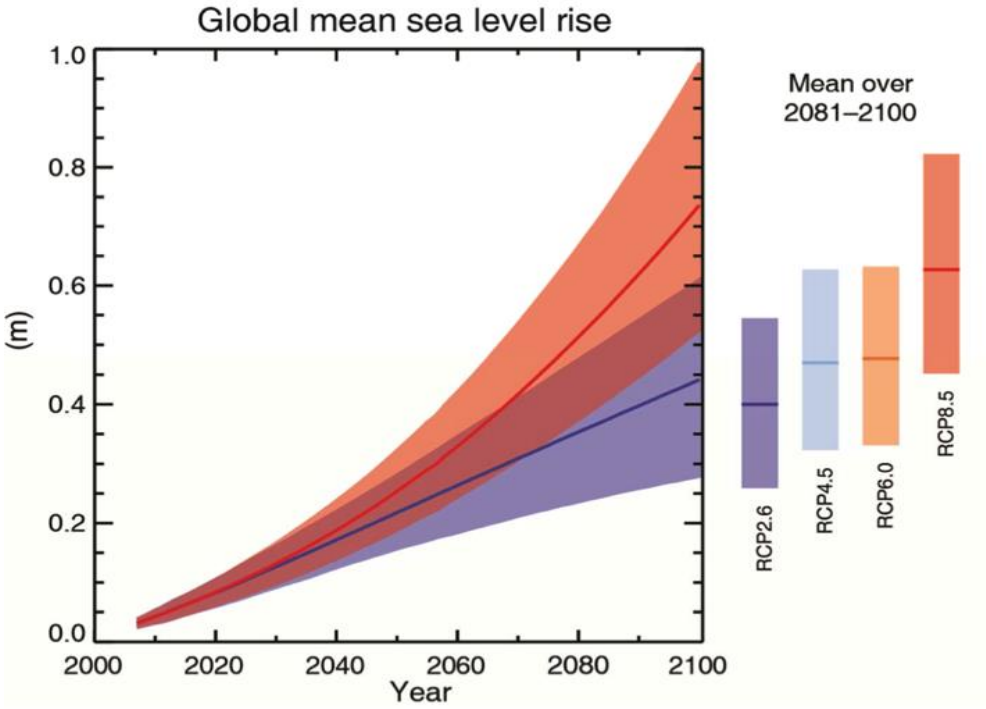
agenzia spaziale italiana

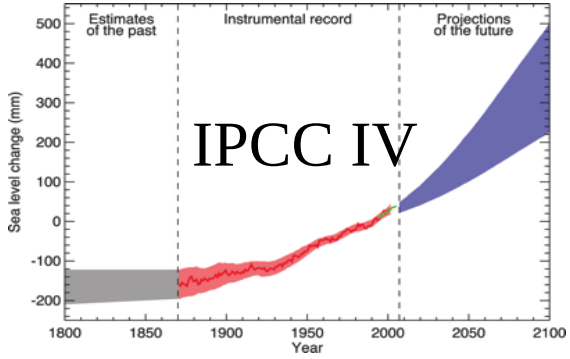
JAXA Japan Aerospace Exploration Agency

NASA

Norsk Romsenter NORWEGIAN SPACE CENTRE

Global mean sea level will continue to rise during the 21st century. Under all RCP scenarios the rate of sea level rise will *very likely* exceed that observed during 1971–2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets.





Working Group I Contribution to the IPCC Fifth Assessment Report *Climate Change 2013: The Physical Science Basis* Summary for Policymakers

Background

Key Question:

Are the ice sheets loosing mass?

Three independent methods are available to measure mass balance

A Reconciled Estimate of Ice-Sheet Mass Balance

Andrew Shepherd,[1*] Erik R. Ivins,[2*] Geruo A,[3] Valentina R. Barletta,[4] Mike J. Bentley,[5] Srinivas Bettadpur,[6] Kate H. Briggs,[1] David H. Bromwich,[7] René Forsberg,[4] Natalia Galin,[8] Martin Horwath,[9] Stan Jacobs,[10] Ian Joughin,[11] Matt A. King,[12,27] Jan T. M. Lenaerts,[13] Jilu Li,[14] Stefan R. M. Ligtenberg,[13] Adrian Luckman,[15] Scott B. Luthcke,[16] Malcolm McMillan,[1] Rakia Meister,[8] Glenn Milne,[17] Jeremie Mouginot,[18] Alan Muir,[8] Julien P. Nicolas,[7] John Paden,[14] Antony J. Payne,[19] Hamish Pritchard,[20] Eric Rignot,[18,2] Helmut Rott,[21] Louise Sandberg Sørensen,[4] Ted A. Scambos,[22] Bernd Scheuchl,[18] Ernst J. O. Schrama,[23] Ben Smith,[11] Aud V. Sundal,[1] Jan H. van Angelen,[13] Willem J. van de Berg,[13] Michiel R. van den Broeke,[13] David G. Vaughan,[20] Isabella Velicogna,[10,2] John Wahr,[3] Pippa L. Whitehouse,[5] Duncan J. Wingham,[8] Donghui Yi,[24] Duncan Young,[25] H. Jay Zwally[26]

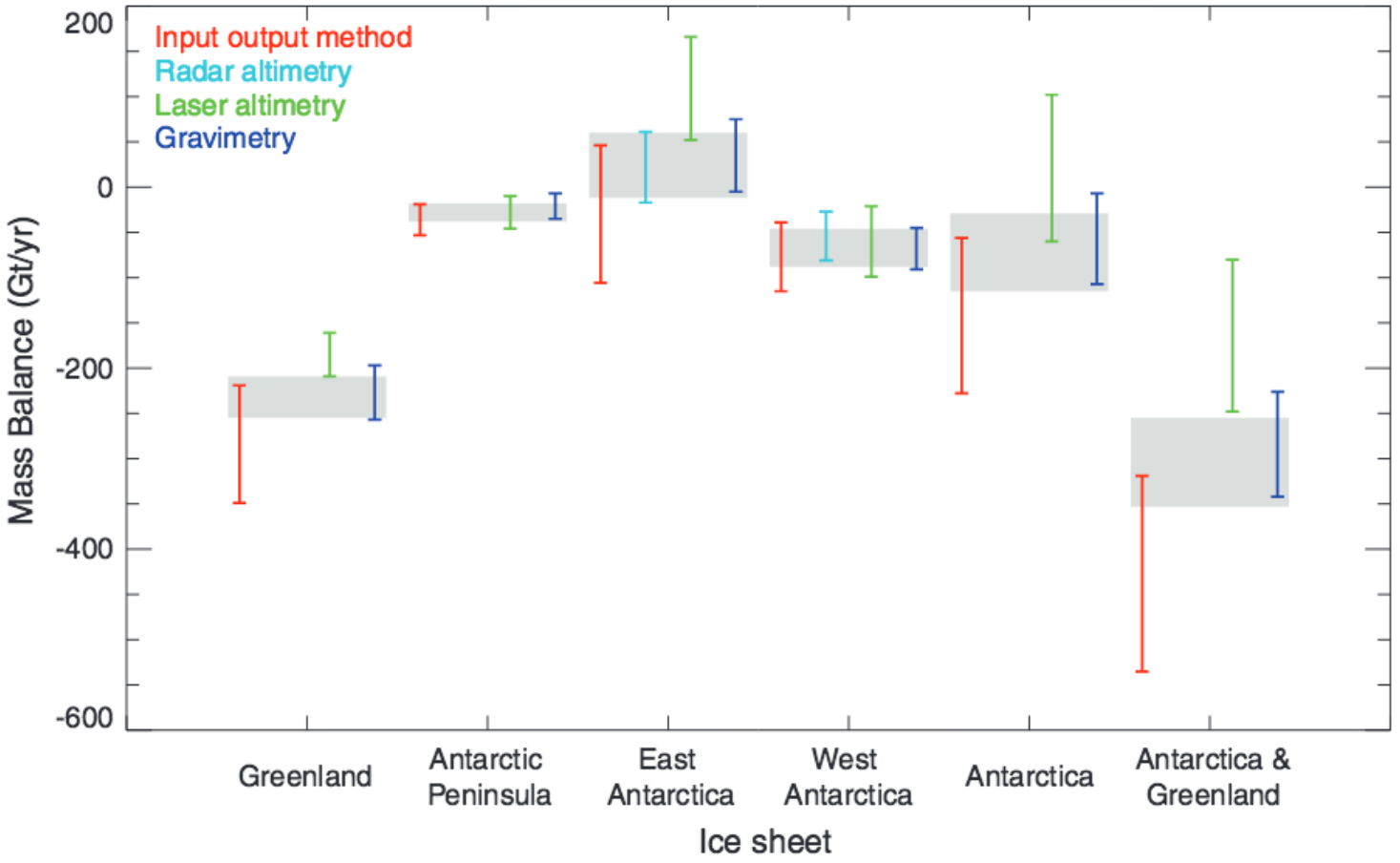


Fig. 3. Intercomparison of mass balance estimates of the GrIS, APIS, EAIS, WAIS, AIS, and the AIS plus GrIS, derived from the four independent geodetic techniques of RA (cyan), IOM (red), LA (green), and gravimetry (blue) over the period 2003 to 2008. Also shown is the reconciled result (gray).

Shepherd et al. Science (47 authors)

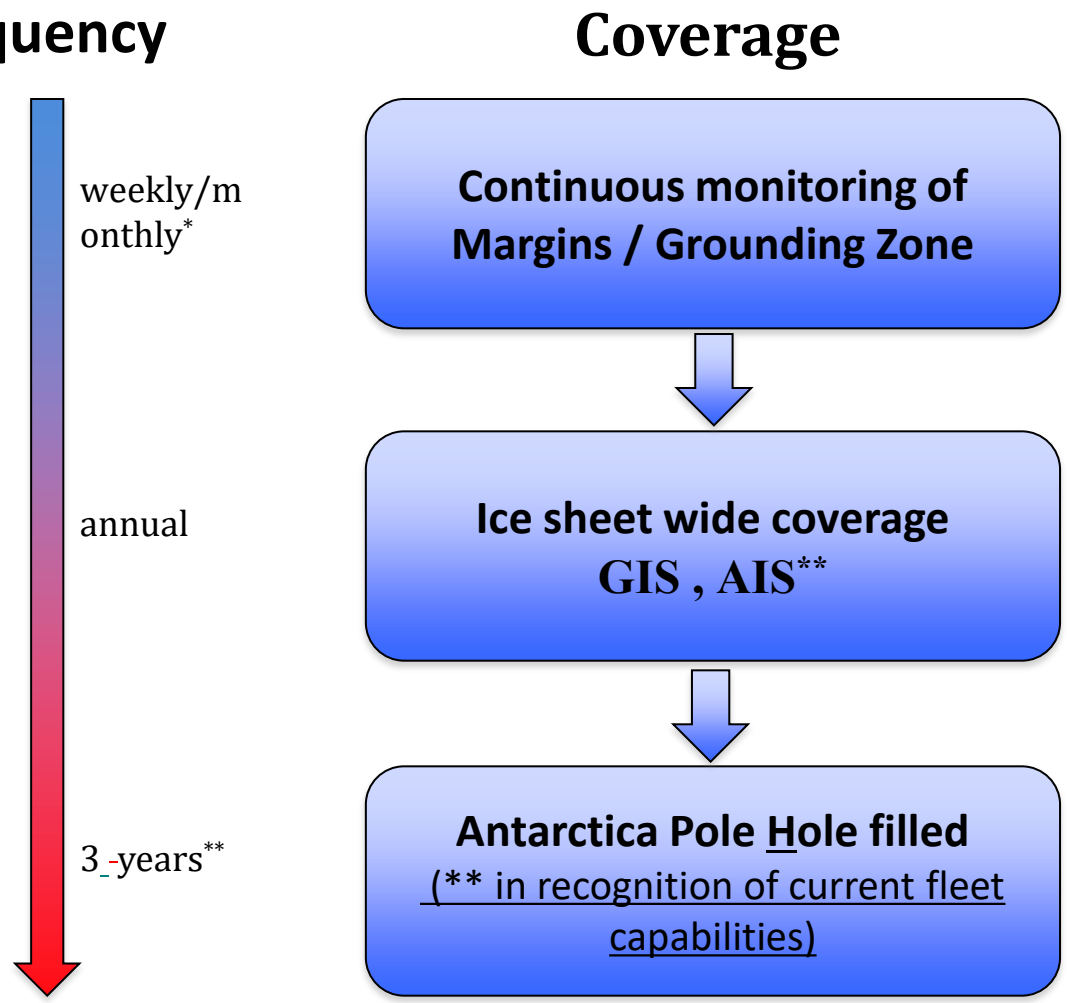
Ice Sheet Acquisition Requirements - PSTG

Key ice sheet science issues include:

Surface elevation change (SEC)
Ice velocity (IV)
Grounding line location (GLL)
Calving front location (CFL)
Ice discharge

	SEC	IV	GLL	CFL
Minimum spatial resolution	1-5 km	100 m – 1 km	100 m – 1 km	100 m – 500 m
Optimum spatial resolution	100 m	50 m	50 m	50 m
Minimum temporal resolution	annual	annual	annual	annual
Optimum temporal resolution	monthly	monthly	monthly	monthly
Minimum Accuracy	0.1-0.5 m/yr	30m/yr	1 km	200 m
Optimum Accuracy	<0.1 m/yr	10 m/yr	-	-
Observations needed	All year	All year	All year	All year

Ice Sheet Acquisition Requirements - PSTG



* Weekly was added here to reflect the 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.

** The 3 year in recognition of current fleet capabilities. More left looking capabilities are being brought online in the future.

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*.

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.

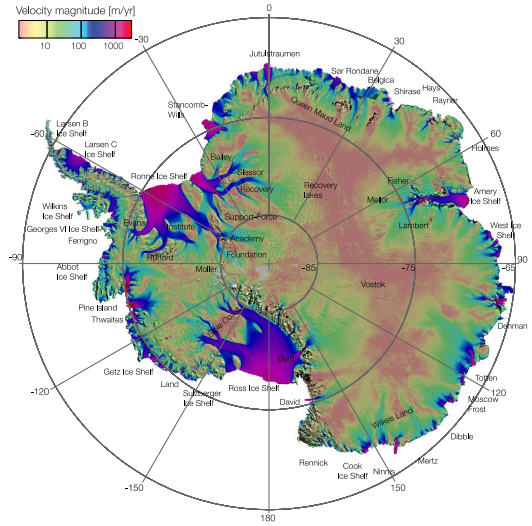
We will publish our findings in the scientific literature.

We do not collect ground truth data for this project but we will share 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

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

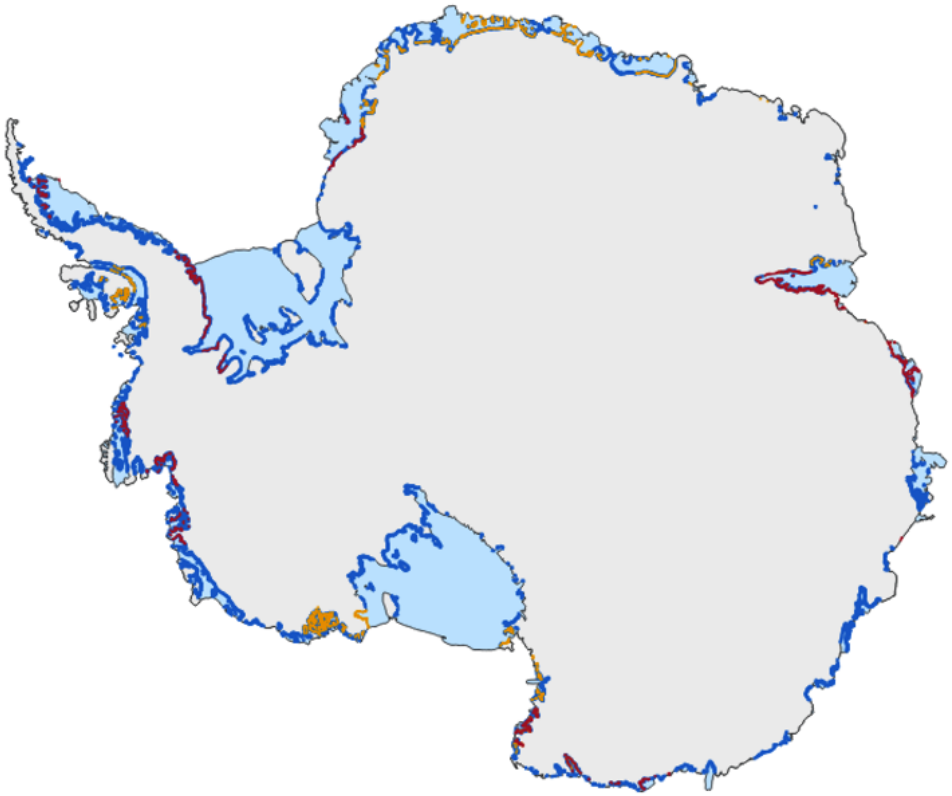
Link
http://nsidc.org/data/NSIDC-0498/

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

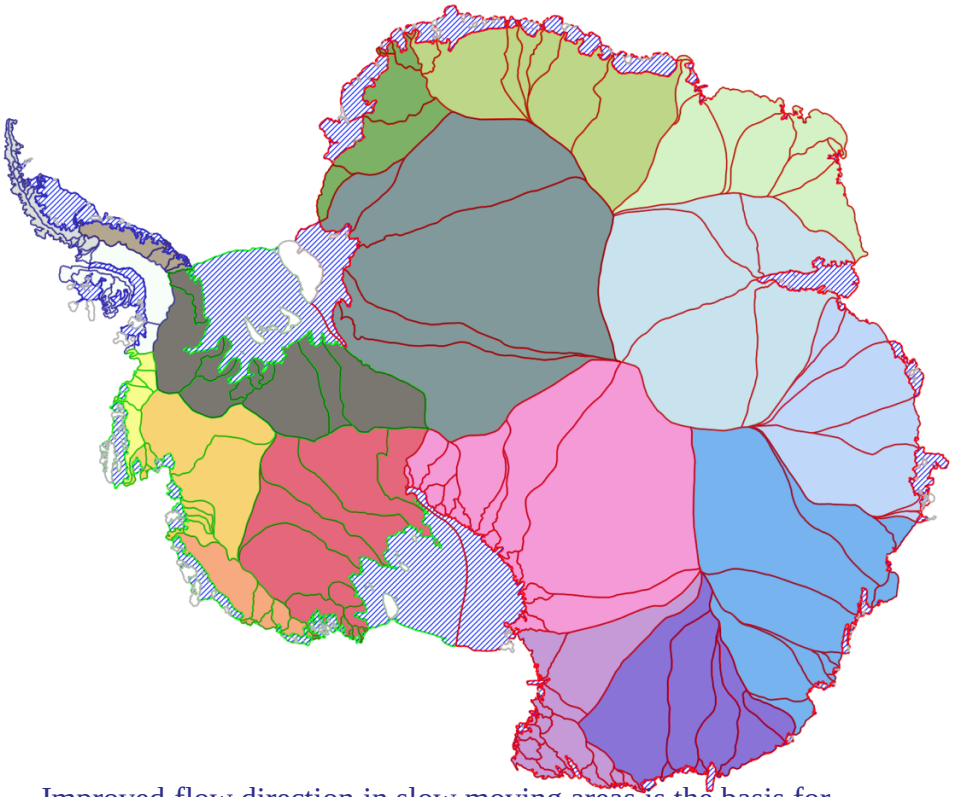
Product
MEaSUREs Antarctic Boundaries for IPY 2007-2009 from Satellite Radar, Version 2

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

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



- 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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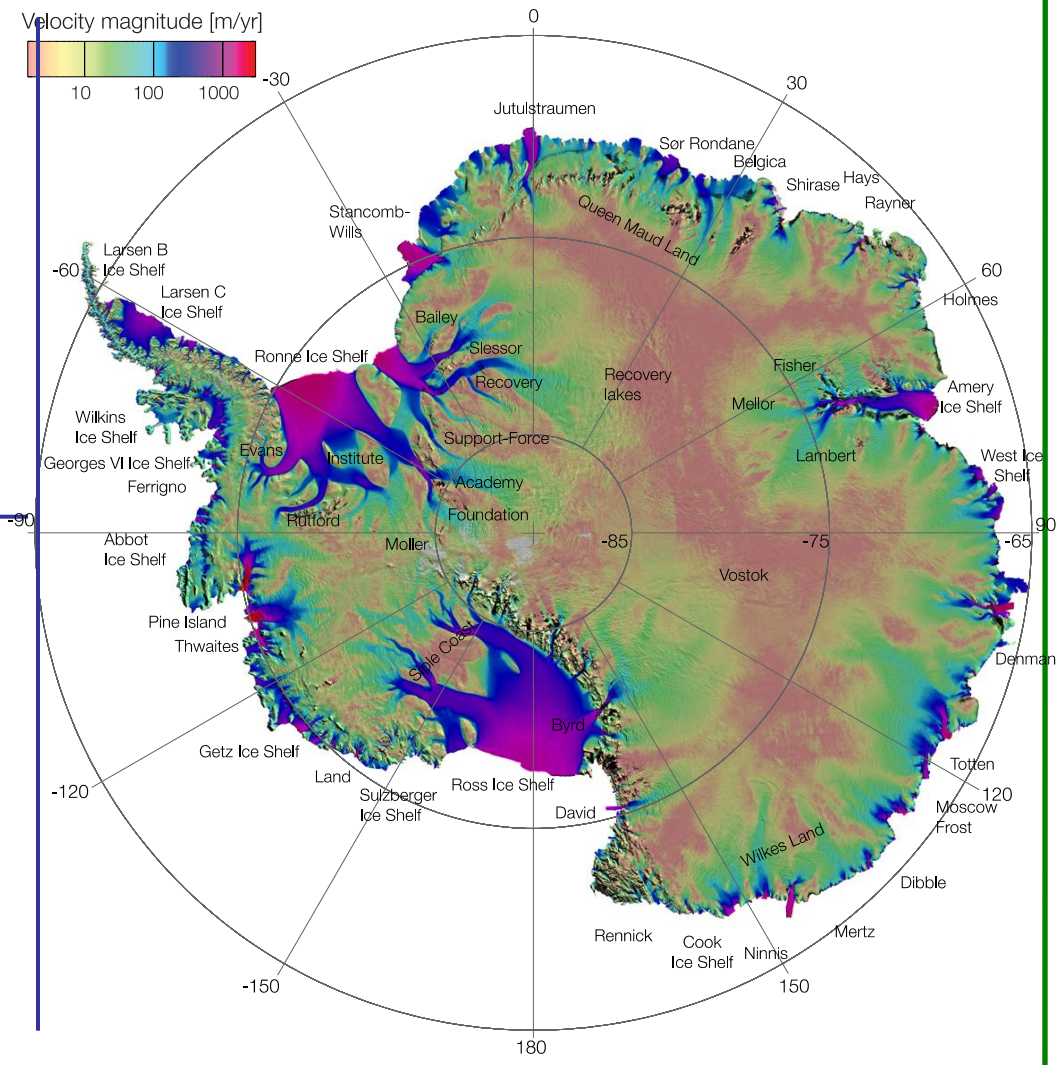
Continent-Wide Ice Velocity Map

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.

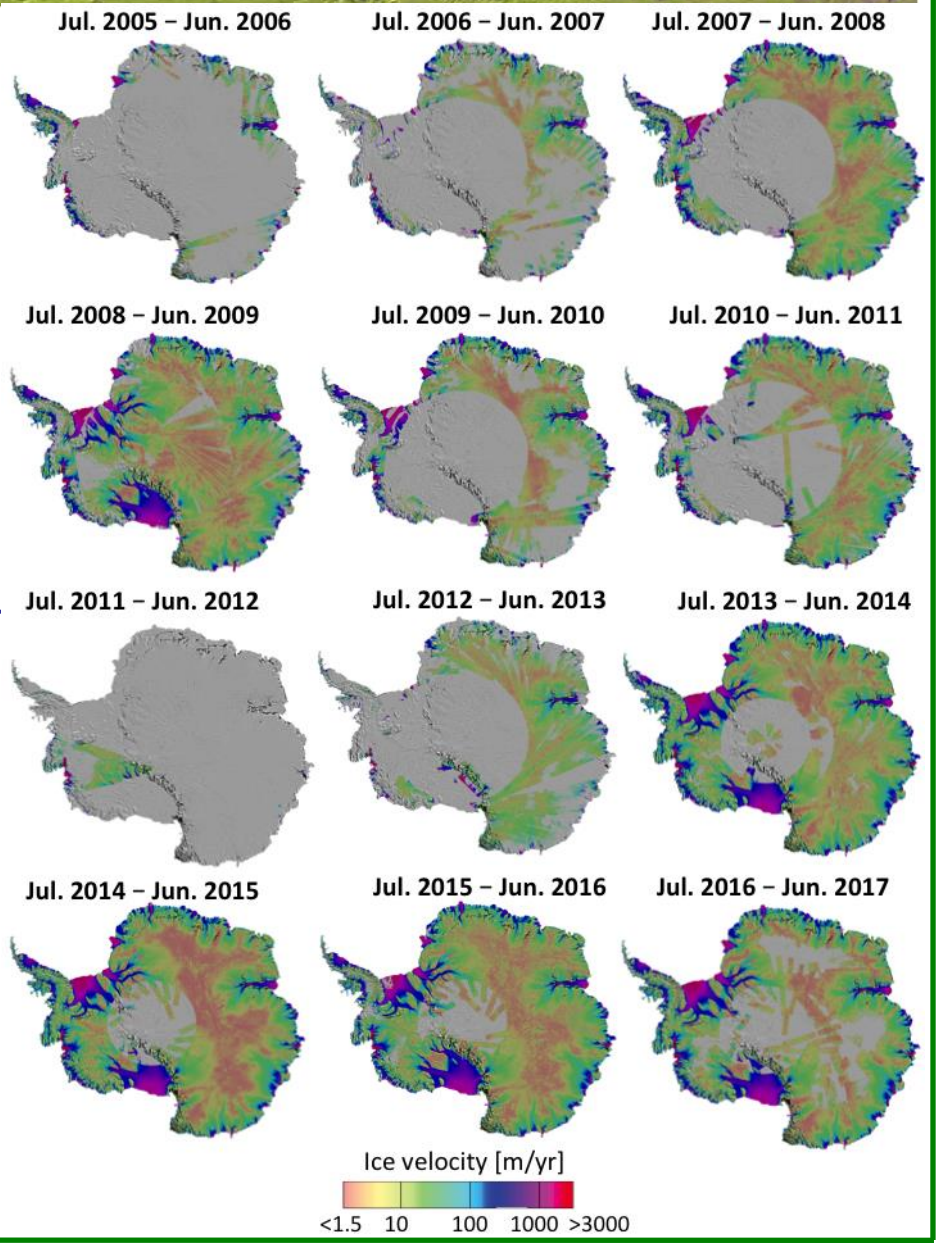
Link
https://nsidc.org/data/NSIDC-0720/

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

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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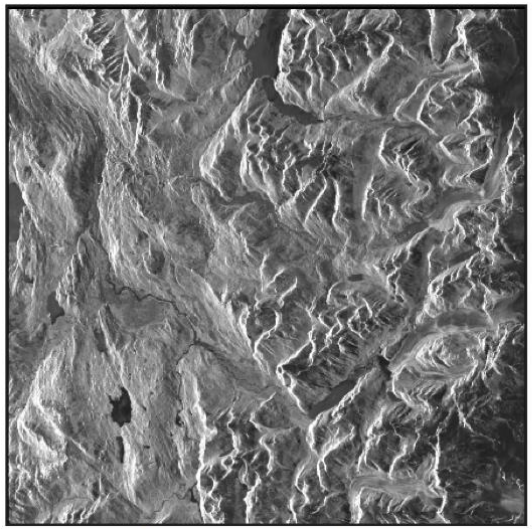
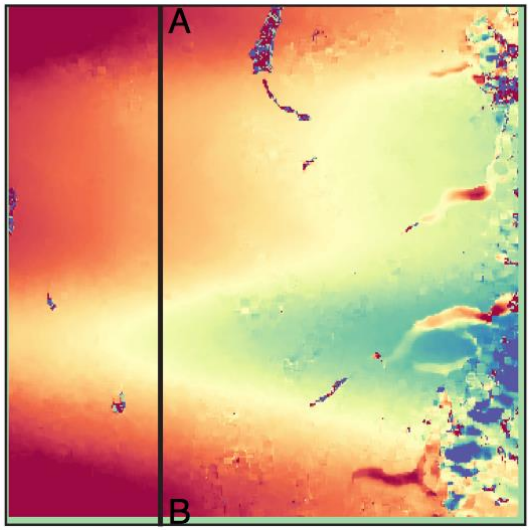
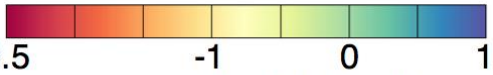
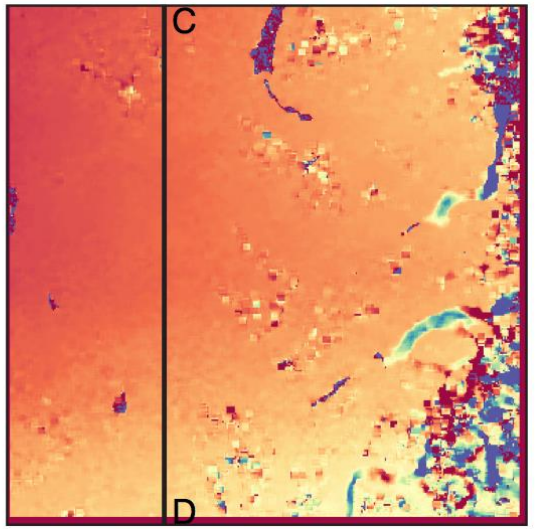


radar power image

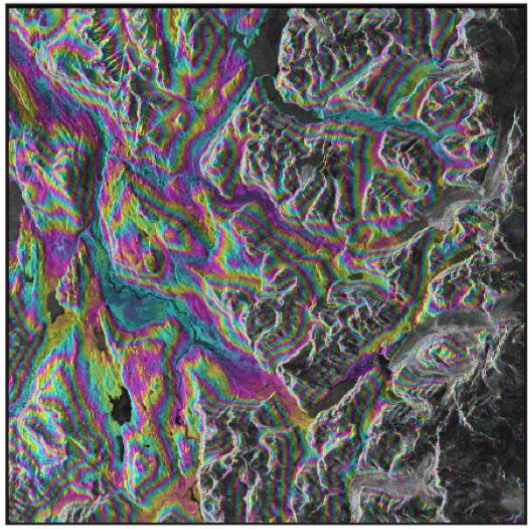




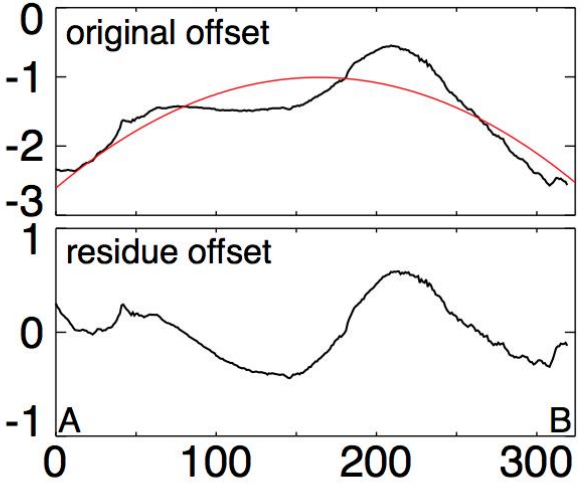
range offset (pixel)

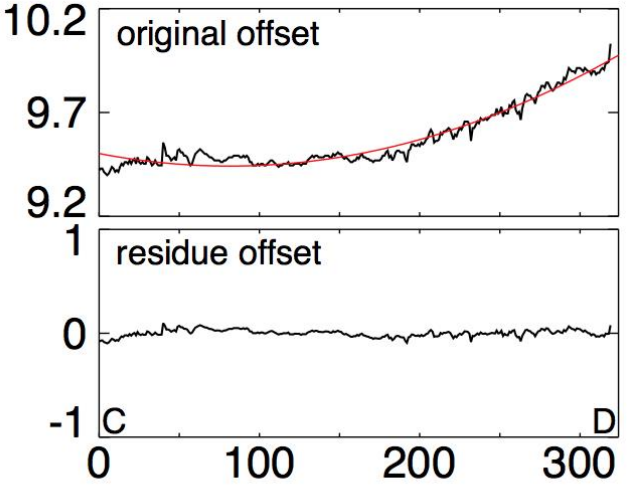


azimuth offset (pixel)



flattened interferogram





2nd order polynomial fit

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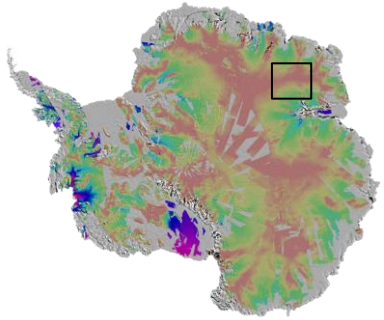
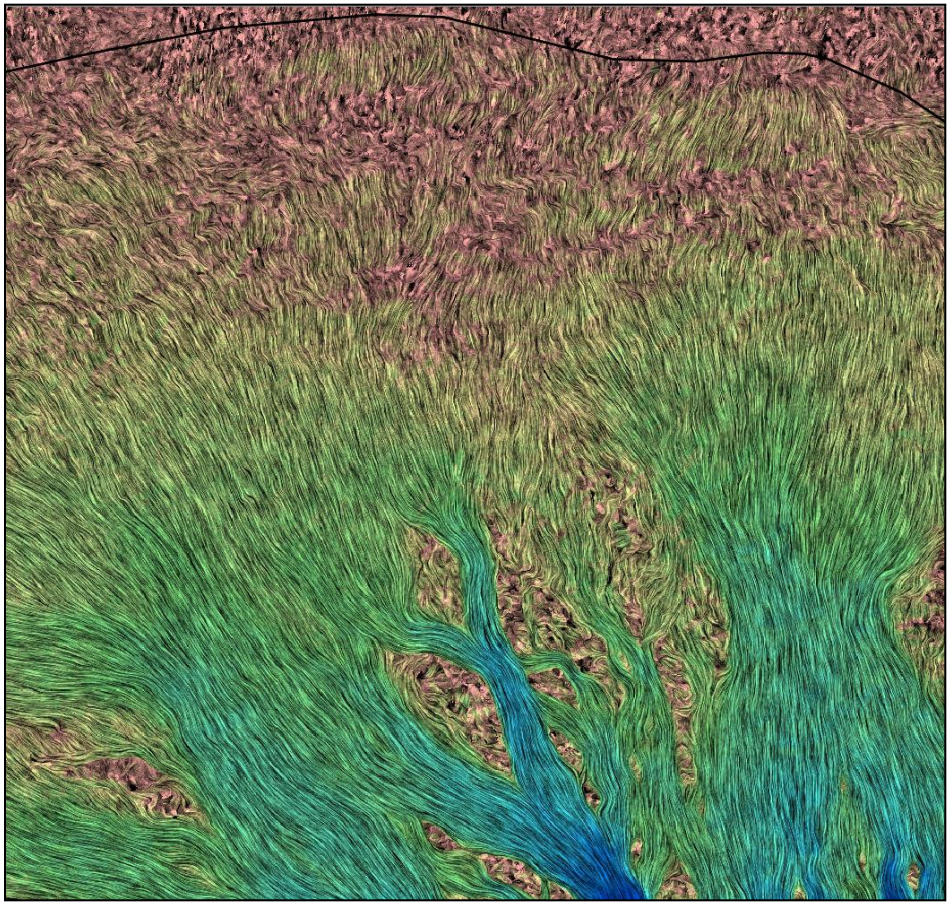
Flow Direction

Speed (km/yr)

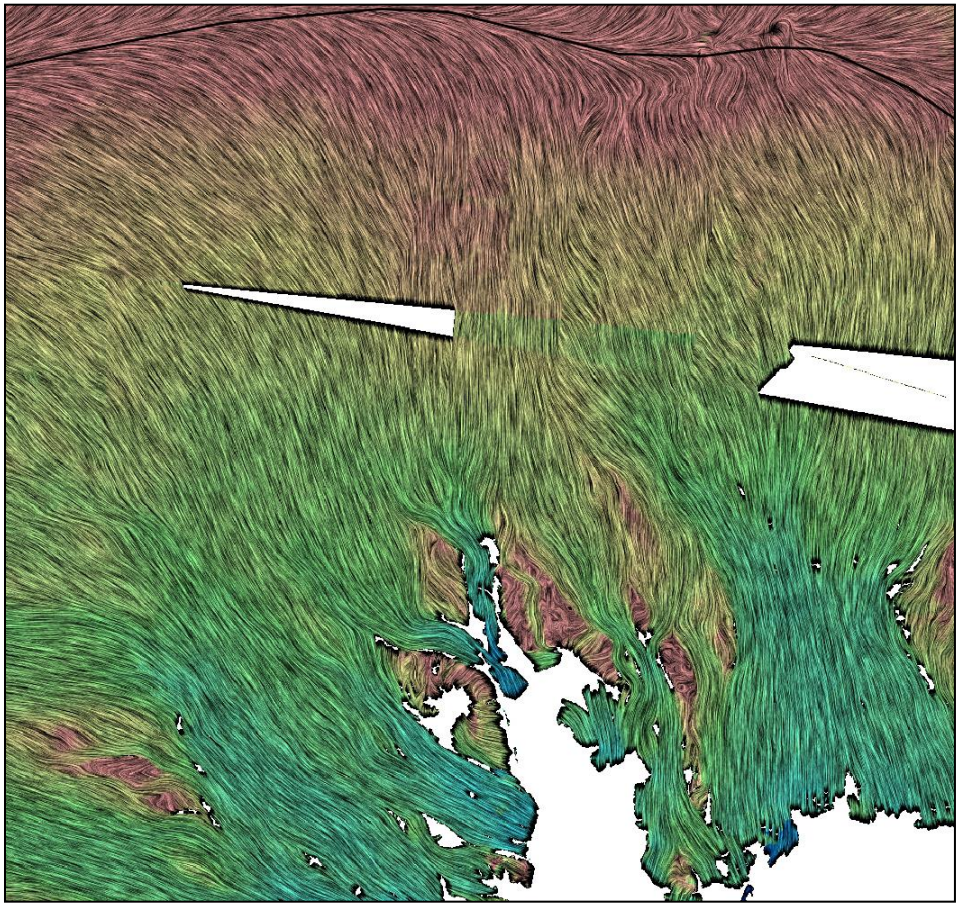
<0.001 0.1 1 >3



Speckle Tracking

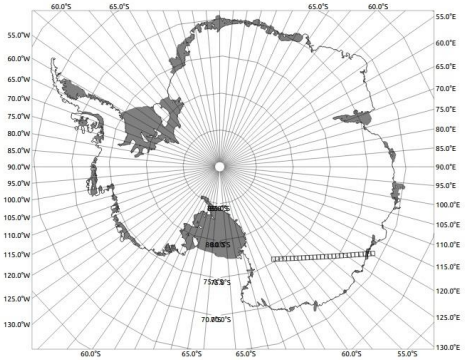


InSAR Phase

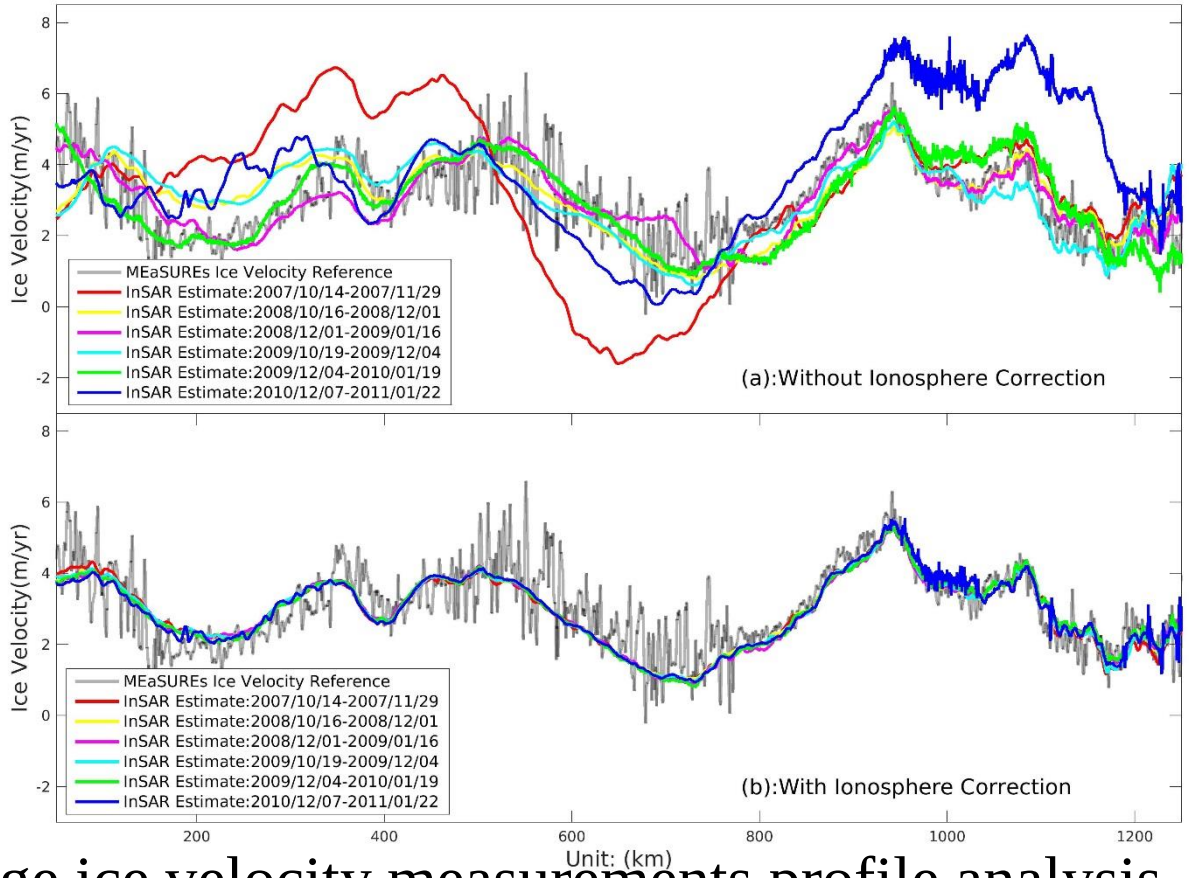


Ionosphere correction

Collaboration with Heming Liao and Franz Meyer, University of Alaska.



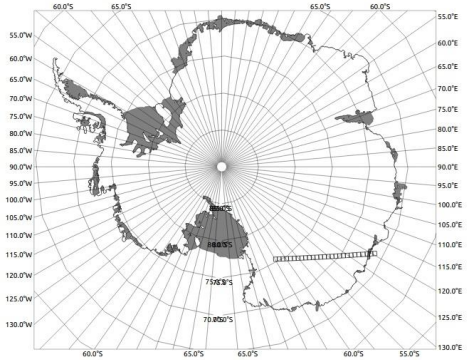
Liao, H., Meyer, F., Scheuchl, B., Mouginot, J., Rignot, E., Joughin, I. (in revision). Ionospheric Correction of InSAR Data for Accurate Ice Velocity Measurement at Polar Regions



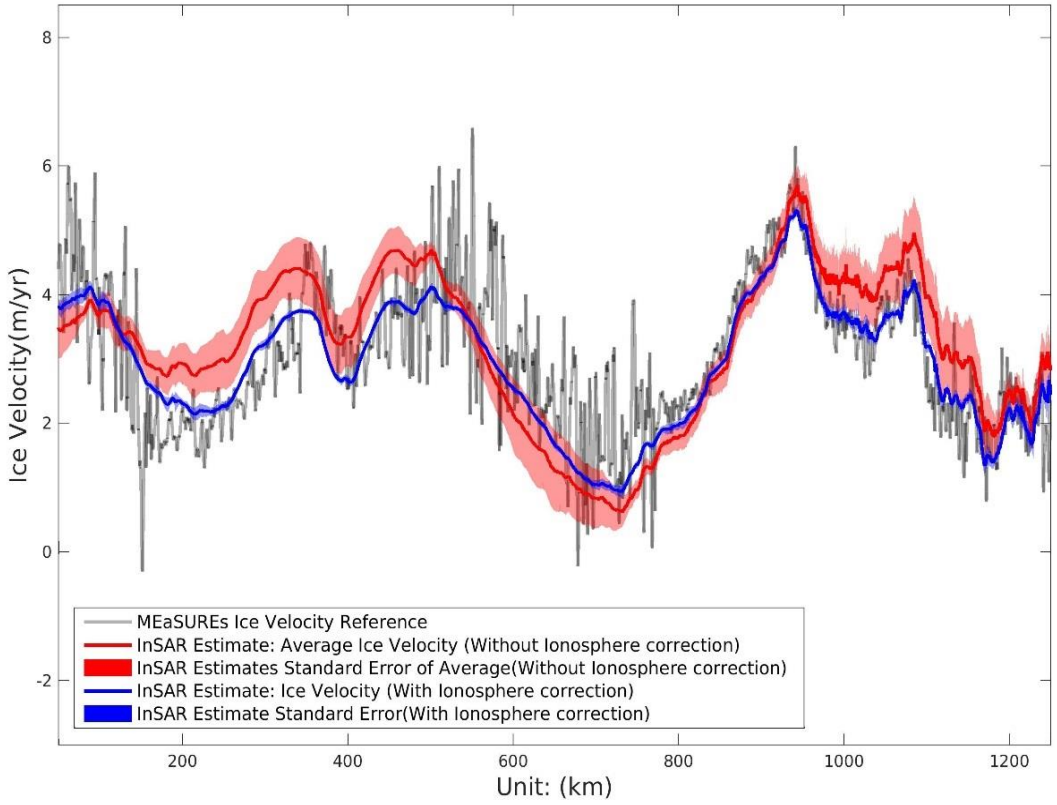
Antarctic time series slant range ice velocity measurements profile analysis without (top) and with ionospheric correction (bottom). Shown in gray is the tracking-based reference ice velocity from MEaSUREs (Mouginot et al., 2012, 2017; Rignot et al., 2011).

Ionosphere correction

Collaboration with Heming Liao and Franz Meyer, University of Alaska.



Liao, H., Meyer, F., Scheuchl, B., Mouginot, J., Rignot, E., Joughin, I. (in revision). Ionospheric Correction of InSAR Data for Accurate Ice Velocity Measurement at Polar Regions



Average ice velocity of non-ionosphere-corrected measurements and its standard error (red line and shading) vs. the ionosphere-corrected ice velocity and its standard error (blue line and shading). Shown in gray is the tracking-based reference ice velocity from MEaSUREs.

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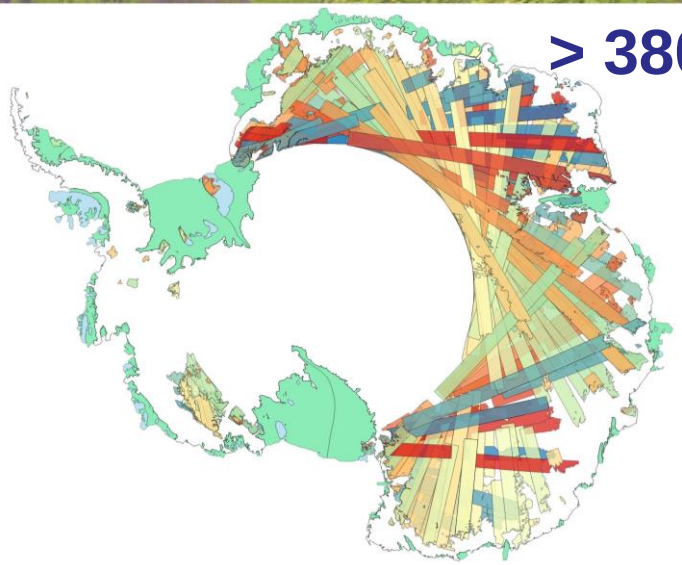
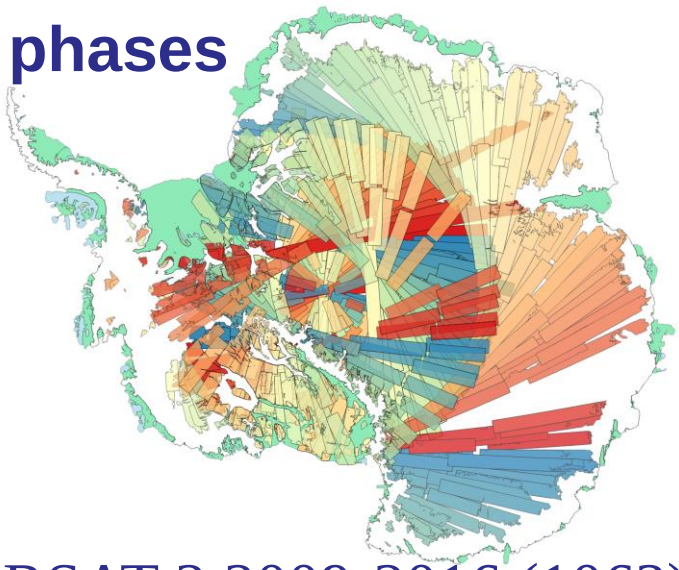
> 3800 unwrapped phases



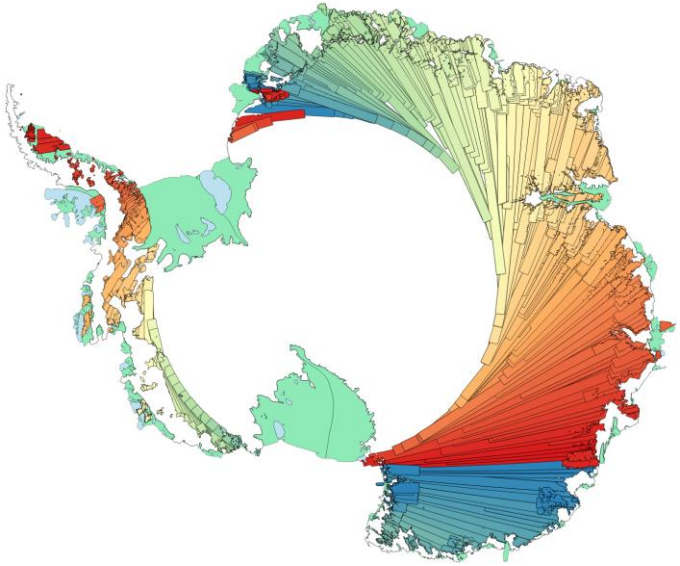
ESA

ENVISAT/ASAR 2007-2009 (627)



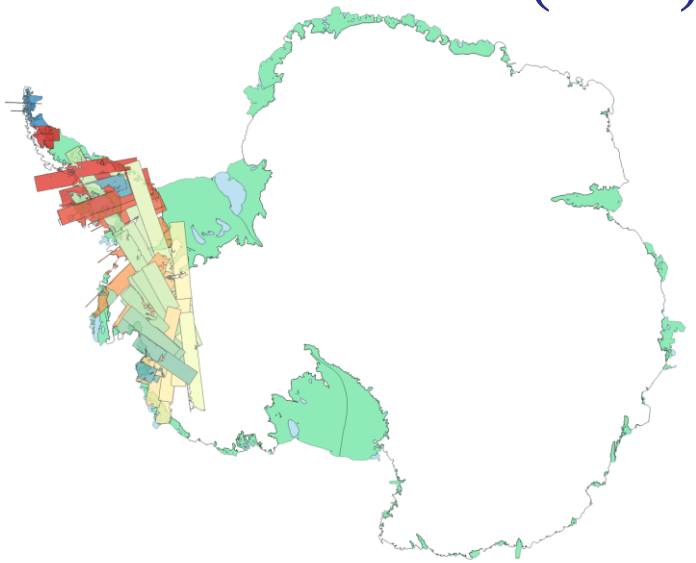
CSA

RADARSAT-2 2009-2016 (1063)



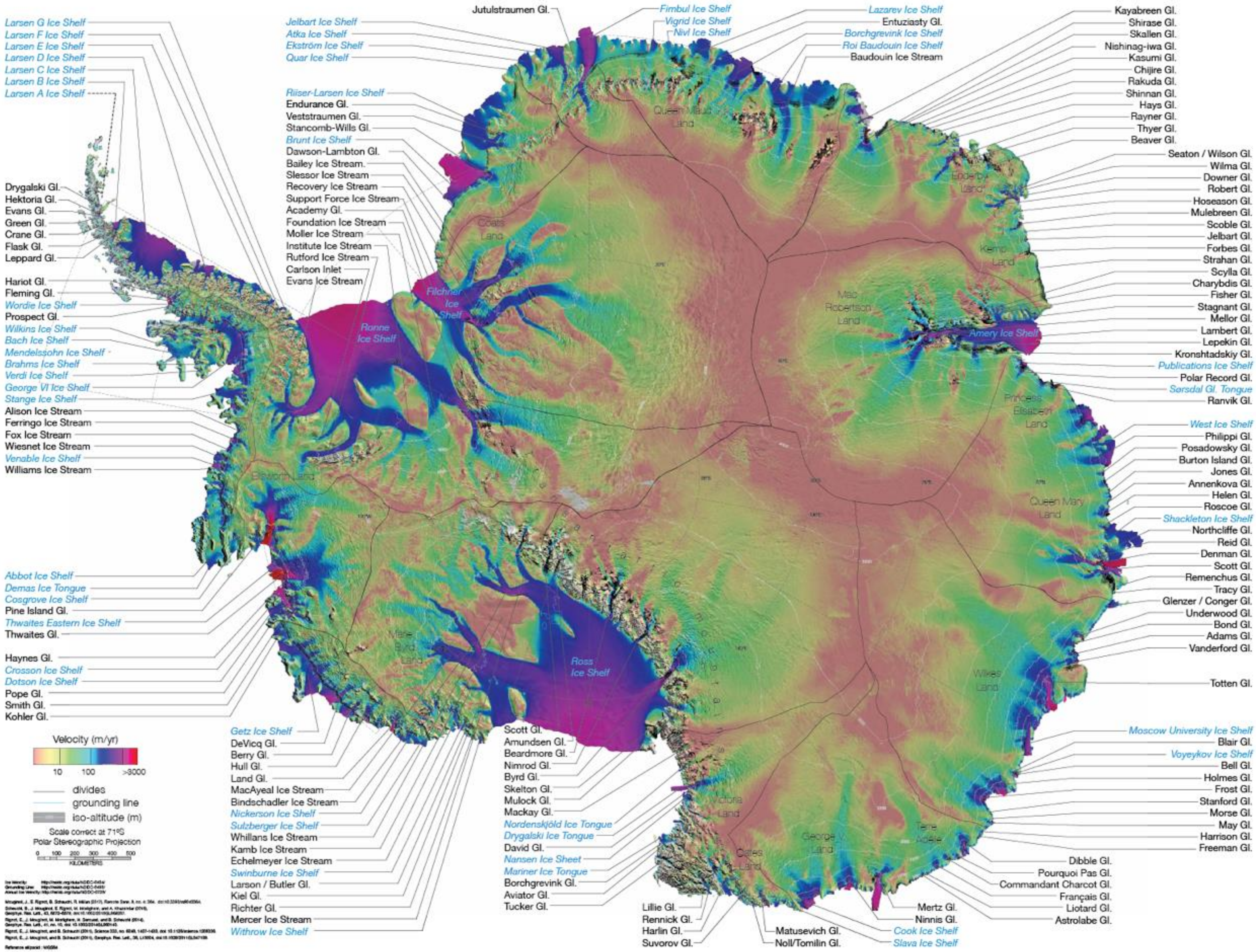
JAXA

ALOS/PALSAR 2006-2009 (2014)



ESA

ERS1996 (164)


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.
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
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
Jutulstraumen Gl.
Fimbul Ice Shelf
Vigrid Ice Shelf
Nivl Ice Shelf
Lazarev Ice Shelf
Entuziasty Gl.
Borchgrevink Ice Shelf
Roi Baudouin Ice Shelf
Baudouin Ice Stream
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.
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.
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.
Dibble Gl.
Pourquoi Pas Gl.
Commandant Charcot Gl.
Français Gl.
Liotard Gl.
Astrolabe Gl.
Mertz Gl.
Ninnis Gl.
Cook Ice Shelf
Slava Ice Shelf
Matusevich Gl.
Noll/Tomilin Gl.
Lillie Gl.
Rennick Gl.
Harlin Gl.
Suvorov Gl.
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.
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
Queen Maud Land
Enderby Land
Coats Land
Kemp Land
Mac Robertson Land
Filchner Ice Shelf
Ronne Ice Shelf
Amery Ice Shelf
Princess Elisabeth Land
Queen Mary Land
Ellsworth Land
Marie Byrd Land
Ross Ice Shelf
Wilkes Land
Victoria Land
Terre Adelie
George V Land
Oates Land

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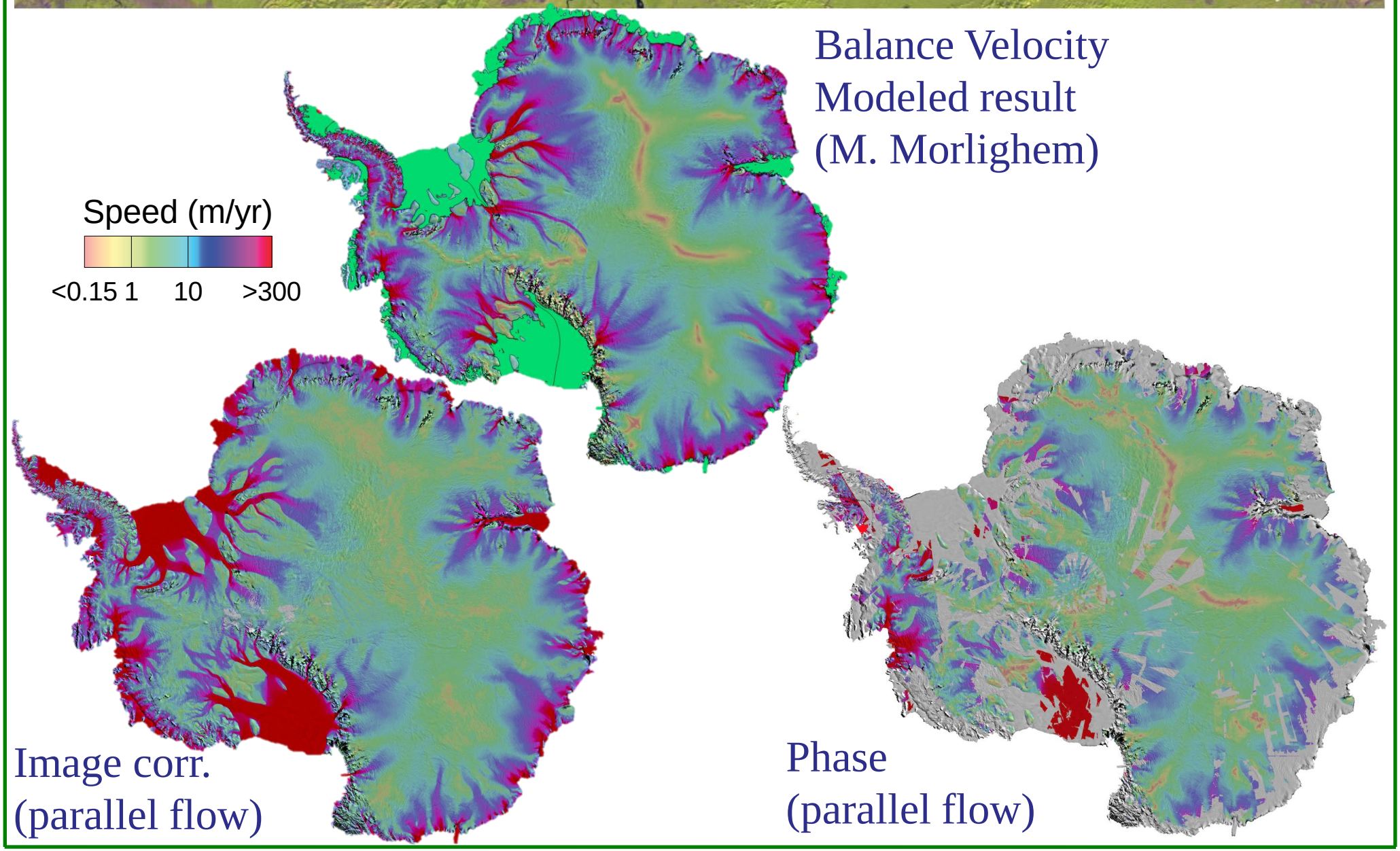

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Canadian High Arctic Research Station (CHARS) 2018

Multi-frequency, polarimetric, scatterometer measurements of sea ice

Goal: collect time series polarimetric L- and C-band backscatter data for first-year and multiyear sea ice types from winter to summer. Sea ice is landfast, enabling fundamental studies of seasonal signature evolution without need for ice tracking.

Data:

- **<u>April (winter)</u>:** airborne survey of first-year and multiyear ice thickness and roughness by EM-induction and laser scanner (baseline conditions).
- **<u>April to June (winter to summer)</u>:**
  - *In situ* collection of polarimetric L- and C-band scatterometer and ice geophysical property data.
  - Coincident ALOS-2 and RADARSAT-2 SAR data.
  - Polarimetric RADARSAT-2 data provided by government of Canada.

Canadian High Arctic Research Station (CHARS) 2018

Multi-frequency, polarimetric, scatterometer measurements of sea ice

L-band

C-band

Specification	C-band	L-band
Centre frequency (GHz)	5.55	1.26
Bandwidth (GHz)	0.5	0.5
Antenna beam-width (°)	5.4	14
Polarizations	Fully-polarimetric (VV, HH, HV, VH)	
Noise floor (dBm²)	-36	-30
Incidence angle range (increments) (°)	21-75 (2)	15-80 (programmable)
Antenna height (m)	2.6	2.5
Range resolution (cm)	30	30
Sampling footprint	0.4m at 17° to 2.6m at 81°	1.2m to ranges of 6m (1/2 far field distance)

- First deployment of L-band scatterometer designed for low temperature environment on sea ice adjacent to CHARS.

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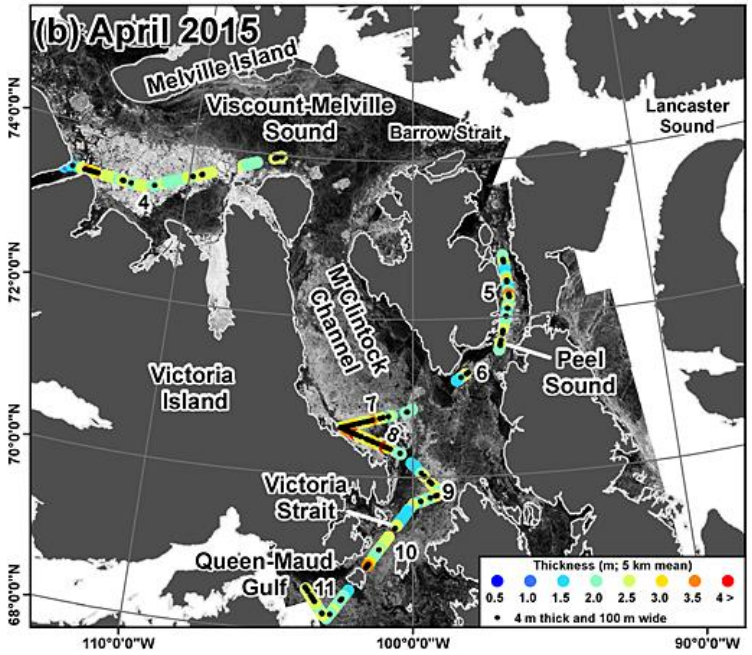
Canadian High Arctic Research Station (CHARS) 2018

Multi-frequency, polarimetric, scatterometer measurements of sea ice

Victoria Strait and M'Clintock Channel regions have been studied extensively since 2015.

Data collection has included Full Polarimetry RADARSAT-2 but limited Full Polarimetry ALOS-2 to date.



Possible location for a super site?

Haas, C., and S. E. L. Howell (2015), Ice thickness in the Northwest Passage, *Geophys. Res. Lett., 42*, 7673–7680, doi:10.1002/2015GL065704.

Conclusions

- Ice Sheets as well as the arctic sea ice are undergoing significant changes in response to a changing climate
- L-band InSAR data make a difference!
- Ice sheet observations should be interferometric stripmap. Prefer at least 3 consecutive cycles (more would be an asset – Super Site consideration).
- 10 m HH/HV is the preferred mode
- HH only would suffice (if this helps to ease downlink)

Thank You

Bernd Scheuchl
Department of Earth System Science
University of California, Irvine
Croul Hall, Irvine, CA 92697-3100
e-mail: bscheuch@uci.edu

Overview of Two Decades of Coordinated Satellite SAR Data Acquisitions over Polar Regions

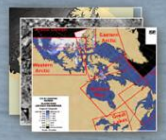
ERS-1/2 (1991-2011)
Envisat ASAR (2002-2012)
ALOS PALSAR-1 (2006-2011)
TerraSAR-X (2007 - present)
TanDEM-X (2008 - present)
RADARSAT-1 (1995-2013)
PALSAR-2 (2014 - present)
COSMO-SkyMed (2007 - present)
RADARSAT-2 (2007 - present)
Sentinel-1A (2014 - present)

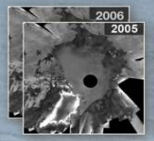
Background Photo: Ice Shelf in the Weddell Sea *Credit:* Ralph Timmermann, Alfred Wegener Institute, Germany

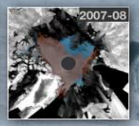
COOPERATION and COORDINATION

Over the past two decades, the collection of large amounts of satellite radar imagery over vast polar regions has become an outstanding example of international cooperation among space agencies and the polar science community. Building on the successful cooperation and coordination during the International Polar Year, the Polar Space Task Group (PSTG) has recently re-enacted the SAR Coordination Working Group. This Group provides coordination among space agencies operating SAR satellites to facilitate acquisition and distribution of fundamental SAR datasets. It also contributes to the development of data products in support of cryospheric scientific research and applications.


RADARSAT-1 Arctic Ocean, ASAP Project (CSA, NASA, 1996-2007)


RADARSAT-1 Cdn. Ice Centre archive data (CSA, EC/CIS, 1996-2013)

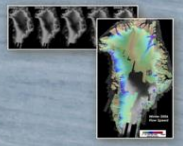




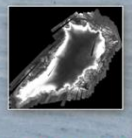
Envisat ASAR Arctic Ocean and Greenland (ESA, 2005-08)

Thematic SAR data collection for selected regions

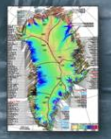

ERS-1 SAR Greenland mosaic and DEM [Ref. 1] (ESA, NSIDC 1993)


RADARSAT-1 InSAR Greenland, backscatter maps, ice velocity (CSA, 2000-01, 2005-09)


TerraSAR-X Greenland outlet glaciers (DLR, 2005-06)

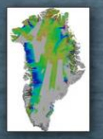


ALOS PALSAR Greenland and Arctic Ocean (JAXA, 2008-2009)

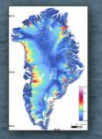

Var. SAR sensors Greenland ice velocity [Ref. 4] (IPY, 2008/09)


TanDEM-X Greenland InSAR map (DLR 2011-13)


RADARSAT-1 Greenland InSAR, dB map (CSA, 2013)


RADARSAT-2 Greenland InSAR (CSA, 2014)


COSMO-SkyMed Greenland (ASI, 2013/14)

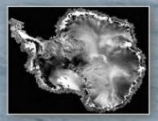

Sentinel-1 Greenland ice velocity [Ref.5] (ESA, 2015)


TerraSAR-X Greenland Outlet glaciers (DLR, 2014-15)

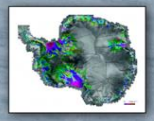
International Polar Year

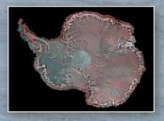
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

Polar Space Task Group - SAR Coordination Working Group >>>


RADARSAT-1 Antarctic Mapping Mission-1 (CSA, 1997)


RADARSAT-1 Antarctic Mapping Mission 2 (CSA, 2000)

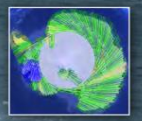

Ice flow dynamics and mass balance, various sources, [Ref. 2]


RADARSAT-2 dual-pol Antarctic Mapping Mission (CSA, MDA, 2007)


ALOS PALSAR Antarctica & Southern Ocean (JAXA 2008-09)

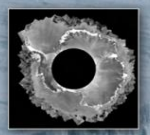

Envisat ASAR Southern Ocean Ice (ESA, 2010)

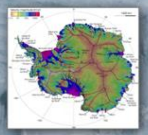
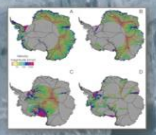

TerraSAR-X InSAR Mapping Antarctica glaciers (DLR, 2008-13)


RADARSAT-2 Antarctica InSAR (CSA, MDA, 2013)

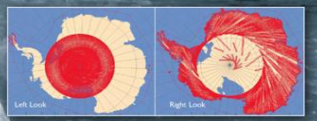

RADARSAT-2 Antarctica InSAR (CSA, MDA, 2014)


ALOS PALSAR-2 SAR Global mapping, incl. polar regions (JAXA)


Envisat ASAR GMM Antarctica (ESA 2004)



Antarctica Ice flow products [Ref. 3]

TanDEM-X Antarctica Mapping Mission DLR, 2013-2016





COSMO-SkyMed Antarctic regions (ASI, 2013-2016)

Polar imaging activities and polar interests are common to several space agencies in support of their policy mandate, science priorities, and science community requirements. Coordinated activities can be highly beneficial. Over the next years, they will continue to provide multi-frequency observations over polar regions. These coordinated activities will ensure high-frequency of revisit in the case of coherent and interoperable datasets from various missions, and they will strive for workload distribution across agencies - consistent with mission constraints and capabilities.

REFERENCES:
[Ref. 1] Fahnestock et al. 1997
[Ref. 2] Rignot et al. 2006
[Ref. 3] Rignot et al. 2011
[Ref. 4] Rignot & Mouginot 2012
[Ref. 5] Nagler et al. 2015

NOTE:
This graphic was prepared on behalf of the Polar Space Task Group's SAR Coordination Working Group. The contributions and advice received from the working group members is gratefully acknowledged. The summary information presented here is not exhaustive. It reflects the status of plans and actual SAR data collections as of 2015.
For further information: http://www.wmo.int/pages/prog/sat/pstg-sarcwg_en.php

Concept & design: Dirk Werle (2015)

Polar Space Task Group: http://www.wmo.int/pages/prog/sat/pstg_en.php
SAR Coordination Working Group: http://www.wmo.int/pages/prog/sat/pstg-sarcwg_en.php

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Processing Status ALOS PALSAR - Antarctica