K&C Phase 4 – Status report

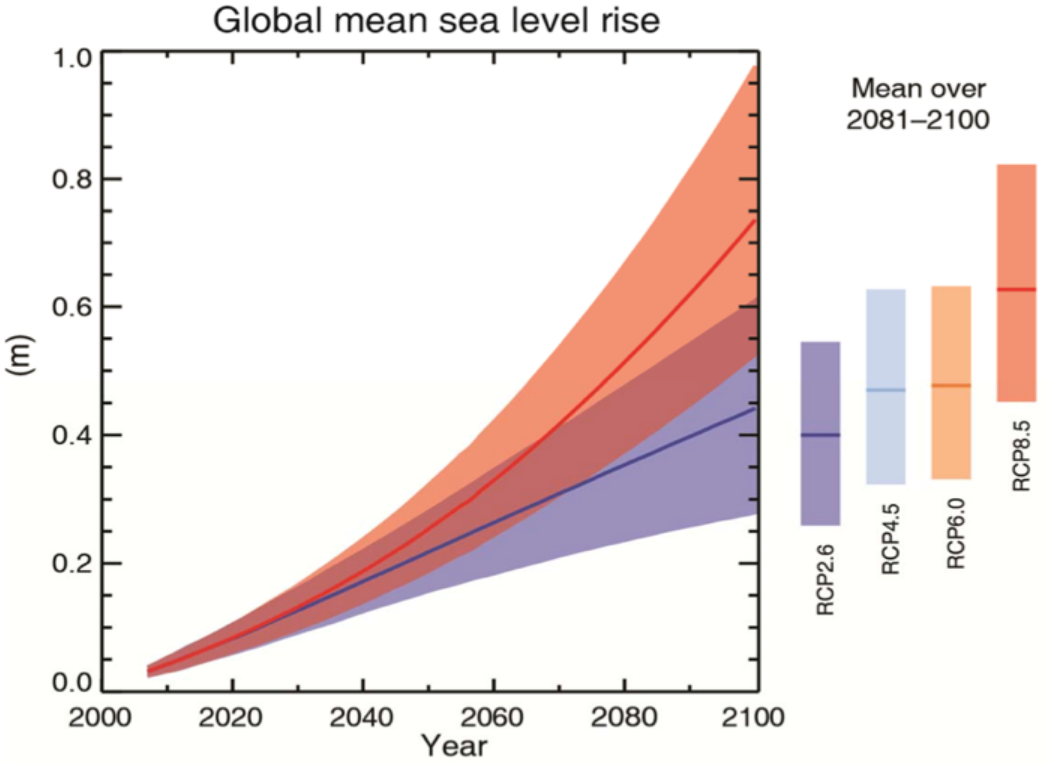
Ice Sheet Monitoring using ALOS-2

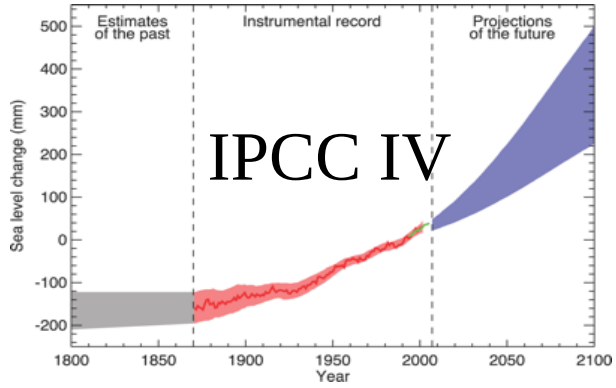
Bernd Scheuchl[1], Jeremie Mouginot[1], Eric Rignot[1,2]

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

Science Team meeting #22
Tokyo, Japan, February 16-18, 2016

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,[18,2] John Wahr,[3] Pippa L. Whitehouse,[5] Duncan J. Wingham,[8] Donghui Yi,[24] Duncan Young,[25] H. Jay Zwally[26]

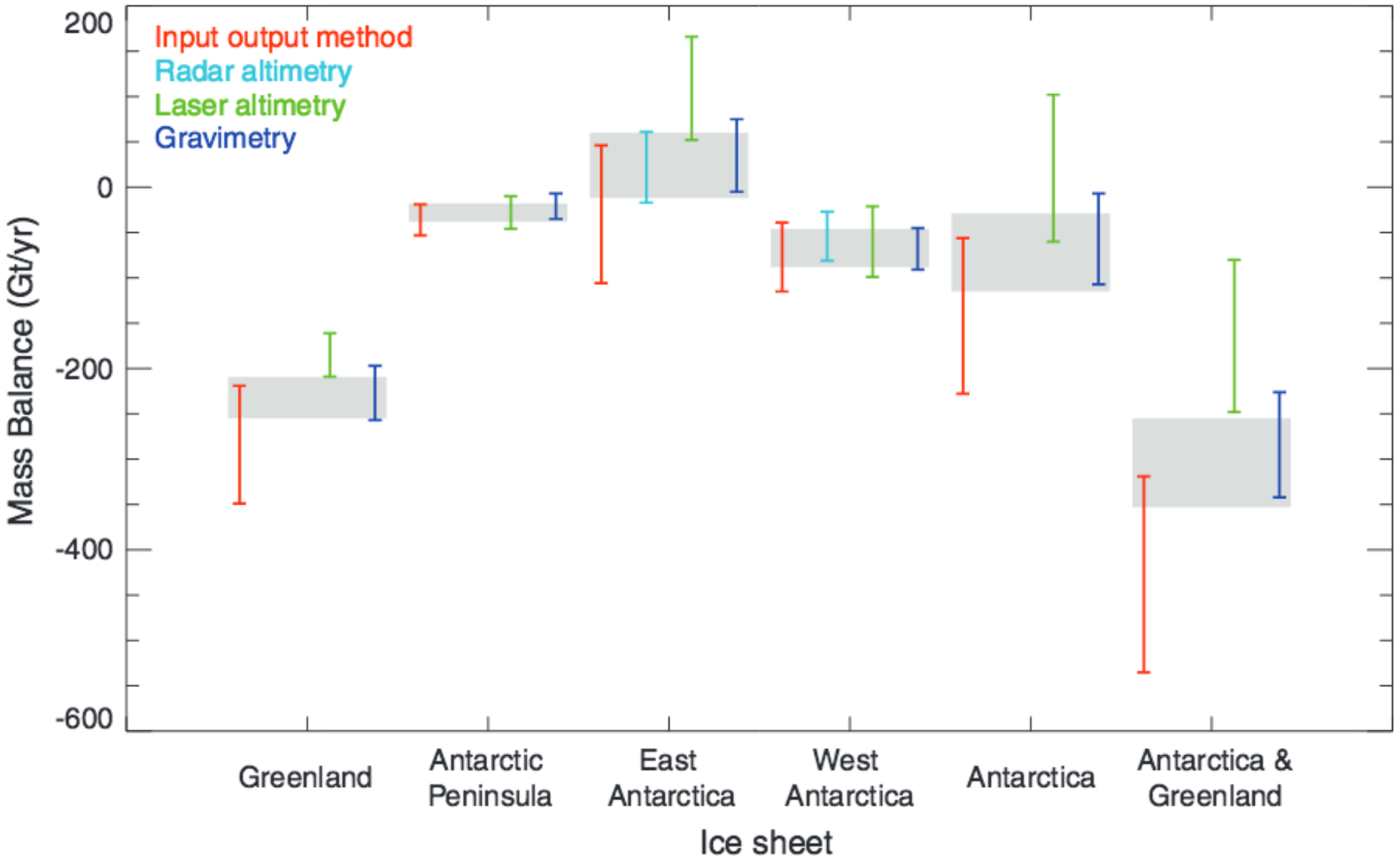
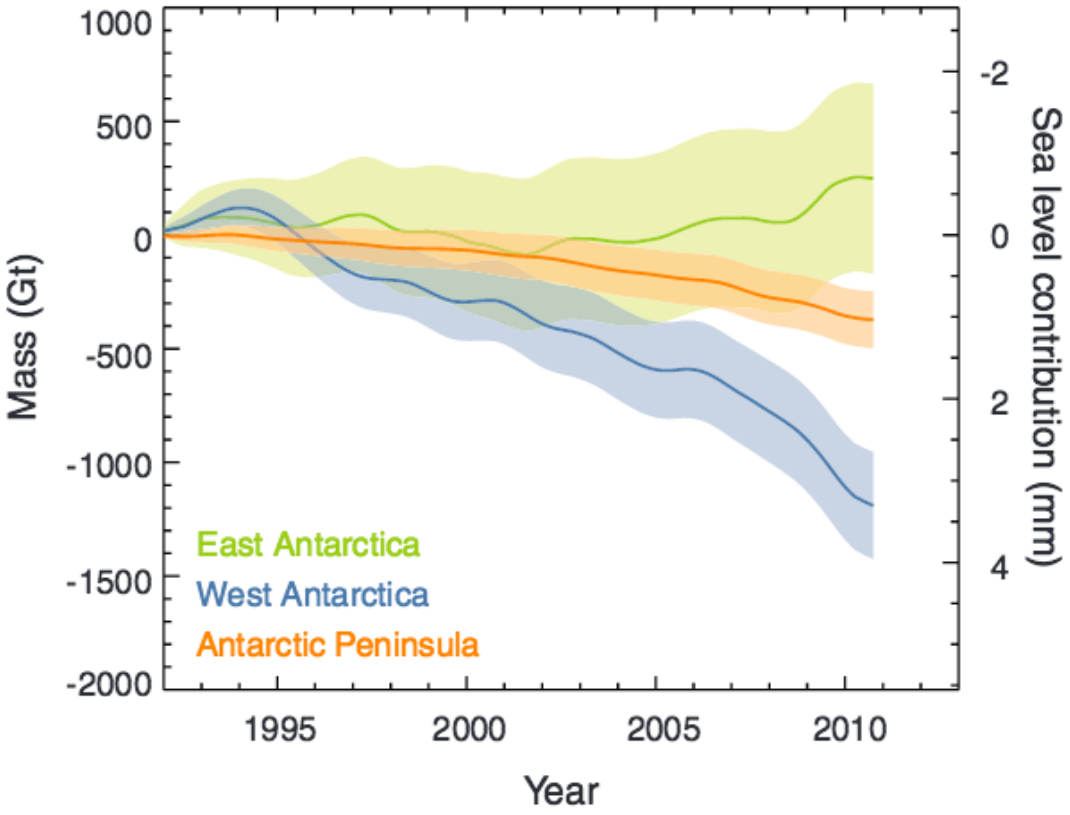


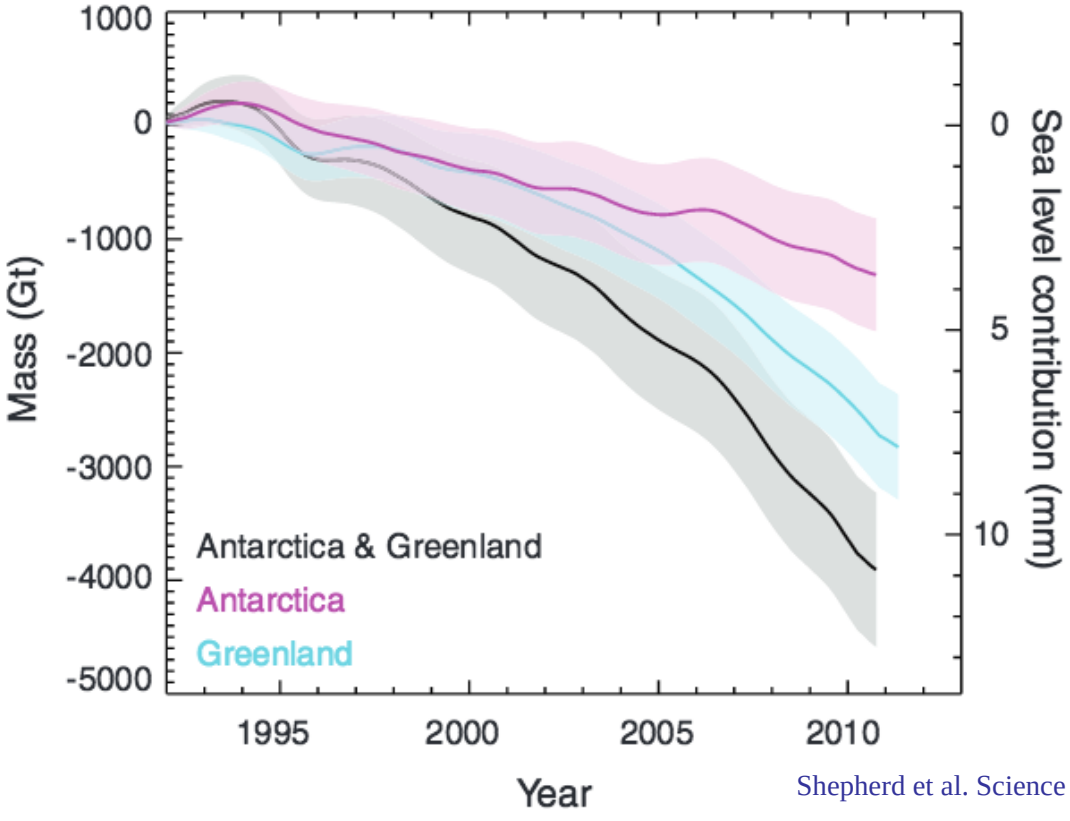
Fig. 3. Intercomparison of mass balance estimates of the GrIS, APIS, EAIS, WAIS, AIS, and the AIS plus GrIS, derived from the four independent geodetic techniques of RA (cyan), IOM (red), LA (green), and gravimetry (blue) over the period 2003 to 2008. Also shown is the reconciled result (gray).

Shepherd et al. Science (47 authors)

Background

Cumulative mass changes for Antarctica and Greenland and equivalent sea level contribution





Shepherd et al. Science

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 outline and objectives

We are interested in continental scale coverage. Appreciating the program data quotas, we focus on selected regions. Within the BOS glacier movement regions covered we have prioritized regions as follows:

- Amundsen Sea Embayment (ASE) West Antarctica
- Antarctic Peninsula
- Totten Glacier – East Antarctica
- Ross and Ronne Ice Shelves (left looking regions)
- Western Greenland
- Other areas in coastal Antarctica

Access to BOS data for all regions may not be possible. Working with JAXA, we will develop an order plan to maximize the impact of the available data.

ALOS

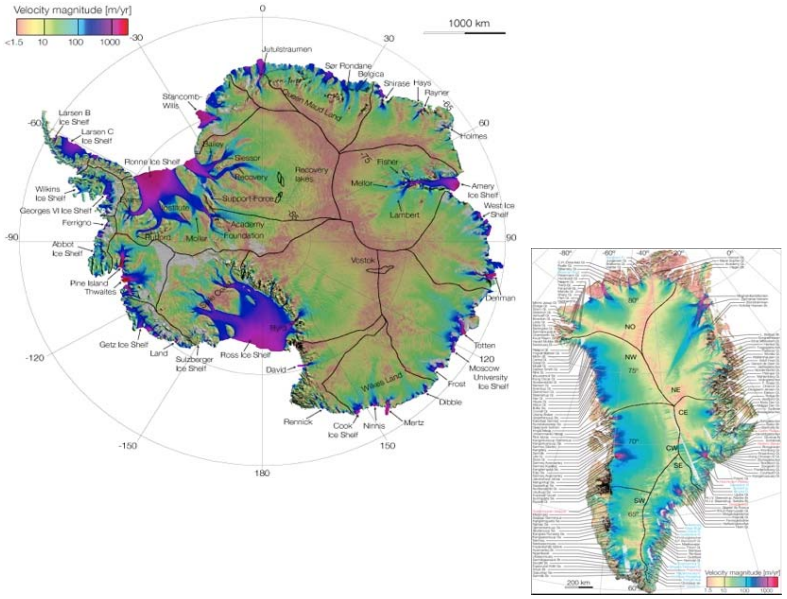
K&C Initiative

An international science collaboration led by JAXA

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: 4 missions went offline in relatively short order – resulting in a data gap.
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

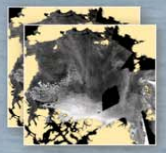
Overview of Two Decades of Coordinated Satellite SAR Data Acquisitions over Polar Regions

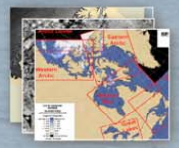
ERS-1/2 (1991-2011)
Envisat ASAR (2002-2012)
ALOS PALSAR-1 (2006-2011)
TerraSAR-X (2007 - present)
TanDEM-X (2008 - present)
RADARSAT-1 (1995-2013)
PALSAR-2 (2014 - present)
COSMO-SkyMed (2007 - present)
RADARSAT-2 (2007 - present)
Sentinel-1A (2014 - present)

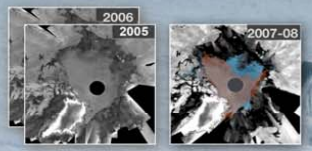
Background Photo: Ice Shelf in the Weddell Sea. Credit: Ralph Timmermann, Alfred Wegener Institute, Germany

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)

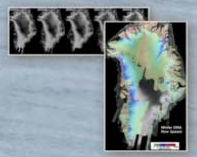

RADARSAT-1 Cdn. Ice Centre archive data (CSA, EC/CIS, 1996-2013)



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

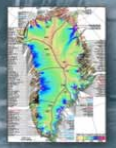
Thematic SAR data collection for selected regions


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)

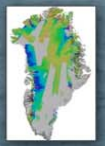

TerraSAR-X Greenland outlet glaciers (DLR, 2005-06)


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

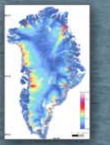

Var. SAR sensors Greenland ice velocity [Ref. 4] (IPY, 2008/09)


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)

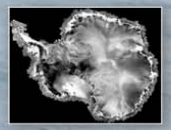

Sentinel-1 Greenland ice velocity [Ref.5] (ESA, 2015)


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

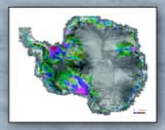
International Polar Year

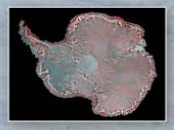
1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018

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


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


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

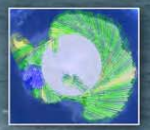

Ice flow dynamics and mass balance, various sources, [Ref. 2]


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


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

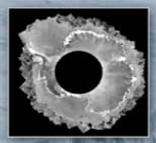

Envisat ASAR Southern Ocean Ice (ESA, 2010)

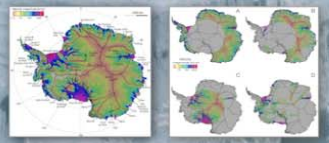

TerraSAR-X InSAR Mapping Antarctica glaciers (DLR, 2008-13)


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

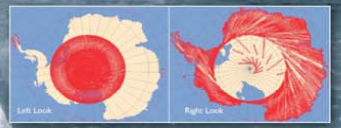

RADARSAT-2 Antarctica InSAR (CSA, MDA, 2014)


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, 2013-2014




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)

CSA ASC · esa · DLR · agenzia spaziale italiana · JAXA · Norsk Romsenter · NASA

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

Results and significant findings thus far

We present results for Antarctica and Greenland to highlight the value of L-band SAR data for ice sheet monitoring:

- Greenland velocity map
  - Zachariae Isstrom
- Antarctica velocity map & Grounding line
  - Antarctica Peninsula
  - Totten Glacier, East Antarctica
  - Amundsen Sea Embayment, West Antarctica

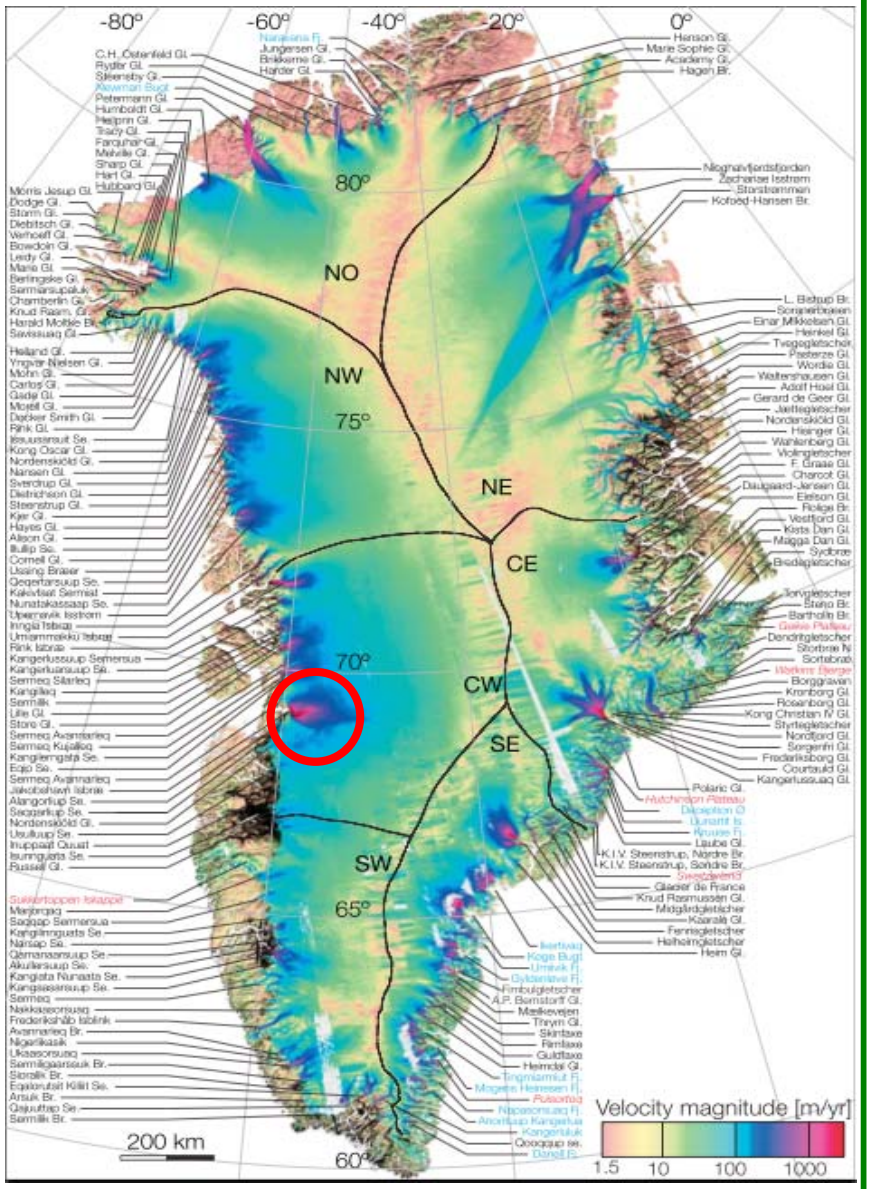
Processing status of ALOS and ALOS-2 data

IPY Velocity Map Greenland

Shown on the right is a continent-wide ice sheet map that used data acquired in 2008 and 2009

The Greenland ice sheet is undergoing significant change. One extreme example is Jakobshavn Isbrae (red circle):

- Increase in speed (from 4km/yr in 1992 to 18km/yr in 2014)
- Ice front retreat (about 56 km in 150 years)
- Elevation loss (ice volume loss)



Rignot, E. and J. Mouginot (2012), Ice flow in Greenland for the International Polar Year 2008–2009, Geophys. Res. Lett., 39, L11501, doi:10.1029/2012GL051634.

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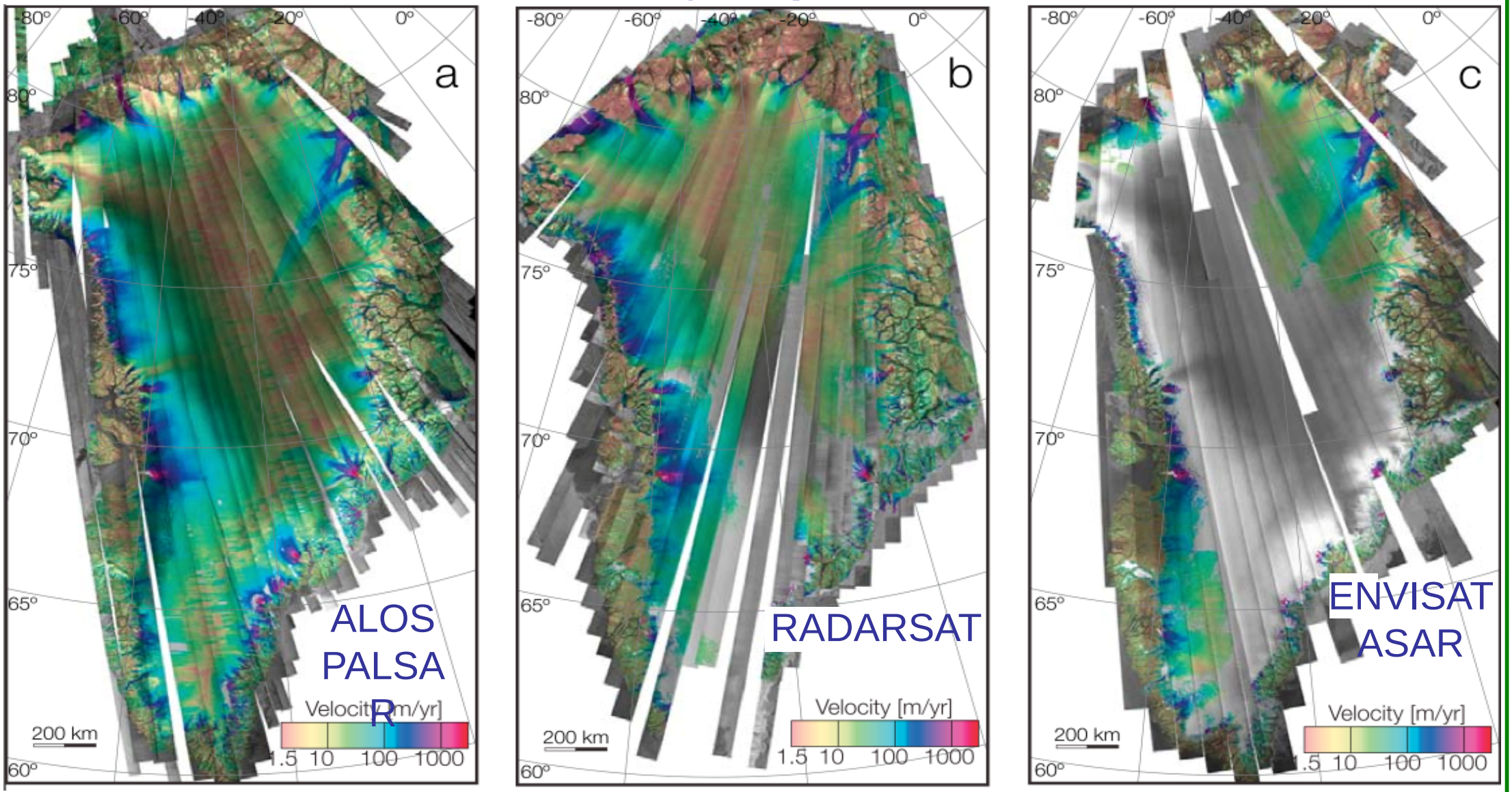
IPY Velocity Map Greenland



Rignot, E. and J. Mouginot (2012), Ice flow in Greenland for the International Polar Year 2008–2009, Geophys. Res. Lett., 39, L11501, doi:10.1029/2012GL051634.

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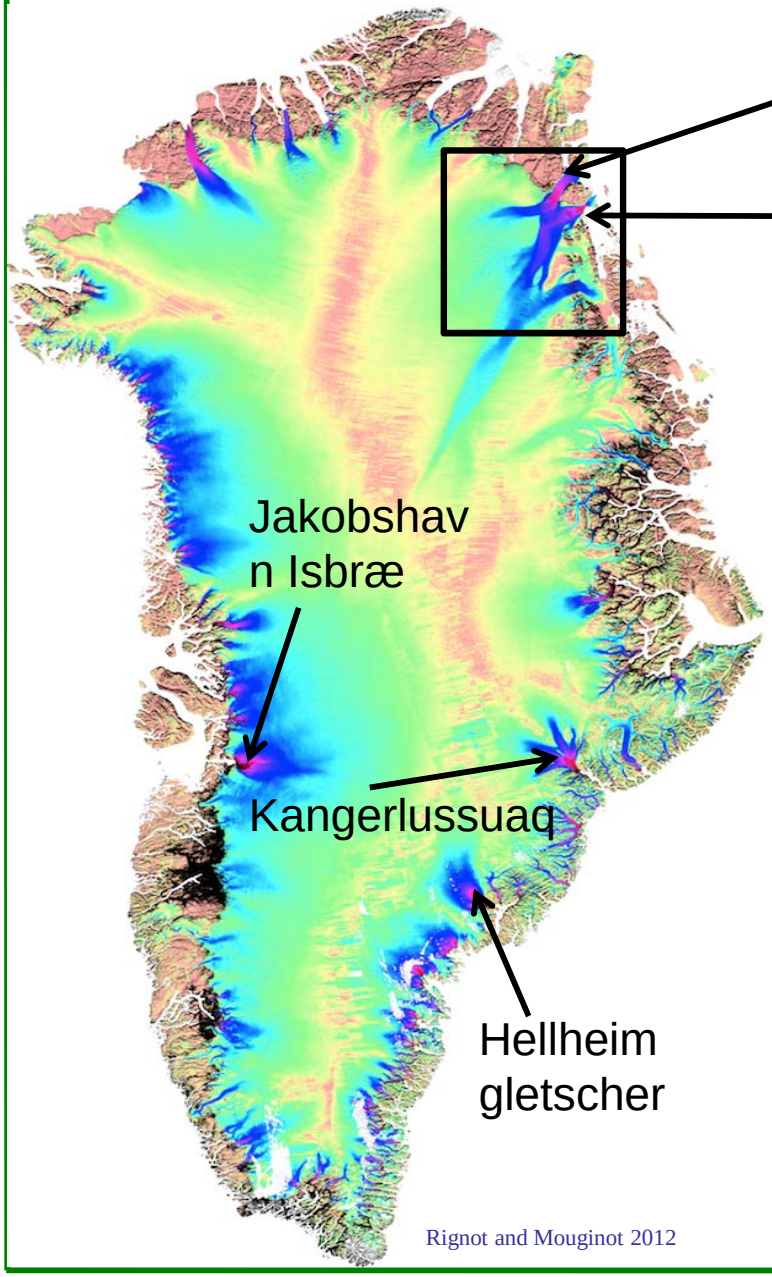
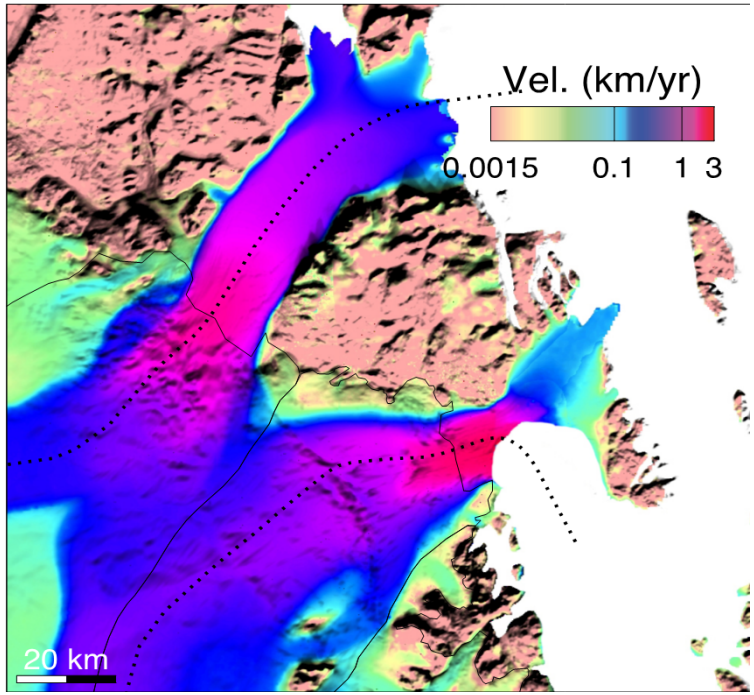
North East Greenland Ice Sheet



Rignot and Mouginot 2012

Nioghalvfjerdsfjorden
(79 North)
Zachariæ
Isstrøm

Basin:
198,380 km^2
12% of GrIS



Sensors used:

- **Landsat**
- **ERS**
- **RADARSAT**
- **ALOS/PALSAR**
- **ENVISAT/ASAR**
- **RADARSAT-2**
- **TerraSAR-X**
- **TanDEM-X**
- **COSMO-SkyMeD**
- **Sentinel-1a**

Mouginot et al. 2015

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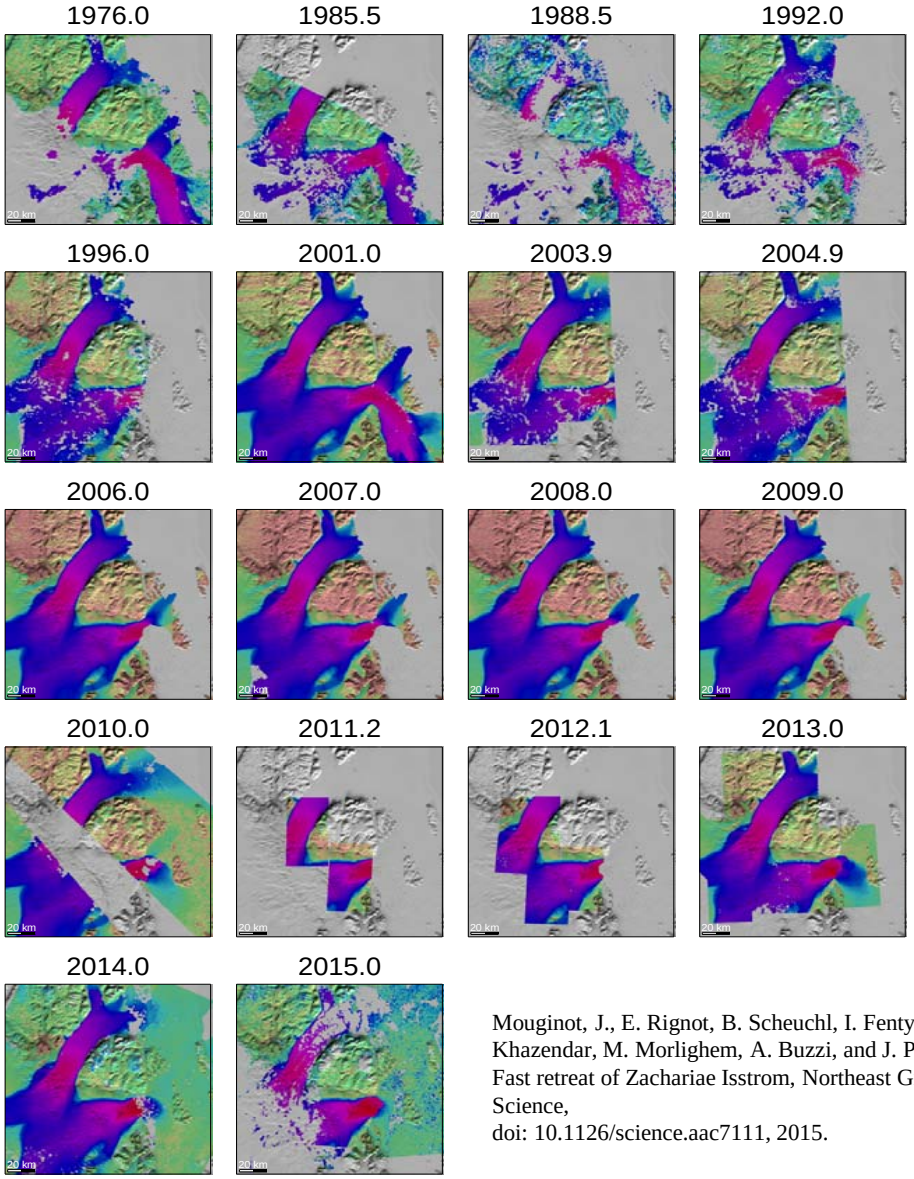
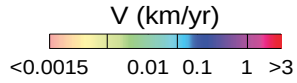
Surface ice velocities





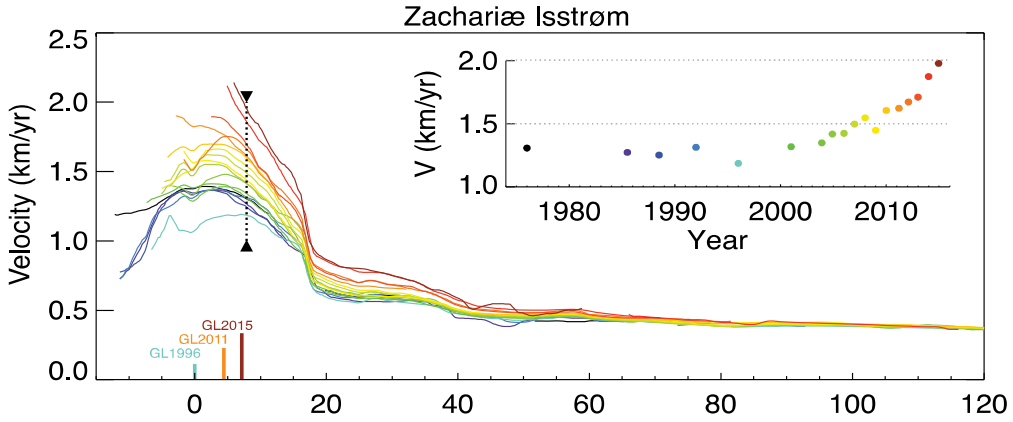
Mouginot, J., E. Rignot, B. Scheuchl, I. Fenty, A. Khazendar, M. Morlighem, A. Buzzi, and J. Paden, Fast retreat of Zachariae Isstrom, Northeast Greenland, Science,
doi: 10.1126/science.aac7111, 2015.

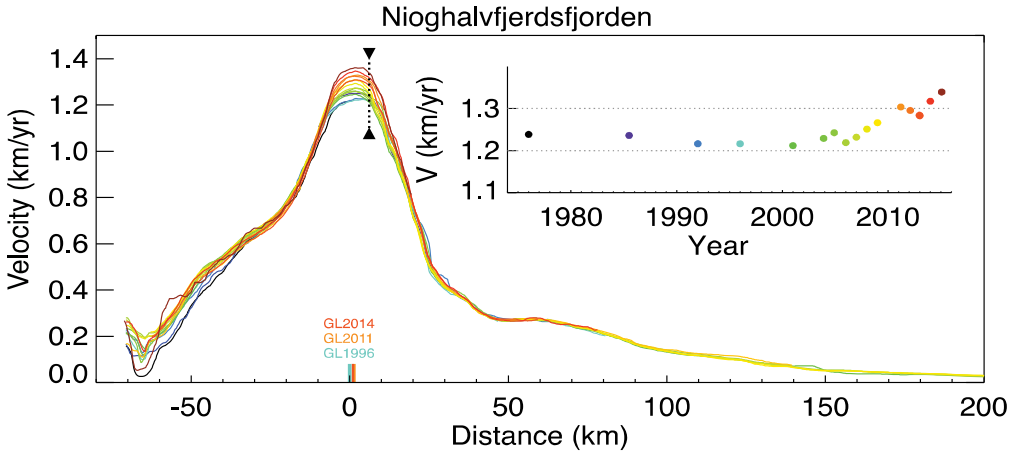
Zachariæ Isstrøm

55% increase since 2000 half of it after 2012

Nioghalvfjerdsfjorden (79 North)

8 % increase since 2000

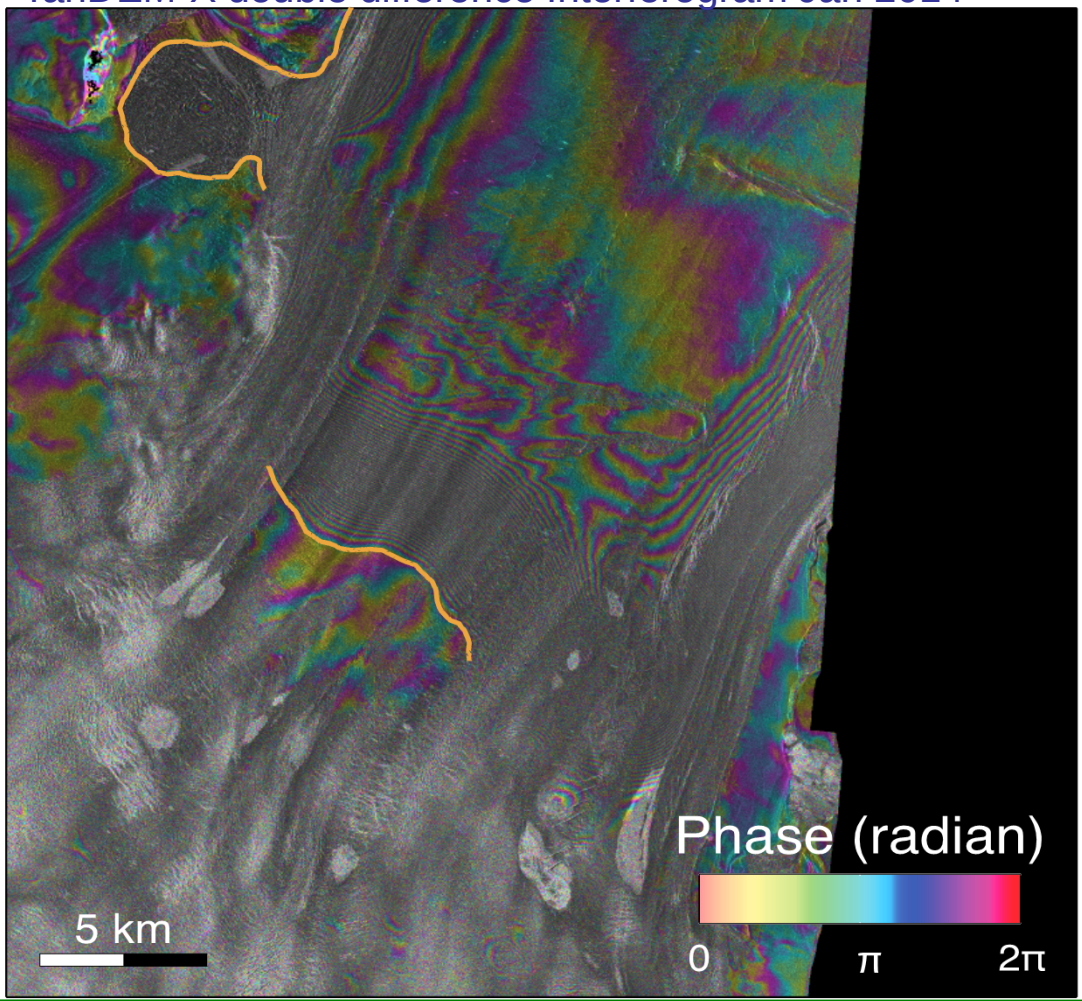




Grounding line dynamic

Nioghalvfjerdsfjorden (79 North)

TanDEM-X double difference Interferogram Jan 2014



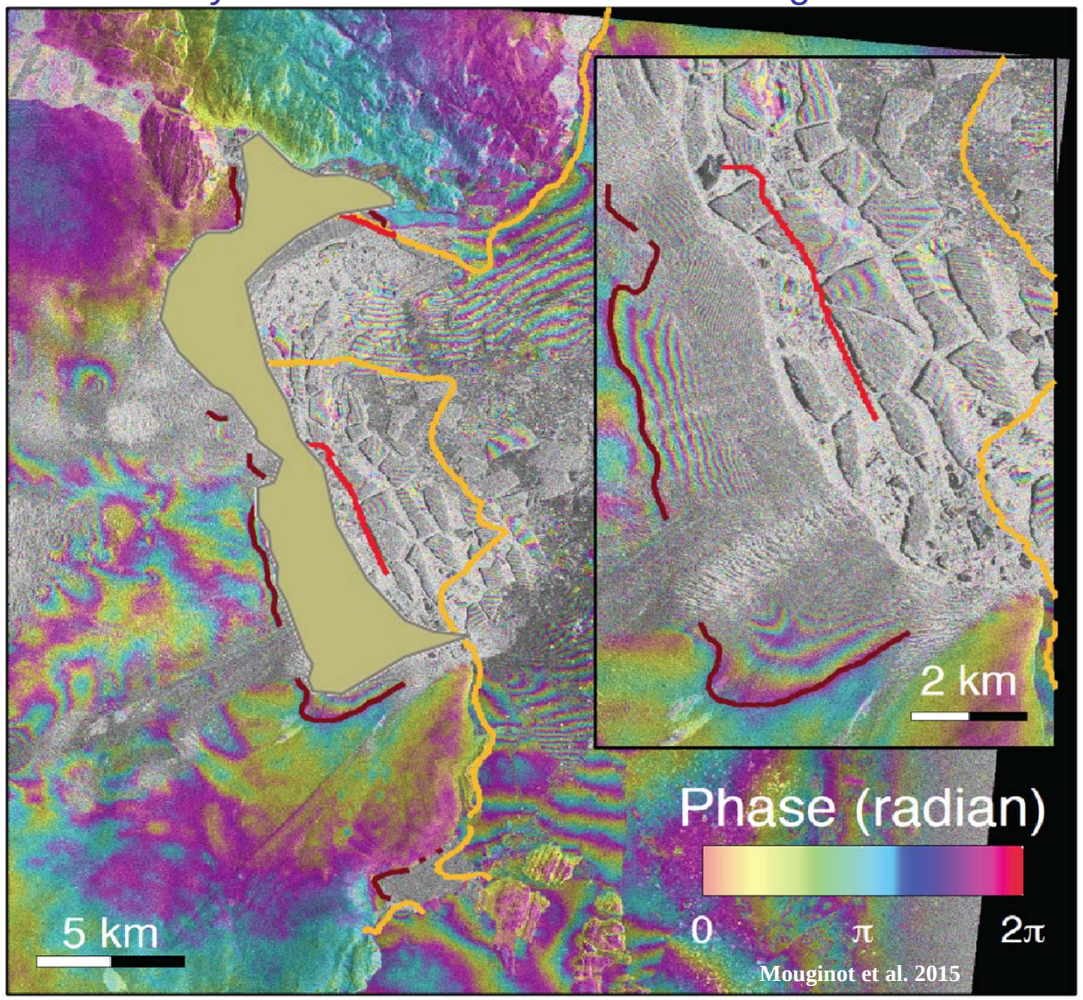
Zachariæ Isstrøm

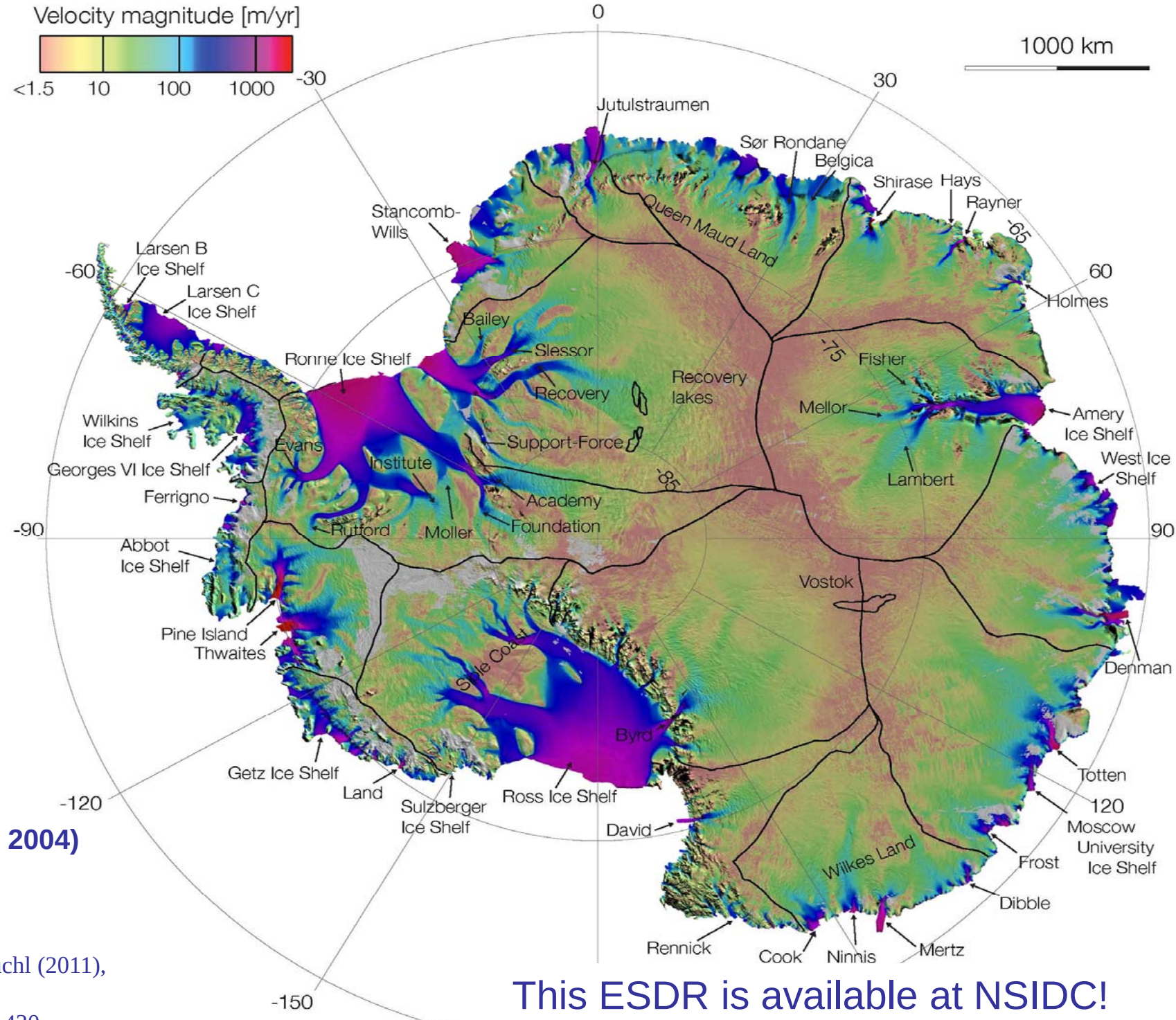
1996-2011 retreat: 3.5 km at the center line (230 m/yr)

2011-2015 retreat: 3.5 km at the center line (875 m/yr)

2015 floating portion: 52 km^2 or 95% less than 2003

COSMO SkyMed double difference Interferogram Dec 2014





Ice Velocity Map

ALOS PALSAR (2006-2008)
ENVISAT ASAR (2007-2009)
RADARSAT-2 (2009)
RADARSAT-1 (1999, 2000, 2004)
ERS-1, ERS-2 (1992,1996)

Rignot, E., J. Mouginot, and B. Scheuchl (2011),
Ice Flow of the Antarctic Ice Sheet.
Science Vol. 333 no. 6048 pp. 1427-1430
DOI: 10.1126/science.1208336

This ESDR is available at NSIDC!
http://nsidc.org/data/nsidc-0484.html

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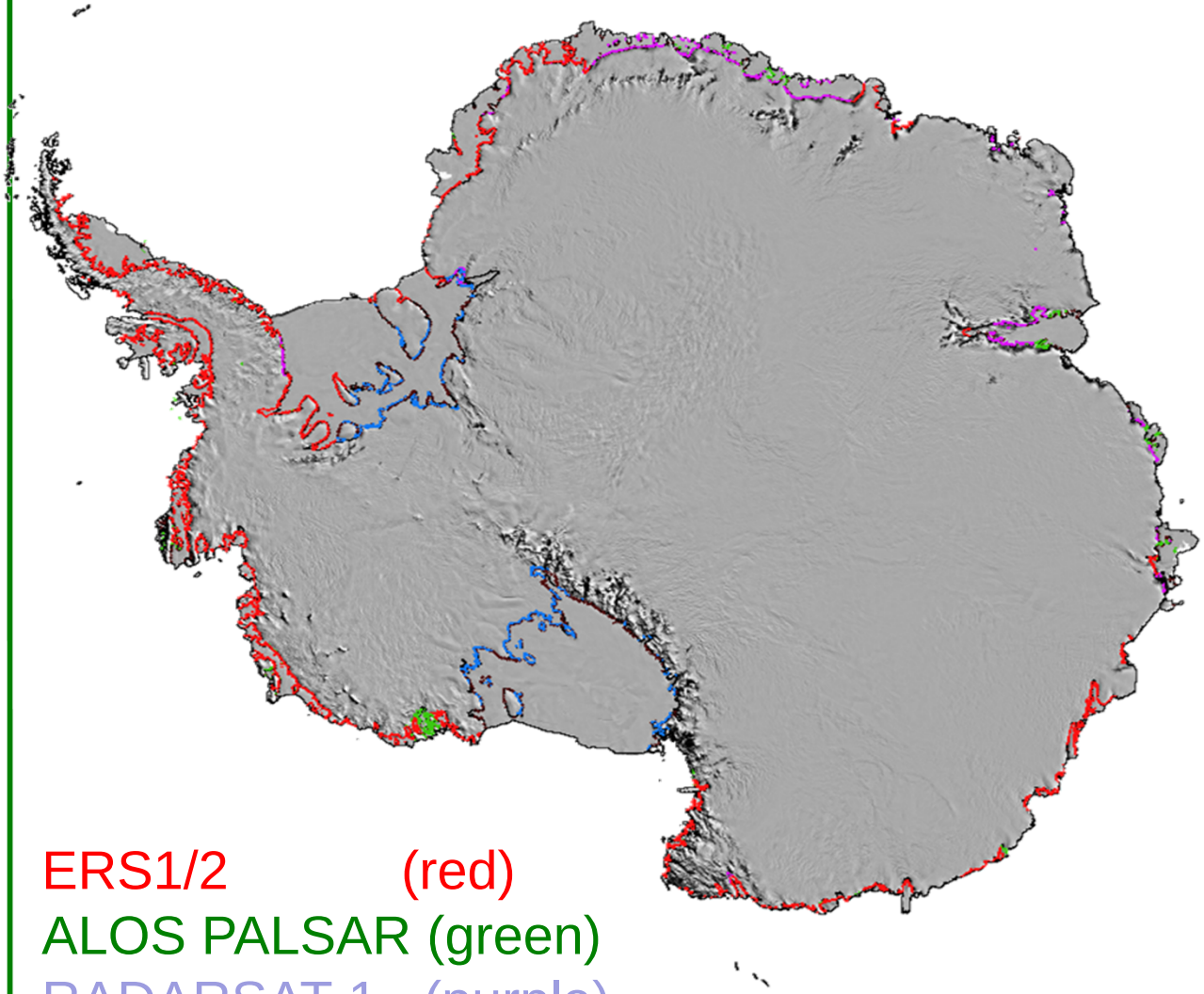
The Antarctic Grounding Line

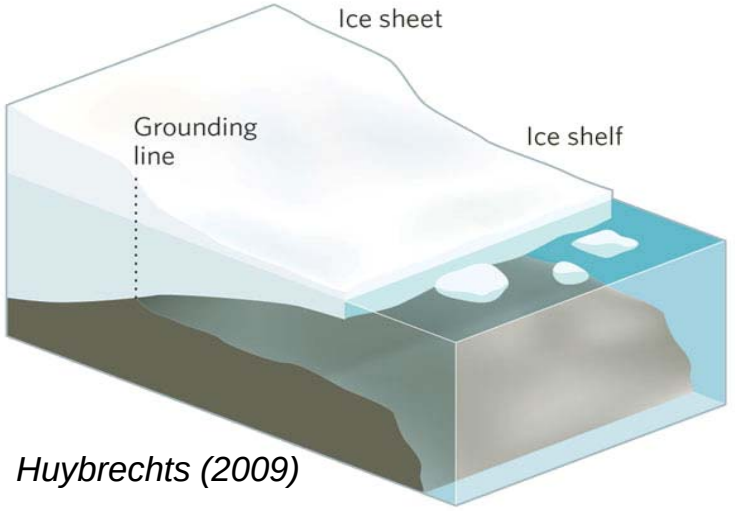


ERS1/2 (red)

ALOS PALSAR (green)

RADARSAT-1 (purple)

RADARSAT-2 (blue)



Huybrechts (2009)

The Grounding line is the boundary between grounded and floating ice.

We mapped 1.4 million grounding line points experiencing tidal flexure based on double difference interferograms.

This ESDR is available at NSIDC!
http://nsidc.org/data/nsidc-0498.html

Rignot, E., J. Mouginot, and B. Scheuchl (2011), Antarctic grounding line mapping from differential satellite radar interferometry, Geophys. Res. Lett., 38, L10504,doi:10.1029/2011GL047109.

ALOS

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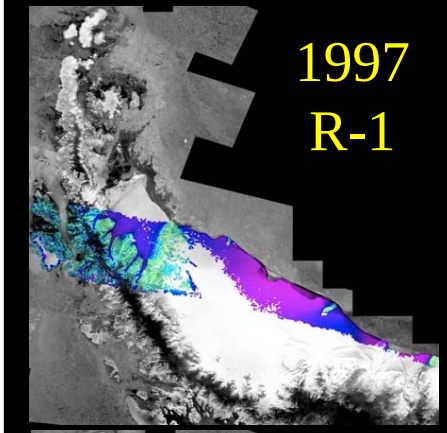
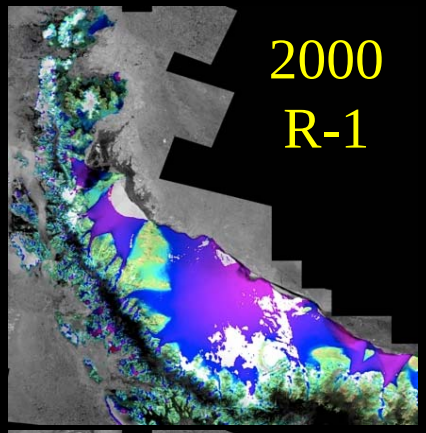
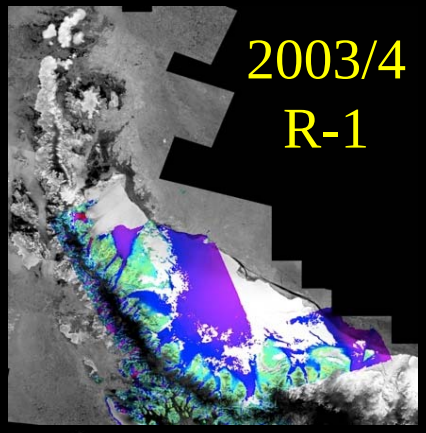
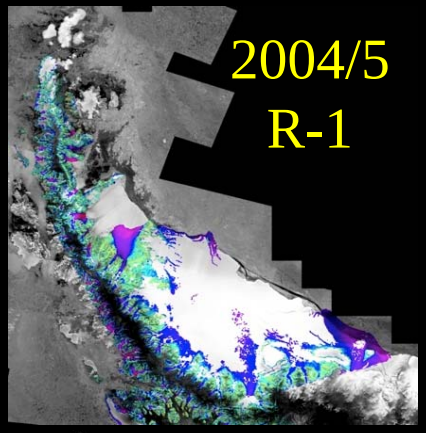
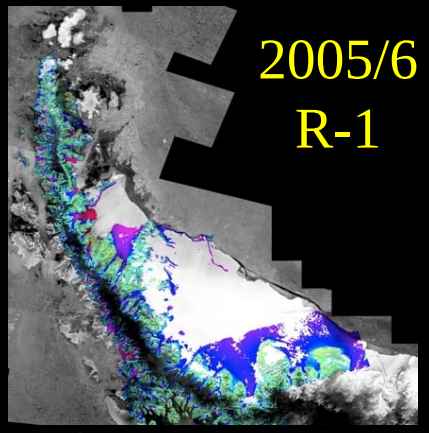
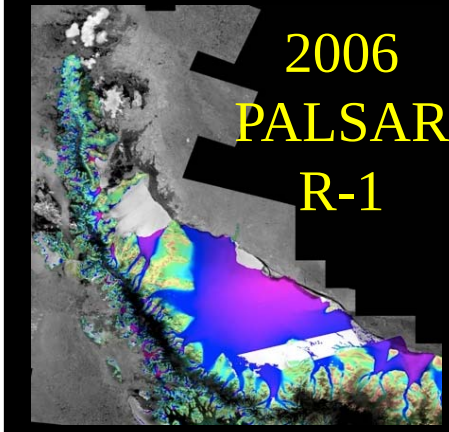


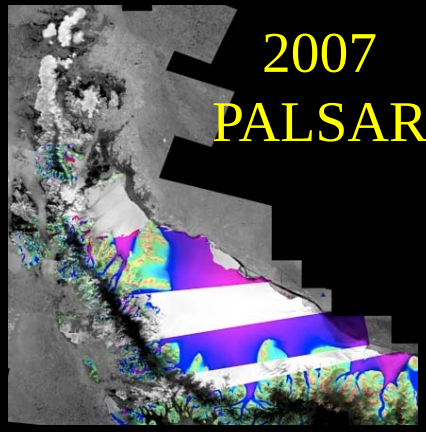


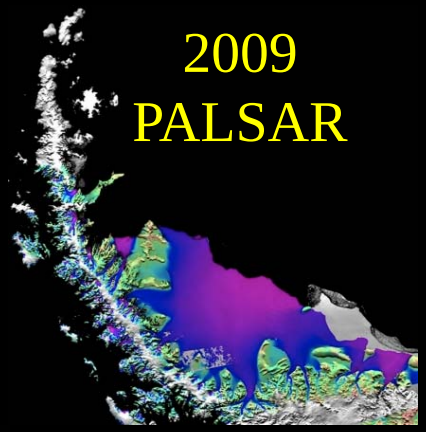


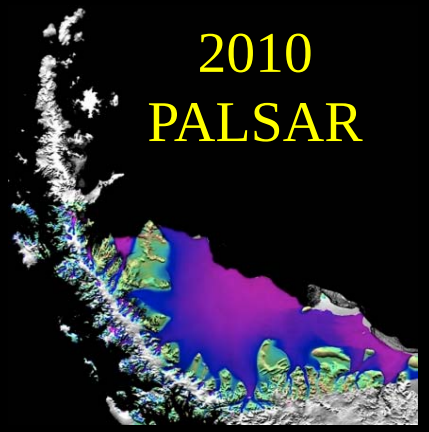


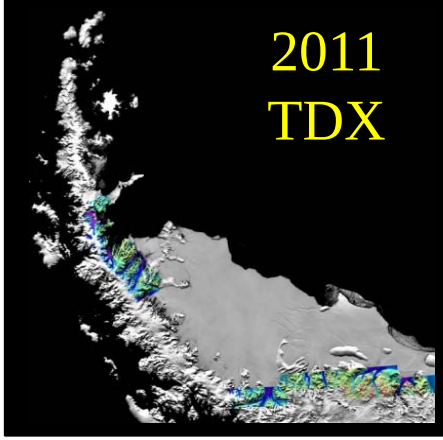


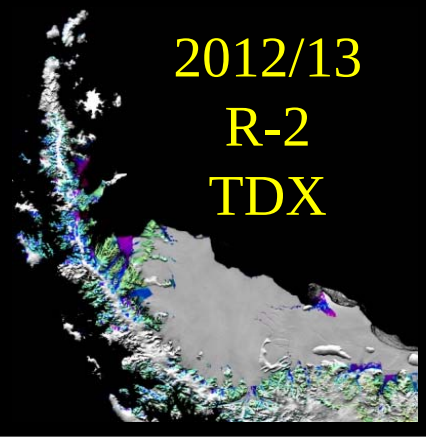


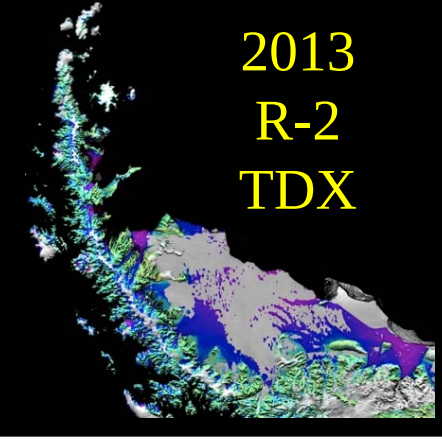




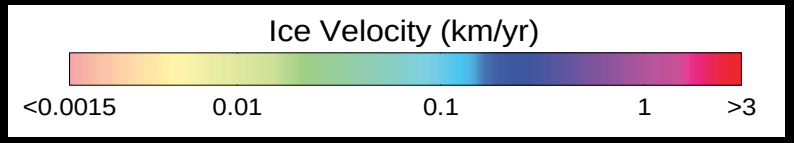








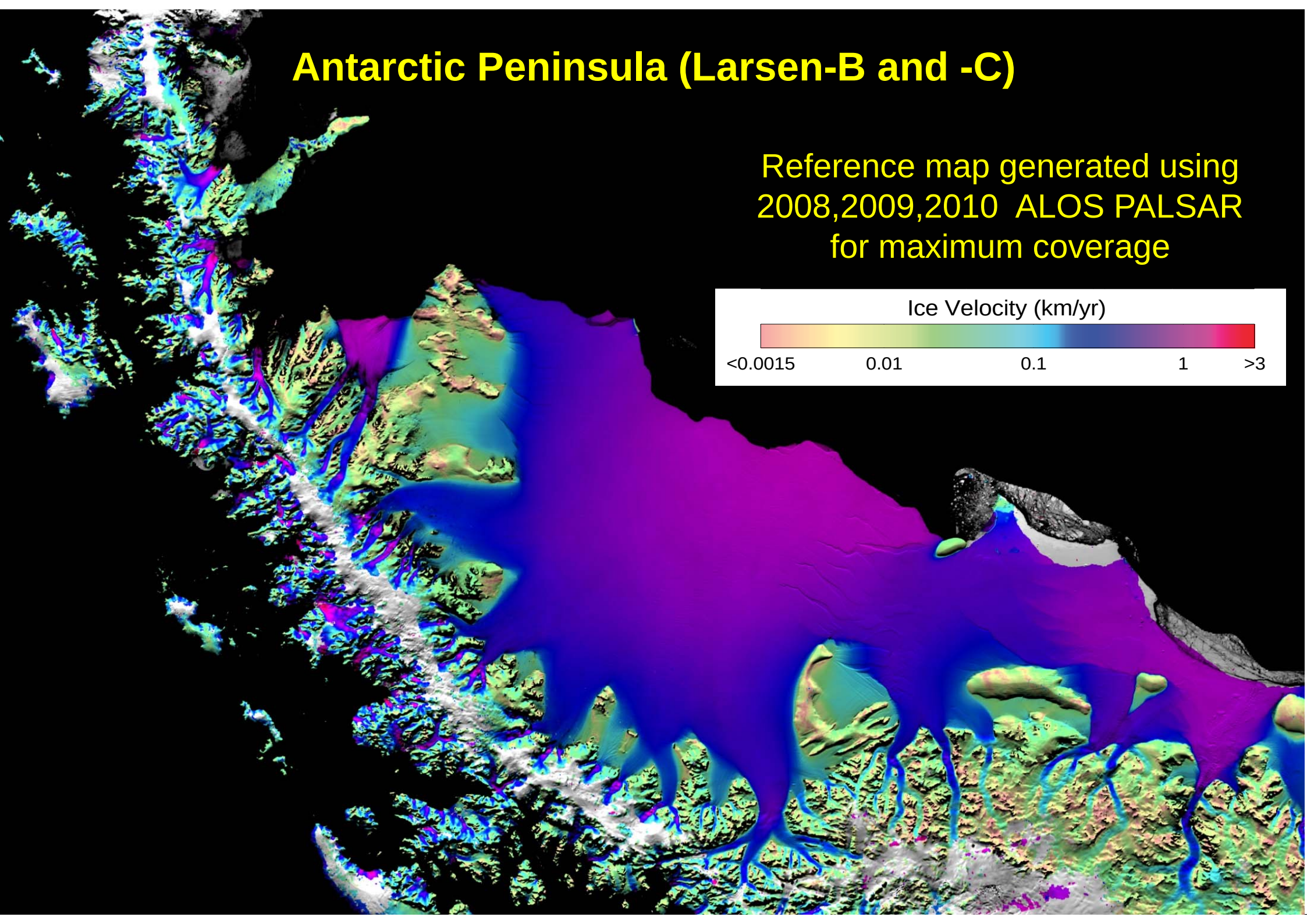
Antarctic Peninsula



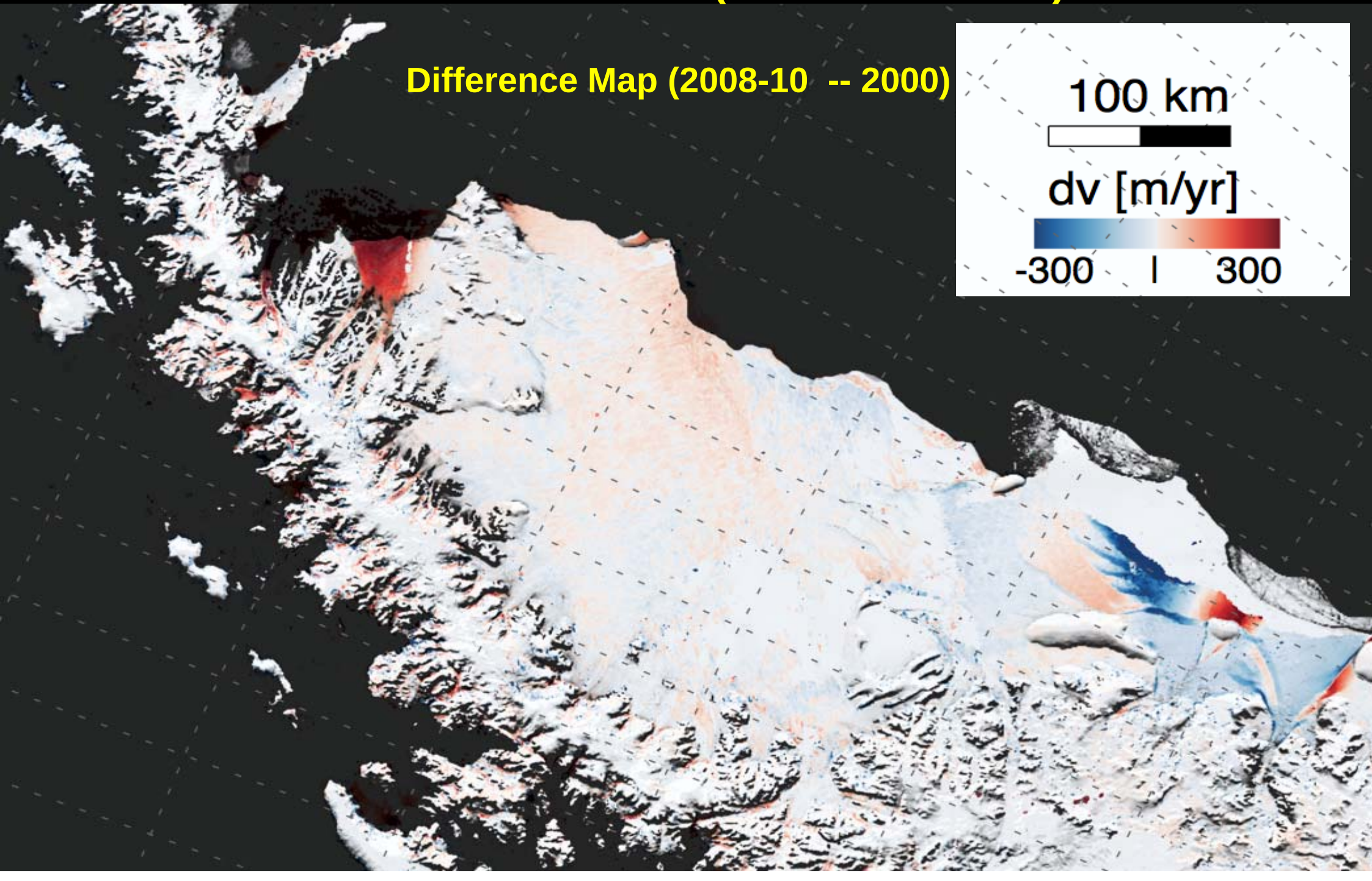
Extension of time series with Sentinel-1A and PALSAR-2

Antarctic Peninsula (Larsen-B and -C)

Reference map generated using
2008,2009,2010 ALOS PALSAR
for maximum coverage



Antarctic Peninsula (Larsen-B and -C)



ALOS

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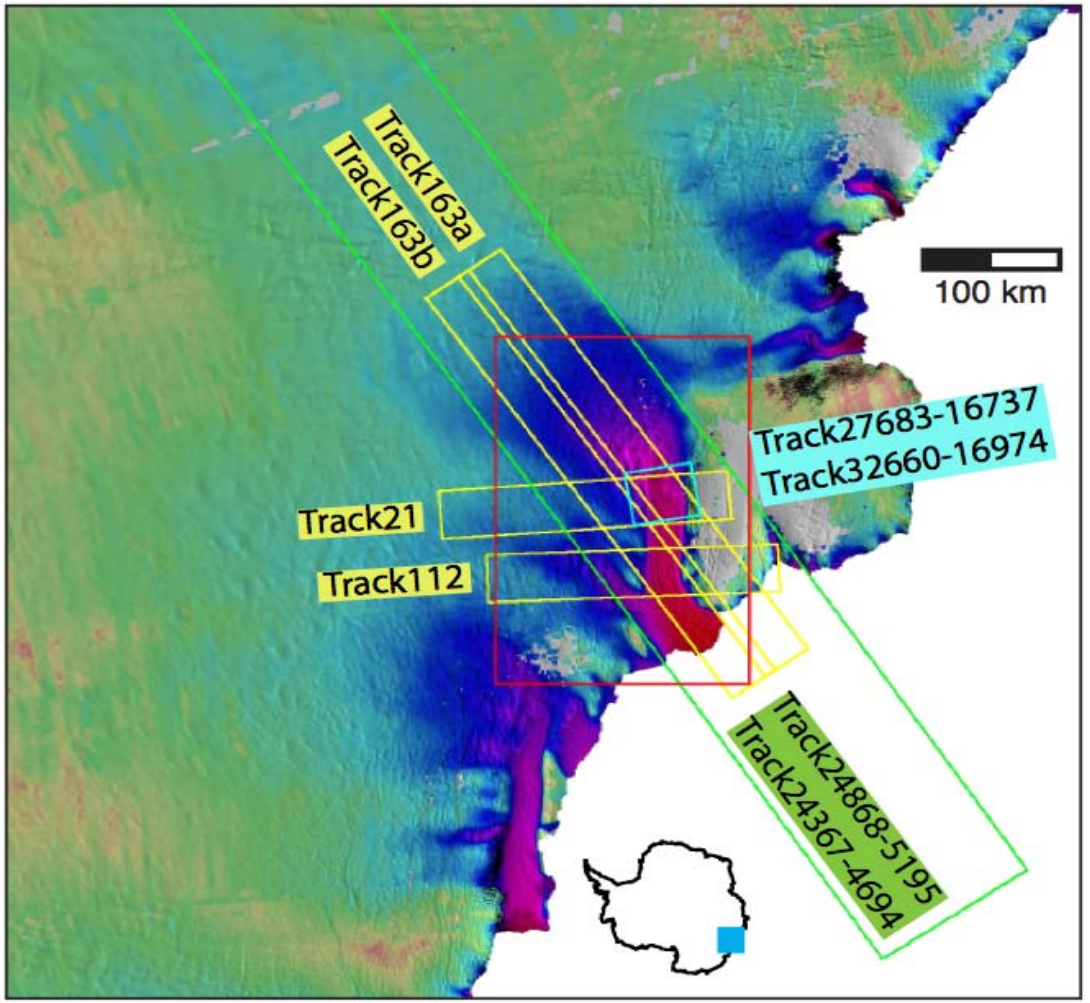
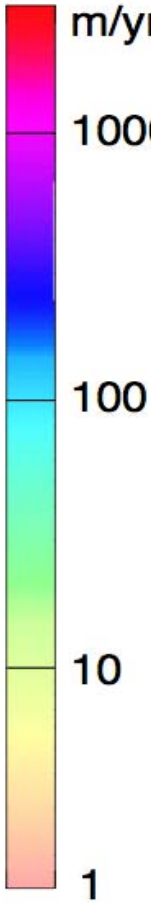
Totten Glacier, East Antarctica

Used a mix of available SAR data to evaluate velocity changes and the grounding line dynamics of Totten Glacier, East Antarctica.





Drainage basin size:	537,900 km^2
Ice shelf size:	5,903 km^2
Sea level potential:	3.9 m (global)
Ice discharge (2007-2008):	71±3 Gt/yr
Snowfall input:	67±3 Gt/yr
Ice berg production:	28±2 Gt/yr
Speed at grounding line:	850 m/yr
Speed at ice front:	1700 m/yr
Ice thickness at the	

Li, X., E. Rignot, M. Morlighem, J. Mouginot, and E. Scheuchl, 2015, Grounding Line Retreat of Totten Glacier, East Antarctica 1996 to 2013, Geophys. Res. Lett., 42, doi: 10.1002/2015GL065701.

ALOS

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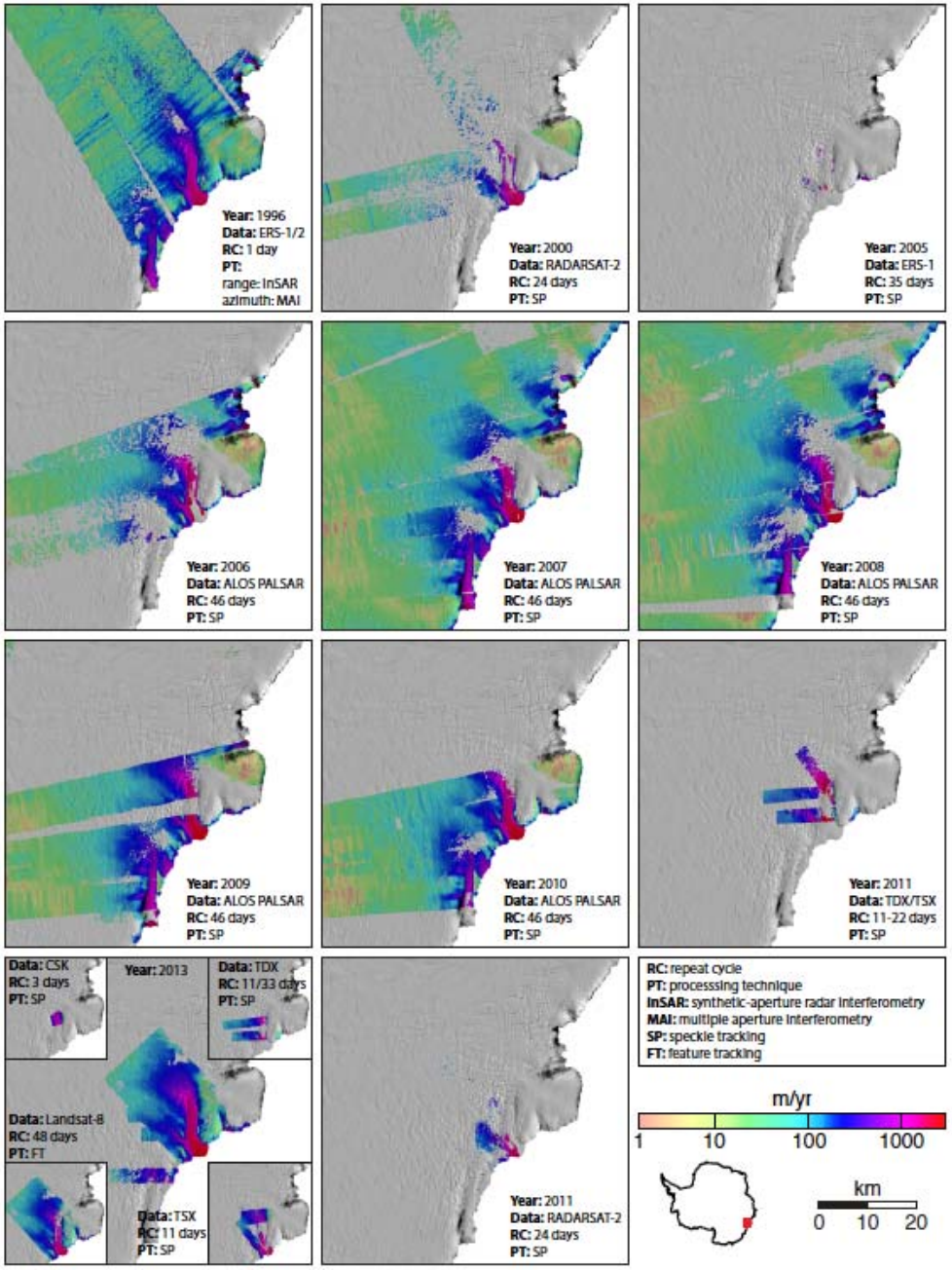
Totten Glacier, East Antarctica

Data coverage for Totten Glacier is still sparse. Available data suffer from decorrelation, particularly if repeat orbits are 11 days and more.

L-band shows best results.



Li, X., E. Rignot, J. Mouginot, and B. Scheuchl (2015), Ice flow dynamics and mass loss of Totten Glacier, East Antarctica from 1989 to 2015 – **Manuscript in revision**

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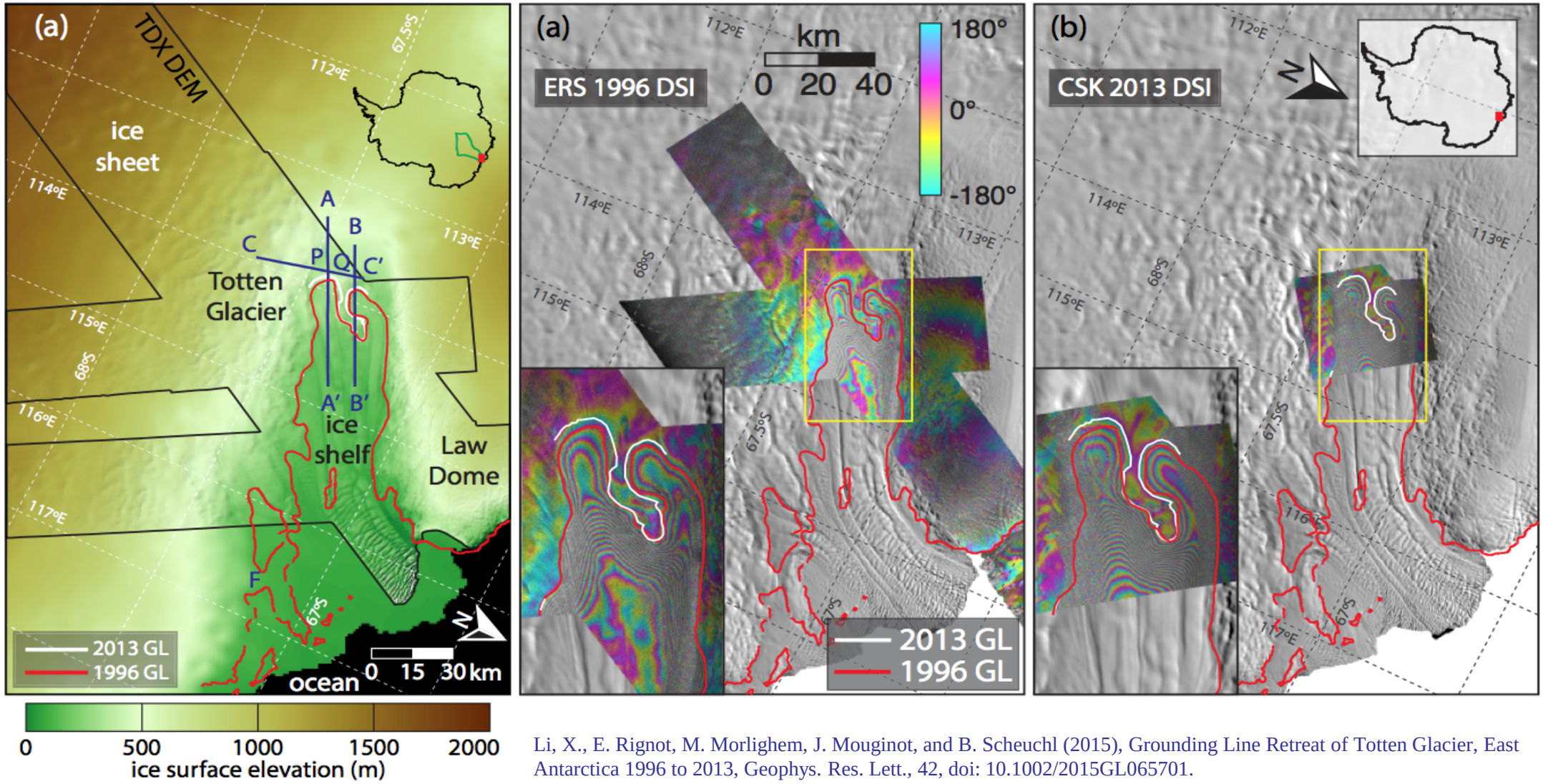
Totten Glacier, East Antarctica

Grounding line analysis shown for completeness. All available data used here.



Li, X., E. Rignot, M. Morlighem, J. Mouginot, and B. Scheuchl (2015), Grounding Line Retreat of Totten Glacier, East Antarctica 1996 to 2013, Geophys. Res. Lett., 42, doi: 10.1002/2015GL065701.

ALOS

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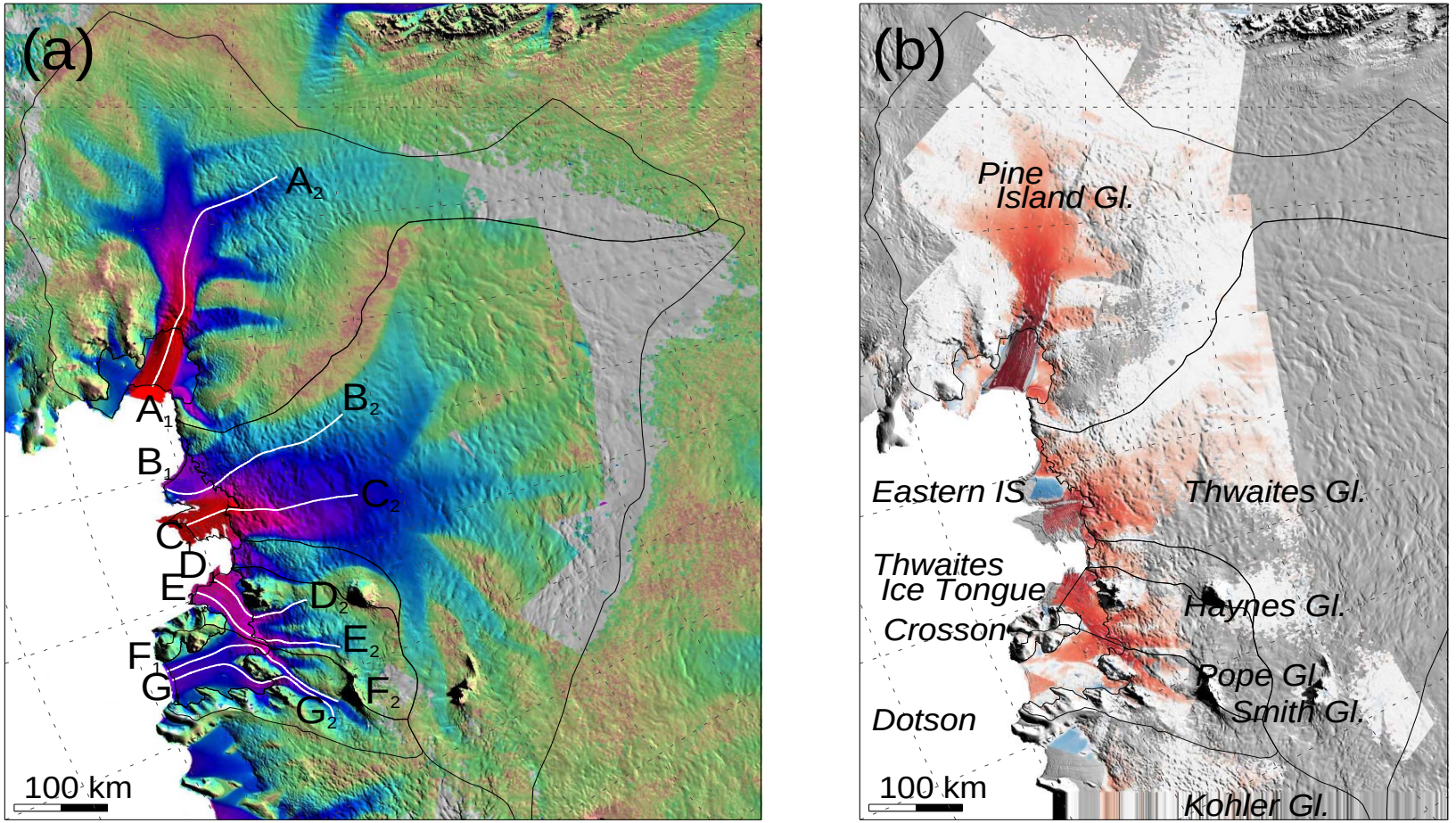
Amundsen Sea Embayment

1996

2008 - 1996



Ice Velocity (km/yr)

<0.0015 0.01 0.1 1 >3

Vel. difference (km/yr)

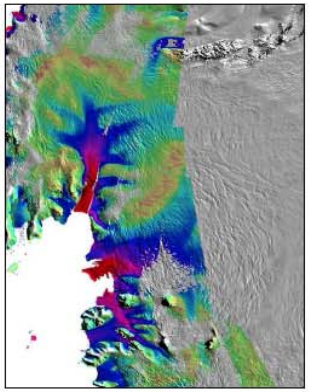
<-1.5 -0.1 -0.01 0.01 0.1 >1.5

Mouginot, J., E. Rignot, B. Scheuchl, Sustained increase in ice discharge from the Amundsen Sea Embayment, West Antarctica, Geophys. Res. Lett., 41/5, doi: 10.1002/2013GL059069

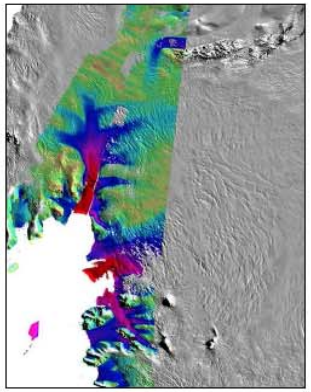
ALOS

Amundsen Sea Emb

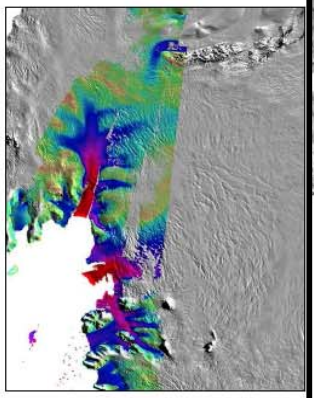
2008 ALOS



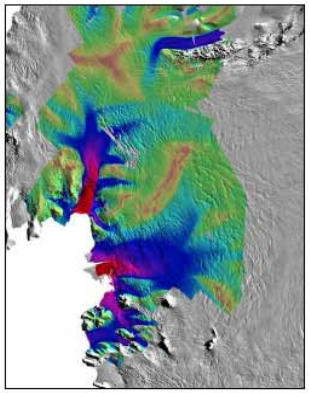
2009 ALOS



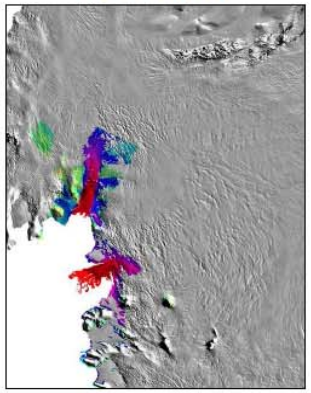
2010 ALOS



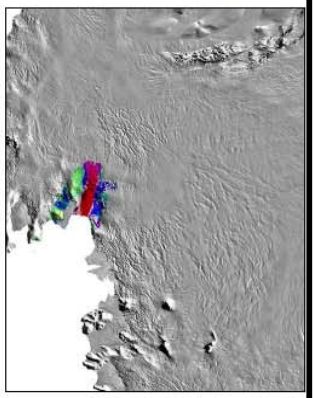
1996 ERS



2000 R1



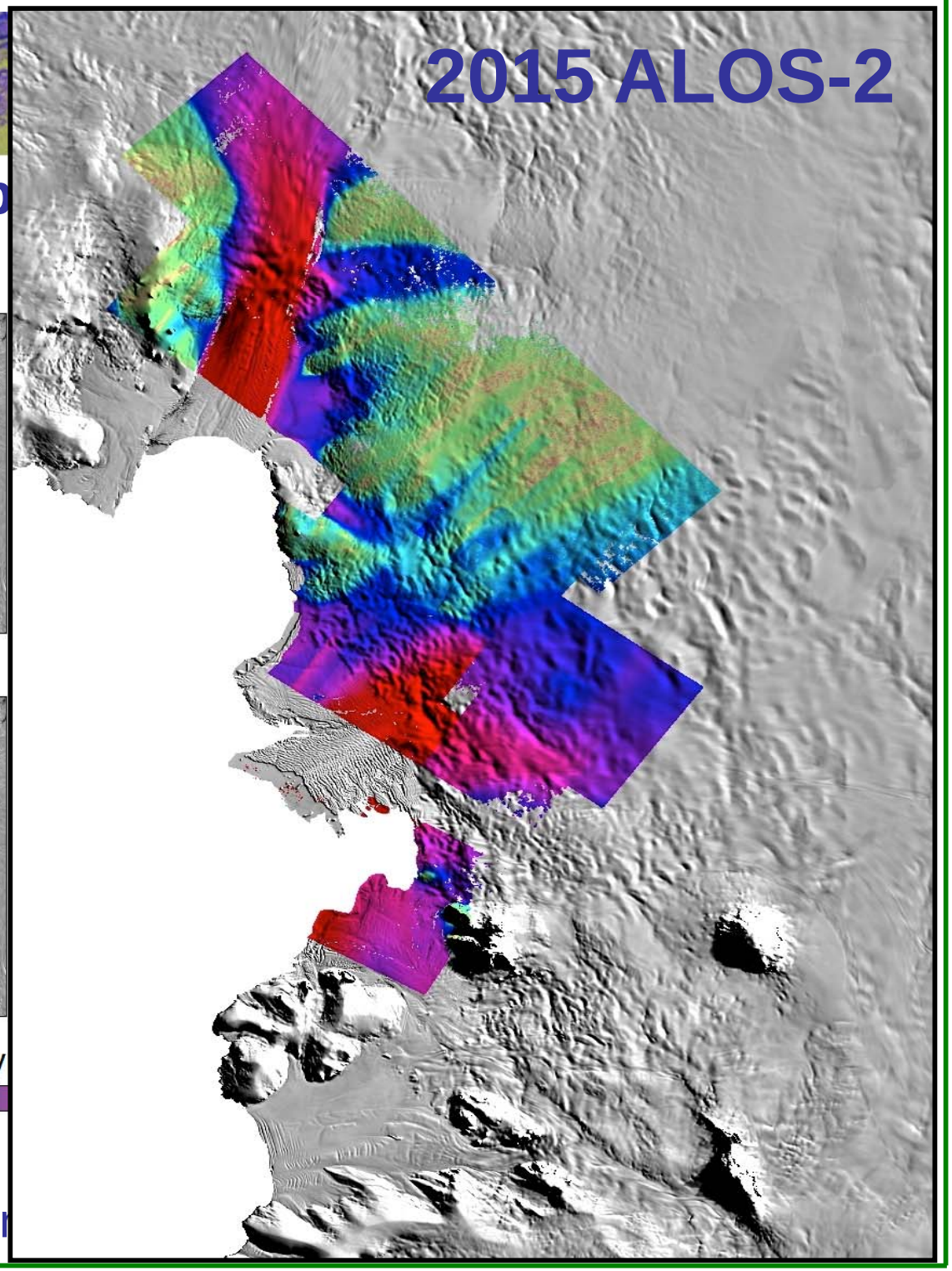
2002 R1



Ice Velocity (km/y

<0.0015 0.01 0.1

41 year satellite data record (including Lar



ALOS

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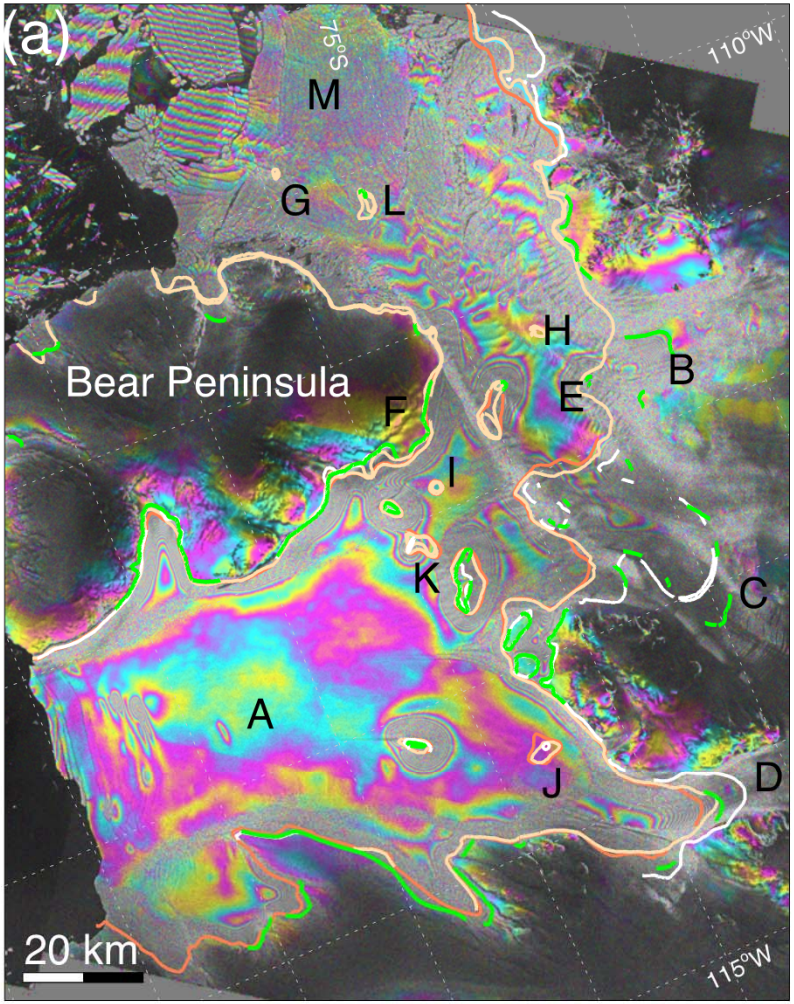
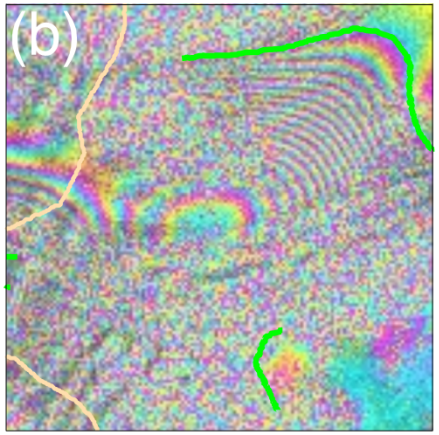
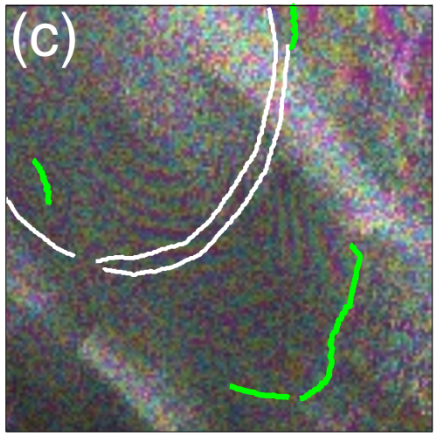
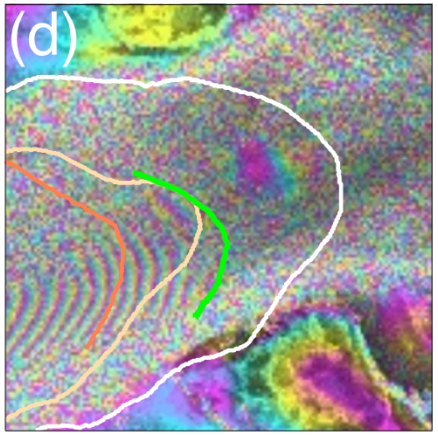
Amundsen Sea Embayment – Grounding Line

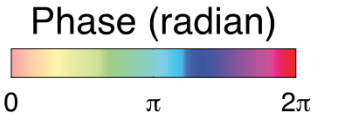
Grounding line dynamics shown for completeness. No ALOS-2 results available yet.

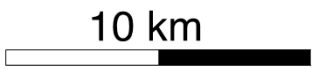


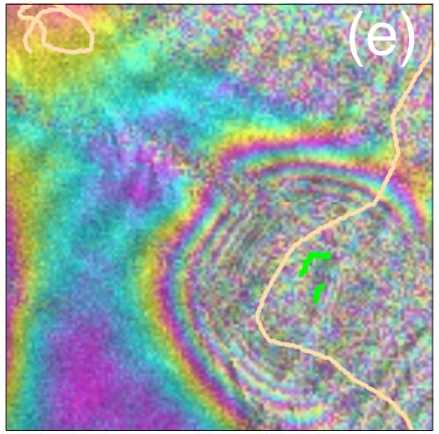


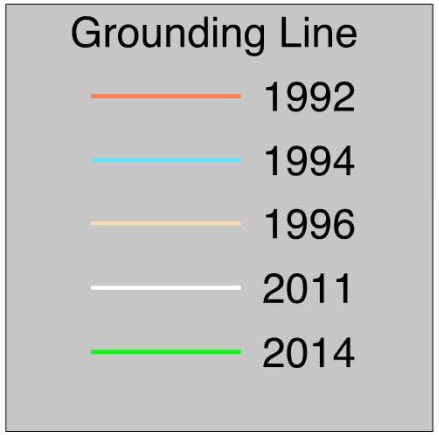


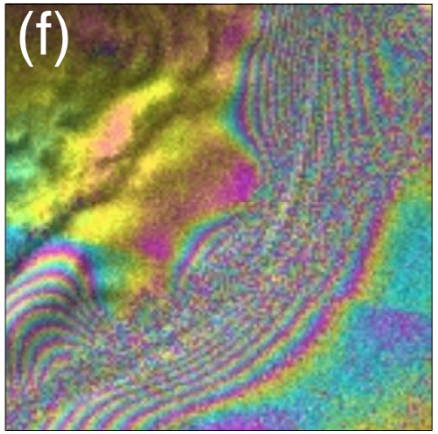












B. Scheuchl et al., Grounding Line Retreat of Pope, Smith, and Kohler Glaciers, West Antarctica. Manuscript in preparation

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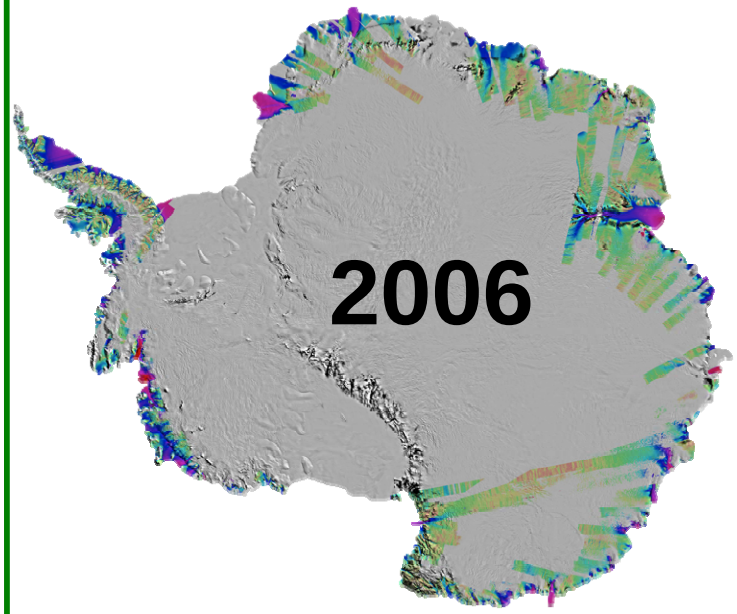
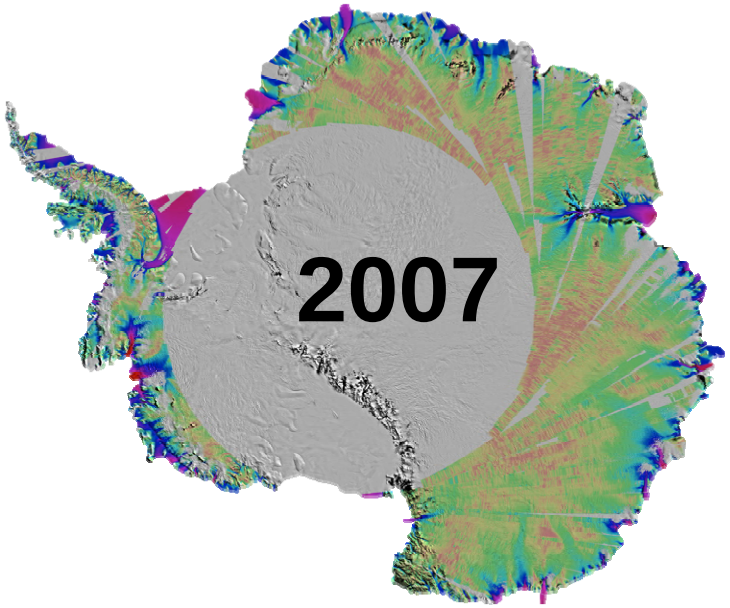
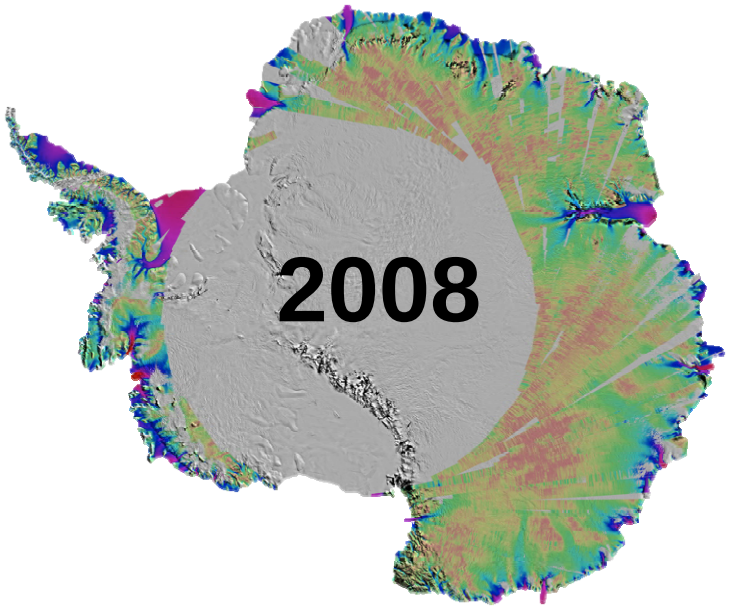
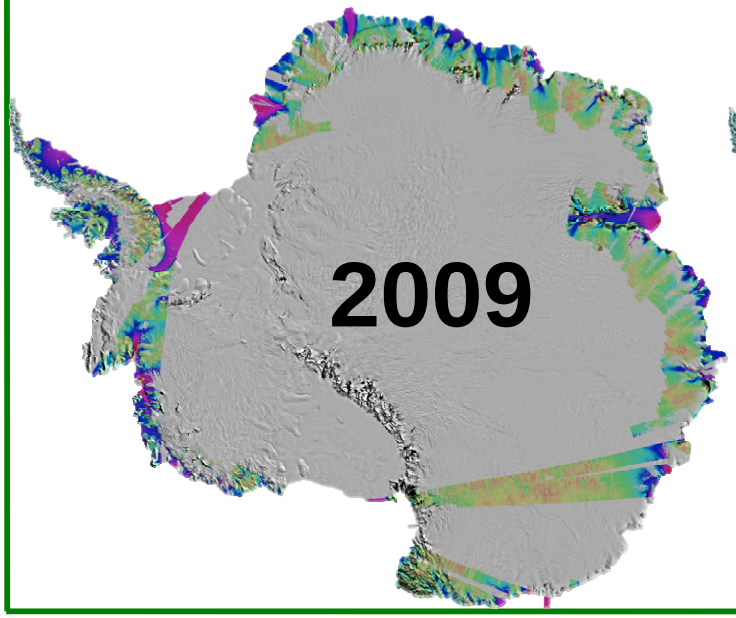
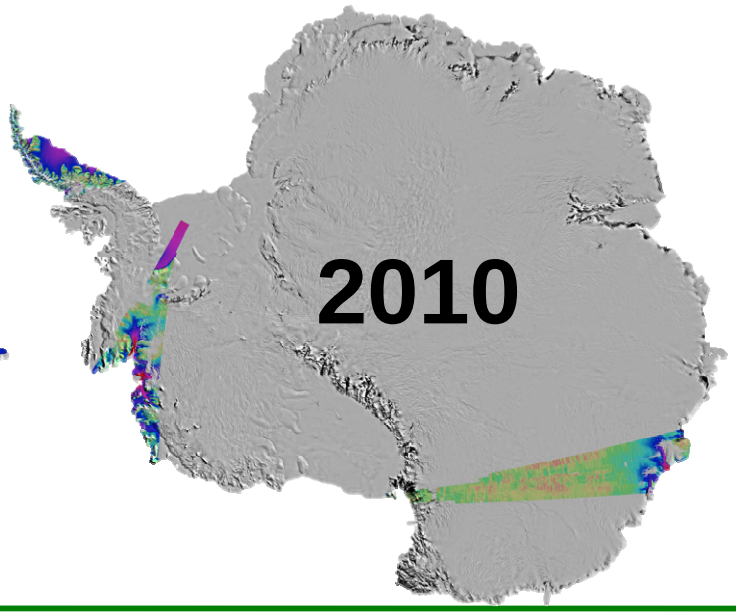
Processing Status ALOS PALSAR - Antarctica

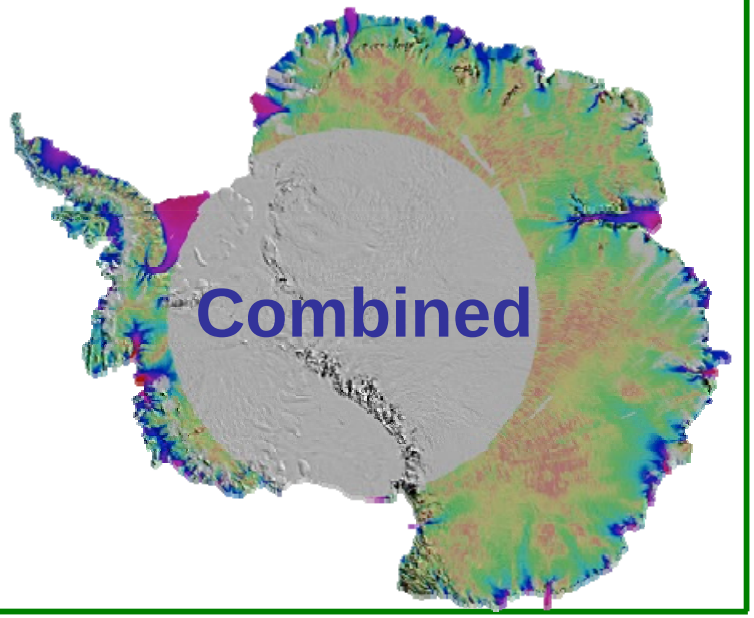












Project milestones &

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

ALOS

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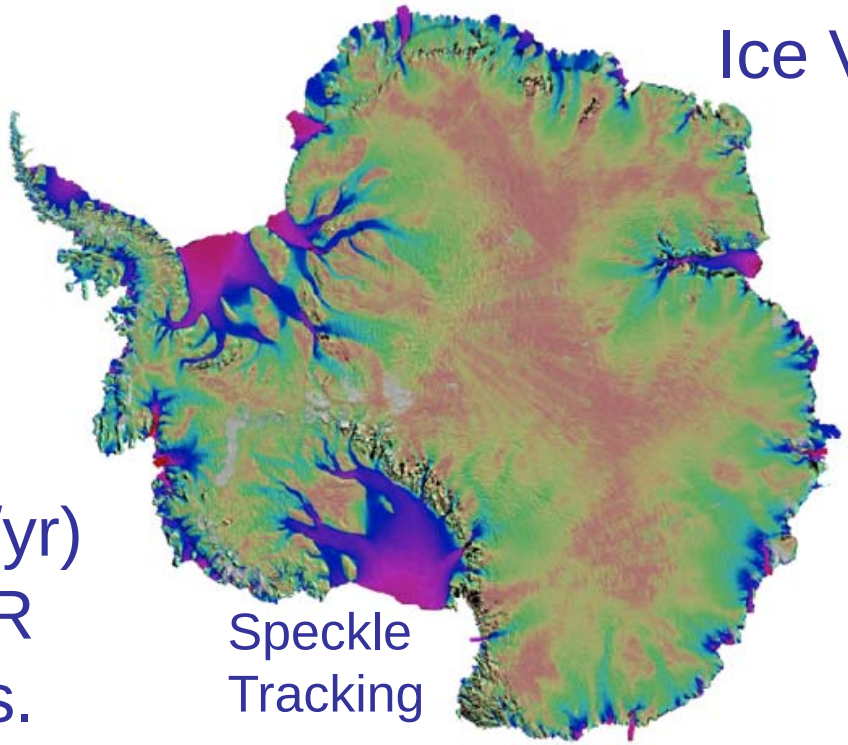
Outlook:

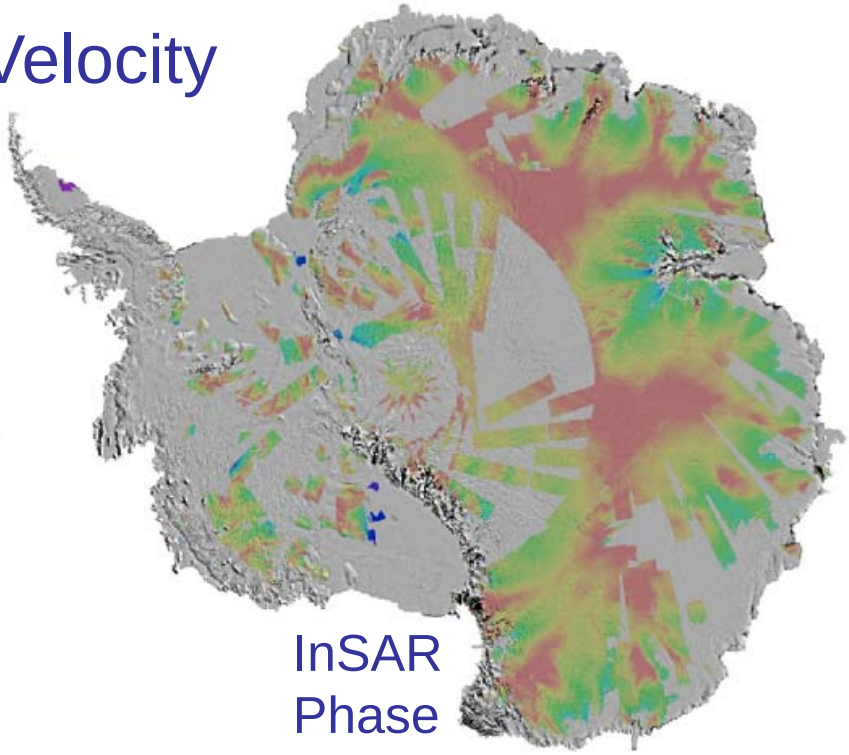
Improving the accuracy for areas with low speed (<20 m/yr) by using InSAR phase analysis.

Problem: Ascending & Descending data are required

Ice Velocity

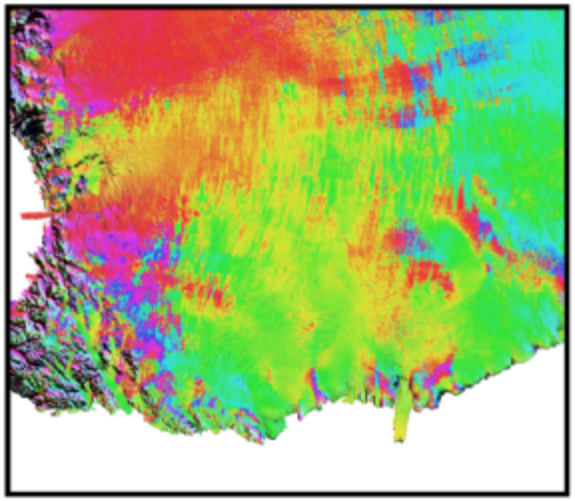


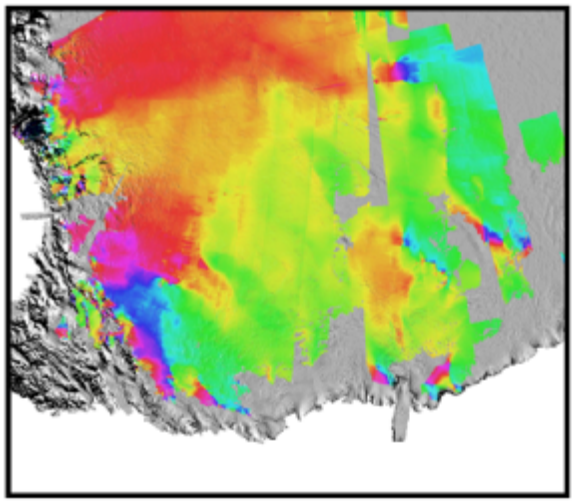
Speckle Tracking



InSAR Phase

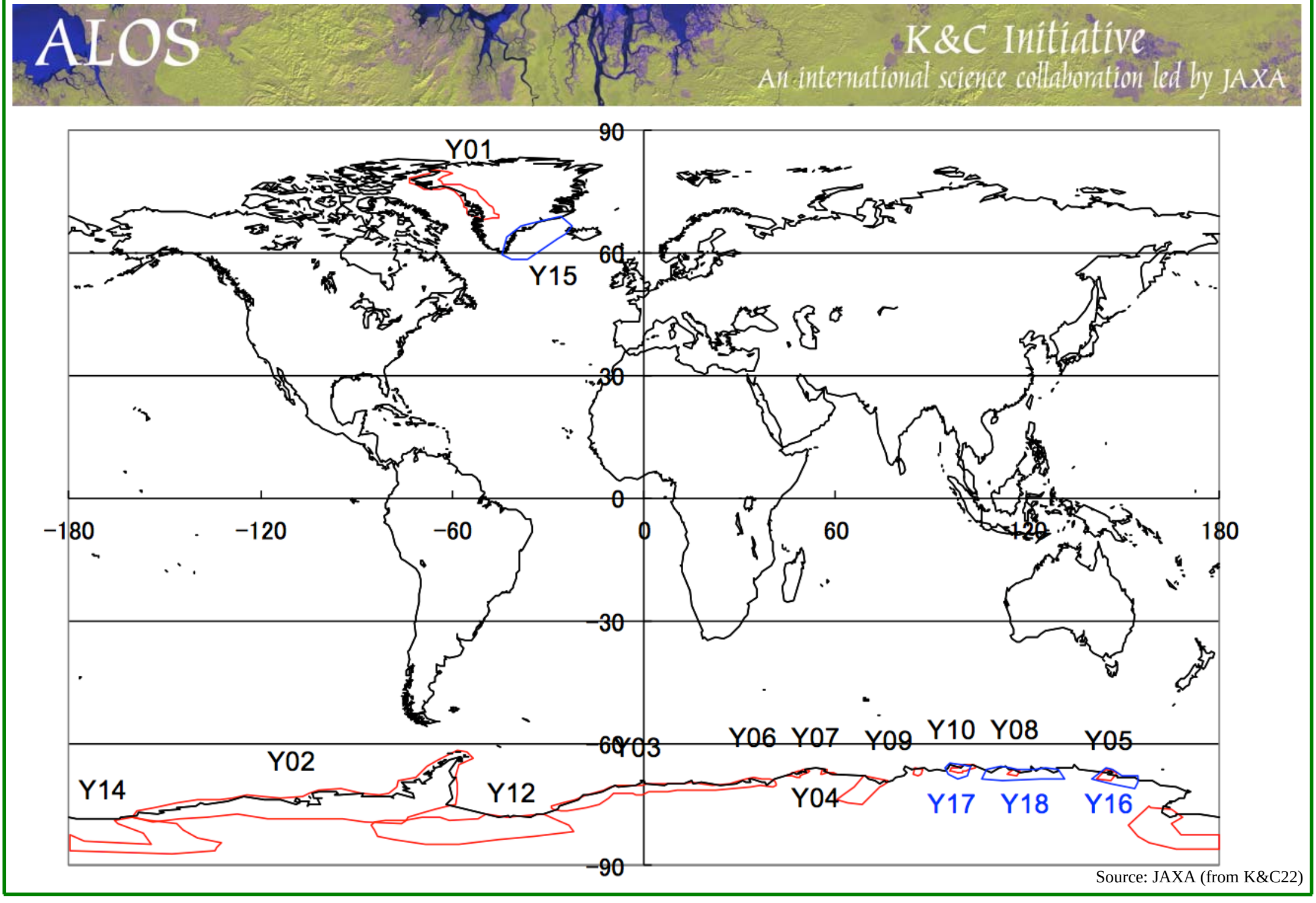
Flow Direction





Recommendations of Ice Users of the Polar Space Task Group (PSTG, courtesy B. Scheuchl)

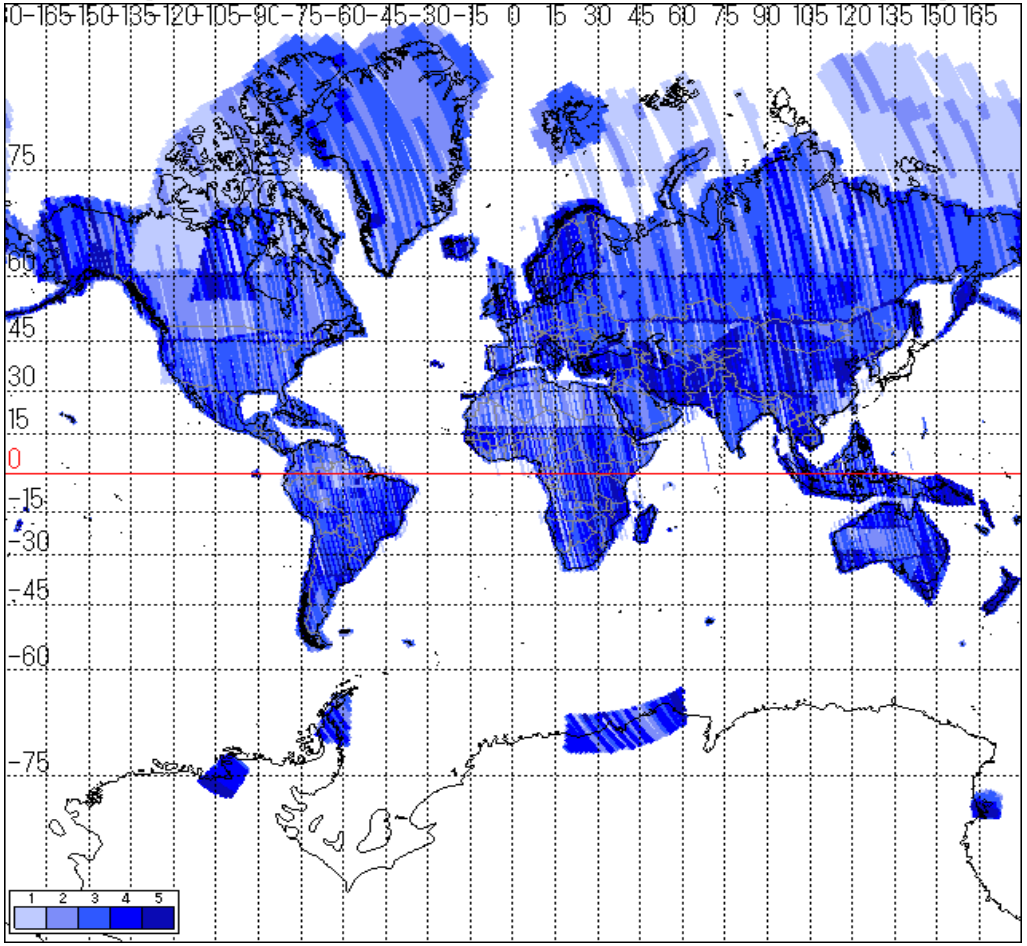
- Efforts of JAXA are to be applauded
- Polar Ice Basic Observation Scenario is ScanSAR 3 cov./year, quality of PALSAR-2 ScanSAR offset-tracking to be further analyzed in winter
- Glacier movement super sites in StripMap Dual-pol. have 3 cov./year, results of offset-tracking are excellent
- It would certainly be great if the number of glacier movement super sites in StripMap could be expanded, e.g.:
  - Glaciers in Northeast Greenland coastline are becoming unstable
  - Much better correlation for L-band than C-band on South of Greenland was observed in the past
  - It would be an asset to see in future the number of coastal Antarctica regions with coverage expanded
- The Basic Observation Scenario for coastal West Antarctica is fine, it would be great to see a coverage assessment
- Given the high science value of the data acquired in Greenland and Antarctica, larger research quotas (e.g. via a specific call) would be considered beneficial



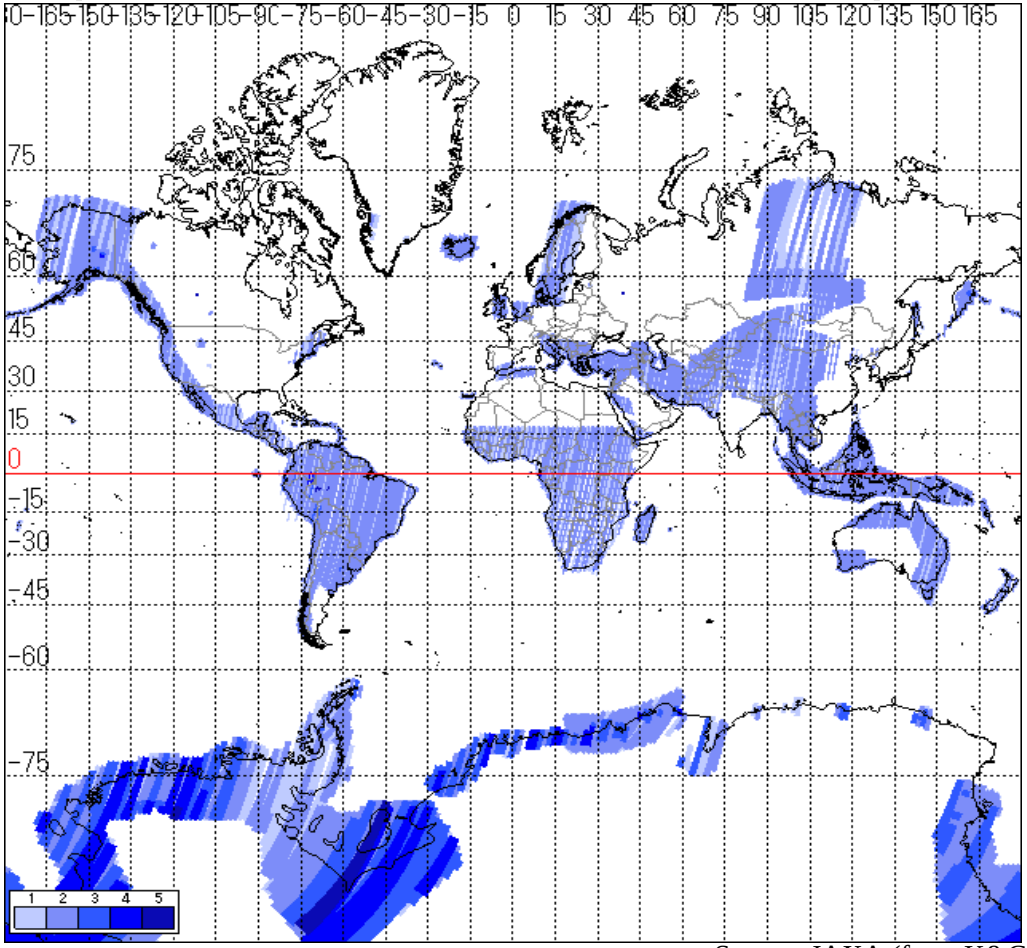
Source: JAXA (from K&C22)

Global 10 m resolution, HH/HV pol.

Beam F2-5,6,7
Ascending, Right
(**Global land observation**)



Beam F2-5,6,7
Descending, Right
(**Deformation, Forest, Ice**)



Source: JAXA (from K&C22)

Conclusions

- Ice Sheets are undergoing significant changes
- L-band InSAR data make a difference!
- Prefer at least 3 consecutive cycles – repeat orbit
- 10 m HH/HV is the preferred mode
- HH only would suffice (if this helps to ease the crunch)
- There is no need for additional ScanSAR coverage

Thank You

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