Note: This document was written and provided by B. Scheuchl.

MEaSUREs Phase-Based Antarctica Ice Velocity MAP, Version 1

This data set, as part of the NASA Making Earth System Data Records for Use in Research Environments (MEaSUREs) Program, combines interferometric phases from multiple satellite interferometric synthetic-aperture radar systems to derive the first comprehensive phase-based map of Antarctic ice velocity. The precision in ice speed (20 cm/yr) and flow direction (5 degrees) over 80% of Antarctica is a **factor 10 better** than prior mappings based on feature and speckle tracking. Phase-derived velocity are mostly for years between 2007 and 2018 while regions covered by tracking-derived velocity (along the coasts) will mostly be representative of years 2013-2017. Additional data acquired between 1996 and 2018 was used as needed to maximize coverage.

See Antarctic Ice Sheet Velocity and Mapping Data for related data.

This is the most recent version of these data.

Version Summary
This is the first data set of its kind and supersedes the tracking-based continent-wide map (MEaSUREs InSAR-Based Antarctica Ice Velocity Map, Version 2) due to significantly higher accuracy.

Overview

Parameter(s): Snow/Ice > Ice Velocity

Data Format(s): NetCDF

Spatial Coverage:
N: -60,
S: -90,
E: 180,
W: -180

Platform(s):
Phase portion:
ALOS, ALOS-2, ENVISAT, ERS-1, ERS-2, RADARSAT-1, RADARSAT-2

Tracking data:
ALOS, ENVISAT, ERS-1, ERS-2, LANDSAT-8, RADARSAT-1, RADARSAT-2, SENTINEL-1A/1B, TanDEM-X, TERRASAR-X

Spatial Resolution: 450 m x 450 m

Sensor(s): ASAR, C-SAR, OLI, PALSAR, PALSAR-2, SAR

Temporal Coverage: 1 January 2007 to 31 December 2018 (with some historic data added to increase coverage)

Version(s): V1

Temporal Resolution: 11 year

Metadata XML: View Metadata Record

Data Contributor(s): Jeremie Mouginot, Eric Rignot, Bernd Scheuchl

Detailed Data Description

Format

The data are formatted in Network Common Data Form, Version 4 (NetCDF-4) (.nc) following version 1.6 of the Climate and Forecast (CF) metadata conventions. For more information about working with NetCDF formatted data, visit the UCAR Unidata Network Common Data Form Web site.

File Naming Convention

This data set includes one file named antarctic_ice_vel_phase_map_v01.nc (450 m grid spacing).

File Size

The size of this data set is approximately 40 GB.

Spatial Coverage

The data set spans the continent of Antarctica. Figure 1 provides a map of the spatial coverage.
Southernmost Latitude: 90° S
Northernmost Latitude: 60° S
Westernmost Longitude: 180° W
Easternmost Longitude: 180° E

Spatial Coverage Map and Sample image

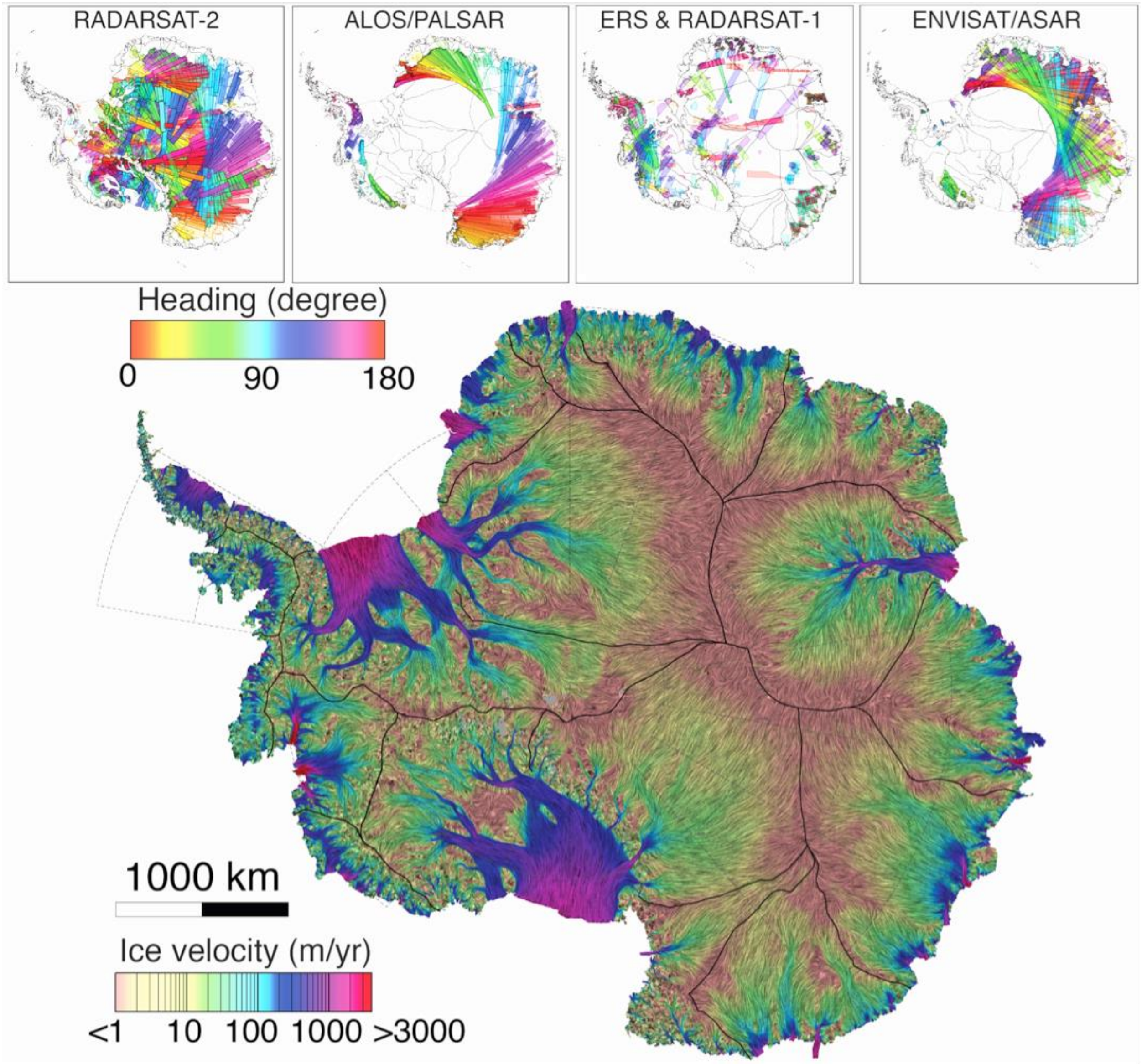

Figure 1. Mapping of ice motion in Antarctica using synthetic-aperture radar interferometric phase data. Upper panels show the distribution of data tracks used from the Canadian RADARSAT-2, Japanese ALOS PALSAR, European ERS and Canadian RADARSAT-1, and European Envisat ASAR. Lower main panel shows a complete map of ice motion in Antarctica combining phase data in the interior and speckle tracking in the fast-moving sectors, with speed colored on a logarithmic scale from brown (less than 1 m/yr) to red (more than 3 km/yr) and flow direction indicated by colored lines and showing the flow pattern of ice across the continent. Projection is polar stereographic at 71° S secant plane [Mouginot et al. 2019].

Spatial Resolution

The spatial resolution of the velocity map is 450 m.

Projection

Polar stereographic with true scale at 71° S. Refer to Polar Stereographic Projection and Grid page for more information and polar stereographic grid definitions.

Temporal Coverage

The data were collected between 1996 and 2016. Detailed information is provided in the Data Acquisition and Processing section.

Parameter or Variable

This data set provides a comprehensive, InSAR phase - based high precision ice velocity map of the Antarctic Ice Sheet posted at 450 m grid spacing. Tracking based results are used to augment the phase-based map in coastal areas, where phase analysis was not possible with the available data. The velocity components for the x and y direction, as defined by the polar stereographic grid, are stored in the NetCDF variables named VX and VY and are recorded in m/yr. Error estimates for the velocity components are provided as variables ERRX and ERRY; however, these values should be used more as an indication of relative quality rather than absolute error. More information about the error estimates is provided in the Quality Assessment section as well as in Mouginot et al. (2019). The data also include the standard deviations for the velocity estimates (STDX,STDY), as well as a count of scenes (CNT) used to estimate the values for each pixel. Figure 2 shows the error and standard deviation estimates for both the phase based map and a tracking based map (the latter was blended with the former to provide maximum coverage). Figure 3 shows the total number of measurements used to estimate the velocity for both, phase-based and tracking-based map. Table 1 provides a complete list of the variables and their descriptions.

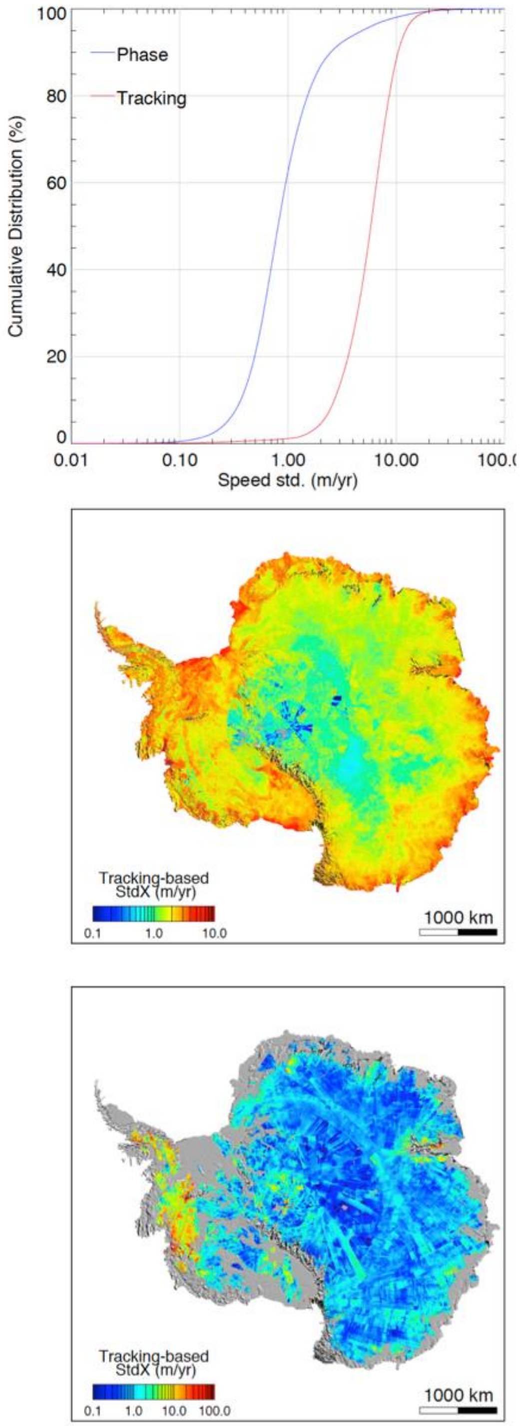

Figure 2. Standard deviation maps of the absolute ice speed measurements in Antarctica. (top) Lognormal cumulative distribution of the standard deviation over area mapped by both methods. Standard deviation maps for tracking-based (middle) and phase-based (bottom) [Mouginot et al. 2019].

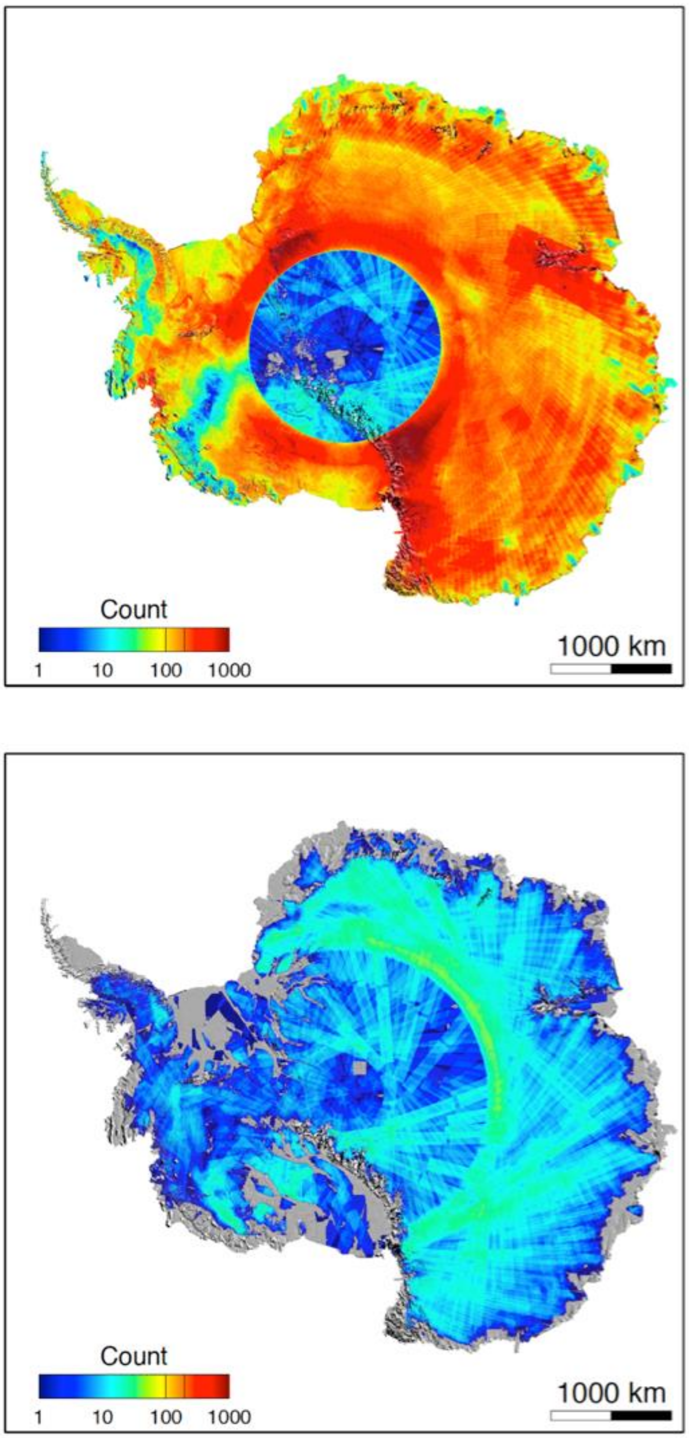

Figure 3. Number of stacked measurements for tracking-based (top) and phase-based (bottom) to compute the composite velocity map [Mouginot et al. 2019].

Variable Description

The variables included in the NetCDF file are described in Table 1. All variables have grid dimensions of 12445 x 12445 and are posted at 450 m spacing.

Variable	Description	Data Type
x	Cartesian x-coordinate	double
y	Cartesian y-coordinate	double
lat	Latitude	double
lon	Longitude	double
VX	Component of velocity in m/yr in x direction	float
VY	Component of velocity in m/yr in y direction	float
STDX	Standard deviation of vx	float
STDY	Standard deviation of vy	float
ERRX	Estimated error in m/yr in x direction	float
ERRY	Estimated error in m/yr in y direction	float
CNT	Count of scenes used per pixel	integer
SOURCE	Method of measurement (phase, tracking, hybrid)	

Note: To convert the VX and VY velocity components into magnitude (speed) and direction (angle), use the following equations:

(1) speed = $\sqrt{(vx^2 + vy^2)}$

(2) angle = arctan (vy / vx)

(3) error = $\sqrt{(errx^2 + erry^2)}$

(4) error of flow direction = error/(2*speed) (see Mouginot et al., 2012)

However, users should take care when computing the inverse tangent due to the function's inherent ambiguities. While the standard arctan function typically does not account for angles that differ by 180°, most modern computer languages and math software packages include the function ATAN2, which uses the signs of both vector components to place the angle in the proper quadrant.

Software and Tools

Unidata at the University Corporation for Atmospheric Research maintains an extensive list of freely available Software for Manipulating or Displaying NetCDF Data.

Quality Assessment

A detailed description of these data and their quality is provided in Mouginot et al. 2019. The precision of ice flow mapping varies with the sensor, the geographic location, the technique of interferometric analysis (refer to Data Acquisition and Processing for details), the time period of analysis, the repeat cycle, and the amount of data stacking. The sensor characteristics for the phase map generation are summarized in Table 2.

The unwrapped phase uses C-Band sensors (~ 5.5 cm) with 1461 tracks from RADARSAT-1 & -2, 76 from ERS-1/2, 319 from Envisat ASAR, and L-Band sensors (~ 23.6 cm): 556 from ALOS/PALSAR and 3 from ALOS2/PALSAR2 (Fig. 1A). The combination of phase and tracking mosaic covers 99.8% of Antarctica (Fig. 1B) with a significantly improved description of ice flow from the ice divides in the deep interior to the periphery. The phase mosaic itself does
not cover all of Antarctica for two reasons: 1) the interferometric phase is aliased in areas of fast flow due to the long temporal baseline of the data (except the ASE); 2) some sectors do not have sufficient multi-track coverage to provide reliable estimates of the vector ice motion. Overall, the phase-based map covers 71% of Antarctica, or 9.9 million square km, while tracking-based map covers 99.6%, or 13.8 million square km (Mouginot et al., 2017) . The improvement in precision is especially significant along ice divides when examining the error in flow direction [Mouginot et al., 2019].

Table 2. Sensor characteristics. Note: Phase error is determined for a single unwrapped phase using the nominal repeat cycle assuming an conservative error of π radians (½ cycle) [Mouginot et al. 2019].

SENSOR	Radar Frequency Band (wavelength in cm)	Repeat Cycle (days)	Period	Number of unwrapped phases	Phase Error (m/yr)
ALOS/PALSAR	L (23.6)	46	2006-2010	556	0.47

ENVISAT/ASAR	C (5.6)	35	2006-2010	319	0.15
ALOS2/PALSAR2	L (23.6)	12	2015	3	1.79
RADARSAT-1	C (5.5)	24	1997-2001	265	0.21
RADARSAT-2	C (5.5)	24	2009-2018	1196	0.21
ERS-1/-2	C (5.6)	1 or 3	1992-1996	76	5.11 or 1.70
Composite phase/speckle map			1992-2018		15-20 cm/yr

Data Acquisition and Processing

Theory of Measurements

This data set provides new ice velocity map of Antarctic ice velocity that is ten times more precise than prior maps and reveals ice motion at a high precision over 80% of the continent versus 20% in the past. The ice motion vector map provides novel constraints on interior ice motion and its connection with the glaciers and ice stream that control the stability and mass balance of the Antarctic Ice Sheet.

The map was derived from a variety of satellite radar interferometry data. (See the Data Sources section for a complete list.) Several analysis techniques using SAR data were used to generate the maps:

1. Combination of interferometric phases of two independent tracks to retrieve the surface flow vector [Mouginot et al. 2019], applied to a vast region of Antarctica
2. Speckle tracking in both along (azimuth) and across (range) track directions, used to augment the phase map in coastal areas [Rignot, et al, 2011; Mouginot et al, 2012; Mouginot et al. 2017].
3. Calculation of two dimensional offsets in amplitude imagery [Mouginot et al. 2012].
4. Combinations of (range) interferometric phases along two independent tracks Mouginot et al, 2012]

In all cases, surface parallel flow is assumed, a conventional approach for ice sheets. The Landsat-8 data are processed using repeat image feature tracking (see Mouginot, et al. 2017).

Data Acquisition Methods

This digital image mosaic was built from the sources listed in Table 3.

Phase-derived velocity are mostly for years between 2007 and 2018 while regions covered by tracking-derived velocity (along the coasts) will mostly be representative of years 2013-2017. Additional data acquired between 1996 and 2018 was used as needed to maximize coverage. SAR acquisitions between 2006 and 2018 were coordinated by the IPY Space Task Group and its successor, the Polar Space Task Group (PSTG).

Data Sources

Table 3 describes the data sources used in this data set.

Platform/Sensor	**Space Agency**	**Look Dir.**	**Mode**	**Repeat Cycle *(day)***	**Incidence Angle**	**Resolution *Rg x Az (m)***	**Frequency *(GHz)***	**Year**
ERS-1 & 2/SAR	European Space Agency (ESA)	Right	N/A	1-3	23	13x4	5.33	1996
RADARSAT-1/SAR	Canadian Space Agency (CSA)	Left/Right	Varies	24	18-47	12x5-17x6	5.33	1997/2000
ENVISAT/ASAR	ESA	Right	IS2	35	23	13x5	5.33	2007-2009
RADARSAT-2/SAR	CSA	Left	S5/EH4	24	41/57	12x5	5.33	2009-2018
ALOS/PALSAR	Japan Aerospace Exploration	Right	FBS	46	39	7x4	1.27	2006-2010

	Agency (JAXA)							
Sentinel-1/SAR	ESA	Right	IW-T OPS	12		12x43	5.33	2014-2018
Landsat-8/OLI	USGS/NASA	N/A	Panchromatic	16	N/A	15x15		2013-2018
TanDEM-X/TerraSAR-X/SAR	German Space Agency (DLR)	right	N/A	11	46.3	1.4x1.8	9.65	2011-2016

Version History

Version 1.0 was released July 2019. Refer to Table 4 for this data set's version history:

Version	Description
V1	Initial version (July, 2019)

References and Related Publications

Rignot, E., J. Mouginot, and B. Scheuchl. 2011. Ice Flow of the Antarctic Ice Sheet. *Science* 333(6048): 1427-1430. doi: 10.1126/science.1208336.

Mouginot, J., B. Scheuchl, and E. Rignot. 2012. Mapping of Ice Motion in Antarctica Using Synthetic-Aperture Radar Data. *Remote Sensing* 4(9): 2753-2767. doi: 10.3390/rs4092753.

Scheuchl, B., J. Mouginot, and E. Rignot. 2012. Ice velocity changes in the Ross and Ronne sectors observed using satellite radar data from 1997 and 2009. *The Cryosphere* 6: 1019-1030. doi: 10.5194/tc-6-1019-2012.

Mouginot, J., E. Rignot, and B. Scheuchl. 2015. Sustained increase in ice discharge from the Amundsen Sea Embayment, West Antarctica, from 1973 to 2013. *Geophysical Research Letters* 41: 1576–1584. doi: 10.1002/2013GL059069.

Mouginot, J., et al. 2017. Comprehensive Annual Ice Sheet Velocity Mapping Using Landsat-8, Sentinel-1, and RADARSAT-2 Data. *Remote Sensing* 9(4): Art. #364. doi: 10.3390/rs9040364.

Mouginot, J., E. Rignot, and B. Scheuchl. 2019. Continent-wide, interferometric SAR phase-mapping of Antarctic ice velocity. GRL (in publication)

RELATED DATA COLLECTIONS

- MEaSUREs InSAR-based Antarctica Ice Velocity Map
- MEaSUREs Antarctic Grounding Line from Differential Satellite Radar Interferometry
- MEaSUREs InSAR-Based Ice Velocity Maps of Central Antarctica: 1997 and 2009
- MEaSUREs InSAR-Based Ice Velocity of the Amundsen Sea Embayment, Antarctica
- MEaSUREs Antarctic Boundaries for IPY 2007-2009 from Satellite Radar

RELATED WEB SITES

- NASA MEaSUREs Data at NSIDC
- NASA MEaSUREs

Contacts and Acknowledgments

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ALOS PALSAR, ALOS-2/PALSAR-2: Japan Aerospace Exploration Agency (JAXA)
ENVISAT ASAR, ERS-1, ERS-2: European Space Agency (ESA)
Sentinel-1: Copernicus/ESA
RADARSAT-1, RADARSAT-2: Canadian Space Agency (CSA), MDA
Landsat-8 (optical) data were made available by United States Geological Survey (USGS).
Data acquisitions between 2006 and 2018 are courtesy of the International Polar Year (IPY) Space Task Group and its successor, the Polar Space Task Group (PSTG).
Contains modified Copernicus Sentinel data (2014-2017), acquired by the European Space Agency, distributed through the Alaska Satellite Facility, and processed by Rignot, E., J. Mouginot, and B. Scheuchl.

Document Information

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