ICE VELOCITY MAP OF ANTARCTICA MEASURED WITH ALOS PALSAR

PI No 115

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ABSTRACT

Ice velocity and grounding line are crucial information for glaciologists and modelers alike. ALOS PALSAR data are crucial component for generating this information on a continental scale. Here we present first results of our effort to map ice velocity and grounding line for all of Antarctica.

1. INTRODUCTION

Ice velocity is fundamental characteristic of the dynamics of ice sheet and is essential to know for measuring the mass budget of ice sheet and for controlling ice sheet numerical models with realistic boundary conditions. Until recently, data were mostly available on a discrete basis over small areas with variable precision.

Since the launch of the European ERS satellites in the early 1990's, spaceborne interferometric Synthetic Aperture Radar (SAR) data have become the most important data source to measure ice velocity [1] [2]. Projects and area coverage have evolved from single glaciers, later ice fields to covering the vast ice caps of Greenland and Antarctica. Several scientific and commercial second-generation SAR missions are in operation to date.

In Antarctica, areas north of 78 degrees south were first covered by RADARSAT-1 during the RAMP campaign [3]. During the International Polar Year (IPY 2007-2008), the IPY Space Task Group (STG) coordinated contributions of 13 Space Agencies [4]. One goal of STG was to achieve full interferometric SAR data coverage of the great ice sheets in Antarctica and Greenland. Standard right looking data covering the coast to about 80 degrees south were acquired by ALOS PALSAR and by ENVISAT ASAR over several years (2007-2010). The region south of 80 degrees South was filled in 2009 using RADARSAT-2 in its left looking modes. This represents the first comprehensive coverage of the area.

Here we report on our results of processing ice velocity from the interferometric ALOS PALSAR synthetic-aperture radar data acquired by the Japan Aerospace Exploration Agency (JAXA) and distributed by NASA's Alaska Satellite Facility (ASF). A first version full coverage map of ice velocity in Antarctica is also shown.

This work was conducted at the Department of Earth System Science, University of California Irvine under a contract with the National Aeronautics and Space Administration's MEaSUREs program.

2. GOAL OF THE PROJECT

The goal of our project is to produce a new set of Earth Science Data Record (ESDR): high-resolution digital maps of ice velocity of the Antarctic ice sheet. This new ESDR will be based on spaceborne SAR data from multiple missions. It will be distributed to the scientific community via institutional links already in place at the National Snow and Ice Data Center (NSIDC).

The EDSR will benefit glaciologists and ice sheet modelers, but also climate modelers interested in how ice sheets are evolving, physical oceanographers studying sea level change and changes in oceanic circulation, solid earth scientists interested in post-glacial rebound, atmospheric scientists interested in surface mass balance in Antarctica. This effort will establish a long-term legacy for quantitative measurements of the dynamics of polar ice sheets.

The data products have a simple definition. Ice velocity, in meters per year, measured on a regular earth fixed grid, at 150 m resolution over as much of the continent as is permitted by the data. The aim is to have a long-term consistent and calibrated product.

3. ALOS PALSAR DATA COVERAGE

Figure 1 shows the 2007 data coverage of Antarctica.

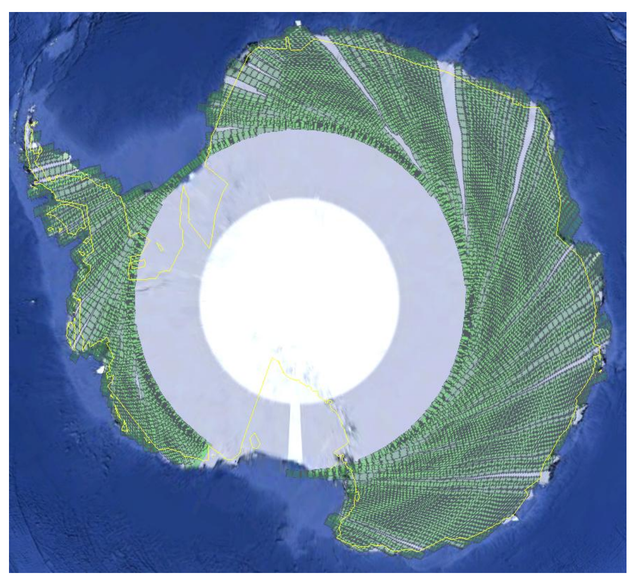

Fig. 1 ALOS PALSAR coverage of Antarctica in 2007

Tab. 1 ALOS data coverage of Antarctica
Mode: FBS 34.3
Incidence Angle: 39°
Polarization: HH
Resolution: 4.7 m (sr) × 3.3 m (az)

Year	Number of Tracks	Approx. Raw data volume
2006	161	3 TB
2007	233	7 TB
2008	308	10 TB
2009	296	11 TB
2010	TBD	TBD

Starting in 2006, JAXA tasked ALOS PALSAR to systematically acquire interferometric SAR data of Antarctica. During IPY these efforts were coordinated through STG to ensure the optimum utilization of the SAR sensors involved. Table 1 summarizes information on the ALOS PALSAR data acquired between 2006 and 2010.

For the most part, three consecutive acquisitions were made for each track once a year between 2007 and 2010. Aside from calculating ice velocity this acquisition strategy also allows the use of differential interferometry (DInSAR) for the identification of the grounding line, i.e. the transition boundary where ice detaches from the bed and becomes afloat in the ocean. The grounding line is critical to ice sheet mass budget calculations, numerical modeling of ice sheet dynamics and time evolution, and studies of ice-ocean interactions, and subglacial environments.

ALOS provides the only available L-band data coverage. L-band is advantageous over C-band particularly in coastal areas as the interferometric correlation is generally higher leading to better coverage of the velocity product.

One challenge for L-band data is the sensitivity to ionosphere disturbances. This is particularly an issue in areas where flow velocities are below a few meters per year (the interior) and noise due to ionospheric disturbances is above the signal.

C-band ENVISAT ASAR data cover approximately the same area as ALOS PALSAR data. C-band data tends to work better in the interior due to less sensitivity to the ionosphere, however, it shows less correlation on the coast, thus making the utilization of both sensors a good combination.

The nominal look direction (right) of most SAR satellites combined with the sun synchronous orbit with about 98 degrees inclination leads to a coverage gap in the southern hemisphere. This gap was closed in 2009 using RADARSAT-2 in a dedicated left looking acquisition campaign.

4. METHODS

4.1 Ice velocity

Ice velocity is measured using an interferometric data pair (i.e. two consecutive acquisitions made in the same mode). The speckle tracking method [1] was chosen for its robustness as well as the fact that it provides the 2D velocity field.

The workflow can be roughly summarized as follows:

1. For each interferometric pair
   i. Focus the RAW SAR data to SLC
   ii. Coregister the SLC pair (coarse registration)
   iii. Generate the offset maps using Speckle Tracking
   iv. Calculate the Interferogram
   v. Geocode the result
   vi. Calculate velocities from the offset maps
   vii. Calibrate the velocities (for tracks where this is immediately possible)
2. Mosaic tracks
3. Calibrate velocities ensuring neighboring tracks combine seamless
4. Check results against other sources

A very important step in this chain is velocity calibration. Typically, points of known (zero) velocities are used to generate absolute velocities from the relative offsets. This approach works well for single glaciers or small ice fields. Covering Antarctica requires long tracks and the acquisition strategy as well as sensor limitations led to tracks that cover areas with low motion only (no suitable ground control points) or tracks that have suitable calibration ground control points only on one side of the track. For this project we therefore developed a more sophisticated approach to calibrate the various tracks making sure that the resulting mosaic is a seamless product.

One challenge of using L-band interferometric SAR data for measuring ice velocity is its increased sensitivity to ionospheric disturbances. Fluctuations in ionospheric electron density can lead to an azimuth shift modulation and result in streaking in ice velocity products [5]. This is an issue particularly in areas with little to no motion, where the signal (ice velocity) can be lower than the noise (pixel offset due to ionosphere).

Several methods have been proposed to correct for ionospheric disturbances [6]. First tests with the data indicate that large streaks can be compensated for, but residual streaking is likely to remain in areas with slow motion. The implementation of ionospheric correction in our production environment is pending.

4.2 Grounding Line

Grounding line detection requires two interferograms spanning the same time interval. Three consecutive acquisitions are often made in support of this application. Each interferogram is sensitive to topography, surface motion of the glacier (mostly a horizontal component), tidal motion (a vertical component), and noise.

The two interferograms have different interferometric baselines; their topographic sensitivity is therefore also different. The sensitivity to motion is independent of the baseline. Assuming a steady flow of the glacier, the horizontal component can be eliminated by calculating the difference between the interferograms. The differential interferogram will then show residual topographic fringes as well as fringes due to vertical motion of the glacier due to differences in tide. A band of narrow fringes indicates elastic banding where the glacier starts to float free and can be used to measure the grounding line. L-band data are particularly well suited for the task due to their generally good correlation in coastal areas. The longer wavelength of L-band data leads to fewer fringes compared to C-band data, which makes accurate depiction of the grounding line a bit more difficult.

Figure 3 shows the workflow for grounding line detection. The concept is described in detail in [7].

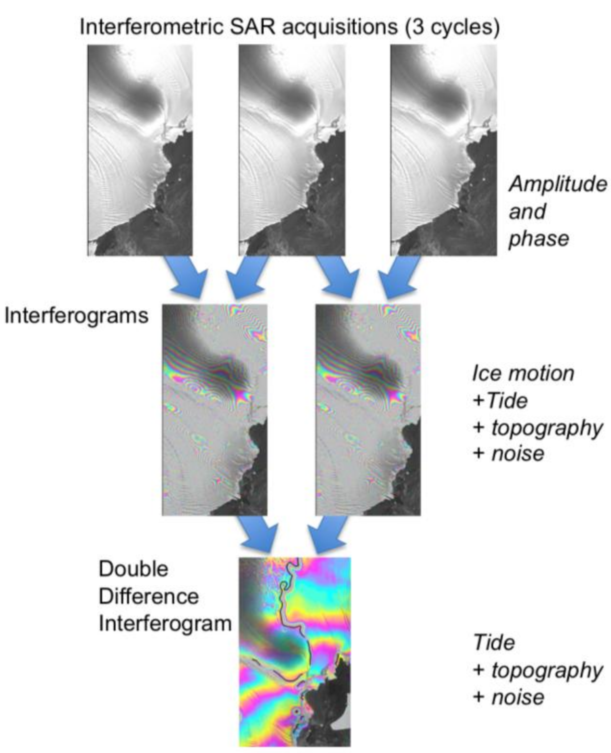

Fig. 2 Grounding line detection workflow

5. RESULTS

Figures 3 and 4 show the uncalibrated velocity results based on ALOS PALSAR for the years 2007 and 2008. The results are also not corrected for ionospheric disturbances and some streaking is visible even at the scale present. Addressing the ionospheric artifacts is an ongoing effort.

A calibrated, seamless result for Larsen C ice shelf is shown in Figure 5. The example illustrates how important the final step, velocity calibration, is in the process. Areas that are known to not move show zero velocity. Also, no track boundaries are visible in the entire image.

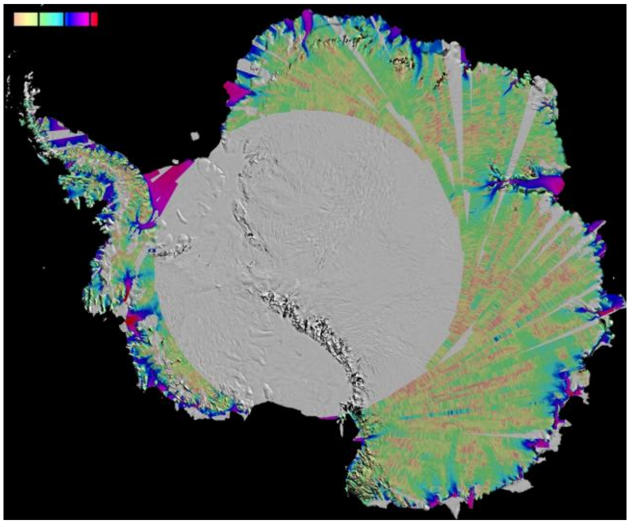

Fig. 3 Uncalibrated ice velocity based on ALOS PALSAR data acquired in 2007

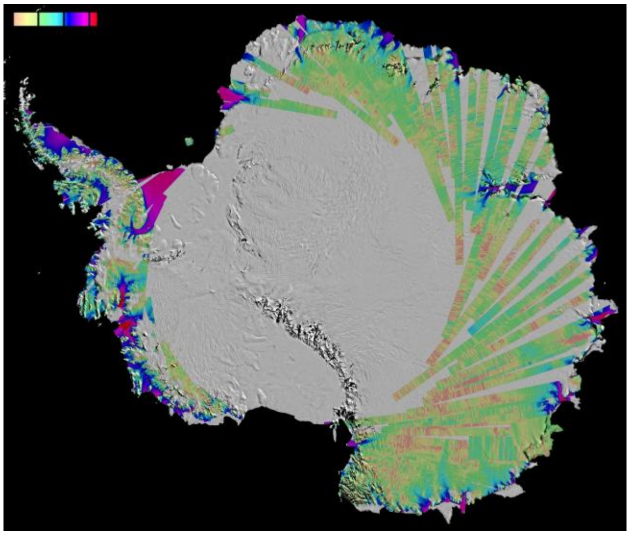

Fig. 4 Uncalibrated ice velocity based on ALOS PALSAR data acquired in 2008 (not complete)

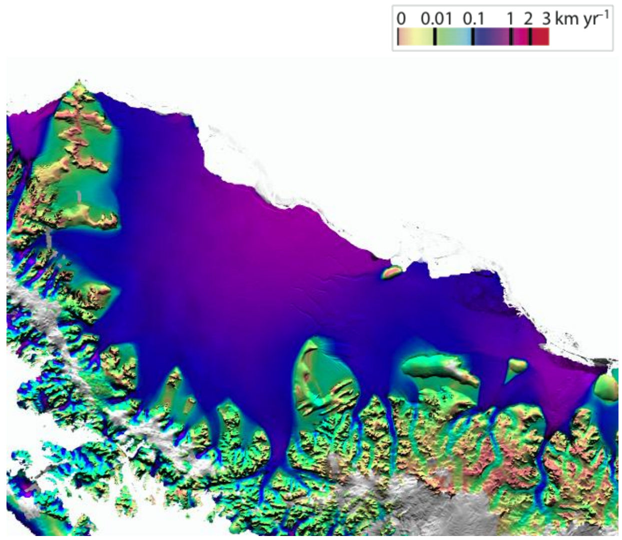

Fig. 5 Calibrated ice velocity of Larsen C Ice Shelf

The ALOS PALSAR based velocities are one crucial input for our ice velocity map covering all of Antarctica. A first version is presented in Figure 7. While large areas are well calibrated already, work is ongoing to improve velocity calibration. The biggest contribution of ALOS is in the coastal areas, the Antarctic Peninsula, and the West Antarctic Ice Sheet.

A comprehensive map of the grounding line of Antarctica was also generated using differential SAR interferometry data from various sensors between 1994 and 2009 [7]. Figure 6 shows an example for the grounding line as identified in a differential interferogram. The grounding for Antarctica line is also included in Figure 7 (grey line). ALOS data were particularly useful to map areas, where a lack of correlation of C-band data did not provide sufficient information previously.

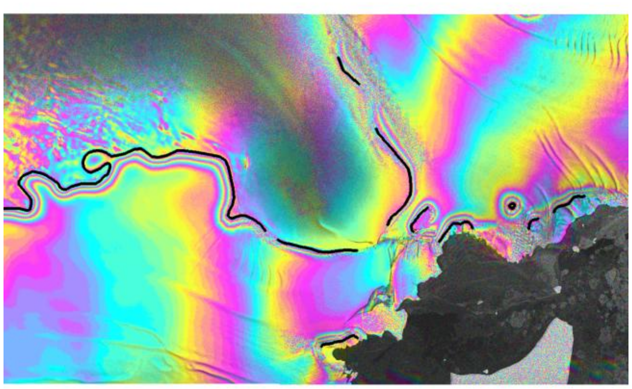

Fig. 6 Example for an ALOS PALSAR based grounding line as delineated on a differential interferogram

6. DISCUSSION AND OUTLOOK

We present our results using ALOS PALSAR interferometric data to map ice velocity in Antarctica. Coverages (north of 78 degrees south) were available for several years, an effort coordinated by the STG during IPY. In addition to ALOS PALSAR data, we have access to ENVISAT ASAR and RADARSAT-2 data to generate the first complete map of ice velocity in Antarctica. This new Earth Science Data Record will be distributed to the scientific community via institutional links already in place at the National Snow and Ice Data Center (NSIDC).

The first version of the velocity map will include ionospheric disturbances, which will be corrected in later iterations of the product. In addition to the complete map, where full coverage is the primary goal, we are working on annual velocity maps for the areas where data are available. Our project is an ongoing, multi-year effort, and while much progress has been made so far, more work is required to generate all planned products in the desired quality.

A secondary, but equally important product is the grounding line, which can be determined using differential interferometry. The grounding line is not static, a continuation of data acquisition is therefore critical to monitor changes. The accuracy of the method and the lack of suitable alternatives justify the additional data requirement (a third acquisition is needed for differential interferometry).

ALOS PALSAR is a crucial component for mapping ice velocity and grounding line in Antarctica. L-band provides good data correlation in coastal areas and areas, where this is not the case for sensors using C- or X-band.

7. RECOMMENDATIONS

We strongly recommend “Ice sheet motion” as a fully recognized major science objective of future ALOS missions because ALOS PALSAR data are extremely useful for mapping glacier motion in Antarctica. Operating ALOS at a shorter repeat cycle will improve the performance of PALSAR at mapping ice motion and grounding lines. The acquisition of three consecutive cycles is critical for grounding line mapping. Adding a left looking capability for ALOS PALSAR to map regions south of the right looking mode would be an asset.

We strongly recommend continued operation of ALOS PALSAR over the Polar Regions to detect changes in glacier motion, which affect ice sheet mass balance and contribution to sea level rise. The systematic mapping of Greenland and Patagonia should also be considered.

8. REFERENCES

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E. Rignot, J. Mouginot, and B. Scheuchl, “Mapping of ice motion in Antarctica: MEaSUREs,” International Polar Year Oslo Science Conference (June 8-12, 2010)

B. Scheuchl, J. Mouginot, and E. Rignot, “Mapping Ice Motion in Antarctica using Envisat ASAR, ALOS PALSAR, ERS-1-2, and RADARSAT-1-2: a Comprehensive View,” ESA Living Planet Symposium in Bergen (June 28 -July 2, 2010)

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J. Mouginot, B. Scheuchl, and E. Rignot, “Ice Velocity Map of Antarctica measured with ALOS PALSAR,” AGU Fall Meeting, San Francisco (December 13-17, 2010)

B Scheuchl, J. Mouginot, and E. Rignot, “Investigation of Antarctic ice streams south of 78 degrees south using interferometric RADARSAT-2 data,” AGU Fall Meeting, San Francisco (December 13-17, 2010)

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ALOS PALSAR data is distributed in North America through the Alaska Satellite Facility (ASF).

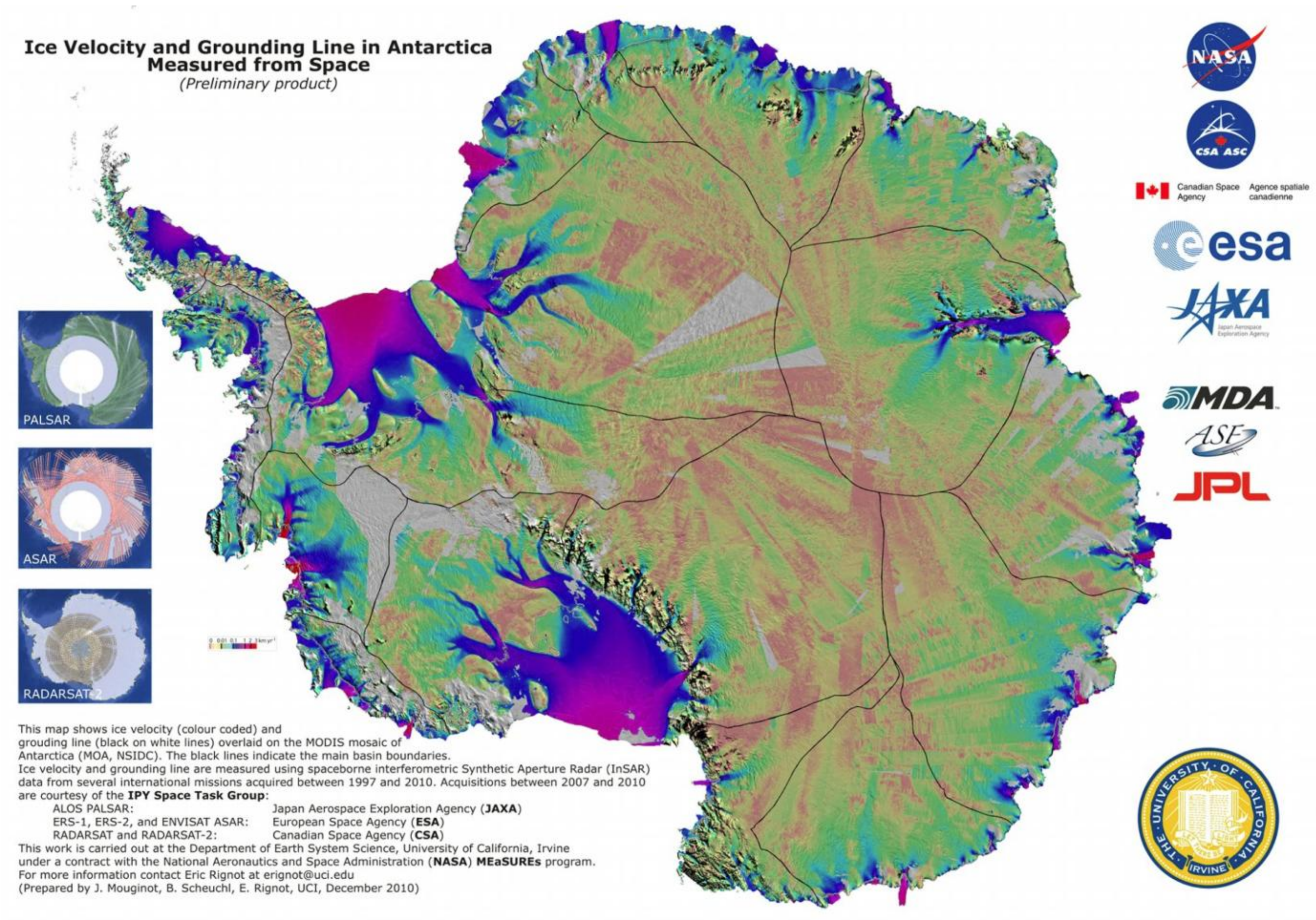

Fig. 7 Uncalibrated MEaSUREs ice velocity map based on ALOS PALSAR, ENVISAT ASAR and RADARSAT-2 interferometric SAR data (This poster was presented at the AFU Fall Meeting in San Francisco in December 2010).