Mapping of ice velocity in Antarctica using ALOS PALSAR repeat pass interferometric data

Eric Rignot[1, 2, 3]

[1] Department of Earth System Science, University of California, Irvine, CA 92697 (USA) erignot@uci.edu
[2] Jet Propulsion Laboratory, Pasadena CA 91109 (USA) eric.rignot@jpl.nasa.gov
[3] University of Colorado, Boulder CO 80303 (USA)

Abstract
We employed ALOS PALSAR fine beam 46-day repeat data to map ice motion in Antarctica using a speckle tracking technique. The results are excellent. As suggested by earlier experiments with L-band radars, signal coherence over snow and ice is higher than at C-band, hence we can measure ice motion in places where long-repeat SARS, e.g. Envisat ASAR and Radarsat-1, have difficulties. The precision of the measurements is 2 m/yr, or 3 times better than with Radarsat-1. In the interior regions, however, the SNR drops to low values and speckle tracking fails. This is however an area where C-band radars are more useful, hence a synergy between instruments offers great promise. Overall, ALOS PALSAR shows strong potential to provide key observations of ice motion in the Antarctic, especially along the coast, which is the most important aspect for mass balance studies. In the case of West Antarctica, the data reveal a massive increase in glacier acceleration in Pine Island Bay since the year 1996 when velocities were measured with ERS-1/2 tandem InSAR.

Keywords: Glaciology, interferometry, climate change.

1. INTRODUCTION

Ice motion is a parameter of fundamental importance in ice sheet studies because it governs the evolution of the mass balance of Antarctica and is also the most desired constraint on numerical models to make them more realistic.

In the first phase of this study, we wanted to evaluate the performance of ALOS PALSAR at measuring ice velocity in Antarctica. One challenge was to overcome the 46-day repeat of the satellite. With such a long repeat cycle, phase aliasing is too severe to maintain fringe visibility in areas of fast flow. On the other hand, PALSAR operates at L-band frequency, which was shown with SIR-C X-, C- and L-band data over Patagonia and Alaska in year 1994 to offer better temporal coherence on snow and ice compared to C- or X- band radar data. We wanted to examine different regions, with different climate and ice flow regimes to determine the capability of ALOS PALSAR at measuring ice motion. We also wanted to compare the performance of ALOS PALSAR with that of ERS-1/2 and Radarsat-1.

2. DATA AND METHODS

5.1. Processing

We obtained several scenes from the Alaska Satellite Facility (ASF) in West Antarctica. We concatenated successive frames and processed them into single look images using the Gamma Remote Sensing commercial software that we have been using for many years now. We then applied a speckle tracking developed at JPL and generated ice velocity maps from the results pixel offsets. The averaging boxes for speckle tracking were 128 (range) x 256 (azimuth) samples in size, with a grid spacing of 32 x 64 samples, and a search window of 64 x 64 samples. The offsets were median filtered to remove bad matches. A plane fit was adjusted through non-moving areas such as ice islands, nunataks, and ice caps.

Filtered offsets were then converted into horizontal displacements on the ground, and to easting and northing velocities assuming surface parallel flow. A digital elevation model of Antarctica that combines ICESAT and ERS-1 radar altimetry (J. Bamber, unpublished) was used to geo-reference the data and mosaic multiple tracks at 200 m posting (Figure 1).

5.2. Products

The precision of PALSAR velocities is 2 m/yr, or 3 times better than Radarsat-1 due to the longer repeat and finer resolution. We compare PALSAR velocities with those measured using ERS-1/2 ascending/descending tracks in spring 1996 (5 m/yr precision); and with Radarsat-1 along the lower reaches of Pine Island and Thwaites glaciers in years 2000 to 2007 (6 m/yr precision). All the passes we analyzed worked well, almost no exception.

3. RESULTS

Figure 1 shows the mapping of ice velocity in Pine Island Bay using ERS-1/2 one day repeat data in 1996, Radarsat-1 24-day repeat data from summer 2006 and ALOS PALSAR data from summer 2006. Signal coherence is

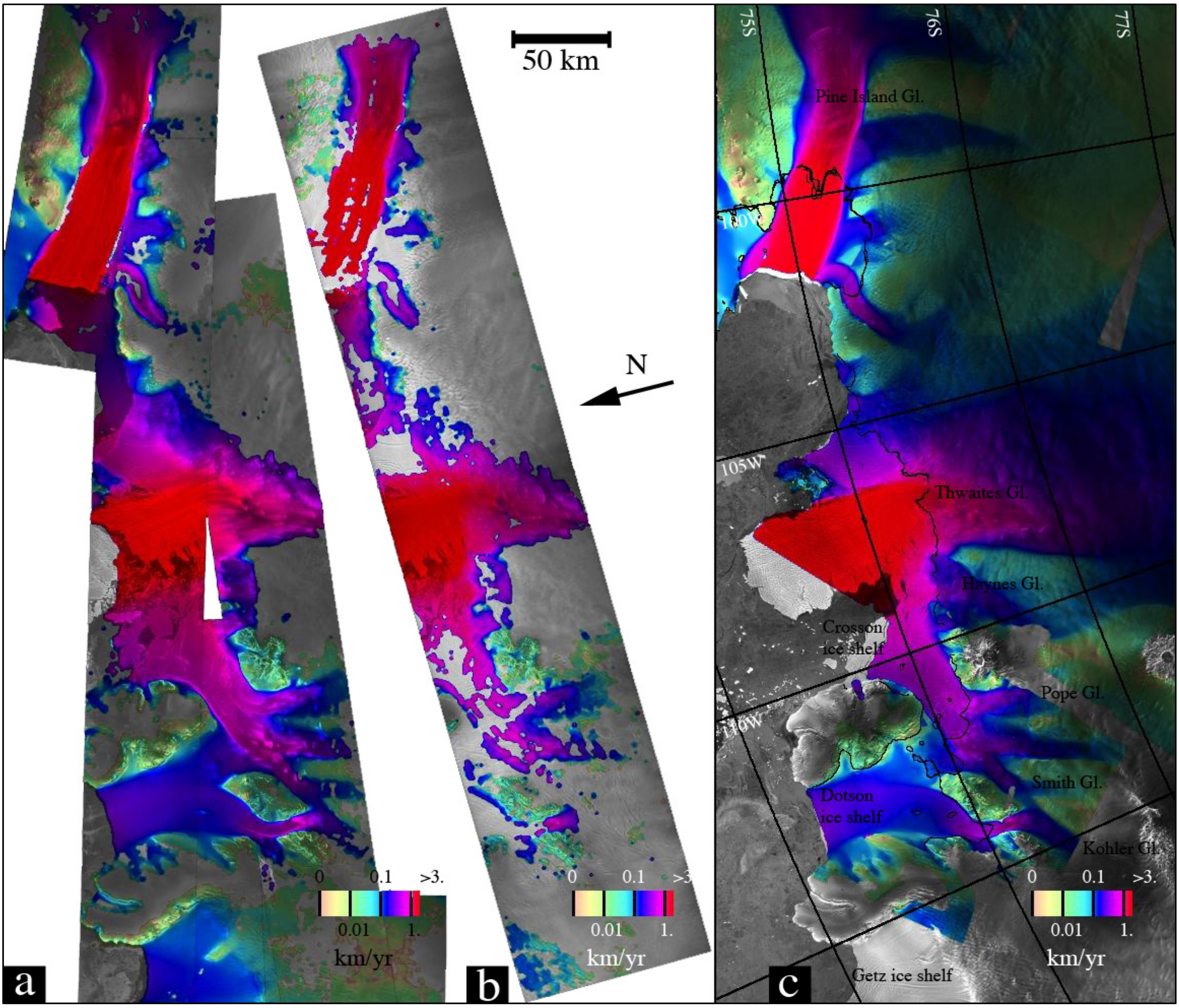

Figure 1. Ice velocity measured with InSAR using (a) PALSAR 46-day repeat data; (b) Radarsat-1 24-day repeat data; and (c) ERS-1/2 1-day repeat data, color coded on a logarithmic scale and overlaid on radar brightness (Rignot, submitted, 2008).

generally higher at C-band compared to L-band, except in interior regions. Signal decorrelation is the product of decorrelation associated with the interferometric baseline, thermal noise, surface weathering, and volume scattering. At C-band, different interferometric baselines and different times of year do not change the results significantly. Moreover, the radar backscatter of the surface is much brighter than the noise equivalent backscatter, so most of the decorrelation must be associated with surface weathering in the 24-days that separate the acquisitions. At L-band, the interferometric baseline is short (100-1000m) compared to the critical baseline (14 km) and there is no volume scattering from snow at that long wavelength. In the interior regions, however, we find that the radar backscatter is only 2-4 dB above the noise level, and this is sufficient to destroy speckle tracking. Greater penetration is unlikely since we measured penetration depths of typically a few 10m in central Greenland in 1995. Most of the decorrelation is due to the fact that “wet”, deep snow appears radar dark and close to the system noise floor.

Despite this limitation, the quality of the ice velocity data, where applicable, is remarkable. Because of its longer repeat cycle and finer spatial resolution, PALSAR speckle tracking yields velocity estimates 3 times more accurate than with Radarsat-1. On ice shelves, tidal contamination of the signal is 2 times less than with Radarsat-1 and our new velocities are probably the most accurate measurements ever made on that surface. Note

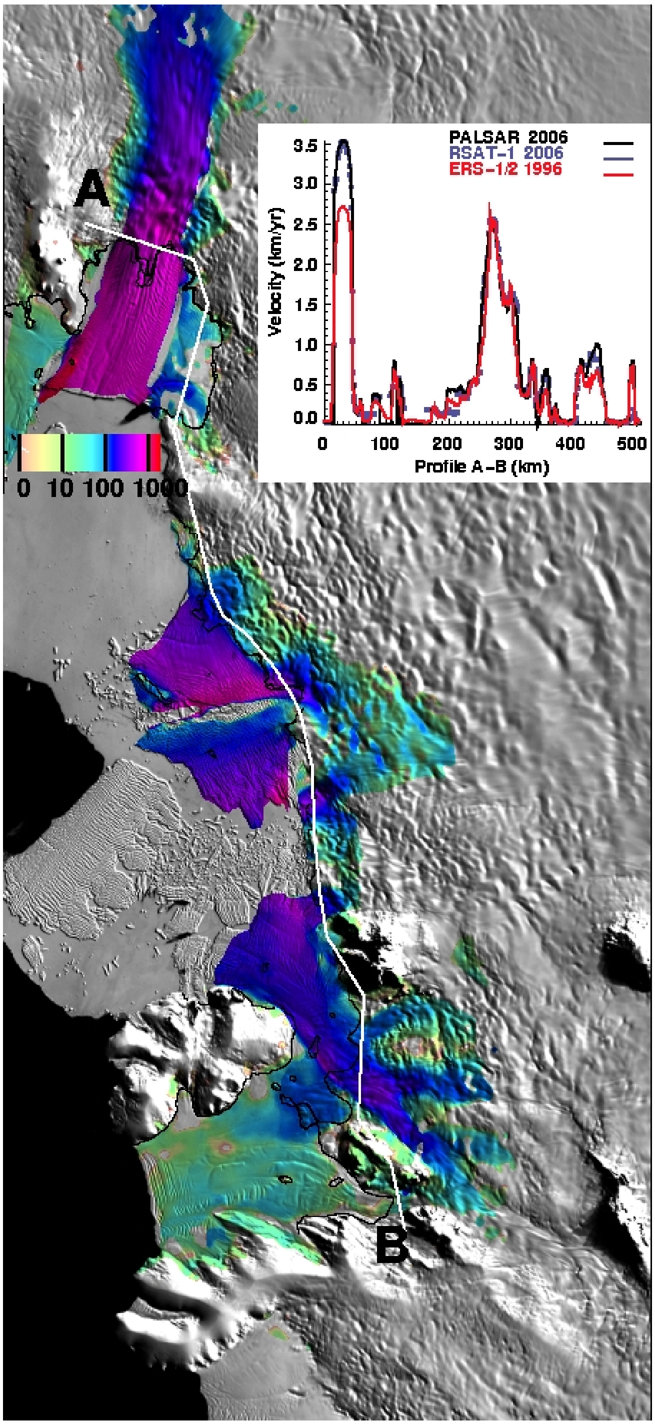

Figure 2. Difference in ice velocity between PALSAR 2006 data and ERS-1/2 1996 data in the Pine Island Bay sector of West Antarctica. The inset shows the velocity extracted along profile A-B. (Rignot, submitted, 2008).

that in the Getz Ice Shelf sector farther west of the area shown here, PALSAR yields very good results as well, whereas Radarsat-1 systematically failed to produce any results after many years of trial.

Figure 2 shows the differencing of the PALSAR data with the ERS-1/2 InSAR map of 1996 (based on ascending and descending tracks acquired one day apart). The map shows pronounced glacier acceleration on Pine Island Glacier, the floating tongues of Thwaites Glacier, the floating tongue of Smith Glacier and Smith Glacier and all its tributaries. No changes are found on Kohler Glacier and Dotson Ice Shelf; no changes are found on the grounded, central part of Thwaites Glacier. On the other hand, Thwaites Glacier is getting wider with time, something we already detected in 1996-2000 and which is now confirmed. Examination of the new data shows that the widening is ongoing, so that Thwaites Glacier ice discharge is increasing with time.

These results have important implications. One is that we were able to establish with precision that the mass loss from this region is increasing with time. Two, the new measurements suggest that the grounding line of several glaciers retreated many kms, so that the retreat may now proceed into the deeper interior basins, with the potential for much larger discharge and mass deficit from this sector of Antarctica.

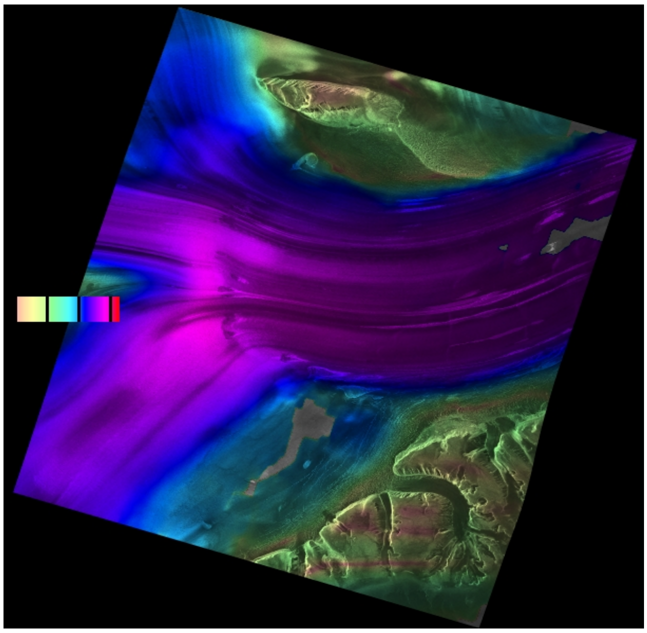

Figure 3. Map of ice velocity of Lambert Glacier obtained from ALOS PALSAR acquired in 2006. Color scale is the same as on Figure 1.

Other results were obtained on Getz Ice Shelf, with a successful complete mapping; on Astrolabe Glacier, with the same high quality results; Lambert Glacier in East Antarctica, same; and Totten Glacier, East Antarctica where signal coherence is lost on Law Dome because of thermal noise and on the center part of the glacier, for reasons that require further investigation. As in West Antarctica, signal coherence drops down in radar-dark regions.

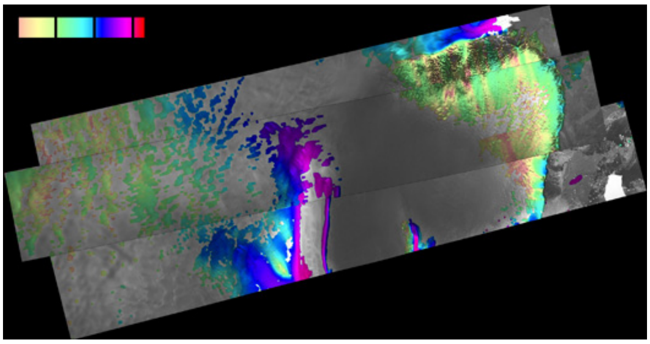

Figure 4. PALSAR mapping of the upper reaches of Totten Glacier, East Antarctica. Law Dome is close the thermal noise limit of the system.

We also examined the influence of the ionosphere. One example is shown in Figure 5, where azimuth offsets caused by plumes of ions are as large as 2 pixels in areas with no ice motion. Among the many pairs examined so far this is the only instance of bad data. In Greenland, we examined two pairs and one of them had similar streaks caused by changes in ionospheric activity. Further studies are therefore required to determine how significant ionospheric perturbations will be on the measurement of ice motion.

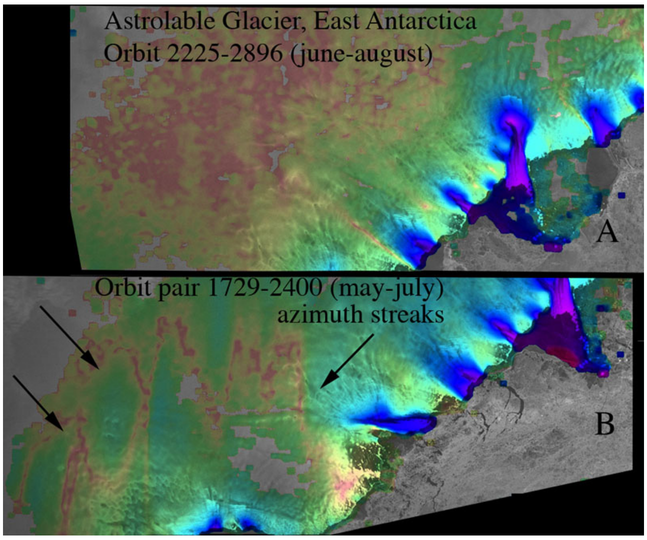

Figure 5. Effect of the ionosphere on ALOS PALSAR speckle tracking data in Antarctica, summer 2006. (A) velocity map of Astrolabe Glacier, East Antarctica with no ionospheric artifacts. (B) Parallel tracks showing large azimuth streaks associated with chutes of electron in the ionosphere and which yields shifts as large as 2 azimuth pixels

4. DISCUSSION AND CONCLUSIONS

These results suggest that ALOS PALSAR will make significant contributions to the study of ice and snow, and in particular for ice sheets in Greenland and Antarctica. Our results indicate that high-precision velocities were obtained in the summer of 2006 along the coastal areas, including ice shelves, whereas data quality degraded in interior regions. The radar map of Antarctica made from PALSAR (Shimada Masanobu, pers. comm.. 2006)) does indicate, however, that not all interior regions are radar dark, so the potential to use ALOS PALSAR in the interior needs to be further investigated.

We suggest that in the next round of acquisition plan, ALOS PALSAR makes systematic measurements of ice sheets in Greenland and Antarctica, in fine beam mode, as well as in Patagonia, Alaska, the Himalayas and other glacier-covered areas. Ice and snow should be upgraded to being a major science objective of the ALOS PALSAR mission.

We are starting a new NASA project entitled MEASURES to make continental scale velocity maps of Antarctica available to the community. We hope to have a strong representation of ALOS PALSAR data in these maps. The first release of results is planned for mid 2008.

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