TerraSAR-X Observations of the Recovery Glacier System, Antarctica

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ABSTRACT

We present a comparison of 1997 RADARSAT Antarctic Mapping Project (RAMP) SAR data with 2008-09 TerraSAR-X observations of a tributary glacier that is part of the Recovery Glacier drainage network in Coates Land Antarctica. The Recovery Glacier system is of scientific interest because of its role in discharging East Antarctic ice to the sea and because it has been subsequently learned that the flow of the glacier is likely controlled by the presence of subglacial lakes near the onset of faster glacier flow.

Index Terms— Geophysics, synthetic aperture radar

1. INTRODUCTION

The polar regions play an important role in the Earth system. The snow and ice covered ocean and land are sensitive indicators of global climate change and are themselves drivers for change. In March 2007 the International Polar Year (IPY) initiated collaborative polar research on a worldwide scale. The IPY is successor to the International Geophysical Year (IGY) of 1957/1958, which ushered in the modern era of polar science. Today's IPY goes beyond IGY by enabling scientists to use for the first time data from spaceborne instruments. By using innovative remote sensing methods and techniques, detailed views of the entire Arctic and Antarctica can be achieved and placed in a global context.

The World Meteorological Organization (WMO), one of the organizers of the IPY, has established the Space Task Group (STG) charged with coordinating Earth observation missions in support of IPY projects [1,2]. This includes satellite operations but also data reception, processing and dissemination. The STG goals are particularly important for high resolution missions with optical and microwave sensors because their data acquisition requires appreciable planning efforts. In particular, microwave Synthetic Aperture Radar (SAR) instruments are capable of making observations through clouds and during either the day or night. Thus, the physical properties of ice sheets such as ice sheet surface motion, ice sheet topography, and ice margin position can be systematically investigated year round.

The German Aerospace Center (DLR) is a member of the Space Task Group and contributes to IPY mainly with its X-band (9.65 GHz) satellite TerraSAR-X (TSX). Under the scientific auspices of the GIIPSY project (Global Inter-agency IPY Polar Snapshot Year) November 2008 marked the beginning of the IPY coordinated activities for TSX with acquisitions over a tributary ice stream feeding into the Recovery Glacier (Figure 1) in Antarctica.

TerraSAR-X and Canadian RADARSAT satellites can image left and right, thus enabling observation of the portion of Antarctica close to the South Pole. Using its large swath width (150 km) and 25-m pixel size, RADARSAT-2 carried out the first dual polarization mapping of Antarctica in late 2008. TSX has a narrower swath (30 km), but extremely fine spatial resolution of 3 meters. So it focuses on selected, smaller, very complex areas of high scientific interest on the ice sheet. In the case of snow and ice, the penetration depth of the microwaves is reduced for the smaller wavelength. Therefore, the radar response at X-band is more sensitive than at C-band to surface and near surface physical properties like wetness and roughness of the imaged area. This makes TSX a valuable tool for regular and spatially extended investigations of fine structures on ice and snow surfaces. Features like flow lines and crevasses can be observed in detail and used to study flow dynamics of glaciers and ice streams.

Here we use TerraSAR-X to study one of the enigmatic tributaries which is part of the Recovery Glacier drainage network located in East Antarctica (Figure 1). The Recovery Glacier region is of considerable scientific interest because of its role in discharging East Antarctic ice to the sea and because it has been recently discovered that the flow of the component glaciers is likely controlled by the presence of subglacial lakes near the onset of faster glacier flow [3].

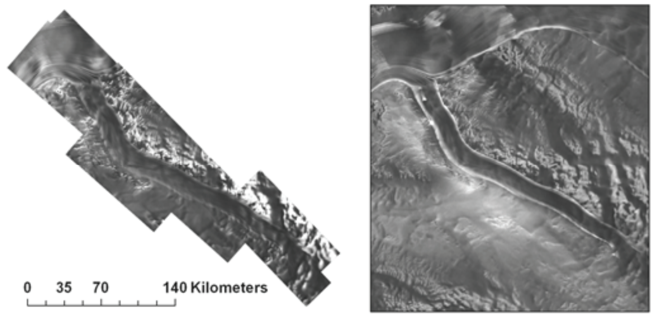


Figure 1. 2008-09 TSX mosaic (left) and 1997 RAMP mosaic (right) of a Recovery Glacier tributary. The main trunk of Recovery Glacier is located in the upper part of the RAMP and TSX mosaics. Scenes are centered on 82.5°S 19°W (Figure 2).

2. RADARSAT-1 and TerraSAR-X SAR OBSERVATIONS

Up to now, the only available SAR mapping of the Recovery Glacier system was carried out in 1997 with RADARSAT-1 (R1) [4]. This was done within the RADARSAT-1 Antarctic Mapping Project (RAMP) which resulted in the first, high resolution radar mosaic of the entire southern continent. Through careful mapping of shear margins and flow stripes, the RAMP measurements revealed for the first time the extent of these glaciers into the deep interior of East Antarctica [4]. Spacecraft operations limited the amount of interferometric data that could be collected during RAMP so only the northerly portion of the main trunk of Recovery Glacier and its confluence with several long but narrow tributary glaciers were mapped interferometrically.

Eleven years later, the next high-resolution spaceborne observations of Recovery Glacier were acquired using the TSX satellite in left looking mode. The acquisition swaths are shown in Figure 2. The imaging was repeated at 11-day intervals between 30 October 2008 and 26 January 2009, thus enabling another estimate of surface velocity using SAR interferometry (InSAR) and speckle retracking.

3. PROCESSING METHODOLGY

High resolution geocoded TerraSAR-X data were used to apply the amplitude correlation technique and to obtain the two dimensional motion vector field. TerraSAR-X EEC-SE geocoded products were used with highest spatial resolution. Only about 1.3 looks were taken, leaving a good part of the coherent speckle for correlation purposes. All correlation is performed in ground range pixels.

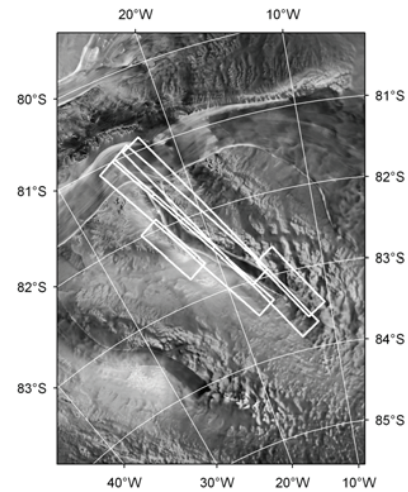
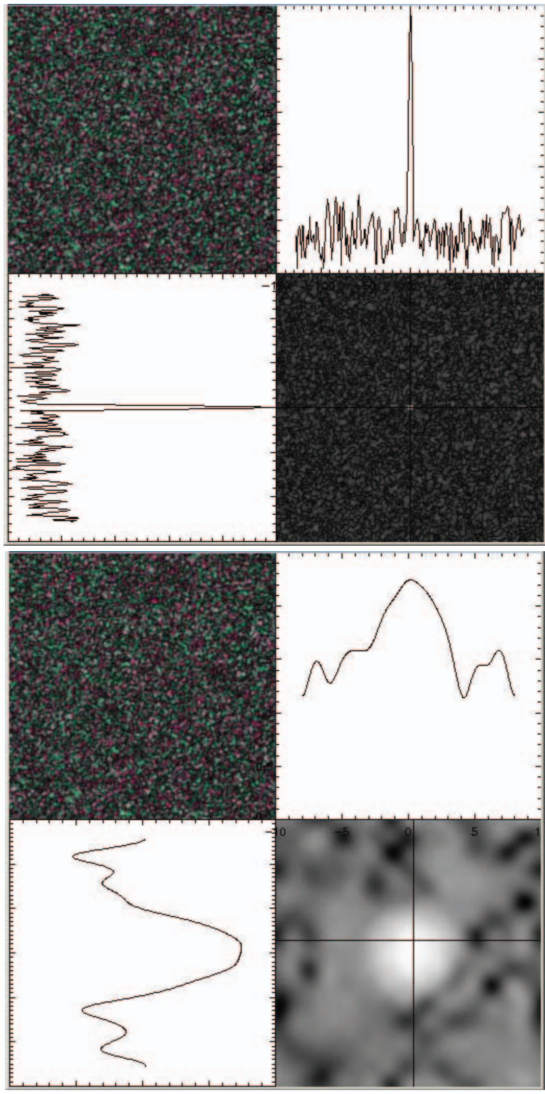


Figure 2. TerraSAR-X acquisition swaths during the 2008-09 austral summer overlain on the RAMP mosaic.

Figure 3a shows a 256^2 pixels patch of a repeat pass TSX data pair over the ice sheet close to Recovery Glacier. The correlation function in East (E) and North (N) directions correspond to the pixel in the center of the patch. The correlation is high (0.3) and thus the speckle signal delivers a well defined peak even on this low-contrast surface. The correlation peak width is 4 pixels (6 m) in both E and N directions and has an estimated accuracy of 0.03 pixels (0.037 m) [5]. Because the maximum correlation is found with integer pixel accuracy only, an oversampling factor was applied to the correlation function and a subpixel offset of 0.156 x 0.375 pixels (0.195 x 0.469 m^2) in E and N directions was obtained (Figure 3b). This corresponds to a speed of 16.6 m y^{-1}. For a pixel located on the ice stream the coherence is lower (0.1), and the displacement is of the order of 0.45 m d^{-1} (166 m y^{-1}).

The described technique is applied over equally distributed patches (template windows) on the entire SAR scene and a two dimensional motion vector field can be generated. The absolute accuracy of the velocity estimates depends on several factors including: atmospheric path delay variation between the two images (max. error 0.20 m in range); orbit errors (0.10 m in range and azimuth); accuracy of the correlation approach (depending on the correlation window size). Over one TSX repeat cycle the overall absolute accuracy as governed by orbital errors and the atmosphere is about 0.03 m d^{-1} which is sufficient for many applications. The relative accuracy for individual motion vectors depends on the correlation coefficient, the correlation patch size and the shape of the correlation function. In our case it is estimated from to about 0.03 m d^{-1} [5].



(a) (b)

Figure 3. (a) Correlation function of a 256² pixels patch of two TerraSAR-X images with 11 day interval over the Recovery Glacier. Upper left R/G composite of the two images. Lower right: Correlation function. Upper right: W-E cut. Lower left: N-S cut. (b) Same as (a) but the correlation function was interpolated by a factor of 32.

4. GLACIOLOGICAL ANALYSIS

The highly detailed TSX data very clearly delineate flow stripes, shear margins and individual crevasses along the 'RAMP' tributary and its confluence with the main trunk of Recovery Glacier. TSX data and 25 m RAMP mosaic data are compared in figure 4, which shows the suture region between the tributary glacier and the main trunk of Recovery Glacier. These C- and X-band images are generally similar although the wider bandwidth TerraSAR-X data better captures the details of surface crevassing. Interestingly, a clear band of crevasses on the right center margin of the TSX image is not obviously associated with a similar band on the R1 image. In general, we observed that the chaotic zones of shear margins appear relatively brighter in the R1 data than in the TSX data. This is most likely attributable to differences in resolution (nominal 4-look 25 m R1 and single look 3 m TSX), look angle (24° R1; 44° TSX) and frequency (5.3 GHz R1; 9.65 GHz TSX). These instrumental differences complicate the interpretation of the data in terms of a recent onset of crevasse formation. That said we have been able to identify the same crevasse patterns in both data sets in a few other instances suggesting that some of the differences in figure 4 may be attributable to real changes in the surface over the 11 year period.

RAMP interferometric data only cover the northerly portion of the main trunk of Recovery Glacier and its confluence with the 'RAMP' tributary. After experiencing a minimum near the confluence regions, speeds along the center line of the tributary vary only slightly in the upstream direction and are on the order of 100–180 m/y [6,7] even though the surface elevation decreases from about 1550 m at the southernmost part of the measurements (about 80 km upstream of the confluence) to about 1150 m at the junction with the main trunk of Recovery Glacier.

In 2008, TerraSAR-X successfully acquired interferometric pairs along the entire 250 km length of the RAMP tributary (Figure 5). Much as observed with the RAMP data, the longitudinal gradients are small along most of the length of the tributary. TSX and RAMP velocities are available from the confluence of RAMP tributary and Recovery Glaciers to a point about 80 km upstream. In this region, the TSX velocities vary from about 171 to about 167 m/yr with a minimum of 133 m/yr just north of the confluence. The minimum supports the notion that Recovery Glacier exerts a back pressure on the outflow of this tributary. Strong shearing is concentrated in the margins. The TSX velocities also show that the longitudinal gradients and hence longitudinal stresses are small along the remainder of the glacier.

5. CONCLUSIONS

The Recovery Glacier system is of considerable scientific interest because of its role in discharging East Antarctic ice to the sea and because it has been subsequently learned that the flow of the glacier is likely controlled by the presence of subglacial lakes near the onset of faster glacier flow. TerraSAR-X data are a unique measurement of the properties of this system and, combined with predecessor measurements made using RADARSAT-1, give a glimpse into how this glacier system might change with time. These detailed investigations will help address a critical limitation in climate models that do not yet have the ability to predict the observed rapid changes in the ice sheet behavior with consequent impacts on local oceanography and global sea level. Further information and images can be found at the following URLs:

http://www.dlr.de/terrasar-x/,
http://bprc.osu.edu/rsl/GIIPSY/
http://bprc.osu.edu/rsl/radarsat/data/ .

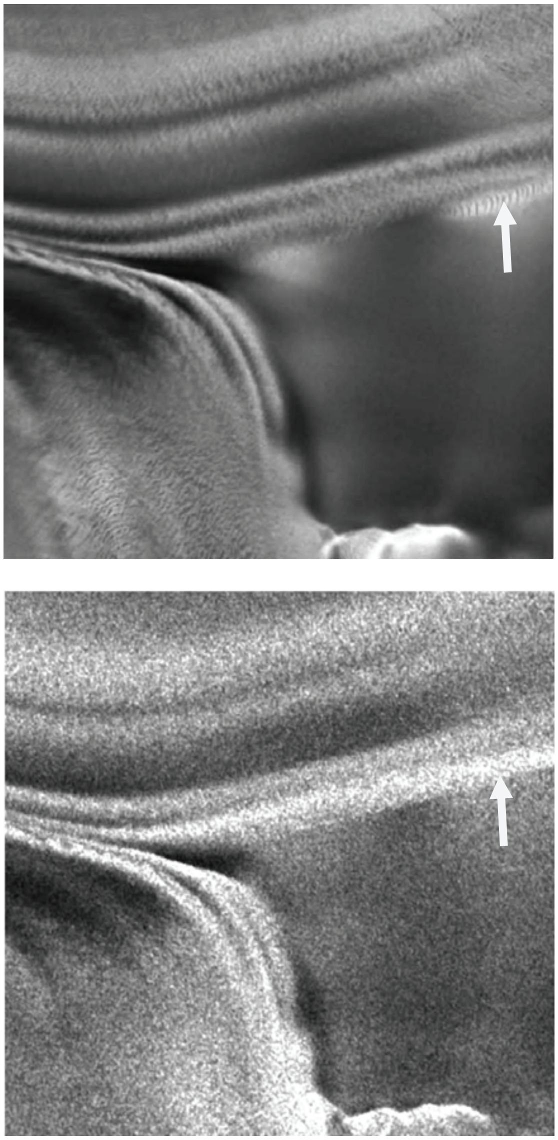


Figure 4. TerraSAR-X (top) (resampled to 32 m) and RAMP 25 m data (bottom). White arrows indicate a crevasse band clearly visible in the TSX image but not the R1 image. Images are 14 km wide.

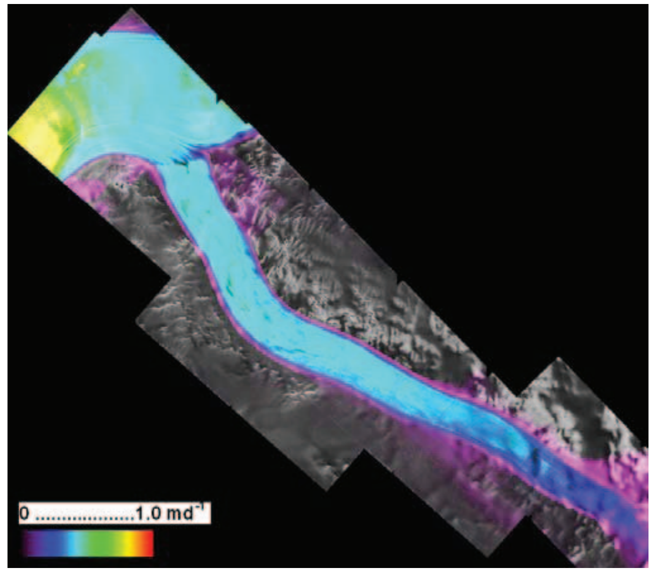


Figure 5. 2008 TerraSAR-X derived surface velocities along the entire 250 km length of the RAMP tributary.

6. REFERENCES

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