InSAR Results from the RADARSAT Antarctic Mapping Mission Data: Estimation of Glacier Motion using a Simple Registration Procedure

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ABSTRACT

An interferometric method is used to derive ice motion from RADARSAT data collected during the Antarctic Mapping Mission. Although one cannot solve for both topography and ice motion using one interferometric pair, it is possible to use a coarsely sampled digital terrain model to estimate ice motion using an image registration method. Less accurate than the usual fringe counting method for estimation of radial displacement, the image registration method allows useful motion estimation in both range and azimuth. The method is described and some results shown for a large area (~17,000 km^2) including ice flow into the Filchner Ice Shelf.

INTRODUCTION

During September and early October 1997, RADARSAT was manoeuvred to operate in a left looking mode and carried out the first high resolution mapping of the complete Antarctic continent. The RADARSAT satellite is in a 24 day repeat orbit and it was suspected that this time period was too long to expect satisfactory coherence, especially for coastal outflow glaciers [1]. However, in interior Antarctica, surface snow or ice melt is very rare. Therefore, there was a possibility that backscatter from the firn and upper ice layers would not change sufficiently in the 24 days between data acquisitions to destroy the necessary coherence for interferometric analysis. The data were collected as part of the Antarctic Mapping Mission (AMM) organized as a result of the NASA/CSA agreement whereby NASA launched RADARSAT in exchange for access to data and the opportunity to map Antarctica. During the last 6 days of the 30 day mission, the coverage of the first 6 days was repeated exactly, thereby generating many pairs of images with which this type of interferometric analysis is possible. The technique used to measure the ice motion is an image correlation approach and depends on the coherent speckle pattern in the 2 images being correlated. The accuracy with which registration can be achieved is an order of magnitude better than with the incoherent cross-correlation approach that depends on image features, like crevasses, to obtain good results.

METHOD

Raw signal data from the 2 passes were processed with a phase preserving SAR processor, dtSAR, supplied by MDA. The single look complex data were oversampled by a factor of 2 in both range and azimuth prior to detection. To avoid aliasing problems with the sin(x)/x kernel used in the oversampling, the azimuth frequency was shifted to be centred on zero Doppler using the Doppler centroid information. After detection, image chips were cross-correlated to obtain the offset in both azimuth and range. The cross-correlation function was then oversampled by an additional factor of 20 in both directions. The position of the peak in the oversampled cross-correlation function was used to determine the pixel shifts and the magnitude was used as a quality factor for poor point rejection. The pixel shifts in image slant range (δ_r) and image azimuth (δ_a) can be related to the 24 day ice displacements in the ground range (D_r) and azimuth (D_a) directions through the relations:

$$\delta_r = B\,cos\,(\chi - \alpha) + D_r\,sin\,(\theta + S_r) \quad (1)$$

and $$\delta_a = D_a\,cos\,(S_a) \quad (2)$$

where the baseline, angle, and slope parameters are defined in Fig. 1. For the baselines estimated for these data, typically less than 200 m, the error associated with the parallel ray approximation implicit in (1) is only a few centimetres, small in comparison with other errors. Knowledge of the baseline is required, as well as a digital terrain model for calculation of the incidence angle, look angle, and terrain slopes.

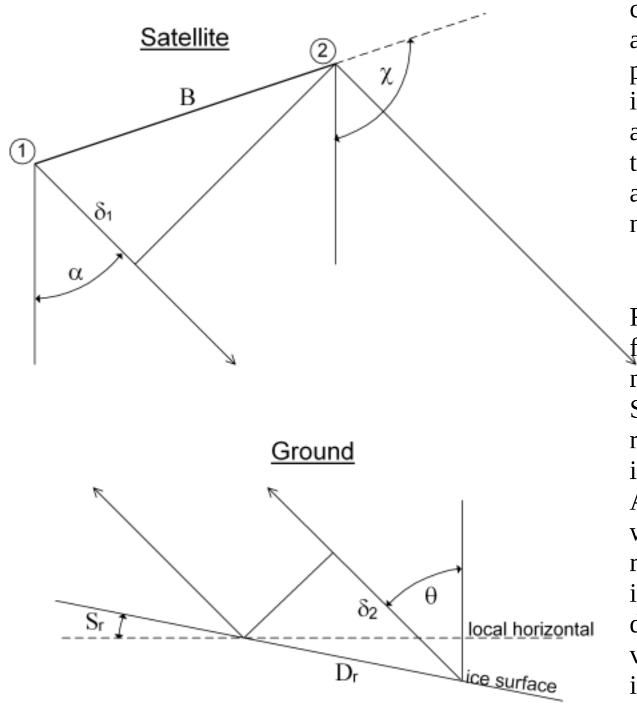

Fig. 1

Illustration of the displacement geometry for calculation of the ground range displacement (D_r). B is the baseline, χ is the baseline angle, α is the radar look angle at the satellite, S_r and S_a are the terrain slopes in range and azimuth respectively (to the local horizontal), θ is the local incidence angle, and $\delta_r = \delta_1 + \delta_2$.

In practice, it is normally possible to use 1 or 2 points in the imagery, which correspond to exposed rock or mountains, to help calibrate the ice displacement information. Radar look and incidence angles are calculated for points in the digital terrain model by using the satellite orbit information and solving for the zero Doppler range between the point on the earth's surface and the satellite track. The orbit data are used to get an initial estimate of the baseline B and the baseline angle χ. The baseline information is refined using the zero velocity points.

A complete error analysis is beyond the scope of this paper but the following points can be made. The pixel registration in areas of good coherence can be done to better than 1/10 of a pixel, the 'unit' of pixel shift in this work is 1/40 of the pixel spacing. Small bias errors in velocity may exist when using an area that is assumed to be stationary. These errors can increase with both baseline and the look angle difference between the reference area and the area for which the velocity estimate is being made. It is anticipated that errors in velocity will be in the range of 10 cm/day in range and around 3 cm/day in azimuth. With poor digital elevation data, or poor baseline information, these errors will increase. Absence of a 'zero velocity' reference area will make the technique more difficult, and the results more uncertain, however it is anticipated that velocity gradients will still be measurable.

RESULTS

Figure 2 illustrates the ice movement derived from two merged pairs of RADARSAT standard mode 2 images (100 km x 170 km) acquired on September 24 and October 18, 1997. The vectors represent the ice motion of the Slessor Glacier as it flows into the Filchner Ice Shelf in Western Antarctica. The vector direction corresponds well with the flow lines in the glacier and, as the range and azimuth displacement estimates are independent, the agreement between the derived directions and the ice stream flow lines helps validate the derived velocities. The acceleration in the ice stream as it enters the floating ice shelf is apparent. Velocities in the more southerly (upper) part of the glacier change from around 250 m/year as the ice enters the area covered by the image to almost 800 m/year as it leaves at the bottom right-hand corner.

CONCLUSIONS

In 24 days time ice displacement can be large enough that a simple image registration technique can lead to useful results for ice motion. The advantages are:

- Displacements in both range and azimuth can be measured.
- Phase analysis is not essential, so that errors due to phase aliasing or incorrect phase unwrapping are avoided.
- Local errors do not propagate through the image as they can with phase analysis.
- In some cases, use of the phase information could be used to improve the range velocity or velocity gradient estimation.
- The accuracy requirements for orbit and terrain topographic data are not as stringent as for conventional interferometric analysis for terrain motion.

ACKNOWLEDGMENTS

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REFERENCE

1. Goldstein, R.M., H. Englehardt, B. Lamb, and R.M. Frolich, Satellite radar interferometry for monitoring ice sheet motion: Application to an Antarctic ice stream, *Science*, 262, 1525-1530, 1993.

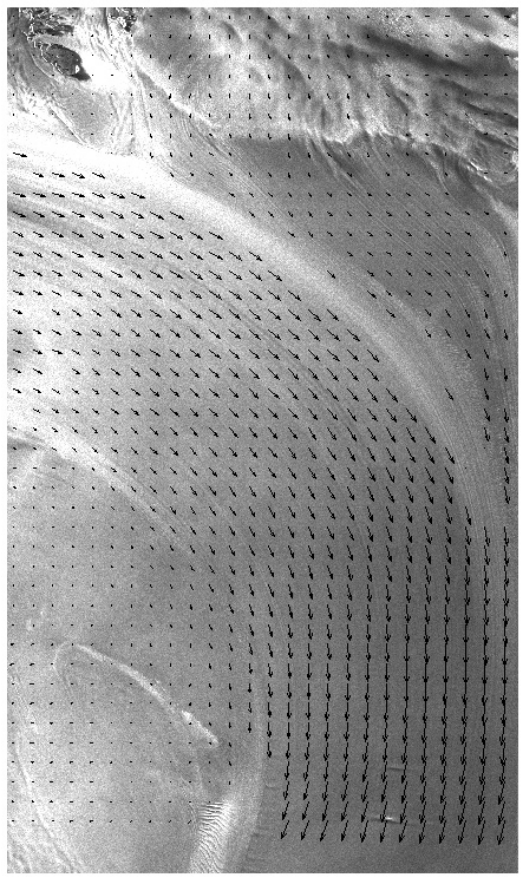

Figure 2

Illustration of ice motion from the Slessor Glacier (upper left) as the ice enters the Filchner Ice Shelf and flows as an ice stream northward towards the shelf edge. Two mosaicked pairs of RADARSAT standard mode 2 images were used to create this image (100 km x 170 km) of ice motion. Velocities in the more southerly (upper) part of the glacier change from around 250 m/year as the ice enters the area covered by the image to almost 800 m/year as it leaves at the bottom right-hand corner.