ESTIMATION OF ICE FLOW VELOCITY OF CALVING GLACIERS USING SAR INTERFEROMETRY AND FEATURE TRACKING

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ABSTRACT

Changes in velocity of the large outlet glaciers and ice streams in Antarctica are important for ice sheet mass balance and hence sea level. The ice flow velocity is also a critical variable in understanding glacier dynamics. Polar Record Glacier, with a calved iceberg in front, is about 50 km to the west of the Zhongshan Station, East Antarctica. SAR interferometry can detect the surface displacement in cm even mm level, while only the displacement in the slant range could be obtained. Offset tracking techniques can estimate the displacement of the glacier and iceberg with the registration offsets of two SAR images in both slant-range and azimuth directions. Feature tracking can also obtain the 2-D displacement from the image sequences. This paper will use a combination of SAR interferometry, offset tracking and feature tracking to measure the ice flow velocity of the Polar Record Glacier and the calved iceberg.

1. INTRODUCTION

Changes in velocity of the large outlet glaciers and ice streams in Antarctica are important for ice sheet mass balance and hence sea level. Observations of Antarctica have revealed rapid changes occurring on the ice sheet on relatively short time scales. The increasing collapse of the ice shelves and glaciers, the increasing rates of ice flow are indicators of the local effects of global changes. The ice flow velocity is also a critical variable in understanding glacier dynamics [1][2].

SAR interferometry can detect the surface change in cm even mm level, while the loss of coherence in fast moving area could make the InSAR velocity irretrievable, and only the displacement in the slant-range could be obtained [3][4]. Intensity tracking, based on patch intensity cross-correlation optimization, and coherence tracking, based on patch coherence optimization, can estimate the movement of glacier surfaces and calved iceberg between two SAR images in both slant-range and azimuth direction [5][6]. Feature tracking is a popular way of extracting motion information from the image sequences, where the same feature can be detected reliably and consistently.

Based on the optical and SAR images from 1970s to now, the interaction of the Polar Record Glacier and calved iceberg are observed through image interpretation and the average velocities are derived from feature tracking. This preliminary study on ice flow velocity provides significative information for the SAR interferometry and offset tracking study.

SAR interferometry and offset tracking are complementary techniques for ice flow velocity measurement [5][6][7]. And feature tracking is also meaningful to be a reference for the analysis of absolute flow velocity.

2. STUDY AREA

Polar Record Glacier is about 50 km to the west of the Zhongshan Station, East Antarctica. It is the largest glacier along the Ingrid Christensen Coast. An enormous tongue of ice has broken free from Polar Record Glacier creating an iceberg tongue more than 25 km long. With the comparison of the MSS and TM images acquired on 4 February 1973 (Fig.1) and 24 November 1989 (Fig.2) respectively, we can see that a giant iceberg has broken off.

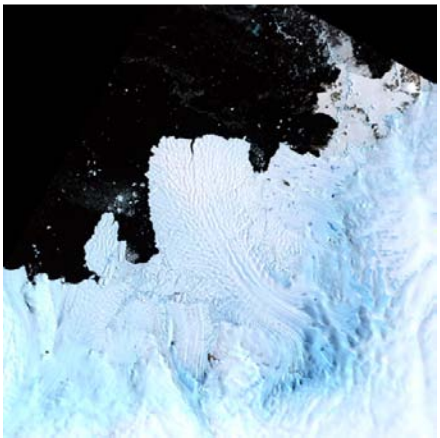

Figure 1. MSS image on 4 February 1973

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19–23 September 2011 (ESA SP-697, January 2012)

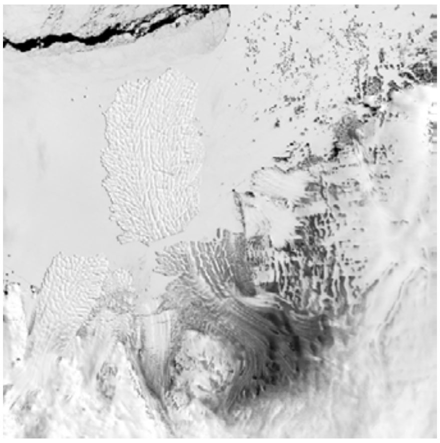

Figure 2. TM image on 24 November 1989

Four image pairs are collected for SAR interferometry and offset tracking study, including one ERS-1/2 tandem pair and three pairs with 35-day interval (Tab.1). Fig.3 shows the Polar Record Glacier in the SAR image collected on 25 May 1996 with profile A, B, C and D, which are used for the following comparison and analysis.

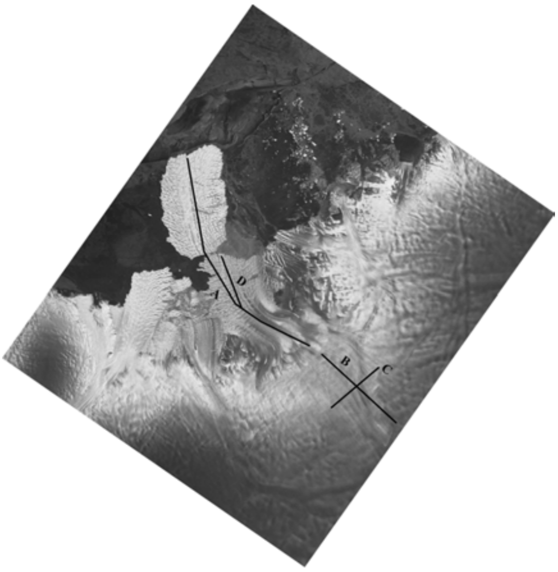

Figure 3. Polar Record Glacier in the SAR image collected on 25 May 1996 with profile A, B, C and D

Table 1. SAR image pairs for the study area

ID	Sensors	Date	Temporal baseline
1	ERS-1 ERS-2	24/05/1996 25/05/1996	1 d
2	ERS-2	17/09/1999 22/10/1999	35 d
3	Envisat	21/10/2007 25/11/2007	35 d
4	Envisat	20/09/2009 25/10/2009	35 d

3. METHODS

Differential SAR interferometry

Surface motion can be estimated from InSAR data within the data repeat interval [1]. Several studies have shown the potentials of phase interferometry in measuring ice motion in Antarctica. For the interferometric method, known as differential SAR interferometry (D-InSAR), the phase difference of the signals is utilized to calculate the surface topography and coherent displacement along the look vector. The topographic contribution to the interferometric phase should be removed to derive the motion contribution. The smaller the perpendicular baseline, the less sensitive the displacement is to the accuracy of the external DEM in differential InSAR data processing. In this study, BAMBER DEM was used to remove the surface topography and the perpendicular baseline is about 20 m. However, InSAR is much more sensitive to the motion along the satellite line of sight (LOS) than the azimuth direction and only the component along LOS can be obtained with single-pass interferometry [8] [9].

Due to decorrelation caused by rapid flow in this area, only ERS-1/2 tandem data are feasible for differential use to get the displacement in slant range. Coherence map of the tandem pair is shown in Fig.4, and we can see most areas were of good coherence. An ice-free area on the rock was selected as a reference point so that the absolute displacement in slant range can be calculated. The slant-range displacement from interferometry may be believed to be accurate in cm scale. And the slant-range displacement derived from phase interferometry can be compared with the results from offset-tracking methods.

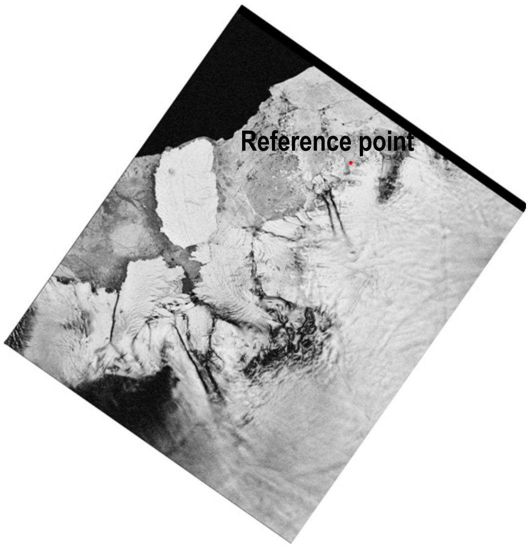

Figure 4. Coherence map of the tandem pair (The reference point is the point of zero displacement.)

Offset tracking

D-InSAR is limited by the phase noise, usually characterized by the coherence. Although the end of the Polar Record Glacier in the SAR images was highly coherent, it was isolated by the areas with low coherence. And thus errors occurred in phase unwrapping. In this case, offset tracking is a welcome complement to SAR interferometry for the measurement of ice flow velocity. Generally, two offset-tracking methods based on SAR data, namely intensity tracking and coherence tracking are used. Intensity tracking makes use of cross-correlation between two SAR images to measure velocity, while velocity measurement with coherence tracking depends on the coherence maximum [6]. Both methods can estimate displacement in the range direction and azimuth direction.

Intensity tracking is free from surface decorrelation, and therefore slant-range displacement is also retrieved based on intensity tracking with both the tandem data and the data acquired with 35-day interval. Since coherence tracking is also limited by coherence, this method is tested with ERS-1/2 tandem data.

4. SLANT RANGE DISPLACEMENT

Due to the decorrelation induced by the rapid flow in this area, ERS-1/2 tandem data are utilized for differential use to get the displacements in slant range. Meanwhile, intensity tracking is tested for slant-range displacement with all the four image pairs. As shown in Fig. 4, the end of the Polar Record Glacier is a fast-flow region with dense fringes. It is obvious that the fringes are far denser at the outlet glaciers near the coast. Meanwhile, the denser fringes in inland area show the ice flow lines of the ice stream.

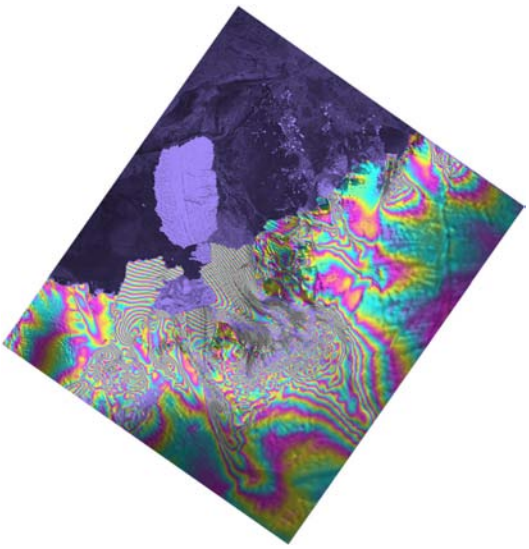

Figure 5. Unwrapped differential interferogram from ERS-1/2 tandem data in May 1996

Because the disconnected areas of high coherence separated by areas of low coherence cannot be properly analyzed, the correct unwrapped-phase is not available in some cases. Here the comparison of velocities measured in ground range with SAR interferometry and intensity tracking is studied along the profile B in the inland area. Fig.6 shows that the velocities in ground range derived from the two methods are consistent.

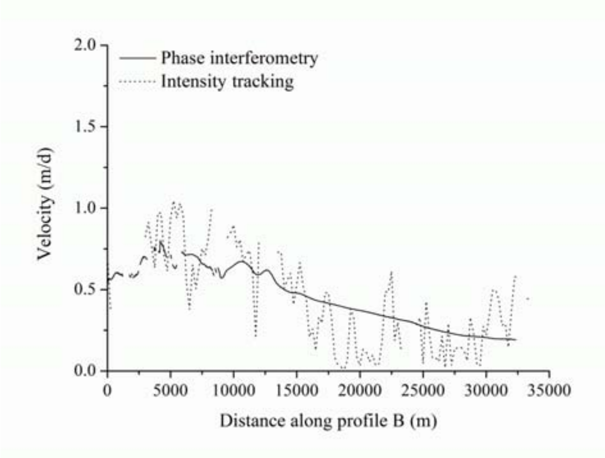

Figure 6. Comparison of velocities in the ground-range direction from phase interferometry (solid line) and intensity tracking (dot line) along profile B in May 1996

Meanwhile, the displacement values in ground range derived from SAR interferometry with tandem data of 1996 and from the intensity tracking with a 35-day pair of 1999 are compared. Fig.7 shows some differences between the two methods. One concern for the differences is the different acquisition time of the two InSAR data since glacier motion changes from different seasons and years. More importantly, intensity tracking is applied based on the assumption that the most areas on the image are stable [6][10], which is not satisfied in this study area. Therefore, some errors are introduced in estimating the offsets because almost all the ices are moving. The velocities along profile C derived from intensity tracking are smaller than the results from phase interferometry. The movements along profile C speed up and then slow down since it goes through the ice stream.

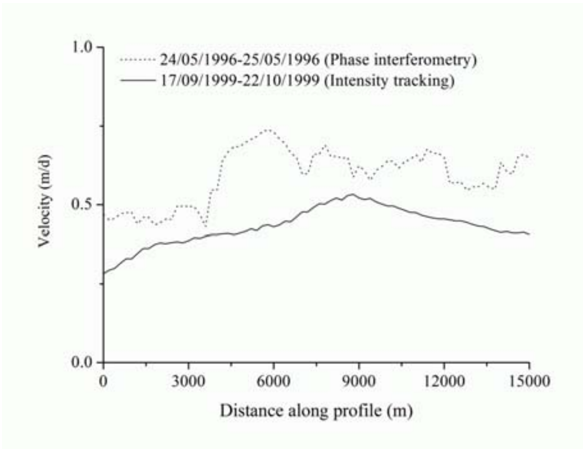

Figure 7. Comparison of velocities in the ground-range direction from phase interferometry with tandem data of 1996 (dot line) and from intensity tracking with 35-day SAR pairs of 1999 (solid line) along profile C

5. 2-D VELOCITY MEASUREMENT

The offset tracking can estimate the movement in both slant-range and azimuth directions to get the 2-D velocity field. The ice flow velocity from intensity tracking with tandem data is presented in Fig.8. The velocity of this area is about 0.5 to 2 meters a day. It is obvious that the ice flow velocity of the glacier and the calved iceberg is larger than other areas, which is about 1.2 m/d.

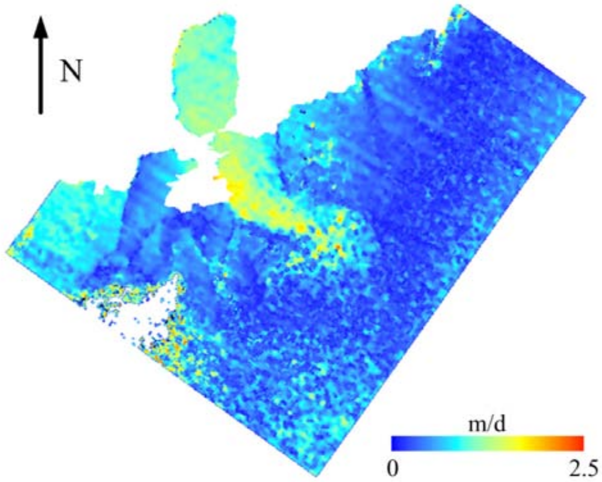

Figure 8. Ice flow velocity from intensity tracking with tandem data in May 1996

The 2-D velocity along profile A from intensity tracking and coherence tracking with tandem data are illustrated in Fig.9. The results are of high correlation. Since the temporal baseline for the tandem pair is only one day, large acquisition time intervals between the two SAR images may increase the accuracy of intensity tracking technique. The ice flow velocity from intensity tracking with tandem pair and three 35-day pairs in September 1999, October 2007 and September 2009 respectively along profile D are shown in Fig.10. Since the uncertainty of the seasons and years influences the velocity, the differences among the pairs need to be further studied.

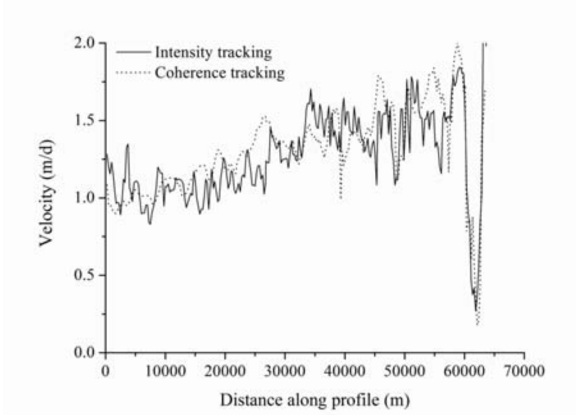

Figure 9. Ice flow velocity from intensity tracking (solid line) and coherence tracking (dot line) along profile A with ERS-1/2 tandem data in May 1996

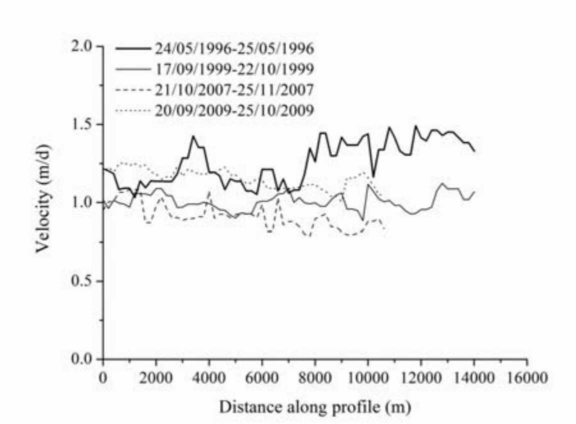

Figure 10. Ice flow velocity from intensity tracking with tandem pair in May 1996 (heavy line) and three 35-day pairs in September 1999 (solid line), October 2007 (dash line) and September 2009 (dot line) along profile D

Moreover, optical and SAR data are used to monitor the changes of the Polar Record Glacier and the calved iceberg in our previous study. The multi-temporal satellite data, including Landsat, HJ-1A, ERS and Envisat, cover from 1970s to now. With the feature tracking applied to the different images acquired in different time, the ice flow velocity of the glacier and the calved iceberg are obtained based on several feature points. It is concluded that the ice flow velocities are various in different years and seasons. Fig.11 shows the different velocity vector in different phases. And Tab. 2

lists part of the velocity value and it is confirmed that the ice flow velocities vary distinctly in summer and winter. The value of the ice flow velocity from feature tracking is a significant reference for other methods.

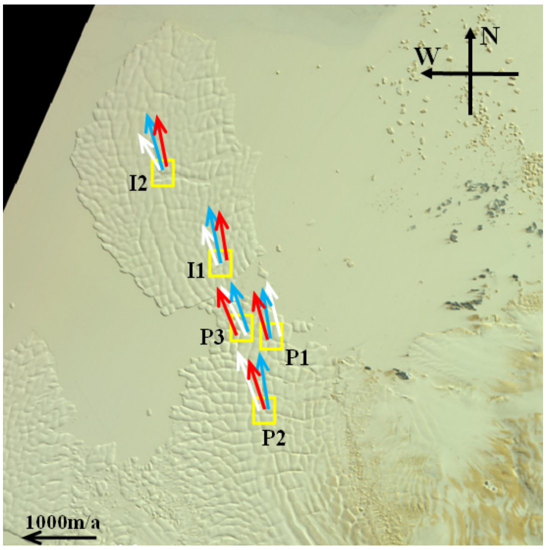

Figure 11. The flow velocity of the feature points at the Polar Record Glacier and calved iceberg in different years (white: from 1989 to1993; blue: from 1993 to 2006; red: from 2006 to 2009)

Table 2. The velocity of the Polar Record Glacier and calved iceberg from feature tracking in different years and seasons

Time	Velocity of the Polar Record Glacier (m/d)			Velocity of the calved iceberg (m/d)	
	P1	P2	P3	I1	I2
2006.1-3	3.74	3.59	3.19	3.13	3.09
2006.5-7	1.67	1.65	1.9	1.73	1.85
2007.2-3	3.57	3.49	3.54	3.47	3.14
2008.5-7	1.77	1.73	1.62	1.38	1.42

6. DISCUSSIONS AND CONCLUSIONS

Due to the absence of both ascending and descending SAR data for estimating the 3-D velocity field in most cases and the low coherence in the fast moving areas, intensity tracking technique is effective to evaluate the ice flow velocity especially for the fast flowing glaciers. In that case, it is a complementary technique for SAR interferometry to estimate ice velocity field. Meanwhile, velocities derived from feature tracking provide the reference value. In this study, coherence tracking can support the interferometric analysis where highly coherent areas were isolated by incoherent areas, but both of them are only applicable for tandem pair. And intensity tracking is the only feasible method for SAR pairs of 35-day intervals.

The ice flow velocities of the Polar Record Glacier and calved iceberg are various in different years and seasons. Although the intensity tracking is the most efficient method for the velocity measurement, the accuracy of the velocity need further study.

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