DETECTING ICE MOTION IN GROVE MOUNTAINS, EAST ANTARCTICA WITH ALOS/PALSAR AND ENVISAT/ASAR DATA

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ABSTRACT

As the ice motion of Grove Mountains area is very complicated, it is hard to derive ice flow velocity because of the very low coherence on the ice surface. In this work, we demonstrate the unique capabilities of Advanced Land Observing Satellite (ALOS) PALSAR data for mapping and monitoring ice flow and deformation using D-InSAR technique. The test area of Grove Mountains in East Antarctica is selected, which is located about 400-500 kilometers to the south of the Chinese Zhongshan Station in Antarctic inland areas. We choose a pair of ALOS images acquired on May 18th, 2007 and Oct 3rd, 2007 respectively to measure the velocity of ice flow. Two scenes ENVISAT/ASAR data with 35 days interval acquired on Jun 3rd, 2007 and Jul 8th, 2007 are processed successfully to derive the velocity as well. Furthermore, the intensity tracking technique based on cross-correlation optimization was also applied for reference information. The results show that D-InSAR technique is an effective tool to monitor the ice flow in Antarctica area. And intensity tracking procedures of SAR images are an alternative to D-InSAR for the estimation of glacier motion when D-InSAR is limited by loss of coherence, i.e., in the case of rapid and incoherent flow and of large acquisition time intervals between the two SAR images. Meanwhile, the results from L-band and C-band are coincident.

1. INTRODUCTION

It is well known that the Antarctic environment can significantly reflect global climate changing, since glacier ablation is a sensitive symbol of the global warming impacts. Within the Antarctic region, monitoring ice flow is very important for the study of glacier dynamics and allows us inverse the mechanism of Antarctic ice sheet. Scientists have been keeping a watch on the Antarctic ice sheet for a long time. It is necessary to accurately measure the change and movement of glaciers, ice streams and so forth.

The conventional measures, such as GPS and levelling network, are limited in the scale of area, time, cost, accuracy and so on especially in the Antarctic region. Due to the fact that Synthetic Aperture Radar (SAR) has all time, all weather data acquisition capability and thus is able to cover large areas with high-resolution imagery, SAR has proven to be an effective tool for topographic mapping and deformation measurement in large, difficult and inaccessible areas. Synthetic Aperture Radar Interferometry (InSAR) is a relatively new technique with a high potential in earth observation. Differential Interferometry Synthetic Aperture Radar (D-InSAR) is one of the important applications of InSAR technique. The use of InSAR techniques can give a more detailed view of the glaciers motion. And this technique has the capability of mapping the subtle change of Antarctic surface in centimeter even millimeter level. The flow velocity of Rutford Ice Stream was successfully derived by Goldstein et al in 1993, which was the first time for detecting ice flow over polar ice sheet using ERS-1 D-InSAR in Antarctica [1]. As more and more Interferometric SAR Data can be provided, InSAR measurements based on different SAR images have revealed various ice motions on ice sheet in the last years of research [2-7].

In this paper, we present the complicated ice flow measurement result using ALOS/PALSAR data as well as the result derived from C-band ENVISAT/ASAR data.

2. D-INSAR MEASUREMENT MODEL OF ICE FLOW

2.1 Interferometric phase model

The interferometric phase can be expressed as Eq. 1 [8].

$$\phi = \phi_{geo} + \phi_{topo} + \phi_{atmos} + \phi_{offset} + \phi_{defo} + \phi_{dem\_error} + \phi_{noi} \quad (1)$$

Where

ϕ_{geo} is the geometric term corresponding to the distance from the SAR platform to a reference Earth model;

ϕ_{topo} is the term corresponding to the variation of the Earth's surface relative to the Earth model;

α_{atoms} corresponds to phase changes introduced by variations in the atmosphere;

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ϕ_{offset} takes into account that during interferometric processing an arbitrary offset is introduced;

ϕ_{defo} is the path length difference related to surface motion occurring between SAR passes;

ϕ_{dem_error} is the residual phase caused by differences between the position of the scatterer and the external DEM elevation;

n_{noise} is the residual phase error due to noise.

The phase resulted from the topography (ϕ_{topo}) can be removed by using the external DEM [9]. Given information of the satellite positions, we can remove the flat Earth phase. Therefore the phase model can be simply written as Eq. 2.

$$\phi_{diff} = \phi_{defo} + \phi_{dem\_error} + \phi_{offset} + \phi_{atmos} + \phi_{noise} \quad (2)$$

And ϕ_{defo} can be explicitly written as Eq. 3.

$$\phi_{defo} = \frac{4\pi}{\lambda} \cdot v\,T \quad (3)$$

Where v is the deformation velocity in the radar line of sight (LOS) direction, and T is the temporal baseline between two SAR acquisitions.

2.2 Estimation of ice flow velocity

As InSAR technique can extract the deformation information in LOS direction, only the displacement of ice flow component in the LOS direction can be detected. It is not possible to obtain the three-dimensional ice flow velocity with only one observation. However, the velocity can be calculated if there are a priori conditions such as direction angle and slope angle of ice flow. The relationship between LOS and actual displacement of ice flow is showed in Fig. 1.

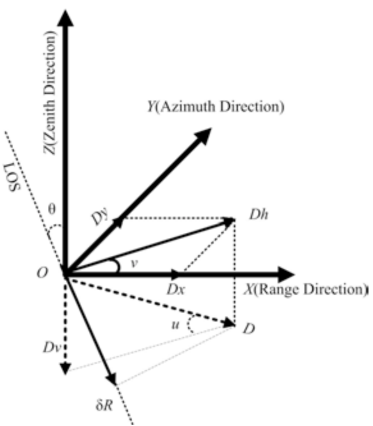


Figure 1. Relationship between LOS and actual displacement of ice flow

In the horizontal plane *XY*, *X*-axis and *Y*-axis represent the direction of radar azimuth and range respectively, and *Z*-axis is oriented perpendicular to the horizontal plane in the zenith direction. The look angle θ is the angle between *Z*-axis and LOS in the *XZ* plane. *D* is the actual displacement vector of ice flow in the *XY* plane. Its projections onto the *XY* plane, *X*-axis, *Y*-axis, *Z*-axis and LOS are D_h, D_x, D_y, D_v and δR. D_h and D_v are the horizontal and vertical components of ice displacements. u is the slope angle of ice flow which is between the horizontal plane *XY* and *D* varying from 0 to 90 degree, while v is the direction angle of ice flow between *X* and D_h varying from -180 to 180 degree. So the surface displacement *D* can be given as Eq.4 [10].

$$D = \frac{\delta R}{|\cos u \cos v \sin\theta + \sin u \cos\theta|} \quad (4)$$

The LOS displacement can also be written as Eq.5.

$$\delta R = D_h \cos v \sin\theta + D_v \cos\theta = D_x \sin\theta + D_v \cos\theta \quad (5)$$

In general，the slope angle of ice flow in Antarctic inland areas is small (usually around 1 degree). Therefore, the vertical component of ice displacement is much less than the horizontal component in most regions of Antarctica ice sheet which means u is very small. The contribution of D_v to δR can be ignored when the ice flow velocity is low.

3. TEST AREA AND DATA SET

3.1 Test area

The test area is selected around Grove Mountains in East Antarctica, which is located about 400-500 kilometers to the south of the Chinese Zhongshan Station in Antarctic inland areas. Grove Mountains is also situated on the eastern slope of Lambert Glacier basin - Amery Ice Shelf system (LAS) -- the largest glacier system in Antarctica. This area is a rock outcrop on the East Antarctica ice sheet and plays an important role in blocking the ice flow to Lambert Glacier.

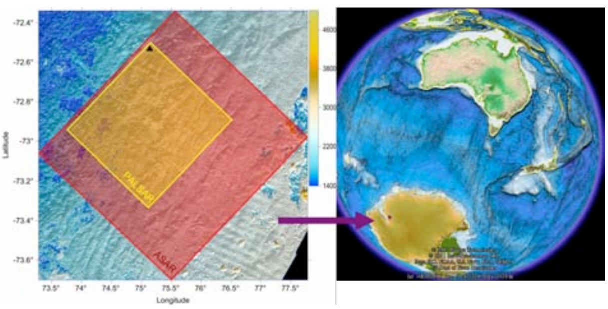


Figure 2. The location of Grove Mountains

Chinese National Antarctic Research Expedition (CHINARE) has carried out the comprehensive survey five times in Grove Mountains area and more than 10,000 meteorites have been found. Moreover, the meteorite concentration is closely related to ice movement features. The region of Grove Mountains is wide and full of horns. As the ice flow pattern is complicated and ice cracks are widely distributed, the traditional plunger ice flow measurement is not available in this region. Therefore we lay emphasis study on the area of Grove Mountains, as showed in fig.2.

3.2 Data set

We choose a pair of complex (SLC) images (Track: 584, Frame: 5630) acquired by L-band PALSAR sensor onboard the ALOS on May 18th, 2007 and Oct 3rd, 2007 respectively. Meanwhile, another pair of complex (SLC) images (Track: 375, Frame: 5121) acquired by C-band ASAR sensor are chosen as reference data for cross validation. The test areas of PALSAR and ASAR are respectively showed with red box and yellow box in Fig.1. The basic information of these images is shown in the Tab. 1. B_T is temporal baseline; $B_\perp$ and $B_{/\!/}$ are the perpendicular and parallel components of the baseline; Ea denotes the elevation ambiguity.

Table 1. The parameters of SAR interferometric pairs

Data	Track Frame	Date	pass	B_T (days)	$B_\perp$ (m)	$B_{/\!/}$ (m)	E_A (m)
ALOS PALSAR	584 5630	20070518 20071003	Asc.	138	1047	265	64
ENVISAT ASAR	375 5121	20070603 20070708	Des.	35	227	16	43

The improved InSAR generated DEM corrected with ICESAT GLAS data is used in our work as well. The resolution of DEM in Grove Mountains area is 30m×30m. It is used as the external DEM to remove the topography phase. Moreover, the GPS benchmark data of ice flow velocity has been acquired during the past decade by Chinese National Antarctic Research Expedition (CHINARE) along the expedition route of LAS. The result of the glacier velocity field in our experiment can be compared with the GPS data.

4. RESULTS AND ANALYSIS

4.1 Processing Results

After D-InSAR processing, two pairs of differential interferograms are generated, which are showed in Fig. 3. ASAR data have a much greater density of interferograms and poor quality fringes than PALSAR data. This is mainly due to the differences of the incidence angle (PALSAR: 23~43degree; ASAR: 15~45 degree) and wavelength (PALSAR: 23.6cm; ASAR: 5.6cm). However, the patterns of them in the mass are similar and the tendencies of the two figures are mostly uniform compared.

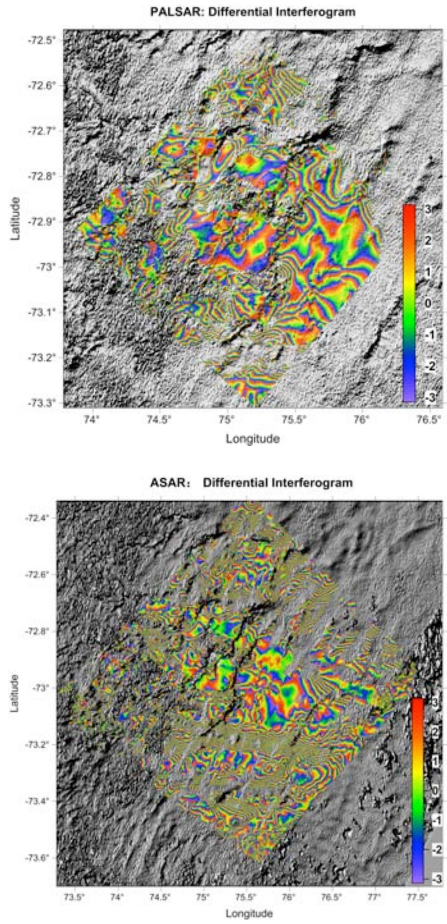
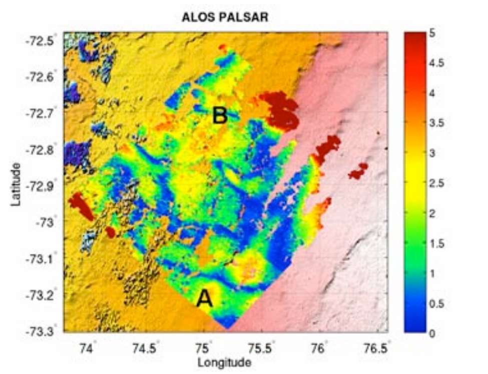


Figure 3. Differential interferograms generated by D-InSAR processing

The intensity tracking technique based on cross-correlation optimization was also applied to PALSAR and ASAR data to map ice motion in the area of Grove Mountains [11]. Preliminary results are shown in Fig. 4 to demonstrate the feasibility of the technique.



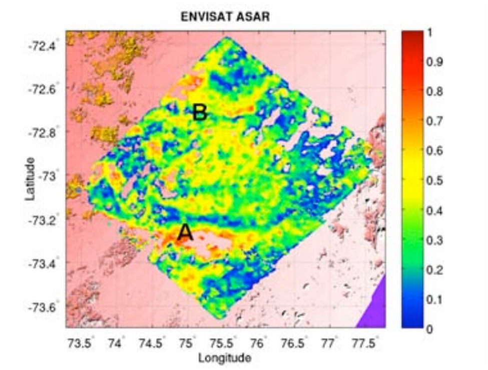


Figure 4. Results of SAR intensity tracking Procedures

As the temporal baselines for PALSAR and ASAR are respectively 138 days and 35 days, the displacement extracted from PALSAR data should be about 3 times more than ASAR data. From area A and B in Fig. 4, we find that the values of displacement are coincident and the tendencies of both figures are almost similar.

4.2 Analysis and discussion

There are two kinds of data can be used as reference. On one hand, ice flow velocities in the Lambert Glacier - Amery Ice Shelf area have been measured form SAR data with 24 days time interval by NASA/JPL. The ice motion maps have been derived using cross-correlation optimization procedure, and the velocity of ice flow in Grove Mountains area is approximately 10m/a [12].

On the other hand, previously ice velocities in our test area were derived only close to the eastern side of Grove Mountains with traditional surveying methods, as show in Tab. 2. These ground truth data were measured via GPS from Jan 17th, 2006 to Jan 31st, 2006.

Table 2. Velocities at GPS sites in the area of Grove Mountains

ID	L (dd.mmss)	L (dd.mmss)	H (m)	V (m/a)	Azimuth (d)
PLE1	-72.5102	75.11290	1979.63	3.53553	340.4017
PLE2	-72.5241	75.12449	2052.641	1.11127	129.1233
PLE3	-72.5142	75.12080	1992.532	0.62347	299.2213
PLE4	-72.5110	75.13138	1982.786	5.98475	328.5916
PLE5	-72.5043	75.14313	1973.337	7.31913	326.0517
PLE6	-72.5028	75.11048	1966.944	5.39689	302.185
PLE7	-72.5116	75.15019	1989.517	12.3392	317.4622

We compare the velocities derived from PALSAR and ASAR data using intensity tracking procedures with GPS points as reference, as showed in Fig. 5. The results from both PALSAR and ASAR data are relatively coincident. However, this comparison can not be used for validation because of the velocities at GPS sites which can vary a lot in different seasons.

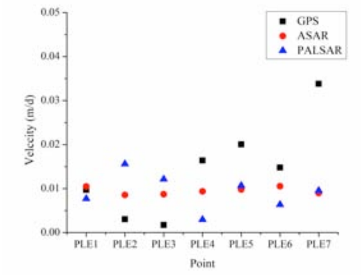


Figure 5. Velocities comparison with GPS points

5. CONCLUSIONS

D-InSAR has been one of the most important and accurate tools for monitoring the surface displacement. However, both coherence and phase unwrapping are the limiting factors for this method, which are crucial to the reliability of image processing and final results of the data processing. In some cases, the information can not be properly analyzed because of the low coherence and discontinuous phase changes. For example, there may be no relationship between different regions on the velocity field map if large de-correlated regions exist. Therefore, data quality and external conditions such as temporal/spatial baseline as well as DEM data should be considered. Furthermore, the implementation of InSAR measurement is relatively difficult due to the complicated procedures of data processing. Intensity tracking method has high efficiency in operation without considering the coherence of SAR data. It can be widely used, especially in the regions where the characteristics of surface feature are obvious. On the contrary, its accuracy decreases in featureless ice sheet regions. Comprehensively considered, it can be an alternative to D-InSAR in fast ice flow regions. This study provides certain reference for detecting ice flow in Antarctic regions with SAR data. The results from L-band and C-band are coincident. The demonstration of these techniques in Antarctica is prospective in environment assessment in Antarctic area and they should be applied more widely to Antarctic research. And further study should be taken for the ice flow velocity, such as velocity fields in different seasons and years.

6. ACKNOWLEDGEMENTS

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