Surface Terrain and Ice Sheet Motion Estimation Using ERS-1 Interferometric SAR

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1. INTRODUCTION

Since about 85% of fresh water existing on the earth is in the form of glacier covers about 10% of the earth's surface, the ice-sheet which cover the most of the polar regions like the Greenland and Antarctica play an important role in earth's climate. Moreover, a sea level change can be brought on by change in the mass balance of an ice-sheet. Interferometric Synthetic Aperture Radar (InSAR) provides means to measure surface motion with excellent accuracy.

In this paper, we focus on accurate estimation of the baseline which has been shown to be an important factor to measure surface velocities using InSAR technique. Since it is often difficult to obtain exact ground control points, we have extracted inaccurate tie points from DEMs and demonstrated that baseline can be estimated accurately using those tie points. Finally, we have created the first ever velocity map of Sondrestrom, Greenland using a pair of ERS-1 images spaced every three days.

2. STUDY AREA

InSAR technique is applied to ice-sheet on Sondrestrom area, Greenland. An InSAR pair used in this research was processed at the German ERS-1 processing and archive facility (D-PAF) in Oberpfaffenhofen, Germany. The InSAR pair 2241 from orbit 1928 and 1885 was acquired on 25-Nov-1991/28-Nov-1991. Figure 1 shows an amplitude image of the study area which is composed of the bedrock area of the left part and the ice-sheet area of the right part.

3. INTERFEROMETRIC BASELINE ESTIMATION

3.1 Baseline Estimation Model

An accurate estimation of the baseline in InSAR has been shown to be an important factor in surface height or motion determination. While baselines can be estimated from the ephemeris data, but the uncertainties may introduce unacceptable errors for many InSAR applications. To measure pixel height in meter order and pixel displacement in centimeter order, baseline separation must be determined in centimeter order. To refine a baseline, tie points of known elevations are needed. These tie points are used in least squares adjustment to estimate baseline parameters.

Baseline varies along track due to the convergence of ERS-1 orbits. Thus, over the length of an ERS-1 interferogram, the baseline is modeled as a linear function of the along-track coordinate, x .

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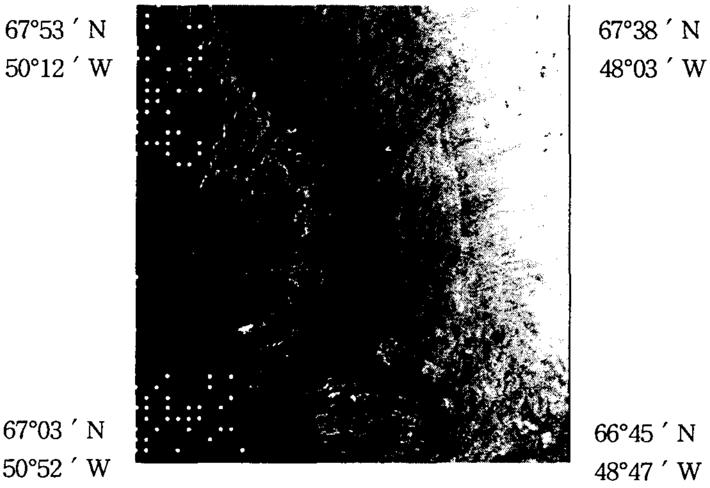

Fig. 1. SAR amplitude image of Sondrestrom area, acquired on 25 November, 1991. The white dots indicate the location of tie points used to estimate the baseline

(Joughin, 1995). Thus, the normal component of baseline can then be modeled as,

$$B_n = B_n^c + \delta B_n \left(\frac{x - x_c}{L_x} \right) \tag{1}$$

where B_n^c is the normal component of baseline at the frame center, x_c, and δB_n is the change of B_n over the length of frame, L_x. Similarly, the parallel component of baseline is represented as,

$$B_p = B_p^c + \delta B_p \left(\frac{x - x_c}{L_x} \right) \tag{2}$$

3.2 Accuracy of Baseline Estimates

To solve for the four baseline parameters: B_n^c, B_p^c, δB_n, δB_p, at least four tie points(points with known elevation) are needed. Errors in the tie points cause error in baseline estimation but it can be reduced by using more number of tie points (Joughin, 1995).

Tie points are extracted from a KMS DEM through three different areas: (1) the bedrock area, (2) the ice-sheet area and (3) the whole area. The results are expressed with the standard deviation, $\sigma_{\tilde{z}-z}$, of the difference between the true topography, z, and the topography $\tilde{z}$, determined from the estimated baseline. Table 1 shows baseline solutions obtained using three different cases of tie points. As shown in the table, the topography calculated from the estimated baseline using the tie points extracted from the bedrock area gives the best result and has relatively great error because the baseline is not long enough for estimating elevation.

To check the accuracy of the estimated baseline parameters, the following uncertainty equations are used (Zebker et al., 1994).

$$\sigma_z = \frac{\rho}{B} \sin\theta \sin\alpha \sigma_{B_n} \tag{3}$$

$$\sigma_z = \frac{\rho}{B} \sin\theta \cos\alpha \sigma_{B_v} \tag{4}$$

where B_h and B_v indicate the horizontal and vertical component of the baseline. Baseline accuracies vary along the length of the frame because the baseline is modeled as a linear function of along-track coordinate. Table 2 shows the baseline accuracies of the top and bottom of the frame. As expected, the resulted baseline parameters obtained using tie points from the bedrock region give the best accuracy.

A DEM of the bedrock area has been created with the estimated baseline and the pattern of the created topography was compared with the original one, which can be another way to check the accuracy of the estimated baseline parameters. Figure 2 shows the DEM of the bedrock area, and the original DEM is shown in Fiture 3. Both DEMs are resampled on a 1 km by 1 km spaced grid and followed Univeral Transverse Mercator (UTM) coordinate system. As can be seen from both DEMs, the general trend of the elevation looks similar.

Table 1. Estimated baseline parameters and errors for the tie points (unit:m)

	B_n^c	B_p^c	δB_n	δB_p	$\sigma_{\hat{z}-z}$
Case (1)	33.5114	-0.7999	3.2350	0.5562	178.546
Case (2)	34.4901	-0.5684	2.7537	0.7561	3090.274
Case (3)	30.9319	-0.6930	0.1731	0.6753	236.986

Table 2. Accuracies of the estimated baselines (unit:cm)

		Using tie points from bedrock area	Using tie points from ice-sheet area	Using tie points from both bedrock and ice-sheet area
σ_{B_h}	Top	4.307	79.512	5.537
	Bottom	4.964	93.995	5.988
σ_{B_v}	Top	1.787	32.498	2.295
	Bottom	1.949	35.885	2.329

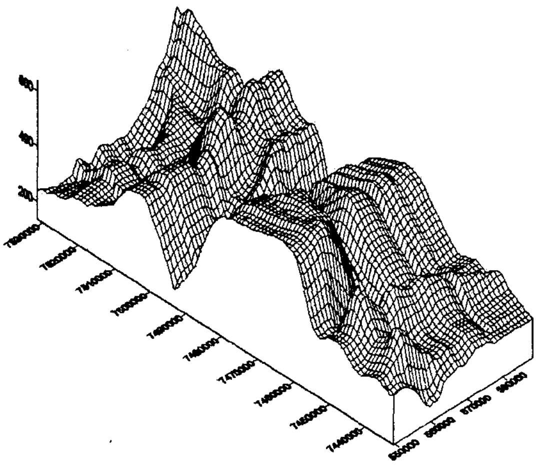

Fig. 2. Estimated DEM of the bedrock area

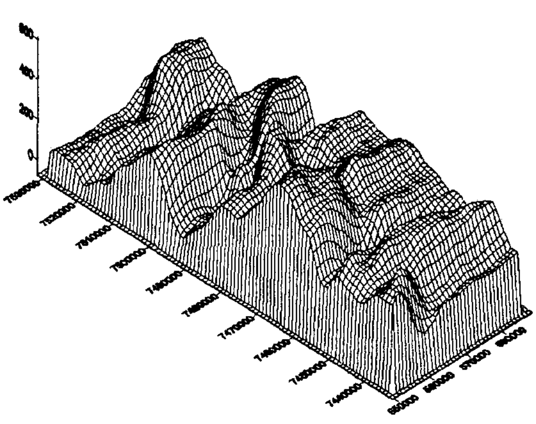

Fig. 3. Generated DEM of the bedrock area

4. ICE-SHEET VELOCITY

To obtain ice-sheet movement information, we need to separate mixed topography and motion interferogram into motion-only interferogram. If a DEM exist, topography effects on phase can be eliminated and only the motion effects remain.

Figure 4 shows the interferogram with the baseline effects removed. As seen in this figure, the lake areas which are indicated with white bold arrows show no fringe pattern because we can assume that there is no elevation change on those areas. Thus, it can be considered that the baseline parameters are estimated correctly. Figure 5 shows the interferogram with the baseline and topography effects removed. In this research, the KMS DEM is used to obtain this motion-only interferogram. The fringe remains in the mountainous regions because the resolution of the DEM is too coarse to cancel the topography effectively.

If the surface velocity is assumed to be constant during the observation period δT, the surface velocity toward the range direction can be calculated as (Joughin et al., 1996)

$$v_y = \frac{\Phi_{motion}}{2k\delta T \sin\psi} \tag{5}$$

where ψ is the incidence angle defined with respect to the local normal ellipsoid.

Figure 6 shows contours of across-track velocity overlaid on SAR amplitude image. Since we do not have any independent estimates of ice velocity of the study area, it is impossible to directly evaluate the accuracy of the results. Instead, the accuracy of velocities on the bedrock area is estimated because the velocity should be zero (Joughin, 1996). After the topography effect is removed, the mean of the phase remained in the bedrock area is -1.206 rad, and the standard deviation is 2.479 rad. This is equivalent to a velocity error with a mean of 1.509 m/year and a standard deviation of 3.107 m/year.

Fig.4. Interferogram with removed baseline effect

Fig.5. Interferogram with removed topography effect

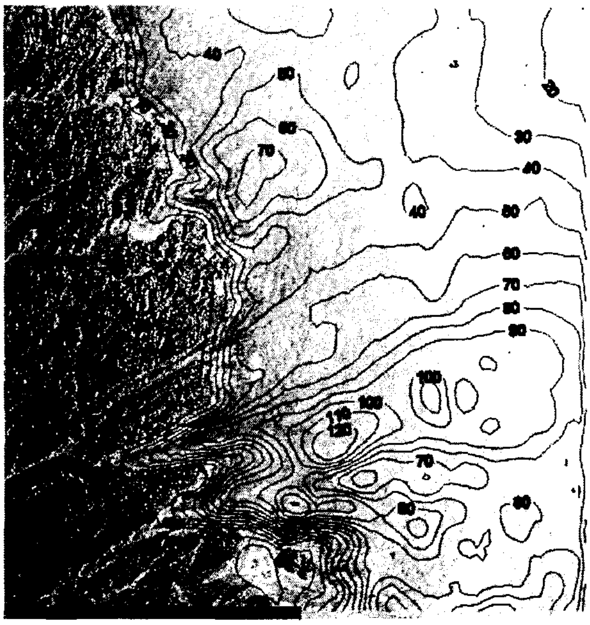

Fig. 6. Velocity map of the Sondrestrom area (unit: m/year)

5. CONCLUSIONS

We have reached the following conclusions by applying InSAR technique to estimated the surface velocity of the Sondrestrom area, Greenland.

1. Interferometric baseline has been accurately estimated using many inaccurate tie points.
2. Interferometric observation of ice-sheet velocity in the radar look direction over the study area has been successfully performed.

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