

INSAR DEM RECONSTRUCTION WITH ICESAT GLAS DATA OF THE GROVE MOUNTAINS AREA

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ABSTRACT

In this paper we presented a case study of DEM generation in the Grove Mountains area using ERS-1/2 SAR tandem data with the interferometric technique. The errors in InSAR DEM caused by sloping terrains and satellite baseline errors make it difficult to go on our geo-spatial study. Therefore, those errors must be eliminated to improve the accuracy of InSAR DEM. Although some field data were collected in the latest expeditions by Chinese geodetic surveyors, the field survey only covered the core area by 110 km². As a result, an accurate DEM covering the whole Grove Mountains over 8000 km² was not available. Thus, we carried out the calibration of residuals in InSAR DEM based on ICESat laser altimetry footprints. Further, we compared our reconstructed InSAR DEM to several DEMs and it was in good agreement with BAMBER DEM, ICESat DEM and RAMP DEM.

1. INTRODUCTION

Antarctic ice sheet has gathered worldwide attention in the recent decades since its behavior is closely related to the global climate, ecology environment and even the future of our human beings. The technology of earth observation from the space makes it more accessible to study the geodynamics of Antarctic ice sheet. Served as a basic dataset in geo-spatial analysis, digital elevation model (DEM) is considerably significant [1]. Traditional methods such as total station surveys, optical imagery and photogrammetry have been well studied in the past [2]-[3], but they are not optimal for obtaining DEM in Antarctica especially in inaccessible environments. Since the potential of using interferometric synthetic aperture radar (InSAR) to estimate the topography was first demonstrated in 1987 by Li and Goldstein [4], InSAR has been developed as a powerful technique to derive DEMs.

In this paper we first demonstrated the generation of InSAR DEM of the Grove Mountains core area using ERS-1/2 SAR tandem data. InSAR has the advantages of all time, all weather operation and cost-effective data acquisition over large areas, especially those more inaccessible areas. Moreover it can provide topography

information with elevation accuracies comparable with optical methods [5]. The accurate topography information is considerably important for Antarctic ice sheet research.

However, some inclination errors deteriorate the accuracy of InSAR DEM to a certain extent. Although some field data were collected in the latest expeditions by Chinese geodetic surveyors [6], the field survey only covered the core area by 110 km². As a result, it was still difficult to generate an accurate DEM of the whole Grove Mountains area over 8 000 km² due to sloping terrains and satellite baseline errors. Fortunately, ICESat GLAS (Geoscience Laser Altimetry System) data of high precision can remove the residual fringe in the interferogram. We adjusted the InSAR DEM using ICESat GLAS data and then compared the result to the several DEMs. It turned out that our adjusted InSAR DEM is coincident with BAMBER DEM [7], ICESat DEM [8] and the Radarsat Antarctic Mapping Project (RAMP) DEM [9].

This paper confirmed that InSAR is a very valuable technique to be utilized in Antarctica albeit some errors are introduced by layover, foreshortening, shadow, surface decorrelation and the atmospheric signal in the data [10]. ICESat laser altimetry footprints can provide several highly accurate height points for calibrating the residuals in InSAR DEM. We concluded that the fusion of InSAR DEM and ICESat GLAS data is necessary to improve the quality of InSAR DEM. In that case InSAR can be introduced to complement field survey.

2. THE GROVE MOUNTAINS AREA

In this study, the area of interest is the core area of Grove Mountains, located in East Antarctica at 72°15' S ~ 73°15' S and 73°40' E ~ 76°00' E. Grove Mountains area has been a key area for Chinese national Antarctic research since 1998 when Chinese carried out the first field work for geological and geodetic study there. The topography declines from the south-east to the north-west resulting in the ice flowing from the south-east to the north-west [11]. This area is of a typical inland character with blustery weather lasting for about half a

year, where is densely covered by ice crevasses resulting from ice flow and blocking effect of mountains [12]. The average altitude is about 2 000 m with the average temperature reaching -30°C . The abominable environments make it extremely difficult for field survey operations.

To perform this study, we used ERS tandem pair (Tab. 1). As on the Fig. 1, Mount Harding can be easily identified. The west area of Mount Harding, shown in the inset, is comparatively stable due to the mountains' blocking effect; therefore, ground control point (GCP) was selected in that area.

Table 1. ERS tandem pair

Images	Acquisition dates	Baseline	
		B_{\parallel}	B_{\perp}
ERS-1	10/02/1996	90 m	160 m
ERS-2	11/02/1996		

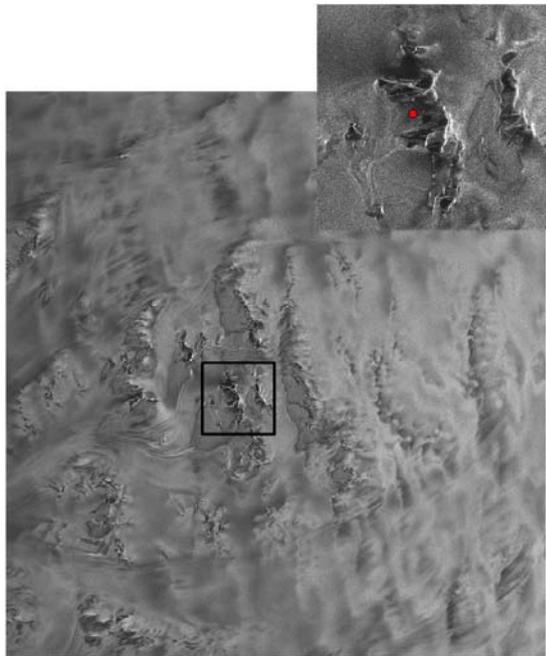


Figure 1. ERS-1 intensity map of Grove Mountains area on 10/02/1996. The GCP (red point) was selected in the west area of Mount Harding (inset) due to its stability.

3. INSAR DEM GENERATION

The theories and methods of InSAR were illustrated by Goldstein et al. [13]-[15]. The SLCs were firstly coregistered with subpixel accuracy. The interferogram and coherence map (Fig. 2) were computed with multi-looking in range (1-look) and azimuth (5-looks). Coherence is the most effective criterion to weigh the quality of interferogram and good coherence in the core area was observed over the image. Baseline was estimated to remove the flat earth phase trend. Before phase unwrapping, adaptive filtering for smoothing was

applied. Fig. 3 shows the interferogram of the Grove Mountains after phase unwrapping using Minimum Cost Flow Algorithm [16]. Furthermore, for the estimation of height, improvement of interferometric baseline based on GCP was performed. The result was geocoded to UTM coordinates (Fig. 4a).

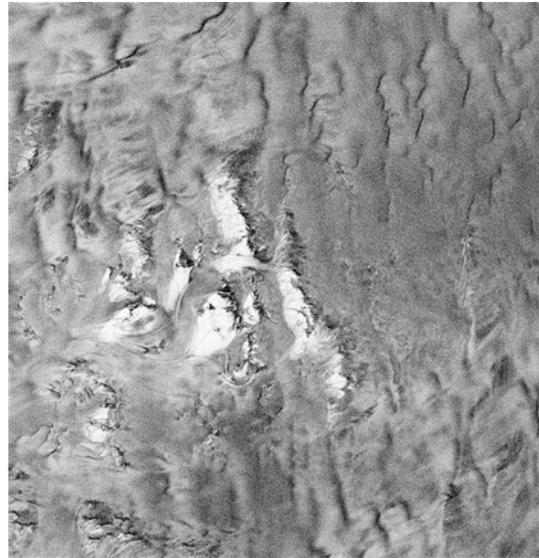


Figure 2. Coherence map in radar geometry. The coherence in most areas is over 0.4.

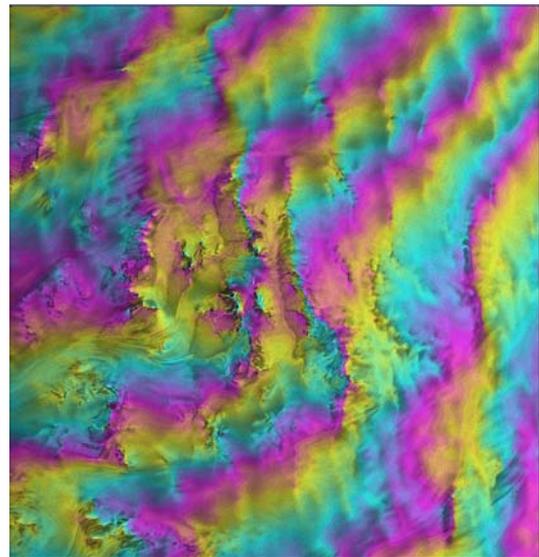


Figure 3. Unwrapped interferometric phase

Due to sloping terrains and satellite baseline errors, some inclination errors occurred in the InSAR DEM, as shown in Fig. 4(b) and (c). Comparing the elevations of InSAR DEM with BAMBER DEM, ICESat DEM and RAMP DEM along the profiles across the Grove Mountains (see Fig. 4(a)), we can clearly observe that InSAR DEM has an inclination tendency. The maximum error is over 600 m and hence, InSAR DEM must be corrected. However, the elevation is in good

agreement with the other DEMs in Mount Harding where GCP was selected.

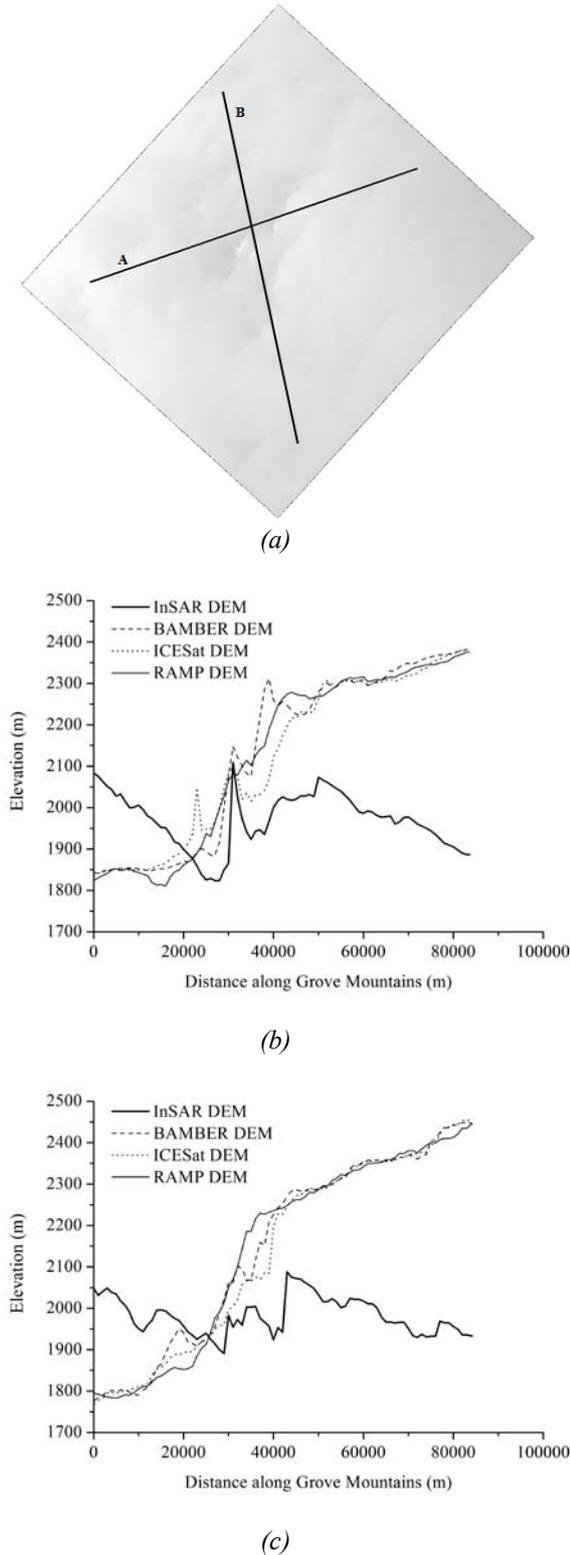


Figure 4. Elevation of InSAR DEM (heavy line), BAMBER DEM (dash line), ICESat DEM (dot line) and RAMP DEM (solid line) along profiles of Grove Mountains. (a) profiles across Grove Mountains; (b) along profile A; (c) along profile B.

4. INSAR DEM RECONSTRUCTION USING ICESAT GLAS DATA

ICESat GLAS has provided a view of the Earth in three dimensions with unprecedented accuracy. A variety of calibration/validation experiments have been executed which show that the elevation products, when fully calibrated, have a horizontal error of $(2.4 \pm 7.3 \text{ m})$ and vertical error of $(0.04 \pm 0.13 \text{ m per degree of incidence angle})$ [17]. We used GLA12 elevation products collected during March-November 2003 and distributed as Release 23. The footprints covering the InSAR DEM are shown in Fig. 5.



Figure 5. ICESat footprints covered the InSAR DEM

For every ICESat footprint, we extracted the corresponding InSAR elevation. ICESat footprints of highly accurate elevations were supposed to be control points and we can get observation equations as

$$V = B \hat{X} - l \quad (1)$$

where V is the residual matrix, B is the coefficient matrix, \hat{X} is the parameter matrix and l is the observation matrix.

The coefficient matrix B is

$$B = [x \quad y \quad 1] \quad (2)$$

where x and y are the coordinates of ICESat footprints.

The parameter matrix \hat{X} is expressed as

$$\hat{X} = [a \quad b \quad c]^T \quad (3)$$

where a , b and c are the transformation parameters. Here we used the 1st polynomial for adjustment.

The observation matrix l is

$$l = h_{ICESat} - h_{InSAR} \quad (4)$$

where h_{ICESat} is the elevation of ICESat footprint and h_{InSAR} is the corresponding elevation of InSAR DEM.

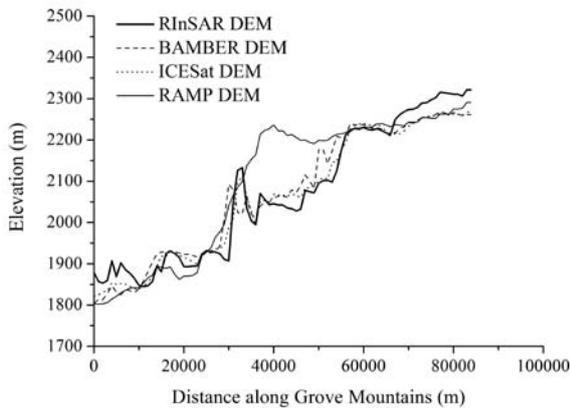
The transformation parameters can be estimated by the least square adjustment,

$$\hat{X} = (B^T P B)^{-1} B^T P l \quad (5)$$

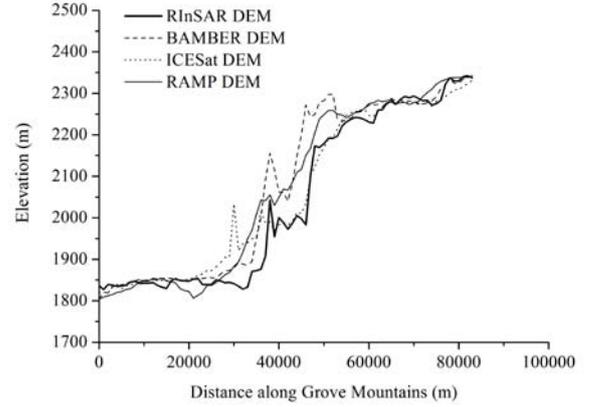
where P is supposed to be the unit weight matrix.

5. RESULTS

InSAR DEM was reconstructed based on least square adjustment. We can evaluate the accuracy by comparing the elevations of reconstructed InSAR DEM (RInSAR DEM) with other DEMs along the profiles across the Grove Mountains in Section 3. For the profiles of Fig. 6(a), the mean difference between elevations of RInSAR DEM and BAMBER DEM along profile A is $-32.77 \text{ m} \pm 56.36 \text{ m}$. The mean difference of elevations between RInSAR DEM and ICESat DEM is $-12.86 \text{ m} \pm 38.74 \text{ m}$ while this mean value between RInSAR DEM and RAMP DEM is $-26.26 \text{ m} \pm 46.92 \text{ m}$. For the profiles of Fig. 6(b), the mean difference between elevations of RInSAR DEM and BAMBER DEM, ICESat DEM, RAMP DEM along profile B is $0.87 \text{ m} \pm 46.29 \text{ m}$, $6.70 \text{ m} \pm 29.24 \text{ m}$ and $-23.39 \text{ m} \pm 78.69 \text{ m}$ respectively. Before least square adjustment, the elevations between InSAR DEM and BAMBER DEM, ICESat DEM, RAMP DEM have a respective mean difference of $-163.51 \text{ m} \pm 214.80 \text{ m}$, $-155.47 \text{ m} \pm 206.69 \text{ m}$ and $-161.65 \text{ m} \pm 215.17 \text{ m}$ along profile A, while along profile B, the corresponding mean differences between InSAR DEM and BAMBER DEM, ICESat DEM, RAMP DEM are $-166.83 \text{ m} \pm 238.10 \text{ m}$, $-159.677 \text{ m} \pm 242.43 \text{ m}$ and $-168.33 \text{ m} \pm 244.01 \text{ m}$. Evidently, the inclination errors in InSAR DEM have been eliminated.



(a)



(b)

Figure 6. Elevation of RInSAR DEM (heavy line), BAMBER DEM (dash line), ICESat DEM (dot line) and RAMP DEM (solid line) along profiles of Grove Mountains. (a) along profile A; (b) along profile B.

6. CONCLUSIONS

This paper presented DEM generation using ERS tandem data. It was tested in the Grove Mountains, East Antarctica. Due to sloping terrains and satellite baseline errors, InSAR DEM is inaccurate. Based on least square adjustment, ICESat GLAS data was utilized to eliminate the errors in the original InSAR DEM. The reconstructed InSAR DEM (RInSAR DEM) turned out to be in good agreement with BAMBER DEM, ICESat DEM and RAMP DEM. The preliminary study has demonstrated the potential and advantages of combining InSAR and ICESat for topographic mapping. We think that it is possible to obtain DEMs with high-resolution and high-accuracy at a large scale using interferometric technique in Antarctica although there are considerable limitations with repeat-pass interferometry in polar regions.

Surface decorrelation due to snow and ice-flow is a main problem; however, tandem data in this study was of good coherence (> 0.4). C-band can penetrate the ice surface, but here, this penetration effect to DEM generation was neglected. Our future study will concentrate on obtaining high-precision DEM along transect from Zhongshan Station to Dome-A including formation of the interferogram, phase unwrapping, and other crucial steps. Moreover, multiple techniques will be combined to achieve our goals.

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