Three-Dimensional Coastal Geomorphology Deformation Modelling Using Differential Synthetic Aperture Interferometry

Maged Marghany

Institute for Science and Technology Geospatial (INSTeG), Universiti Teknologi Malaysia, 81310 UTM, Skudai, Johor Bahru, Malaysia

Reprint requests to M. M.; E-mail: maged@utm.my

This work presents a new approach for three-dimensional (3D) coastal deformation simulation using differential synthetic aperture interferometry (DInSAR). In doing so, conventional InSAR procedures are implemented to three repeat passes of RADARSAT-1 SAR fine mode data (F1). Further, the DInSAR method is implemented with the phase unwrapping technique. Consequently, DInSAR is used to eliminate the phase decorrelation impact from the interferograms. The study shows the accurate performance of DInSAR with a root mean square error of 0.02 ± 0.21 m and 90% confidence intervals. In conclusion, the DInSAR technique produces an accurate 3D coastal geomorphology reconstruction.

Key words: RADARSAT-1 SAR; DInSAR; 3D; Coastal Geomorphology.

1. Introduction

Interferometric synthetic aperture radar (InSAR or IfSAR) is a geodetic technique using two or more single look complex synthetic aperture radar (SAR) images to produce maps of surface deformations or digital elevations [1, 2]. InSAR, consequently, provides digital elevation models (DEMs) with $1 – 10$ cm accuracy, which can be improved to millimetre level by the differential synthetic apreature radar interferometry (DInSAR). In this regard, a millimetric target displacement can be detected using DInSAR along the sensor-target direction [3]. Taking advantage of the fact that DInSAR can detect millimetric ground surface deformation and precious digital elevation model with accuracy of less than ±1 cm more accurate coastal geomorphology deformation can be studied. In this regard, the DInSAR technique has an excellent promising for Earth surface deformations of 1 mm compared with ground surveying and other remote sensing technologies [3]. The aim of this paper is to explore the precision of the digital elevation models derived from RADARSAT-1 fine mode data (F1) and, thus, the potential of the sensor for mapping coastal geomorphologic feature changes.

According to Luo et al. [3], the surface displacement can be estimated using the acquisition times of three SAR complex images. The component of surface displacement thus, in the radar-look direction, contributes to the further interferometric phase (ϕ) as

$$\phi_{\mathrm{d}} = \frac{4\pi}{\lambda}\partial\zeta, \qquad (1)$$

where λ is the RADARSAT-1 SAR fine mode wavelength which is about 5.6 cm for the C_{HH}-band, and ϕ_{d} is the coastal geomorphology feature deformation phase. So the displacement of coastal digital elevation $\partial\zeta$ can be given by

$$\partial\zeta = \frac{\phi_{\mathrm{d}}\lambda}{4\pi}. \qquad (2)$$

2. Results and Conclusion

3D coastal features' reconstruction from DInSAR was trained on three RADARSAT-1 SAR fine mode data (Fig. 1). The master data was acquired on 23 November 1999, the slave 1 data was acquired on 23 December 2003, while slave 2 data acquisition was on 26 March 2005, respectively. The master data was ascending while both slave data were descending. Figure 2 shows the variation of the backscatter intensity for the F1 mode data along Terengganu's estuary. The urban areas have the highest backscatter of -10 dB as compared to the water body and the vegetation area (Fig. 1).
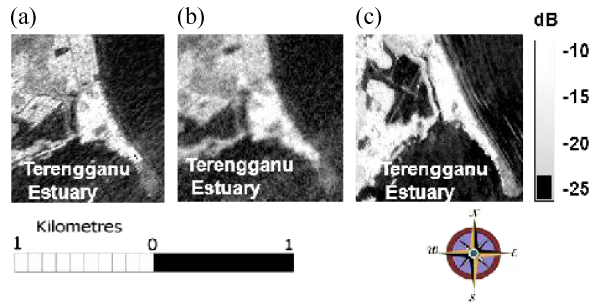
(a)   (b)   (c)   dB

Fig. 1 (colour online). RADARSAT-1 SAR fine mode data acquisition: master data (a), slave 1 data (b), and slave 2 data (c).
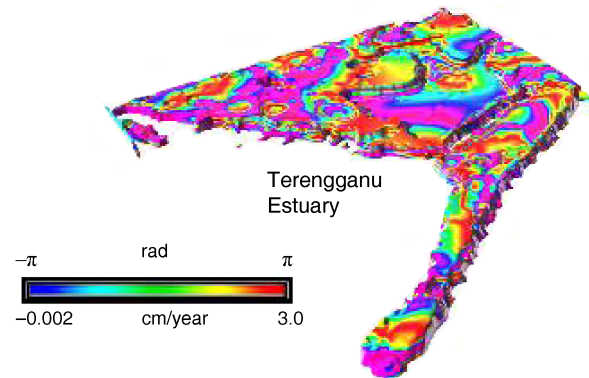

Fig. 2 (colour online). Fringe interferometry generated using DInSAR.

Figure 2 shows the interferogram created using the DInSAR method. The full colour cycle represents a phase cycle, covering range between $-\pi$ to π. In this context, the phase difference is given module 2π; which its colour encoded in the fringes. Seemingly, the colour bands change in the reverse order, indicating that the center has a great deformation along the spit. This shift corresponds to 0.4 cm of coastal deformation over a distance of 500 m. The urban area is dominated by a deformation of 2.8 cm because of rapid development of urban areas along the coastline (Fig. 2c).

Figure 2 represents the 3D spit reconstruction using DInSAR with the maximum spit elevation of 3 m with gentle slope of 0.86 m. It is clear that DInSAR can de-

Table 1. Statistical comparison between DInSAR and ground measurements.

Statistical parameters	3-D techniques			
	Ground measurements		DInSAR	
Bias	9.5		-0.05	
Standard error of the mean	8.5		0.034	
	Lower	Upper	Lower	Upper
90% confidence interval	1.2	2.6	0.02	0.42
95% confidence interval	5	6.5	0.21	0.32

tect tiny erosion of -0.002 cm/year and deposition of 3 cm/year (Fig. 2).

DInSAR produced perfect pattern of fringe interfeormetry (Fig. 2). It shows that there are many deformations of over several centimetres. In these deformations, the deformation in the spit is known because of coastline sedimentation [4]. Further, it can be noticed that the DInSAR preserves detailed edges with discernible fringes. Indeed, Figure 2 shows a smooth interferogram, in terms of spatial resolution maintenance, and noise reduction, compared to conventional methods [4].

Finally, a difference statistical comparison confirms the results of Figure 2. Table 1 shows the statistical comparison between the simulated DEM from the DInSAR and the real ground measurements. This table represents the standard error of the mean, 90 and 95% confidence intervals, respectively. Evidently, the DInSAR bias of -0.05 m is lower than ground measurements. Therefore, DInSAR has a standard error of the mean of ± 0.034 m lower than ground measurements. The overall performance of the DInSAR method is better than ground measurements which is validated by a lower range of error (0.02 ± 0.21) m with 90% confidence intervals. This study agrees with the work done by Luo et al. [3]. In conclusion, the DInSAR method could be an excellent tool for 3D coastal geomorphology reconstruction from SAR data.

[1] V. Nizalapur, R. Madugundu, and C. Shekhar, J. Appl. Remote Sens. 5, 059501 (2011).
[2] K. S. Rao and H. K. Al Jassar, J. Appl. Remote Sens. 4, 24 (2010).
[3] X. Luo, F. Huang, and G. Liu, J. New Zea. Inst. Surv. 296, 20 (2006).
[4] M. Marghany, M. Hashim, and A. P. Cracknell, Int. J. Dig. Eart. 3, 187 (2010).