DEM generation Using JERS-1 SAR Interferometry for Kagoshima area, Kyushu, Japan

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ABSTRACT

Digital Elevation Models (DEMs) and their products are widely used for numerous environmental applications within the geoscientific community. Recent advances in repeat-pass spaceborn Synthetic Aperture Radar (SAR) interferometry have made possible extremely accurate and more reliable height data extraction from Radar signal data. The potential gain from interferometric exploitation is significant, since accuracy of measurements can be determined to within a resolution element of wavelength dimension.

Two-pass raw radar signal data from the JERS-1 L-band synthetic aperture radar instrument acquired in 2 March 1997 and 15 April 1997 with baseline perpendicular of 464.4973 m are used to generate a high-resolution DEM for Kagoshima area, Kyushu, Southern Japan using the GAMMA SAR interferometry system comprising of a calibrated range/Doppler processor, interferogram calculation applying adaptive filtering and phase unwrapping, height map generation based on tie points or ground control points (GCPs) derived from topographic maps, and finally georeferencing the SAR data and its products to map projection using a reference 50 m resolution DEM in UTM projection. The accuracy of the resulted DEM was assessed by comparison with a reference DEM and proved a quite good accuracy.

1. INTRODUCTION

Synthetic Aperture Radar (SAR) is a high-resolution ground-mapping technique that effectively synthesizes a large receiving antenna by processing the phase of the reflected radar return. It is an active remote sensing technology that uses microwave energy to illuminate the earth's surface and records the elapsed time and energy (amplitude) intensity of the return pulse received by the antenna. Elapsed time of the pulse determines position of the feature in the image. Amplitude of the returned pulse tells us about the nature of the feature like mountains, rivers, lakes, cities, and other useful information. The phase of a single SAR image is of no practical use. On the contrary, if two SAR images from slightly different viewing angles are considered their phase difference can be usefully exploited to generate Digital Elevation Models (DEMs).

Synthetic aperture radar (SAR) processing systems can generate a highly accurate and reliable height models that may serve as a basic input for many environmental applications. While these powerful tools are available to prepare and analyze the data, data analysis process is not a one-shot process requiring significant expertise to optimize the processing parameters to properly extract useful and accurate information from the raw data. There are several aspects such as data selection and processing parameters that have a significant impact on the quality of the derived products such as coherence maps, interferograms and the final height models.

In the present work, GAMMA SAR interferometry processing system (Werner *et al.*, 2000) for analyzing spaceborn SAR data is used to generate an accurate height model for Kagoshima area, Kyushu, Southern Japan (Fig. 1), using L-Band 44-day repeat-pass JERS-1 SAR data. GRASS GIS (Geographic Resources Analysis Support System, GRASS Development Team) is used for quality assessment of the InSAR DEM.

The basic approach and the processing steps for height model generation from SAR interferometry will be outlined conceptually here, although a number of excellent sources describe the theory and mathematics behind the processing (Alaska SAR Facility, 1999; Massonet, 1997; Madsen *et al.*, 1993; Zebker and Villasenor, 1992).

2. INTERFEROMETRIC SAR FOR TOPOGRAPHIC MAPPING

2.1 SAR principles and imaging geometry

Repeat-pass synthetic aperture radar (SAR) data acquired from displaced vantage points provide the basis for calculating DEMs by interferometric processing of two complex (phase and magnitude) SAR images. Substracting phase from another SAR image's phase that covers approximately the same area results in an interferogram. The raw interferogram contains systematic range and azimuth dependent terms, as well as topographic information. Systematic trends can be substracted from the interferogram leaving dominantly the topographic information.

For repeat-pass imaging geometries, topography depends only on the phase of the interferogram and the INSAR parameters (baseline length, used wavelength etc.), not on the interferometric magnitude. Basic imaging geometry for repeat-pass JERS-1 SAR together with some orbit/radar specifications is shown in Fig. 2.

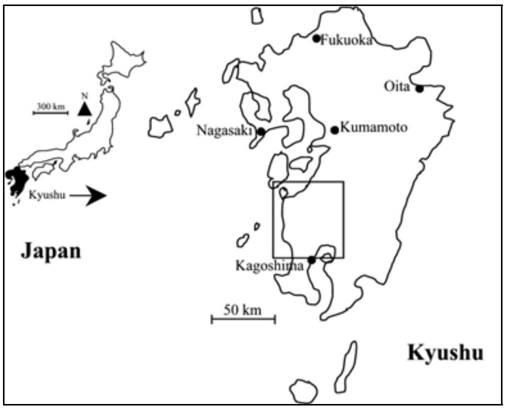

Figure 1. Location Map of the study area.

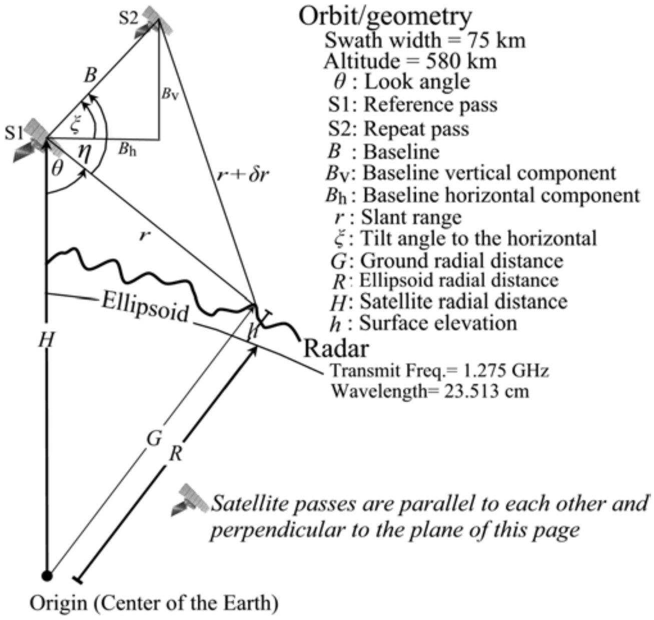

Figure 2. JERS-1 SAR geometry.

2.2 InSAR basic approach for surface topography derivation

The difference in phase between two SAR images covering the same area is sensitive to both viewing geometry and the elevation of the point above the reference surface, in our case, the ellipsoid used to georeference the SAR products. The phase difference φ between the two radar signals received from the same surface element at the two antenna positions according to Li and Goldstein, 1990, can be calculated as:

$$\varphi = 4\pi(\delta r)/\lambda = 4\pi(B_h \sin\theta - B_v \cos\theta)/\lambda \tag{1}$$

Where λ is the wavelength and δr is the range difference, B_h, B_v, and θ are shown in the above figure. Based on the range difference and the look angle changes through the scene, the phase difference (interferometric phase) between two sensor positions and the target terrain point (pixelwise) can be generated. This interferometric phase (interferogram) records phase differences that result from two sources, topography, which is the objective of this study and the flat earth phase that is a systematic range and azimuth dependent terms due to simple geometry of the satellites with respect to each other. Interferogram must be flattened by removing the flat earth phase effect, leaving only the component due to topography. The degree of coherence between the interferogram and the co-registered intensity images is then determined and the interferogram is then enhanced by adaptive filtering to reduce phase noise. The filtered interferogram shows the differences in phase, but only in terms of 2π. Phase unwrapping sums these 2π terms across the scene to calculate the total difference. The resulted unwrapped phase is almost linearly proportional to the topographic height.

For height map generation, unwrapped phase together with the precision refined baseline are used to derive the topographic heights and true ground ranges based on the SAR geometric relationships shown in Fig.2. Elevation for every pixel in the scene can be calculated according to the simplified equations listed as follow:

$$h = G - R \tag{2}$$

According to the law of cosines we can get:

$$G = \sqrt{(H^2 + r^2 - 2Hr\cos\theta} \tag{3}$$

However,

$$\cos\theta = \sin(\eta - \xi) = \sin\eta \ \cos\xi - \cos\eta \ \sin\xi = \sin\eta \ B_{\mathrm{h}} / B - \cos\eta \ B_{\mathrm{v}} / B \tag{4}$$

where, $$\cos\eta = (B^2 + r^2 - (r + \delta r)^2)/2\,B\ \ r \tag{5}$$

and $$\sin\eta = \pm\sqrt{1 - \cos^2\eta} \tag{6}$$

Since, B, B_{h}, B_{v}, r, $r+\delta r$, and R are known values, terrain heights h from a reference ellipsoid can be derived as:

$$h = \sqrt{H^2 + r^2 - 2H\ r\ (\sin\eta\ B_{\mathrm{h}} / B - \cos\eta\ B_{\mathrm{v}} / B)} - R \tag{7}$$

From the ellipsoid information together with the geoidal heights of the Mean Sea Level (MSL) through the study area, topographic elevations from the MSL can be determined for every pixel in the scene.

3. SAR PROCESSING

Data processing is a complex task and its performance is one of the aspects to improve the quality of the derived products such as coherence maps, interferograms and the height models. A better co-registration of the two images and an accurate estimation of the baseline determine the coherence accuracy that is a standard measure of the interferogram quality. Adaptive filtering improves the phase unwrapping and decreases the noise. All of these parameters together with a better selection of the data based on coverage, time interval and baseline considerations can be optimized and the quality of the resulting products can be improved.

Data processing was carried out on the JERS-1 raw data acquired on 2 March 1997 and 15 April 1997, using the GAMMA SAR interferometry processing system comprising principally of calibrated range/Doppler processor, interferogram generation applying spectral and adaptive non-linear filtering, and phase unwrapping using an algorithm based on minimum-cost-flow (MCF) optimization in a triangular irregular network (TIN) that permits robust phase unwrapping in many cases of isolated areas of high coherence. This is particularly advantageous in the case of long interval differential interferograms (Werner *et al.*, 2002). The Multi-Look Intensity image (MLI), coherence and unwrapped phase image are shown in Fig. 3a, b, and c.

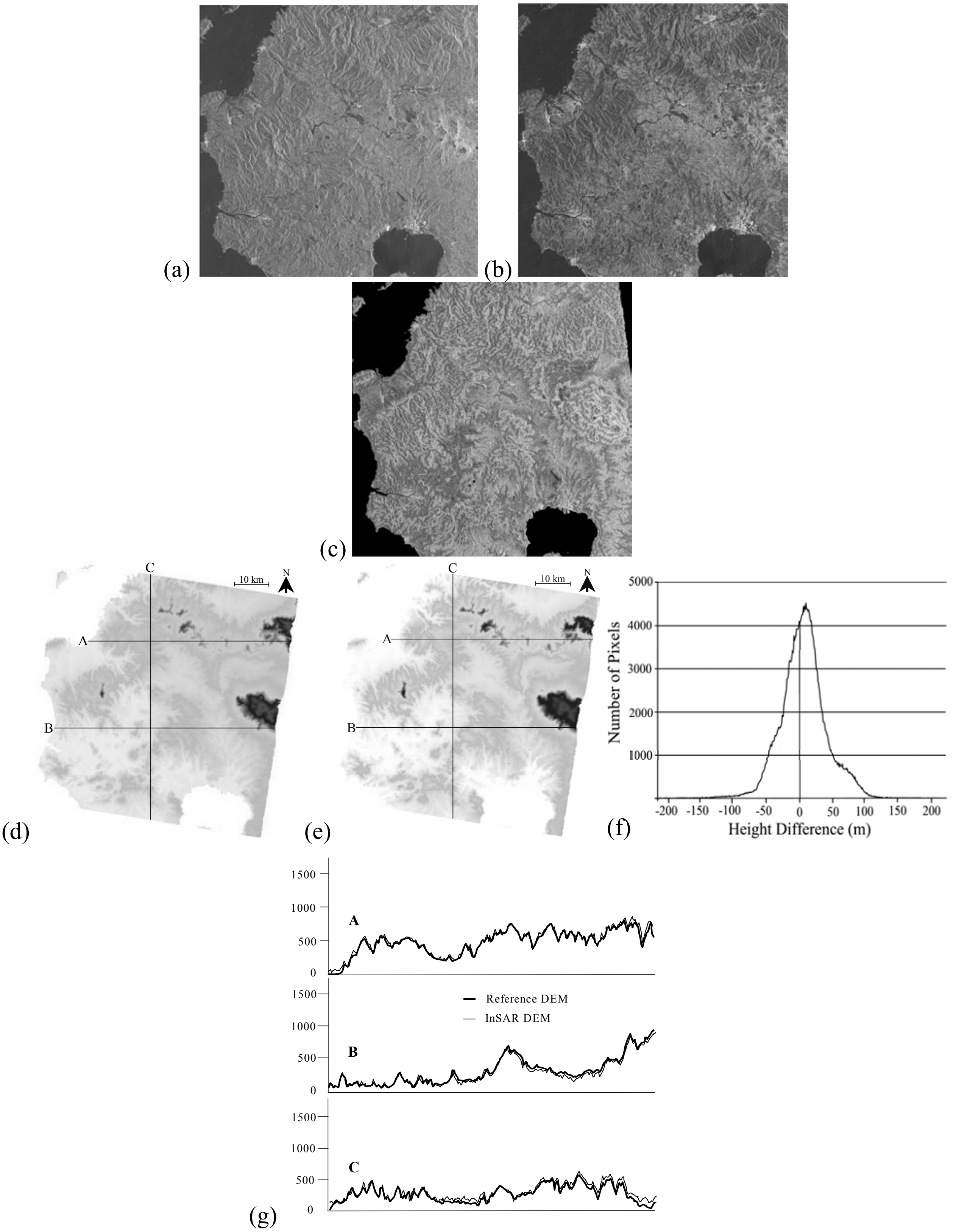

Figure 3. Interferometric SAR processing, a) MLI image, b) Coherence, white color refers to high coherence and black color refers to low coherence, c) height map with 200 m grayscale color cycle, d) InSAR DEM with 50 m spacing, geocoded to UTM coordinates, e) Reference DEM, f) Frequency diagram of Height difference, and g) Profile sections.

Heights reconstruction requires accurate estimation of the time varying baseline. An iterative non-linear least squares fit algorithm is used to estimate that baseline based on height tie points extracted from topographic maps and well distributed across range and azimuth. A simulated SAR image derived from 50 m DEM was used to estimate residual geolocation errors. The interferometric height map produced at 17.556 m range pixel spacing and 27.046 m azimuth pixel spacing derived from the unwrapped phase and the baseline is resampled to 50 m grid InSAR DEM in UTM coordinates as shown in Fig. 3 d.

4. QUALITY ASSESSMENTS

The accuracy of the final DEM is assessed by comparing its height information with the reference DEM (Fig.3e). Frequency diagram of the height difference between the reference DEM and the InSAR DEM of the test area (Fig.3f) together with three profile sections across them (Fig.3g) showed a height difference at the peak frequency of 11.00 m and an average difference of 7.827 m. It can be noted that the INSAR derived DEM, accurately reflects the shape of the topography. But, in our opinion, a comprehensive analysis that deals with INSAR data of different baselines could lead to good qualitative and quantitative analysis for DEM validation of this test area.

5. CONCLUSIONS

Optimizing the interferometric processing parameters together with data selection based on time interval and baseline considerations successfully generated an InSAR DEM from the unwrapped phase data for the test site. The produced InSAR DEM is validated against the reference 50 m DEM and proved a quite good accuracy. Generally, it can be concluded that INSAR derived DEMs give height information with quite high resolution and acceptable errors and can be used as a database for many environmental applications. But to come to qualitative and quantitative conclusions on the INSAR derived DEMs, further work still needs to be performed for the validation of INSAR derived DEMs. These could typically consist of data sets of different baselines for the DEM generation process.

6. REFERENCES

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