ACCURACY OF TOPOGRAPHICAL MAPS DERIVED FROM JERS-1 SAR INTERFEROMETRY

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ABSTRACT

Recently Synthetic Aperture Radar (SAR) were applied in many researchs, such as DEM generation, change detection, and soil moisture determination. In this paper, we describe the technique for deriving digital elevation models (DEM) from InSAR by JERS-1 data over Hanoi city – Vietnam. Hanoi situated on the flood plain of Red river and in the area of strong monsoons, high relative humidity prevails during most of the year around 70%. The high humidity influences interferometric data and it remains to the results. The objective of this paper is to access the influence of water vapor into DEM generated from JERS-1 SAR data. DEM were generated from three pairs of JERS-1 with time interval is 44 days. The accuracy of DEM was evaluated from 9 leveling benchmarks on the area about 18 km wide and 23 km long. Through the analysis of accuracy for three DEM we recognized that the errors may be mitigated by choosing interferometric pairs with long baselines but the baseline chosen must less than critical baseline for avoiding decorrelation. For Hanoi region we found that the best (longest) baseline pair was 198.03 m, and the height error was 3.9 m whereas the poorest baseline was 38.59 m and the height error was 7.2m.

1. INTRODUCTION

SAR interferometry is an established technique based on combining two synthetic aperture radar (SAR) images of the same scene acquired from different viewpoints and different time or from two antennas mounted on the spacecraft. Graham (1974) was the first to introduce synthetic aperture radar (SAR) for topographic mapping using data supplied by the first civilian remote sensing satellite SeaSAT. Zebker and Goldstein (1986) presented the first results with side looking airborne in 1986 that mounted two SAR antennas on an aircraft with 11.1m from each other. Since then there were many Interferometric SAR (InSAR) systems were designed and constructed and consequently, variety of application were generated such as surface deformation studies (Massonet et al., 1993), or ice flow analysis (Goldstein et al., 1993)

For topographic generation, precise spatial relationship of the two imaging orbits and the interferometer "baseline" permits reconstruction of the surface topography from the two dimensional phase field measurements. In this paper we would like to discuss about the capability of DEM generation from InSAR and examine in detail phase defects data acquired by three pairs of JERS-1 over Hanoi – Vietnam to understand the relation of the spatial baseline with error propagation to DEM.

2. DEM GENERATION OF HANOI FROM JERS-1 SAR INTERFEROMETRY

2.1 Overview of DEM generation from InSAR

SAR is acronym of Synthetic Aperture Radar. Imaging radar (radio detection and ranging) is a technique to collect information about the target through transmission and reception of pulses of electrical energy at the microwave frequency with wavelengths in order from one to a few tens of centimeters.

SAR interferometry (InSAR) is relatively new signal processing technique that combines two or more SAR radar of the same area, recorded by imaging radar systems onboard satellite platform. InSAR operates on the principle of extracting the phase change between two images of the same area taken from different positions to measure the path length differences. The path length differences can then be related to important parameters such as the terrain height, deformation of the surface of the Earth and excess atmospheric delay (Goldstein et al. 1988). Figure. 1(a) illustrates the basic geometrical configuration of InSAR

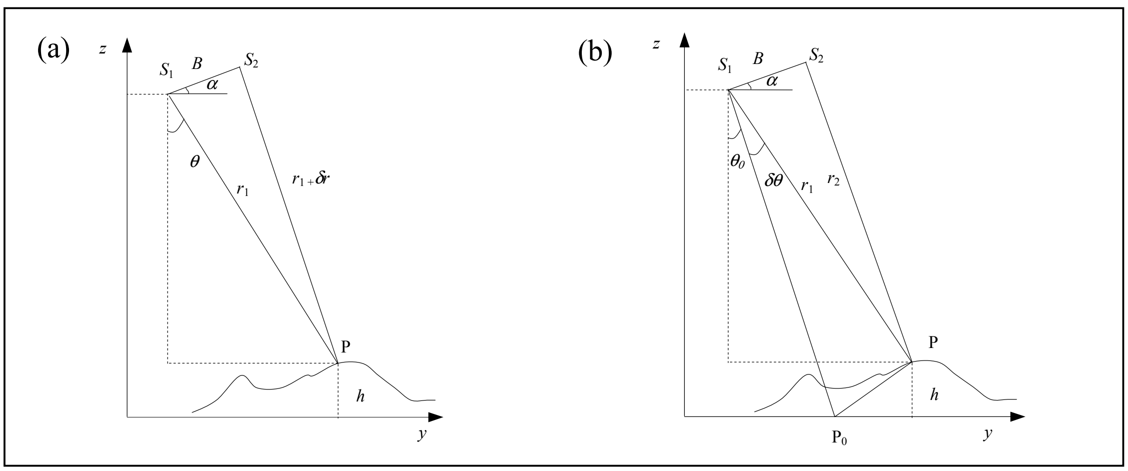

Figure 1. Geometrical configuration of InSAR. (a) Interferometer imaging geometry, (b) Phase flatten geometry

Both of two radar systems S_1 (master or reference) and S_2 (repeat) illuminate the same ground patch of the Earth. B is the distance between two antennas, call baselines, θ is the look angles, *r* and $r+\delta r$ are slant ranges to a point P on the ground, α is the angle between baseline and the horizontal.

To obtain the height *h* from the interferometric phase, one term is proposed that is flat earth phase (phase at point P_0), see Figure. 1(b). The height of the ground can be computed from removal of flat earth phase by the following equation:

$$\varphi_p - \varphi_0 = -\frac{4\pi B\cos(\theta_0 - \alpha)}{\lambda r \sin\theta_0} h \qquad (2\text{-}1)$$

$$h = -\frac{\lambda r \sin\theta_0}{4\pi B\cos(\theta_0 - \alpha)} \Delta\varphi \qquad (2\text{-}2)$$

$$B\cos(\theta_0 - \alpha) = B_\perp$$

where $B_{\perp}$ is the perpendicular component of baseline, θ_0 is the look angle to the image point P_0. φ_0 is usually called the reference body phase or the flat earth phase, φ_p is the interferometric phase for image point P, and $\Delta\varphi=\varphi_p-\varphi_0$ is called flat-earth corrected phase φ_{flat},

2.2 Influence of water vapor in topography measurement from InSAR

The effect of variable atmosphere induces phase error that is able to estimate on repeat-pass topographic measurements. As mention above the individual radar echoes from distributed targets have random phases, which are in turn modified by propagation effects, and are not easily determined before the interferogram difference is generated. Thus the interferogram phase is used as basic measurement. Height error as a function of phase error for topographic analysis is given by (Zebker and Goldstein, 1986):

$$\sigma_z = \frac{\lambda r}{4\pi B}\frac{\sin\theta}{\cos(\theta-\alpha)}\sigma_\phi \qquad (2\text{-}7)$$

where σ_ϕ is the phase error in the interferogram, and σ_z is the resultant height error.

2.3 Geography and climate of Hanoi

Hanoi, the capital of Vietnam is situated in a flood plain of the Red River and the second largest province in Vietnam. Hanoi is located at latitudes 20°53' – 21°23' N and longitudes 105°44' – 106°02' E. Most of the Hanoi area is flat with elevations below 20 m except the northern mountainous part up to 400 m height. The climate of Hanoi is typical of the Red River Delta region, i.e., sunny and tropical along with heavy monsoon. The average annual rainfall in Hanoi is about 1,600 mm. High humidity prevails during most of the year about 70% is a reason to reduces the capability of Radar signal.

2.4 Data sources

We have produced topographic maps from JERS-1 SAR observation. JERS-1 is the Japanese satellite with the repeat periods of 44 days and the nominal altitude of 568 km. JERS-1 SAR uses L band with λ=23.5 cm, and the off-nadir angle is 35 degree. Figure 2 shows a list of images, and acquisition time, image combinations and baselines evaluated from orbit data.

Our research region focuses on the urban area and surrounded area on the area of 18 km wide and 23 km long, Figure 3 (a), (b) shows JERS-1 frame over Hanoi city on Vietnam map and study area on JERS-1 multi look image.

2.5 DEM generation and error evaluation

2.5.1 *Data processing procedure*

From the table of data set, three pairs of images in the year 1995 with time interval of 44 days were chosen. These are Pair-1, Pair-2 and Pair-3. The GAMMA software was used in this research and processing procedure is as follow

- Raw data processing for single look complex (SLC) data

- Co-registration of SLC data.
- Interferogram Generation
- Flattening of Interferogram
- Coherence estimation
- Filtering
- Phase unwrapping
- Phase to height conversion
- Geocoding of height map

According to the steps showed above, three pairs of images were co-registrated and interferogram are created. In order to improve the estimation of the interferometric phase, the multi-look is performed. The aim of multi-look generation is speckle reducing. It is usually 2 pixels in range and 6 in azimuth with JERS-1 data.

Date	95/05/09	95/06/22	95/08/05	95/09/18

	Pair-1	Pair-2	Pair-3
Perpendicular baseline $B_{\perp}$	-148.7m	197.9m	-39.5m
Parallel baseline $B_{//}$	-376.9m	100.7m	96.2m
Look angle θ	38.79^{o}	38.76^{o}	38.75^{o}
Range r	716881m	716881m	716881m
Time interval	44days	44days	44days

Figure 2. JERS-1 images and their parameters

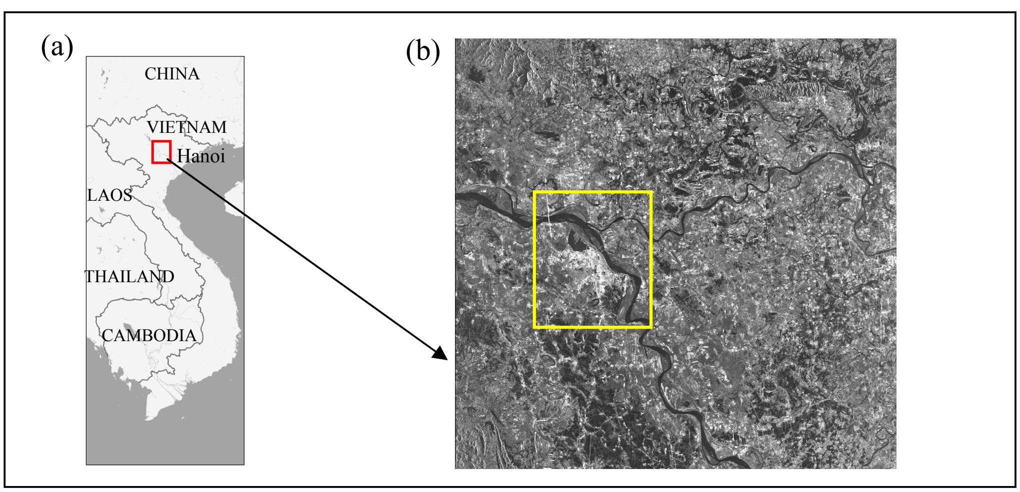

Figure 3. Study area. (a) JERS-1 frame over Hanoi on Vietnam map, (b) Study area on JERS-1 multi look image

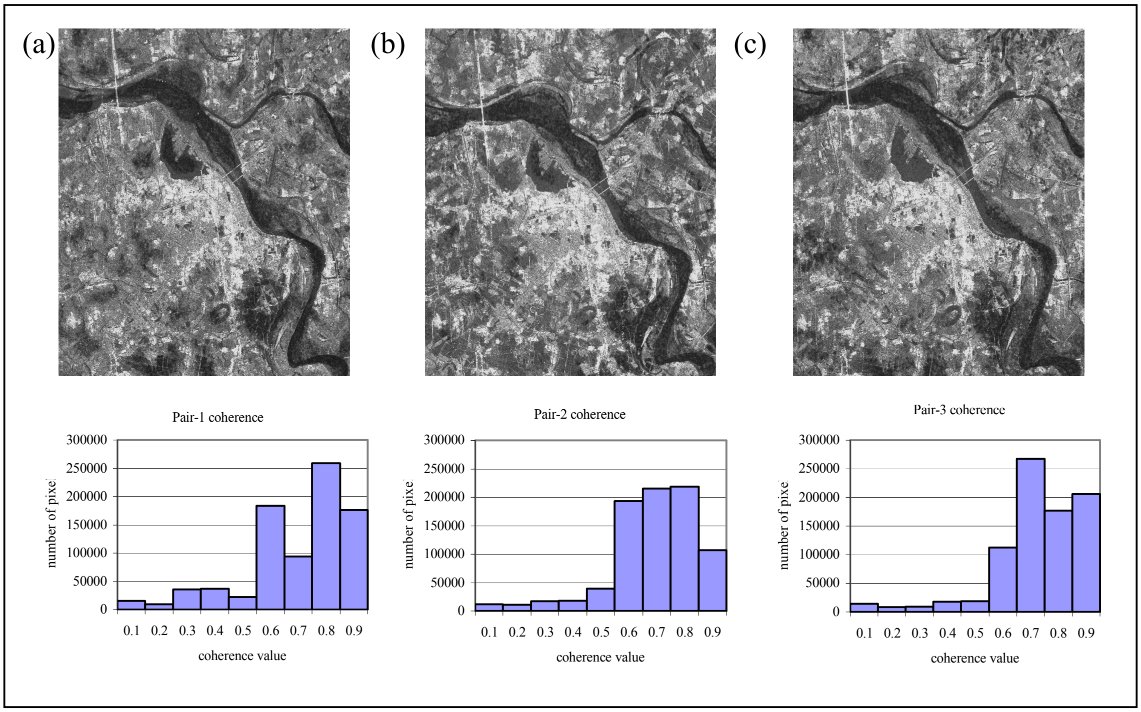

Figure 4. Coherence image and graph of coherence, (a) Pair 1, (b) Pair-2, (c) Pair-3

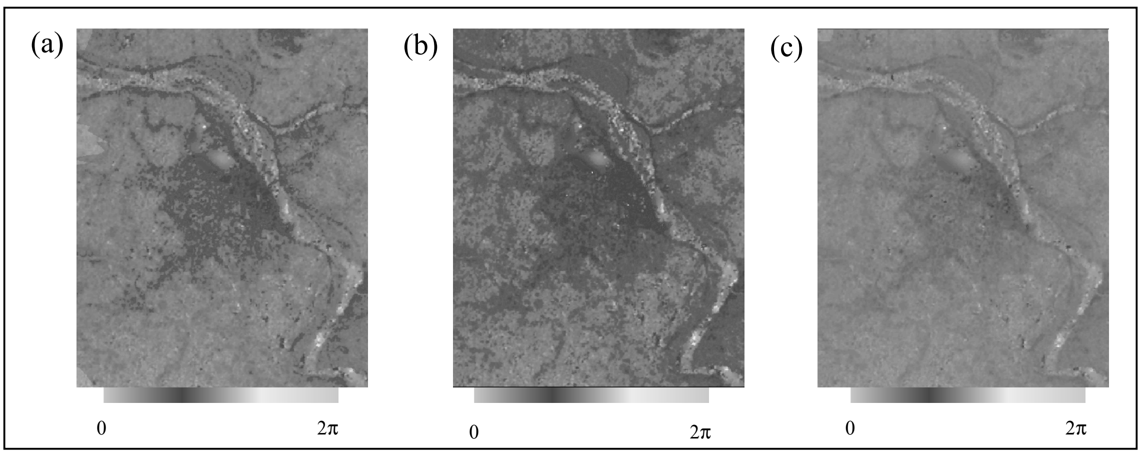

Figure 5. Phase unwrapping of three pair. (a) Pair-1, (b) Pair-2, (c) Pair-3

In order to determine the quality of the image pairs, the correlation of all pairs need evaluate. Figure 4 (a), (b), (c) displays the coherence of three pairs. The bright color is high coherence while dark color is low coherence. It is easy to recognize that low coherence is happened in the water area and some parts of vegetation. The coherence are also depicted by three graphs, with coherence greater than 0.5 of 83%, 86% and 89% of Pair-1, Pair-2 and Pair-3 respectively.

To reduce the phase noise the filter was carried out. In this research we used the Fast Fourier Transform (FFT) for filtering the data.

The interferogram is the function of arctangent, and therefore it varies from $-\pi$ to π; this is called wrapped interferometric phase. We have to determine the relative phases for all the points in the interferogram using the so call "phase unwrapping", which adds the proper multiple of 2π to each phase measurement. Phase fringe after unwrapping are shown in the figure 5(a), (b), (c).

From unwrapped phase, the height map can be computed. As mentioned in the equation (2-2), the height depends on the perpendicular baseline, and so the accurate baseline has to computed. In order to determine the accurate baseline we have to collect the ground control points (GCPs). These height points are chosen on the topographical map or from accurate DEM. Accordance with each height points, the phase values are extracted from phase unwrapping file. Base on (2-2), using known height points and phase we can get the baseline by Least Square Fit algorithm. 32 ground control points were selected from topographical map of 1:10000 scale, and Table 1 illustrates the refined baseline, altitude rms error of 32 GCPs of three pairs. Because the study area is very flat, it is difficult to recognize the topography by default color table in GAMMA. Therefore we imported the height results into Grass6.0 which is open source GIS software, and rather robust in image processing. The aim of this transfer is to change the color table to highlight the difference of small topography and geocode the heights maps to UTM system, datum WGS84 zone 48N. Figure 6 (a),(b),(c) illustrates the geocoded height maps in Grass6.0.

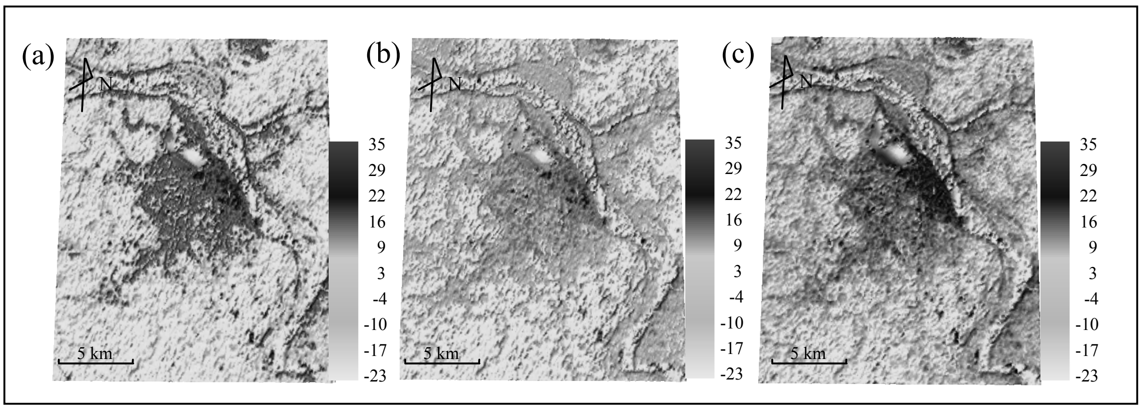

Figure 6. Geocode Height map in Grass6.0, (a) Pair-1, (b) Pair-2, (c) Pair-3, Unit: meters

Table 1. Baseline refinement

Pair	Perpendicular baseline(m)	Error (m)
Pair-1	-154.30	3.0
Pair-2	198.03	2.6
Pair-3	-38.59	6.4

2.5.2 *Error evaluation*

To evaluate the accuracy of DEM generation from JERS-1 SAR interferometry, we considered the coherences given in the previous section. Fact that these coherences were rather high proves that time interval was not long to influence to the results. There was only atmospheric effect that is main error to maintain to the results. We now analyze the error of three DEMs from JERS-1 SAR data by using the equation (2-7). In order to estimate error σ_ϕ, we have to know the σ_z. Unfortunately accurate digital elevation models of Hanoi do not exist and this greatly constrains our ability to test the accuracy of our approach to topographic mapping. We checked the altitude of three digital elevation models with nine benchmarks shown in Figure 7(a). The benchmarks were settled to detect subsidence in Hanoi city. The measurement was organized by the Department of Resources and Environment (Dang., 1997). Nine height points were overlaid on DEM from JERS-1 SAR data, and corresponding elevation points were extracted from DEM SAR. Table 2 summarized the accuracy of three DEMs at nine places. The phase error was computed from the inverse of equation (2-7), where λ=23.5cm, r≈716881m and θ≈39 degrees

Table 2. Leveling survey and DEM from JERS-1 SAR comparison

Leveling data(m)	Pair-1(m)	Pair-2(m)	Pair-3(m)
8.04	8.78	8.72	12.03
6.79	10.94	10.88	14.83
6.92	15.81	13.25	16.98
10.14	11.73	12.17	15.25
7.15	16.15	12.59	16.67
7.63	16.88	15.02	20.16
8.05	9.34	7.44	10.52
7.42	9.64	12.45	14.03
8.02	7.64	7.08	11.42
rms height error (m)	4.9	3.8	7.2
phase error (rad)	0.09	0.09	0.03

Phase error in Table 2 reflects the influence of atmospheric water vapor on DEM generation. The error of two pair Pair-1 and Pair-2 are relatively high 0.09rad. The last pair Pair 3 is lowest, 0.03 rad. According to equation (2-7), the height error is inversely proportional to perpendicular baseline. Although the last pair Pair-3 had lowest phase error, the height error was highest 7.2 m because this pair had short baseline (38.59 m). The Pair-1 and the Pair-2 had perpendicular baseline of 154.3m and 198.03 m that height errors were 4.9 m and 3.8 m respectively. From that point we can say that the perpendicular baseline is very important factor. It influences largely to the accuracy of DEM generation from InSAR. The long baseline will increase the accuracy, even in the high moisture condition, but the baseline must be shorter than some critical length because the increase of baseline causes decorrelation of image pair.

To evaluate the difference of three DEM, three profiles were sketched the on three DEM Figure 7(b). The trends of three profiles were rather similar except in some parts in the city from distance 0 to -5000 m. Observe three DEM from InSAR we recognized that the DEMs from JERS-1 SAR had general trend be elevated. This was probably due to water vapor in the atmosphere.

3. CONCLUSION

After analyzing the data for DEM generation and error evaluation over Hanoi-Vietnam we had some conclusions below.

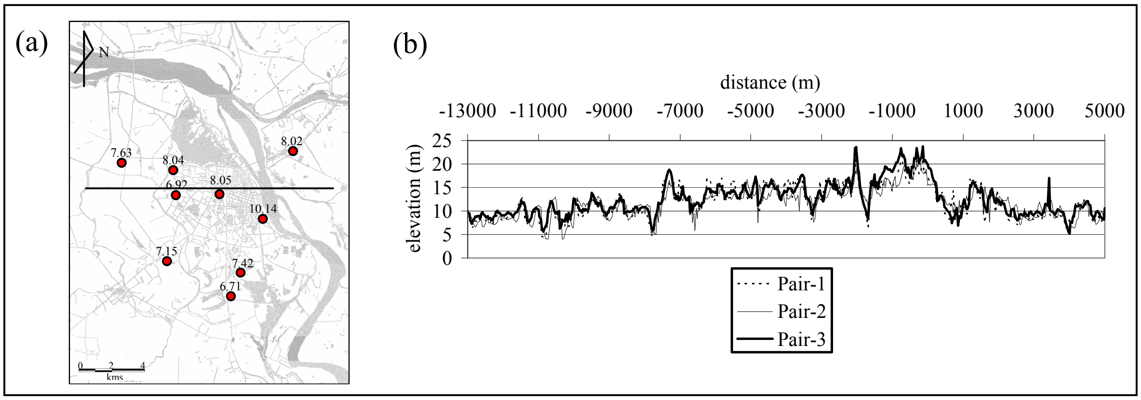

Figure 7. (a) The elevation benchmarks
(b) Profiles of three DEM

JERS-1 SAR with L band is able to penetrate the precipitation and vegetation therefore it is very useful for the regions of high humidity. The JERS-1 SAR data set over Hanoi city was composed of three pairs of images that were acquired from 1995/05/09 to 1995/09/18. Although the humidity was very high, the coherences of three pairs were rather high. The pixels with coherence greater than 0.5 cover 83% in first pair (Pair-1), 86% in second pair (Pair-2) and 89% in the last pair (Pair-3) respectively.

The digital elevation model that created from SAR data are usually influenced by atmospheric water vapor and time interval. The errors may be mitigated by choosing interferometric pairs with relatively long baselines, as the error amplitude is inversely propotional to the perpendicular component of the interferometric baseline. For Hanoi region we found that the best (longest) baseline pair was 198.03 m**,** and the height error was 3.8 m whereas the poorest baseline was 38.59 m and the height error was 7.2 m. The baseline chosen must still conform to the critical baseline criterion for avoiding decorrelation.

4. REFERENCES

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