INSAR APPLICATION FOR LAND SUBSIDENCE MONITORING IN CLOUD-COVERED AREA OF ASIAN REGION

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ABSTRACT

Synthetic aperture radar (SAR) imagery is known as a base map for land mapping and monitoring in GIS system over cloud-covered regions in the most of eastern Asian countries. In those countries, heavily populated cities are situated on deltas and nearby coastal zones, and some of cities are damaged by land subsidence which come from natural subsurface compaction and the withdrawal of under-ground materials, such as ground water, geothermal fluids and so on. The paper presents some results of land subsidence mapping in these urban areas, using SAR interferometry of L-band JERS-1/SAR data acquired during the period from 1992 to 1998. Hanoi, the capital city of Vietnam, and its surroundings are investigated and the preliminary result shows no large and severe subsided region in the period at least.

1. INTRODUCTION

Some cities in eastern Asian countries, which are significantly populated and industrialized on deltas or nearby coastal zones, have been damaged by land subsidence. The causes of land subsidence are natural compaction of Earth's subsurface, excessive withdrawal of groundwater, over-loading by heavy buildings on unconsolidated and soft subsurface layers, and so on. Floods often damage subsided areas when heavy storms hit there. The traditional method to monitor land subsidence in details is well-known leveling survey using many benchmarks and groundwater monitoring wells. Leveling survey is applicable only in the selected regions, costly to install and maintain the benchmark network, and time-consuming to carry out in the wide area.

On the other hand, synthetic aperture radar (SAR) interferometry has been known to be a very powerful technique for the measurement of land deformations, which are caused by large earthquake, volcanic eruption, landslides, glacier movement, and land subsidence (Massonnet, 1993; Rosen, 1996; Massonnet, 1995; Nakagawa, 1999; Strozzi et al., 2001). Land subsidence mapping by SAR interferometry (INSAR) has been applied on known subsided regions, because of the capability for its wide coverage and convenience. This paper shows the INSAR results for preliminary mapping of land subsidence in Hanoi city and its surroundings, using L-band SAR data acquired by JERS-1 (Japanese Earth Resources Satellite-1) during its operational period between 1992 and 1998.

2. SAR INTERFEROMETRY

For repeat-pass SAR interferometry, two SAR images (master and slave images) acquired from slightly different satellite orbit at different times are combined to measure the phase difference of the microwave signals at each pixel. The interferometric phase ϕ is sensitive measure of the range difference $\delta\rho$ (= $\delta 2$ - $\delta 1$) as follows.

$$\phi = (4\pi / \lambda) \cdot \delta\rho \quad (1)$$

where λ is the wavelength of SAR signal and $\delta 1$ is the distance from the SAR antenna to the scattering object on the ground by the first observation, and $\delta 2$ is the distance by the second observation. In the case of JERS-1 L-band SAR, the wavelength λ is about 23 cm.

The interferometric phase is determined as the argument of the interferogram, defined as the normalized complex correlation coefficient of complex microwave signals S1 (the first image) and S2 (the second image).

$$\gamma = <S1S2^*>/(<S1S1^*><S2S2^*>)1/2 \quad (2)$$

where the bracket <S> means the ensemble averaging of S, and * stand for the complex conjugate. The coherence $|\gamma|$ is the magnitude of the normalized interferogram γ and provides a measure of the phase noise. The coherence is bounded to values in the interval from 0 to 1. The pair of images with high coherence value allows generating less noisy and coherent interferogram.

The interferometric phase includes components of topographic phase, displacement in the viewing direction between two SAR acquisitions, and phase noise. Phase noise is the main error source of SAR interferometry, which includes atmospheric artifacts on the microwave propagation delay in the atmosphere with heterogeneous water vapor. That is,

$$\phi = \phi_{Orbit} + \phi_{Topo.} + \phi_{Disp.} + \phi_{Noise} + 2n\pi \quad (3)$$

where ϕ is an observed interferometric phase, ϕ Orbit is phase related to the orbit estimation error and will be eliminated by the accurate orbit estimation, ϕ Topo. is topographic-related phase, ϕ Disp. is displacement-related phase, ϕ Noise is phase noise, and the last term ($2n\pi$) shows Modulo 2π and n is determined in the process of "phase unwrapping".

For the differential SAR interferometry, major task is to separate the topographic phase and displacement related phase for mapping of displacement or surface deformation. The topographic phase is calculated from DEM, if available. When a DEM is not available, the topographic phase is also estimated by so-called three-pass differential SAR interferometry approach. In the three-pass differential SAR interferometry, the same SAR image is used as a master image to map the topography and the deformation with different slave images, which acquired at different times. For mapping of topography, short time interval between master and slave image acquisitions is required to neglect the deformation information. For example, tandem pair of ERS (European Remote Sensing Satellite) is often utilized for this purpose, because the time interval of ERS tandem pair is one day. In the case of JERS-1, however the shortest time interval is 44 days.

3. STUDY SITE AND DATA SELECTION

The study area is around the city of Hanoi and its surroundings, in the northern part of Vietnam. Hanoi city is located along the Red River on the Red River Delta, which is well known for the primary agricultural production area. Clouds usually cover the study area, even not in rainy season, and cloud-free optical remote sensing data set is limited even for long time period. Therefore, it is expected that radar remote sensing will provide more effective and frequent monitoring for various applications in the tropical regions. It is also rational to utilize INSAR monitoring for land subsidence in tropical urban areas.

The JERS-1 was launched on February 11, 1992 and its mission was terminated on October 12, 1998. The nominal altitude is 568 km and the orbit is sun synchronous and sub-recurrent with a repeat period of 44 days. The JERS-1 carried a L-band SAR (the wavelength = 23 cm). The off-nadir angle of SAR illumination is 35 degrees. From JERS-1 SAR archive at NASDA/EOC (the National Space Development Agency of Japan/the Earth Observation Center), the radar images were selected by considering baseline and time interval, whose characteristics are given in the Table 1.

Table 1. JERS-1/L-band SAR pairs to be used in the study.

NO.	MASTER	SLAVE	Bperp.	Bpara.	INTERVAL
1	1995/02/10	1998/09/22	423.9m	346.9m	3.5 years (approx.)
2	1995/05/09	1998/09/22	428.6m	379.7m	3.3 years(approx.)
3	1997/01/14	1997/04/12	1122.6m	787.0m	0.25 years(approx.)

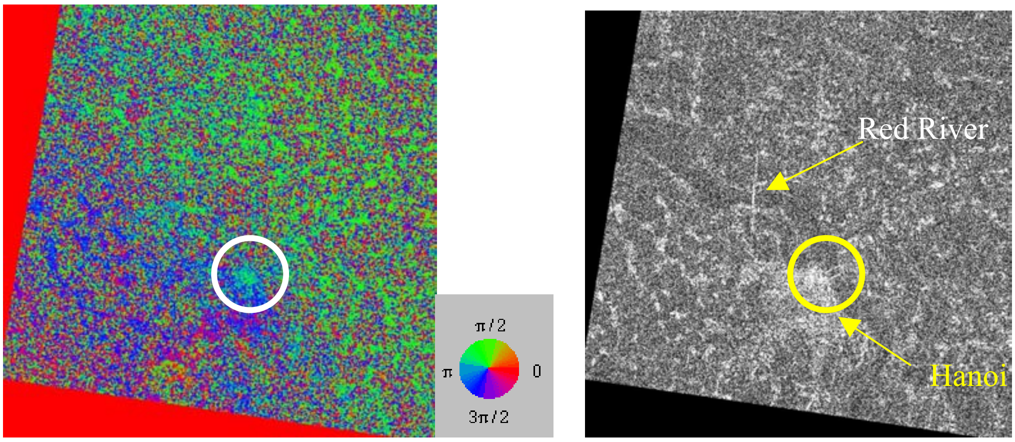
NOTE: The first column shows the pair number to be used in this study. The fourth and fifth columns show perpendicular and parallel baseline lengths, respectively. The last is the time interval in days between master and slave image acquisitions. No.3 pair was selected for checking surface flatness of Hanoi area.

The path and row of JERS-1 SAR data used is 119 and 256 respectively in descending orbit. The scene includes Hanoi city in the southwestern part of the full scene with 75 km x 75 km.

4. DATA PROCESSING AND ITS RESULTS

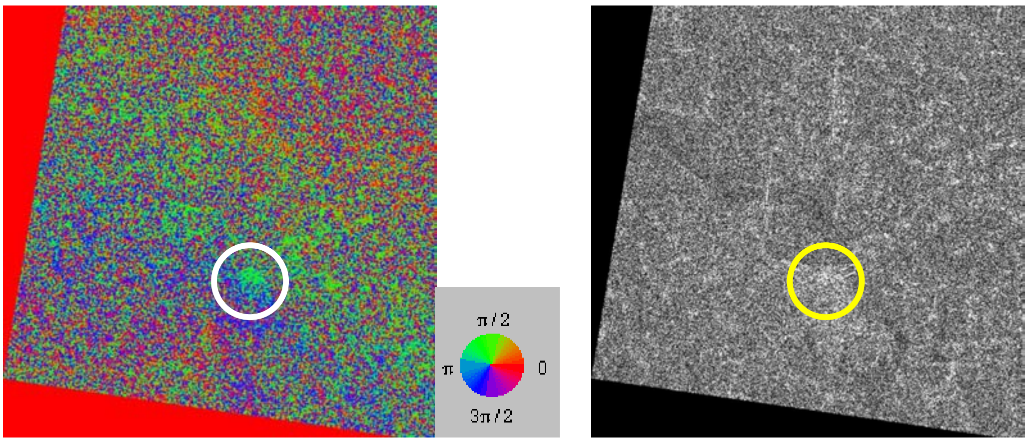
The raw signal data is processed into single look complex (SLC) image with preserving phase values, using a commercial SAR processing software. Two SLC images are co-registered with an accuracy of about 1/5 pixel. Then, initial interferogram is calculated. The initial interferometric phase includes three major phase components (except for phase noise) of orbital phase, topographic phase, and phase related to surface movements. The third phase component corresponds to surface deformation, such as surface uplift or subsidence, and disappears when no deformation exits. In general, orbital phase and topographic phase will be subtracted by accurate orbit estimation and DEM respectively for surface change detection using INSAR technique. In the case of the study, DEM data of the target region is not available at this time. Although three-pass differential INSAR approach, as described previously, is known to be usual procedure for change detection, a more simplified procedure was applied, considering the target region is situated over flat plain with low elevation, except for mountainous area in the northern part of scene. That is, we assumed that ϕ Topo. in Equation (3) will be neglected in the case of very flat plain (Sato, 2001).

Then, the interferogram derived from two scenes with a selected time interval can show deformation component after correcting orbital phase error, assuming no topographic phase in the flat plain. To reduce mis-interpretation of resulting interferograms, DEM generation was carried out to delineate hilly areas in the plain.



(a) Interferometric phase (b) Coherence

Figure 1. INSAR result of pair No.1 (1995/02/10 – 1998/09/22). The phase is running from 0-2 π via the color wheel. One cycle of phase correspond to 0-12 cm of deformation. The circle in (a) shows a possible subsided area. The coherence image provides a measure of interferogram's quality and also location information such as river, bridges, and urban areas. Brightness of coherence image is enhanced for display purpose.

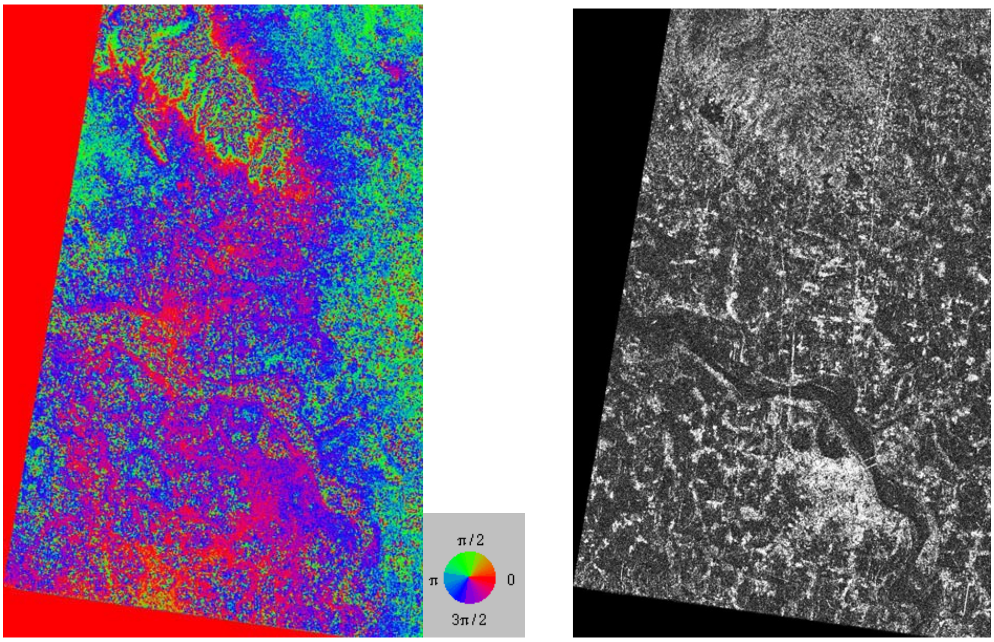


(a) Interferometric phase (b) Coherence

Figure 2. INSAR result of pair No.2 (1995/05/09 – 1998/09/22). The circle in (a) shows possible subsided area over Hanoi city. Brightness of coherence image is enhanced for display purpose.

Figure 1 and 2 cover southwestern part of a full scene, which also includes Hanoi city. Both interferometric phase of No.1 and No.2 pairs show small scale (or subtle) of deformation in the Hanoi city. Those surface changes move downward or subside, which is decided by the color change direction of those interferogram. The phase change is about one third of cycle, or 4 cm of deformation in the slant range direction. Assuming no horizontal displacement, the deformation translates to a vertical displacement of about 5 cm. Then, the estimated rate of subsidence is 1.4 cm/year between 1995 and 1998. The No.3 pair with relatively short time interval (about 3 months) does not show apparent phase change near Hanoi city (Figure 3). This means Hanoi city and its surroundings are very flat and no topographic deformation happens to be during the period. This will support the previously described assumption qualitatively. Figure 4 shows false color composite image of the study area, which acquired by ASTER/VNIR (the Advanced Spaceborne Thermal Emission and Reflection Radiometer/Visible and Near-Infrared Radiometer) instrument on September 29th, 2001. It also shows there are not hilly areas near Hanoi city from visual point of view.

Therefore, we may conclude that the above interferograms of No.1 and No.2 correspond to land subsidence with small subsidence rate, but shows severe subsidence in Hanoi city.



(a) Interferometric phase (b) Coherence

Figure 3. INSAR result of the pair No.3 (1997/01/14 – 1997/04/12).

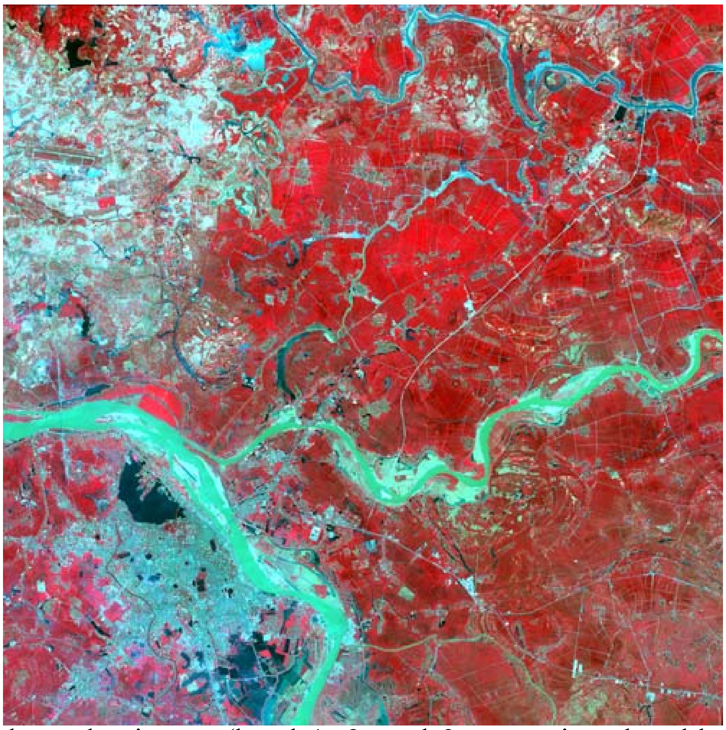


Figure 4. False color image (band 1, 2, and 3 are assigned to blue, green, and red colors, respectively) of the study area, which observed on 2001/09/29 by ASTER instrument on the Terra Satellite. Copyright: METI/NASA.

5. CONCLUSIONS

Interferograms of JERS-1/L-band SAR, which were acquired in the period between 1995 and 1998, suggest that there is a subtle subsided part in Hanoi city. The detected subsided area is located in the northern area of Hanoi city, just southern part of Tay Lake (Ho Tay). The estimated subsidence rate is approximately 1-2 cm/year in vertical direction. This preliminary result shows no large and severe subsided region in Hanoi and its surroundings, at least during the operation period of JERS-1. This estimate should be validated by available leveling data, C-band SAR data of ERS or Radarsat with higher spatial resolution and shorter wavelength, and so on.

L-band SAR interferometry provides us a powerful and convenient tool for mapping land subsidence in tropical region, where fine or cloud-free day is usually limited even not in rainy season. According to our experiences, the merit of SAR interferometry using L-band data is its higher coherency of L-band SAR data pair with relatively longer time scale. However, L-band SAR interferometry have a limitation of resolved deformation because the wavelength of L-band SAR is more than 20 cm and longer than one of C-band (about 6 cm). Thus, it should be recognized this will provide convenient tool for relatively severe subsidence over the wide areas synoptically, but is a supplementary tool for monitoring land subsidence by precise leveling survey.

At present, operational L-band SAR does not exit since 1998. The successor of L-band SAR will be launched onboard ALOS (Advanced Land Observing Satellite) satellite near future by NASDA, Japan. It is expected the L-band SAR will provide an effective tool for mapping land subsided areas in the world.

6. REFERENCES

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