PS-INSAR MEASUREMENT OF LAND SUBSIDENCE IN BANGKOK METROPOLITAN AREA

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ABSTRACT: It is well known that the metropolitan area of Bangkok, Thailand, has been subsiding during the past decades. This ground deformation has been monitored using leveling networks on annual basis since 1978. However, the employed technique is costly, time-consuming, and able to monitor only on a limited number of benchmarks. InSAR (Interferometric Synthetic Aperture Radar), which can provide sub-centimeter accuracy when time series analysis method such as PSI is employed, has the additional advantage of having a large number of observations. Therefore, it is an attractive alternative technique to such task. Permanent Scatterer InSAR (PSI) is employed in this study to determine land subsidence in Bangkok Metropolitan Area. We used 13 Radarsat-1 Single Look Complex images in Fine Beam Mode (F1N) acquired from October 2005 to February 2009. The interferograms generated by DORIS, and StaMPS were then used to perform PS analysis. Result from PSI reveals subsidence rates as large as 15 mm/year in eastern central Bangkok with respect to other areas detected as stable. Unwrapping errors may affect also our results due to the sub-optimal number of images in the time-series and also from orbital errors of Radarsat-1 which has no on-board GPS. Nevertheless, PSI successfully detects more than 300,000 pixels that can serve as monitoring points, a number that is two orders of magnitude greater than all benchmarks of the level network in Bangkok. As such the study clearly demonstrates the potential of PSI as operational tool for geodetic task like land subsidence monitoring.

1. INTRODUCTION

The city of Bangkok is located on either side of the Chao Phraya River (see figure 1) with an elevation of 0.5 to 1.5 m above mean sea level. The issue of land subsidence in Bangkok was first raised by Haley & Aldrioh (1970) and was first investigated by Brand & Paveenehana (1972) (Edward, 1976), but surface subsidence had not been determined quantitatively until early 1978 (Natalaya, 1981). Satellite interferometry has already been applied to study deformation in Bangkok. For example, Kuehn et al. (2004) and Jirathana W. (2006) applied InSAR techniques to study land subsidence in the area. The results from Kuehn et al. (2004) indicated approximate the maximum subsidence rate 3 cm/year from ERS1/2 data recorded on 20 February 1996 and 23 October 1996. Besides, Jirathana W. (2006) applied PSI technique for deformation estimate in Bangkok (16 and 10 interferograms), and there were able to provide sufficient accuracy (S.D. about 6-8 mm/year) for subsidence planning purpose. The subsidence rates were classified in 3 levels which are high (> 20 mm/year), medium (> 10 mm/year), and low (< 10 mm/year).

The basic principles of PSI consist first in detecting those scatterers that are almost not affected by
noise and estimate from their phase parameters such as deformation rates and height differences. However, the phase values are wrapped between –\( \pi \) and \( \pi \), and an appropriate technique is then employed to unwrap them to obtain the absolute phase value.

In this work, we present the preliminary results of applying PSI to 13 RADARSAT-1 images covering Bangkok Metropolitan area, Thailand. The result demonstrates the capability of the PSI method to detect and monitor even with low deformation rates such as the case of Land Subsidence. In particular, we processed the data using the Stanford Method for Persistent Scatterers (StaMPS) (Hooper et al., 2007) to analyze the data acquired from 23 October 2005 to 04 February 2009 in ascending orbit to determine line-of-sight (LOS) displacements.

2. STUDY AREA AND DATA SET

2.1 Study Area

Bangkok is in the Lower Central Plain of Thailand and is situated on flood plain and delta of the Chao Phraya River. It is facing considerable land subsidence problem, which is the result from over-extraction of groundwater for long time causing the water level decline pumping, shift of soil mass, and ruptures of underground pipes etc. The general land surface of Bangkok is relatively flat with the elevation only 0.5 to 1.50 meters above mean sea level. The study area covers a zone of about 50x50 kilometers.

2.2 Data Set

We applied 13-F1N beam mode with azimuth resolution 8.9 m and range resolution 6.0 m to this study. As by the products available, fine beam mode is the best spatial resolution available from the RADARSAT-1 system. Each original Fine beam position can either be shifted closer to or further away from Nadir by modifying timing parameters and adding 10 new positions with offset ground coverage. The resulting positions are denoted by either an N (Near) or F (Far). The swath width is 50 km to keep the downlink signal within its allocated bandwidth. Besides, the Product Generation System (PGS) was used for making Single Look Complex (SLC) product at GISTDA earth observation center. SLC products performed interpolation of the slant range coordinates, and
each image pixel is represented by complex I and Q numbers to maintain the magnitude and phase information which is useful for SAR interferometry.

Table 1: Radarsat-1 SAR data used in this study

<table>
<thead>
<tr>
<th>Date UTC</th>
<th>Beam</th>
<th>Look Angle</th>
<th>Cycle</th>
<th>Orbit</th>
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<td>151</td>
<td>52035</td>
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<td>52721</td>
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<td>186</td>
<td>64040</td>
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<td>187</td>
<td>64383</td>
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<td>F1N</td>
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<td>188</td>
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</table>

3. PERSISTENT SCATTERER INTERFEROMETRY (PSI)

The Persistent Scatterers (PS) InSAR is an advanced technique in contrast with conventional InSAR technique, which addresses to alleviate the problem of decorrelation for generating a time series of phase changes without atmospheric and DEM residual effects. This technique was developed in the late 1990s by A. Ferretti, F. Rocca, and C. Prati of the Technical University of Milan (POLIMI). In a SAR image, the complex signal reflected by a resolution element is the results of the sum of all individual returns produced by the scatterers within resolution cell.

Therefore, any change in a resolution cell between 2 acquisitions leads to a decrease of coherence (or noise increase). That is the reason why conventional InSAR cannot have good result in an area with dense vegetation. Persistent Scatterers technique detects those cells whose reflections are dominated by a single scatter. Examples of such objects are bridges, buildings, dams, water-pipelines, antennae, stable natural reflectors. Since the reflections are only due to one element it is less probable that it will be affected by changes in the objects around (temporal decorrelation) and changes in the radar looking angle (geometrical decorrelation). The main steps of the PSI technique can be summarized as 1) Formation of Differential Interferograms, 2) Selection of Stable Point Target, 3) Phase unwrapping 4) Extraction of the parameters of interest (deformation and residual heights) and removal of atmospheric artifacts.

4. RESULTS AND DISCUSSION

To perform PS analysis, we used StaMPS (Stanford Method for Persistent Scatterers) software (Hooper et al., 2007). We started with 13 single look complex (SLC) images, and we formed 12 single-look interferograms with StaMPS version 3.0 with respect to the same master on 27 July 2008. This software employs Doris for computing the interferograms but has its own strategy for
coregistration to a single master. It consists of using intermediate images for coregistering long baseline pairs. Afterward, we subtract the reference phase and phase due to height of an object using SRTM DEM. The final interferograms are shown in figure 2. The fringe pattern visible in all interferograms is due to orbital errors (the higher the fringe rate the greater the error in the satellite position).

In the StaMPS implementation of PSI, the persistent scatterer (PS) pixels are selected first from the series of interferograms we formed. The wrapped phase will be corrected for spatially-uncorrelated look angle error, and noise associated with the master image, which is present in every interferogram. We will then unwrap the phase of these PS pixels, and estimate deformation rates for the region. For more details on the inner workings, see Hooper et al. (2007).

Subsequently, we utilized StaMPS to analyze phase account with 389321 reference PS candidates identified in our study area. After phase unwrappung step and filtering spatially correlated noise, it calculates a mean velocity line-of-sight LOS value for each PS pixels from 2005 to 2009. The deformation rates obtained fall in the interval -7.72 mm/year and uplift +7.88 mm/year, relative to the mean estimated value of the scene. Finally, the result is remapped to geodetic coordinate system as shown in figure 3.

PSI produces results that are relative to a given PS or set of PS, which means the estimated velocities are not absolute but relative. For a correct interpretation, one should consider a PS that is stable and calculate the differences respect to it. Without any priori information, we considered as reference the whole area and calculated the deformation respect to the average deformation of all PS. This is shown in figure 3. Therefore, blue areas mean not absolute uplifting but uplifting respect the mean deformation value. Taking into account that no uplifting is expected, we can consider the blue areas actually stable and the rest subsiding. In this case, we obtain the center of Bangkok to be subsiding with a rate of ~ 15m/yr. In figure 3, we can also see that the estimated
deformation field is not as smooth as expected probably due to unwrapping errors, which can occur when the number of images is small (usually 20 or more are required) and when the interferogram lacks of correlation. Even more in our case, the interferograms of 10 Feb. 2008 and 29 Mar. 2008 in figure 2 show high fringe rate. This is likely to be caused by orbital errors or strong atmospheric signal.

Nevertheless, under those circumstances, phase unwrapping as implemented in StaMPS will have a high chance of being correct in areas with high density of PS. Thus, we believe the estimations are correct for the center of Bangkok where the density of detected PS was very high. However, unwrapping seems to fail in some parts of eastern area, where jumps in the deformation are seen.

Finally, we can also see some error is the geocoding (the mapping of the data to cartographic orientation), due to errors in the annotated radar time and/or heights of the PS obtained through the SRTM.

Figure 3: Mean velocity LOS 2005 -2009 (mm/yr)

5. CONCLUSIONS AND FUTURE WORK

This preliminary work demonstrates the potential of SAR time-series scenes to monitor point and pattern of subsidence phenomenon in Bangkok Metropolitan area. When the PS remains coherent within multi-temporal SAR data-set, it is possible to detect and measure millimeter variations in the line of sight distance over time. Currently, we are working on applying Small Baseline Processing method to select those interferogram combinations whose temporal baselines and geometrical distance is small to increase the coherent areas. The results will be refined by the application of a multi-temporal InSAR approach (MTI) that combines both Persistent Scatterer and Small Baseline Subset methods (StaMPS/MTI). Finally, the scope in this paper is limited to
preliminary results. In the next phase of the project, we will improve and validate the result by collecting more data and applying ancillary data such as leveling data. Additionally, a time series of TerraSAR-X images is being built and once optimum number is reached it will be used to determine annual subsidence rate.

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