URBAN DEFORMATION MONITORING IN BANGKOK METROPOLITAN (THAILAND) USING PERMANENT SCATTERER AND DIFFERENTIAL INTERFEROMETRY TECHNIQUES

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1 ABSTRACT

Extensive ground water extraction has been identified as the principle cause of land subsidence in Bangkok and its vicinity. To mitigate major damages from large subsidence magnitudes the phenomenon must be well understood in this area. Up-to-date and reliable subsidence information is indispensable to develop this understanding. Conventionally, surface leveling has served as the primary method for measuring subsidence in Bangkok. But this is costly and time consuming. Differential SAR interferometry (DInSAR) can be an alternative means to obtain measurements of the surface displacement providing better resolution and comparable accuracy while being less time consuming. However, spatial and temporal decorrelation and atmospheric signal contributions in repeat-pass SAR interferometry often hamper the accurate measurement of surface displacements in SAR interferograms. The recently developed Permanent Scatterer (PS) technique invented by POLIMI researchers [1],[2],[3], overcomes these difficulties by interpreting time-series of interferometric phases at coherent point scatterers. In this study, we apply both DInSAR and PS techniques using two time-series of 17 and 11 ERS-SAR acquisitions for two partly overlapping image frames. This study is the first attempt to apply the PS technique to derive urban displacement information in Bangkok. We investigate the feasibility and reliability of using this technique with relatively few acquisitions and in a tropical location for deformation estimation. Using a linear deformation model and network algorithm, we estimate spatially varying displacement rates for the metropolitan area. Our first PS estimation results agree well with available ground leveling measurements.

2 INTRODUCTION

Subsidence due to groundwater extraction has known to be a major problem in many mega cities around the world, for example in Shanghai, Tokyo, Mexico City, San Joaquin Valley (USA) and Bangkok, with varieties in spatial extent and severity [4]. Subsidence in Bangkok has been evidenced since 1968, however surface subsidence had not been determined quantitatively until early 1978 [5]. This study is a part of on-going doctoral research aiming to study the feasibility of combining the two techniques namely the Differential Interferometry (DInSAR) and Permanent Scatterer Interferometry (PSInSAR) techniques, to obtain reliable deformation estimates of the area of interest, Bangkok and its vicinity using relatively few acquisitions.

3 INTERFEROMETRIC STACKS

Fig.1 shows the ERS-1/2 satellite coverage over Bangkok and its surrounding provinces. In this study we present the first result obtained from the overlapping area between two ERS adjacent tracks (both in descending mode). This aims to increase number of usable interferograms that cover the same area to apply PSInSAR technique. The test area is indicated in red rectangle (Fig.1b) and covers an area of approximately 8x12 km^2. Total of 17 and 11 Single Look Complex (SLC) images of the left stack (track 247) and the right stack (track 018) were processed with the scientific permanent scatterer system developed by DLR [6]. The area located southeast of Bangkok was selected as the initial test area due to two reasons, firstly, this area is located in the overlapping area of the two radar scenes and secondly, the relatively large subsidence rate occurs in this area (maximum mean subsidence rate about 3 cm/year).

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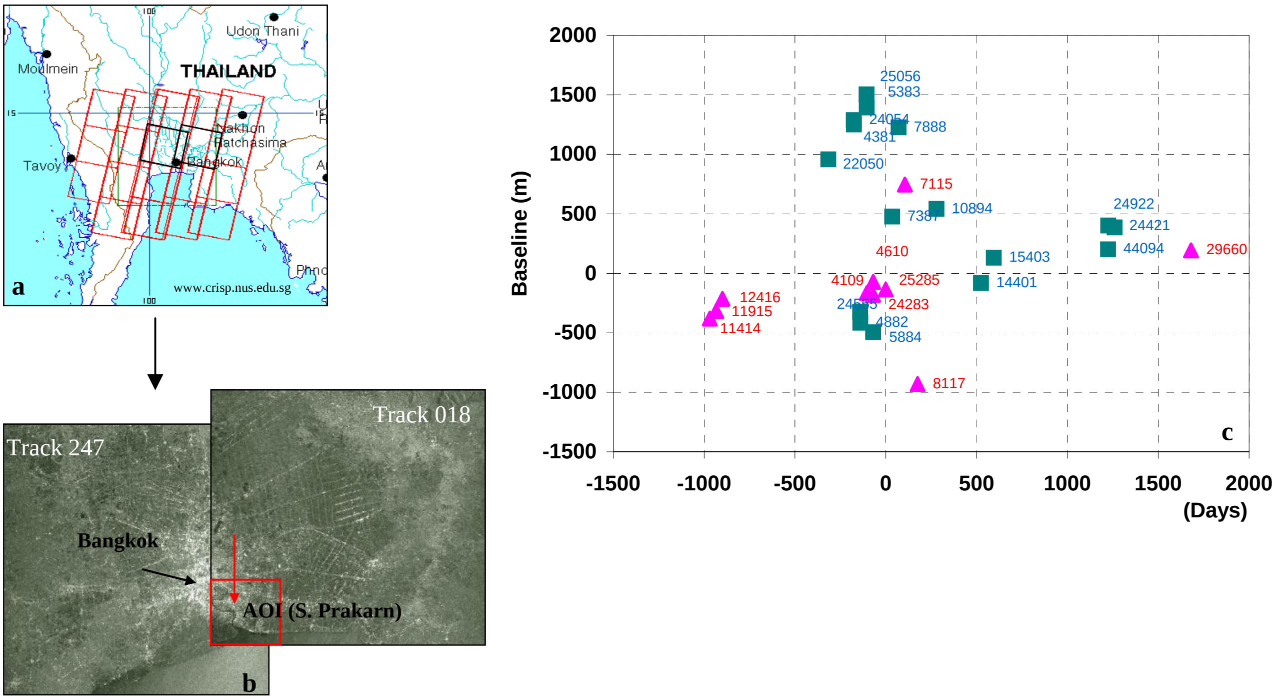

Fig.1 (a) Two scenes of ERS coverage (black squares) over Bangkok and its surroundings obtained for PSInSAR (b) Shows the Area of Interest (AOI) located southeast of Bangkok as the initial test site used for this study. (c) Shows temporal-spatial baseline distribution of the two interferometric stacks (magenta triangle: left stack, green square: right stack).

4 GENERATION OF DIFFERENTIAL INTERFEROGRAMS AND PERMANENT SCATTERER MAP

4.1 Differential Interferograms Generation

The phase of an interferogram at particular point P can be expressed as

$$\phi_p = Wrap\left(\phi_{TOPO} + \phi_{DEFO} + \phi_{ATM} + \phi_{ORBIT} + \phi_{NOISE}\right) \tag{1}$$

Eq.1 shows that phase of an interferogram is the wrapped phase and it is the contribution of different phase components namely changes in elevation ϕ_{TOPO}, in deformation rate ϕ_{DEFO}, atmospheric contribution ϕ_{ATM}, orbit error ϕ_{ORBIT} and noise ϕ_{NOISE}. The differential interferograms are then generated using a reference DEM from SRTM mission, and can be expressed as

$$\phi_p = Wrap\left(\phi_{DEMerror} + \phi_{DEFO} + \phi_{ATM} + \phi_{ORBIT} + \phi_{NOISE}\right) \tag{2}$$

Topography of Bangkok area is extremely flat with elevation ranges from 0.5 to 1.5 above mean sea level (MSL) [7]. Therefore, the topographic phase contribution in this case is not so significant. To succeed with the classical repeat-pass interferometry technique, the coherent conditions should be maintained. Major sources of decorrelations are 1) phase gradient and 2) temporal variation. Decorrelation due to phase gradient depends on length of spatial baseline, steepness of the topography and the gradient of deformation rate in the area [8]. If the phase gradient is too large, decorrelation occurs and the useful signal cannot be detected. Temporal decorrelation occurs when the returned signal from the unstable scatterers inside a resolution cell becomes significant compared to the signal from the stable scatterers. Often that temporal decorrelation prevents the successful applicability of long-term repeat-pass interferometry in many parts of the world.

4.2 Generation of Permanent Scatterer Map

Permanent scatterer (PS) defines as the scatterer that exhibit coherently over long time intervals [1],[3]. It has been demonstrated by group of researchers from POLIMI that at these PS pixels, one can achieve millimetric ground deformation detection, if the atmospheric phase screen is estimated and removed [1]. However, in our study, we used the implementation developed at DLR [9] where the atmospheric signal is treated stochastically and is not estimated.

At this step, we would like to identify the pixels in series of radar images that possess PS characteristic and then later to estimate deformation rate from their phase difference time-series. To obtain the PS map, first the amplitude of all SLC images are formed and calibrated. Then applying the amplitude dispersion index (D_A) [3] in Eq.3, we identify PS candidates for two stacks of radar images.

$$D_A = \frac{\sigma_A}{M_A} \qquad (3)$$

According to Eq.2, because the phase contribution due to orbit error was preliminarily corrected and the atmospheric delay is assumed to be correlated for PS located closely to each other, thus the phase difference between nearby PS is expected to be composed of little noise and caused by differences in subsidence and DEM error.

5 NETWORK ALGORITHM

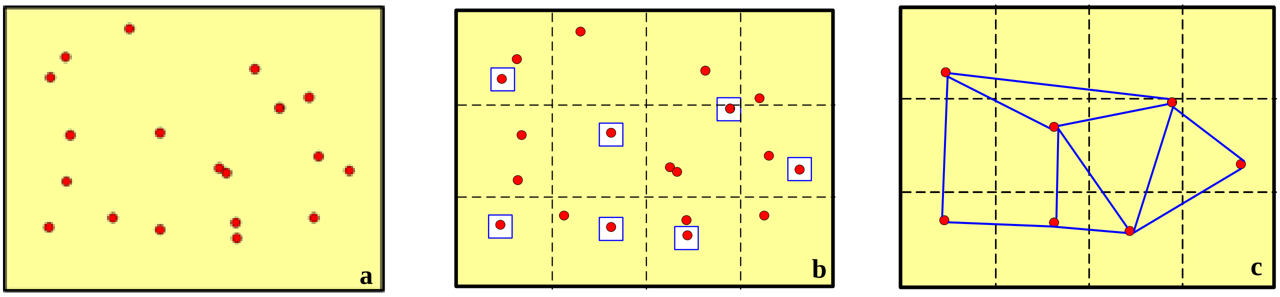

Fig.2 Concept of network algorithm

In this step, we would like to obtain a set of PS pixels whose phase was induced mainly by elevation and (linear) deformation, and are evenly distributed in the area of interest. Fig.2a shows the possible PS pixels on the interferograms. A few hundreds meter grid size is placed on the interferogram and the pixel with smallest ratio between amplitude standard deviation and mean amplitude in each grid cell is selected (pixels surrounded by blue square in Fig.2b). Between the selected points, the DEM error, deformation rate (subsidence), and a bias are estimated. The least square adjustment is then carried out to obtain the value of these parameters at the points. Test statistics are also applied to remove points and arcs that are not consistent until the stable solution is obtained. Once the reference network is estimated, the pixels that are not in the reference network are estimated with respect to the established reference network (Fig.2c). The more detailed explanation of network algorithm can be found in [9]. To derive spatial deformation pattern of the test area, we calculate semi-variogram from deformation estimates at PS points, fit a model to it and then apply Kriging interpolation.

6 RESULTS AND DISCUSSIONS

6.1 Differential Interferograms (southeast of Bangkok)

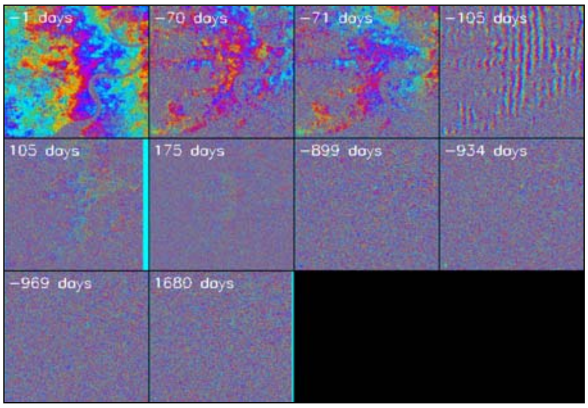

Fig.4. Sample of differential interferograms obtained from the right stack ordered by temporal baseline.

Fig.4 shows that the interferogram of Bangkok is noisy. Coherent condition can be preserved only when the temporal baseline does not exceed 70 days. Most of the case, the short temporal baseline condition, when coherence can be preserved, is not suitable for deformation signal detection unless there exist high deformation rates in the area. Due to the large amount of temporal decorrelation, the classical DInSAR is considered not so applicable for subsidence detection in Bangkok.

6.2 Spatial Subsidence Pattern

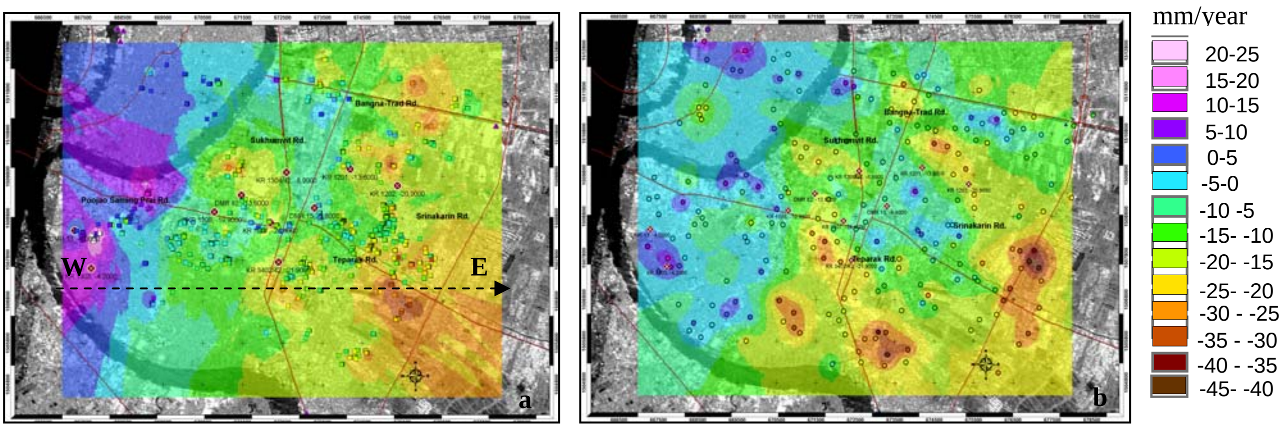

Fig.5. Derived spatial subsidence pattern from two interferometric stacks using PSInSAR technique. The left stack (a) contains 16 IFGMs, the W-E comparison profile is also indicated in black, the right stack (b) contains 10 IFGMs.

In general, the two independently derived subsidence patterns obtained from PSInSAR processing of different interferometric stacks show reasonable agreement with each other. Similar in the two patterns, the uplift area is found on the upper left part, while subsidence rate is increasing as we proceed to the lower right part of the area. There are some critical points where the maximum subsidence rate is beyond 40 mm/year situated near to the main road. At those points (indicated by brown color), however, the two patterns do not correspond. This might be because no PS were found at that location in the left stack and thus the deformation rate could not be estimated. The distribution of PS in the test area of left and right stack is also different. Applying Kriging interpolation, one have to keep in mind that more weight has been given to the nearer points, than the further points and therefore, the evenly distributed of PS in the area could give less biased interpolation result. Note that, the variogram calculated here, is assumed to be isotropic. If additional information e.g. tectonic fault is available, the more complicate multi-directional variograms can be computed to improve the interpolation result.

6.3 Comparison with Ground Leveling

To validate the result of deformation estimates from PSInSAR technique, first the LOS deformation is converted to vertical deformation rate and compared point-wise at the leveling benchmarks distributed in the test area. There are 10 benchmarks (indicated by red circle in Fig.5a) and only the leveling information from the benchmark at depth not more than 1 meter is used. The temporal baseline is also scaled to be the same for both leveling data and PS estimates, and not all the benchmarks possess the same quality of measurements (standard deviation of leveling measurements vary from benchmark to benchmark, depending on the number of leveling measurements).

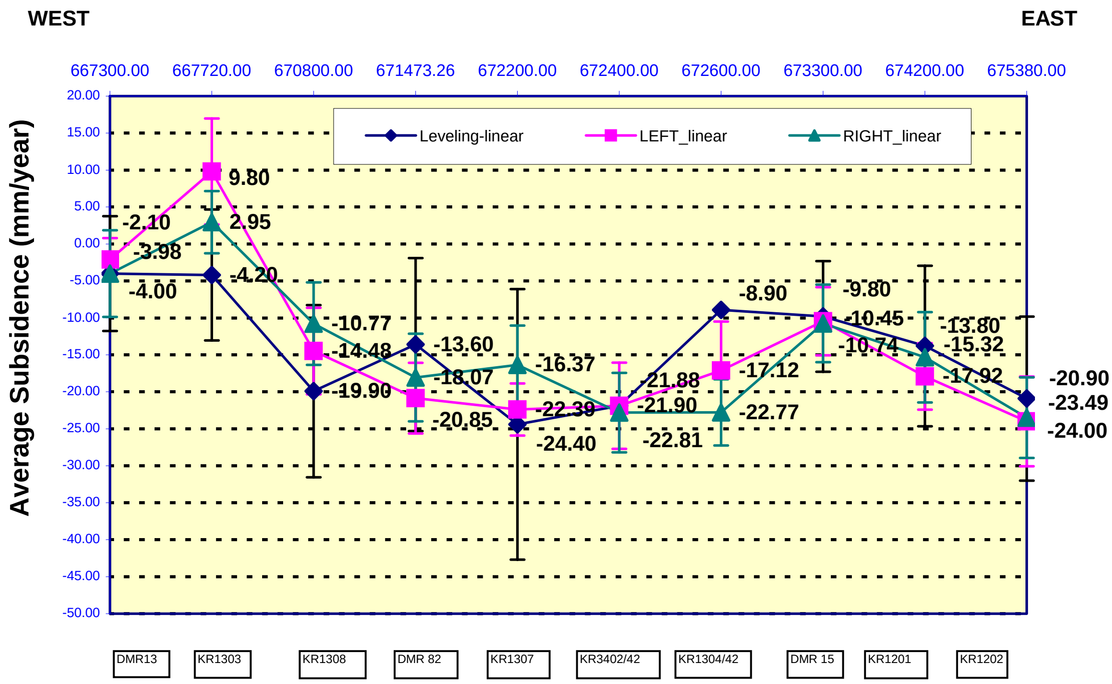

Fig.6. Subsidence measurement comparison between ground leveling (blue line) and PS estimation (magenta: left stack, green: right stack), the error bar of ± 1 standard deviation is also indicated.

Comparison result from West to East direction demonstrates reasonable agreement between leveling data and PS deformation estimates. The differences found between these two measurements can be also explained as we tried to apply the PS technique using few interferograms over a high atmospheric contribution location where high subsidence rate occur like Bangkok. Hence, it is not likely that the PS whose phase is mainly induced by elevation and linear deformation are always to be found. Despite the fact that the number of interferograms used in the estimation is limited, the PS estimation result provides acceptable and sufficient accuracy with minimum discrepancy at benchmark DMR13 0.02 mm/year and maximum discrepancy at benchmark KR1303 of 13 mm/year.

Detail analysis at reliable benchmark by comparing leveling history at the same time frame as our image stacks reveals that the difference could rise from non-linear deformation of that area, which is not taken into account at the moment for PS estimation.

There still have also difference in deformation estimates resulted from the two interferometric stacks, this might be due to the quality of all selected PS for network construction is not guaranteed. Some PS might still contain high level of phase noise.

7 CONCLUSIONS AND FUTURE WORK

Applying PSInSAR technique for deformation estimation in Bangkok and its surroundings with the limited number of interferograms (16 and 10 inteferograms) can provide sufficient accuracy (S.D. about 6-8 mm/year) for subsidence planning purpose. However, the accuracy might be able to be improved by doing quality measure of each PS selected for reference network construction. The combination of estimates from two stacks would be possible provided that criteria of combination are well defined and understood e.g. to combine the interpolated result where there is no PS

presented in that particular area in one stack with the other. From the application point of view, at the most critical point found in the test area (with maximum linear deformation rate of 24.4 mm/year), one can predict that continuing with this linear deformation rate, this area will be at 0 meter MSL in the year 2075.
Improving the estimation results by means of PSInSAR is foreseen to be the next step of work. The signal-to-clutter ratio could be exploited to predict how good a selected pixel exhibit as PS and can assist in PS selection process. Because the amplitude dispersion index based on a small number of images might not be the optimal criterion for PS selection. Once the best estimation obtained, attempt will also be made to study the feasibility to combine estimations from these two stacks in a reasonable way.

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