MEASURING LAND SUBSIDENCE IN HO CHI MINH CITY BY MEANS OF RADAR INTERFEROMETRY TECHNIQUES

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ABSTRACT

The water table in the area of Ho Chi Minh City (HCMC) is sinking at the same time as huge structures are being build throughout the area, causing deformations of the local ground topology. Surface deformations are most apparent around pumping stations.

Although many traditional methods such as precise levelling and GPS techniques can provide subsidence information, they are costly and time consuming. This paper demonstrates the ability of radar interferometry to detect the deformations in HCMC. The goal is to employ this powerful new technique to measure the land subsidence phenomenon in HCMC using ERS SAR SLC scenes acquired over HCMC in descending orbit from 5 February 1996 to 26 November 2002.

Keywords: Land subsidence; Permanent Scatterer InSAR

1. INTRODUCTION

The water table in the area of Ho Chi Minh City (HCMC) is sinking at the same time as huge structures are being built throughout the area, causing ground deformations and subsidence. Surface deformations are most apparent around pumping stations because of exploiting underground-water. Up to 600,000 cubic meters of groundwater are being pumped from underneath HCMC daily [NRED, 2005], a third of which was replaced naturally every year. Moreover, in recent years, many places have had ominous subsidence signs. Hence, it is important to be able to measure the subsidence values as a support to a better management of groundwater, in order to minimize future subsidence.

Although many traditional methods such as precise levelling and GPS techniques can provide subsidence information, they are costly and time-consuming. This study demonstrates the ability of radar interferometry to detect the deformations in HCMC. The goal is to employ this powerful new technique to measure the land subsidence phenomenon in HCMC using ERS SAR SLC scenes acquired over HCMC in descending orbit from 5 February 1996 to 26 November 2002.

2. AREA STUDY

The study area is in Ho Chi Minh City, which is a mega city with more than 6 million people, the biggest industrial and commercial center in Vietnam. Ho Chi Minh City can be classified into three regions based on urbanization: Urban inner core region - this region has completed urbanization; Urban fringe region - this region is quickly undergoing urbanization; Suburban region - this region has mainly agriculture land. The study area is composed of the urban inner core region and a part of the urban fringe region of Ho Chi Minh. It is located at $10^0 50'$ northern latitude, $106^0 40'$ eastern longitude, and lies ~ 55 km inland at 2 m average altitude. The topographic variation is approximately 15 m in the study area. The urbanized area is approximately 15 x 15 km^2 and HCMC has a population of ~4.96 million people in 1998, ~5.17 million people in 2000 and ~6.24 million people in 2005 [Luong T.T.T, 2008].

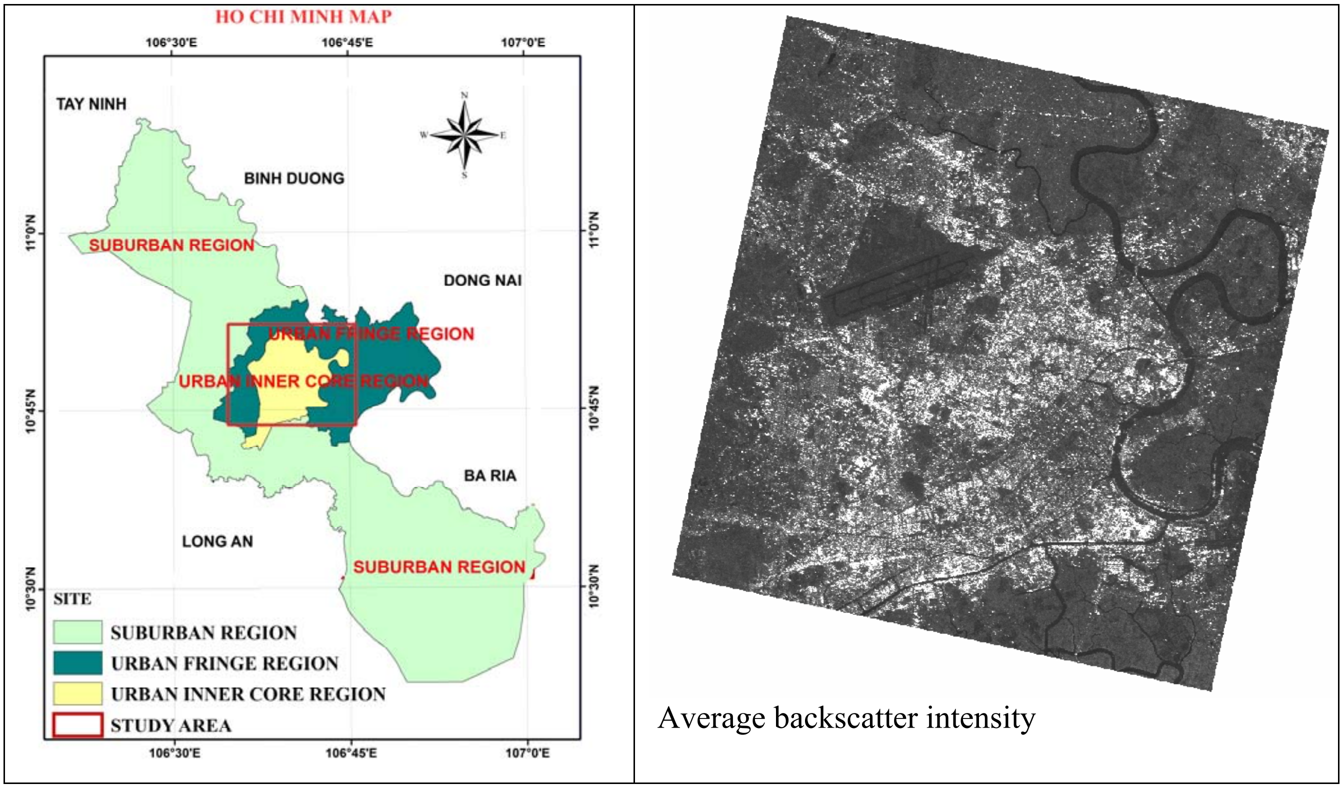

Figure 1: Study Area, Ho Chi Minh City, Vietnam

SAR images used for this study are ERS-1 and ERS-2, which have information given in table 1.

No	Sensor	Date	Orbit
1	ERS-1	05-Feb-1996	23839
2	ERS-2	06-Feb-1996	4166
3	ERS-1	15-Apr-1996	24841
4	ERS-2	16-Apr-1996	5168
5	ERS-1	20-May-1996	25342
6	ERS-2	21-May-1996	5669
7	ERS-2	03-Sep-1996	7172
8	ERS-2	28-Oct-1997	13184
9	ERS-2	17-Nov-1998	18695
10	ERS-2	11-Jan-2000	24707
11	ERS-2	15-Feb-2000	25208
12	ERS-2	17-Oct-2000	28715
13	ERS-2	26-Nov-2002	39737

Table 1 **:** SAR satellite data used in this study

We choose SRTM DEM data for our processing. In Ho Chi Minh City, this DEM at 90-m posting (3 arc second) is available for download (ftp://e0srp01u.ecs.nasa.gov).

3. PERMANENT SCATTERER INSAR (PSInSAR)

Radar interferometry or Interferometric Synthetic Aperture Radar (InSAR) is a technique first suggested in the early 1970s [Graham, 1974]. The technique produces an 'interferogram' from the phase difference between two SAR images acquired over the same region.

Permanent scatterer InSAR is an extension of the conventional InSAR, which offers a practical way to reduce the main errors in conventional methods: atmospheric delay, temporal and spatial decorrelation. This technique was developed in the late 1990s by A. Ferretti, F. Rocca, and C. Prati of the Politecnico di Milano (POLIMI). The main characteristics of this method are that it utilizes a single master in a stack of differential interferograms, and that only time-coherent pixels, i.e "Permanent Scatterers" (PS) are considered [Ferretti, et al, 2000, 2001], [Kampes, B. M., 2005]. These pixels are also referred to as point targets [Werner, et al, 2003], or persistent scatterers [Hooper, et al. , 2007].

PS typically corresponds to objects on man-made structures such as buildings, bridges, dams, water-pipelines, antennae, as well as to stable natural reflectors. Indeed, the PS comprises a sort of "natural geodetic network" for accurately monitoring surface deformation phenomena, as well as the stability of individual structures [Ferretti, et al, 2000, 2007], [Rocca, 2008].

Hooper, et al., 2007 have developed a good PS processor – StaMPS and fortunately this processor is free for scientific research (www.hi.is/~ahooper/stamps). Therefore, in this study, we follow Hooper's approach and use StaMPS to detect the land subsidence in Ho Chi Minh City.

There are four parts to StaMPS, each discussed in detail can be found in [Hooper, et al. , 2007]:

1. Interferogram Formation : There are aspects of interferogram formation for PS processing that differ from conventional interferogram formation. First of all, we choose as the "master", the image that minimizes the sum decorrelation, i.e., maximizes the sum correlation, of all the interferograms. Secondly, for coregistration, the function that maps the "master" image to each other image is estimated by weighted least-squares inversion. Once the mapping functions are estimated, we resample each image to the "master" coordinate system, using a 12

point raised cosine interpolation kernel. Then we form a raw interferogram by differencing the phase of each image to the phase of the "master'. Finally, we remove the geometric phase terms which are due to the "master" and 'slave' images being acquired from different points in space.

2. Phase Stability Estimation : We make an initial selection of candidate pixels based on analysis of amplitude, and then use phase analysis to estimate the phase stability of these pixels in an iterative process.

3. PS Selection : We estimate for each pixel the probability if it is a PS pixel based on a combination of amplitude and estimated phase stability. We then use the estimated probabilities to select PS pixels, rejecting those that appear to be persistent only in certain interferograms and those that appear to be dominated by scatterers in adjacent PS pixels.

4. Displacement Estimation : Once selected, we isolate the signal due to deformation in the PS pixels. This involves "unwrapping" the phase values and subtracting estimates of various nuisance terms.

4. RESULTS

4.1. Choice of 'Master' Image

As A. Hooper (2007), we choose as a master, the image that minimizes the sum decorrelation, i.e., maximizes the sum correlation, of all the interferograms. The correlation is a product of four terms, dependent on time interval (T), perpendicular baseline ($B_\perp$), difference in Doppler centroid (F_{DC}) and thermal noise [*Zebker and Villasenor*, 1992]. A simple model for the total correlation, ρ_{total}, is

$$\rho_{total} = \rho_{temporal}\rho_{spatial}\rho_{doppler}\rho_{thermal}$$
$$\approx \left[1 - f\left(\frac{T}{T^c}\right)\right]\left[1 - f\left(\frac{B_\perp}{B_\perp^c}\right)\right]\left[1 - f\left(\frac{F_{DC}}{F_{DC}^c}\right)\right]\rho_{thermal},$$

where

$$f(x) = \begin{cases} x, \text{for } x \leq 1 \\ 1, \text{for } x > 1 \end{cases},$$

N : number of interferograms

ρ denotes correlation and superscript c denotes the critical parameter values, i.e., the value beyond which an interferogram exhibits almost complete decorrelation. The critical values are dependent on the data set, but typical values for data acquired by the ERS satellites in arid regions are T^c = 5 years, $B_{\perp}^{c}$ = 1100 m and F_{DC}^{c} = 1380 Hz. We choose the 'master' that maximizes $\sum_{i=1}^{N} p_{total}$, assuming a constant value for $\rho_{thermal}$.

We calculate the sum ρ_{total} of each "master" and get the result as figure 2.

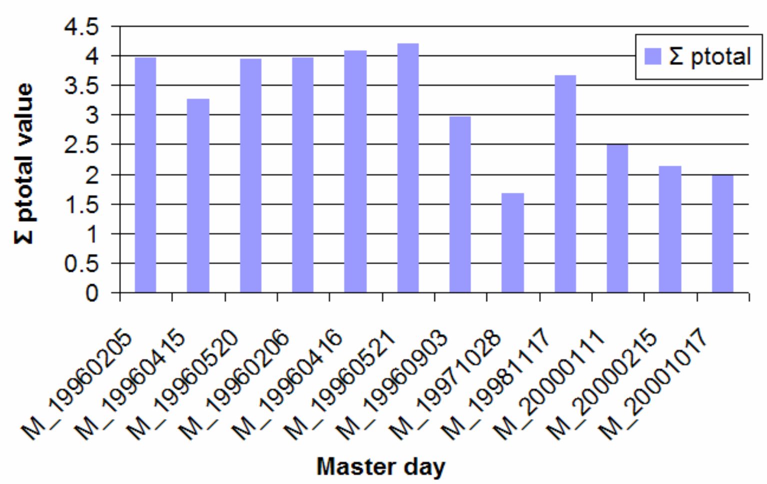

Figure 2: ρ_{total} value

Therefore, we choose SAR ERS-2, acquired in 21 May 1996, the highest ρ_{total} value, as the "master". Figure 3 shows baseline distribution and doppler centroid frequency with respect to this master.

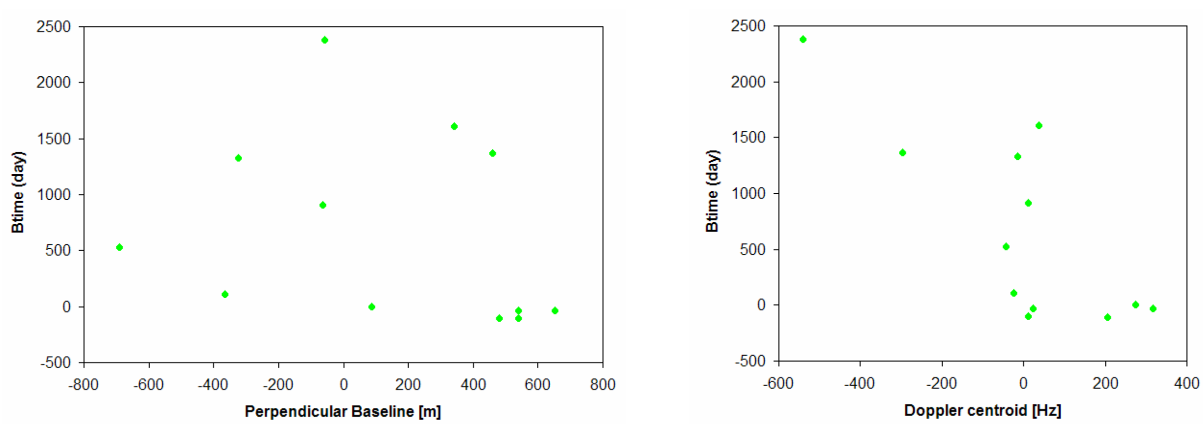

Figure 3: Baseline distribution and doppler centroid frequency for HCMC data set

4.2. Experimental results

First of all, we form 12 single-look interferograms from 13 scenes, all with respect to one ‘super master’ image, using DORIS [Hanssen, 2001]. Then, we subtract the reference phase and SRTM DEM simulated phase as figure 4.

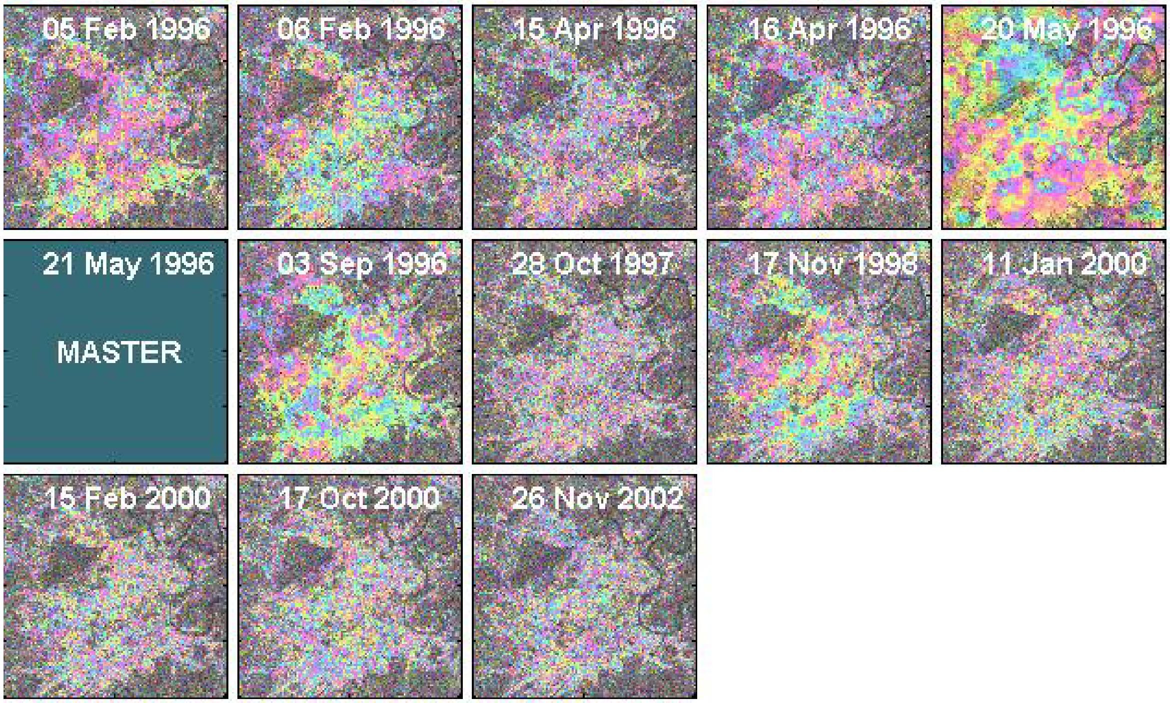

Figure 4: Differential Interferograms

Then, we apply StaMPS to analyze phase history. 20019 stable-phase pixels, PS candidates, are identified in our study area. Ultimately, after unwrapping phase and filtering spatially correlated noise, it calculates a mean velocity light-of-sight LOS value for each PS pixels from 1996 to 2002. These velocity values of PS pixels are given relative to PS pixels in the northeast. The result is remapped from the SAR coordinate system to cartographic orientation and projection, UTM, zone 48N, WGS84 ellipsoid as figure 5.

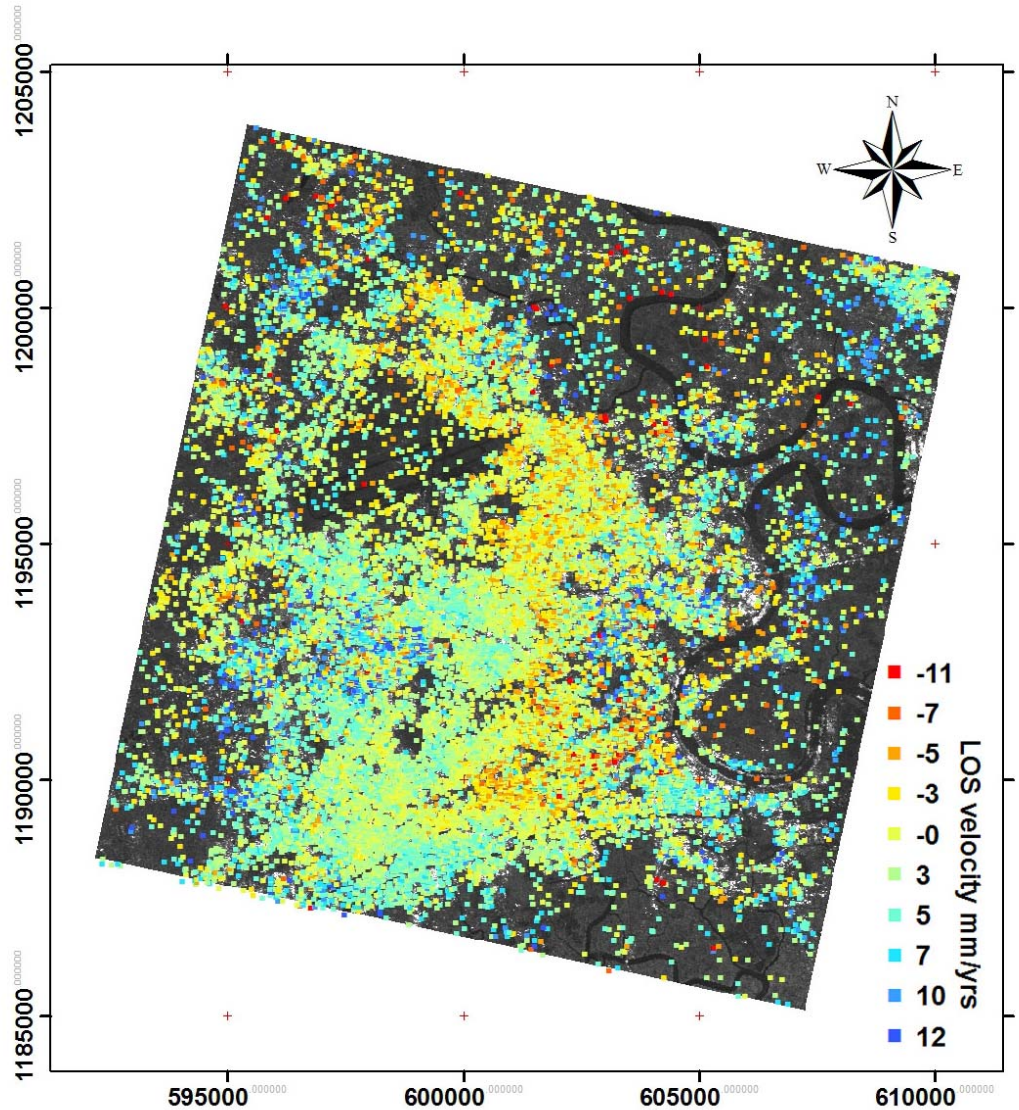

Figure 5: Mean velocity LOS 1996 -2002 (mm/yrs)

The preliminary result shows a mean velocity light-of-sight value for each PS pixels from 1996 to 2002 in Ho Chi Minh City by means of PSInSAR technique. The deformation rates obtained fall in the interval -11mm/yr and +12 mm/yr. As urbanization and population increase, more underground-water is exploited and more huge structures are built.

5. CONCLUSIONS

In this paper, we have shown the capability of using radar interferometry techniques to map land subsidence phenomenon in Ho Chi Minh City. The PSInSAR technique makes it possible to study the extent and pattern of land subsidence phenomenon more efficiently than any other method available today. When the PS remains coherent within a multi-temporal radar data-set, it is possible to detect and measure millimeter variations in the light of sight distance over time. Therefore, in future, more data will be collected and ancillary data will be applied to get the best result and validation.

This study indicates that progressing urbanization and a rising population, cause more exploitation of underground-water and more large structures to be built. This is effecting HCMC surface causing significant ground deformation.

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REFERENCES

Graham, L.C., (1974), Synthetic interferometer radar for topographic mapping, Proc. IEEE, 62, 763-768.

Rocca, F. (2008), Lecture note of Radar Interferometry, March 2008, Hanoi.

Hanssen, R. F. (2001), Radar Interferometry Data Interpretation and Error Analysis, 328 pp., Springer, New York.

Ferretti A., Andrea Monti-Guarnieri, Claudio Prati, Fabio Rocca, Didier Massonnet, InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation, European Space Agency (ESA), TM-19, February 2007.

Hooper, A., P. Segall, and H. Zebker (2007), Persistent scatterer interferometric synthetic aperture radar for crustal deformation analysis, with application to Volcáno Alcedo, Galápagos, Journal of Geophysical Research, Vol. 112, B07407, doi:10.1029/2006JB004763.

Ferretti, A., C. Prati, and F. Rocca (2000), Nonlinear subsidence rate estimation using permanent scatterers in differential SAR interferometry, IEEE Trans. Geosci. Remote Sens., 38(5), 2202–2212.

Ferretti, A., C. Prati, and F. Rocca (2001), Permanent scatterers in SAR interferometry, IEEE Trans. Geosci. Remote Sens., 39(1), 8 –20.

Werner, C., U. Wegmuller, T. Strozzi, and A. Wiesmann (2003), Interferometric point target analysis for deformation mapping, paper presented at International Geoscience and Remote Sensing Symposium, Geosci. And Remote Sens. Soc., Toulouse, France.

Kampes, B. M. (2005), Displacement parameter estimation using permanent scatterer interferometry, Ph.D. thesis, Delft University of Technology, Delft, Netherlands.

Zebker, H. A., and J. Villasenor, Decorrelation in Interferometric radar echoes, IEEE Trans. Geosci. Remote Sens., *30*(5), 950 . 9, 1992.

Ho Chi Minh City Natural Resources and Environment Department (NRED), internal report 2005, (Vietnamese).

Luong T. T. T, (2008), Managing and using urban area in Ho Chi Minh city, 301 pp, Vietnam National University press, (Vietnamese).