Monitoring of urban subsidence with Cosmo Sky-med Data by the PSI technique in Central Shanghai

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KEY WORDS: urban land subsidence, Cosmo Sky-med (CSK), high resolution, Permanent Scatterer Interferometry (PSI).

ABSTRACT: Large-scale constructions during the rapid development of city aggravate the local land subsidence to a certain degree, which affects the important urban infrastructures maintaining the basic function of the city, e.g., high buildings, rail transport, viaducts. In order to mitigate and reduce this effect, a scientific, efficient and comprehensive monitoring technology is needed. With the launch of new high-resolution radar satellite with short revisit time and high spatial resolution, high resolution Permanent Scatterer Interferometry (PSI) technique offers a prompt and accurate method for monitoring of urban infrastructures deformation. In this paper we present the PSI analysis with Cosmo Sky-med (CSK) data for urban subsidence mapping in central city of Shanghai in China. Totally 30 scenes strip mode SAR images have been collected from March 2008 to May 2010 to perform the PSI analysis. Comparison between PSI result of CSK and ENVISAT can demonstrate the capability of CSK data for urban subsidence monitoring for its advantages of dense PS sampling and high temporal frequency.

1. INTRODUCTION

With the rapid development of the city in recent years, city project constructions aggravate urban subsidence in certain level, which are more prominent reflected in the economic development city such as Bejing, Shanghai, and Tianjin city (Xu et al., 2011). Differential synthetic aperture radar interferometry (D-InSAR) technology is a common technique for the extraction of ground subsidence information (Bamler & Hartl, 1998). Specifically, time series D-InSAR techniques (Ferretti e al., 2001; Berardino et al., 2002; Mora et al., 2003; Hooper et al., 2004; Werner et al., 2003; Ferretti et al., 2011), represented by the Permanent Scatterer Interferometry technique (PSI), have been proposed to resolve the problem of loss coherence of temporal and spatial and atmospheric retardation, which affect the conventional D-InSAR technique. Ongoing medium resolution SAR system, i.e. ERS, ENVISAT and RADASAT are supposed to be one of the major applications of the sensor. However, due to its wide coverage and cell size effect, the medium resolution PSI technique is more suitable for regional investigation [9-10](Tomas et al., 2005; Bell et al., 2008). For well understand the better resolution for deformation mapping of individual infrastructure in urban, the medium resolution PSI technique is virtually powerless.

New type of radar satellite such as Cosmo Sky-med (CSK) carrying X-band SAR system provides a relative high resolution data with different imaging mode and incidence angle. The high spatial resolution and short repeat interval data will be more suitable to PSI analysis, since more coherent target (PSs) could be identified in high resolution data even in case of long time intervals (Adam et al., 2008). Thus, with CSK data it is expected that deformation signals of urban infrastructures such as high buildings can be detected in detail by PSI analysis.

In this work we present the result of urban subsidence mapping in the central city of Shanghai with CSK data by PSI processing and comparison of its properties to ENVISAT data.

2. STUDY AREA AND DATA

The area selected for this work is in the central of Shanghai city, located in the Yangtze River Basin, where has been suffering serious subsidence since long term groundwater pumping. However, in the recent years, large-scale city constructions during the rapid development of the central of Shanghai city aggravate the local land subsidence, which has become an important factor affecting land subsidence in Shanghai central. Figure 1 shows the location of the study area.

For our investigation, we used a significant series of CSK repeat observations in fine-resolution single polarization stripmap mode, with an incidence angle of 40◦ at HH polarization. From May 2008 to March 2010, 30 scenes were acquired over our area of interest. Table 1 reports the acquisition data related images.The comparable ENVISAT data result is the average subsidence rate for the year 2009, which is within the monitoring period of CSK data.

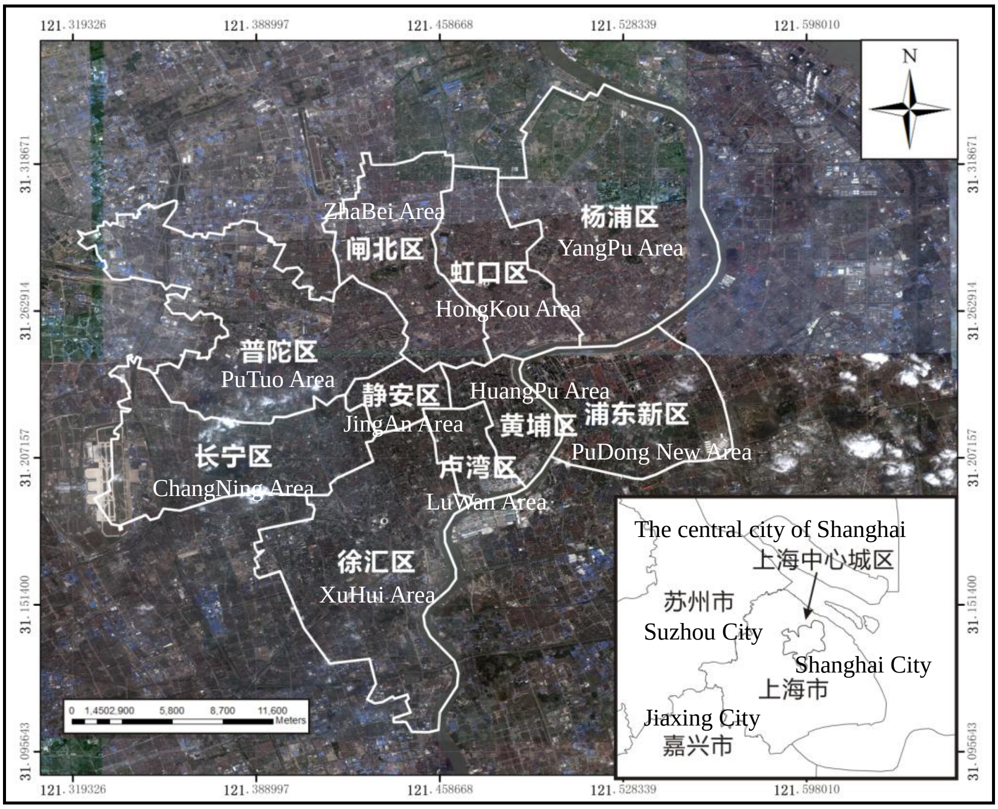


Figure 1 Location of the study area

Table 1 CSK acquisition dates

ID	Date	ID	Date	ID	Date
1	20080518	11	20090521	21	20091105
2	20080816	12	20090606	22	20091121
3	20081126	13	20090708	23	20091207
4	20081212	14	20090716	24	20091223
5	20081220	15	20090825	25	20091231
6	20090105	16	20090910	26	20100201
7	20090113	17	20090926	27	20100217
8	20090310	18	20091004	28	20100313
9	20090326	19	20091020	29	20100321
10	20090411	20	20091028	30	20100329

3. PSI PROCESSING

1.1. Multi-reference Stack Combination

In order to increase the number of interferograms for improving the accuracy of the building elevation estimate, we combine those images with a small temporal baseline to generate differential interferometric phase. The usage of multiple small temporal baseline combination allows the redundancy of interferograms and enables a better estimation of the building elevation. In this paper pairs with relative temporal baseline within 60 days are selected, which ensure elevation signals are dominant in interferometric phase. After the elevation signals are estimated, the deformation signals are estimated using Single-reference stack Combination.

1.2. Phase Unwrapping of Iterative Combination of Short and Long Baseline

Phase unwrapping in PSI analysis is the 2-D frequency estimation of displacement velocity and height error between neighboring PSs, which is usually performed in time domain by applying the 2-D periodogram. In this paper, we utilized two steps to this purpose. The first step is to apply the 1-D periodogram to estimate the height, and then the second step is to apply the 1-D periodogram to estimate the displacement velocity. Due to the high phase gradient between the high-rise buildings and the background easily which results in phase unwrapping errors, we apply an iterative combination of short and long baseline phase unwrapping method. Initially, unwrapping may only be successful for pairs with relatively short baselines. Based on these, a height correction can be estimated. Using the improved point heights, it is then typically also possible to unwrap the point interferometric phases of pairs with longer baselines. This methodology is better applicable in the case of the high phase gradient between the high-rise buildings and the background.

4. PSI RESULTS AND DISCUSIONS

The 30 scenes CSK data have been combined to generate 83 baseline pairs to estimate the height and 29 baseline pairs to estimate the displacement velocity. An average subsidence velocity map with an extent of 24×19 km2 has been generated from two data sets by PSI processing. Figure 2 and Figure 3 respectively indicate the results. From the results, we can found that subsidence center mainly concentrated in the vicinity of the Hongkou Football Stadium, the maximum subsidence rate is up to 40mm/yea. It’s worth noting that the large regional land subsidence center has been divided into discrete isolated settlement distribution center, which fully reflects that the large-scale construction projects and other factors leading to the subsidence characteristics of "small funnel".

Comparison between both datasets shows the very similarity on the space changes of the subsidence especially in subsidence areas A, B, C, and D, i.e. the maximum subsidence areas are found in the same places and with similar rates. Compared to the ENVISAT result, the number of PSs in CSK result increases dramatically from typically 300 per km^2 to more than 45,00 per km^2, i.e. to several tens per building, allowing the mapping of the 3-D structure of the city and its deformations. In addition to this, as shown in box E and F, some deformation signals respectively caused by subway excavation or city building load that were hardly identifiable in the ENVISAT results due to the rough resolution are clearly seen in CSK results.

As is shown in figure 4, correlation coefficient of two datasets reached 0.68 above in subsidence areas A, B, C, D, and RMSE (The Root Mean Square Error) difference between the two datasets is at 3.5mm/year, which indicates the subsidence rate of both datasets is consistent and similar. However, from the correlation coefficient results, we can found the main difference between the two datasets is reflected in the difference between the maximum subsidence rates. In order to verify this conclusion, we made a cross line in subsidence area A to compare the deformation signals of the two datasets along the cross line. From the figure 5, we can found the subsidence rates difference is smaller at the end of the cross line (subsidence center edge) and larger toward the middle of cross line (subsidence center), while in CSK result the deformation rate of PSs with velocity are higher than that of ENVISAT data up to 15-20mm/year, which indicates that the main differences are highlighted on particular high deformation that can be detected with CSK, due to the high PS density, and can't be seen with ENVISAT data.

Comparison between PSI result of CSK and ENVISAT demonstrates the ability of high resolution data for detailed monitoring of urban subsidence. Owing to the spatial and temporal high density sampling, the PSI result of CSK show the potential of detailed monitoring and detect the potential deformation for most infrastructures including buildings, roads and railways in urban area.

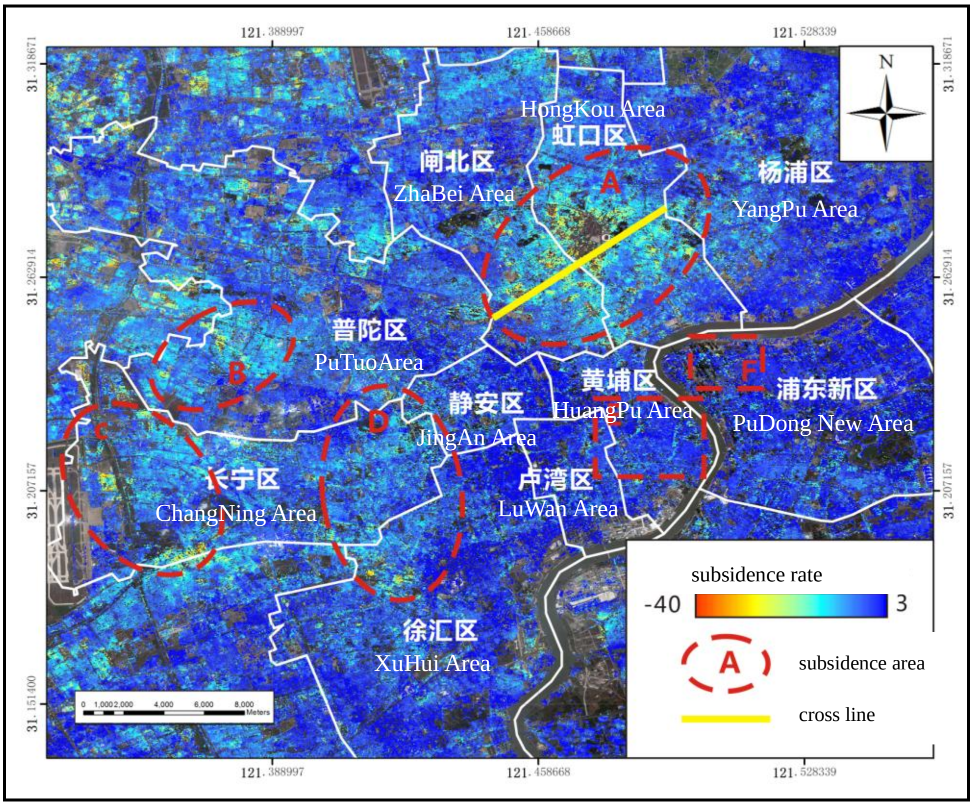


Figure 2 PSI derive velocity map by using CSK data (2008.03-2010.05), which shows detail urban

subsidence in the central city of Shanghai.

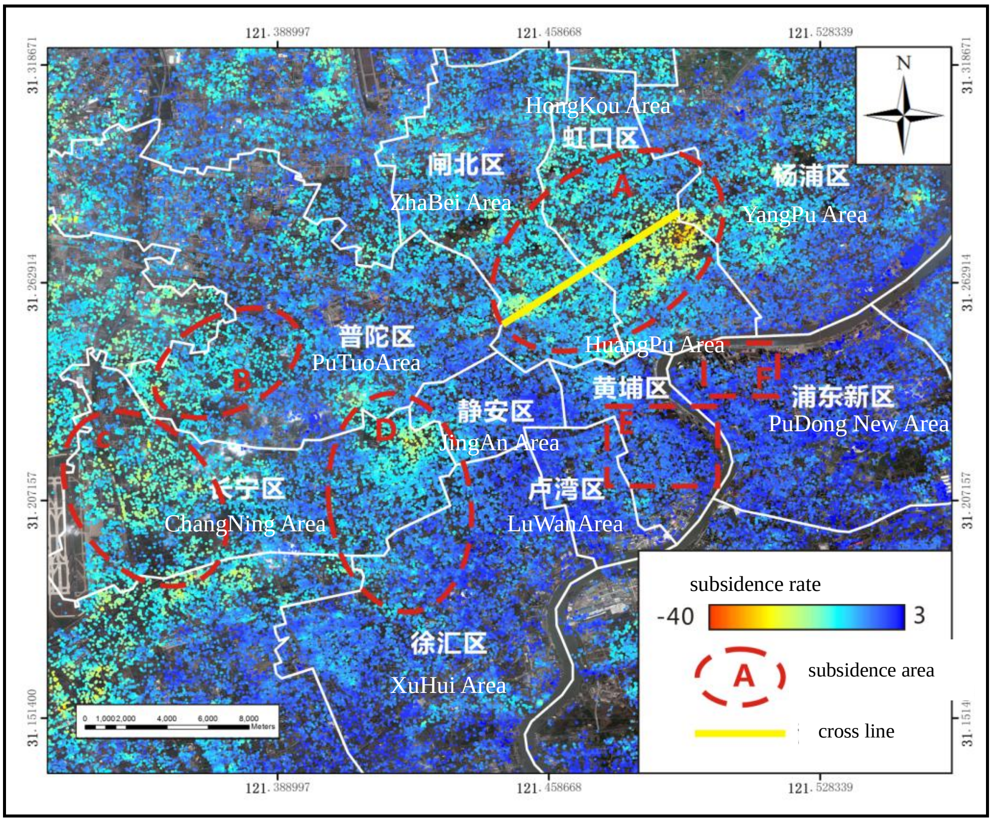
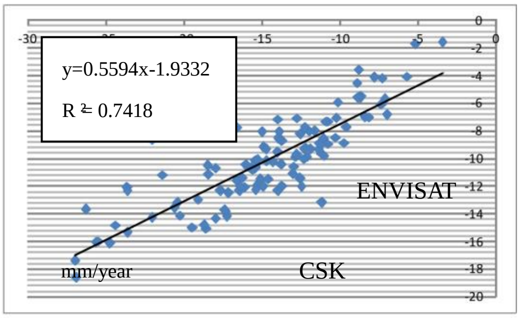
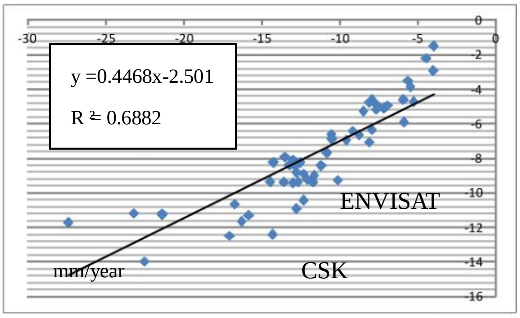


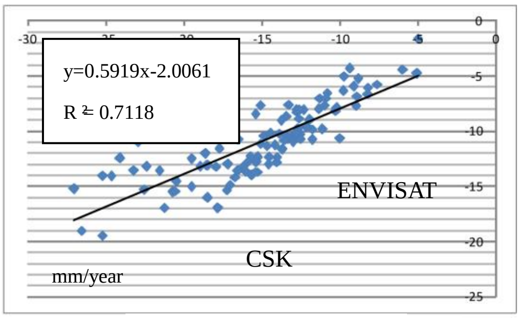
Figure 3 PSI derive velocity map by using ENVISAT data (2009), which shows similar subsidence trend in the central city of Shanghai with figure 2.



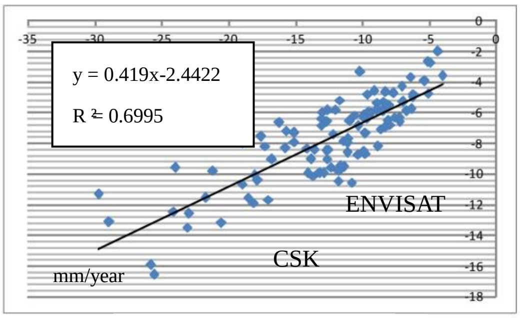
(a) subsidence area A



(b) subsidence area B



(c) subsidence area C



(d) subsidence area D

Figure 4 Correlation coefficient of two datasets in subsidence area A, B, C and D

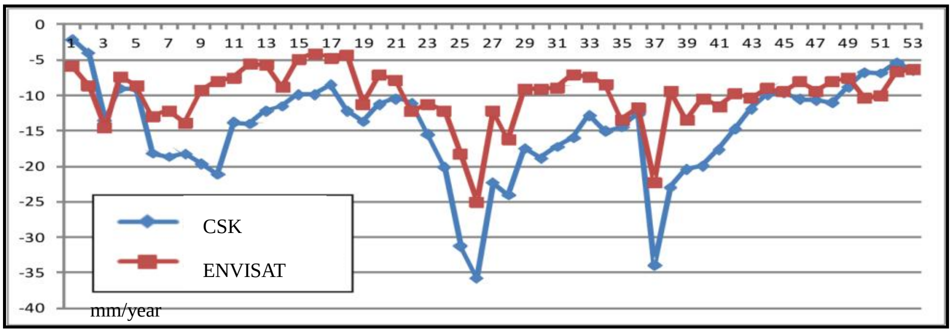


Figure 5 Comparison of two datasets (CSK and ENVISAT) along the cross line.

5. ACKNOWLEDGEMENT

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