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Subsidence detection by TerraSAR-X interferometry on a network of natural persistent scatterers and artificial corner reflectors

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ABSTRACT

The German satellite TerraSAR-X (TSX) is able to provide high-resolution synthetic aperture radar (SAR) images for mapping surface deformation by the persistent scatterer interferometry (PSI) technique. To extend the application of PSI in detecting subsidence in areas with frequent surface changes, this paper presents a method of TSX PSI on a network of natural persistent scatterers (NPSs) and artificial corner reflectors (CRs) deployed on site. We select a suburban area of southwest Tianjin (China) as the testing site where 16 CRs and 10 leveling points (LPs) are deployed, and utilize 13 TSX images collected over this area between 2009 and 2010 to extract subsidence by the method proposed. Two types of CRs are set around the fishponds and crop parcels. 6 CRs are the conventional ones, i.e., fixed CRs (FCRs), while 10 CRs are the newly-designed ones, i.e., so-called portable CRs (PCRs) with capability of repeatable installation. The numerical analysis shows that the PCRs have the higher temporal stability of radar backscattering than the FCRs, and both of them are better than the NPSs in performance of radar reflectivity. The comparison with the leveling data at the CRs and LPs indicates that the subsidence measurements derived by the TSX PSI method can reach up to a millimeter level accuracy. This demonstrates that the TSX PSI method based on a network of NPSs and CRs is useful for detecting land subsidence in cultivated lands.

1. Introduction

As a geodetic technique, spaceborne interferometric synthetic aperture radar (InSAR) (Rosen et al., 2000), especially persistent scatterer interferometry (PSI) (Ferretti et al., 2000, 2001; Liu et al., 2009; Hooper et al., 2012), has exhibited great potential in mapping subsidence with advantage in spatial resolution and coverage (Buckley, 2000; Strozzi et al., 2003; Helmut, 2009; Ge et al., 2010; Cigna et al., 2012). The recent radar sensor evolution has resulted in a remarkable improvement of spatial resolution, e.g., the typical X-band radar sensor onboard the German satellite TerraSAR-X (TSX) with capability of providing SAR images at a resolution of about 1–3 m (Pitz and Miller, 2010). This extends the data availability for subsidence detection by PSI (Wegmüller et al., 2010; Liu et al., 2011).

Although the PSI technique has been widely used to monitor land subsidence in various areas, it is a challenging task to detect subsidence in vegetated areas and cultivated lands where the random surface changes occur frequently (Xia et al., 2004; Marinkovic et al., 2004; Ferretti et al., 2007; Crosetto et al., 2010) and few "natural PSs (NPSs)" are available. The NPSs here mean the existing hard objects (e.g., rocks, pylons, buildings and bridges) with temporal stability of radar backscattering (Ferretti et al., 2001). Previous investigations indicate that the man-made corner reflectors (CRs) can be deployed as the artificial PSs in the difficult areas to increase the density of PSs (Xia et al., 2004; Marinkovic et al., 2004). With availability of high-resolution SAR images, it is desired to further investigate the combined use of NPSs and CRs for subsidence detection over the difficult areas. This is vital for tracking subsidence troughs by PSI in a huge area with vegetation coverage and cultivated lands. For example, severe land subsidence should be monitored around the North China Plain due to excessive exploitation of groundwater (Liu et al., 2001). It is reported that most of the subsidence troughs in the North China Plain are being expanded in the cultivated lands (Hu et al., 2004).

To extend the application of PSI in detecting subsidence in areas with frequent surface changes, this paper presents a method of TSX PSI with a network of NPSs and CRs deployed on site. The primary procedures include detection of NPSs, identification of CRs, NPS-CR networking, phase modeling and subsidence estimation. For validation purpose, we select a suburban area of southwest Tianjin (China) in the North China Plain as the testing site, and utilize 13 TSX images collected over this area between April of 2009 and July of 2010 to extract subsidence by the method proposed. 16 CRs and 10 leveling points (LPs) are deployed in the study area. For comparison analysis, we set two types of CRs with different size

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around the fishponds and crop parcels. 6 CRs are the conventional ones, i.e., fixed CRs (FCRs), while 10 CRs are the ones newly designed by our research group, i.e., so-called portable CRs (PCRs) with capability of repeatable installation. The performance of the CRs is evaluated by statistical analysis of radar signatures, and the quality of subsidence measurements derived by the TSX PSI method is assessed by comparing with the leveling data.

2. Study area, data source and deployment of CRs

2.1. Study area and data source

Fig. 1 shows the study area and the location map around Tianjin, China. A suburban area of southwest Tianjin is selected as the testing site (Xiqing district of Tianjin, marked by a smaller rectangle). The entire coverage of the TSX scene used for subsidence detection is marked by a larger rectangle in Fig. 1. Tianjin is located at the eastern coastal region of the North China Plain, bordering Beijing, the Yanshan Mountains and the Bohai Bay to the northwest, the north and the east, respectively. It is well known that Tianjin suffers water shortage due to its natural geographic condition and semi-arid climate (Hu et al., 2004). To meet the industrial and agricultural needs, a large amount of groundwater (especially the deep well water) has been exploited in Tianjin, thus leading to severe land subsidence in many areas (Hu et al., 2004; Enviro-Library, 2008). In recent years, some effective measures have been taken to mitigate subsidence and prevent the relevant disasters in Tianjin. It is reported that the subsidence rates in urban areas have been slowed down to about 10–20 mm/yr (Enviro-Library, 2008). However, the serious subsidence is still ongoing around suburban areas due to overuse of groundwater.

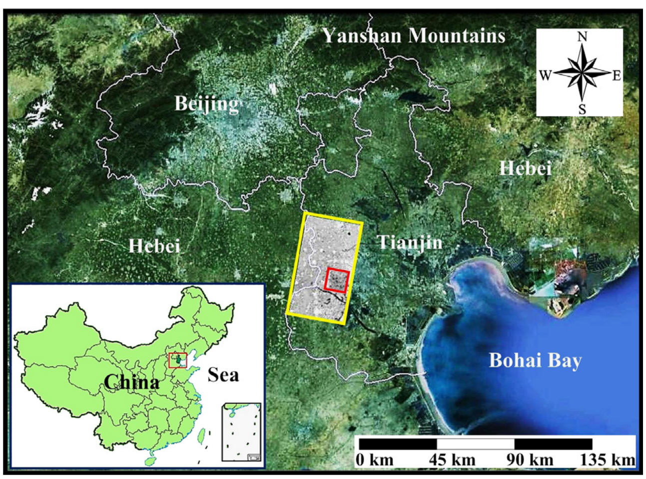

Fig. 1. The study area and the location map around Tianjin (China) with a background of optical image. The study area selected for subsidence detection is marked by a smaller rectangle, while the entire coverage of the TSX scene is marked by a larger rectangle.

To detect subsidence in this study area, we use the time series of 13 X-band SAR images acquired along descending orbits by the satellite TSX between April 29, 2009 and July 2, 2010. The original datasets were provided as the single look complex (SLC) images with pixel spacing of 1.36 m in slant range (i.e., 2.07 m in ground range) and 1.90 m in azimuth. Fig. 2(a) shows the averaged TSX amplitude image of the study area of about $10 \times 10\ \mathrm{km}^2$ with annotation of 16 CRs (CR1–16) and 10 LPs (BM1–10), while Fig. 2(b) shows the enlarged map of the dashed rectangle in Fig. 2(a), which corresponds to an area of about $5.6 \times 5.3\ \mathrm{km}^2$ with the fishing ponds (marked by dashed polygons) and crop parcels (marked by solid polygons). It is very easy to identify the roads, highways, individual buildings, fishponds and crop parcels from Fig. 2. Most of the buildings in the study area are of uniform height, thus decreasing possibility of radar shadowing and layover. This will be advantageous for identifying the NPSs in the built-up areas. However, few NPSs will be available around the fishponds and crop parcels. Therefore we deploy the man-made CRs around the parts with absence or sparsity of NPSs. For validation, three epochs of leveling campaigns were carried out on 16 CRs and 10 LPs during the period of 13 TSX acquisitions. The leveling dates for the three epochs are around April of 2009, September of 2009 and April of 2010, respectively.

We will generate 78 interferometric pairs by full combination of the 13 TSX SLC images. Fig. 3 shows the spatial (perpendicular) and temporal baselines of all the interferometric pairs. It should be pointed out that the abbreviations are used here for the TSX acquisition dates. For example, one can read 090429 as April 29, 2009, and 100702 as July 2, 2010. It can be seen from Fig. 3 that

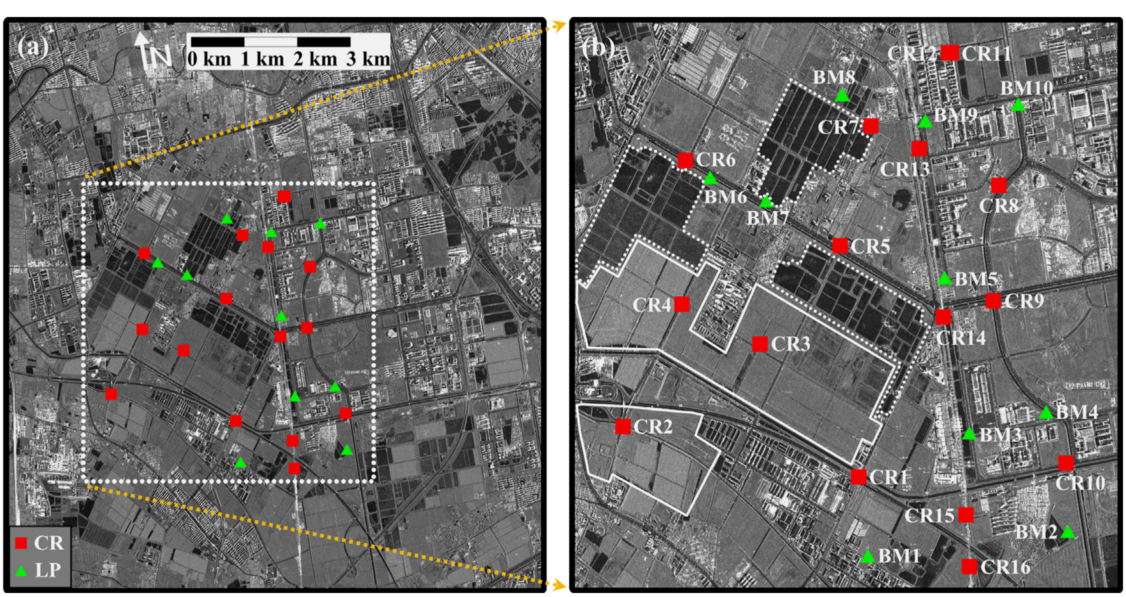

Fig. 2. The averaged TSX amplitude image of the study area with annotation of CRs and LPs.