Abstract

Ground settlement of reclaimed lands lasts for decades or more. The determining of long-term deformation time series combination retrieved by Multi-temporal Interferometric synthetic aperture radar (MT-InSAR) is Multi-platform SAR data and Multi-strategy. In this work, a comparative study using two joint methods was undertaken in Shanghai (China) megacity. One method is that we combined the deformation time-series derived by ENVISAT/ASAR (ENV) data, COSMO-SkyMed (CSK) data and Sentinel-1A (S1A) data spanning the time period between 2007 and 2017. The other method, TerraSAR-X (TSX) MT-InSAR was added to ENV+CSK+S1A, forming ENV+TSX+CSK+S1A. In the areas with obvious subsidence, such as the fourth and fifth runway of Pudong Airport, the annual deformation rate of the two combination fluctuate most with ±2.5 mm/y, and within 1 mm/y elsewhere.

Keywords: MT-InSAR; Multi-platform; Comparative analysis; Small Baseline Subset; Shanghai

1. Introduction

Shanghai is characterized by high urban density and ground subsidence phenomena due to groundwater extraction and consolidation of high-tall buildings, as revealed by several analyses. Q Zhao et al combined the deformation time series obtained from three SAR datasets through geotechnical model, investigating the evolution of ground deformation in the Shanghai coastal region. In this work, 4 deformation time-series as well as deformation rates are derived by 4 independent SAR datasets with the using of Small Baseline Subset (SBAS) algorithm. Then, we not only derived 3 ENV+CSK+S1A also 4 ENV+TSX+CSK+S1A deformation time-series, and the time span of the two methods is both 2007-2017. Through comparative analysis, we find the consistency between the two combinations is well.

2. Study area

Shanghai is located on the east of the Asian continent, at the center of the north-south coast of China. It is bound to the north by the Yangtze River estuary, to the south by Hangzhou Bay, and to the east by the East China Sea, to the west by the Jiangsu and Zhejiang provinces. A large supply of sediment from the Yangtze river made it possible for Shanghai to reclaim new land along its eastern coastal areas, mainly including Lingang New City and Pudong International Airport. After reclamation, the consolidation and compaction process will inevitably occur due to the unique soil.

3. Data and Methods

3.1 SAR data

Specifically, four independent Synthetic Aperture Radar (SAR) datasets are used for this study. The first dataset consists of 35 images, collected by ENVISAT/ASAR (ENV) sensor operated at C band (Ascending, VV polarization) from February 2007 to September 2010. The second dataset consists of 11 images, collected by TerraSAR-X sensor operated at X band (TSX, Ascending, HH polarization) from December 2009 to December 2010. The third dataset consists of 61 images, collected by COSMO-SkyMed(CSK) sensor operated at X band (Descending, HH polarization) from December 2013 to March 2016. The last dataset consist of 33 images, collected by Sentinel-1A(S1A) sensor operated at C band (Ascending, VV polarization) from February 2015 to April 2017.

3.2 Methods

The 4 SAR datasets were independently processed by employing the multi-pass SBAS algorithm. SBAS is a well-established technique that allows the detection of the temporal evolution of Earth’s surface deformation by generating mean LOS velocity maps as well as LOS displacement time-series.

We combined deformation time-series of time-overlapped datasets by using Singular Value Decomposition (SVD) method and time-gapped datasets by using geotechnical models. The specific formula of the model can be expressed as:

\[ S(t) = S_0 \left( t - \delta \right)^k + (t - \delta)^\lambda \]

In the above formula, \( t \) is the consolidation time (including the first consolidation and secondary compression process); \( S_0 \) is the sedimentation cumulation at time \( t \); \( S_0 \) is the corresponding cumulative deformation amount when \( t \) is infinite (the total shape); \( k \) and \( \lambda \) are the curvature parameters of the model, which mainly determine the bending course of the model; \( \delta \) is the time delay coefficient, which corresponds to the actual starting time of the sedimentation process.

4. Results

By applying the SBAS technique, the relevant ENV (2007-2010), TSX (2009-2010), CSK (2013-2016) and S1A (2015-2017) line-of-sight (LOS)-projected displacement time-series were recovered. Since the horizontal deformation is less than the up-down component, we focus on the generation of combined long-term vertical displacement time-series covering the period from 2007 to 2017. ENV and TSX overlap about 1 year, from 2009 to 2010, meanwhile, CSK and S1A overlap 1 year, form 2015 to 2016. The combination of ENV+TSX and CSK+S1A were performed using SVD method, respectively. Then, we combined ENV and CSK+S1A by using geotechnical model to obtain the long-term deformation time-series of ENV+CSK+S1A. Four deformation time-series combination, ENV+TSX+CSK+S1A, was also performed. Fig 2 shows a zoomed view of the map, reporting the mean displacement rate of the vertical deformation in the Shanghai area, as retrieved by two strategy combination.

5. Discussion

In order to quantify the correctness of the achieved two long-term deformation products, we also produced, for each point of the common ENV+CSK+S1A / ENV+TSX+CSK+S1A geocoded grid, the residual between the two combinations. As is shown in Fig3, the difference is minimal, and most of the values are within ±1 mm/year. However, there are also relatively large changes in Pudong International Airport.

We focus on the comparative analysis of the achieved deformation time-series, calculating four pixels labeled as a-d, as shown in Fig4. Two long-term deformation time-series have same tendency of subsidence slowing down with the time going. Nevertheless, the difference in Pudong International Airport is relatively large. Pixel b shows the maximum difference in cumulative settlement in 10 years is 47 mm.

6. Conclusion

Two combination strategy, including ENV+CSK +S1A and ENV+TSX+CSK+S1A, were performed to obtain the annual ground deformation velocity and deformation time-series in Shanghai area from 2007 to 2017. In this work, through the comparative analysis of three platforms’ combination and four platforms’ combination, we found that annual deformation velocity difference is less than 1 mm/y in most of area. However, in the fourth and fifth runway of Pudong Airport, the annual deformation velocity of the two combination fluctuate by ±2.5 mm/y. In terms of deformation time-series, two combinations have consistent settlement trends.