Abstract
Land reclamation areas of Shanghai megacity has been suffered from land subsidence for decades. In order to rebuild the evolution process of long-term ground deformation, we need to combine the deformation time-series retrieved by Multi-platform SAR data with Multi-temporal Interferometric synthetic aperture radar (MT-InSAR) technology. In this work, we performed a Small Baseline subset InSAR (SBAS-InSAR) analysis based on the exploitation of four independent SAR datasets acquired by the ASAR ENVISAT (ENV), COSMO-SkyMed (CSK), TerraSAR-X (TSX) and Sentinel-1A (S1A) sensors, respectively. The four datasets consist of a long time period subsidence monitoring results between 2007 and 2017. Then, a comparative study by using two kinds of combination methods was performed. The results shows that 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/yr, and within 1 mm/yr otherwise.

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

1. Introduction
Ground subsidence in Shanghai is partly induced by land reclamation and the filling soil properties, as revealed by several analyses. (Zhao et al., 2016) combined the deformation time series obtained from three SAR datasets through geotechnical model, and investigated the evolution of ground deformation in Shanghai coastal region. In this work, 4 deformation time-series as well as deformation rates are derived by 4 independent SAR datasets respectively by using SBAS algorithm. Then, we combined the 3 (ENV+CSK+S1A) and 4 (ENV+TSX-CSK+S1A) deformation time-series. The time span of the two combined deformation time-series is both 2007-2017. We find the consistence of the two combination methods is agree 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, the south by Hangzhou Bay, the east by the East China Sea, and the west by the Jiangsu and Zhejiang provinces. A large supply of sediment from the Yangtze river make it possible for Shanghai to reclaim new land along its eastern coastal areas. After reclamation, the consolidation and compaction process will inevitably occur due to the filling soil properties.

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 Method
The four 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 were combined by using geotechnical models. The specific formula of the model can be expressed as:

$$S_{CMT}(t) = S_m \frac{(t - \delta)^k}{k^2 + (t - \delta)^2}$$

In the above formula, $t$ is the consolidation time (including the first consolidation and secondary compression process); $S_{CMT}(t)$ is the sedimentation cumulation at time $t$; $S_m$ is the corresponding cumulative deformation amount when $t$ is infinite (the total shape); $k$ and $k$ 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 (Lei et al., 2017), we focus on the generation of combined long-term displacement time-series covering the period from 2007 to 2017 in the vertical direction. Since ENV-TSX and CSK-S1A datasets both have one year overlapping time comibination of ENV+TSX eriod, from 2009 to 2010, and from 2015 to 2016, respectively. The and CSK+S1A were performed by 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. ENV+TSX and CSK+S1A were also combined by geotechnical model forming ENV+TSX+CSK+S1A. Fig. 2 is the mean displacement velocity map of the long-term vertical deformation in the Shanghai area retrieved by two combination strategy.

5. Discussion
In order to study the consistency of the achieved two long-term deformation products, we geocoded ENV+CSK+S1A and ENV+TSX+CSK+S1A products a common grid, and calculated the difference between the two combination strategies. As is shown in Fig. 3, the difference is generally minimal, and most of the values are within ±1 mm/year, with the exception of the Pudong International Airport area.

We also analysis the consistence of the two combination strategies from the deformation time-series perspective. Four pixels labeled as a-d, as shown in Fig4, are selected to present the analysis results. It can be seen from all the four points that the subsidence velocity of the two combination strategies both have the tendency of slowing down with time. Furthermore, it can be seen that the two combination strategies time-series of point a,c,d agree with each other well. However, point b which located at the Pudong International Airport is unique, as we can see in Fig. 4. After ten years of ground deformation, the maximal difference in cumulative deformation of two combination strategies can up to 47mm.

6. Conclusion
The combination strategies 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. Through the comparative analysis of three platforms’ combination and four platforms’ combination, we found that as for the deformation velocity, the difference is generally minimal, and most of the values are within ±1 mm/year, with the exception of the Pudong International Airport area. In terms of deformation time-series, the subsidence of the two combination strategies both have the tendency of slowing down with time.