Retraction

Retraction: Land subsidence in Beijing from 2017-2018 revealed by Sentinel-1A TOPS time series interferometry (IOP Conf. Ser.: Earth Environ. Sci. 638 012043)

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This article has been retracted by the authors, who have admitted a very similar version has already been published [1]. In accordance with the COPE guidelines, IOP Publishing agrees to retract this paper. The authors agree with the retraction and apologise for the mistake.

[1] Gou J et al 2019, Revealing Land Subsidence in Beijing by Sentinel-1 Time Series InSAR, The 2019 International Conference on Big Data Analytics for Cyber-Physical System in Smart City, AISC 928, pp. 113-119

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Land subsidence in Beijing from 2017-2018 revealed by Sentinel-1A TOPS time series interferometry

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Abstract: Beijing is one of the largest cities in China, which has suffered from land subsidence for a long time. According to the study from 2005 to 2017, the maximum subsidence rate of Beijing is more than 10 cm/year. This paper will use Sentinel-1A TOPS data for the first time to reveal the land subsidence of Beijing from 2017 to 2018 by using time series interferometry. SBAS-InSAR technology was used for time series analysis. The annual mean subsidence rate and time series subsidence of Beijing were obtained. The results show that the east of Chaoyang district and the northwest of Tongzhou district were the severe subsidence areas in Beijing, and the subsidence rate is more than 10 cm/year, which indicates that the subsidence area in Beijing is continuous in recent years, and corresponding measures should be taken by the government.

1. Introduction
Beijing is one of the largest cities in China, which has suffered from land subsidence for a long time. According to a large number of reports, newspaper, studies etc., the land subsidence in Beijing has lasted a long time with a wide coverage and rapid subsidence rates. Urban land subsidence will bring potential threats to urban infrastructure, such as buildings, subway tunnels and high-speed railways. The subsidence distribution map is an important basis to support the relative disaster prevention and reduction.

Interferometric synthetic aperture radar (InSAR) is a new kind of space-based geodetic technique, which has the characteristics of high precision, wide monitoring range, whole day time and high efficiency. It has great advantages in landslide, urban land subsidence [1-6] and other fields. Since 2010, SBAS-InSAR technology has been widely used to monitor land subsidence in Beijing, and a series of important research results have been achieved. For example, Hu et al. [7] based on SBAS-InSAR technology, used ENVISAT ASAR data to extract the land subsidence results of Beijing from 2003 to 2010, and analyzed the relationship between groundwater level and land subsidence. Three subsidence funnels were found in Shunyi district and Chaoyang district, with the subsidence rate exceeding 11 cm/year; Chen et al. [8] based on SBAS-InSAR technology, used ENVISAT ASAR and
TerraSAR-X data to extract the land subsidence results of Beijing from 2003 to 2010 and 2010 to 2011, and verified the reliability of land subsidence results obtained based on SBAS-InSAR technology using GPS data. The land subsidence results in Beijing after 2017 was not obtained by SBAS-InSAR technology yet.

In this paper, we used SBAS-InSAR technology to monitor the land subsidence in Beijing from 2017 to 2018, and obtained the mean velocity subsidence map and time series results, and the serious land subsidence areas were analyzed in detail.

2. Study Area and Data Sets
In order to grasp the situation of land subsidence in Beijing from 2017 to 2018, we selected the Sentinel-1A descending image of 20 scenes C band covering the Beijing in 2017 to 2018 to extract the land subsidence rate and accumulated subsidence of the Beijing. The main parameters of these Sentinel-1A data were shown in Table 1.

| Parameters              | Value                |
|-------------------------|----------------------|
| Incidence angle         | 39.1 (degrees)       |
| Range pixel spacing     | 2.3 (m)              |
| Azimuth pixel spacing   | 13.9 (m)             |
| Wavelength              | 5.55 (cm)            |
| Center range            | 902000 (m)           |

As shown in Figure 1, according to the given threshold, 70 interferograms were generated, 165 m is the perpendicular baseline threshold and 80 days is the temporal baseline threshold. The acquisition date of each image were labelled and their interferometric pairs were connected with dashed lines. The spatiotemporal baseline of sentinel-1A data sets were given. A robust network can be seen with these plenty of interferometric pairs, which can ensure the accuracy of the final results.

3. Methodology
SBAS-InSAR technology freely combines to generate time series interferograms of multi-master images according to the principle of small temporal baselines, and uses the singular value decomposition (SVD) method of the matrix to obtain the deformation sequence and average deformation rate during the observation time of the study area. The SBAS-InSAR technical process is shown in Figure 2, the specific steps are as follows:

(1) Acquire N+1 scenes of SAR images in the same area arranged in chronological order, choose one scene as the main image for registration, and register other SAR images to the main image by
setting appropriate time and space baseline thresholds, N +1 scene SAR image can generate 
\( \frac{N(2^N + 1)}{2} \) at most sub-interference pairs.

(2) Differential interference is performed on the combined image pair to generate a time series interferogram of multi-master images. The interference phase composition is as follows:

\[
\Delta \phi(x, y) = \Delta \phi_{\text{disp}} + \Delta \phi_{\text{topo}} + \Delta \phi_{\text{atm}} + \Delta \phi_{\text{res}}
\]

\( \Delta \phi_{\text{disp}} \) represents the deformation phase (along the radar line of sight), \( \Delta \phi_{\text{topo}} \) represents the terrain phase, \( \Delta \phi_{\text{atm}} \) represents the atmospheric phase, and \( \Delta \phi_{\text{res}} \) represents the noise phase. \( \Delta \phi_{\text{disp}} \) and \( \Delta \phi_{\text{topo}} \) can be written as:

\[
\Delta \phi_{\text{disp}} = \frac{4\pi}{\lambda} \left[ d_{i_1}(x, y) - d_{i_2}(x, y) \right]
\]

\( \Delta \phi_{\text{topo}} = \frac{4\pi}{\lambda} \frac{B_{i_i}}{r \sin \theta} \Delta Z(x, y)
\]

\( \lambda \) and \( \theta \) represent the wavelength and incident angle, \( d_{i_1}(x, y) \) and \( d_{i_2}(x, y) \) are the cumulative deformation (relative to the reference time \( i_1 \)) along the radar line of sight (LOS) from \( i_1 \) to \( i_2 \), \( \Delta Z(x, y) \) and are the terrain errors.

The external digital elevation model (DEM) is used to remove the terrain phase, and the noise is effectively removed through multi-view and filtering. In order to obtain the cumulative deformation in the radar line of sight (LOS), the minimum cost flow method (MCF) is used for phase unwrapping.

(3) Ground control points (GCPs) are selected for orbit refinement and reflattening. The purpose is to correct orbit parameters, estimate and remove residual phase and phase jumps.

(4) First estimate the residual elevation and deformation rate based on the linear model, and unwrap the unwrapped phase twice, then remove the atmospheric phase through spatial high-pass filtering and temporal low-pass filtering, and invert the temporal deformation sequence and average deformation rate, and finally perform geocoding to obtain the time deformation sequence and average deformation rate in the geographic coordinate system.

**Figure 2. Flowchart of SBAS-InSAR technology**

**4. Results and Discussions**

According to the experimental steps described in section 3, the SBAS-InSAR technology is used to monitor the land subsidence in Beijing from 2017 to 2018, and the annual mean velocity subsidence map of Beijing is obtained, as shown in Figure 3. The black line indicates the boundary of Beijing, and
the red solid points indicate the location of the districts in Beijing. The mean velocity subsidence rate of Beijing is about 12 cm/year in the line-of-sight direction (positive value means far away from the sensors). There were three main subsidence zones with red color can be seen.

As shown in Figure 3, continuous subsidence areas are formed in the northwest of Haidian district, southeast of Changping district, southwest of Shunyi district, east of Chaoyang district and north of Tongzhou district, of which Chaoyang district and Tongzhou district have the largest subsidence. The mean velocity subsidence rate of the subsidence area in the northwest of Haidian district is more than 8 cm/year, that in the southeast of Changping district is more than 7 cm/year, that in the southwest of Shunyi district is more than 6 cm/year, and that in the eastern of Chaoyang district and the northern of Tongzhou district is more than 10 cm/year.

Figure 3. Mean velocity map subsidence covering Beijing
Figure 4. Time series result from 11th August 2017 to 25th July 2018

Assuming that the SAR image of 11th August 2017 is taken as the reference image, the remaining SAR images will take the SAR image of 11th August 2017 as the reference image, and there will be cumulative deformation in the time series. As shown in figure 4, from 11th August 2017 to 25th July 2018 the land subsidence phenomenon gradually became obvious with the accumulation of time, and the deformation area continued to expand and developed in a funnel-shaped trend.

As shown in Figure 5, the land subsidence in the east of Chaoyang district and the northwest of Tongzhou district in Beijing is relatively serious, with a mean velocity subsidence rate of more than 10 cm/year, and the most serious land subsidence area is between the 5th ring road and 6th ring road in Beijing.

Figure 5. Local subsidence map of Chaoyang district and TongZhou district in Beijing
5. Conclusion
In this paper, SBAS-InSAR technology is used to monitor the land subsidence in Beijing from 2017 to 2018. The results show that the overall distribution of land subsidence in Beijing is uneven. The land subsidence in the west, north and south of Beijing is relatively stable. The subsidence in Chaoyang district and Tongzhou district in the east of Beijing is the most serious, and the mean velocity subsidence rate is more than 10 cm/year, which indicates that the land subsidence area still exists in Beijing in recent years, and the government should take corresponding measures.

Acknowledgements
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