Urban Ground Surface Subsidence Monitoring Based on Time Series InSAR Technology

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Abstract. D-InSAR technology can measure the settlement of the surface millimeter level. Due to the influence of time and space loss coherence and atmospheric delay, its application in surface settlement monitoring is limited. As a D-InSAR technology innovation, SBAS can overcome the influence of related errors and make the results of interference processing more accurate. In the paper, Jiangjin District of Chongqing City was used as the experimental area. Using the radar image data of 23 scenes sentinel1, the short baseline set (SBAS) technology was used to obtain the range of surface subsidence and cumulative accumulation of time series in Jiangjin City. Provide reference for land and resources utilization and large-scale project construction.

Keywords: Settlement monitoring, Sentinel1, time series InSAR, short baseline set SBAS

1. Introduction
Under the influence of natural factors and human factors, uneven settlement of urban surface has brought some harm to urban construction, industrial and mining enterprises and people's production and life [1-3]. The monitoring of surface deformation is an important basis for carrying out surface deformation analysis and research and development of prevention and control measures. Traditional land subsidence monitoring methods are various, including precision leveling and GNSS measurement [4], which have short observation period, large workload, high measurement cost, few sampling points, unstable measurement points, and low efficiency [5], and the spatial resolution is low, the coverage is small, and it is difficult to meet the time scale and spatial scale requirements. Differential Radar Interferometry (DInSAR) is a remote sensing technology that uses SAR (Synthetic Aperture Radar) sensor data to measure surface deformation [6]. It has all-weather, large-area, high-precision advantages, and is displayed in surface deformation monitoring applications. A lot of potential and advantages [7]. However, due to the influence of time-space loss coherence and atmospheric delay phase, the accuracy and reliability of DInSAR acquisition deformation results are greatly limited [8]. In order to solve the problem of time-space decoherence and atmospheric delay, time-series InSAR technology emerges. Representatives include Permanent Scatterer InSAR (PS) technology and Small baseline subset (SBAS) technology. This paper uses SBAS technology. Taking Jiangjin District of Chongqing as an example, it discusses and studies the monitoring of urban settlement.

2. Principle of Settlement Monitoring Based on Sbas Technology
The short baseline set (SBAS) technology makes full use of the coherent information of the short-term time-base image, which can effectively suppress the influence of phase noise on the terrain phase, so as to obtain the evolution law of long-term slow surface deformation. SBAS technology is a time
series InSAR analysis method proposed by researchers such as Berardino and Lanari [9]. The method inherits the advantages of the conventional DInSAR method. The image is generated by using a shorter time-space baseline image to improve the coherence, and the acquired data is appropriately combined to obtain a series of short-space baseline differential interferograms, which can better overcome the space. Related phenomena. When solving the deformation rate, the SBAS method uses Singular Value Decomposition (SVD), which can connect isolated SAR data sets separated by a large spatial baseline to improve the sampling rate of the observed data. The following is a brief discussion of SBAS-based surface settlement monitoring methods [10-11].

Suppose \((t_0, t_1, \ldots, t_N)\) acquires \(N+1\) SAR image maps covering the same area, and assumes that all SAR images have been registered to the same coordinate system, so that \(M\) pairs of space-time baselines are less than a certain threshold. Multi-view differential interference pairs, and \(M\) satisfies the following conditions:

\[
N+1/2 \leq M \leq N[(N+1)/2]
\]

Suppose that the \(j\)-th interferogram is generated from the SAR images obtained from \(t_A\) and \(t_B\) at two times, and assuming \(t_B > t_A\), after removing the terrain phase, a simplified model without considering atmospheric phase, terrain error, and out-of-correlation noise can be established. The interference phase of the graph at pixel \(x\) can be expressed as:

\[
\delta \Phi(x) = \Phi(t_B, x) - \Phi(t_A, x) \approx 4\pi[d(t_B, x) - d(t_A, x)]/\lambda
\]

In the equation, \(\lambda\) is the radar wavelength, \(d(t_B, x)\) and \(d(t_A, x)\) are the surface deformations of the radar line of sight LOS with respect to the initial time \(t_0\) at the time \(t_A\) and \(t_B\), respectively, i.e \(d(t_0, x) = 0\), assuming the phase is the unwrapped phase, all interferograms are registered and the same unwrapping starting point (stability point or known deformation point) is selected. This method performs a time-series analysis of the interferograms on a per-pixel basis. Therefore, the following discussion uses a certain pixel as an example to establish an equation.

Assume the main image timing set \(IE = \{IE_1, IE_2, \ldots, IEM\}\) and Secondary image set \(IS = \{IS_1, IS_2, \ldots, ISM\}\) and it is:

\[
IE_k > IS_k, k = 1, 2, \ldots, M
\]

Then all differential interferogram phases can be composed of the following observation equations

\[
\Phi_k = \Phi(t_{IE_k}) - \Phi(t_{IS_k}), k = 1, 2, \ldots, M
\]

For all interferograms, the linear model of the above equation can be represented as a matrix, where \(A\) is an \(M \times N\)-dimensional matrix. When \(M \geq N\), then the matrix rank is \(N\), and the estimated value can be solved by least squares the equation (4):

\[
\phi = (A^T A)^{-1} A^T \delta \Phi
\]

Usually, in order to reduce the decoherence effect of the baseline, the interference pairs are grouped, so that the \(M\) of the matrix \(A\) is often less than \(N\), and the coefficient matrix of the corresponding equation is deficient, which can be solved by the SVD decomposition method [12-13].

Using a shorter baseline (usually less than 200m) interference pattern atlas can reduce the effect of geometric decoherence on them. In addition, their sensitivity to DEM errors is reduced due to the large elevation ambiguities. Measuring the crustal deformation by cumulative differential interference pattern is the common point of the method and the permanent scatterer coherence technology. The advantage is that the nonlinear deformation can be measured, but the average removal of the combined multi-view interference pattern is still certain when removing the atmospheric effect. The uncertainty, thus increasing the complexity of the method.
3. Application of SBAS Technology in Settlement Monitoring

3.1. Small Baseline Interference Pair Combination
Small baseline interference pair selection is a very important step in the processing of SBAS technology. By setting the space-time baseline threshold, small baseline interference pairs can be selected from the set of freely combined InSAR interference pairs. In order to ensure that all images are in the same reference, all images are registered with the super master image. Here, October 10, 2015 is the super master image, as shown in Figure 1.

3.2. Differential Interference Processing
The main steps of differential interference processing include image registration, interference processing, flat and terrain phase removal, phase filtering, phase unwrapping, and geocoding. This step mainly consists of four parts: generating an interferogram, de-leveling and terrain phase removal, adaptive filtering and generating a coherent map, and phase unwrapping. To facilitate interference processing, all images are accurately registered with the super master image. In the phase unwrapping, the Delauny grid algorithm consisting of the region growth method, the minimum cost flow method and the irregular triangles can be used. The Delauny method is capable of handling two relatively isolated strongly coherent regions. The Delauny unwrapping method uses 3D unwrapping, and better results are obtained in some discontinuous regions. Especially for low coherence regions, interferograms with high coherence can be used to estimate the interference of establishing new low coherence. Figure.

3.3. Orbital Refining and Re-Leveling
Before the orbit refining and re-leveling, 342 interference pairs are screened. By looking at the unwrapped phase diagram, some interference pairs with poor interference effects can be eliminated, and the quality of the interferogram during the inversion process is improved. Deformation inversion accuracy. In the SBAS process, there is a certain residual error when the ground phase is removed for the first time, and a second removal is required to obtain a better deformation result. Re-leveling all interferograms with Ground Control Point (GCP) is an important step in SBAS processing. The choice of GCP is very important, avoiding the choice of where there are residual streaks, and not where the phase jump occurs. Because in SBAS processing, it is difficult to find a perfect GCP that can be used.
for all interferograms. The coherence of each interferogram is different, so you can select as many GCPs as possible to perform orbit refinement and re-leveling. Generally, the number of GCPs is more than 30, and the number of GCPs in this paper is 100.

3.4. SBAS Deformation Results Inversion

The SBAS deformation inversion is based on the coherent pixel points. By constructing the model, the equations are constructed, and the singular value (SVD) decomposition method is used to solve the equations to solve the linear deformation rate. The SBAS deformation inversion can be performed in two steps. In the first inversion process, the linear deformation rate can be obtained by estimating the DEM residual phase and the model solution. In the inversion process of the second step, the focus is on calculating the shape variables in the time series. It is necessary to estimate the phase of the atmospheric delay, and to filter and eliminate the phase error caused by the atmospheric effect. Estimating the atmospheric delay phase component of each scene image, eliminating the nonlinear deformation phase component, can obtain more accurate time series deformation results. SBAS processing of 23 scenes sentinel1 data covering Jiangjin District, from July 30, 2015 to October 4, 2016, with the super-master image as October 10, 2015, by setting the time-space baseline threshold A total of 342 small baseline interference pairs were obtained by differential interference processing and SBAS inversion to obtain the spatial distribution map of Xuzhou urban deformation (Fig. 2). The urban rail transit map of Jiangjin District and the geological map of Chongqing City were imaged and matched with the deformation rate map of Jiangjin City, and the following results were obtained, as shown in Figure 3, Figure 4 and Figure 5.

![Figure 2. Surface settlement distribution and remote sensing image map](image-url)
4. Conclusion
Through analysis, it is found that the Jiangjin urban area is uplifted in the northwest and southwest, and settled in the southeast. Among them, the Jiangjin old town has obvious ground settlement due to the new foundation project, with an average of 5-8 mm/a, near the high-speed railway station, there is weak subsidence on the surface. Phenomenon, the average is 2-3 mm/a, due to the construction of the rail transit line 5 project, there is surface subsidence near the line, with an average of 3-4 mm/a, northwest of Jiangjin City, the riverside between the outer ring and the Heyun Mountain Xincheng, Shuangfu New District and Degan Industrial Park have surface elevations due to geological effects, with an average of 6-8 mm/a. The Jiangjin Old Town has obvious surface settlement along the Yangtze River, with an average of 7-8 mm/a.

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