InSAR Deformation Monitoring and 3D Modeling of Landslides in Jinsha River Basin

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Abstract:

Traditional landslide susceptibility evaluations mostly use evaluation models based on optical images combined with multiple influencing factors. Interferometric synthetic aperture radar (InSAR) technology has the characteristics of not being restricted by weather, strong penetrating ability, and strong ability to detect small deformations. At the same time, the method can quantify the surface deformation, which provides a more reliable and accurate basis for decision-making. In recent years, it has played an increasingly important role in landslide monitoring.

The main work of this paper is as follows: 1) adopts the SBAS InSAR technology. Selecting 10 scenes of Sentinel-1A ascending and descending orbit from January to October 2019 in the study area respectively, and finally the deformation rate of ascending and descending line of sight(LOS) in the area was obtained; 2) combines DEM and satellite orbit parameters to decompose the LOS-direction deformation, and calculates the slope-direction deformation to intuitively reflect the landslide deformation; 3) combined with the ascending and descending orbit LOS deformation to carry out the 3D modelling and calculation of the deformation, and obtained the deformation rate of horizontal (east-west) and vertical. 4) Finally, analysed of the above deformation results.

Keywords: InSAR, Landslide, LOS decomposition

1.Introduction

In October 11, 2018, a large-scale landslide disaster occurred on the right bank of the Jinsha River near Bai Ge Village, Tibet, Jiangda County, Tibet Autonomous Region, and another landslide occurred on November 03, forming an event of river blocking. The maximum capacity of the dammed lake reservoir was more than 5 * 10^8m^3. In the case of emergency measures taken by relevant national departments, the dam break threat of the barrier lake has been greatly reduced, the safety of people's lives and property has been guaranteed, and the occurrence of mass casualties has been avoided. However, due to the intense activity of geological disasters, the strong downward cutting of the valley, the steep slope bank and the more broken rock mass, to a certain extent, exacerbated the instability of the regional geological environment. After the landslide, the geological body in the back edge still has continuous deformation, which is very likely to breed large-scale disasters again, which poses a great threat to the safety of the surrounding residents' lives and property. At the same time, the Sichuan Tibet Railway in the survey site selection just passes through the downstream of Baige landslide. Therefore, it is of great significance to carry out continuous deformation monitoring in this area.

Synthetic aperture Interferometric Radar (InSAR) is a new type of earth observation technology, which mainly uses the phase information of radar images to obtain the deformation information of the target point in the radar line of sight. Its main characteristics are that it has the advantages of all-weather, all-weather working conditions, wide coverage, high precision of deformation detection and low comprehensive cost. It is very suitable for surface deformation monitoring Now, it has been successfully applied in the fields of urban settlement, surface deformation along railway, landslide disaster monitoring and so on, and has broad application prospects. In 1996, fruneau et al[1]. First used the synthetic aperture radar differential interferometry (DInSAR) to monitor the deformation of small-scale landslide, and proved its feasibility. But DInSAR technology can only aim at the relative deformation of two phases, and the surface deformation often occurs slowly in a long time scale, so it can not completely reflect the actual deformation of the surface in a certain period of time. In addition, because InSAR technology itself is limited by the principle, if the interval is too long, it may lead to incoherence phenomenon due to the rapid change of the ground surface, which can not effectively detect geological disasters in real time. From the perspective of error propagation, the accuracy of DInSAR applied to regional deformation measurement is mainly affected by orbit data error, terrain influence, phase noise caused by interference decorrelation, phase unwrapping error and atmospheric delay error[2]-[4]. Among them, the interference decorrelation and atmospheric delay error are the bottleneck problems restricting the popularization and application of DInSAR. In order to solve the above problems, many scholars have gradually shifted their research focus to the idea of detecting the spatiotemporal evolution law of ground deformation based on SAR image sequence, and put forward a variety of methods, such as the development of InSAR Technology Based on time series. In 2000, Ferretti of Milan University of science and technology, Italy [5][6] first proposed the concept of Permanent Scatterers, and gave a complete data modeling and settlement algorithm PSInSAR. In the following ten years, a large number of scholars used a lot of related technologies and theories to improve and expand the method, and finally formed the technical theoretical system of TDRI. For example, the classic PSInSAR method theory, the small-baseline set time series analysis method (SBAS) [7]-[9].

2. Method

In recent years, many scholars have carried out in-depth research on landslide deformation monitoring using InSAR technology. In 2018, Sheng Huijun[10]used SBAS technology to process sentinel-1 data in Boluo township of Jinsha River for multi period interference, and obtained the landslide results. In 2019, Zeng Zhu[11] used SBAS technology to monitor and analyze the surface of Heifangtai area in Gansu Province, and compared with the field survey results, it proved that the technology could monitor the potential landslide areas in a large range, which made it possible to provide data support for local landslide early warning. However, since the deformation direction is mainly vertical in urban and plain areas, it can be approximately regarded as equivalent to the line of sight deformation rate of satellite. But for the landslide problem, because it develops in the high mountain area, and its deformation can not be considered as vertical development, this approximate method causes the inaccuracy of the results to a certain extent, and may have an impact on the conclusion. Therefore, in this paper, two settlement methods are used to analyze and solve the line of sight deformation of landslide, and the deformation results in vertical and horizontal direction and in slope direction are finally obtained. Sentinel-1 satellite image, which consists of two satellites and carries C-band SAR, is selected for the experiment.

In order to further explain the principle of this method, mathematical derivation will be carried out from the perspective of satellite imaging. SAR image is obtained by side looking imaging principle. Figure 1 shows SAR side view imaging geometry (taking orbit ascending imaging as an example) and angle parameters in three-dimensional coordinate system. Taking the sub satellite point of the satellite at the imaging time as the coordinate origin o, and taking the East, North and vertical directions as the reference, the spatial rectangular coordinate frame is constructed. S is the position of the satellite at the imaging time, P is the ground target, the line between S and P is the radar line of sight (LOS) direction, the angle between LOS direction and vertical direction θ is the radar signal incidence angle, the sub satellite point track is the projection of satellite orbit on the horizontal plane; φ is the satellite heading angle; the line between the sub satellite point O and the target point P is the LOS projection on the horizontal plane.

It can be concluded that the shape variable of satellite line of sight direction of point P (represented by D) is the sum of the projection of the three-dimensional displacement component of the point in the LOS direction, as follow:

$$D = D_{\mathrm{v}} \cos\theta + D_n \sin\varphi \sin\theta - D_e \cos\varphi \sin\theta \tag{1}$$

Where D_e is the East-West deformation component of point p; D_n is the North-South deformation component of point p; and D_v is the vertical deformation component of point P. By calculating the partial derivative of formula (1) and taking the absolute value, the sensitivity coefficient of LOS observation results to three-dimensional deformation vectors can be obtained:

$$\left|\frac{\partial R}{\partial D_e}\right| = \left|-\cos\varphi\sin\theta\right|, \left|\frac{\partial R}{\partial D_n}\right| = \left|\sin\varphi\sin\theta\right|, \left|\frac{\partial R}{\partial D_v}\right| = \left|\cos\theta\right| \tag{2}$$

Combined with the orbit of SAR satellite, the heading angle is generally 190 ° (descending orbit) or 350 ° (ascending orbit). It can be concluded that InSAR is the most sensitive to vertical displacement and the least sensitive to North-South displacement.

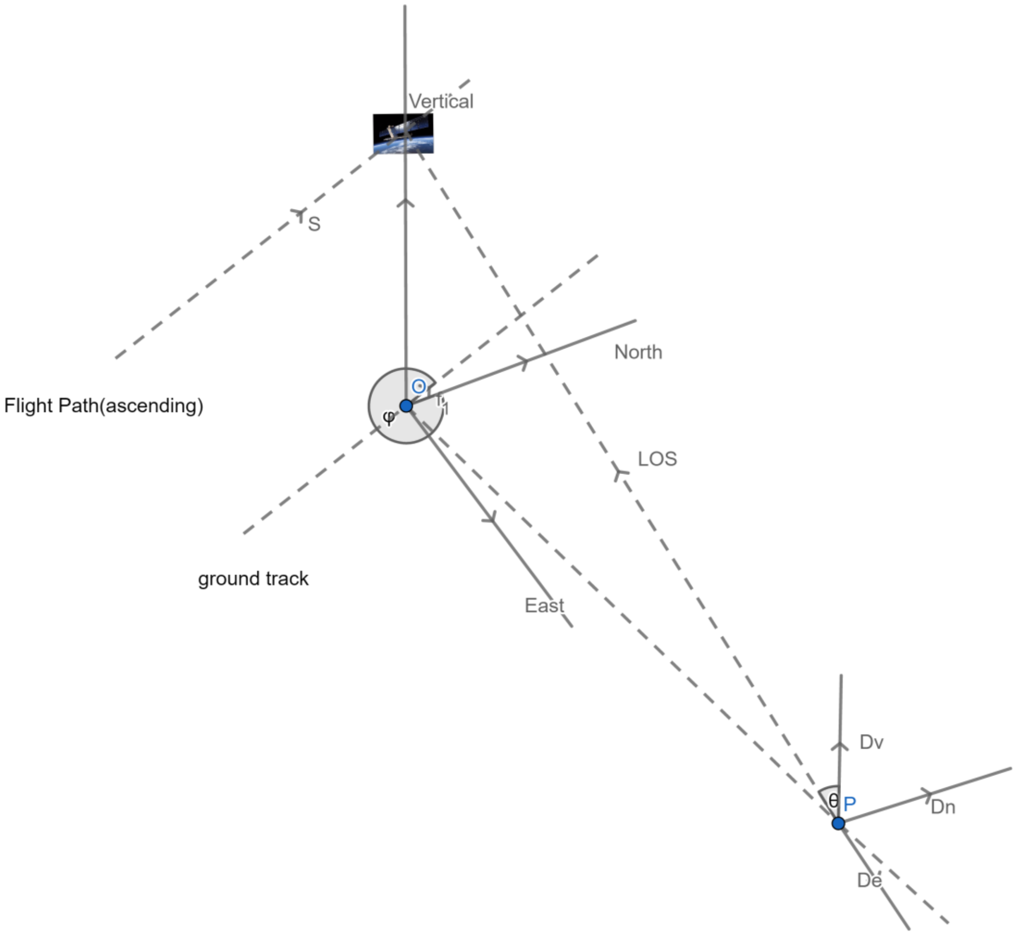


Figure 1 Geometric angle parameters of SAR side looking imaging

Therefore, the North-South displacement can be approximately ignored. By calculating the deformation of the lifting orbit in the same area at the same time, the local incidence angle θ_n, the satellite heading angle φ_n and the Los direction interferometry results R_n are respectively substituted. The vector equation of the joint three-dimensional deformation modeling of the lift orbit is obtained as follows:

$$\begin{cases} R_1^{(i,j)} = D_v^{(i,j)}\cos\theta_1^{(j)} - D_e^{(i,j)}\cos\varphi_1\sin\theta_1^{(j)} \\ R_2^{(i,j)} = D_v^{(i,j)}\cos\theta_2^{(j)} - D_e^{(i,j)}\cos\varphi_2\sin\theta_2^{(j)} \end{cases} \tag{3}$$

Where (i, j) is the sequence number of the target point in the image space. By solving the equations, we can get the 3D deformation results (east-west and vertical).

Unfortunately, this is not always possible owing to the lack of valid ascending and descending SAR orbit datasets that coincide with one another. Hence, we projected the velocity in the LOS (VLOS) along the steepest slope. This projection was designed to compare landslide velocities with different slope aspects. To calculate the velocity projected along the slope (V_{SLOPE} mm/year), we used a formula derived from those proposed by Colesanti and Wasowski[12] and Plank et al.[13], with the difference that with the method proposed in this work it is also possible estimate whether the movement is going towards or away from the satellite. The parameters for calculating coefficient C are the slope (S) and aspect (A), which are derived from the DEM using the direction cosine of the LOS (N, H, and E) and can be calculated from the incidence angle (α) and LOS azimuth (γ) in radians.

$$V_{SLOPE} = \frac{V_{LOS}}{C} \tag{4}$$

$$C = N\cdot(\cos(S)\cdot\sin(A-90°)) + E\cdot(-1\cdot\cos(S)\cdot\cos(A-90°)) + H\cdot(\sin(S)) \tag{5}$$

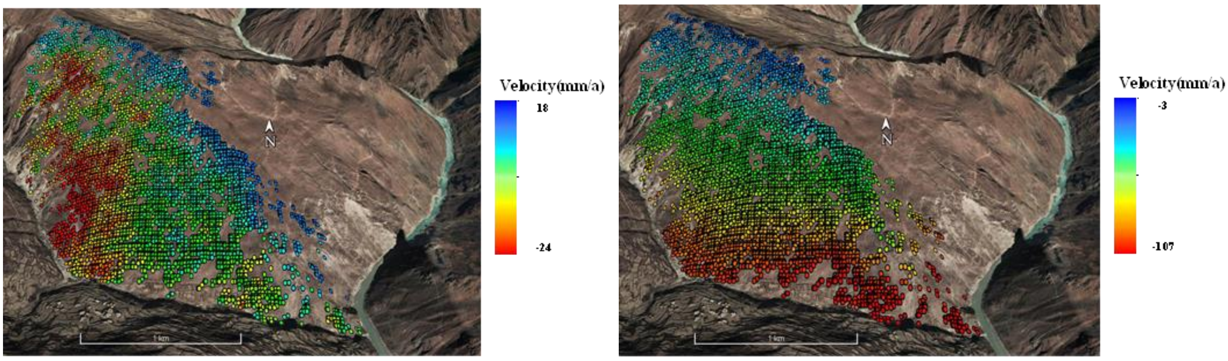
$$N = \cos(90° - \alpha)\cdot\cos(180° - \gamma) \tag{6}$$

$$E = \cos(90° - \alpha)\cdot\cos(270° - \gamma) \tag{7}$$

$$H = \cos(\alpha) \tag{8}$$

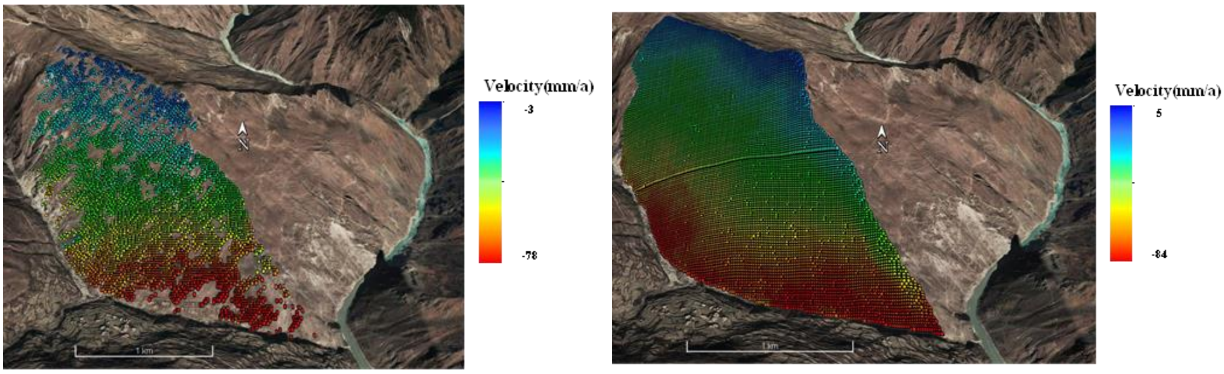
3.Result

Small baseline time series deformation monitoring was carried out for a large landslide in Jinsha River Basin, and LOS deformation results were obtained. Through the above two decomposition modeling methods, the results were further analyzed, and the results are as follows:



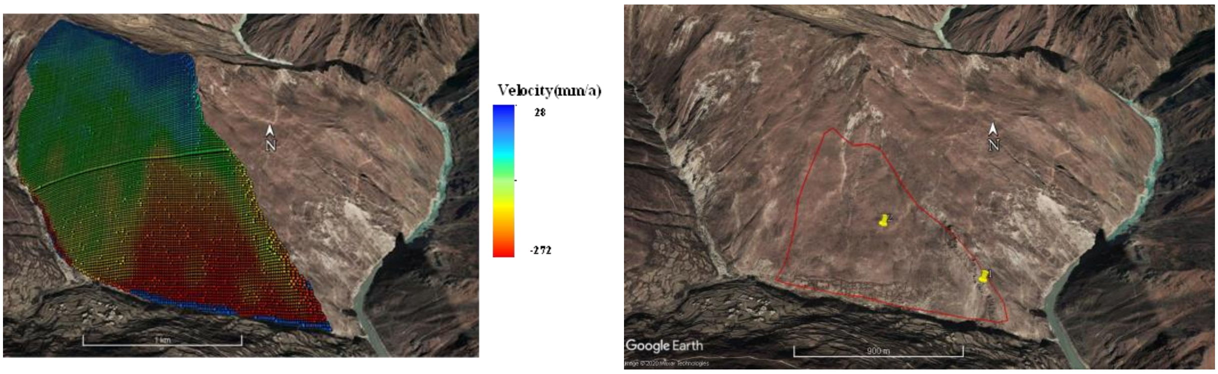
A. Horizontal deformation displacement

B. Vertical deformation displacement



C. LOS deformation of ascending orbit

D. LOS deformation of descending orbit



E. Aspect decomposition

F. High resolution image

Figure 2 Result. A) Horizontal deformation displacement ; B) Vertical deformation displacement; C)LOS deformation of ascending orbit; D) LOS deformation of descending orbit; E) Aspect decomposition; F) High resolution image.

Compared with the deformation results of ascending and descending orbit, it can be found that the larger deformation areas are concentrated at the bottom of the slope, and the deformation rate is consistent, which also confirms the reliability of the results. In combination with the settlement results of the lift rail, the vertical and horizontal decomposition results show that the main deformation of the slope changes weakly in the horizontal direction, and the main deformation is concentrated in the vertical direction, which also reflects the instability of the slope bottom. In the process of slope direction deformation decomposition combined with digital terrain elevation data, new problems can be found. In the process of slope development, the stability of the right area is poor. Combined with image analysis, it can be found that there are large-scale cracks in this area, and the landslide wall is clearly visible. This method is further used to identify the unstable slope, which has high application value.

4.Discussion

In this paper, by using the spatial relationship of satellite imaging, two decomposition modeling methods are used to obtain the three-dimensional spatial deformation and slope deformation of a landslide in Jinshajiang River.

The results show that these two methods are very important for InSAR Technology in landslide deformation monitoring. There is still continuous deformation, of which the vertical direction deformation occupies the dominant position, and it is mainly concentrated around the fault cracks and the old landslide area. The area with a deformation rate greater than 100mm/a reaches 2.510km^2, and with a deformation rate greater than 200mm/a reaches 0.268km^2. For severe areas, the slope-direction deformation rate reaches a maximum of 272mm/a. The results show that there is still a risk of landslides in this area, and monitoring should be maintained to minimize losses.

At the same time, through these two ways to further analyze the results of LOS settlement, which makes the results more spatial significance, can further identify potential landslides, and has practical application value.

However, there are also some problems in this experiment. For example, in the process of analysis and calculation, the error value of the original deformation results is greatly affected. How to effectively remove the error points in this process needs further research. At the same time, in the process of three-dimensional modeling and decomposition of the joint lifting orbit, because the data of the lifting orbit points are inconsistent in space, how to select a more accurate matching algorithm of the same name is also an effective means to improve the accuracy.

In a word, with the popularity of InSAR technology, its application field is more and more extensive, but at the same time, we should pay more attention to the application of practical problems. We can not blindly use LOS to deformation results as the final result, we should consider the physical meaning of the problem synchronously, so that we can get correct and effective results and provide guidance for solving practical problems.

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