Landslides Identification along Ultra-High Voltage Transmission Channels in the Three Gorges Reservoir Area using Time Series InSAR

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ABSTRACT: Landslides threaten the safety of Ultra-High Voltage (UHV) transmission channels in its vicinity. Due to the wide range with long lines and usually passing through many areas with harsh environmental conditions, complex geology, and changing climates， manual monitoring and inspection is difficult. Space-borne Interferometric Synthetic Aperture (InSAR) is a potentially feasible and economic monitoring approach. The Three Gorges Reservoir hosts over 10,000 UHV transmission towers. The complex topography and geological conditions and abundant annual precipitation, contribute to frequent natural disasters in the Three Gorges Reservoir including landslide. Therefore, the early identification of potential landslides in UHV transmission channels is particularly important. However, dense vegetation and complex terrain in the Three Gorges Reservoir pose challenges for time-series InSAR processing. In this study, we collected 59 Sentinel-1 data covering the area from Wanzhou to Badong in the Three Gorges Reservoir area between June 2018 and April 2020 recently proposed workflow of small baseline InSAR to investigate the landslide hazard. The new workflow can be split into two steps: i) invert network of interferograms for raw phase time-series and ii) separate tropospheric delay, topographic residual, timing error, and orbital error from raw phase time-series to derive the displacement time-series(Yunjun et al. 2019). We identified 16 potential landslides within the buffer of 5km around the transmission channel from the result of InSAR-derived displacements. To assess the accuracy of the InSAR results, we compared time-series cumulative displacement from BeiDou Navigation Satellite System (BDS) sites with InSAR results and found that the discrepancy between BDS displacements and InSAR results are within 10mm on most dates with a mean difference of ±3 mm and the standard deviation (std) of the discrepancies is ±8 mm.

1. Introduction

At present, the number of 500kv UHV(Ultra-High Voltage) transmission towers in the Three Gorges Reservoir area has exceeded 10,000 and UHV transmission system networks such as

Huangwan Line, Shenwan Line, Changwan Line, Panlong Line have been built. The complex topography, abundant precipitation, and human engineering activities have caused frequent geological disasters in the Three Gorges Reservoir area(Liao et al. 2012). And landslide is the major type of geological hazard accounting for more than 70% of geological disasters. The surface displacement caused by landslides poses a serious threat to the safety of transmission towers. Therefore, early identification of landslides in the Three Gorges Reservoir area is of great significance to the safe operation of the transmission network(Yuan et al. 2009, Guo and Zheng 2010).

Traditional landslide monitoring mainly relies on field surveys, which has the disadvantages of high cost and time-consuming in large-scale landslide monitoring(Yang et al. 2017). The emergence of differential Interferometric Synthetic Aperture Radar(D-InSAR)technology provides an effective supplementary method for traditional field measurement. However, the limitations of time-space decorrelation and atmospheric delay of D-InSAR technology limit its accuracy(Gabriel et al. 1989, Liao et al. 2012). To solve this problem, the advanced D-InSAR technologies, such as permanent scatterer(PS) methods(Ferretti et al. 2001, Hooper et al. 2004), small baseline subsets (SBAS) InSAR method(Berardino et al. 2002), permanent scatterer (PS)methods(Ferretti et al. 2001, Hooper et al. 2004) and SqueeSAR(Ferretti et al. 2011) have been developed. At present, InSAR technology has been widely used in landslide location detection and landslide deformation monitoring(Intrieri et al. 2018, Zhao et al. 2018). Li(Li et al. 2018) monitored the surface deformation near the transmission channel of the Jinsu Line in Sichuan Province using D-InSAR technology and found severe surface deformations. Peraya Tantianuparp(Peraya et al. 2013)monitored the surface deformation of Badong in the Three Gorges Reservoir area and identified two obvious landslide areas with ALOS PALSAR and ENVISAT ASAR datasets. Zhao(Zhao et al. 2016) analyzed the Xingyuan landslide in Shaanxi Province using SBAS InSAR technology.

The Three Gorges area has large terrain undulations, dense vegetation coverage, and rainy weather, which brings challenges to apply time-series InSAR analysis for landslide investigation. In this study, we monitored the surface deformation from the region of Wanzhou to Badong in the Three Gorges Reservoir area with a new processing workflow of SBAS InSAR and preliminarily identified potential landslides with a buffer of 5km around the transmission tower. The new workflow includes three new methods to correct the unwrapping phase error, which reduced the environmental impact on InSAR results.

2. Study Area and Datasets

2.1 Study Area

The Three Gorges Reservoir refers to the upstream region of the Yangtze River. The UHV transmission tower in this study spanning from Wanzhou in Chongqing city to Badong in HuBei Province in the Three Gorges reservoir(Figure1). The region is located in the transition zone from the second to the third topographic step, and the secondary folds and fault structures are well developed. The area is dominated by mountains and valleys, with complex geological conditions and abundant precipitation.

2.2 Datasets

The European Space Agency successfully launched two satellites, Sentinel-1A and Sentinel-1B in April 2014 and April 2016. The datasets of Sentinel-1 are in the C band with the center wavelength of 5.6cm and the revisit period of 12d. Sentinel-1 has the characteristics of a short revisit period and large coverage, and it is suitable for monitoring a wide range of geological and environmental disasters. In this study, 59 ascending images between June 2018 and April 2020 from path 84 were collected.

The location of the UHV transmission tower was obtained to investigate the potential landslide within a buffer of 5km around the tower. Displacement data of 5 observation stations measured by the Beidou Satellite Navigation System (BDS) were obtained to verify the InSAR results.

The precise orbit datas were employed for orbit correction and the 30m SRTM DEM data issued by the United States Geological Survey (USGS) was selected to remove the topographic residual in the results.

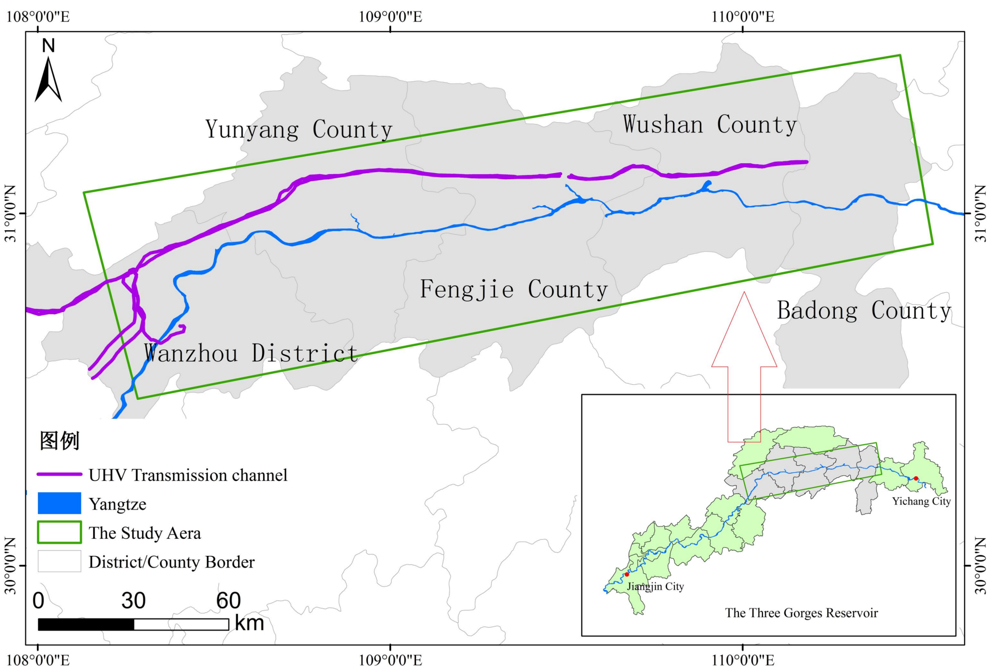

Figure 1. Study Area

3. Methodology

3.1 Small Baselines Subset InSAR Analysis

We assume that there are N+1 SAR images covering the same area acquired at t_0, t_1,...t_N, and each image can interfere with at least one image,this means that each short baseline subset consists of at least 2 images. This will generate M interferograms, M satisfies the following formula (assuming N is an odd number).

$$\frac{N+1}{2} \le M \le N\left(\frac{N+1}{2}\right) \tag{1}$$

We assume the i-th interferogram is generated from two SAR images obtained at time t_A and $t_B(t_B>t_A)$, The interference phase at i (x, r) can be expressed as $\varphi_i(x,r)$, where x and r represent the azimuth and range coordinates respectively, $i \in (1,2,3,\cdots, M)$:

$$\delta\varphi_i(x,r) = \varphi_B(x,r) - \varphi_A(x,r) \approx \delta\varphi^i_{disp}(x,r) + \delta\varphi^i_{topo}(x,r) + \delta\varphi^i_{atm}(x,r) + \delta\varphi^i_{noise}(x,r) \tag{2}$$

Where $\delta\varphi^i_{disp}(x,r)$ is the displacements phase, $\delta\varphi^i_{topo}(x,r)$ is the topographic residual phase, $\delta\varphi^i_{\mathrm{atm}}(x,r)$ is the tropospheric delay phase, $\delta\varphi^i_{\mathrm{noise}}(x,r)$ is the noise phase. The displacements phase can be expressed as:

$$\delta\varphi^i_{disp}(x,r) = \frac{4\pi}{\lambda}\left[d(t_B,x,r) - d(t_A,x,r)\right] \tag{3}$$

Where λ is the wavelength of SAR data， $d(t_A,x,r)$ and $d(t_B,x,r)$ are respectively the cumulative deformation at time t_A and t_B relative to the reference time t_0 in the radar line of sight (LOS), we generally assume $d(t_0,x,r)=0$.

After removing the topographic residual, atmospheric delay, and ignoring the influence of noise, Formula 1 can be simplified to:

$$\delta\varphi_i(x,r) \approx \frac{4\pi}{\lambda}\left[d(t_B,x,r) - d(t_A,x,r)\right] \tag{4}$$

The displacement of the time series can be expressed as $d(t_i,x,r)$, $i \in (1,2,3,\cdots,N)$ and the corresponding phase can be set as $\varphi(t_i,x,r)$：

$$\varphi(t_i,x,r) \approx \frac{4\pi}{\lambda} d(t_i,x,r) \tag{5}$$

The N unknown phase values corresponding to the deformation of the analyzed pixel point are expressed as a vector as：

$$\varphi^T = \left[\varphi(t_1),\cdots,\varphi(t_N)\right] \tag{6}$$

The M values calculated from the differential interferogram are expressed as a vector:

$$\delta\varphi^{T} = [\delta\varphi_1, \cdots \delta\varphi_M] \tag{7}$$

Then convert it into matrix form, where A is the M×N order matrix:

$$\boldsymbol{A}\varphi = \boldsymbol{\delta}\varphi \tag{8}$$

Since the interferograms of the small baseline subset are composed of multiple master-slave image pairs, it is necessary to obtain the generalized inverse matrix of matrix A through the matrix singular value decomposition (SVD) method, and finally, obtain the deformation variables of each time period.

In this study, MintPy software(Yunjun et al. 2019)was used for InSAR time-series analysis in the study area. It is a new workflow of SBAS InSAR, which can be split into two steps:(i)we first invert interferograms network for raw phase time series，(ii) then correct tropospheric delay, the topographic residual and noise phase to derive the displacement time-series.

3.2 Interferogram processing

Interferometric processing was performed on the 59 SAR images and each image was connected with 5 images around it. A total of 280 interferograms pairs were generated. We calculated the coherence of each interferogram and took the coherence of 0.35 as the benchmark to eliminate the interferograms with poor coherence, figure 2 shows the networks of interferograms used for the time-series analysis. The Global Atmospheric Models(GAMs) model was used to estimate the atmospheric delay with the datasets of ERA-5.

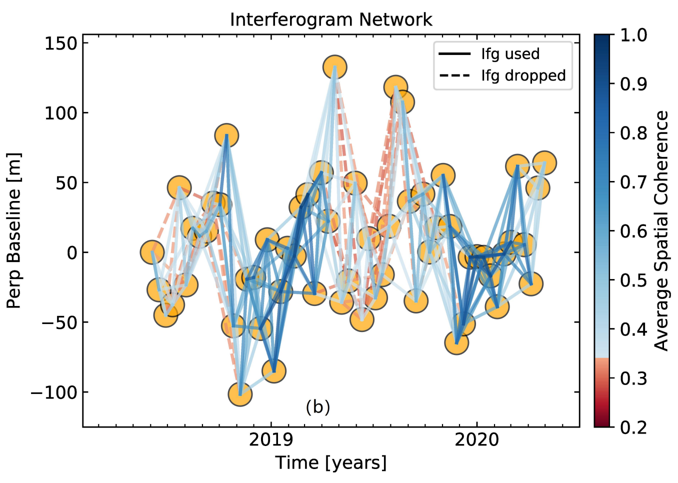

Figure 2. Interfergram Network

4. Results

4.1 Landslides Identification Results

We obtained the annual average displacement rate in line of sight(LOS) direction over the Three Gorges Reservoir from Wanzhou to Badong, as shown in Figure 3- Figure6. In these figures,the red and yellow negative values represent the displacement away from the satellite, and the blue positive values represents the displacement close to the satellite(Dai et al. 2020). In this study, we detected potential landslides in the area within 5km around the transmission tower line from the InSAR results. It should be mentioned that not all of the displacement information is caused by landslides, land remediation, construction, mining, and seasonal movements of the surface may also contribute to displacement information in the InSAR results(Wang et al. 2020). Therefore, the slope and aspect of mountains and topography information were combined to identify potential landslide.

For the convenience of analysis, the study area is divided into 4 sections: Wanzhou-Yunyang(A), Yunyang-Fengjie(B), Fengjie-Wushan(C), and Wushan-Badong(D). In this study, 16 potential landslides are preliminarily identified. there are 3 landslides in section A, 2 landslides in section B, 4 landslides in section C, and 7 landslides in section D, as shown in Figure 3-Figure 6.

4.2 Dangerous landslides

Landslides No. 6-8 are very close to the UHV transmission towers, which pose a direct threat to the safety of the transmission towers and they need special attention.

Landslide No. 6 and No. 7 are located in Wushan County of Chongqing City in Section C, as shown in Figure 7(a). According to the aspect and slope of the location of NO.6 landslide, if this landslide occurs, the deposits may slide to the UHV transmission tower to threaten the safety of the UHV transmission tower.

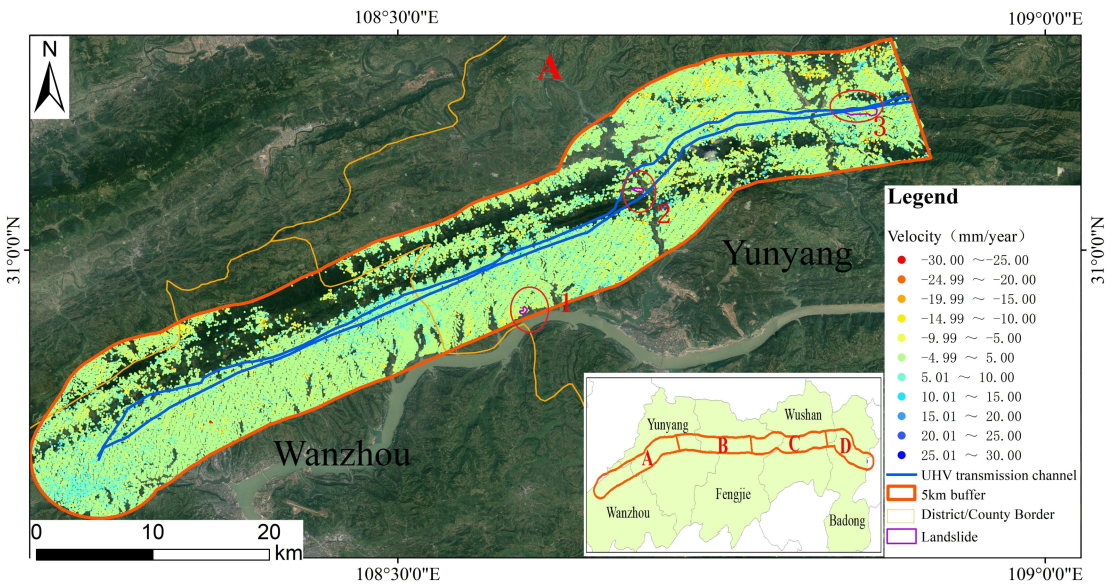

Figure 3. Average displacement rate in the LOS direction from Wanzhou to Yunyang

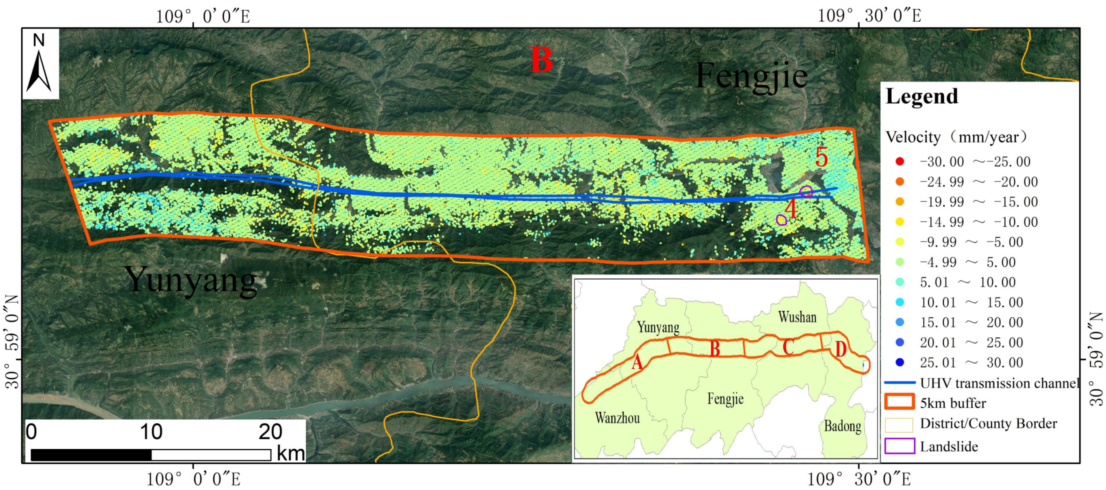

Figure 4. Average displacement rate in the LOS direction from Yunyang to Fengjie

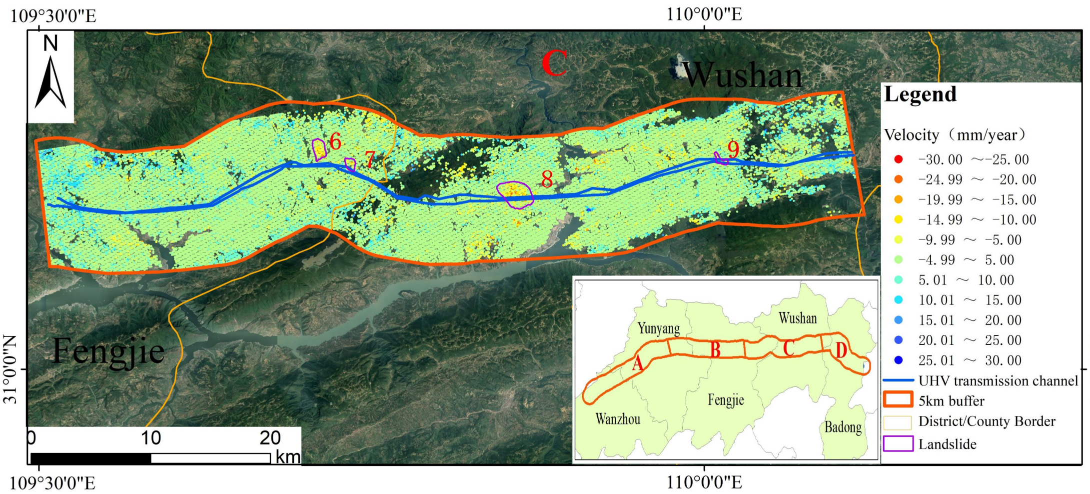

Figure 5. Average displacement rate in the LOS direction from Fengjie to Wushan

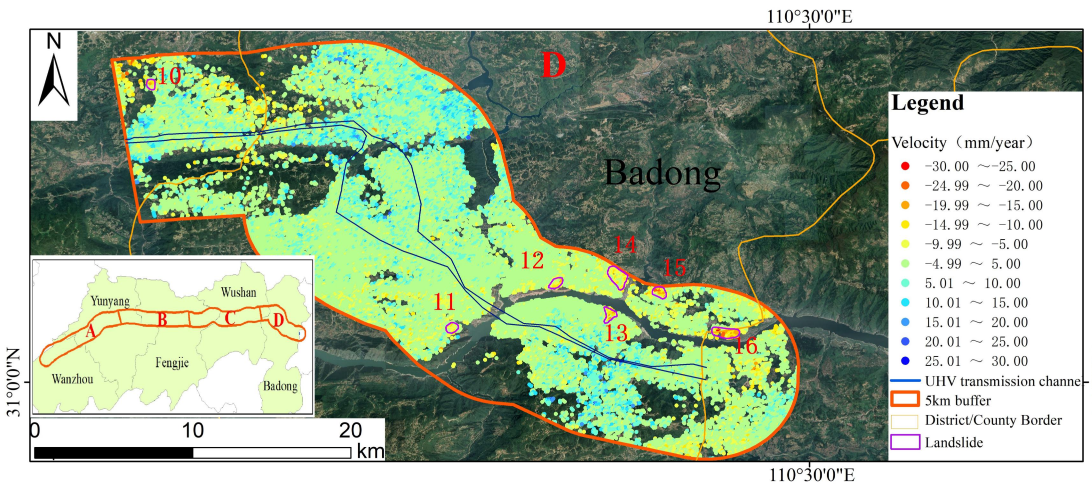

Figure 6. Average displacement rate in the LOS direction from Wushan to Badong

Landslide No. 8 is located along the Yangtze in Wushan County, Chongqing City in Section C, as shown in Figure 7(b). This landslide affects many UHV transmission towers, if this landslide occurs, it will threaten the UHV transmission towers and the Yangtze River.

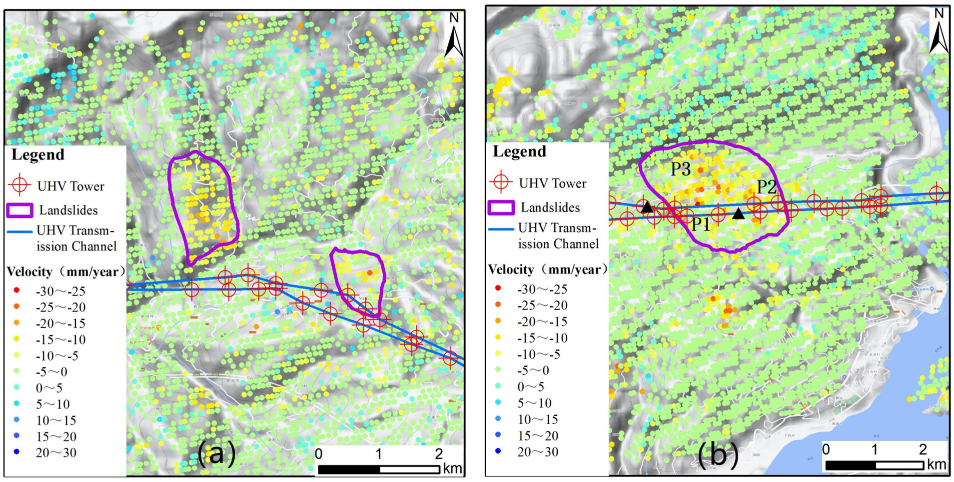

Figure 7. Displacement rate maps of the landslide directly threatening the UHV towers(a) Landslide No. 6 and No. 7 (b) Landslide No. 8

5. Comparison of time series InSAR results with BDS displacement

In this study, we obtained ground displacement data from 5 BDS sites in Badong County, Hubei Province from May 6, 2019 to April 30, 2020, as shown in Figure 8. The displacement data of BDS and the results of InSAR were compared in time series and we selected two BDS points for display,as shown in Figure 9. We found that in most of the monitoring dates, the differences between BDS displacements and InSAR results are within 10mm, which verifies the accuracy of InSAR results.

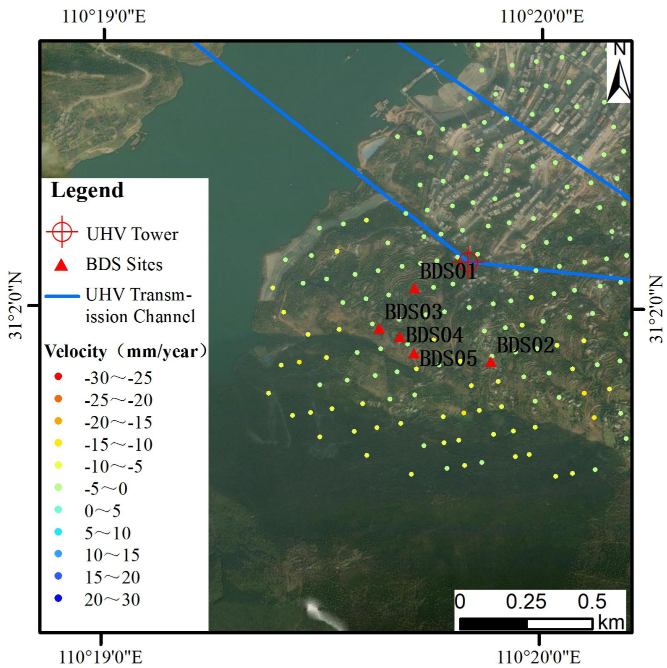

Figure 8. Location of BDS sites

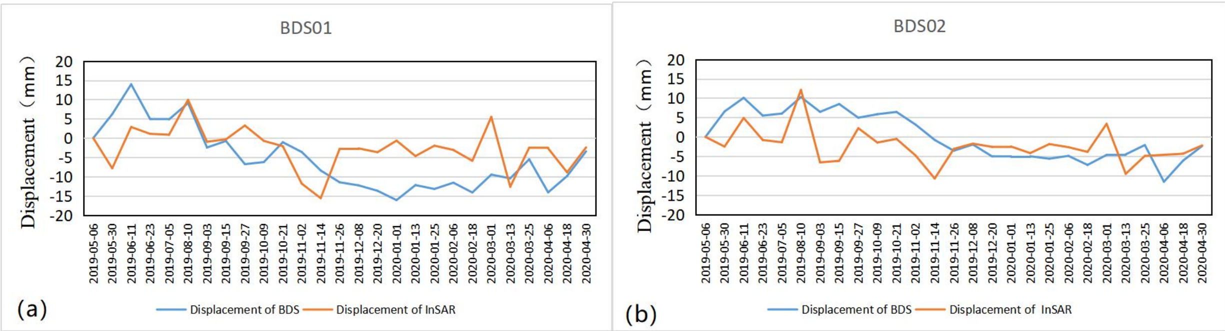

Figure 9. Comparison of InSAR results and BDS sites displacement (a)BDS01(b)BDS02

6. Conclusion

In this paper, we conducted a time-series InSAR analysis of sentinel-1 data covering the area from Wanzhou to Badong and interpreted the InSAR derived results of the 5km area around the UHV transmission tower. We successfully identified 16 potential landslide hazards and validated the InSAR results with ground displacement data of the BDS site. It demonstrated that InSAR technology can be used for early identification of landslides along with UHV Transmission Channels in The Three Gorges Reservoir Area.

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