Present-day crustal deformation around Kalpin block, Xinjiang, China, observed by InSAR

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Abstract: Due to the effect of the collision between the Indian plate and Eurasian plate, Pamirs is constantly moving to the north. Under the interaction among multiple tectonic blocks, strong earthquakes often occurred around the Kalpin block which is located in western Tianshan of Chinese continent. In this paper, we used Interferometric Synthetic Aperture Radar (InSAR) technique and adopted stacking algorithm to achieve the present-day crustal deformation field of the Kalpin block region based on 38 Envisat ASAR images. The results show that the deformation in radar line of sight around Kalpin block is mainly compressive between south and north with magnitude 1-1.5 mm/a. Displacement decreases gradually from northwest to southeast, which is consistent with the deformation characteristics shown in Tianshan, i.e. crust is gradually shortening from west to east detected by the GPS observations. Also, the Piqiang fault zone is uplifting. And there is an obvious displacement difference between the two sides of the Aozigeertawu fault.

Key words: InSAR; stacking; Kalpin block; deformation velocity

1 Introduction

The collision between Indian plate and Eurasian plate is the main tectonic dynamic source of the Chinese continent\cite{1-5}. The Cenozoic tectonic uplift of the Tianshan Range was a response to the intracontinental deformation within the India–Eurasia convergent system\cite{6}. Active faulting and folding affects the southern foreland basins of the Tianshan Range, indicating Cenozoic crustal shortening and uplift\cite{3,4,8}. The Pamir Plateau is one of the most prominent ongoing crustal deformation regions on earth, located at the western end of the India–Eurasia collision zone. Formation of the Pamir Plateau was associated with the northward displacement of the India Plate, with the extrusion of the Eurasian plate, Pamirs become the deepest parts due to the subduction effect of the Indian plate\cite{7,8-10}. Paleomagnetic and geological survey results prove that the distance from south to north has been reduced at least 200–300 km since the Oligocene\cite{9,11}. The Tarim block is moving towards north pressed by the Pamirs, while Tianshan is located between the Tarim block and Junggar block\cite{12-14}. Therefore, under this compressive tectonic background, many strong earthquakes occurred at the Wushi region which is located at the border between south Tianshan and Pamirs\cite{5,8}. Those strong earthquakes include 1902 Aushi M8.1 earthquake, 1993 Manas M7.7 earthquake, 1931 Fuyun M8.0 earthquake, 1996 Atushi M6.9 earthquake, M6 strong earthquake swarms of Jiashi in 1997 and M6.8 earthquake of Bachu, Jiashi in 2003\cite{15}. The GPS results show that the crust shortening rate is about 6–8 mm/a around the south Tianshan and northwestern margin of the Tarim block due to the thrusting effect\cite{16-18}. And the crust shortening magnitude for both sides of the
Piqiang fault achieved 40 km and 45 km, respectively\(^{19}\). China Earthquake Administration also considered this region has the potential of moderate to strong earthquake in the next 10 years\(^{20}\). Regional gravity data acquired over the past a few years indicates that this region is capable of generating moderate-strong earthquakes (personal communications). Therefore, it is significant for understanding regional tectonic deformation of the Kalpin block. As a new spatial observation technology, InSAR technology was developed in the last 20 years. Owing to the advantage of wide range and continuous space observation, InSAR has been widely used in detecting regional deformation\(^{21}\). In this paper, we present crustal deformation around the Kalpin block region by using InSAR data and stacking algorithm. Our results provide a regional deformation background which is helpful for local earthquake monitoring and prediction.

2 Data and method

2.1 InSAR data

We collected SAR images covering the Kalpin block from ENVISAT satellite, operating on C band. Between August 2003 and June 2010, ENVISAT acquired 38 radar images covering Kalpin block region, providing 7 years of continuous observations.

2.2 InSAR data processing strategy

Traditional D-InSAR technique is vulnerable to atmospheric artefacts. Studies show that the 20% relative humidity changes of cloud within spatial or temporal domain would lead to 10–14 cm deformation error\(^{23}\). Taking into account the atmospheric artefacts, we chose interferograms stacking algorithm\(^{24–26}\) to achieve the average deformation rate. By weighted average (generally using interval of each interferogram for weight) to multiple interferograms covering the same area, interferograms stacking technique carried out weakening residual errors of atmospheric delay phase and track contained in each interferogram, achieved the aim to improve the reliability of deformation result.

Considering long perpendicular baseline could lead to spatial decorrelation, we only chose the interferograms with perpendicular baselines shorter than 150 m. Moreover, taking into account the actual deformation situation of Kalpin region, if interferogram time interval is too short, the deformation signal will be small, so we only chose the interferograms with time interval longer than 6 months. 135 interferograms was generated by random combination. Getting rid of the interferograms obviously contaminated by atmospheric errors caused by troposphere turbulent, 40 interferograms (Fig. 2) with better coherence were obtained.

For each interferogram, we used the two-pass InSAR approach\(^{27}\) to form deformation interferograms. Effects of topography were removed from the interferograms using a filled 3 arc sec (about 90 m) resolution Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM)\(^{28}\) obtained from the Consultative Group on International Agricultural Research ‘s Consortium for Spatial Information (CGIAR-CSI, http://...
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Figure 2 Baselines and InSAR combinations. Images are denoted by solid circles. Black solid lines connecting circles represent perpendicular baselines of the corresponding interferograms.

To improve the signal-to-noise ratio, interferograms were downsampled to 4 looks in range and 20 looks in azimuth (80 m × 80 m) and were filtered twice using an adaptive filter function based on the local fringe spectrum [29], with the dimensions of the windows are 128×128 and 32×32 pixels, respectively. This filtering strategy removes the high frequency noise efficiently [30], and makes the phase unwrapping much easier. Minimum cost network flow (MCF) algorithm [31] was used during phase unwrapping, and pixels with coherent coefficient greater than 0.8 were unwrapped. To remove residual orbit errors, a fine estimation of the interferogram baseline is obtained by nonlinear least-square adjustment of the observed phase over presumably stable areas [32,33]. For the interferograms that are obviously contaminated by topography-correlated atmospheric delays, we make a linear correction based on topographic height, using phase observations of areas far from the deformed areas as a guide.

Figure 3 shows the average rate of crustal deformation along the radar's line of sight from 2003–2010 in Kalpin region. The Tianshan orogen uplifts relative to the Tarim Basin with the uplift rate of 1–1.5 mm/a. This result is slightly larger than the present-day thrusting uplift rate of the folds in Kalpin, i.e. 0.06–0.98 mm/a [34]. However, our results are consistent with the InSAR-derived results made by Qiao et al. [35].

GPS data show the western Tarim Basin moving about at a speed of 20 mm/a, and the eastern Tarim Basin moving at a speed of 14 mm/a [36]; the rates that Tianshan Mountains have shorten from north to south are different. For example the shorten rate is 3 mm/a in the eastern region and the shorten rate is 10–12 mm/a in the western region [36]. Relative to the Kazakh platform, horizontal motion speed is about 19–22 mm/a in the western Tianshan mountains, and the eastern region is about 7–8 mm/a [17]; The shorten rates are also the western areas is bigger than the eastern areas [17]. The same time, the western Tarim Basin is currently moving northeastward, as well as eastern Tarim Basin is moving northward [36]; western Tianshan mountains is moving northeastward at rate of (3.8 ± 4.5°), eastern Tianshan Mountains is moving northeastward at rate of (18 ± 16°)°. In summary, although the results of GPS referenced datums are different, changes of the western region are bigger than the eastern region, no

3 InSAR results
matter where are Tarim Basin and Tianshan Mountains and no matter horizontal movement speed and shorten rate; The direction of motion displays some certain clockwise movement form. In the aspect of vertical deformation, The results of InSAR show that the Tianshan Mountains and Tarim Basin have the characteristics of the vertical deformation rate decreased gradually from west to east, but the interior Tarim Basin does not show apparent deformation. The results of GPS and InSAR have the very good consistency. Two aspects of horizontal deformation and vertical deformation attest that northern margin of west Kunlun-Pamir arc nappe structure belt wedged into Tianshan tectonic belt has the characteristic that the strength-deformation of the west region is stronger than the east region. This characteristic is the mainly reason in currently situation of region tectonic movement of Tianshan Mountains and Tarim Basin.

Three sections shown in figure 4 were further done in allusion to Aozigeertawu fault, Yiketuokekalawuer fault and Kekeya fault (Fig.4). It is visible that it does not have correlation between the deformation rate and terrain. Therefore, it eliminated the errors caused by deformation rate to vertical layered effect of atmospheric water vapor in the troposphere, which shows the result of rate is reliable.

Both sides of Aozigeertawu fault, the differential movement of tectonic zone of Tianshan along the radar sight reached 4 mm/a with respect to Wushi sag. There were differential movement on both sides of Yiketuokekalawuer fault, but its magnitude was smaller, at around 1–2 mm/a. Nearby Kekeya fault in the southern of parcel had the small scope of crustal uplift, the magnitude was smaller, at around 1.5 mm/a. This crustal uplift is different on both sides of Qiqiang fault, the results of InSAR show that the scope of rising region in the eastern fault belt is more larger than it the in western fault. The reason is the Bachu fault uplift block the Kalpin fault uplift pushing to the Tarim Basin. Qiqiang fault is the important the transform fault coordinating the different tectonic movement of the west and east of the Kalpin fault uplift.

4 Conclusion

Kalpin fault uplift is the strongest thrust and fold deformation region in the northwest Tianshan Mountains. The deformation of Kalpin along the radar’s line of sight is mainly compressive between southern and northern. Tectonic deformation decreases gradually from northwest to southeast, which is consistent with the characteristics that Tianshan crustal is gradually shortening from west to east from the GPS observations\(^37\). The result is the new evidence that the Indian plate pushed the Eurasian plate caused the arc tectonic zone in the north edge of Kunlun-Pamir has the character that the western is more intensity than eastern when it wedged into the Tianshan tectonic zone.

The interior of thrust belt in Kalpin, both sides of thrust belt in Qiqiang exist rising uplift region, and the scope of rising region in eastern of thrust belt is more larger than it in western. This results reveal because of the Bachu fault uplift blocking, the tectonic dynamic conditions are very complex in the eastern Kalpin fault uplift.

It is significant for the difference of deformation on two sides of Aozigeertawu fault, but the distribution of medium-strong earthquakes has been relatively scarce since 1970, therefore, it has the seismogenic background of earthquakes above medium-strong around the fault.

![Figure 4](image-url)
References


