The Analysis of the Abnormal Characteristics of GPS Data before the 2013 Minxian-Zhangxian M_S6.6 Earthquake

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Abstract. To study the movement characteristics of crustal deformation around the epicenter before the M_S6.6 earthquake in Minxian-Zhangxian in 2013, the paper analyzes the GPS velocity field, the baseline time series between stations and the time series of the epicentral region strain, and then discusses the characteristics of the crustal deformation before the earthquake. It is shown from the results that the Lintan-Tanchang fault and the Northern Xiqinling fault are in the inner circle of the clockwise vortex, which have obvious stress accumulation. Among the two velocity fields in 2004-2007 and 2009-2011, there are significant differences in the direction and amplitude of the movement around the Lintan-Tanchang fault, which may cause the risk of earthquake events. The baseline time series reflect the strain accumulation in NE side of Lintan-Tanchang thrust fault with NE-trending was quite high before the earthquake, and the velocity of the SW side was accelerating, which might be the main cause of the earthquake. Since 2013, the extrusion deformation of EW direction and plane shrinkage rate near the epicenter had shown an obvious weakening tendency, as well as the left-lateral shear of NW direction of the causative fault. The evidence of deformation loss before the earthquake was significant and the accumulation of strain was relatively obvious.

1. Introduction

At 07:45 on July 22nd, 2013, an M_S6.6 earthquake occurred at the junction of Minxian-Zhangxian in Dingxi City, Gansu Province. The focal depth is about 20 km (http://www.csi.ac.cn). The earthquake occurred in the region between the Lintan-Tanchang fault and the Northern Xiqinling fault, about 9.3 km from the Lintan-Tanchang fault. The Lintan-Tanchang fault is in the north segment of the North-South Seismic Belt and the fault generally goes NW-NWW, which is a thrust fault with a slight left-lateral strike-slip component with a tendency of NE and dip angle of 50-70° [1, 2]. The complex structure in the region is composed of multiple different sizes sub-faults which are parallel or oblique, belonging to the intermediate transitional region of the two deep faults between the East Kunlun fault and Northern Xiqinling fault. In the structural position, it belongs to the position of strain accumulation and conversion transition [3, 4]. The seismic activity of the fault has the segmented characteristics and overall strong of the east and weak of the west, with strong historical seismic activity. Before the earthquake, a lot of GPS continuous and flow observation data were accumulated in this region. Based on GPS flow observation data since 1999 and GPS continuous observation data since 2010 provided by the First Monitoring and Application Center, China Earthquake

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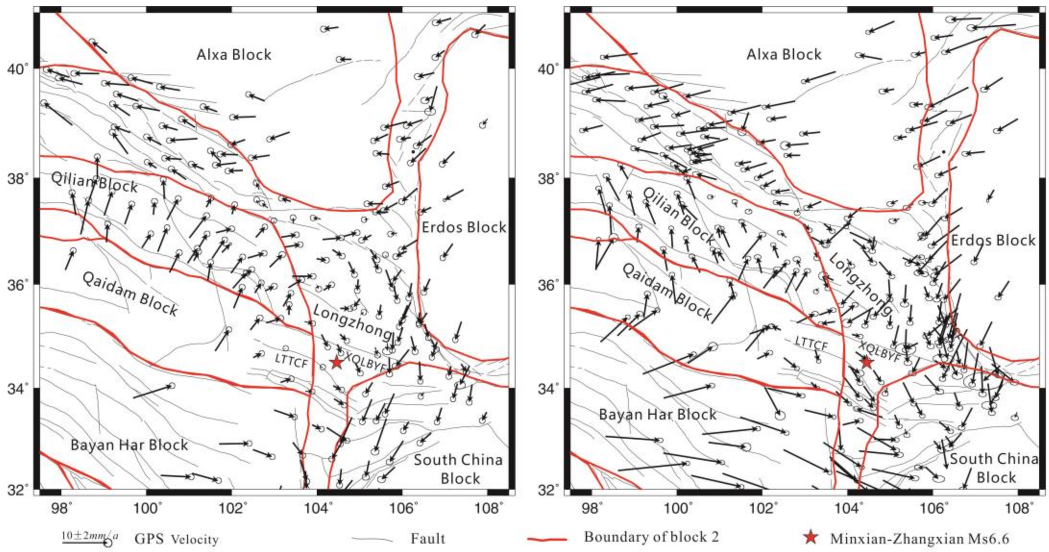
Administration, the GPS velocity field in the focal region of the earthquake, the baseline time series between the stations and the strain time series of the deformation units near the epicenter have been analyzed, and the characteristics of the crustal deformation before the earthquake have been discussed. The study helps to understand the seismogenic process and mechanism of the earthquake and provides basic research data.

2. GPS velocity field analysis

With many groups of GPS observation data since 1999 disposed by the GAMIT / GLOBK software and the QOCA software [5-7], GPS velocity fields in 2004-2007 period and 2009-2011 period are obtained (the velocity field in 2008 was affected by the Wenchuan earthquake, so no analysis in this year), and the specific treatment strategy can refer to the literature [8]. To reflect the relative movement and deformation of the crust more intuitively and clearly through the GPS observation of velocity field, it is usually possible to deduct the rigid motion without deformation information of the study area [9]. Since the earthquake occurred in the Lintan-Tanchang fault stretching across the Longzhong Basin and the Qaidam block, and its south side is south China block, the largest relatively stable block in mainland China, when using GPS data to study the Lintan-Tanchang fault movement and deformation, taking the stable South China block as a reference is the most appropriate choice. Therefore, based on the results of the velocity field of the ITRF2005 reference frame, this paper discusses the GPS velocity field taking the South China block as a reference. Figure 1 shows the distribution of velocity fields in the two periods. XQLBYF represent Northern Xiqinling fault, LTTCF represent Lintan-Tanchang fault in Figure. 1.



2004～2007 period GPS velocity field 2009～2011 period GPS velocity field

Figure 1. Results of GPS velocity field (south China datum)

The results of the GPS velocity field in Figure. 1 show that there are significant differences of the motor direction and amplitude of the GPS velocity field in the Lintan-Tanchang fault in 2009-2011 period in comparison with the velocity field of 2004-2007 period.

From the distribution of relative movement in the large area, velocity fields of the two periods show that the overall differential movement of the Qinghai-Tibet block by the thrust of the Indian plate is the most notable, showing the NE shortening and NW stretching of crustal. The eastern part of Qinghai-Tibet block pushes the South China block to the east, and the velocity vector in GPS station shows obvious north-south difference. Lateral extrusion slip deformation of the Sichuan-Yunnan rhomb blocks leads to the most significant differential movement in the southeastern part of the

Qinghai-Tibet block, showing the clockwise twisting movement character around the Assam. In the clockwise twisting movement pattern in this large area, the Lintan-Tanchang fault and the Northern Xiqinling fault are in the inner circle stress accumulation zone of the clockwise vortex, and the direction is deflected from near NNE to SE direction, which is a stress accumulation zone with the possibility of an earthquake.

There are significant differences of the motor direction and amplitude of the GPS velocity field near the Lintan-Tanchang fault of 2009-2011 period in comparison with the velocity field of 2004-2007 period. In the velocity field of 2009-2011 period, the velocity in the area near the Lintan-Tanchang fault is significantly larger than the 2004-2007 period, and the motor direction of the NE side of the Northern Xiqinling fault changed from SE of 2004-2007 to SSW of 2009-2011, that is, perpendicular to the Northern Xiqinling fault. Hence, the significant differences of the motor direction and amplitude near the Lintan-Tanchang fault can be seen in comparison with the 2004-2007 period, which is at risk of an earthquake.

3. Result analysis of GPS baseline time series before the earthquake

The continuous stations of the Crustal Movement Observation Network of China started the test run in succession in June 2010, obtaining large-scale and high-precision continuous observation data of crustal movement deformation, which can get GPS baseline time series characteristics analysis and the baseline trend movement characteristics can be discussed. In addition, with the rigid motion strain model of the block in the plate, the cumulative time series of the continuous deformation parameters in the research area can be obtained by accumulative displacement difference calculation, and the strain time series analysis of the study area can be carried out. The continuous station distribution of GPS stations near the epicenter of Minxian-Zhangxian are shown in Figure 2.

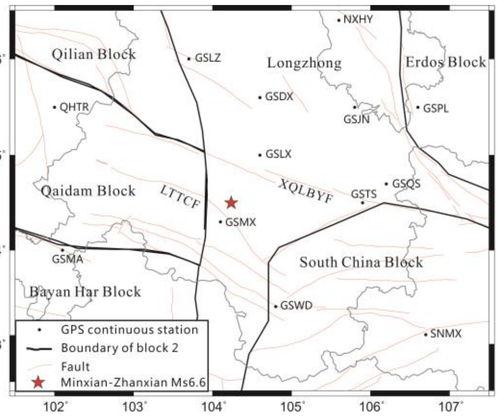


Figure 2. GPS continous station at Minxian-Zhangxian epicenter surrounding

As GPS baseline time series can weaken the influence of system error and common mode noise to a certain extent, the baseline time series reflects the change of surrounding tectonic environment more sensitively than the single station coordinate time series [10]. The baseline time series among the GPS stations are basically unaffected by the reference datum, and can directly reflect the shortening or elongation of the crust in the connecting direction of two stations, which is the dynamic change of relative motion between two stations [10]. The baseline of the area across the fault in the epicenter and its vicinity is selected to analyze the movement characteristics of the GPS baseline time series. The baselines of the anomalous features before the earthquake are GSMX-GSMA, GSMX-GSQS, GSMX-GSLX, GSMX-GSJN, GSMX-GSDX, GSMX-GSWD, as shown in Figure 3.

From the velocity field of Figure 1, it can be seen that the area near the Lintan-Tanchang fault was pushed by the NE trending movement of the Qinghai-Tibet Plateau and moved towards NE overall. Due to the obstruct of the two rigid blocks, the Erdos block in the east and the Alxa block in the north, there has been a large area clockwise twisting movement pattern, in which the Lintan-Tanchang fault and the Northern Xiqinling fault are in the inner circle zone of the clockwise vortex, showing the NE crustal shortening and SE stretching. The baseline of GPS continuous stations in this region of also reflects the movement (as shown in Figure 3). The slopes of the time series curves of the NE trending baselines GSMX-GSMA, GSMX-GSQS, GSMX-GSLX, GSMX-GSJN and GSMX-GSDX are all negative, indicating that the NE baselines are all shortened; the slope of the time series curve of the SE trending baseline GSMX-GSWD is positive, indicating that the SE baseline is stretched.

According to Figure 3, the movement patterns of the baselines on both sides of Lintan-Tanchang fault are obviously different. The baseline GSMX-GSMA on the SW side had an accelerating shortening phenomenon in the six months before the earthquake, indicating that the area on the SW side of the fault borne more push from NE side. The baselines GSMX-GSQS, GSMX-GSLX, GSMX-GSJN and GSMX-GSDX of NE side obviously shortened slower in the six months before earthquakes, indicating that the strain accumulation in NE side area before the earthquake had reached a certain level. As the Lintan-Tanchang fault was a NE trending thrust fault, the strain accumulation of NE side in Lintan-Tanchang fault before the earthquake was quite high and the velocity on the SW side was accelerating, which could be the main reason for the earthquake.

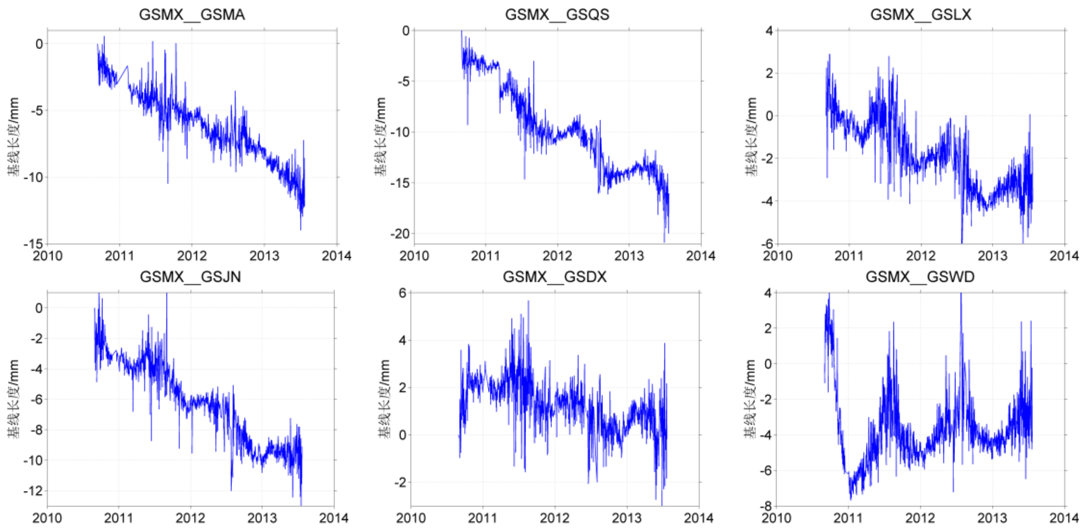


Figure 3. The GPS baseline time series nearby the Lintan-Tanchang fault
GSMX(Minxian)—GSMA(Maqu); GSMX—GSQS(Qingshui); GSMX—GSLX(Longxi); GSMX—GSJN(Jingning); GSMX—GSDX (Dingxi); GSMX—GSWD(Wudu).

4. Feature analysis of strain time series before the earthquake

The baseline among the stations reflects the deformation of the crust in the direction of the connection. When more than three GPS continuous stations are grouped together to form an area, the geometric deformation parameters of the area can be calculated. The time series changes of these deformation parameters can be analyzed to study out the regional deformation properties, strength and dynamic deformation characteristics [11]. The strain deformation parameters are basically unaffected by the reference datum, which can more reliably reflect the deformation properties and the degree of strain accumulation in this area. To further discuss the dynamic changes of the tectonics dynamic background in the epicenter before the Minxian-Zhangxian earthquake, the paper calculates the time series (As shown in Figure 4) of the continuous deformation parameters of deformation units composed of GSMX, GSLX and GSWD GPS continuous stations around the epicenter (east-west strain ε_e, north-south strain ε_n, principal stretching strain rate ε_1, principal squeezing strain rate ε_2, first shear strain rate γ_1, plane strain rate Δ) to reveal the dynamic process of crustal deformation before the earthquake area of the GPS continuous stations near the epicenter.

In this paper, for the time series of east-west strain ε_e and north-south strain ε_n, the negative value indicates the squeezing state, and the positive value indicates the stretching state. The value of the principal strain rate (principal stretching strain rate ε_1, principal squeezing strain rate ε_2) reflects corresponding principal stress changes and their relative magnitude. The first shear strain γ_1 reflects the shear deformation in the NE and NW directions, positive values indicating left-lateral shear in the N45 ° E direction or right-lateral shear in the N45 ° W direction caused by north-south squeezing and east-west stretching (negative values with deformation in the opposite direction). For plane strain, negative values of Δ mean squeezing and positive values mean expanding.

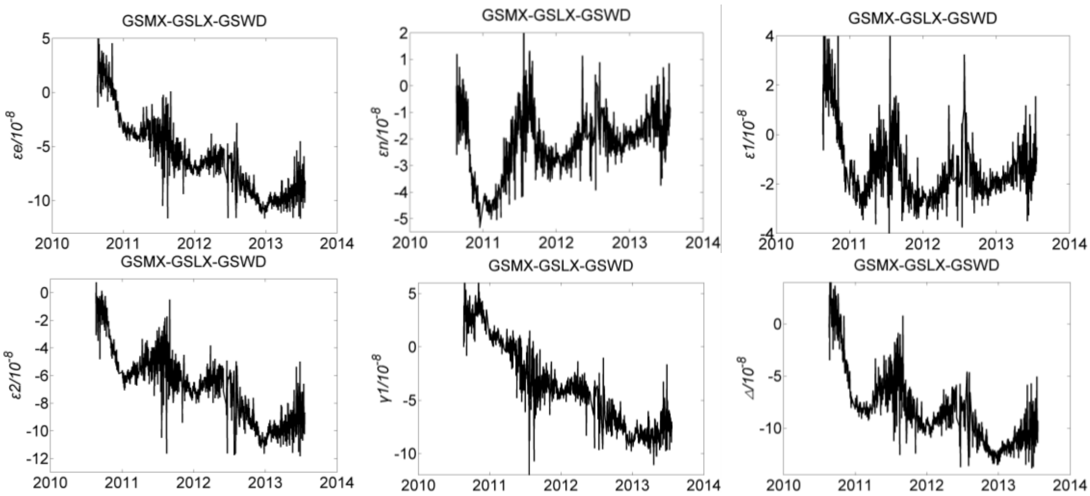


Figure 4. GPS strain timeseries nearby the region of Menyuan earthquake

According to the curve tendency of the strain time series of three GPS continuous stations in Figure 4, GSMX (Minxian), GSLX (Longxi) and GSWD (Wudu), the principal squeezing strain ε_2 is similar to the EW linear strain ε_e and has the characteristics of a certain annual cycle. The EW linear strain ε_e is greater than NS linear strain ε_n, with the squeezing strain rate ε_2 significantly greater than the stretching strain rate ε_1, so this area shows that the EW squeezing strain rate is dominated. The first shear strain rate γ_1 is negative, indicating that the area had been subjected to the influence of NW left-lateral shear before the Minxian-Zhangxian M_S6.6 earthquake in 2013. The cumulative trend of plane strain Δ is squeezing. The east-west line strain ε_e, the principle squeezing strain ε_2, the first shear strain γ_1 and the plane strain Δ have almost the same values and trend of change, and are all negative, indicating that the region is always subject to squeezing. It can be concluded that the area was affected by plane contractions, crustal shortening in the NNE-near-EW direction, and NW left-lateral shearing before the Minxian-Zhangxian M_S6.6 earthquake in 2013. This is consistent with the seismogenic structure of the earthquake (left-lateral converse strike slip fault).

The East-west line strain ε_e, the principle squeezing strain ε_2, the first shear strain γ_1 and the plane strain Δ have almost the same trend of time series curves, and all have the characteristics of non-linear accumulation, showing as the faster to slower process. The four time series curves all deviate from the original squeezing rate from 2013. In mid-2013, the peak position is higher than the trend and does not decrease to the trend value. The squeezing rate after 2013 has been significantly slower down than the trend before 2013, reflecting that since 2013, near the epicenter, the EW side extrusion deformation, plane shrinkage rate and causative fault left-lateral shear action of NW had an obvious weakening tendency, that is, there were signs of deformation loss in the area before the earthquake and the region had accumulated a high degree of strain energy before the earthquake. Hence, the surrounding anomalous change before the earthquake cannot be ruled out.

5. Results and discussion

(a) The study results of velocity field show that the Lintan-Tanchang fault and the Northern Xiqinling fault are in the inner circle stress accumulation zone of the clockwise vortex. Among the two velocity fields in 2004-2007 period and 2009-2011 period, there are significant differences in the direction and amplitude of the movement around the Lintan-Tanchang fault, which may cause the risk of earthquake events.

(b) The time series of GPS baseline around the epicenter reflect the strain accumulation in NE side of the Lintan-Tanchang fault was quite high before the earthquake, and the velocity of the SW side was accelerating, which could be the main cause of the earthquake.

(c) The strain time series results of the epicentral region reflect the existence of deformation loss and the strain energy accumulation of higher degree in the region before the earthquake.

(d) The surrounding anomalous change before the earthquake cannot be ruled out, but the anomalous change of the impending earthquake is not obvious.

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