Crustal Movement Characteristics in the North-eastern Region of the Qinghai-Tibet Plateau Based on GPS reference station

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Abstract. To discuss the crustal movement characteristics in the northeastern region of the Qinghai-Tibet Plateau, the crustal deformation state and the annual movement rate of the GPS continuous baseline time series between the station in the stable blocks and the stations inter the Qinghai-Tibet Plateau are calculated based on the GPS data observed by the continuous stations in the Qinghai-Tibet Plateau and surrounding areas since 1999. The results demonstrate that the compression and shortening movements between the Qilianshan block, the Qaidam block, the Bayan Har block and the two rigid blocks, Alxa block and the Ordos block, are relatively strong. However, the extension or compression rate between the two rigid blocks and the Qilianshan seismic belt, the Longzhong basin tectonic region and the South China block is quite small. It is indicated that the compressed or extended movement between the suture zone of the two blocks and the northeast edge of the Qinghai-Tibet Plateau is small. It is illustrated that certain strain energy may accumulate in the region and have a relatively high potential for strong earthquakes.

1. Introduction

The northeastern arc-shaped tectonic belt of the Qinghai-Tibet Plateau is an important active tectonic belt between the three inlaid blocks: the Qinghai-Tibet Plateau, the Ordos block and the Alxa block [1]. The Alxa block is located in the north of the northeastern margin of the Qinghai-Tibet Plateau, and the Ordos block is located in the east of the northeastern margin of the Qinghai-Tibet Plateau. Moreover, the Alxa block and the Ordos block are relatively stable. Considering that it is located in the drastically-uplifting frontier part in the northeastern Qinghai-Tibet Plateau, this region becomes one of the zones where the structural activities are the most active and the seismic activities are the most frequent in Qinghai-Tibet Plateau. In this region, active fault zones, such as the Qilian Mountain, the Haiyuan Fault, the Liupanshan Fault and the northern fault zone of the West Qinling Mountain, have been developed from north to south since the Neotectonic era. Driven by the main active force by northward extrusion and impact onto the Eurasia Continent by the Indian Plate, and blocked by the rigid Alxa Block and Ordos Block, the characteristics of geological structural activities in the active
fault zone in the northeastern edge of the Qinghai-Tibet Plateau are mainly demonstrated as NE extrusion-thrust and sinistral strike slip-rotation [2]. The Huining Ms7.0 earthquake in 1352, the Zhongwei Ms7.2 earthquake in 1561, the Guyuan Ms7.0 earthquake in 1622, the Tianshui South Ms8.0 earthquake in 1654, the Zhongwei Ms7.5 earthquake in 1709, the Yinchuan-Pingluo Ms8 earthquake in 1739, the Wudu Ms8 earthquake in 1879, the Haiyuan Ms8.5 earthquake in 1920, the Gulang Ms8 earthquake in 1927 and over ten M6~6.9 earthquakes occurred in this region [3, 4], and thus this region is equipped with strong seismic development background.

Earthquake results from the sudden release of all the long-term accumulated strain during crustal movement [5]. The energy for earthquake preparation comes from the accumulation of strain energy generated in the crustal movement process under the impact of structural boundary dynamic force [6]. Considering that GPS observation can provide the relative movement information in multiple spatial dimensions, applying these observation results into the research of relation between temporal-spatial distribution dynamics of the crustal movement and strong earthquakes as well as the seismic deformation process and mechanism might become a vital aspect for seismic forecasting research to expand into physical forecasting. Generally, strong earthquakes usually occur in a local region where the crustal movement remains low or some small regions where the trend of the crustal deformation to slow. These regions often have a high possibility of strong earthquakes because the elastic deformations of the regions may reach a limit state and the fault may remain locked [7, 8].

The 25 continuous stations established based on the "Crustal Movement Observation Network of China (CMONOC)" have observed since 1998. Besides, the 260 continuous stations based on the "China Mainland Tectonics Environment Monitoring Network (CMTEMN)" have observed since August 2010. The high-precision and large-scale continuous observation data provide the necessary support for analyzing the dynamic characteristics of regional crustal deformation. The GPS baseline time series refers to the variation curve of the length of the ground line between two stations versus time. It is calculated using data from two GPS continuous stations. The baseline time series between GPS stations is generally not affected by the reference datum. It is capable of directly reflecting the shortening or extension of the crust between the stations. In other words, it can reflect the dynamic characteristics of the relative movement between the two stations. Thus, the baselines often use to describe the extension, compression or slippage characteristics of the fault zone or the boundary zone of the block [10]. If the slope of the baseline time series curve is positive, representing the baseline is in an extended state. It is illustrated that the extension or strike-slip state occurs between the two blocks or both sides of the fault zone. However, if the slope of the baseline time series curve is negative, representing the baseline is shortening, and also reflecting a compression or strike-slip state is occurred between two blocks or both sides of the fault zone.

To analyze the movement characteristics of the blocks in the northeastern Qinghai-Tibet Plateau, two rigid blocks, the Alxa block and the Ordos block, are selected. The DXIN station and the NMEJ station located in the Alxa block, the YANC station located in the Ordos block, 11 stations in the Qinghai-Tibet Plateau (the LHAS station in the Lhasa block, the DLHA station, the QHGE station and the QHDL station in the Qaidam block, the QHMD station and the QHBM station in the Bayan Har block, the GSAX station, the GSJY station, the QHQL station and the QHME station in the Qilianshan seismic belt, and the GSDX station, the GSJT station and the NXHY station in the Longzhong basin tectonic region) and the SNTB station in the South China block are chosen. The continuous baseline time series between the stations are calculated based on the GPS continuous station data which resolved by the First Monitoring Center, China Earthquake Administration in the northeastern margin of the Qinghai-Tibet Plateau since 1999. The crustal deformation characteristics of the northeastern Qinghai-Tibet Plateau in the past 20 years are analyzed [11,12]. Furthermore, the characteristics of the internal deformation of the Qinghai-Tibet Plateau and the external movement between the blocks in the northeastern part of the Qinghai-Tibet Plateau and the two rigid blocks are discussed. The results can provide a valuable basis for studying the movement characteristics of the blocks in the northeastern margin of the Qinghai-Tibet Plateau. Moreover, it may afford some basis for predicting strong earthquakes in this region.
2. Characteristics of the GPS baseline time series between the Alxa block, the Ordos block and the Qinghai-Tibet block

Figure 1 is a diagram of GPS baselines between the CMONOC base stations in the two stable blocks and those in the Qinghai-Tibet block. The DXIN station is located in the Alxa block, the YANC station is located in the Ordos block, the DLHA station is located in the Qaidam block and the LHAS station is located in the Lhasa block. Figure 2 to Figure 6 show the GPS baseline length time-series of the stations. Table 1 shows the movement direction, state, the annual variation ratio (AVR) and the trends of the baselines which are shown in Figure 2 to Figure 6.

![Figure 1. GPS baseline of CMONOC between the two stable blocks and the Qinghai-Tibet block](image1)

![Figure 2. The baseline length time series of DXIN-LHAS, (a) original curve, (b) detrended results](image2)

![Figure 3. The baseline length time series of DXIN-DLHA, (a) original curve, (b) detrended results](image3)
Figure 4. The baseline length time series of YANC-LHAS, (a) original curve, (b) detrended results

Figure 5. The baseline length time series of YANC-DLHA, (a) original curve, (b) detrended results

Figure 6. The baseline length time series of LHAS-DLHA, (a) original curve, (b) detrended results
Table 1. The AVR and trends of GPS baseline in Figure 1.

| Baseline   | Direction | State  | AVR (10^{-7}a^{-1}) | Trends                                                                 |
|------------|-----------|--------|----------------------|------------------------------------------------------------------------|
| DXIN-LHAS  | NNE       | Shorten| -20.21               | Shortening rate slowed down after the 2008 Wenchuan M8.0 earthquake, and then accelerated after the 2010 Yushu M7.1 earthquake, finally slowed down after the 2012 Sumatra M8.6 earthquake. |
| DXIN-DLHA  | NNE       | Shorten| -3.63                | Shortening rate slowed down after the 2001 Kunlun Mountain M8.1 earthquake, then accelerated after the 2010 Yushu M7.1 earthquake. |
| YANC-LHAS  | NE        | Shorten| -20.05               | Shortening rate slowed down after the 2008 Wenchuan M8.0 earthquake, then accelerated after the 2010 Yushu M7.1 earthquake, finally slowed down after the 2012 Sumatra M8.6 earthquake. |
| YANC-DLHA  | NEE       | Shorten| -2.71                | Shortening rate slowed down after the 2001 Kunlun Mountain M8.1 earthquake, then accelerated after the 2010 Yushu M7.1 earthquake. |
| LHAS-DLHA  | NNE       | Shorten| -7.77                | Shortening rate accelerated after the 2012 Sumatra M8.6 earthquake. |

As shown between Figure 2 and Figure 6, the AVR of the baselines DXIN-LHAS, DXIN-DLHA, YANC-LHAS, YANC-DLHA and LHAS-DLHA are -20.21×10^{-7}/a, -3.63×10^{-7}/a, -20.05×10^{-7}/a, -2.71×10^{-7}/a and -7.77×10^{-7}/a, respectively. The AVR of the baseline DXIN-LHAS is 5.6 times larger than that of the baseline DXIN-DLHA, and the AVR of the baseline YANC-LHAS is 7.4 times larger than that of the baseline YANC-DLHA. It is illustrated that the AVR between the two rigid blocks (the Alxa block and the Erdos block) and the Lhasa block is significantly larger than that between the two rigid blocks and the Qaidam block, indicating that the internal deformation is relatively strong in the Qiangtang block and Bayan Har block between the LHAS station and the DLHA station.

The detrended curves of the baselines DXIN-LHAS and YANC-LHAS which are respectively shown in Figure 2 and Figure 4 are similar, which with the same trends after the three major earthquakes occurred in the Qinghai-Tibet block and surrounding areas between 2008 and 2012. The shortening of the baselines slowed down after the Wenchuan M8.0 earthquake, and then accelerated after the Yushu M7.1 Earthquake, however, it re-slowed down after the Sumatra M8.6 Earthquake in 2012. The detrended curves of the baselines YANC-DLHA and DXIN-DLHA which are respectively shown in Figure 3 and Figure 5 are similar, which with the same trends after the 2001 Kunlun Mountain M8.1 earthquake and the Yushu M7.1 earthquake. The shortening of the baselines slowed down after the M8.1 earthquake and then accelerated after the M7.1 earthquake. The detrended time series of the baseline LHSA-DLHA in Figure 6 shows that the shortening of the baseline accelerated after the Sumatra M8.6 earthquake in 2012.

3. Characteristics of the GPS baseline time series between the Alxa block, the Ordos block and other blocks

As the base stations of the CMTEMN have observed since August 2010, the data accumulation duration is less than that of the base stations of the CMONOC. Moreover, the variations of the baseline curves are inconspicuous. The schematic diagram of the GPS baseline between the CMTEMN stations in the Alxa block and that in other blocks in the Qinghai-Tibet Plateau and surrounding areas are shown in Figure 7. The schematic diagram of the GPS baseline between the
CMTEMN stations in the Ordos block and that in other blocks in the Qinghai-Tibet Plateau and surrounding areas are shown in Figure 8. The AVR of the baselines are shown in Table 2.

### 3.1. Characteristics of the GPS baseline time series between the Alxa block and other blocks

As shown in Figure 7 and Table 2, the AVR of the four baselines NMEJ-QHGE, NMEJ-DLHA, NMEJ-QHDL and NMEJ-QHMD, which between the Ejinaqi station located in the Alxa block (NMEJ) and four stations in the Qaidam and Bayan Har blocks, are $-4.37 \times 10^{-7}/a$, $-3.91 \times 10^{-7}/a$, $-3.63 \times 10^{-7}/a$ and $-2.80 \times 10^{-7}/a$, respectively. The AVR of the four baselines NMEJ-GSAX, NMEJ-GSJY, NMEJ-QHQL and NMEJ-QHME from NMEJ to the Qilianshan seismic belt are $-0.34 \times 10^{-7}/a$, $-0.62 \times 10^{-7}/a$, $-0.68 \times 10^{-7}/a$ and $-0.79 \times 10^{-7}/a$, respectively. The results show that the AVR between the Alxa block and the Bayan Har block / the Qaidam block is 3.5 to 12.6 times larger than that between the Alxa block and the Qilianshan seismic belt. It is indicated that the internal deformation of the Qaidam and Bayan Har blocks is relatively strong. The AVR of the baselines between NMEJ and two stations located in the Longzhong basin tectonic region (NMEJ-GSDX and NMEJ-NXHY) are $1.23 \times 10^{-7}/a$ and $0.88 \times 10^{-7}/a$, respectively. However, the AVR of the baseline between NMEJ and the YANC station which located in the Ordos block is $1.15 \times 10^{-7}/a$. The three baselines are in an extension state with NW direction, which is significantly different from the above eight baselines in a compression state with NE direction. Moreover, the AVR of the three baselines is 2 to 5 times less than those between NMEJ and the Bayan Har block / the Qaidam blocks. However, the AVR between the three baselines is quite similar to those between NMEJ and the Qilianshan seismic belt, indicating that the compression rate with an NW direction is relatively small in the northeastern margin of the Qinghai-Tibet Plateau.

### 3.2. The CMTEMN GPS baselines between the Ordos block and other blocks

As shown in Figure 8 and Table 2, the AVR of the baselines YANC-QHME, YANC-QHDL, YANC-QHMD and YANC-QHBM which between the Yanchi station in the Ordos block and the stations in the Qilian block, the Qaidam block and the Bayan Har block are $-2.48 \times 10^{-7}/a$, $-3.04 \times 10^{-7}/a$, $-4.67 \times 10^{-7}/a$ and $-4.22 \times 10^{-7}/a$, respectively. The AVR of the baseline YANC-GSJY which between the YANC and the Jiayuguan station in the Qilianshan seismic belt is $1.15 \times 10^{-7}/a$. The AVR of the baselines YANC-GSJY, YANC-GSDX and YANC-SNTB which between the YANC station and the stations in the Longzhong basin tectonic region are $-1.21 \times 10^{-7}/a$, $-1.66 \times 10^{-7}/a$ and $-0.21 \times 10^{-7}/a$,
respectively. The results show that the annual variation ratio between the Ordos block and the Qilian block, the Qaidam block and the Bayan Har block is 2.2 to 4.1 times larger than that between the Ordos block and the Qilianshan seismic belt, and it is 1.5 to 3.9 times larger than that between the Ordos block and the Longzhong basin tectonic region. However, it is 11.8 to 22.2 times larger than that between the Ordos block and the South China block. It is illustrated that the annual compressed variation ratios between the Ordos block and the Qilian block, the Qaidam block and the Bayan Har block are relatively high, and it between the Ordos block and the Longzhong basin tectonic zone is relatively low. The annual extended variation ratio between the Ordos block and the Qilianshan earthquake belt is much lower, and it between the Ordos block and the South China block is the lowest.

**Figure 8.** Schematic diagram of the CMTEMN GPS baseline between the Ordos block and other blocks

| Baseline | Direction | State | AVR ($10^{-7}$·a$^{-1}$) |
|----------|-----------|-------|--------------------------|
| NMEJ-DLHA | NNE | Shorten | -3.91 |
| NMEJ-QHDL | NNE | Shorten | -3.63 |
| NMEJ-QHGE | NNE | Shorten | -4.37 |
| NMEJ-QHMD | NNE | Shorten | -2.80 |
| NMEJ-GSAX | NNE | Shorten | -0.34 |
| NMEJ-GS1Y | NE | Shorten | -0.62 |
| NMEJ-QHQL | NS | Shorten | -0.68 |
| NMEJ-QHME | NS | Shorten | -0.79 |
| NMEJ-YANC | NW | Extension | 1.15 |
| NMEJ-NXHY | NW | Extension | 0.88 |
| NMEJ-GS1DX | NW | Extension | 1.23 |

| Baseline | Direction | State | AVR ($10^{-7}$·a$^{-1}$) |
|----------|-----------|-------|--------------------------|
| YANC-QHME | EW | Shorten | -2.48 |
| YANC-QHDL | NEE | Shorten | -3.04 |
| YANC-QHMD | NEE | Shorten | -4.67 |
| YANC-QHBM | NE | Shorten | -4.22 |
| YANC-GS1DX | NE | Shorten | -1.66 |
| YANC-GS1JY | EW | Shorten | -1.21 |
| YANC-SNTB | NS | Extension | 0.21 |

### Table 2. The AVR of GPS baselines.

4. Conclusion and discussion
The adjustments after the strong earthquakes occurred in western China since 1999 are well reflected by the long-distance baselines based on the data from CMONOC stations. The annual variation ratios
between Lhasa block and the two rigid blocks, the Alxa block and the Ordos block located in the northeast edge of the Qinghai-Tibet Plateau, are extremely larger than the AVR between the two rigid blocks and the Qaidam block. It is indicated that the current crustal deformation of the Qiangtang block and the Bayan Hara block in the Qinghai-Tibet Plateau is strong.

According to the short-distance baselines based on the data from the CMTEMN illustrate that the variation ratio in the northeastern region of the Qinghai-Tibet Plateau wasn’t obvious since 2010. The difference of the AVR between different blocks was quite large, indicating the compressed movement between the two rigid blocks and the Qilian block, the Qindam block and the Bayan Hara block was extremely strong. However, the variation ratio between the two rigid blocks and the Qilianshan seismic belt, the Longzhong basin tectonic region and the South China block is relatively small, indicating the compressed or extended movement between the suture zone of the two blocks and the northeast edge of the Qinghai-Tibet Plateau is small. It is illustrated that certain strain energy may accumulate in the region and have a relatively high potential for strong earthquakes.

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