Velocity Field, Block Motion and Strain Field in Mainland China derived from GPS observations*

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Abstract

On the basis of horizontal velocity field at 932 GPS sites derived from the GPS observations during the period from the establishment of Crustal Movement Observation Network Of China (CMONOC) in 1998 to the end of 2001, the current characteristics of horizontal motion and deformation in Mainland China are studied under the so-called block motion and deformation model. The results show that at present, the Mainland China can be divided into 12 active tectonic blocks with obvious relative motions between each other. Taking the North-South Seismic Belt as the boundary, the relative motions in the eastern part are small except the motions of Yanshan block relative to its neighboring blocks on the north and south. In the contrast to the eastern part, the relative motions in the western part are much stronger between the blocks with the trend of gradual decrease from the south to the north. The patterns and magnitudes of the activities along the boundaries among the 12 active blocks are studied quantitatively. And the calculated entire and local deformations of all active blocks are discussed one by one.

Key words: GPS, velocity filed, block motion, deformation, strain, China

1. Introduction

In 1998, 25 continuously observed GPS fiducial stations of CMONOC were put into operation normally. In the same year, 56 GPS basic stations were observed for the first time (each station was observed continuously for 8 days and nights at least). From March to June in 1999, 1000 local GPS stations were observed for the first time (each station was observed continuously for 4 days and nights at least). From March to August in 2001, 56 basic stations and 895 out of the 1000 local GPS stations were observed repeatedly (still 8 and 4 days and nights for the basic stations and local stations, respectively). Till the end of 2001, we had obtained the high-quality GPS re-measurement data from almost 1000 stations, which provides the possibility to study the current deformation in Mainland China.

In fact, the deformation in Mainland China has been studied by many geo-scientists on the basis of GPS observations (Huang et al., 1997; Zhou et al., 1998; Huang et al., 2003a,b; Gu et al., 2000; Zhu et al., 1997; Zhang et al., 2000; Ma et al., 2001; Wang et al., 2001). All the data used in the studies were obtained under the project of the so-called Climbing Project, or the data obtained from 25 GPS fiducial stations and 56 GPS basic stations of CMONOC. The main difficulty in the studies is insufficient data, especially in the study on the tectonic block motion and deformation in Mainland China. The detailed study could not be made and the reliability of the

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quantitative results is affected due to the insufficient density and accuracy of data. To solve the problem, Wang Qi et al.(Qi Wang et al., 2001) synthetically re-processed the data taken from the monitoring network of ‘Climbing Project’, the fiducial and basic stations of CMONOC and other monitoring networks and stations distributed in Tianshan, Sichuan-Yunnan, Longmenshan, Qilianshan and North China areas established and observed by different institutions or organizations. Then, the map of velocity field distribution in Mainland China containing over 400 GPS stations was given (Qi Wang et al., 2001; Zhang et al., 2002a,b). However, these data were observed in accordance with different standards and as a result, they had unequal accuracies. Generally speaking, except for the data from CMONOC, the data from the other monitoring networks and stations are of slightly lower accuracy. Now, we have obtained the data with better accuracy and better density of GPS stations from the overall re-observation of CMONOC, so that it is possible to make a more detailed study on the current crustal movement and deformation in Mainland China.

2. Acquirement of crustal horizontal velocity field in Mainland China

When the field observation was finished in the August of 2001, the re-observed data with high accuracy at 932 GPS sites in Mainland China were obtained (see the previous section). The data were processed individually according to the same processing strategy and software (GAMIT and GLOBK) by several units that took part in the establishment of CMONOC under the organization of Engineering Center of CMONOC. During the period of data processing, the preprimary results obtained by different units were compared and the processing strategy were discussed and improved for many times. In January of 2003, the data processing concluded. However, it was found by comparison that the final velocity fields obtained by two units still had some small differences. The statistics of the differences between the velocity field solutions A and B are listed in Tab.1.

A synthesized solution is derived from both sets of solutions according to the method given by Ma et al 2003, which is taken as the basis for the deformation analysis hereafter.

Table 1

The comparisons between the synthesized solution and the solutions A and B are listed respectively in Tab.2.

Table 2

The above velocity field solution is derived with respective to ITRF2000. In order to make the study on the relative deformation in Mainland China more visual, the velocity of Euro-Asia plate with respective to ITRF2000 is deducted from the velocity field, so the remained velocity can be considered as the motion of Mainland China relative to the Euro-Asia plate. The motion of Euro-Asia plate can be easily derived by either the parameters of model NUVAL1A (DeMets C. et al., 1990; Donald F. Argus et al., 1991) or the parameters of the so-called “Global plate motion model NNR-ITRF2000VEL” given by Zhu Wenyao (Zhu et al., 2002). Fig.1 shows the velocity field at 932 stations in Mainland China, in which the motion of Euro-Asia plate obtained by model NUVAL1A has been deduced.

Fig. 1

3. Model for motion and deformation analysis

The model employed to describe the motion and deformation in Mainland China is the one of "Block relative motion + Block homogeneous strain + Local strain in block" (BBL), in which the observed horizontal displacements (or horizontal motion velocities) v_n, v_e (with the corresponding errors e_n, e_e) at each station can be described as the sum of the three parts as follows (Huang et al., 2003):

$$\begin{cases} V_n + e_n = V_{n1} + V_{n2} + V_{n3} \\ V_e + e_e = V_{e1} + V_{e2} + V_{e3} \end{cases} \qquad (1)$$

Where, V_{n1}, V_{e1} are the displacements along with the motion of the whole Euro-Asia plate, which can be derived from the position of the observation site and Euler's rotation vector of Euro-Asia plate. In the paper, the parameters of Euler's rotation of Euro-Asia plate are taken from the model NNR-NUVAL1A (Ye et al., 2000). V_{n2}, V_{e2} denote the site displacements caused by the homogeneous strain of the block where the observation site is located. V_{n3}, V_{e3} denote the site displacements caused by the local deformation occurred at the observation site. The relationship between the displacement and the strain parameters has been given (Huang et al., 2003). It is not necessary to go into details here.

It should be noticed that V_{n2} and V_{n3}, V_{e2} and V_{e3} are piled up together and should be separated by a certain method. If the sites containing obvious V_{e3} and V_{n3} are considered as a kind of interference on the observation of the entire motion and deformation of the block, or as a kind of "gross error" in the observations, the sites should be picked out from the parameter calculation of the entire motion and deformation of the block. Then the remained observation sites (considering as a group of relatively stable sites) can be used to derived V_{n2} and V_{e2}. After V_{n1}, V_{e1} and V_{n2}, V_{e2} are deducted from the observed displacements for all the observation sites, the remains with the observation errors are considered as V_{n3} and V_{e3} that are used to derive the local strain parameters. Here, a popularized QUAD (Quasi-Accurate Detection of gross errors) method (Huang, 2002) is used to determine the group of relatively stable sites within the active blocks.

4. Movement and deformation of active blocks in Mainland China

Based on the evidences in many aspects, such as seismogeology, deep structure background, active fault investigation, geophysics (seismic activity, geomagnetism, gravity etc.), the Mainland China can be divided into 6 first grade active blocks and 21 second grade blocks by Professor Zhang Pei-zhen (Zhang et al., 2002). They are North-East Asia block that consists of 3 secondary blocks of China-Mongolia, China-Korea and Yanshan, North China block that consists of 3 secondary blocks of Erdos, North-China Plain and Eastern Shandong−Yellow Sea, South China block that consists of 2 secondary blocks of South China and South China Sea, Western Region block that consists of 6 secondary blocks of Tarim, Tianshan, Junggar, Alxa, Altai and Sayan (outside China), Qingzang block that consists of 6 secondary blocks of Lhasa, Qiangtang, Bayankela, Qaidam, Qilian and Sichuan-Yunnan, and China-Burma block that consists of 2 secondary blocks of South Yunnan and West Yunnan. There are boundary zones with various widths and different variations among the first and secondary blocks (see Fig. 2).

The following characteristics of crustal movement in Mainland China can be seen from the comparison between the velocity field obtained in Section 2 and the active blocks mentioned above.

1). There is a boundary zone between the first grade blocks in the eastern part of China (including North-East Asia, North China and South China blocks) and the first grade blocks in the western part of China (including Western Region, Qingzang and China-Burma blocks), which is the famous North-South tectonic zone in geology, the North-South seismic zone in seismology and the most distinct gradient zone in topography in Mainland China. It can be seen from Fig.1 that this zone is also the most significant boundary for the variation of velocity field in Mainland China. The eastern and western parts of Mainland China have a distinct difference in the current crustal movement. The motion vectors in the western part are much larger than those in the eastern part, which shows very clearly the feature of strong crustal movement in the west and weak crustal movement in the east. On the other hand, the obvious difference also exists in the motion directions in the two parts: the eastern part has a NEE direction, while the western part has an inconsistent direction with the east direction in the northwestern part and the SE direction in the southwestern part (see Fig.1).

2) The boundary zone between the two first grade blocks (West Region block and China-Burma block) goes along the Alkin−Qilian Mountain−Haiyuan faults. The magnitudes and directions of motion vectors are quite different on the north and south sides of the boundary zone, indicating that there is relative motion between the two first grade blocks. The motion vectors on the south side are larger with a predominated direction of NE, showing the motion and deformation trend of Qingzang plateau under the impacting and pushing of the moving plate. In contrast, the motion vectors on the north side are smaller and the direction of the vectors turns gradually from northwards to slightly westwards, reflecting that the blocks located in the northern part are mainly affected by Qingzang plateau.

3) The boundary zones of first grade blocks in the eastern part of Mainland China are also shown in Fig.1. For example, China-Mongolia block with Yanshan zone as the boundary and North China block (including Erdos, North China plain and Eastern Shandong−Yellow Sea secondary blocks) on its south have an obvious difference in both motion magnitude and direction. In fact, China-Mongolia block is the most stable one with the smallest motion in Mainland China.

4) Another boundary zone between the two first grade blocks of North China block and South China block in the eastern part of China also show different motions on both sides. The motion on the south side (South China block) has a larger component

towards the south as compared with that on the north side (North China block), indicating the proximate NS-trending extensional deformation between the two blocks with Qingling-Dabieshan mountains as the boundary.

5) Another distinct feature in Fig.1 is that the directions of motion vectors in Yunnan-Sichuan block rotate gradually from southeastwards in the north to southwards or even southwestwards in the south, indicating the clockwise rotation of the block relative to the surrounding blocks. The dynamic mechanism of the phenomenon is an important problem to be studied. One of the most eye-catching features in Fig.1 is that the eastern part of Qingzang plateau rotates clockwise around the eastern Himalayan tectonic knot. In Fig.1, the directions of the motion at the GPS stations to the east of the eastern Himalayan tectonic knot are about NE45-55°. Then the directions turn gradually to about NE65-80° towards the east, to SE105-115° to the western part of Sichuan that is located to the east of the eastern Himalayan tectonic knot, further to SE120-135° along the eastern boundary of Qingzang plateau southwards to the southern part of Sichuan-Yunnan rhomb tectonic block, and then to SE155-165° southwards to the western region of Yunnan. This kind of rotation is different from that of rigid plate, which may be caused by the plastic flow of the relatively weak crustal material of Qingzang plateau under the pushing of the moving plate (King et al., 1997; Royden et al., 1997; Zhang et al., 2002b). The vector difference in the EW component between the eastern part of Qingzang plateau and South China block hasn't been transformed to shortening and thrusting of the crust but has been absorbed and adjusted by the clockwise rotation instead.

6) It can be found from the investigation of the secondary tectonic blocks that there is no significant difference between some neighboring secondary tectonic blocks, which indicates that they have no relative motions, while there are really significant relative motions between some neighboring secondary tectonic blocks. This kind of difference may be related to the medium properties of the blocks or to the fact that the combination patterns of the active blocks may be different during different time periods (Zhang et al., 2002a).

In order to investigate the activities of the boundaries between the blocks, the active blocks are identified by the QUAD method. And the activity patterns and intensities of the boundary zones are calculated with Eulerian vectors for the rigid bodies introduced above (Huang et al., 2003a). Based on the distinguished result, 21 secondary tectonic blocks are combined into 12 active blocks with obvious relative motions between them. The Eulerian vectors and activity intensities of the boundary zones are listed in Tab.3.

Table 3

Table 4

The homogeneous strain parameters of 12 active blocks are listed in Tab.4. Considering from the strain parameters in Tab.2 and taking the 2 factors of r.m.s as the distinguishing criterion for significance, we should say that most parameters are not significant. However, the mechanics features of some blocks can still be recognized from certain parameters. For examples, the NS-directional intensive compression of Tianshan and Tarim blocks, the NS-trending strong extension and EW-trending compression of QiangTang and Bayankela blocks, the intensive shear strain of Sichuan-Yunnan block, the NS-directional compression and shear strain of West Yunnan block, the EW-directional compression of South Yunnan block (including the wide boundary zone between West Yunnan and South Yunnan blocks on the west side) and the NS-trending compression of Yanshan block. In addition, except Yanshan block, the entire deformations of other blocks (China-Mongolia, China-Korea, North China plain, Eastern Shandong, Yellow Sea, Erdos and South China blocks) in the eastern part of China are not significant.

5. Strain fields in active blocks

Based on the surplus displacements V_{n3}, V_{e3} mentioned above, the inner local strain in each active block is calculated at the net points with the density of $0.25^{\circ}\times0.25^{\circ}$. Fig. 2 shows the contour map of the maximum shear strain R of the active blocks and Fig. 3 the contour map of surface expansion.

Fig. 2

It can be seen from the magnitude and distribution of the maximum shear strain (Fig.2) that among the 12 active blocks, China-Mongolia + China-Korea block is the one with the smallest and weakest variation in strain distribution. North China + Eastern Shangdong-Yellow Sea block and Erdos block are of small strain with no obvious variation. Taking the North-South tectonic zone that divides the Mainland China into the eastern and western parts mentioned in Section 4 as the boundary, only Yanshan block in the eastern part has the heavily concentrated maximum shear strain contour lines with large magnitude. It is a tectonic block that suffers from significant compression (“–“ means compression). Considering from the analyzed results in the previous section, it can be concluded that both the north and south boundaries of the block have obvious relative motions, especially the south boundary. The distribution characteristics of the surface extension and shear strain are basically the same in the total eastern part of Mainland China. That is to say, where the shear strain is larger with significant variation, the surface extension here is also larger and the variation is significant.

Although there is no significant relative motion along the boundary zone between the Erdos block and North China block (the so-called ‘Shanxi belt’) in eastern part of China according to the analysis of block motion, however its maximum shear strain and surface extension are more significant than the boundary zone（the so-called Tanlu belt）between North China Plain block and Eatern Shandong-Yellow Sea block. In addition, the area around Erdos block is a strain concentrated area, which indicates that the motion of Erdos block is different from the surrounding blocks and may result in tectonic activity and strain accumulation (Zhang et al., 2003).

Fig. 3

In the total western part of China (taking the North-South tectonic zone as the boundary), the strain distribution is more intensive and complicated than that in the eastern part. Sichuan-Yunnan, West Yunnan, South Yunnan + South-West Yunnan blocks are the most eye-catching blocks, in which the contour lines of maximum shear strain and surface extension are crowded together with large values. Two small regions in Sichuan–Yunnan block and one small region in South Yunnan block are the strain concentrated locations (There are also two strain concentrated locations in the west of West Yunan block. They are close to the boundary line between China and Burma where no GPS sites are situated). In these regions, no large earthquake has taken place although the seismic activities in these regions are active in recent years. The deformation features observed by GPS deserve great attention.

Another block with significant deformation in the western part of China is Qiangtang + Bayankela block. We have noticed that there are strain concentrated locations along its two boundaries (see Fig.3). One can see from the surface extension in Fig.3 that it is a compressed tectonic active block. Lhasa block to the south of Qiangtang + Bayankela block has only a few observation sites. As a result, it is not only impossible to study the motion with respect to Qiangtang block on its north, but also the deformation of itself can be calculated neither. So that, the gaps (without contour lines) on Lhasa block in Fig.2 and Fig.3 does not mean there is no significant deformation in the block.

To the north of Qiangtang + Bayankela block, it is Qaidam + Qilian block. The locations with relatively significant deformations are the northeast and northwest margins of the block. Generally, Qiangtang + Bayankela block is also a compressed block.

From Qaidam + Qilian block to the north, it goes successively into Tarim + Tianshan block and Junggar + Altai +Alax block. The most significant characteristics here is that the deformation becomes smaller and smaller (In fact, the deformation in the total western part of China becomes weaker and weaker from Qiangtang + Bayankela block in the south to Tarim + Tianshan block and Junggar + Altai +Alax block in the north). At the same time, the mechanical property of the blocks changes gradually from the compression in the south to the extension in the north. The transition zone of mechanical property transformation is just located along the north margin of Qaidam + Qilian block. In addition, we have noticed from Fig.2 and Fig.3 that in the inner of the merged blocks (The mergence is made because there is no significant relative motions between these blocks), the boundary zones between the merged blocks (e.g. the belt between south and north Tianshan) show slightly larger deformations than the other places of the block.

6. Conclusive remarks

Based on the latest observations from CMONOC, the active blocks, the relative motions between the blocks and the deformation of the active blocks are determined. The characteristics of horizontal movements and deformations in Mainland China are studied and analyzed. The results have provided an effective surface deformation constrain for inferring the dynamic mechanism that causes the deformation in Mainland China.

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