The Current Crust Strain Fields in the Continent of China and Its Adjacent Areas from GPS Measurement Results

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Abstract

The movement and strain model of the crust block is presented in this paper, and the strain fields given according to the velocity fields from GPS networks in the continent of China and its adjacent areas. The space distribution of the strain fields is not homogenous, and there is the obvious regional feature. On the whole, the strain fields in the continent of China are strong and compressive in the west, and weak and expansive in the east. Furthermore, There are three regions of the higher compressive and shear strain, Taiwan, Himalayas mountain and Jiashi of Xijiang. Their maximum compressive strain rates are respectively 1.6×10^{-7}/yr, 8.9×10^{-8}/yr and 5.3×10^{-8}/yr; and the maximum shear strain rates respectively2.45×10^{-7}/yr , 6.5×10^{-8}/yr and 8.1×10^{-8}/yr. The strain fields in the continent of China and its adjacent areas are resulted from the interactive force among Indian plate, Philibin-sea plate and Eurasian plate. The direction of the principal compressive strain from GPS measurement data in this paper is ultimately consistent with that from geology and seismology.

1. Introduction

It is an important studying task on geodetics to observe the crustal movement and compute its strain. In the past, as the capability of measurement was limited, only could the strain fields in the local region be studied by conventional geodetic method, such as the triangle measurement, or three-length-measurement. In the recent decade years, a lot of precision GPS networks had gradually been established in China. The basic data sets for studying the crustal strain fields in the larger range would be provided by the repeated GPS measurements. In terms of the data sets, some geodetic scholars have researched on the strain fields in the parts of China continent. A rigid and elastic-plastic model of crust blocks can be established in this paper. Moreover, Based on the horizontal velocity fields from GPS measurements, the content of China and its adjacent areas will be divided into 54 blocks. The strain parameters of every block can be calculated respectively, and then the strain fields obtained in the continent of China and its adjacent areas.

2.The velocity fields in the continent of China and its adjacent areas

By using the data combination method of GPS networks (Li Yanxing, et al., 2001), the velocity fields in ITRF97 can be obtained in the continent of China and its adjacent areas (shown in fig. 1). It includes the velocity vectors of 423 GPS points, and its coverage area gets to 1200 million km^2. The average accuracy of velocity vectors of GPS points is 2.1 mm/yr.

3. Model of the strain fields

3.1. The model of rigid body motion

Based on Eular displacement law in rigid-body kinematics, the displacement of the rigid body with a fixed point can be described as a rotation rounding the axis through the fixed point (T. Doff, 1997). If the crust block can be regarded as the rigid body, its motion described as the rotation rounding the axis through the center of earth as a fixed point. In the coordinates with the center of the earth selected as the origin, if the absolute Eular vectors of the crust block is $\Omega(w_x$, w_y, $w_z)$, then the velocity of the point on the block V_G (V_x, V_y, V_z), whose vector-length is r (x, y, z), may be expressed as:

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} = \begin{bmatrix} 0 & z & -y \\ -z & 0 & x \\ y & -x & 0 \end{bmatrix} \begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix} \tag{1}$$

Supposed that the earth is regarded approximately as a sphere, and l and j are respectively the longitude and latitude of the point, then expression (1) may be changed into:

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} = \begin{bmatrix} 0 & r\sin j & -r\cos j\sin l \\ -r\sin l & 0 & r\cos j\cos l \\ r\cos j\sin l & -r\cos j\cos l & 0 \end{bmatrix} \begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix} \tag{2}$$

In expression (1) and (2), (V_x, V_y, V_z) is the velocity in the coordinates with the center of the earth selected as the origin. It can be translated into that of the station (observing point) as the origin. That is,

$$\begin{bmatrix} V_e \\ V_n \\ V_u \end{bmatrix} = \begin{bmatrix} -\sin l & \cos l & 0 \\ -\sin j\cos j & \sin j\sin l & \cos j \\ \cos j\cos l & \cos j\sin l & \sin j \end{bmatrix} \begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix} \tag{3}$$

Where V_e, V_n and V_u are respectively the velocity components on the longitudinal way, the latitudinal way and the vertical way in the coordinates with the station selected as the origin. When expression (2) is placed into (3), and V_u is not considered, thus the following expression can be derived:

$$\begin{bmatrix} V_e \\ V_n \end{bmatrix}_r = \begin{bmatrix} -r\cos l \sin j & -r\sin l \sin j & r\cos j \\ r\sin l & -r\cos l & 0 \end{bmatrix} \begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix} \quad (4)$$

Expression (4) is called the rotation model of the rigid crust block.

3.2. The elastic-plastic strain model of the crust block

For the crust block in the tectonic stress fields, there would be the deformation in its interior. Generally, certain point during deformation of the crust block is always elastic and plastic. That is, there is more or less elastic or plastic in the period (An Ou, 1992). Therefore, the strain of the crust block would be an elastic-plastic strain. The ortho-curve coordinate is frequently deployed on the sphere while the crust strain fields discussed in the larger range and the earth regarded as the sphere. Moreover, it is well known that the longitudinal and latitudinal line are orthogonality each other. In the investigated block, the ortho-curve-coordinates, which the geometric center (l_0, j_0) of the block is selected as the origin and the longitudinal and latitudinal line respectively as the y-axis and x-axis, can be established. Meantime, the longitude l and latitude j are taken on variables. Therefore, the point's coordinates (x, y) on the block can be expressed as:

$$x = (l - l_0) r \cos j \qquad y = (j - j_0) r \quad (5)$$

The point's displacements along the longitudinal line and latitudinal line can be described respectively as follows:

$$u = u(x, y) \qquad v = v(x, y) \quad (6)、(7)$$

As the displacement resulted from the deformation of the crust block is generally very small, above function (6) and (7) may be expanded at the origin by Tailor series and its 2nd order and more ignored. That is,

$$u = u_0 + \frac{\partial u}{\partial x}dx + \frac{\partial u}{\partial y}dy \quad v = v_0 + \frac{\partial v}{\partial x}dx + \frac{\partial v}{\partial y}dy \quad (8)、(9)$$

Where $u_0 = 0$, $v_0 = 0$, $\frac{\partial u}{\partial x} = e_e$, $\frac{\partial u}{\partial y} = e_{en}$, $\frac{\partial v}{\partial x} = e_{ne}$, $\frac{\partial v}{\partial y} = e_y$, $dx = x$, and $dy = y$.

Expression (8) and (9) can be changed further into:

$$u = e_e x + e_{en} y \qquad v = e_{vx} x + e_y y \quad (10)、(11)$$

If u and v are the displacements per time unit, then they are the velocity rates from the deformation respectively along x-axis and y-axis. Hence, expression (10) and (11) may be changed again into:

$$V_e = e_e x + e_{en} y \qquad V_n = e_{ne} x + e_n y \quad (12)、(13)$$

x and y are placed into above expression, the following expression can be obtained:

$$\begin{bmatrix} V_e \\ V_n \end{bmatrix}_s = \begin{bmatrix} e_e & e_{en} \\ e_{ne} & e_n \end{bmatrix} \begin{bmatrix} (l - l_0) r \cos j \\ (j - j_0) r \end{bmatrix} \quad (14)$$

where r is the average radius of the earth. Expression (14) is called the elastic-plastic strain model of the crust block.

3.3. The rigid and elastic-plastic movement and strain model of the block

The movement and deformation of the block is continuously variable with time. The deformation in the block interior may be regarded as the motion between the points. Therefore, the movement and strain model can be derived from expression (4) and (14).

$$\begin{bmatrix} V_e \\ V_n \end{bmatrix} = \begin{bmatrix} V_e \\ V_n \end{bmatrix}_r + \begin{bmatrix} V_e \\ V_n \end{bmatrix}_s$$

Further, the following expression may be acquired:

$$\begin{bmatrix} V_e \\ V_n \end{bmatrix} = \begin{bmatrix} -r\cos l \sin j & -r \sin l \sin j & r \cos j \\ r \sin l & -r\cos l & 0 \end{bmatrix} \begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix} + \begin{bmatrix} e_e & e_{en} \\ e_{ne} & e_n \end{bmatrix} \begin{bmatrix} (l - l_0) r \cos j \\ (j - j_0) r \end{bmatrix} \quad (15)$$

Expression (15) is called the rigid and elastic-plastic movement and strain model of the block.

4. The strain fields in the continent of China and its adjacent areas

The continent of China and its adjacent areas are divided into 54 blocks and there are 5 and more GPS station deployed on each block. According to the horizontal velocity components (V_e, V_n) of GPS station, four strain parameters of each block (e_e, e_{en}, e_{ne} and e_n) can be derived from expression (15). Moreover, based on the strain parameters, the principal strain (e_1, e_2) and its azimuth A, the shear strain between the east and north g_{en}, maximum shear strain $g_{\max}$ and surface strain Δ of each block can also be calculated respectively by the following expressions.

$$\begin{cases} e_1 = \dfrac{e_e + e_n}{2} + \dfrac{1}{2}\sqrt{g_{en}^2 + (e_e - e_n)^2} \\ e_2 = \dfrac{e_e + e_n}{2} - \dfrac{1}{2}\sqrt{g_{en}^2 + (e_e - e_n)^2} \\ A = \tan^{-1} \dfrac{g_{en}}{2(e_2 - e_e)} \\ g_{en} = e_{en} + e_{ne} \\ g_{\max} = e_1 - e_2 \\ \Delta = e_1 + e_2 \end{cases} \quad (16)$$

The calculated results of every block are given in table 1. Furthermore, based on the results, the strain contours in the continent of China and its adjacent areas, including the linear-strain contour on east, linear-strain on north, maximum shear strain and surface strain, are drawn respectively in figure 2～6.

5.The strain analysis in the continent of China and its adjacent areas

(1). The spatial change of the strain fields in the China continent and its adjacent areas would be non-linear, and represent the obvious regional feature. It can be seen from the table 1 and figure 2～6 that the space distribution of the strain fields in the continent of China and its adjacent areas is not homogenous and their changes is non-linear. In the different regions, the characteristics (compressive or expansive strain), direction and velocity of the strain fields show considerably discrepant. From the strain feature, the space distribution of the west-east linear-strain is expansive on the west of 95° **E**, the northeast and between Yangzi river and Zhujiang river, and compressive on the large east parts of 95° **E** and the south of Zhujiang river. For the south-north linear-strain, the seismic north-south zone is basically a boundary, compressive on its west, Taiwan and southeast-sea-zone, and expansive on its east. For the surface strain, its distribution is compressive on the west and north of Xinjiang, the center and south of Tibet, Gan-Qing-Ning, Bohai, Taiwan regions and southeast-sea-zone. And yet expansive on the east and southeast of Xinjiang, the north of Tibet, the northeast of China and between the south of Huanghe river and the north of Zhujiang river. From the direction of principal compressive strain, the west of 85° **E** presents NS or NNW, the east of 85° **E** largely NNE or NE, the northeast of China NE, the north of China approximate to the west-east, the south of China NW, the north of Taiwan near NS, and its center and south NW. From the quantity of principal compressive strain, the changed range of different area is basically from $1\times 10^{-10}/yr$ to $2\times 10^{-7}/yr$, and the difference between the maximum and minimum can get to three magnitudes.

(2). There are 3 regions of the higher compressive and shear strain and 2 sub-high shear ones. It can be seen from figure 4 and 5 that there are very obviously 3 regions of the higher compressive and shear strain regions. They are respectively Taiwan and Taiwan straits, Hima-Layas and Jiashi of Xinjiang. Their maximum compressive strain rates are respectively $1.6\times 10^{-7}/yr$, $8.9\times 10^{-8}/yr$ and $5.3\times 10^{-8}/yr$; and the maximum shear strain rates respectively $2.45\times 10^{-7}/yr$, $6.5\times 10^{-8}/yr$ and $8.1\times 10^{-8}/yr$. Two sub-high shear strain regions are respectively the center of the seismic north south zone and the west of Bohai gulf. And their quantity are respectively $4.8\times 10^{-8}/yr$ and $4.3\times 10^{-8}/yr$.

(3). There are the strong compressive NNE region in the south of Tibet plateau, and the expansive zone from northwest to southeast in its north. After it gets to 100° **E**, the expansive zone expands respectively to east and south. It can be shown clearly that the matter of Tibet plateau is moving to southeast.

(4). The principal compressive strain in the continent of China and its adjacent areas may mainly be effected from the collision between Indian plate and Eurasian plate and the subduction of Philibin-sea plate. It can be seen from figure 6 that the collision center between Indian plate and Eurasian plate is located basically in Qomolangma peak of Himalayas. Mountain The center-axis of the collison is basically along the longitudinal line in the north of Qomolangma peak. The azimuth of the principal compressive strain is basically NS or NNW in the west of the center-axis, and gradually returns to east in its east. That is, N13° E in the south of Tibet plateau→N35° E in the north of Tibet plateau→N56° E in Gan-Qing area → approximate to the west-east in North of China. It can be discovered obviously that the clockwise rotation of the principal compressive strain direction is resulted from Eurasian plate crashed on NE by Indian plate and the obstruction of Xiboliya block. The azimuth of the principal compressive strain is basically NW in the south, center and west in South of China. Compared with North of China, its change is very large. It may be resulted from Eurasian plate dived on NW by Philibin-sea plate.

6. Conclusion and Discussion

(1). The space distribution of the strain fields in the continent of China is not homogenous. Its general feature is strong and compressive in the west, and weak and expansive in the east. The boundary between east and west is located basically in $105^{\circ}E$, and just in the seismic north-south-zone.

(2). Synthetically analyzed figure 5 and 6, it can be concluded that the current strain fields in the continent of China is largely resulted from the interaction among Indian plate, Philibin-sea plate and Eurasian plate.

(3). The direction of the principal compressive strain from GPS measurement data in this paper is on the whole consistent with that from geology and seismology. The direction of the principal compressive stress in figure 7 is derived from geology and seismology (Ma xingyuan, 1989). After comparing figure 6 with 7, it can be shown that their direction is very accordant each other, especially in the west, center, north of China and southeast along sea in which there are the greater strain. By using the method presented in this paper, the quantity and direction can be calculated altogether with GPS data. However, the direction of stress can only be obtained generally, and the quantity never by that of geology and seismology.

(4). The strain parameters can be estimated by deploying the above method for the region, and not just for a point. If its coverage is very small, then the region can be regarded as a point. On the contrary, the estimated parameters are of the general or average strain. It is just distinguished the above method from that of geology and seismology. That is, it can be shown sufficiently that there is difference in some regions in figure 6 and 7.

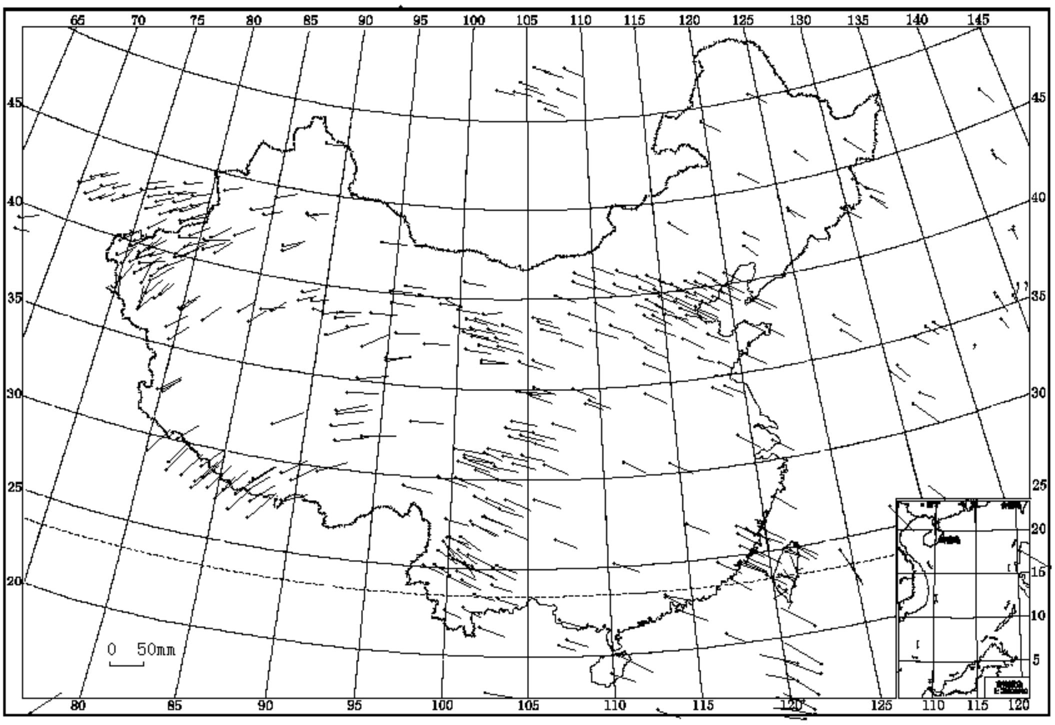
Reference

1. Ma Xingyuan, Atlas of the Rock Sphere Geo-dynamics of China, Beijing: China Map publishing House, 1989.
2. Wang Suyun and Chen Peishan, Numerical Simulation of Current Tectonic Stress Fields in China and Its Adjacent Areas, Acta of Seismology, 22(1), 2000.
3. Fu Rongshan, Huang Jianhua and Xu Yaomin, et al., Numerical Simulation of the Crash between Indian plate and European-Asian plate and Deformation in the continent of China, Acta of Seismology, 18(1), 1998.
4. Huang Liren, Ma Qing and Ge Liangqian, et al., Mechanism of Mechanics of the Horizontal Deformation in North of China, Acta of Seismology, 21(1): 50～56,1999.

5. Wang Qi, Ding Guoyu and Qiao Xuejun, et al., Research on The Current Crust Deformation in the South of Tianshan with GPS, Acta of Seismology, 22(3): 263～270, 2000.
6. Li Yanxing, Huang Cheng and Zhu Wenyao, et al., Mechanics Analysis and Feature of the Horizontal Movement in the Continent of China, Seismology (supplement): 28～33, 2000.
7. Zhang Yongzhi, Chui Duxin and Wang Qi, et al, Research on Relationship between the Regional Crust Deformation and Earthquake Activity by GPS Data, Acta of Seismology, 22(5): 449～456, 2000.
8. Zhang Qiang and Zhu Wenyao, The Initial Establishment of the Tectonic Block Motion Model of China from Space Geodetic Data, Chinese Science Bulletin, 45(16): 1523～1528, 2000.
9. Zhou Shuoyu, Wu Yun and Shi Shunying, et al., A Synthetical Reasearch on the Present Crust Movement and Seismic Dynamics in the Southeast Fringe of China Continent, Crustial Deformation and Earthquake, 21(1): 1～13, 2001.
10. Li Yanxing and Hu Xinkang, et al., Establishment and Analysis of the Uniform Crustial Horizontal Motion velocity fields in the Continent of China, Acta of Seismology, 2001.
11. Writen by T. Doff , Translated by Huang Nianning, Theoretic Mechanics, Beijing: People Education Publishing House, 1979.
12. An Ou, Tectonic Stress Fields, Beijing: Seismology Publishing House, 6～110, 1992.

Table3 The strain Parameters of every block in the continent of China and its adjacent areas

No.	λ °E	φ °N	ε_e (10^{-9})	ε_n (10^{-9})	ε_1 (10^{-9})	ε_2 (10^{-9})	γ_{max} (10^{-9})	Δ (10^{-9})	A (Az. °)
1	71.9	42.1	2.20	-26.47	-30.13	5.85	35.98	-24.27	-18.6
2	75.2	42.1	1.62	-40.69	-43.51	4.44	47.94	-39.07	-14.0
3	76.4	38.1	32.09	-27.25	-29.48	34.33	63.81	4.84	10.8
4	77.9	42.8	3.07	-42.94	-44.12	4.25	48.37	-39.87	-9.0
5	79.4	40.6	13.65	-66.83	-67.02	13.85	80.88	-53.18	-2.8
6	80.0	36.0	4.73	-10.16	-10.87	5.24	15.51	-5.43	10.1
7	81.9	28.8	-3.61	-64.06	-66.40	-1.27	65.13	-67.67	10.9
8	83.1	39.9	10.13	7.31	-7.77	25.21	32.98	17.44	42.6
9	83.6	33.2	21.04	-14.89	-17.19	23.44	40.63	6.25	14.0
10	84.2	27.8	-28.09	-61.13	-64.09	-25.12	38.97	-89.21	16.0
11	84.5	44.1	4.20	-17.34	-17.53	4.38	21.91	-13.15	-5.3
12	87.3	27.8	8.66	-16.01	-24.46	17.10	41.56	-7.35	26.8
13	88.6	38.7	-4.63	-6.75	-26.03	14.65	40.68	-11.38	43.1
14	88.8	41.4	17.59	-7.03	-9.83	20.38	30.21	10.56	17.7
15	90.4	30.7	8.15	-21.97	-22.04	8.22	30.26	-13.82	-2.7
16	92.1	39.2	8.15	-16.97	-17.00	8.18	25.17	-8.82	1.8
17	93.1	33.0	1.89	-3.72	-12.07	10.24	22.31	-1.83	37.7
18	93.6	37.0	-0.01	-14.33	-27.91	13.56	41.47	-14.34	34.5
19	97.1	39.3	-9.68	-12.27	-20.01	-1.93	18.09	-21.94	40.9
20	97.8	38.2	-0.09	-13.73	-23.03	9.22	32.25	-13.81	32.5
21	98.5	31.1	-1.89	26.02	-2.26	26.40	28.66	24.14	-83.4
22	99.3	26.3	-10.99	7.66	-14.80	11.47	26.28	-3.33	-67.6
23	101.1	35.3	-5.34	1.35	-10.68	6.69	17.36	-3.99	56.3
24	101.4	28.4	-3.89	10.04	-15.53	21.69	37.22	6.15	-56.0
25	101.5	27.1	6.75	2.96	-12.00	21.71	33.71	9.71	-41.8
26	102.0	37.8	-17.64	8.18	-24.44	14.98	39.42	-9.46	65.6
27	103.0	32.3	-34.77	3.96	-39.32	8.49	47.79	-30.83	-72.1
28	104.9	31.7	-11.65	19.11	-13.00	20.47	33.47	7.46	78.4
29	105.2	47.5	-1.11	-0.16	-2.46	1.18	3.64	-1.28	52.0
30	105.6	37.5	-11.62	1.64	-11.83	1.86	13.68	-9.98	-82.9
31	105.6	24.7	7.80	-2.26	-4.15	9.69	13.85	5.54	-21.7
32	109.6	28.1	-0.07	-2.54	-3.25	0.64	3.89	-2.60	25.3
33	109.8	28.2	5.39	2.21	0.10	7.50	7.40	7.60	-57.7
34	111.3	35.8	-8.40	-1.96	-12.11	1.75	13.86	-10.36	-58.8
35	111.5	39.9	-3.21	6.83	-7.48	11.09	18.57	3.61	61.4
36	114.3	46.9	1.64	-0.15	-0.46	1.95	2.41	1.49	21.1
37	114.4	38.6	-1.02	2.12	-1.61	2.70	4.31	1.09	68.2
38	114.9	39.3	-15.44	6.90	-18.25	9.72	27.97	-8.53	71.5
39	116.1	40.1	1.01	-6.37	-7.15	1.80	8.95	-5.35	-17.2
40	116.4	31.8	-7.30	12.73	-10.42	15.85	26.28	5.43	69.8
41	116.7	38.4	12.76	-20.22	-25.48	18.02	43.49	-7.46	-20.3
42	117.9	39.4	1.79	-0.69	-7.10	8.19	15.29	1.10	40.3
43	118.0	24.0	-15.05	-10.54	-28.29	2.67	30.95	-25.62	-49.2
44	118.3	39.0	-1.83	-4.11	-5.87	-0.07	5.80	-5.94	33.4
45	118.4	26.2	-3.88	12.46	-6.12	14.69	20.81	8.57	70.9
46	119.2	24.4	-64.15	-22.91	-95.66	8.60	104.26	-87.07	-56.7
47	119.8	22.3	-116.11	-21.46	-162.68	25.11	187.79	-137.57	-60.1
48	120.5	23.4	-184.01	-19.69	-204.34	40.64	244.99	-203.70	-65.2
49	121.0	25.2	12.63	-73.27	-73.35	12.70	86.05	-60.64	1.7
50	121.0	43.3	-0.78	-0.68	-7.01	5.55	12.56	-1.46	45.2
51	121.2	38.0	-15.96	-4.18	-18.96	-1.18	17.77	-20.14	-65.7
52	121.4	34.8	0.41	13.90	-5.93	20.24	26.17	14.32	60.8
53	124.9	40.6	9.48	2.24	1.45	10.27	8.83	11.72	17.4
54	129.0	44.8	11.43	-6.32	-6.39	11.50	17.89	5.11	3.7



Tigure1 The Velocity field of the crustal horizontal movement In the continent of China and adjacent areas.

Note:The velocity is relative to ITRF97.

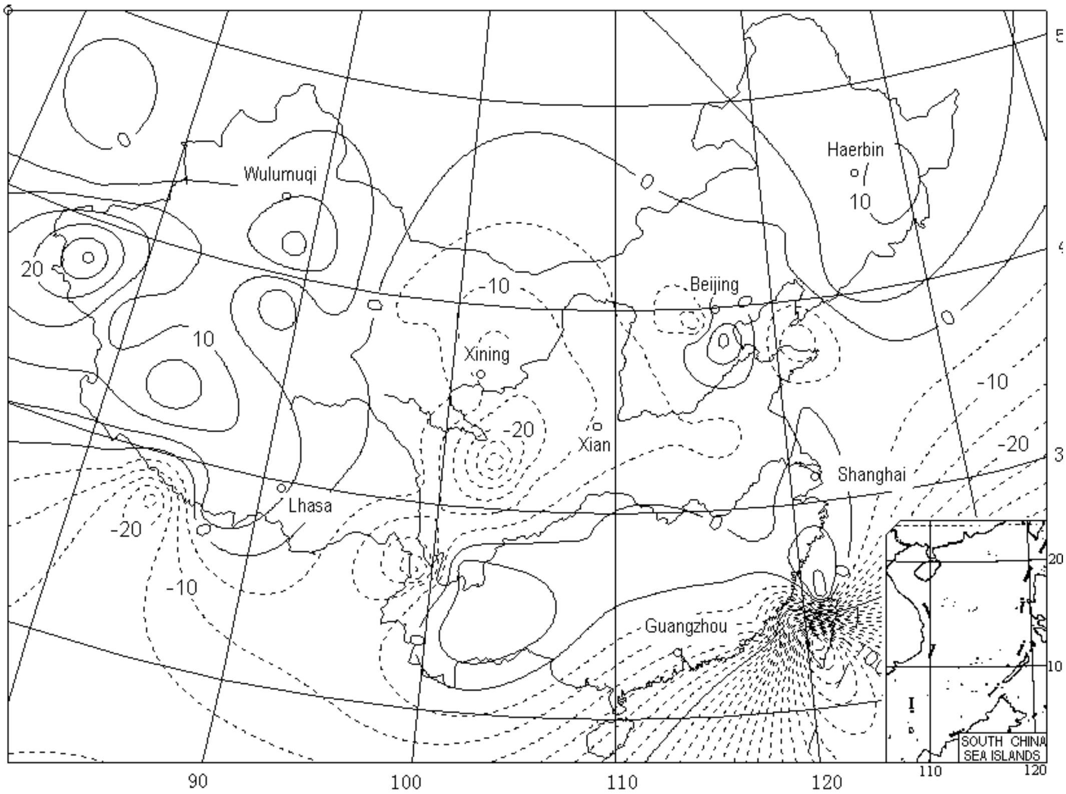


Figure 2 The linear strain of east-west direction in the continet of China and its adjacent areas.

Note: "-" indicats compressive strain ; "+" indicats expansive indicats ; The unit of strain is 10^{-9} .

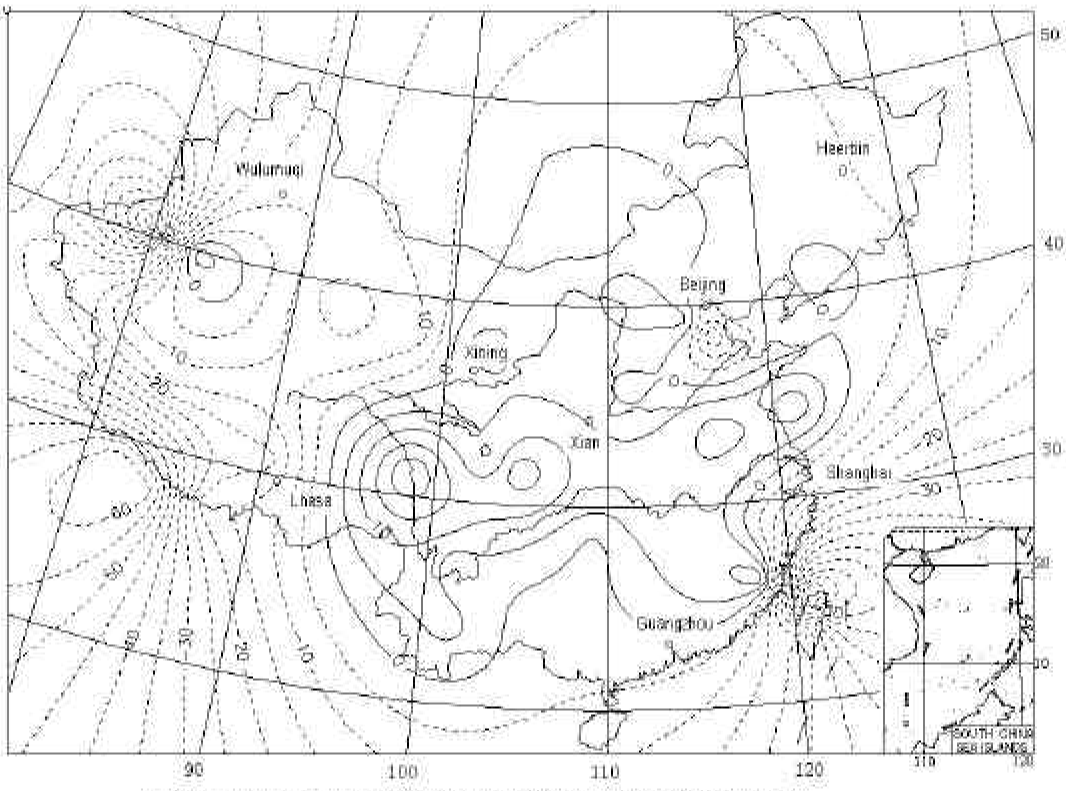


Figure 3 The linear strain of north-south direction in the continet of China and its adjacent areas
Note: "-" indicate compressive strain , "+" indicate expensive indicate ; The unit of strain is 10^{-9} .

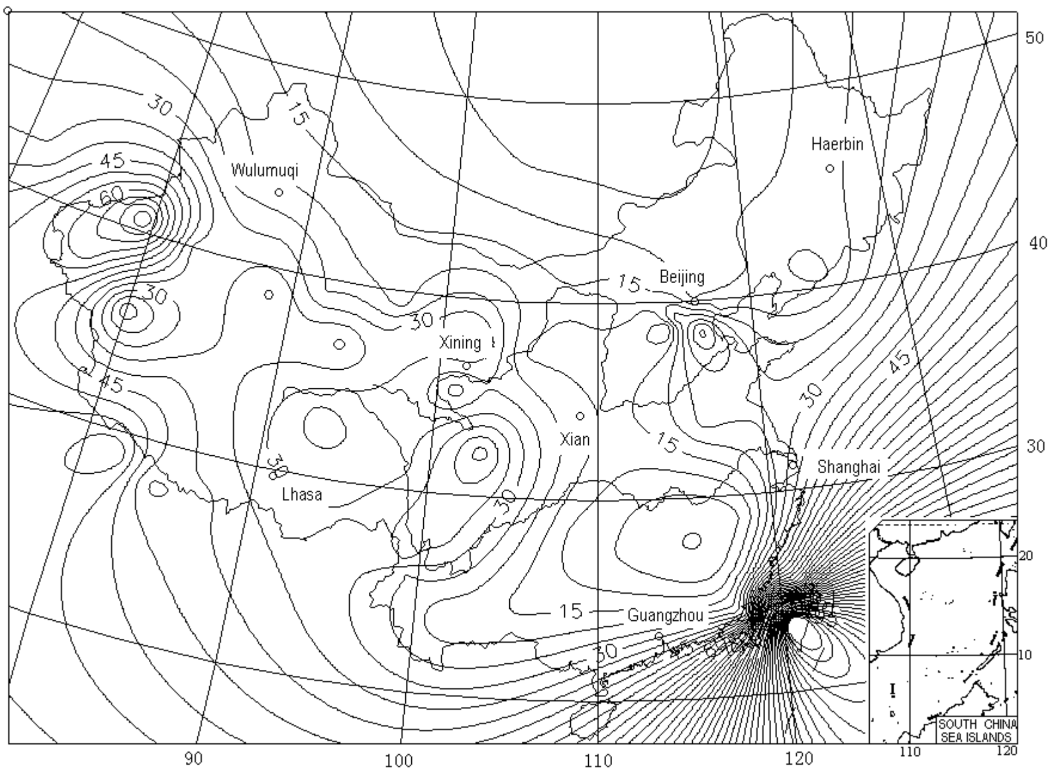


Figure 4 The maximum shear strain in the continet of China and its adjacent areas.
Note: The unit of strain is 10^{-9}.

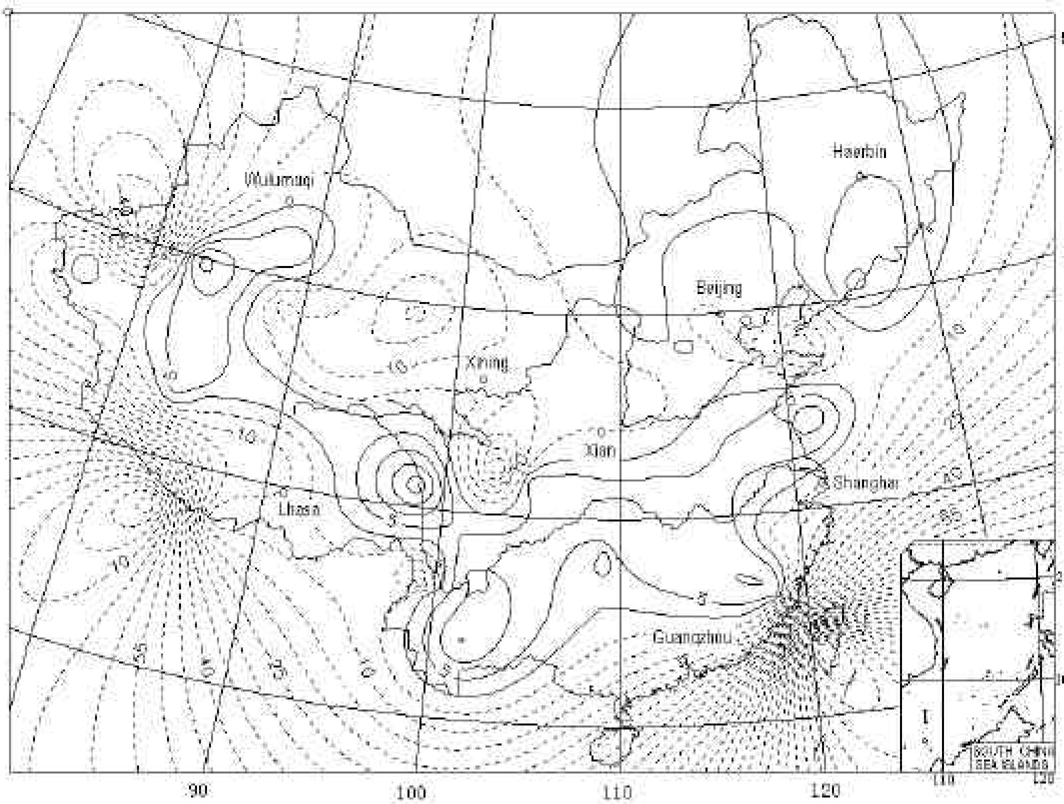


Figure 5 The scerface strain in the continet of China and its adjacent areas.
Note: "-" indicats compressive area ; "+" indicats expensive area. The unit of strain is 10^{-9}

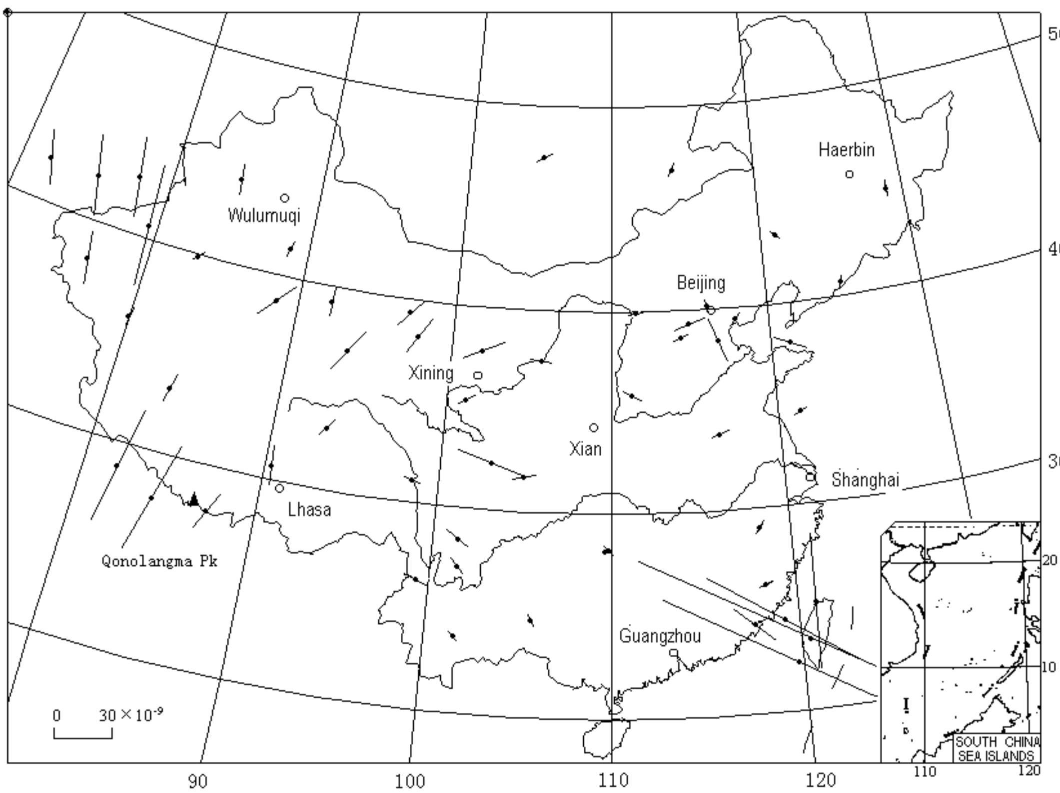


Figure 6 The principal-compressive strain in the continet of China and its adjacent areas.

Figure7 The state of the recent crustal stress in the continent of China