Researches on Application of GPS to Earthquake Monitoring and Prediction

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ABSTRACT

The earliest researches on application of GPS to earthquake monitoring and prediction in China began in 1980s, and it was limited to learn some relative technology from other countries and do some test with a few of equipments. As the improvement of software for data processing and the depreciating of hardware, several local GPS network had been gradually set up till the end of 1990s, and then more systematically GPS monitoring, data processing and its application research have been done gradually. In this paper, 3 research examples of the application of GPS to earthquake monitoring and prediction are presented.

Key words: GPS, Earthquake monitoring and prediction, Crust movement observation, Strain, Sichuan Yunnan area, Crust Deformation, and Fault.

1. THE JUDGMENT OF EARTHQUAKE SITUATION IN CHINA AFTER THE GREAT EARTHQUAKE IN INDIAN OCEAN.

Three repetitions of GPS measurement on China Crust Movement Observation Network were done respectively in 1999, 2001 and 2004(Gan Weijun *et al*, [1]). On 26 Dec 2004, the Indonesia great earthquake with *M*s8.7 occurred. At the same time, in the region of Yunnan and Sichuan of China a series of anomalies appeared, such as the intensifying of earthquake activity, ground water anomalies, *etc*. For judging the earthquake situation in this region, the regional GPS network re-measurement was done from Jan to Feb, 2005. Based on the former researches, all the re-measurement GPS data and the GPS data from a few of relatively continuous observation stations are processed and studied.

Because of the last re-measurement interval is only a half-year, the precision of signal must be very poor if we only use the GPS data measured in 2004 and 2005. Thus, we suppose that there is a regular variation of crust deformation from 1999 to 2005, and an increasing component due to the great earthquake with *M*s8.7 in Indian Ocean. So we can make a set of equations with all the GPS data of 1999, 2001, 2004 and 2005, with which we can calculate out the increasing vectors for each GPS point. Based on further analysis of the increasing component, the estimation of the influence of the great earthquake on China can be made.

The increasing components of vectors of GPS points in Sichuan, Yunnan area are further processed with formula (1) (Li Yanxing *et al*, [2]).

$$\begin{bmatrix} v_e \\ v_n \end{bmatrix} = r\begin{bmatrix} -\cos\lambda\sin\varphi & -\sin\lambda\sin\varphi & \cos\varphi \\ \sin\lambda & -\cos\lambda & 0 \end{bmatrix}\begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} + \begin{bmatrix} \varepsilon_e & \varepsilon_{en} \\ \varepsilon_{en} & \varepsilon_n \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix} \qquad (1)$$

In formula （1），

$$\begin{cases} x = r\cos\varphi(\lambda - \lambda_0) \\ y = r(\varphi - \varphi_0) \end{cases} ; \qquad \begin{cases} \varepsilon_e = A_0 + A_1 x + A_2 y \\ \varepsilon_{en} = B_0 + B_1 x + B_2 y \\ \varepsilon_n = C_0 + C_1 x + C_2 y \end{cases}$$

Bring it to formula (1) , then ：

$$\begin{bmatrix} v_e \\ v_n \end{bmatrix} = r\begin{bmatrix} -\cos\lambda\sin\varphi & -\sin\lambda\sin\varphi & \cos\varphi \\ \sin\lambda & -\cos\lambda & 0 \end{bmatrix}\begin{bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{bmatrix} + \begin{bmatrix} A_0 & B_0 \\ B_0 & C_0 \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix}$$

$$+\frac{1}{2}\begin{bmatrix} A_1 & B_2 \\ B_1 & C_2 \end{bmatrix}\begin{bmatrix} x^2 \\ y^2 \end{bmatrix} + \begin{bmatrix} A_2 & B_1 \\ B_2 & C_1 \end{bmatrix} x\,y \qquad (2)$$

In formula (1) and (2), v_e and v_n denote the eastward and northward velocities of a point (λ, φ) on the plate respectively, r is the radius of the Earth, and ω_x, ω_y, ω_z are the Euler vectors of the plate; λ denotes the geographical longitude of GPS points; φ denotes geographical latitude of GPS points; x, y and z denote three dimensional coordinates of the earth surface under ITRF 2000; ε denotes strain in the direction of its subscription. Here, ε is not constant yet, it is varied with x, y and z. In fact, the distribution of strain may be more complicated, but the varied ε can be closer to real strain than a constant ε .

The map of increasing vectors is shown in Fig 1. After processing with formula (1) and (2), the Maxi-strain contours are shown in Fig. 2, and the Mini—strain contours are shown in Fig 3.

From Fig.1, the increasing vectors are becoming larger from north to south. It means this area has a tensile increment. From Fig.2 and Fig.3, the Maxi-strain is tensile strain, and most of the Mini-strain contours are shown as compressional strain, and some of them are also shown as tensile. By comparison, the contours' values on Fig2 are larger than that on Fig3 in general. So, the influence of the increasing vectors induced by the great earthquake is tensile in general. There are also other evidences to support the viewpoint. With strain from formula (1), the relative crust movement

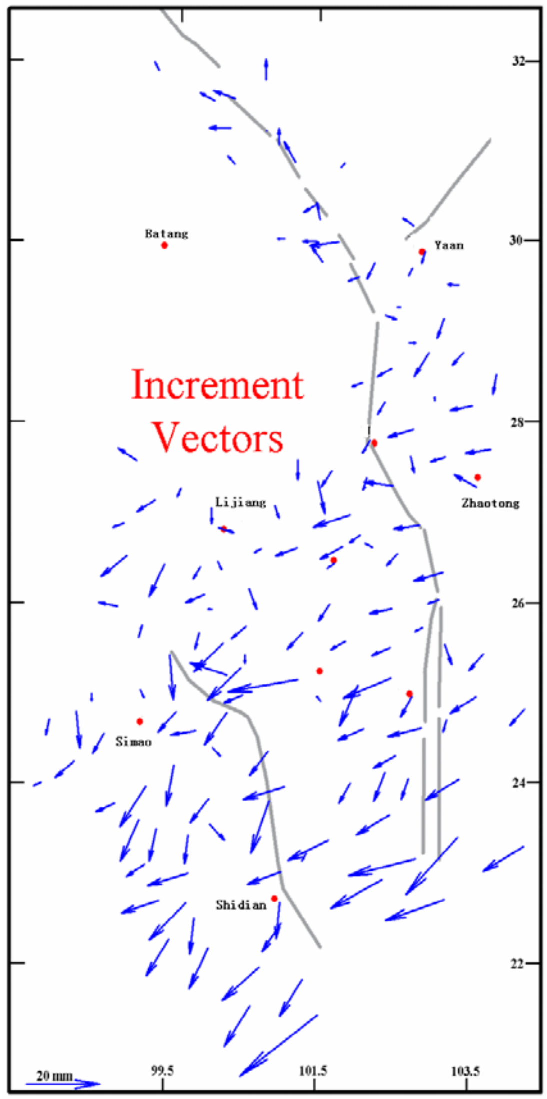

Figure 1. The increasing vectors of GPS

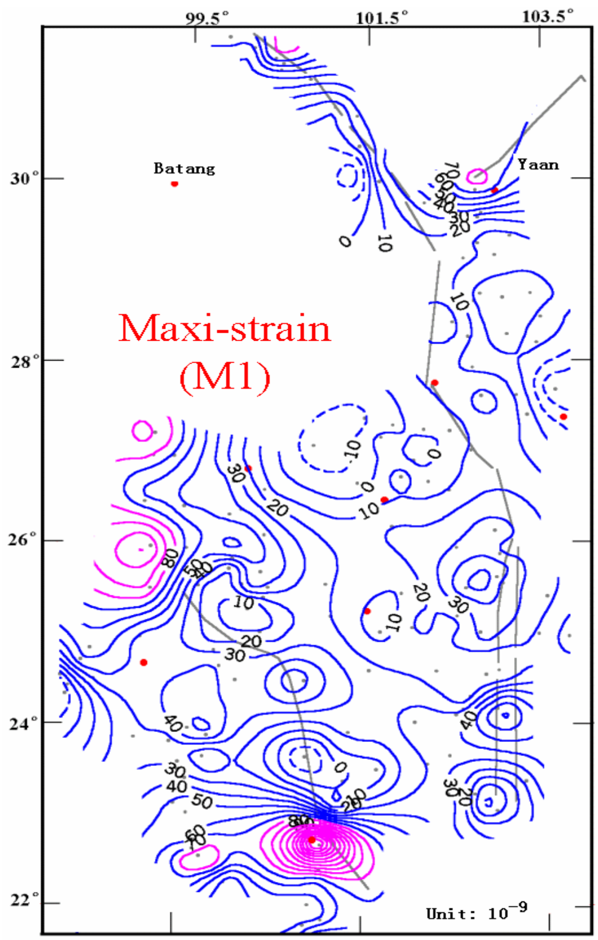

Fig 2 Maxi-strain contours based on the increasing vectors

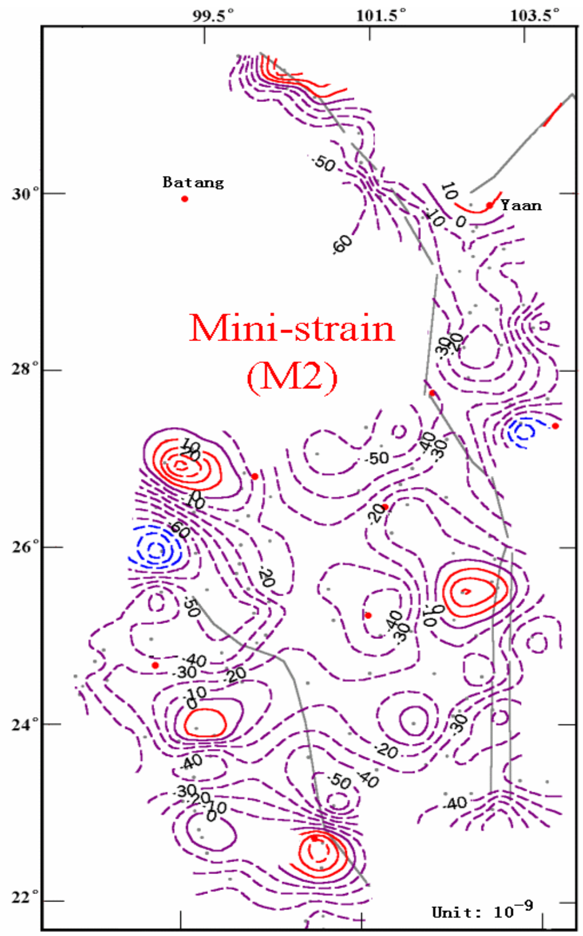

Fig 3 Mini-strain contours based on the increasing vectors

vectors from the central line of fault zone along two sides of it can be calculated by integral. So we have calculated out the crust movement vectors relative the central line of fault belt in this area with GPS data in different period, and Fig4 give us an example. In Fig 4a, the relative movement along two sides of Xianshuihe fault zone is well balanced and expanded from 2001 to 2004. It can explain why no strong earthquake in a long period there although the fault activities are remarkable. In Fig 4b, the increased movement vectors are relative small, expanded in north part and weakly compressed in south part. With similar analysis for other faults in this area, it seems no evidence to support a strong earthquake will generate in this area in a short time after the great earthquake in Indian Ocean.

Some baselines variation from continuously recorded GPS stations in south China and surrounding area have been analyzed, it also shown that there is a extensional movement in this area in quake time and a period after.

From the study above mentioned, a few points are given as follows: (1) The Indonesia great earthquake with *M*s8.7 induced some crust deformation in the region of Yunnan, Sichuan and Tibet at the quake time and a period after that, but the deformation was induced mainly by mechanic vibration. (2) Processing the GPS data in different way, it showed us that crust deformation in the region of Yunnan and Sichuan of Chin was relatively loosening in the period after the great quake. (3) Such a deformation is favorable to trigger quake with *M*s5-6 in a short period. (4) Before the further strengthening of crust stress, it seems

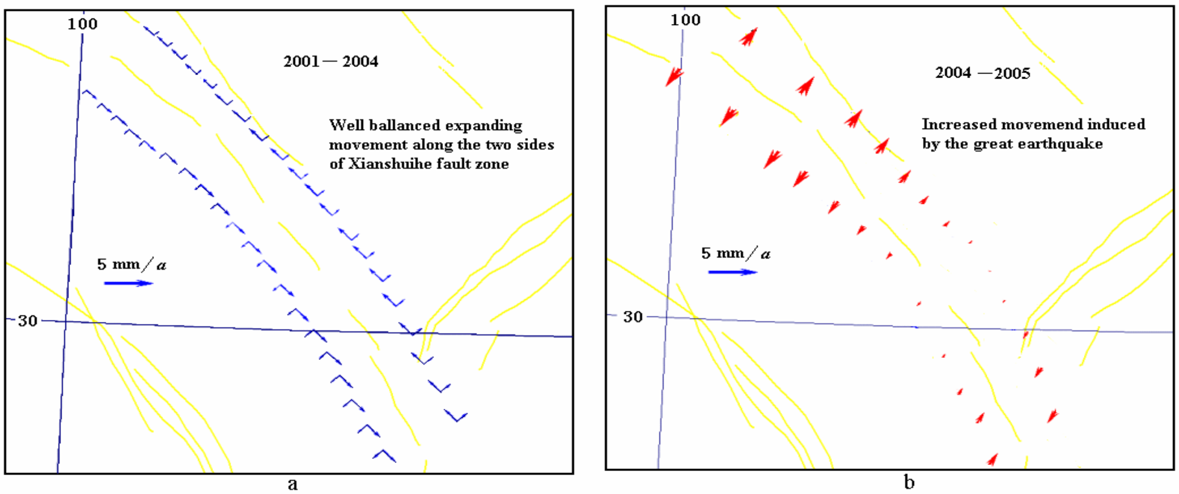

Fig 4 Relative movement along two sides of Xianshuihe fault zone
a: From 2001 to 2004; b: From 2004 to 2005

impossible to generate an earthquake stronger than *M*s7. The judgments above are also correct at present, more than one year after the great earthquake (Bo Wanju, Liu Guangyu *et al*, [3]).

2. LONG- AND MEDIUM-TERM PREDICTION OF KUNLUNSHAN M_S8.1 EARTHQUAKE

Through research on various crust deformation data in China for the key task of CEA for long- and medium-term earthquake prediction in the period from 1996 to 2000, 13 strong earthquake dangerous areas were given with *M*s⩾6 in East China and *M*s⩾7 in West China in which the No.5 dangerous area just located on the rupture of Kunlunshan *M*s8.1 earthquake (Fig 5). There are short of precursory observation data in this area, and the main evidence for the dangerous area is the obviously shortening of the GPS baseline from Q14 to Q15 in 1994-1996 (Fig. 6). In Fig 6, other given areas are not based on GPS. By the way, in the same time the GPS baseline from Wuhan (Q02) to Xiamen (Q03) was also shortened greatly. We thought it was induced by the push of Philippine block, and if there were an earthquake, it would occur in Taiwan. Because our task was focusing on the main continent and there was lack of relative data from Taiwan, there was no prediction for Taiwan area. Afterwards, the great Jiji earthquake with *M*s7.4 occurred on 21 Sep, 1999. It seems that the shortening of baseline of Q02-Q03 implied something for the earthquake.

All the research result about Fig.5 and Fig.6 had been published in 2001 before Kunlunshan *M*s8.1 earthquake occurred (Bo Wanju *et al*, [4]).

3. THE YEARLY PREDICTION OF WUSHI XINJIANG EARTHQUAKE WITH M_S6.2 OCCURRED ON 15 FEB. 2005

In the stage work of CEA for earthquake medium-term prediction research in the period of 2001-2005, an earthquake dangerous area with *M*s=6 was given in the west of Wulumuqi with earth tilt data in 2003(Fig 7). The third re-measurement of China Crust Movement Observation Network was made in 2004, and all the GPS data were processed up to Oct 2004. The result shown that there were obvious different levels of movement between different GPS stations near Bachu-Akesu area, and the Maximum of shear strain appeared as high value. It is a prone-earthquake area, not far from the dangerous area

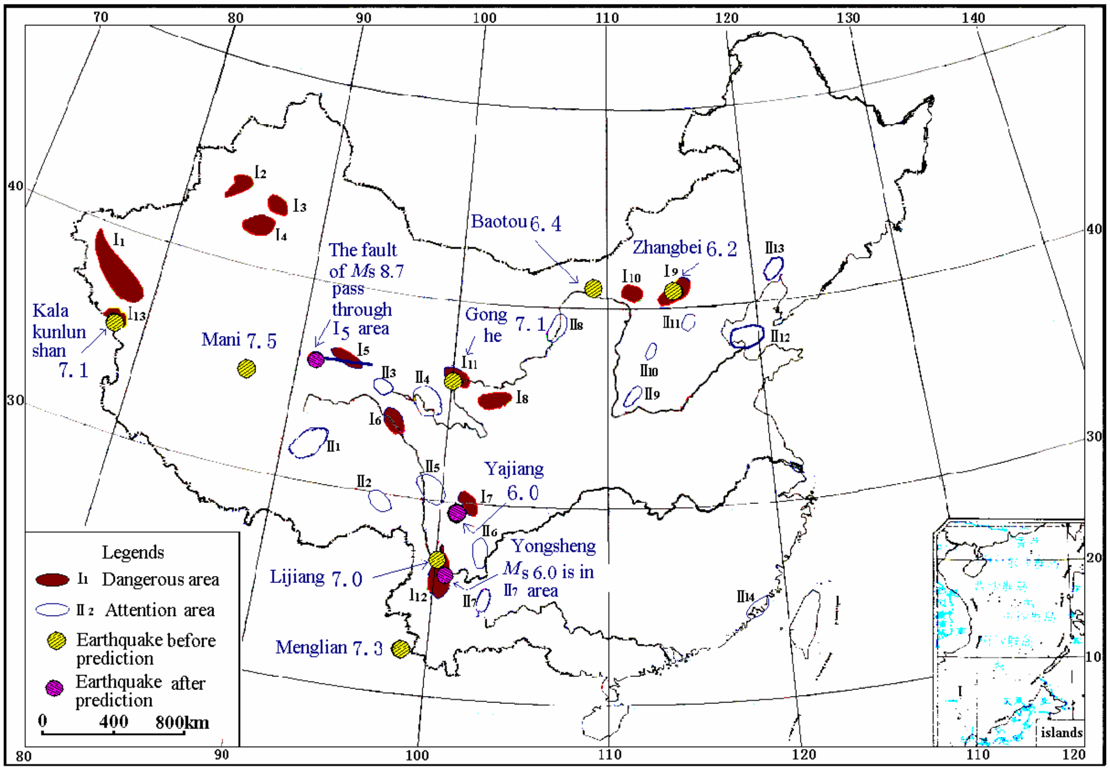

Fig. 5 Earthquakes and predicted dangerous areas

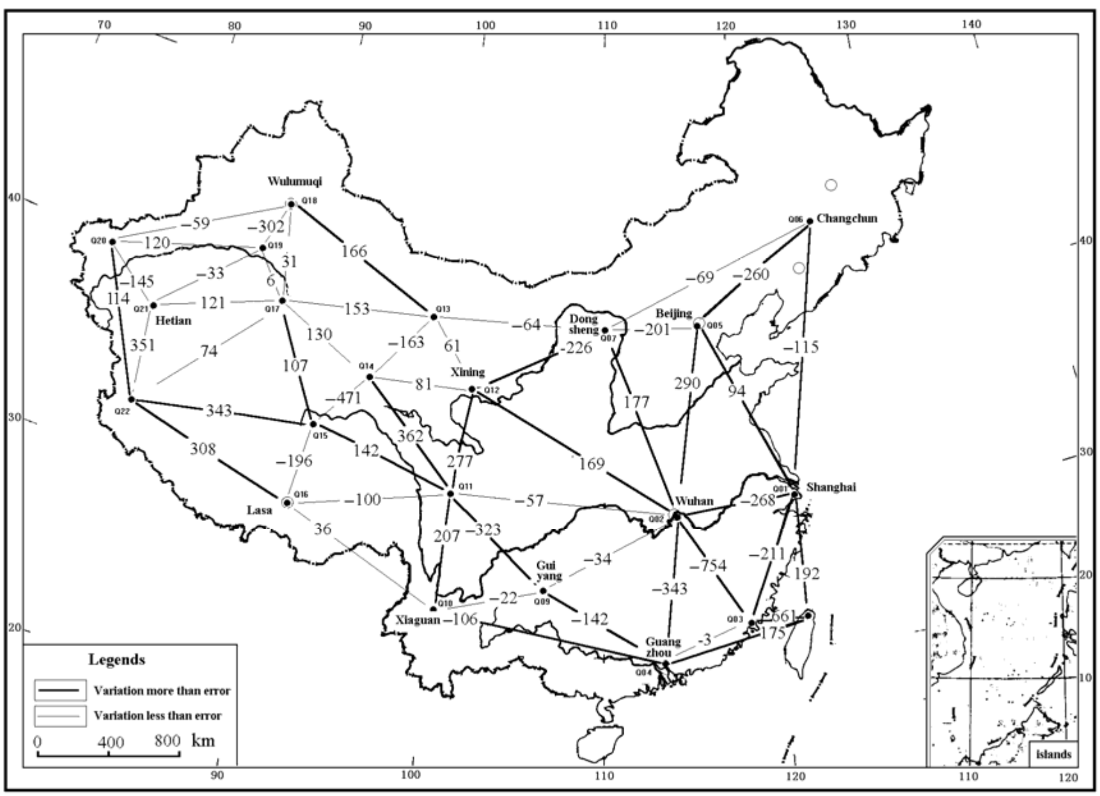

Fig. 6 GPS baselines and their variations

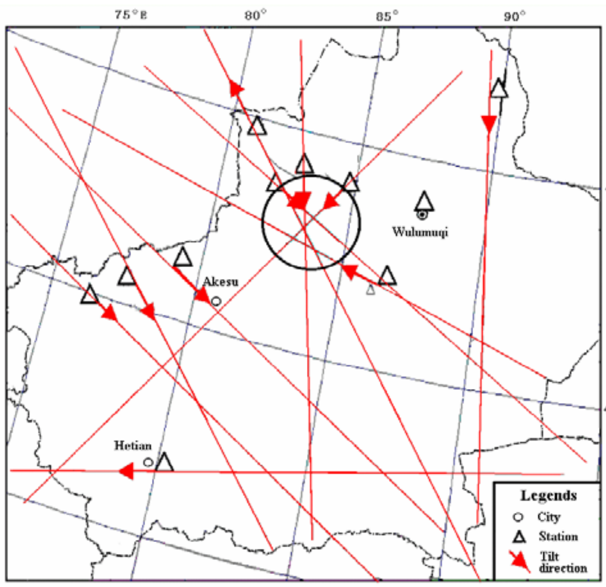

Fig 7 The predicted dangerous area with *M*s6

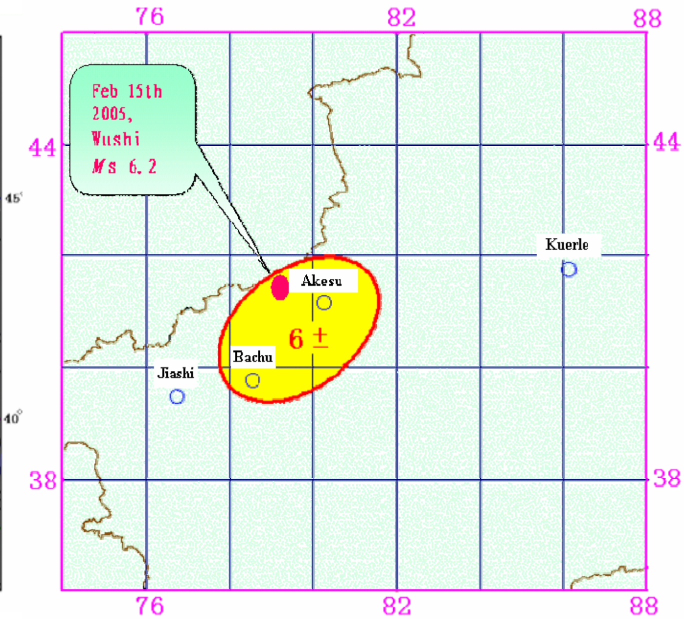

Fig 8 The final prediction area and the earthquake

above mentioned, and there is Keping fault here. Through analysis and discussion, the dangerous area was moved from Shenglidaban-Kaiduhe to Bachu -Akesu area in the earthquake situation research report of First Crust Deformation Monitoring and Application Center, CEA, in Oct 2004, and the time scale was changed from medium-term to yearly, the predicted magnitude was also around 6. The location, time and magnitude are all correct (Bo Wanju, Zhang Siya *et al*, [5]).

Earthquake prediction is a complicated scientific problem in the world, and nobody can solve the problem perfectly yet up to now. But some progresses have been made by practice and exploration for many years, and it is worth to give a summarization.

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