Study on Large Area Crust Deformation with GNSS Vertical Components

Wanju BO, Shengtao FENG and Jianfeng SU, China

Key words: GNSS, vertical component, crust movement, strong earthquake activity

SUMMARY

Crust deformation monitoring is an important way to study on mechanism of strong earthquake preparation and strong earthquake prediction. And the vertical crust deformation has more sensitive relation to the stress variation inside the crust. Thus to monitor the vertical crust deformation and to study their distribution in space and variation in time is an important part of researches on crust deformation. The traditional method to monitor vertical crust deformation is precise leveling. But because of the huge workload, to do the precise leveling for all the networks in China continent needs a few years or even longer, and it is difficult to extract the vertical crust deformation during the leveling period, and of cause it is impossible to analyze and use it reasonably. By contrast, the period of re-measurement of relatively dense regional (mobile) GNSS covering mainland China is shorten greatly, and it make us possible to extract vertical crust deformation in large area within a shorter time. In this paper, the vertical component data from some auto-recorded GNSS stations and the multi-period of data from the nationwide GNSS regional stations in China Continent are preliminarily processed and analyzed, and, it is studied and discussed how to extract and use the information of vertical GNSS component under high noise background; Combined with the mechanisms of crust movement and that of earthquake generation, the possibility of strong earthquake prediction and crust movement study are further discussed with the use of GNSS vertical components. Although there are many kinds of disturbances including from the ionosphere, atmospheric moisture, satellite orbit perturbation in vertical direction and earth tidal etc. in the GNSS data, the differences of vertical components between two periods of Preliminary processing data of GNSS have shown that the distribution of relative ascending points and descending points are closely related with geotectonic structures and great earthquake generation areas, and this means that there may be a certain relationship between them on the internal mechanism. With fine data processing such an abnormal ascending and descending can be weakened or eliminated by corrections based on some disturbing factors. But the factors' abnormal variations are also in all probability related with great earthquake generation. The cognitions above have referential value for crust deformation research and great earthquake prediction study.

SUMMARY (in Chinese)

摘 要：地壳形变监测是研究强震孕震机理和进行强震预测的重要手段，其中地壳垂直形变对地壳应力变化尤其敏感，因此监测地壳垂直形变的时空分布及其变化规律是地壳形变研究中的重要组成部分。传统方法监测地壳垂直形变主要靠精密水准测量，但因其工作量十分浩大，在中国大陆进行一次全面的精密水准测量需要数年之久，难提取测量期间的地壳垂直形变信息并进行合理的分析和应用。相比之下，覆盖中国大陆较为密集的区域（流动）GNSS 测量的复测周期大大缩短，使之在较短时段内提取较大区域内地壳垂直形变信息成为可能。本文对部分 GNSS 连续站和中国大陆多期 GNSS 区域流动站垂向复测资料进行了初步的处理和分析，对如何提取和利用 GNSS 垂向分量在高噪声背景下的有用信息进行了研究和讨论；结合地壳运动和地震孕育发生的机理，进一步讨论了 GNSS 垂向分量应用于地壳运动与强震预测的可能性；尽管 GNSS 观测值垂向分量中含有电离层、大气含水量、卫星轨道垂向摄动、固体潮等多种干扰因素的影响，但每两期观测结果差异的初步数据处理结果显示其升降分布格局往往与大地构造格局和大地震孕育发生的区域密切相关，说明在机理上二者可能存在内在的联系。这些异常升降变化在精细的数据处理中通过某些要素的改正能够减弱或消除，但这种要素的异常也很可能与大地震的孕育过程相关。这一认识对地形变研究和大地震预测具有参考价值。

关键词：GNSS；垂向分量；地壳运动；强震活动

Study on Large Area Crust Deformation with GNSS Vertical Components

Wanju BO, Shengtao FENG and Jianfeng SU, China

1. INTRODUCTION

In recent years, Global Navigation Satellite System (GNSS) as an earth observation technology is developing rapidly in China. GNSS are one of the main technologies used in Crustal Movement Observation Network of China (CMONOC 1), the Tectonic and Environmental Observation Network of Mainland China (CMONOC 2) and other major scientific projects. More and more researches on pre-seismic, co-seismic, and post-seismic deformation as well as the field of deformation and strain are carried on and a lot of scientific results have been obtained (Chen C Y *et al*, 2014; Dong Y H *et al*, 2011; Yang G H *et al*, 2011; Bo W J *et al*, 2011). GNSS measurements are well developed for monitoring the horizontal movement of the crust with high accuracy, wide applications and lots of research results. Up to now, there are over 1000 GNSS regional stations that have been measured in several campaigns since 1999, which can be used to get several maps of national crustal movement that contain lots of known and unknown information to be further analyzed and used. It is accepted that the vertical variations of GNSS sites contains lots of information, but because of the frequency spectrums of the vertical components are complicated and their observation errors are larger than in horizontal ones, the extraction of different information from the vertical components is relatively difficult, which causes limitation to the use of the vertical components of the data and few results in application. The methods to extract and analyze the useful information in the data with high noise background are studied in this paper through processing and analysis of the vertical components of several campaign GNSS measurements. The extraction of micro-dynamic information of crustal movement from the vertical components of GNSS data, and, the relationship between the information and strong earthquake activity is discussed, and, ideas and ways for medium- and long-term prediction of great earthquake are presented in which the earthquake's location might be given by identifying seismogenic deformation fields.

2. RESEARCH ON VERTICAL DEFORMATION WITH GNSS

Pre-processing of GNSS data are made mainly with GAMIT/GLOBK/QOCK software, and the data processing includes 4 steps: (1) The loose one-day-solutions of coordinates of GNSS stations and orbits of satellite are obtained with GAMIT software. The data should be processed in groups respectively because too many stations are recorded in same epoch. (2) With GLOBK software the loose one-day-solutions are combined with those loose one-day-solutions of

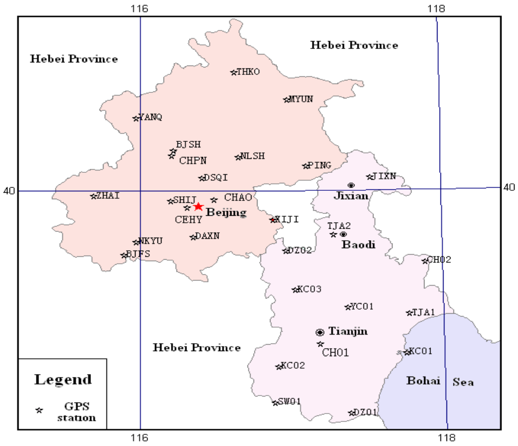


Figure 1 The distribution of GNSS stations in Beijing and Tianjin area

global IGS tracing stations given by SOPAC from IGS data center; (3) Estimate the position and moving velocity of GNSS station by synthesize all the loose one-day-solutions with QOCA software. And then the moving velocities of GNSS stations in different periods are calculated respectively under the constraint of ITRF's moving velocity. (4) Calculate the vertical compnent of moving velocity of GNSS station for further study in this paper.

Select the IGS stations as reference stations with reasonable distribution in and around China continent; The model is the newest one recommended by GAMIT; The ephemeris used is accuracy ephemeris given by the SP3 software.

The data processed in this paper are mainly from campaign GNSS measurement (epoch data). It is because the continuous GNSS stations are much less and most of them are set up later than campaign ones. But for understanding the variation characterestic of GNSS vertical component and the possibility of using the component for vertical deformation analysis, The continuous GNSS observations in the Beijing and Tianjin area are processed (Zhang F S and Bo W J, 2012) where the subsidence are more obvious, and the results indicate the importance of the vertical components of GNSS measurements in the analysis of the crust vertical deformation despite the high noise and disturbances exist in it. The GNSS stations are shown in Figure 1, and the time series of some continuous GNSS vertical component are shown in Figure 2 (together with some GNSS sites outside the area as tied control points in the solution).

It can be seen from Figure 2, (1) that the annual cycle in the vertical component of GNSS data is obvious, up to 10 to 20 mm, which indicates the variation relates to time and it is considered to be mainly attributed to the variation of meteorological factors; (2) that the characteristics of the variations are similar for nearby stations, which indicates that the variation relates to locations of the stations and major common-mode variation is exhibited for nearby ones. Such as Beijing and Tianjin area with significant variation of land subsidence as an example, the 6 sites BJFS, BJSH, MYUN, SHIJ, THKO, and YANQ are located in the Beijing area with no obvious subsidence, of which the characteristics of vertical variation are similar with seasonal variation; DSQI, DAXN, and PING with obvious subsidence are located in the subsidence area in Beijing. It is shown in figure 2(9) that the annual variation is not so significant, which is related to the large variation of the long-term trend. In other words, severe land subsidence to some extent conceals the annual variation in some places. More sites with similar variations can be found in the subsidence area in Tianjin, such as DZ02, KC03, KC01, KC02, SW01, YC01, etc. The 4 separated sites DZ01, CH02, NLSH, and XIJI exhibit significant irregular variations, which probably implicates local irregular variations or other unknown disturbance. It's specially emphasized that the only 2 sites JIXN and TJA2 respectively located in Jixian and Baodi are ascending, and they are not contradictory with many years accurate leveling results in this region (Huang L R and Guo L Q, 1998; Huang L R and Kuang S J, 2000; Huang L R et al, 2003; Huang L R et al , 2002) , taking different reference frames into consideration. Other sites shown in Figure 2 are far from the Beijing and Tianjin area with no relevant importance for comparison.

The annual variation shown in Figure 2(2) appears to be obvious with the amplitude of only about 10mm, which is actually small compared with that of BJSH shown in Figure 2(9), and that is because the subsidence isn't apparent and the long-term trend is relatively small, which makes the annual variation apparent.

Strong earthquake recurrence intervals are long, and, seismic risk isn't the same for different

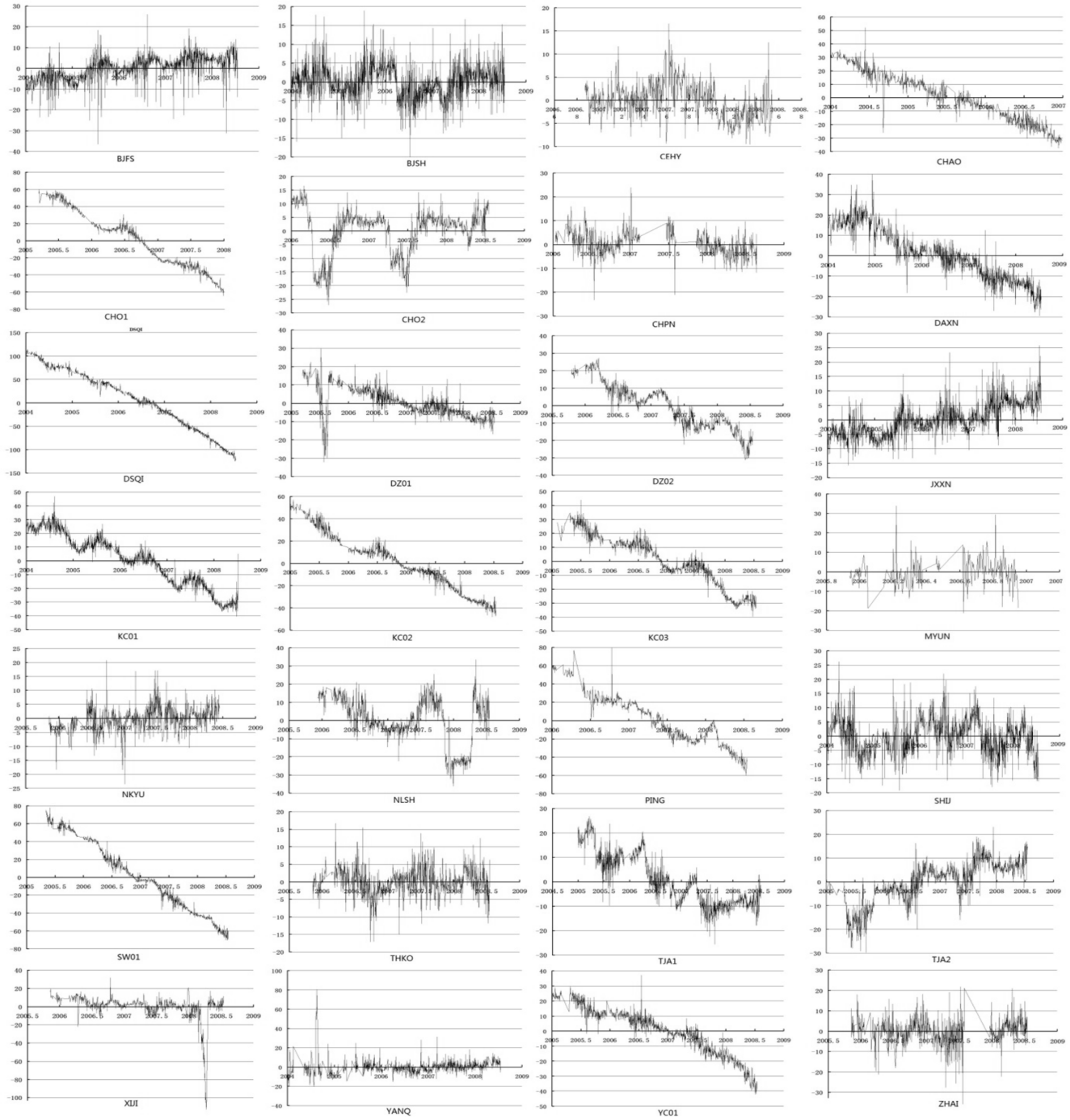
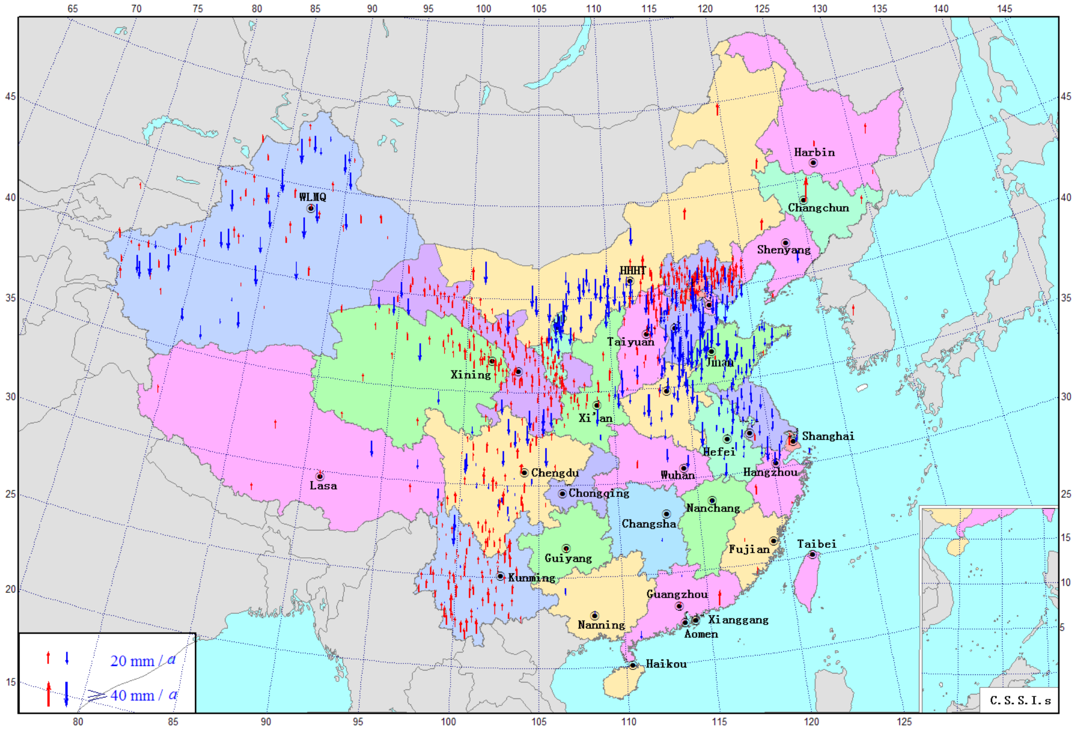
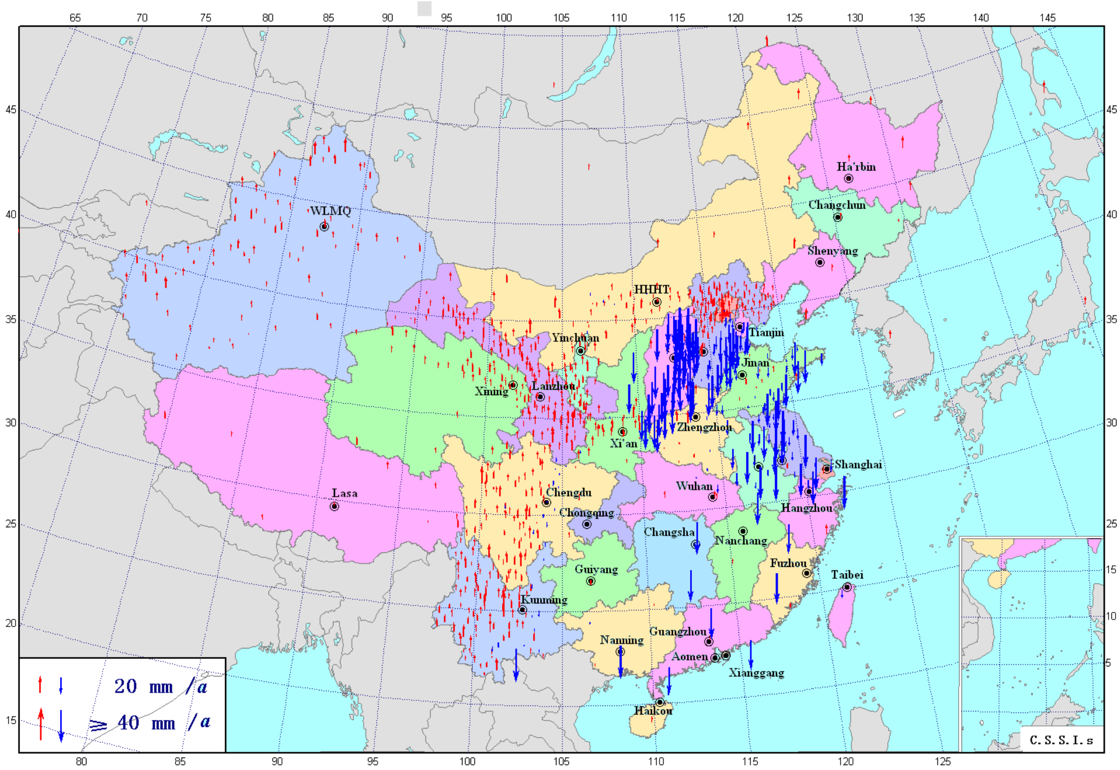


Figure 2 Vertical component time series of some GNSS observations

places, and strong earthquakes' distribution is very complicated. So it is needed to have GNSS data with large coverage and high density for research on crustal movement and the trend of strong earthquake activity by using vertical components of the data. Therefore, some campaign GNSS observations in China are processed and analyzed. These campaign GNSS measurements are normally carried out for dozens of hours each time, and the interval between two times is longer than 2 years. Thus the dispersion of vertical components of epoch date are larger than those of continuous GNSS data, and the averages of one time of observations may deviate from the averages of long-term observations due to the season related systematic errors. If the interval is long enough, it is possible to distinguish the abnormal zones with large amount of uplifting or subsidence according to the vertical velocity derived from these repeated surveys. In the mean time, it is recommended that GNSS campaigns should be conducted in the same season to mitigate or eliminate the seasonal effects. The map of vertical crust deformation based on the isostatic datum for Mainland China is shown in Figure 3. It can be seen from Figure 3: (1) the spatial distribution of the magnitudes and signs of the vertical components of GNSS shows both with regular and random in some way, that is clearly related to the distribution of tectonic structures, despite there are many kind of unknown variations and errors in the data. For instance, the distribution shows obvious zoning pattern along the south-north seismic belt, the Qilian seismic belt, the Yinshan-Yanshan seismic belt, the Shanxi seismic belt, the Tan-Lu seismic belt, the Tianshan seismic belt, and the subsidence belt in North China plain, etc. In other words, the map of vertical deformation for Mainland China based on the isostatic datum derived from multiple sites covering large areas could reflect the difference of vertical deformation to some extent between different tectonic zones despite there are many unknown factors in the vertical components of GNSS data. The map can show the obvious difference between different tectonic zones, it is possible to show anomalies of vertical deformation induced by great earthquakes. Earthquakes occur only when crust stress accumulates to high level enough， and material in the crust is constrained strongly in all directions except the upward direction due to the ground is a free surface. Therefore, the ground surface should be significantly uplifting if the accumulated stress is strong enough especially when a strong earthquake is impending right before the rupture. With the limitation of anisotropy of the crust and the spatial and temporal resolution of GNSS, the real uplifting image is still hard to be captured, but its existence should not be denied and further research should be continued. Additionally, inappropriate reference frame and constraints in GNSS data processing are obstacles for the extraction of abnormal uplifting information which possibly exists locally. (2)The magnitude of subsidence in the subsidence area of North China increased significantly from 2001 to 2004. Great Kunlun Mountain earthquake with *M*s8.1 occurred in 2001, and it can be seen from Figure 4 that the 300 to 400 kilometers long rupture of the quake with left-lateral strike-slip in the east-west direction is consistent with the horizontal deformation field shown in Figure 4. If the horizontal deformation field is analyzed respectively by different period, it can be seen that an extension component is added in the east-west direction in North China after the *M*s 8.1 Kunlun Mountain earthquake (Bo W J, 2013) and the magnitude of subsidence in North China (in Figure 3) gets bigger correspondingly, which indicates that the increase of subsidence in North China is caused probably in part by the effect of the far-field *M*s8.1 earthquake and structural activities. It can also be seen in the preliminary processing results that the Sichuan Basin significantly uplifts from 1999 to 2004 in Figure 5, which is worth to be further studied. But some abnormal observations are usually filtered out by data processing if some constraints are induced. It is easy to eliminate some information that is assumed to be inappropriate using some constraints, however, it should be careful, need to elaborate. As is known, large quantity of co-seismic subsidence occurred in Chengdu Basin during the 2008 Wenchuan *M*s8.0 Earthquake, which is possibly the recovery from the long-term pre-seismic uplifting under the east-west extrusion in the area. The deduction is supported by many years' leveling data in this area (See Figure 6; Wang Q L *et al*, 2008; Bo



a. 1999—2001



b. 2001—2004

Figure 3 Vertical crust deformation shown by regional GNSS

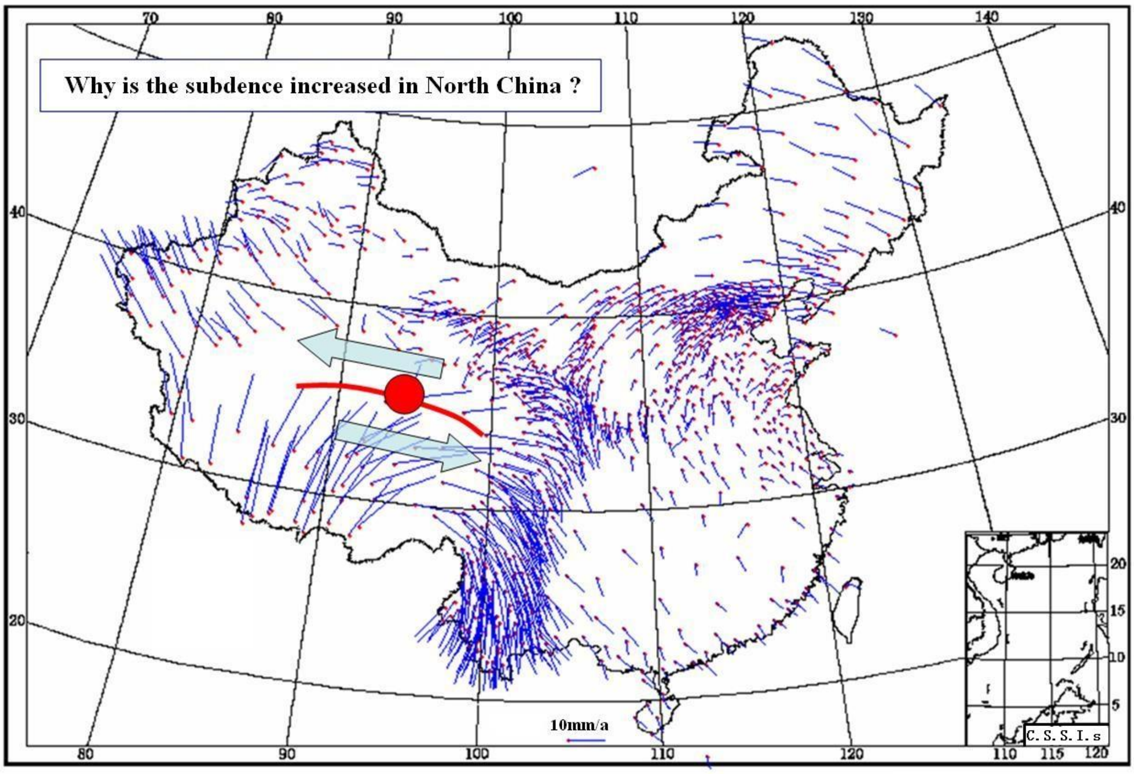


Figure 4 Sketch map of the left-lateral rupture of *M*s8.1 Kunlun Mountain earthquake and horizontal deformation field of China Continent under regional no-net-rotation reference frame (Hu X K *et al,* 2007)

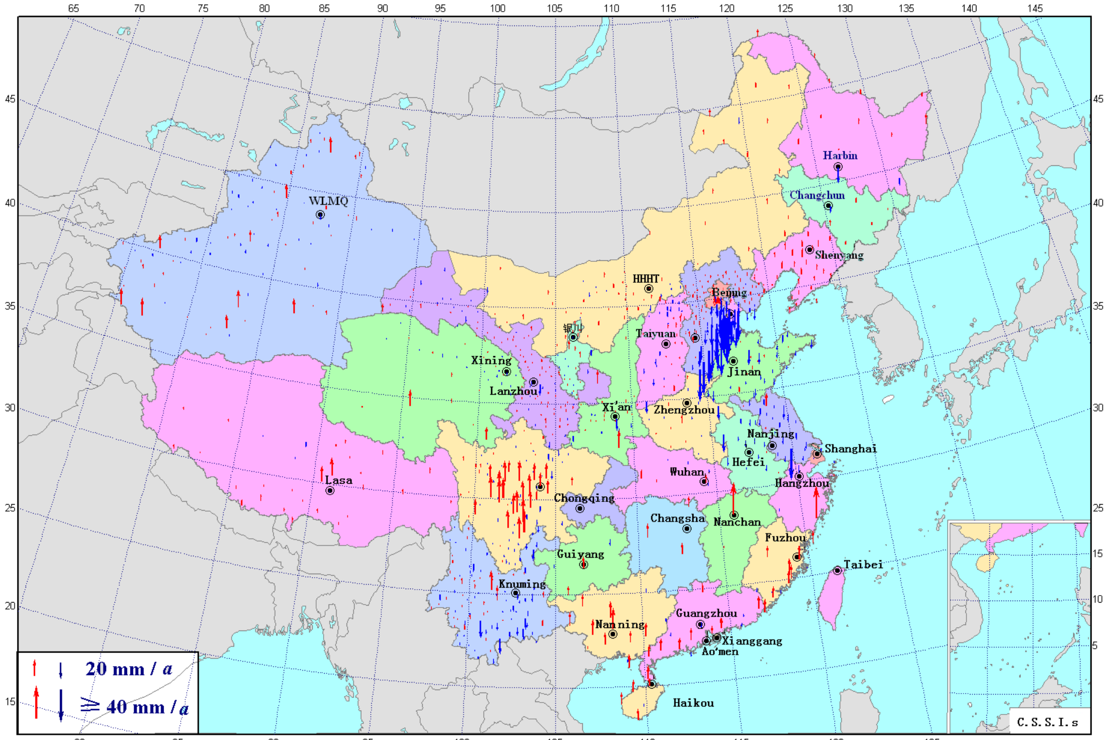


Figure 5 Vertical deformation field from GNSS(1999-2004)

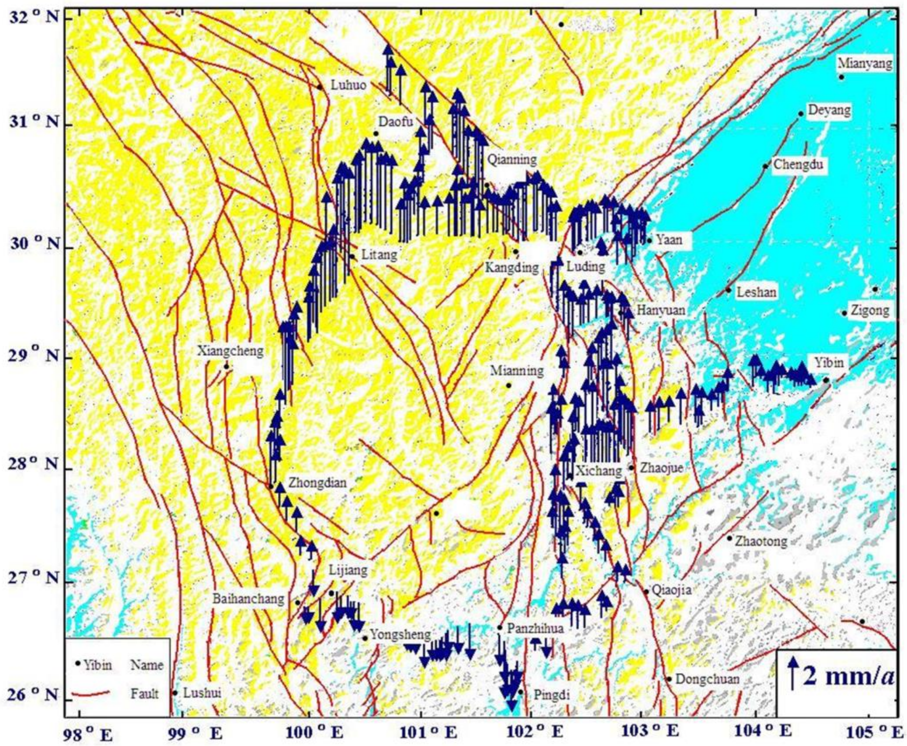


Figure 6 Vertical displacement rates of leveling bench marks in sichuan-yunnan region(with a reference mark of Yibin, according to Wang Q L)

W J *et al*, 2009).

It can be seen from Figure 7 that a huge NE subsidence belt appeared from South Yunnan province to Beijing in Mainland China during 2007 to 2009, the magnitude and range of which are rare in the historic records. This result is normally hard to be accepted. But by the analysis in this paper, we know that in some extent it is reasonable to appear such kind of distribution of vertical deformation. Ground subsidences have existed in the North China Plain, the Fenhe-weihe seismic Belt and the Chengdu Plain, but the magnitude and range of the ground subsidence are never such significant in the years recorded before. Taking the 2008 Wenchuan *M*s8.0 Earthquake into consideration, the thrust main shock followed by several right-lateral strike-slip aftershocks with magnitude around 6 which make the western part of the subsidence belt move to the northeast. Meanwhile, the eastern part has been moving to southwest in a long time (Figure 4, and see Bo W J, 2013) and was strenthened due to Indonesia earthquakes (as is shown in Figure 7, and see Bo W J, 2013; Bo W J *et al*, 2006). It is obvious that the distribution of the crust movement is in favor of the formation and enhancement of the huge subsidence belt. And such a huge subsidence belt should be outcome of combined action of ground subsidence and tectonic movement.

3. THE RELATIVE DATUM OF VERTICAL DEFORMATION

The description of crustal movement is based on specific reference datum because the movement is relative. Different researchers could get different images of the crustal movement using the same GNSS data, because one reference datum is different usually from

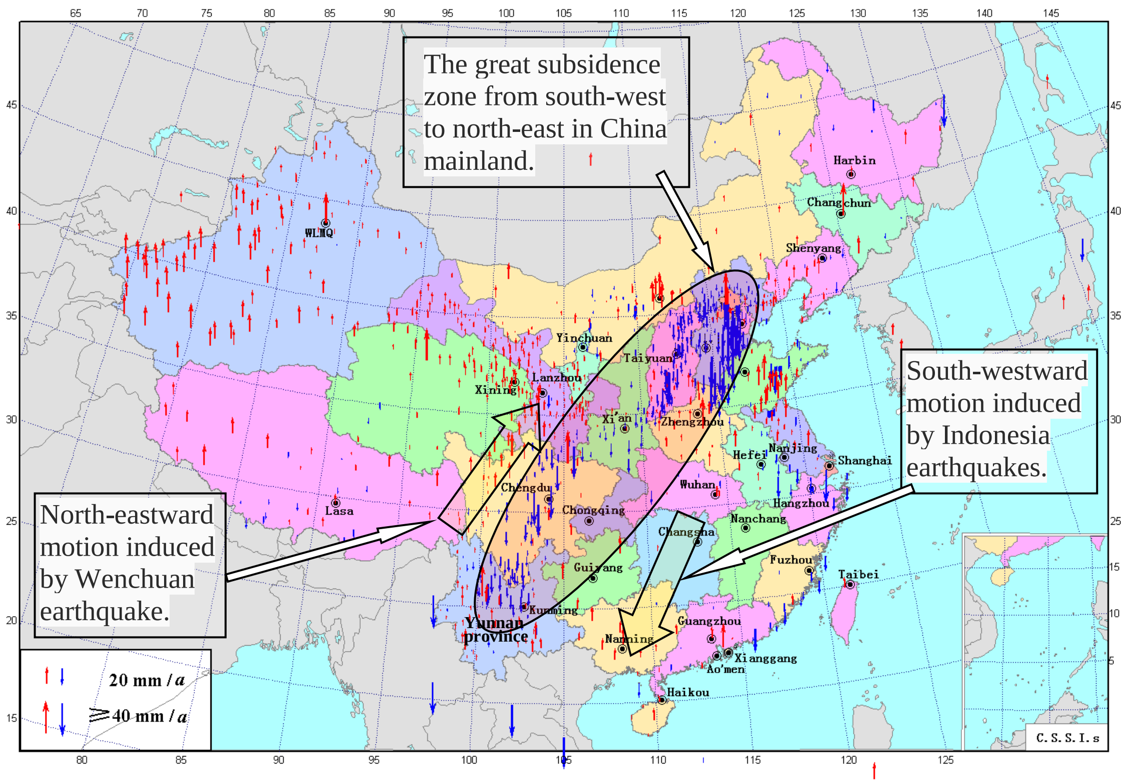


Figure 7 Vertical deformation field from GNSS (2007-2009)

another. By study of vertical crust deformation, it is wanted to know where relatively rise, where relatively decline and where is the high gradient belt of vertical deformation, so as to determine the place where have risk with strong earthquake occurrence in the future. In fact, the whole earth is moving all the time, so there is no absolutely still reference point. But any a point can be assumed to be still and taken as a reference point to determine the relatively vertical motion of other points and the map of vertical deformation can then be derived. The question is which point is the best to choose for the reference. Former researches show that the isostatic datum is relatively better for researches on vertical deformation than others (Huang L R and Yang G H, 1991; Yang G H and Ma Q, 1992). If we assume the quantities of the material that flows into and out of the study area due to underground lateral deformation are approximately equal, and ignore the variation of the crust density, then the volume of the relatively uplifting material approximates or equals to the volume of the subsidence material. The corresponding reference datum that is consistent with the assumption is called as the isostatic reference datum. The figure 3, 5, 7 and 8 in this paper are all based on the isostatic reference datum.

Theoretically to say, the isostatic reference datum is unique. Under the datum the amount of rising crust equal to the amount of descending crust in any time period for the same area (ignore the crust density variation). For China continent as an example, suppose all the amount of crust and its density is not changed during the time intervals, then the amount of rising crust will equal to the amount of descending crust. Here V_i expresses vertical velocity of station i with a any reference datum, if GNSS stations are distributed evenly with enough density, it can be proved that with isostatic reference datum the station i's velocity V'_i can be approximately denoted as: $V'_i = V_i - \frac{1}{n}\sum_{\mathrm{i}=1}^{n} V_i$ (in which n denotes the sum of GNSS station).

4. THE POSSIBLE RISK PLACES AND THEIR CHARACTERISTICS OF DEFORMATION FOR FUTURE STRONG EARTHQUAKES

Earthquake prediction is still a hard problem in science. However, there should be some significant deformation anomalies before great earthquakes. To distinguish the anomaly is usually very difficult due to the existence of various disturbances. But statistic, partially quantitative, or qualitative analysis is still possible and is necessary for researches on such complicated problems. One of the necessary conditions for crust ruptures is that the local crust stress is increasing to or even exceeding the intensity of crustal rupture. For the movement and deformation of crust near surface, there is confining pressure on any horizontal direction which is a strong constraint, but in the upward direction the ground is free to rise. Thus under the enhancement of local crust stress for longer time, the plasticity of crust appears and a compressional uprising must occur. Due to tectonic movement is fluctuant and local crust stress fluctuates in the same time, the vertical crust deformation should appear fluctuation as well. This kind of fluctuation should be enhanced before occurrence of great earthquakes, and the magnitudes of fluctuation should be magnified in so-called fracture zone, unstable or plastic areas. These phenomena are seldom observed, which is probably resulted from the principles of the deployment of observation sites that the sites should be located in stable places with less disturbances which leads to lose some chances to observe sensitive areas with compressional uprising. Although the vertical deformation of the crust we have observed contains a variety of disturbances, these disturbances are added together with vertical crust deformation, and the total would appear with very large scale before and after a great earthquake. If the large scale anomalous variations appear after an earthquake, they are after-shock effects, which are beyond the scope of this paper; and if they appear before an earthquake, they are easily taken as results of disturbances, and this is a problem needed to be studied seriously. Disturbances always exist in observations, which will not be affected by human being. Normally, corrections of disturbance are not accurate or adequate, and former researches have shown that many disturbances themselves such as the temperature, air pressure, drought and flood, ground water, and ionosphere etc can cause deformation or influence on the observations of deformation, and, such kind of disturbances are probably connected to the generation of great earthquakes (Geng Q G, 1985; Xu G J *et al*, 1993; Fang H X *et al*, 2010). Therefore, directly to study vertical components of GNSS and their characteristics of distribution in time and space without removing any disturbance may be more especially significant to find enormous deformation precursors before great earthquake occurrence. At least this is a way worth to try and get attention to. The map of vertical deformation of China during 2004 to 2007 using GNSS data is shown in Figure 8. Large magnitude of uplifting in the Shanxi Belt can be seen from Figure 8, which is hard to believe. A series of obvious anomalies have been observed in the Shanxi Belt since 2009, and the existing disturbances that are found in the author's field investigations are inadequate to explain these anomalies. In North China it has been a long time for lack of earthquake, and several earthquakes with magnitude larger than 7 occurred in the Shanxi Belt in history, such as the 1303 *M*8 Shanxi Hongdong earthquake (Gao M T *et al*) and the 1695 $M\,7\frac{1}{2}$ Shanxi Linfen earthquake (Yuan Z M *et al*, 1995). The interval is 392years, and now 320 years have passed again. In combination with research results on tectonic activities in North China from horizontal crustal deformation with GNSS data (Bo W J, 2013), it is recommended in this paper that the Shanxi Belt should be taken as the major seismic risk zone in North China. Especially when the unusual long time quiet appears again after remarkable anomalies, the tracing monitoring should be strengthened. There are some cases that, obvious deformation anomalies followed by several years' quiet time and then, strong earthquakes occurred (Bo W J *et al*, 2007), so more attention should be paid now. From figure 2 we can see, the vertical components of GNSS varied with a large scale of fluctuations. But the fluctuations that temporally, spatially, or in amplitude exceed the regular patterns exhibited by many years' observation could be of great importance for indication of anomaly. Although these anomalies should not be blindly trusted in case of being misled by some disturbance or blunder, more dialectical thinking and deduction are needed to fully understand such complicated problems. Nevertheless, these suspicious phenomena should not be dropped easily before they are confirmed to be caused by disturbing factors other than earthquakes.

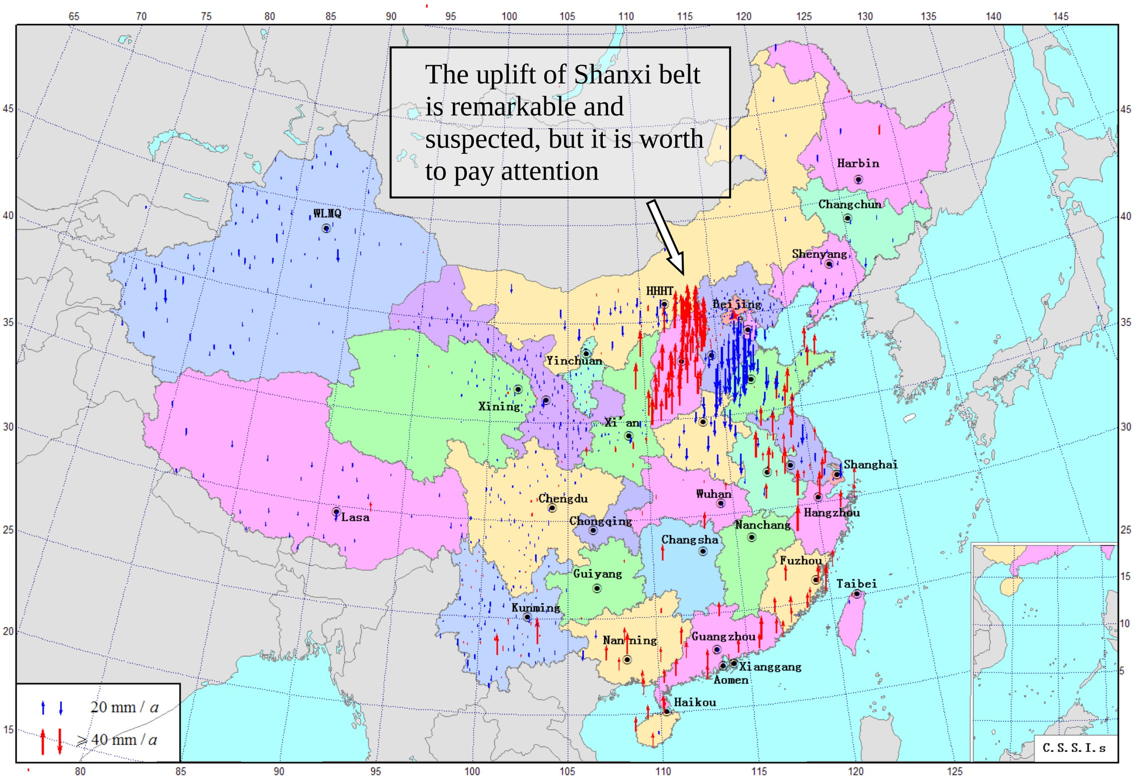


Figure 8 Vertical deformation field from GNSS (2004-2007)

The common characteristics in the North China Plain and in the Shanxi Belt can be seen from the maps of vertical deformation from GNSS data in Figure 3, Figure 5, Figure 7, and Figure 8, that the magnitudes of vertical deformation in these areas are large and their variations are intense. Because the equipments, the methods, the surveyors, and the technology all are the same in these observations, so we can make sure that the anomalous characteristics are mainly determined by the geological tectonic structure and its activities. These areas could be where are easily deformed with relatively weak crust, and could be liable to generate great earthquakes. The ground is vertically a free surface for uplift, so the displacement caused by the strain should be most significantly exhibited in the vertical direction when the crustal stress varies, which is well proved by the variations of solid-earth tides. Undoubtedly, significant variations of the crustal stress field will be caused by great earthquakes. Large magnitude non-uniform spatio-temporal variations of the stress field will definitely cause large magnitude non-uniform spatio-temporal vertical displacements of the crust, which is just very difficult to identify. Once the observed variations largely differ from what researchers expect, the results are hard to be accepted. Large magnitude variations of the crustal stress in large area must have occurred before the 2008 Wenchuan *M*s8.0 Earthquake. The significant vertical crustal deformation near the epicenter before the earthquake is shown in Figure 5 and Figure 6. These anomalous variations must have actually occurred, and it was abnormal if no variations had occurred.

According to the research results of vertical deformation and the long-term aseismic background of North China above mentioned, together with the research results of horizontal deformation of North China (Bo W J, 2013; Yang G H *et al*, 1999) , the research results of geodynamics and geophysics (Liu X *et al*, 2010; Jiang Z S *et al*, 2003; Jiang Z S *et al*, 2006; Li Y X *et al*, 2004) , and the results of deep-earth tectonic structure (Huang J L and Zhao D P， 2006) , the Yinshan-Yanshan Belt, the Zhangjiakou-Bohai Belt, the Tan-Lu Belt, the North-China Plain Belt, and the Shanxi Belt in North China are all in a seismogenic background of magnitude around 6, but as for the location at the highest seismic risk, with relatively more impending events or even with the possibility of earthquake of magnitude larger than 7, the Shanxi Belt should be paid more attention. And the middle-south segment of the Shanxi belt should be paid even more attention if the orderly distribution characteristics of deformation anomalies in recent years (Bo W J, 2013) and the activity characteristics of historical earthquakes (Gao M T *et al*, 2004; Yuan Z M *et al*, 1995) are taken into consideration.
Our knowledge of the generation of great earthquake is very limited now and few cases can be used to test the knowledge. The precursor phenomena of earthquake with magnitude under 6 are different from that larger than 7, and the cases of earthquake with magnitude larger than 7 are even less. Therefore, prediction of great earthquake with magnitude larger than 7 is much more difficult. However, the losses of life and property are mainly caused by great earthquakes with magnitude more than 7. By contrast, the losses caused by earthquakes with magnitude under 6 are much smaller. So the prediction of great earthquake with magnitude more than 7 is more important. The fact is known that the prediction is inaccurate, but, for the area with more potential dangerous, it is practically significant and viable to intensify trace monitoring and researches on seismic evolution, propaganda of anti-seismic and earthquake prevention, as well as propaganda of seismic science knowledge. As to the side effects of public panic, the negative impact can be eliminated by proper propaganda, by which the public immunity to irrational hearsays will be strengthened gradually.

5. DISCUSSION AND CONCLUSION

It's been decades since the observations of deformation begun to be used in seismic survey and earthquake prediction, and some data and experiences have been accumulated. But earthquake prediction is a hard work, and the progress has been slow yet. At the very beginning, public surveys and public precautions were carried out using backward technology with low accuracy, and lots of ambiguous precursors from anomalous deformation information were obtained. With the precursors a few predictions were made successfully to some extent, which encourages us to continually improve the technology and accuracy. With the higher accuracy, lots of disturbances are observed such as from the temperature, the air pressure, the surface water, the drought, and the ionosphere etc, so we strive to make corrections. All the series of work is undoubtedly significant to precisely understand scientific problems, which is the way to promote the development of earth monitoring technology and science. It can be seen from the review of the development of earthquake prediction for decades that, despite the observation technologies have been improved greatly and a certain progresses have been made in prediction of moderate-strong earthquake, the prediction of strong earthquakes hasn't been satisfactorily improved, which is worth to think deeply. As for the

efficiency of prediction of great earthquake, the satisfactory progress hasn't been made by scientists using observations based on large quantity of accurate data, compared with the preliminary results from backward technology in the early stage. It is so that especially for great earthquake prediction.
There are relatively more moderate-strong earthquakes for case study, while the strong earthquakes are rare for that. Since quantitative changes may lead to qualitative changes, the knowledge from moderate-strong earthquake case study could possibly be inapplicable to predict strong earthquakes, which could be one of the main factors that the prediction of great earthquakes is hard to improve. Through the analysis in this paper, a new way of thinking is presented in which the relationship between great earthquakes and the spatio-temporaly remarkable anomalies, giving up some delicate corrections of disturbance, from high background noise data is studied. It is because, in many circumstances, "big anomalies" could disappear after some kinds of corrections such as the corrections from the air pressure, the temperature, the humidity (drought), and, from the ionosphere etc; But conversely, some meteorological anomalies could be the response to strong earthquakes (Geng Q G, 1985; Xu G J *et al*, 1993), and ionospheric anomalies are proved to be connected to strong earthquakes also (Fang H X *et al*, 2010), so it is possible to lose anomalous information that, by similar corrections above mentioned, could be used for strong earthquake prediction.
The grade of sea wind can be roughly estimated by sea wave, but the precise altitudes of wave crests and troughs are hard to know, and many kinds of disturbances need to be corrected to get the actual altitudes. But without the actual altitudes the rough estimation of magnitudes of sea winds can be done also according to the fluctuations and spatial variations of sea waves by experiences. Based on this idea, we needn't pay much attention to the questions whether the vertical components of GNSS are reliable, whether there are disturbances, or how big the deviation it is from the true value. Instead, we only consider the spatio-temporal characteristics of fluctuations, and study the coordination and the orderliness of GNSS site in groups, through which some corresponding relationship between them and the distribution and activities of crustal tectonic structures could possibly be revealed, then the possible relationship between the generation of strong earthquakes and the characteristics of fluctuations and anomalous variations could be further discussed. Based on these researches and discussion, several conclusions and ideas are as follows: (1) as for the extraction of information from vertical components of GNSS data with high noise background, researches on eliminating disturbances are necessary. But some disturbances are possibly connected to precursors of earthquakes. From the other point of view, we might observe the overall information and analyze the relationship between their spatio-temporal fluctuations and strong earthquakes' generation and occurrence. (2) As to different space-time spectrum information, some errors could have common mode within a certain time and space. Common mode errors can be eliminated or mostly eliminated in the difference among nearby points (the isostatic reference for instance), so the useful information of relative deformation among nearby points can be more effectively extracted. (3)Crustal stress must rise greatly and be accompanied by fluctuations before the occurrence of earthquake's rupture. The ground surface is a free one. In the zone where crust stress raised greatly, local uplift of crust surface must occur due to the plasticity of the crust, and obvious vertical deformation waves must be generated (similar as the tide waves of solid earth). In the great earthquake generation area, the abnormal fluctuation of deformation must differ from that in other ordinary areas, and the original normal vertical deformation could be changed also in time.

Through the analysis of vertical components of several campaign GNSS and re-leveling data, the abnormal variation characteristics in time and space can be found, and then the area and period for occurrence of crust stress anomalies can be judged, as well as the place of great earthquake occurrence and its developing trend can be studied. (4) The distribution of upward and downward vertical components of GNSS is closely related to the distribution of earth tectonic structures and the earthquake generation areas. Through further study and deep analysis, we don't think that's an incidental coincidence， and there must be internal relationship between them in mechanisms, which can be well explained. Thus it is possible to capture the precursor information of seismic deformation using large quantity of data with the high noise background. Though the deformation information of moderate-strong earthquake is mixed with all kinds of disturbances, and it is hard to distinguish, the large scale anomaly of deformation information related with strong earthquake may be identified before the quake. Great earthquake and the large scale anomaly all belong to a small probability event, but to identify such event is the goal for earthquake prediction and disaster reduction. The approach well avoid the difficulties caused by weak information, big errors and complicated components in the data, for us to fully use vertical components of GNSS data on the crust dynamic vertical deformation study and earthquake prediction. So our confusions are eliminated to some extent, and the idea provides us support and reference for fully exploring and using some useful spectral information with high noisy data when we have to do that.

Acknowledgments
We thank professor Yang Guohua and senior engineer Hu Xinkang for the preliminary calculation results of GNSS data.

REFERENCES

Bo W J, 2013. Mainly relative deformation features on China continent revealed by GPS and researches on strong earthquake activities, Progress in Geophysics[J], 28(2)：0599—0606(in Chinese).

Bo W J *et al*, 2006. Estimation of the earthquake situations in the Sichuan-Yunnan area after the Ms8.7 great earthquake in the Indian Ocean [J]. Journal of Seismological Research, 2006,29(1):1-6(in Chinese).

Bo W J *et al*, 2007. Review and thinking about the application of geodetic data to earthquake prediction, Earthquake[J], 27(4): 68-76(in Chinese).

Bo W J *et al*, 2009. Deformation evidence and model deduction about the generation mechanism of the Wenchuan Ms8.0 earthquake, Earthquake[J], 29(1)：85—91(in Chinese)．

Bo W J *et al*，2011. Preparatory mechanism of Ms8. 0 Wenchuan earthquake evidenced by crust-deformation data. Geodesy and Geodynamics[J],2(2):23-28.

Chen C Y *et al*, 2014. Preseismic deformation associated with the 2014 Ms7.3 Yutian earthquake derived from GPS data. Geodesy and Geodynamics[J]，5(2):48-53. DOI: Doi:10.3724/SP.J.1246.2014.02048

Dong Y H et al , 2011. Co-and post-seismic vertical displacements of Wenchuan Ms 8.0 earthquake near Beichuan[J]. Geodesy and Geodynamics[J], 2(2): 29- 32.
Fang H X et al, 2010. The use of the ionosphere in short-term earthquakes prediction, Science technology and engineering[J], 10(27):6698-6706(in Chinese).
Gao M T et al, 2004. The GIS and analysis of earthquake damage distribution of the 1303 Hongtong M=8 earthquake. Acta seismologica sinica[J], 26(4)：363-368(in Chinese).
Geng Q G, 1985. Researches on relationship between drought and earthquake[M]. Beijing: china ocean press(in Chinese).
Huang J L and Zhao D P，2006．High-resolution mantle tomography of China and surrounding regions． Journal of Geophysical Research[J]， 111(B9)： B09305， doi： 0.1029 / 2005JB004066．
Huang L R and Guo L Q, 1998. GPS measurement(1995-1996) in the northern area of North China and its explanation. Seismology and Geology[J], 10(4)：423-430(in Chinese).
Huang L R and Kuang S J, 2000. Possibility of application of technique to vertical deformation measurement. Crustal deformation and earthquake[J]. 20(1) ：30-37(in Chinese).
Huang L R and Yang G H, 1991. The isostatic datum for studing of the sea level changes along the coast of China. Seismology and Geology[J], 13(1): 1-14(in Chinese).
Huang L R *et al* , 2002. Recent deformation deduced from GPS observation in Tianjin area, Journal of Geodesy and Geodynamics[J], 22(4)：17-20(in Chinese).
Huang L R *et al*, 2003. Spatial and temporal variations of ionospheric delay correction in Beijing-Tianjin area, Journal of Geodesy and Geodynamics[J], 23(3)：31-34(in Chinese).
Hu X K *et al* , 2007. Research and application of regional no-net-rotation reference frame. Journal of Geodesy and Geodynamics[J], 27(2)：52-60(in Chinese).
Jiang Z S *et al*, 2003. Horizontal strain field and tectonic deformation of China mainland revealed by preliminary GPS result, Chinese journal of Geophysics[J], 46(3)：352—358(in Chinese).
Jiang Z S *et al*, 2006. On crustal movement in China continent and its relationship with strong earthquakes, Journal of Geodesy and Geodynamics[J], 26(3)：1-8(in Chinese).
Liu X *et al*, 2010. Primary study on the dynamics of the present-day crustal motion in North China Region. Chinese journal of Geophysics[J], 53(6)：1418—1427(in Chinese).
Li Y X *et al*, 2004. Horizontal strain field in the Chinese mainland and its surrounding areas, Chinese journal of Geophysics[J], 47(2)：222—231(in Chinese).
Wang Q L *et al*, 2008. Researches on recent crust vertical movement in West Sichuan area[A]. See: Bo W J et al, The system of crust deformation mobile monitoring[C], P.67-81. Beijing: Seismological Press(in Chinese).
Xu G J *et al*, 1993. The relationship between destructive earthquake and meteorologic factors in Yunnan province, Journal of seismological research[J] , 16(2)：148-155(in Chinese).
Yang G H and Ma Q, 1992. Present vertical crustal movement and its gradient in the mainland of China under the flux-isostatic datum and some relations between them and tectonic activity, Crustal deformation and earthquake[J]. 12(4) ：49-54(in Chinese).

Yang G H et al, 1999. Present crustal horizontal movement and activity of Shanxi fault belt determined by GPS, Crustal deformation and earthquake[J]. 19(4):50 -55(in Chinese).
Yang G H *et al*, 2011. Several problems about strain calculation and analysis and correction of related deviation[J]. Geodesy and Geodynamics[J],2(1):29-35.
Yuan Z M *et al*, 1995. Sure don't forget the danger and Nip in the bud, Earthquake research in Shanxi[J], (3、4)：5-9(in Chinese).
Zhang F S and Bo W J, 2012. Primary discussion about the application of GPS results to research of ground subsidence[J]. Science of Surveying and Mapping, 7(4): 37-39(in Chinese).

BIOGRAPHICAL NOTES

Wanju Bo, was born in 1957, Tianjin, China; Registered Surveyor of the People’s Republic of China; Research professor, senior engineer, and deputy director of First Crust Deformation Monitoring and Application Center, China Earthquake Administration; Member in the Council of Seismology Society of China; Member in the Council of Chinese Society for Surveying, Mapping and Geoinformation. He is working on geodesy, data processing, crust deformation monitoring, earthquake prediction, earthquake prevention and disaster reduction and so on. He has published more than 100 papers and 4 volumes of works on his research field, most of his works are in Chinese.

CONTACTS

Title Given name and family name: Prof. Wanju Bo
Institution: First Crust Deformation Monitoring and Application Center, CEA, China
Address: No.7, Aihuo road, Yihaoqiao, Hedong District
City: Tianjin, Zip Code: 300180
COUNTRY: P. R. of China,
Tel. +(86)2224391357
Fax + (86)2224391357
Email: bowanju@163.com
Web site: http://www.eq-gc1.com/345.html