

Tidal wave anomalies of geoelectrical field before remote earthquakes^{*}

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Abstract

In this paper, geoelectrical field anomalies at Changli and Xingji station in Hebei Province were analyzed before five remote earthquakes. It was found that the anomalies mainly occurred two or three months before earthquakes, which is of importance to short-term and impendent earthquake prediction. There exhibited different characteristics in geoelectrical field anomalies, but they were closely related to tidal waves, for example, the increasing in amplitude at semidiurnal and semimonthly periods of tidal waves; the decreasing or disappearing in amplitude of tidal waves that should have been recorded normally at that time; while there accompanied incremental signals with high frequency, such as jump variations. It was thought that the formation mechanism of the geoelectrical anomalies before strong earthquakes resulted from stress-strain resonance effects when rock was weakened during the preparation process in seismic area, and then signals of electric field propagated to remote stations in free space or crust, and superposed on the geoelectric field tidal waves recorded at the stations, leading to increasing or decreasing in amplitude of geoelectrical tidal waves. The high frequency signals may be related to the variation of rock porosity, permeability and so on beneath the stations, as a result of the dynamic effects of remote earthquakes.

Key words: geoelectrical field; geoelectrical tidal waves; semidiurnal period; strain wave; imminent seismic prediction

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Introduction

Geoelectrical field is a kind of intrinsic geophysical field of the earth, affected by kinds of current systems in outer space and electric properties of media underground, so it carries abundant interior information of the earth. Since 1981 when the group of "VAN" in Greece carried out the study of electric field observation by multi-polar distances (Varotsos and Alexopoulous, 1984a, b), more and more scientists in the world paid extensive attention to it due to its better response to earthquakes (RUAN, 1998; Orihara *et al.*, 2002; Sharma and Baranwal, 2005). Electrokinetic effect and resonance effect during seismogenic process are the main ideas and starting points (ZHAO and QIAN, 1981; Fitterman, 1979; Dobrovolsky *et al.*, 1989; QIAN *et al.*, 1998; CHEN *et al.*, 1999). With the development of geoelectric field instrument ZD9A in China, the quality and sampling density has been improved a lot in observation of geoelectric field, which provides reliable guar-

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antee for picking up anomalous signals before earthquakes. It is illustrated in many researches that, solid earth tides have the function of modulation in crustal movement, earthquake preparation and triggering (ZHANG *et al*, 2001; CHI and ZHONG, 1993). The phenomena of earth tides results from the gravitation of the sun and the moon, which leads to regular ground deformation with diurnal, semidiurnal, monthly and semimonthly periods. In this paper, based on the analysis of geoelectric field data before a few strong earthquakes; it is found that the anomalies of geoelectric field before earthquakes are related to the phenomena of earth tides. Its mechanism has been studied also. It is thought that, the electric field anomalies occurring during the process of earthquake preparation propagate to the stations, then are overlapped on normal electric tidal wave and recorded by observation instrument of geoelectric field, which are with complicated variation features.

1 Basic information of stations

Since 2001, four geoelectric field stations were set up in succession by the Earthquake Administration of Hebei Province, which all rely on former electromagnetic station. Their observation ground is arranged in the observation region of earth resistivity. The underground apparent resistivity is observed by symmetrical four poles, with power supply of DC and pole distance of about 1 km, the observation pole distance being about 300 m. While using multi electrodes to observe electric field, five poles are buried to obtain measurement results of three directions with different spacing, that is defined as WE, E'W, SN, SN', NE, N'E' six components of electric field (Figure 1a), in which the long spacing of two crossing directions is 300 m (EW, SN), short spacing being 150 m (E'W, SN'). Geoelectrical data is observed by the instrument of ZD9A, which can record the low-frequency parts with a period larger than 10 s, resolution being 0.1 mV. Former

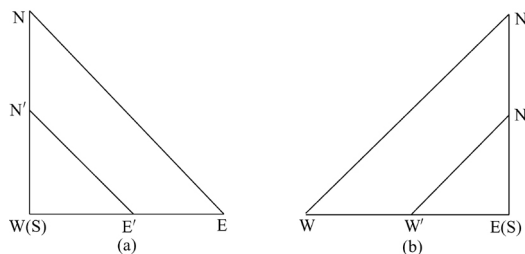


Figure 1 Sketch map of two kinds of arrangement of poles in geoelectrical observation

study (ZHANG *et al*, 2006) on geoelectrical field illustrated that the stations in Hebei Province can record the signals with semidiurnal and semimonthly period related to solid earth tides, which reflects their sensitivity to underground strain response. In this paper, data recorded at Changli station and Xingji station in Cangzhou is used and geoelectrical anomalies before some remote strong earthquakes at these stations are summarized and analyzed.

2 Features of geoelectrical precursory signals before earthquakes

2.1 Kunlun Mountain Pass west $M=8.1$ earthquake on November 14, 2001

Since September of 2001, the observed geoelectrical data gradually began to normalize and standardize. Figure 2 shows the curves of Changli in EW, Changli in SN, Yangyuan in EW and Xingji in NW, from which it can be seen that the information of Yangyuan in EW direction is with the longest observing time, while Xingji station began its record from November. The anomalies were prominently shown in the figure, where geoelectric field showed diurnal, semidiurnal periodic variation at Changli station (detailed information is shown in the small figure at top right

corner, during the time from October 15, 2001 to October 25, 2001), which is apparently different from its previous shape. After this kind of signals continued nearly a month, Kunlun Mountain Pass west $M=8.1$ earthquake (90.54°E , 35.95°N) took place on November 14 with a distance of 2 490 km to Changli station, and the obvious quasi-periodic waveforms still presented itself after the earthquake on this station. At Xingji station, distinct diurnal periodic variation began from November 5 and continued after the earthquake also; during the period from November 27 to December 13 a decreasing step-variation lasted for 17 days. Although with the longest recorded time

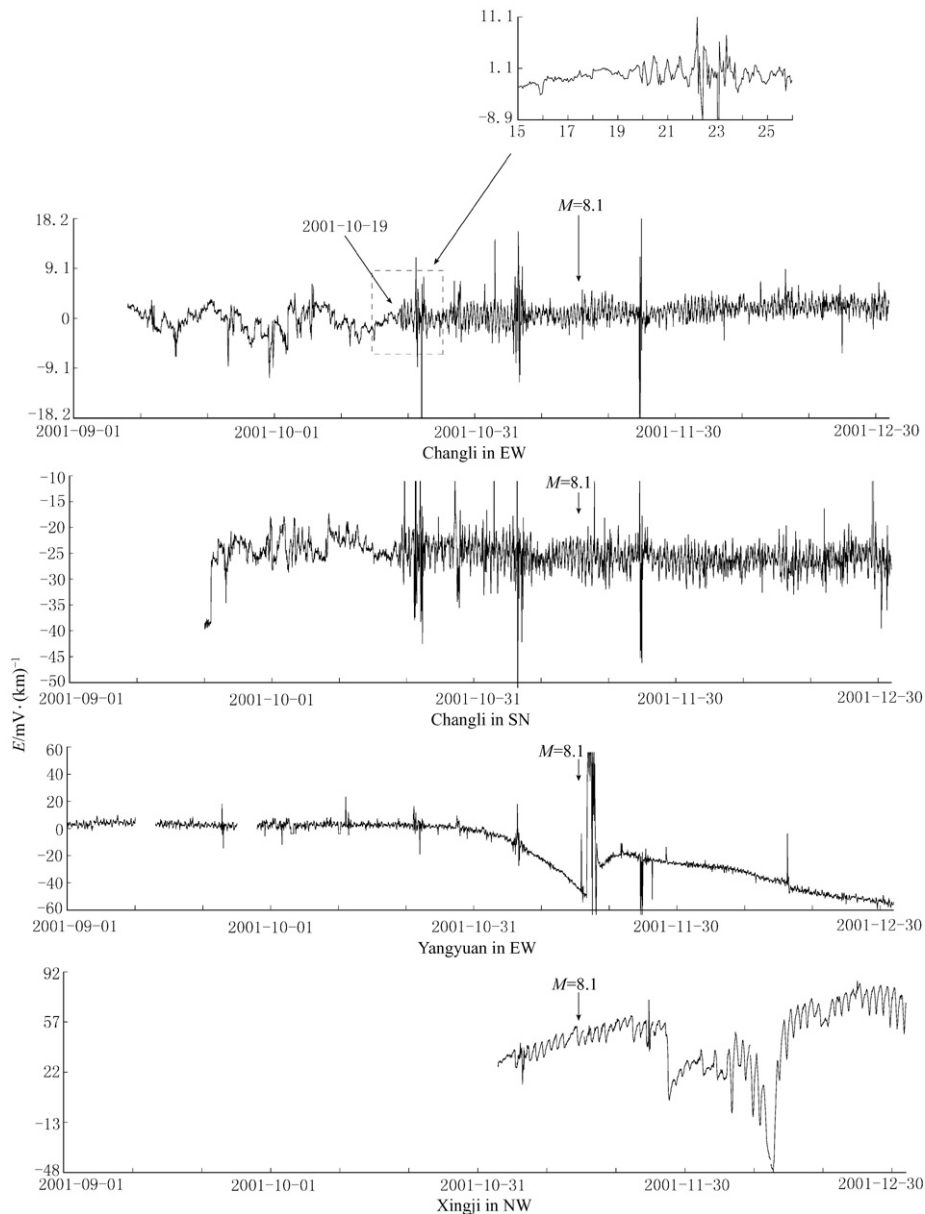


Figure 2 Geoelectrical anomalies before Kunlun Mountain Pass west $M=8.1$ earthquake in 2001

at Yangyuan station, no anomaly related to this earthquake was recorded, however, a large amplitude step-variation appeared two days after this earthquake. During this period, the instruments were installed in a relative short time, so these phenomena maybe resulted from the instability of observation system. Whether these anomalies were associated with this $M=8$ earthquake still need other proofs.

2.2 Taiwan $M=7.4$ earthquake on March 31, 2002

On March 31, 2002, there occurred a $M=7.4$ earthquake in Taiwan (122.18°E , 24.28°N), with a distance of 1 740 km to Changli station, Hebei Province. Figure 3 shows the observed curves of three long spacing (EW, SN, NE) at Changli station, in which similar variation characteristics are presented. Since March 10, 2002, accompanying the diurnal and semidiurnal periodic features strengthened and much bigger amplitude variations than those in previous months, there presented evidence of semimonthly period in EW observational direction of this station. The calculated theoretical gravitational tidal wave exhibits that, March in this year is the time interval with relatively weak tidal undulation, so this strengthened tidal variation in geoelectrical field cannot be owing to the earth tidal gravitation, but they are anomalies. In order to reflect the anomalous information characteristics during this time interval, wavelet analysis was done on the data at SN observational direction in Changli station (LU *et al.*, 2000). The third order wavelet transform results (Figure 3b) shows that most daily amplitude variations are larger than 2 times of mean square errors (the upper and lower lines in Figure 3b) in this whole time interval since March 10, which demonstrates that the geoelectrical field were strengthened indeed at this station. Daily averaged amplitude was computed, being 4 mV/km in January of 2002, but increasing to 6 mV/km in middle and last ten-day of March.

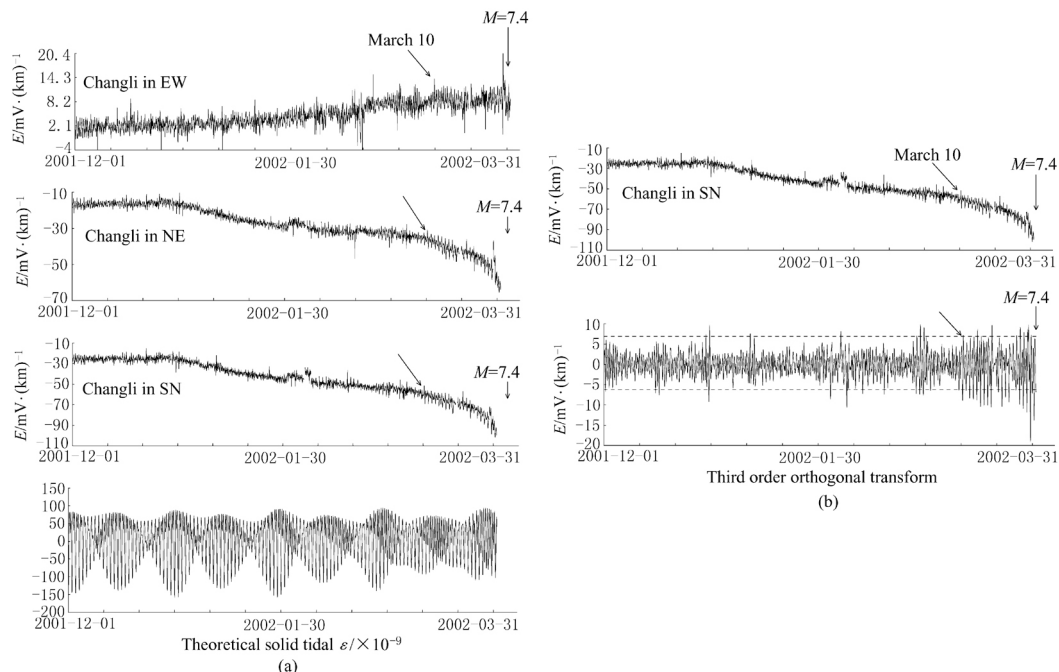


Figure 3 Geoelectrical anomalies before Taiwan $M=7.4$ earthquake in 2002

(a) Comparison among original data curves of geoelectrical field at different observing directions and theoretical solid tidal wave in Changli station; (b) Wavelet transformation curves of SN direction at Changli station)

2.3 Japan $M=8.3$ earthquake on September 26, 2003

Two earthquakes of $M=8.3$ (143.91°E , 41.81°N) and $M=7.4$ took place during 2 hours on September 26, 2003 at the same region in Japan, which are located at the northeast of Changli station with a distance of 2 090 km and 2 310 km respectively. Figure 4 provides curves of long and short spacing geoelectric field in Changli EW direction and long spacing at Xingji EW observational direction, from which it can be seen that the anomalous characteristics in this time are evidently different from those of the above-mentioned two earthquakes. Preseismic daily variations at two stations were normal; no apparent enhanced signal was presented. In August, the maximum geomagnetic index K larger than 5 occurred on 6, 8, 18, and 21. While there was a magnetic storm during 16 to 17 in September, with the biggest index K reaching to 6 and 7 in those two days. The biggest K index during the period from 18 to 20 in September was 5, 3 during 21 to 23, and 5 during 24 to 25, and then till the end of this month it is a quiet period of magnetic field. It can be seen that these variations with larger-amplitude waveform in August and September at both stations, especially that during 16 to 17 in September lasting longer time, should be correlated to magnetic storms, which is completely isochronous in their occurring time at both stations. After September 17, the activity of magnetic storm is weak, and geoelectric field observation showed no obvious daily-variation, but mainly presenting small amplitude and high frequency signals. On September 22, data at Changli station exhibited large amplitude step-variation, with similar relative variation in amplitude at long and short spacing geoelectric field in the same observational direction, which reflects that it was not disturbance due to any problems on common electrodes, but it might be a group of far-field signals. This step-variation continued to 23, then recovered to previous changing level. But after this anomaly, daily variation signals suddenly augmented in Changli station on

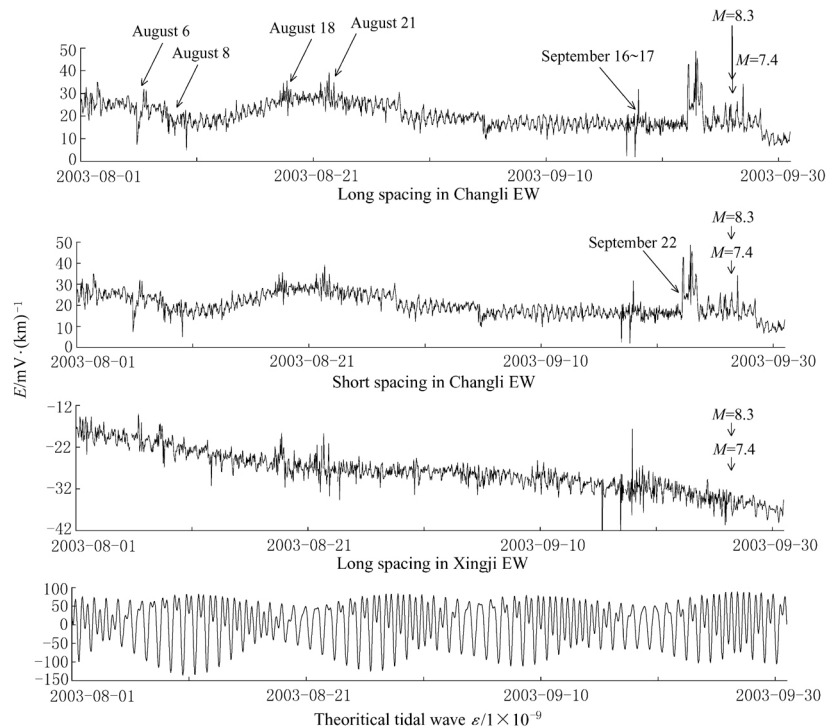


Figure 4 Geoelectrical anomalies before Japan $M=8.3$ earthquake in September, 2003

September 25 and the $M=8.3$ earthquake in Japan took place just one day after it, and the larger-amplitude geoelectrical field anomaly variation recovered in one day after the earthquakes. By analyzing this anomaly and comparing it with theoretical solid tidal wave, it is found that at the trough of semimonthly period of tidal wave, the geoelectric field changed with small amplitude, so the phenomenon of decreasing daily amplitude generally occurred at this time interval. Except for some sudden jumps due to magnetic storms, the reducing amplitude during September 17 to 22 corresponded to the weakest tidal waves, but compared with other reducing characteristics during similar time intervals, there still might contain some seismic anomalies. After this variation, firstly the step-variation occurred on September 22, and then daily variation began to strengthen in Changli station, while the daily variation did not recover till earthquake occurrence at Xingji station. During this time interval, there was no any change in surrounding environment of stations, and no moderate or group of small earthquakes taking place around them, which suggested that these anomalous signals must be related to the remote strong earthquakes in Japan.

2.4 Japan $M=7.4$ earthquake on September 5, 2004

During 18h~22h on September 5, 2004, two earthquakes above 7 took place in succession in Japan, in which the epicentral location of the bigger earthquake with $M=7.4$ is 137.07°E , 33.18°N , located at the southeast of Changli station, the distance to Changli station is 1 760 km, 300 km nearer than the earthquake above-mentioned in September, 2003. Figure 5 exhibits geoelectrical field curves after wavelet transform (The program is from LU *et al*, 2000) at EW and SN direction in Changli station, in which the first order transform curves mainly give prominence to high frequency information in original records. They showed much more high frequency signals appeared in August, 2004, in a dense state and with large amplitude exceeding the error lines of 2σ , especially were notable at EW direction with large amplitude signals apparently decreasing after the above-mentioned earthquakes. The third order wavelet transform results reflect semidiurnal, diurnal and longer period variations. It is found that since the end of June in 2004, the daily variation amplitudes in EW direction began to increase, although there existed phenomena of data missed, the shape of data variation were not affected before and after this time interval, and the large amplitude undulation continued till the earthquakes occurrence. Since August, these signals

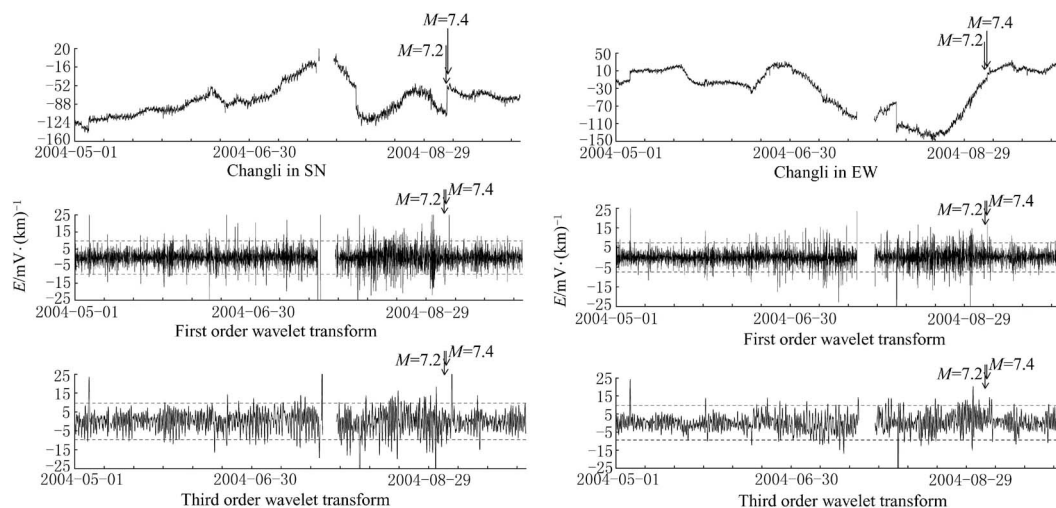


Figure 5 Geoelectric field anomalies before Japan $M=7.4$ earthquake in September, 2004

in SN direction became much more prominent. In addition, a decreasing step-variation occurred on August 5 at other two directions. They also were observed at NE direction, so they did not result from the disturbances of common electrodes. At 22h on September 5, that is the time of main earthquake occurring, the anomaly ended by a sudden increase step-variation at SN direction as well as NE direction, however at EW direction, the geoelectrical data was in a rising state all the while, only showing small amplitude of isochronous step-variation.

2.5 Indonesia $M=9.0$ earthquake on December 26, 2004

On December 26, 2004, a $M=9.0$ earthquake took place in Indonesia (95.98°E , 3.3°N), resulting in postseismic tsunami and vast casualty. The epicenter of this earthquake is in a distance of 4 670 km, southwest to Changli station. Figure 6 presents the original curves of Changli station at EW direction and its first and third order wavelet transform. In the first order curves, high frequency part was prominent, it can be seen that high frequency signals increased since the middle especially last ten-day of October and this phenomenon continued to the middle ten-day of November in 2004. The third order wavelet transform presented obvious tidal periods in geoelectrical field in September of 2004, semimonthly period feature of geoelectrical field was very clear (Figure 6). But since the last ten-day of October, the semimonthly period in geoelectrical tidal waves was destroyed, and difficult to distinguish, which was replaced by large amplitude undulations. The anomalous amplitudes decreased since the middle ten-day of November, but routine diurnal and semidiurnal periods in geoelectrical data did not emerge all the while. The small amplitude variation maintained till the earthquake occurrence, and then all kinds of periods recovered quickly as well as the amplitudes getting back to preseismic level.

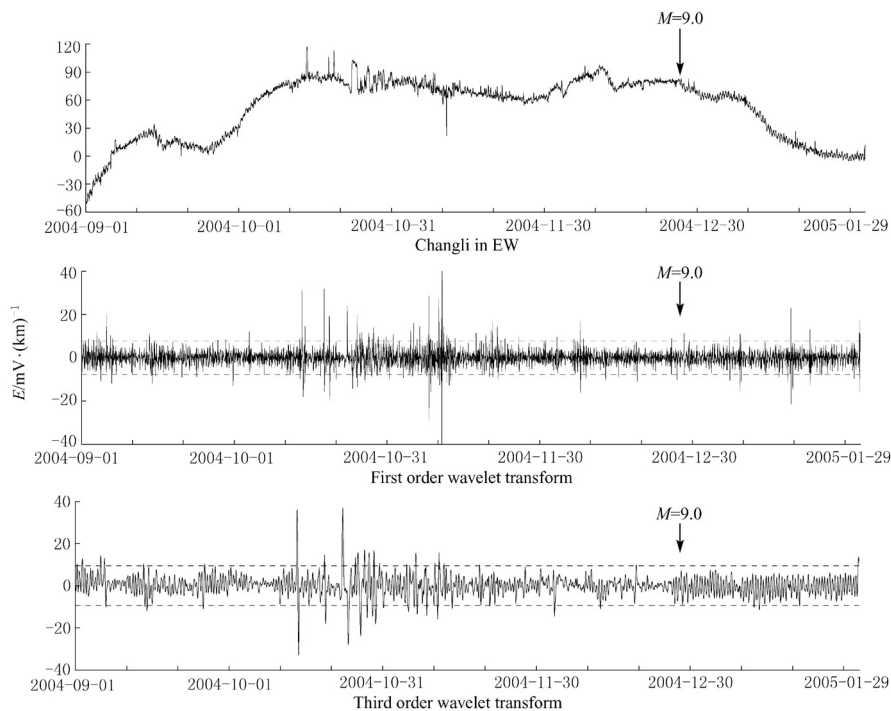


Figure 6 Geoelectrical anomalies before Indonesia $M=9.0$ earthquake in December, 2004

2.6 Summarization of anomalous characteristics

The geoelectrical field data used in this paper is collected hourly. In order to reflect the periodic information, power-spectrum analysis (LU *et al*, 2000) was done to the data of January and March before Taiwan $M=7.4$ earthquake on March 31, 2002 (detailed data seen 2.2 section). Due to the short anomalous time, data of 1~22 in both months were collected respectively. The results show that, during normal time interval (Figure 7, 2002-01) there existed the periods of tidal wave in geoelectrical field, in which semidiurnal and 1/3 diurnal waves were prominent, larger than diurnal wave. While during anomalous time interval (2002-03), there was no big change in periodic characteristics, but the power-spectrum of semidiurnal and 1/3 diurnal waves increased greatly, being 3 times of that in normal time. The power-spectrum of diurnal wave changed a little. It is known that, diurnal variation in geoelectrical records is owing to the effects of the sun on geomagnetic field, while semidiurnal and 1/3 diurnal variation are not the inherent periods of geomagnetic field, but the periods of solid earth tidal waves, so the anomalies reflect the change of solid tides. Due to short time interval, long periods such as semimonthly, monthly and so on cannot be reflected naturally here.

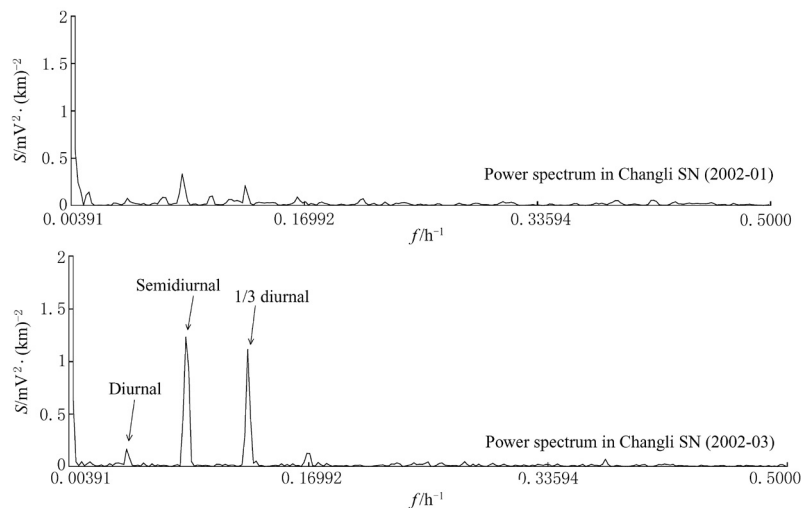


Figure 7 Power-spectrum anomaly before Taiwan $M=7.4$ earthquake on March 31, 2002

Based on the analysis of five examples of earthquake, it is found that, geoelectric anomalies generally occurred in 2~3 months or much shorter time before earthquakes. Accompanying with the earthquake occurrence, anomalies ended quickly, so they are well temporally consistent with the earthquakes. The longest duration of anomalies was only more than 2 months, with typical imminent characteristics. Before and after these remote strong earthquakes, there are three kinds of shapes in geoelectrical anomalies related to tidal wave, that is amplitude augmenting, periods nearly disappearing and high frequency signals increasing, or mixed shape of these three kinds. In Figure 7, the characteristics of one kind of anomaly is exhibited as that the anomalous variation overlaps on tidal wave, with no new periods occurring, reflecting that this kind of anomaly is correlated with modulation of tidal force. The phenomena of reduced amplitude before Indonesia earthquake maybe resulted from the differences of phase between tidal wave from focal area and local normal electromagnetic field at stations.

3 Mechanism analysis of anomaly

3.1 Reliability of far-field geoelectrical field anomalies

Near-field geoelectrical anomalies have been reported many times (ZHAO *et al.*, 2001; MA *et al.*, 2004), but there are few studies on far-field geoelectric anomaly, because electromagnetic wave decays very fast, and cannot propagate long distance. In this paper, geoelectrical tidal waves recorded at geoelectric observational stations are selected to reflect far-field anomalous information. Saraev *et al.* (2002) obtained that the correlated coefficient is 0.95 between earth resistivity and tidal variation in the observation of low frequency electromagnetic field. The experiences using electromagnetic field to detect gravitational wave has been carried out in some countries, and the facts illustrate it feasible (SHI and CHENG, 2004). In this paper earthquakes with large magnitude or their epicenters were much closer to stations were chosen, so it is understandable that preseismic anomalies can be recorded by these stations.

Some tests that scholars of former Soviet carried out in Garm during 1970 to 1980 and studies of western scientists illustrated that, crustal deformation, change of seismic wave velocity, gases radiating from crust and variation of crustal resistivity and so on could be observed not only in epicentral areas, but in a much large-scale zone. On the basis of this feature, an expanding theory was developed, that is the main faulted region due to crustal deformation and fractures was defined as seismogenic belt (Scholz *et al.*, 1973; Mjachkin *et al.*, 1975). Dobrovolsky *et al.* (1979) estimated the scale of this belt, giving $r=10^{0.43M}$, in which elastic horizontal deformation employs 10^{-8} order, r is radius of seismogenic belt (km) and M represents magnitude. Figure 8 presents the seismogenic scale calculated by this equation. It can be seen that, as to a $M=7.4$ earthquake, its seismogenic radius can reach to 1 520 km, 2 754 km for a $M=8$ earthquake, while being 7 413 km to a $M=9$ earthquake.

Scholz *et al.* (1973) built physical mechanism of earthquake prediction taking radon as a kind of seismic precursors. It is known that radon is also a probable formation mechanism of electromagnetic field anomalies, which means that anomalous region of seismic geoelectrical field should be equivalent to that of radon ions. Toutain and Baubron (1999) listed geochemical measurement of earthquake precursors from 150 different authors, and estimated the functional relation between geochemical anomalous belts with magnitude. Their conclusion went all the way to that of Dobrovolsky *et al.* (1979). Therefore, it can be demonstrated that the distribution scale of preseismic anomalous electric field can be estimated by the formula above, that is to say, the geoelectrical anomalies also can be detected in a large area.

Indonesia earthquake in 2004 is the biggest one in these earthquakes analyzed in this paper. Underground water level, geotherm and other precursors related to this earthquake have been recorded by many stations in Jiangsu and Hebei province (ZHENG *et al.*, 2005; ZHANG *et al.*, 2005). One reliable gaseous anomaly was observed one and a half hour before Indonesia earthquake at the spot of the Chinese Continental Scientific Drilling in Donghai, Jiangsu Province (ZENG *et al.*, 2005). It presented concretely that the liquid samples they collected there that never contained Ar,

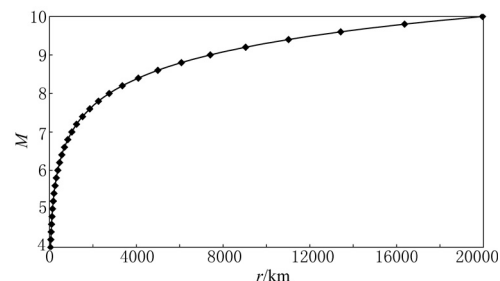


Figure 8 Seismogenic scale of earthquake with different magnitude

He, N₂, were full of these three gases before the earthquake. The observation point is in an epicentral distance of 4 170 km. Similarly, 2 days before Kunlun Mountain Pass west $M=8.1$ earthquake in 2001, one station in an epicentral distance of 1 030 km recorded sudden changes of water radon. Therefore, both static and dynamic anomalous variation in focal region can be noted at far-field electric observations. Moreover, the beginning and ending time of anomalies we picked up are well temporally coincident with the earthquake occurrence, which reflects that these seismogenic anomalies are believable.

3.2 Formation mechanism of anomalies

Strong earthquakes can excite the change of earthquake activity near or far, underground water level, ground temperature and so on, mainly through two kinds of mechanism: ① During the process of earthquake preparation, static stress changes, that is the static excitation; ② By propagation of seismic surface wave, the rock physical properties under the stations will be transformed, that is the dynamic excitation; both static and dynamic excitation can result in the anomalous phenomenon at the time of earthquake occurrence or before it. Lots of studies indicate that, the variation of static stress caused by earthquakes is inversely proportional to the epicentral distance or its square, and at the place with epicentral distance three times of length of seismic fractures, the static stress will decay to the level of that due to tidal force (Freed, 2005), but it may be well reflected in geoelectrical observation when it is sensitive to gravitational strain field, that is the foundation of physical mechanism we based on to analyze the relation between geoelectrical anomalies with earthquake preparation.

So why were the periods of anomalous signals consistent to that of tidal waves? Many researches (ZHANG *et al*, 2001; CHI and ZHONG, 1993) illustrate that, by loading and unloading function on the earth, the tidal force acts to some extent in earthquake triggering, magma activity, and directional movement of media, which cannot be ignored in mechanism of crustal movement. In previous studies on resistivity and geoelectrical field at Changli, Baodi and other stations before Tangshan $M=7.8$ earthquake in 1976 (QIAN *et al*, 1990; ZHAO and QIAN, 1981; Qian and Zhao, 1990), it was found that there exhibited apparent semidiurnal and semimonthly periods in resistivity and geoelectrical observation at a few stations, with the anomalous semidiurnal amplitude of resistivity at Changli reaching 7% just before the earthquake occurrence, which had never been observed during other time intervals. They thought that, because the crust of focal region weakens during imminent seismic time interval, the slope of stress-strain constitutive relation of underground rock is near to zero, producing resonance effects with coincident periods or double frequencies of tidal waves.

Tidal force is a long-standing force source. Presuming that static stress in focal region is a durative steady force, so relative to nonseismic time intervals, the change of stress is to add an approximate invariable static stress on the tidal force. The kinetic electrical potential underground is represented generally as $\Delta U=0.77\rho_w\Delta p$ (CHEN *et al*, 1999), in which ρ_w is resistivity of fluid, and Δp is pressure difference that contains tidal force and static stress in focal region. The overlapping of static stress in focal area and tidal force will form a kind of stress-strain anomalous signals similar to tidal wave, leading to "sponge effect" in media and pore liquid in it (Saraev *et al*, 2002), and then will also excite geoelectrical anomalous signals with semblable periods, propagating long distance in free space and crust. When this anomaly occurred in geoelectrical stations, it will interact with the environmental electromagnetic field and normal geoelectrical tidal waves on stations, resulting in geoelectrical tidal amplitude increase when it is with identical phase as the

normal records, or decrease, distorting even disappearance of geoelectrical tidal waves when their phases differ greatly.

As for the high frequency jump variations before earthquakes, they may be closely related to dynamic excitation from focal region, that is stress strengthened in earthquake preparation zone propagates to remote stations by surface wave, leading to the change of media physical parameters such as rock porosity, permeability and so on, and the movement of underground fluid, then producing kinetic geoelectrical potential, and exciting electromagnetic signals near stations, which can be validated by dense small earthquake activity, hydro-chemical anomaly, and surface displacement by GPS observation at remote areas resulted from strong earthquakes (WANG *et al.*, 2006; ZENG *et al.*, 2005).

4 Conclusions

In this paper, geoelectrical anomalies before five remote strong earthquakes were summarized, in which it is found that geoelectrical tidal waves present anomalies with different shapes, sometimes enhanced, sometimes weakened, accompanying increase of high frequency signals and sudden jump variations. Most anomalies began 2~3 months before earthquakes, and the duration time may be related to epicentral distance and magnitude, which provides new idea and method for imminent prediction of far field strong earthquakes. In addition, the possibility and physical mechanism of far-field anomalous seismogenic signals recorded by geoelectrical observation were demonstrated and discussed from multi-aspect. It is thought that although geoelectrical field and earth resistivity are not the direct observational tools to detect stress and strain field, they are well sensitive to weak stress-strain response (ZHAO *et al.*, 1990; Saraev *et al.*, 2002), so they can note down some anomalies forming during the process of earthquake preparation. The anomaly characteristics of geoelectrical tidal waves before strong earthquakes are mainly owing to the destroy of stress-strain constitutive relation during earthquake preparation, and the electric field resonance effects similar to tidal wave due to the influence of tidal force, which propagates in free space or crustal media to distant stations, and adds on the normal records of stations, producing anomalous phenomenon of amplitude increasing or decreasing in geoelectrical tidal wave records. While, high frequency signals and jump variations of geoelectrical field should be correlated with dynamic effects during earthquake preparation.

Geoelectrical tidal wave anomalies can be noted down not only in focal region of strong earthquakes, but can respond to remote earthquakes, which provides a better research platform for analysis on seismogenic mechanism and long-distance propagation of electric signals from seismic zone. Present shortage is the lacking of denser station distribution and data with high sampling rate, for example the data collection of low-frequency electric field and resistivity of 1 Hz to a few kHz that can spread in a long distance, so it is impossible to do further analysis on the velocity and propagating characteristics of this kind of far-field electric field waves. It should be improved and enhanced in future observation, in order to ensure that geoelectrical data provide much powerful support for further study in future on imminent earthquake prediction, overlapping mode of far-field strain wave and excitation effects.

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