Multi-dipole observation system and study on the abnormal variation of the geoelectric field observed at Capital Circle area before the Wen'an $M_S5.1$ earthquake*

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Abstract

On July 4, 2006, a $M_S5.1$ earthquake occurred in Wen'an county of Hebei Province of which the epicenter is near the Beijing city. The six geoelectric field monitoring stations have been in operation for several years around the Beijing area to examine the relationship between electric field changes and earthquake. This paper firstly explains the principle of the eliminating noise method by using multi-dipole observation system of the geoelectric field. Then the data observed at the stations are studied and a lot of abnormal signals preceding the Wen'an earthquake are selected, of which five abnormal signals of the geoelectric field are finally recognized as the precursory signals. The result shows that ① there probably exists the precursory signals of the geoelectric field preceding the Wen'an earthquake; ② there are sensitive sites in the spatial distribution of the abnormal variation of the geoelectric field before the quake; ③ the anomalous signals do not appear synchronously, and their durations are not same at different stations; ④ the amplitudes of the abnormal signals recorded at Baodi station are small, but large at Changli station, while the latter is farther from the epicentral area than the former.

Keywords: Wen'an earthquake, geoelectric field, multi-dipole observation, signal recognition

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Introduction

The observations of the related geoelectric and geomagnetic fields are the important parts for geophysical field observations. However, at present the former observation is much less popular than that of latter one worldwide, because the former needs the buried electrodes as signal receivers and requires good observation conditions, which is difficult to realize in most cases. Nevertheless, the improvement of the electrode technique has provided favorable conditions for the observation of the geoelectric fields. The digital geoelectric observation network comprising 80 stations has been established in China since 1995, and its monitoring scope is the most extensive in the world. It has an important scientific meaning to make fully use of available data for earthquake prediction.

The geoelectric field mainly includes the telluric and spontaneous electric fields. The former is distributed on the whole ground surface or extensive areas because it originates from the high-altitude electromagnetic induction (*i.e.*, ionosphere, magnetosphere, electric current system

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in troposphere); while the latter comes from the earth interior (especially from shallow crust) where the electric current is produced due to the electric charge separation between the positive and negative ones. Compared with the telluric field, the spontaneous electric field is dominant in local areas. The geoelectric field is controlled by the sources and influenced by the electrical properties of the local subsurface medium, so that they are different from each other in different locations. Generally, the spatial source scale of the spontaneous electric field is more confined than that of the telluric field. Thus, the spatial distributing discrepancy of the spontaneous electric field caused by the local electrical properties is larger than that of the telluric field. For earthquake prediction the field and local electrical properties are two important kinds of precursory parameters in seismo-electricity. The precursor of the spontaneous electric field belongs to the field precursor, while the telluric field is attributed to local precursor, which can be studied to obtain the features of the earth medium. The anomalous behaviour of the spontaneous electric field has been reported in a number of cases relating to the seismic activity (*e.g.*, Corwin and Morrison, 1977; ZHAO and QIAN, 1981; Kinoshita *et al*, 1989; Varotsos *et al*, 1993; Nagao *et al*, 1996; QIAN *et al*, 1998; MAO *et al*, 1999; Uyeda *et al*, 2000; Tsutsui, 2002; Orihara *et al*, 2002; Telesca *et al*, 2004; MA *et al*, 2004; Varotsos, 2005). Therefore, studying the variation characteristics of the spontaneous electric field is one of the objectives to apply the geoelectric field observation to earthquake prediction.

The electric field is a vector field in the sense of physics. For the measurement of a vector, the basic method is to measure its components and magnitude in a given coordinate system. At present, studying the geoelectric field mainly concern about its horizontal component on the earth surface, so it becomes a two-dimensional vector (or say a plane vector), of which the magnitude and direction can be determined by its components in the plane coordinate system. To measure the components, a pair of electrodes is distributed in a given direction (generally, in N-S and E-W directions) to capture the signals of the electric field. The potential difference of the two electrodes is divided by the dipole separation, which is the measurement of the component in the given direction. The geoelectric field changes when the source of the field varies with time. One of the main tasks in seismo-geoelectricity is to study the variation characteristics of the geoelectric field with time and establish the relationship between them for explanation the process of the earthquake preparation. The observation of the geoelectric field is different from that of the geomagnetic field in that the earth electrode is needed in the setting system, in which the magnitude of the potential difference between the electrodes, the site condition and its stability are more important factors to produce right solution. Besides, similar to the other geophysical observations, distinguishing and removing ambient noise are essential technique requirement in the observation and data processing of the geoelectric field. Accordingly, when the China geoelectric observation network was deployed the followed two kinds of techniques were used: ① non-polarized electrode was used, and the special technique was required in electrode embedding so that the potential difference between the electrode and earth was small and its stability can be kept for a longer time; ② multi-dipole observation system was distributed at stations in order to distinguish ambient noises and remove them, so that the data quality can be kept well.

A network of six geoelectric field monitoring stations has been in operation around the Beijing area (Capital Network) since 1990s. Based on the data of the Capital Network, this paper uses the principle of the multi-dipole observation system to the data processing, and studies the precursors before Wen'an ($M_S 5.1$) earthquake, which occurred On July 4, 2006 in Hebei Province.

1 Theory of eliminating noises base d on the multi-dipole observation system

The method of eliminating the noises near stations by the multi-dipole observation system was firstly reported by the “VAN” group of Athens University in 1982 (Varotsos and Alexopoulos, 1984a, b). They set up the multi-dipole observation system instead of the single dipole observation system for the geoelectric field observation, in which long dipoles and short dipoles were distributed in the same direction, for example, in E-W and N-S directions respectively. By comparing the magnitudes of the different components along on the long dipoles with that on short dipoles, the local noises near a station can be recognized. The principle chart is shown in Figure 1, in which both a long dipole AB and a short dipole $A'B'$ are distributed in the same orientation in order to measure the potential difference $V_A - V_B$ and $V_{A'} - V_{B'}$, respectively. The components of the electric intensity E_{AB} and $E_{A'B'}$ can be obtained as follows:

$$E_{AB} = \frac{V_A - V_B}{L_{AB}} \quad (1)$$

$$E_{A'B'} = \frac{V_{A'} - V_{B'}}{L_{A'B'}} \quad (2)$$

$$V_{O_i} \propto \frac{1}{r_{O_{ij}}} \quad i=1, 2; j=A, B$$

where V_A , V_B , $V_{A'}$ and $V_{B'}$ represent the potentials at points A , B , A' and B' , respectively, and L_{AB} and $L_{A'B'}$, the lengths of the dipoles AB and $A'B'$, respectively. In Figure 2, two kinds of signal sources are assumed, namely a distant source and near source. Here, r represents the distance from measuring point to the source of the electric signal. In this way, the influence of the sources to the signals of the geoelectric field could be obtained.

Figure 1 Comparison chart of long electric dipole and short electric dipole deployment

Because potential V is inverse proportional to the distance r , for distant signal sources with same intensity, the components of the electric field intensity recorded at the observation site on the long dipole are roughly equal to that of the short dipole. While for the near signal sources they can be substantially different from that on the short dipole. If the signal source is located inside the electrode distribution

area its sign on the long dipole can be opposite to that on the short dipole. Hence, for the multi-dipole observation system one can distinguish the signals from the near source to the distant source, *i.e.*, the field is uniform or quasi-uniform for the distant source but not uniform for the near source. In fact, measuring the geoelectric field by using the multi-dipole observation system is to measure the uniformity of the geoelectric field in the area of the observation setting system.

To pick up the valuable precursory information of the spontaneous electric field, noises identification is a critical factor under consideration. The noises are classified into three categories: ① additional electrical signals on the electrodes due to the cultural generalized electric current pass-

ing through the survey region; ② the noises due to the local underground electric heterogeneity caused by rain near stations and the changes of temperature; ③ the noises of the polarized electrode due to the changes of the electrode performance or buried condition. Generally speaking, they have the near source characteristics, *i.e.*, the source locates at the site near the station and the obvious local inhomogeneities of the electric field components along the long and the short dipoles. Figure 2 shows one example of the local inhomogeneities, which are the signals of the geoelectric field for some events recorded on the E-W, N-S and NE directions at Changli station in Hebei Province on April 1, 2006 (diagram c) and June 16, 2006 (diagrams a and b) respectively. From Figure 2 we can see that the abnormal signals of the geoelectric field observed on the long dipoles are great different from that on the short dipoles in the same directions. This indicates that they are likely disturbed signals although their cause is still unknown.

Figure 2 Typical example of the nonuniformity of the geoelectric field recorded at a station (a) A geoelectric field event recorded at Changli station at 1:30~2:30 on April 16, 2006; (b) A geoelectric field event recorded at Changli station at 13:30~14:30 on April 16, 2006; (c) A geoelectric field event recorded at Changli station on April 1, 2006. In the figure, EW (L), EW (S), NS (L), NS (S), NE (L) and NE (S) represent the long dipoles and short dipoles of the directions of east-west, north-south and north-east, respectively. E represents intensity of geoelectric field

In this way, according to the method mentioned above we can compare the calculating results between the long dipoles and short dipoles. If their correlation coefficients are larger than 0.9 they could be considered as the criterion of the uniformity so as to recognize the noises from near source. In fact, additional potential difference could be produced in the measurement of the geoelectric field when the electrode is in unstable condition. Because the influence of the unsteady

polarization is only related to the electrode itself and the ambient environment, the synchronizing variation of the geoelectric field could not occur on the long dipole and short dipole in the same direction. Therefore, the instability of the electrode polarization must lead to the difference of the geoelectric field components on different dipoles, which shows their uniformity decrease and hence could be distinguished by the multi-dipole observation system.

Generally speaking, the signal of the telluric field belongs to the distant source and it can meet the uniformity requirement. The abnormal signals of the spontaneous electric field can be classified into two kinds: First, these come from focal zone and their epicentral distances are larger than the dimensions of the survey area, and they possess the characteristics of distant sources that satisfy the good uniformity. Second, these come from noise sources but not focal zone, which may be located at the survey area or near the station that don't satisfy the uniformity demand. The signals of the spontaneous electric field from a distant source but not from focal zone generally seldom disturb the records at the station because of its small source dimension. Therefore such kinds of signals may be ignored.

The difference between the telluric and spontaneous electric field is that the former has larger spatial uniformity than latter one. Hence the former could change synchronously at the different observing sites in an extensive area. Figure 3 shows one example of the synchronous variations of the geoelectric field recorded on the Capital Network when a event of magnetic storm occurred at Beijing time 22:30~24:00 on May 23, 2006 (geomagnetic index $K=6$ at geomagnetic station of Shanghai), in which the variations were not recorded on the NE component at Jinghai station and

Figure 3 Abnormal variation forms of the geoelectrical storm recorded at 23:00 on May 6, 2006 at the stations of Baodi, Xinji, Jinghai, Yangyuan, Tongzhou and Changli, respectively

EW components at Changli and Tongzhou stations due to some high frequency disturbances. This synchronous variation is related to the intensity of the abnormal high-altitude electric current system. Generally the dimension of the telluric field source and its distances to the observation stations are larger greatly than that of the spontaneous electric field.

In the data analysis in this paper, author consider these kinds of the geoelectric field signals as the noises or interferes according to the above mentioned method, in which their forms and amplitudes on long dipoles differ from that on short dipoles greatly, and they may come from a known disturbing source or the one that needs to investigate more.

2 Capital Network of the geoelectric field and the abnormal signals recorded at single station

The Capital Network consist of six geoelectric stations, which are distributed around Beijing area included Baodi station (117.38°E, 39.55°N), Jinghai station (38.6°N, 116.8°E), Tongzhou station (39.7°N, 116.67°E), Xinji station (38°N, 116.7°E), Yangyuan station (40.12°N, 114.15°E) and Changli station (39.72°N, 119.15°E), respectively (Figure 4). The technique parameters and dipole distribution (orientations and lengths of the dipoles) of the six stations are shown in Figure 5, in which the distributions are set up in the form of triangle with a commonality electrode but crisscross form at Baodi station. The separation ratio of the long dipole to the short dipoles is 2:1 at each station.

Figure 4 Distribution of the geoelectric field stations around Beijing and the epicentral location of the Wen'an earthquake

Based on the multi-dipole observation system, the data recorded at the six stations in the year of 2006 are checked and analyzed comprehensively in the paper. Two kinds of the signals are dominant, one is the signal with synchronization variation recorded at each station and the other is the signal recorded at a single station. The former is related to the ionosphere disturbance, and the latter need to investigate if they were related to the interferences near the station. They could be recognized by the theory of eliminating noises mentioned above.

In 2006, some abnormal signals of the geoelectric field were recorded at single station among the six stations, which means that they were only recorded at one station but not detected at the other stations. So the signals could not come of the ionosphere source. By the method of the

multi-dipole observation system to analyze data, we could get rid of these signals, which could not be considered as signal from the spontaneous electric field. Figure 6 shows some examples, in which the dashed frame scalar product does not satisfies the multi-dipole analyses method, but the solid does, so the signals in the solid frame are the signal from the spontaneous electric field. Figures 7 and 8 shows the detected signals of the spontaneous electric field, and they were mainly recorded at Baodi and Changli stations.

Figure 5 Distribution of the electrodes at the stations of Baodi, Changli, Xingji, Yangyuan, Jinghai and Tongzhou

Figure 6 Abnormal signal recognition of the geoelectric field recorded at Changli station on June 16, 2006
In the figure the solid frame scalar product satisfies the multi-dipole analyses method while the dashed does not. E represent intensity of geoelectric field

Figure 7 The distinguished abnormal signals of the spontaneous electric field recorded at Changli station on June 16 (a) and June 21 (b)

Figure 8 The distinguished abnormal signals of the spontaneous electric field recorded at Baodi station on June 26 (a) and June 27 (b)

The variable characteristics of the geoelectric field recorded on the Capital Network before $M_S5.1$ Wen'an earthquake occurred on July 4, 2006 are listed in Table 1. They are all the abnormal signals selected by author during the period from April to July 2006, in which so called precursory signals satisfy the principle of eliminating noises based on the multi-dipole observation system and they could not be related to the surrounding interferences near the stations and the noises of the electrode polarization.

Table 1 The abnormal characteristics of the geoelectric field recorded at capital network before Wen'an ($M_S5.1$) earthquake

Station	Dipole	Intensity /mV·km ⁻¹	Start time		Anomaly cause	Origin time after anomaly signal
			mo-d	h:min		
Baodi	EW, NS, NE	12.5	04-05	20:00~21:00	magnetic storm	
Baodi	EW, NS, NE	24	04-14	18:00~19:00	magnetic storm	
Baodi	EW, NS, NE	23.2	05-06	22:30~23:30	magnetic storm	
Baodi	EW, NS, NE	20	06-10	06:00~14:00	seismic anomaly	24d:5h:42m
Baodi	EW, NS, NE	13.2	06-15	22:00~23:00	magnetic storm	
Baodi	EW, NS, NE	4.6	06-26	10:00~18:20	seismic anomaly	8d:1h:56m
Baodi	EW, NS, NE	5.7	06-27	06:00~17:00	seismic anomaly	7d:5h:56m
Changli	EW, NS, NE	28	04-05	20:00~21:00	magnetic storm	
Changli	EW, NS, NE	28.5	04-14	18:00~19:00	magnetic storm	
Changli	EW, NS, NE	20	05-06	22:30~23:30	magnetic storm	
Changli	EW, NS, NE	23	06-15	22:00~23:00	magnetic storm	
Changli	EW, NS, NE	90	06-16	14:30~15:00	seismic anomaly	17d:21h:26m
Changli	EW, NS, NE	25	06-21	14:30~15:20	seismic anomaly	12d:21h:26m
Changli	EW, NS, NE	40.8	06-26	18:00~19:00	noises near the station	
Tongzhou	EW, NS, NE	14	04-05	20:00~21:00	magnetic storm	
Tongzhou	EW, NS, NE	10.3	04-14	18:00~19:00	magnetic storm	
Tongzhou	EW, NS, NE	8.0	05-06	22:30~23:30	magnetic storm	
Tongzhou	EW, NS, NE	18	05-26	15:00~16:00	noises near the station	
Tongzhou	EW, NS, NE	23.5	06-15	22:00~23:00	magnetic storm	
Tongzhou	EW, NS, NE	28.2	06-24	19:00~21:00	noises near the station	
Jinghai	EW, NS, NE	18	04-05	20:00~21:00	magnetic storm	
Jinghai	EW, NS, NE	12.6	04-14	18:00~19:00	magnetic storm	
Jinghai	EW, NS, NE	10.2	05-06	22:30~23:30	magnetic storm	
Jinghai	EW, NS, NE	7.3	06-15	22:00~23:00	magnetic storm	
Xinji	EW, NS, NE	16.5	04-05	20:00~21:00	magnetic storm	
Xinji	EW, NS, NE	11.8	04-14	18:00~19:00	magnetic storm	
Xinji	EW, NS, NE	9.3	05-06	22:30~23:30	magnetic storm	
Xinji	EW, NE	145	05-26	16:30~17:00	electrochemical noise	
Xinji	EW, NS, NE	246	06-13	02:00~3:00	noises near the station	
Xinji	EW, NS, NE	6.0	06-15	22:00~23:00	magnetic storm	
Xinji	EW, NS, NE	121	06-17	05:00~06:00	noises near the station	
Yangyuan	EW, NS, NE	23	04-05	20:00~21:00	magnetic storm	
Yangyuan	EW, NS, NE	21.5	04-14	18:00~19:00	magnetic storm	
Yangyuan	EW, NS, NE	13.4	05-06	22:30~23:30	magnetic storm	
Yangyuan	EW, NS, NE	34.75	05-26	15:40	noises near the station	
Yangyuan	EW, NS, NE	10.5	06-15	22:00~23:00	magnetic storm	

3 Precursory signal characteristics before the Wen'an earthquake

From the analysis of the data recorded at the six stations mentioned above, we could see that the characteristics of the precursory signals of the geoelectric field before the Wen'an ($M_S5.1$) earthquake are described as follows.

1) The abnormal signals were recorded only at a few stations. That is that the precursor signals were only detected at Baodi and Changli stations but not at other four (Jinghai, Tongzhou,

Xinji and Yangyuan) stations through the analysis of the multi-dipole observation system. Surprisingly the nearest epicentral stations (Jinghai and Tongzhou) did not show the precursor signals at all.

Author analyzes the data observed at Baodi and Changli stations in the whole year of 2006, and do not find another precursor signal similar to that shown in Figures 7 and 8.

2) The precursory signals were recorded in non-synchronization at Baodi and Changli stations. They were detected during the different time lags: from June 10 to June 14, from 10:00 to 18:20 of June 26 and from 6:00 to 17:00 of June 27 at Baodi station, and from 14:30 to 15:00 of June 16 and from 14:30 to 15:20 of June 21 at Changli station, respectively. The lead times before the earthquake were different at Baodi and Changli stations. Many earthquake examples showed the phenomenon.

3) The intensity characteristics of the abnormal signals do not show the relation. The nearer the station from the epicenter zone, the bigger the amplitudes of the abnormal signals. For example, the maximum amplitude of the abnormal signals appears at Baodi and is 20 mV/km, which is smaller than that at Changli with 90 mV/km, while the former station is nearer to the epicenter zone than the later. Its mechanism may be explained mainly by the nonuniformity of the underground electrical property.

4) The characteristic form of the abnormal signals recorded at Baodi station is different from that at Changli. At Baodi station the first precursory signal lasted a longer period of time (from June 10 to June 14, 2006), while the second and the third abnormal signals lasted about 8 hours and 11 hours respectively. Such abnormal signal form is similar to the so-called "SES activity" reported in Greece (Varotsos *et al*, 1993 and 2005). The precursory signals recorded at Changli station lasted only a shorter period time, which is about 30 min on June 16, 2006 with positive polarity and 50 min on June 21, 2006 with negative polarity.

4 Conclusions

This paper expounds the theory of eliminating noises based on the analysis of multi-dipole observation system, and furthermore shows how to distinguish the precursory signals from the noise signals. The work of the paper provides an alternative approach to the short-term earthquake prediction in our country by the method of the geoelectric field. By analyzing the data recorded on the Capital Network before and after the Wen'an ($M_s 5.1$) earthquake, we can draw the preliminary conclusion as follows.

1) The precursory signals of the geoelectric field do exist preceding to the Wen'an earthquake. They successively appear 24 days and 8 days at Baodi station before the Wen'an earthquake, and 17 days and 12 days at Changli station before the quake.

2) The observation of the geoelectric field on the Capital Network has shown that there exist the sensitive sites in the spatial distribution of the precursory signals before the Wen'an earthquake. The signals were recorded at Baodi and Changli stations but not at Jinghai, Tongzhou, Xinji and yangyuan stations, and especially not at Jinghai and Xinji stations which were the nearest to the epicenter area.

3) The anomalous signals do not appear in the same time at different stations, and the intervals of the time from the end of the precursors to the quake occurrence are also not same at different stations.

4) The amplitudes of the abnormal signals recorded at Baodi are smaller than that at Changli,

while the former station is near the epicentral area and the later is far from it.

The study of the paper shows that the precursory signals of the geoelectric field before earthquake could be recorded at some 'sensitive site'. The words 'sensitive site' is used more frequently in the study of earthquake prediction when people could not clearly understand the mechanism of precursory anomaly during the period of thumb rule. The so-called 'sensitive site' means that there are some observatory sites at which seismic abnormal signals could be detected although the sites could be farther from epicenter zone than some other sites. Baodi and Changli stations were such sites before the Wen'an earthquake as analyzed in the paper. Of course, in the study of the seismo-electromagnetism the so-called 'sensitive site' could be explained in some extent in the theory: the different underground electric properties at each station may result in the signal diversity of the geoelectric field; even the conjunction of the abnormal variation of the geoelectric field to that of the underground medium resistivity at site may be the main cause of the abnormal signal diversity of the geoelectric field. Based on the conjunction, we may boost the observation of the geoelectric field and make it play an important role in the study of the short-term earthquake prediction.

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