Correlation between abnormal trends in the spontaneous fields of tectonic plates and strong seismicities

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Abstract Tectonic activities, electrical structures, and electromagnetic environments are major factors that affect the stability of spontaneous fields. The method of correlating regional synchronization contrasts (CRSC) can determine the reliability of multi-site data trends or short-impending anomalies. From 2008 to 2013, there were three strong earthquake cluster periods in the North–South seismic belt that lasted for 8–12 months. By applying the CRSC method to analyze the spontaneous field E_{SP} at 25 sites of the region in the past 6 years, it was discovered that for each strong earthquake cluster period, the E_{SP} strength of credible anomalous trends was present at minimum 30% of the stations. In the southern section of the Tan-Lu fault zone, the E_{SP} at four main geoelectric field stations showed significant anomalous trends after June 2015, which could be associated with the major earthquakes of the East China Sea waters (M_S 7.2) in November 2015 and Japan’s Kyushu island (M_S 7.3) in April 2016.

Keywords Spontaneous field · Anomalous trend · Reliability · Strong earthquake · Correlation

1 Introduction

In seismic predictions, geoelectric fields are mainly applied in disputed and short-impending precursory information

analysis (Geller 1996; Wyss et al. 1997; Uyeda 2000). Complex electromagnetic environments, dynamically rich observation data, developing observation techniques and theoretical understanding, and basic dysfunctional short-impending predictions of catastrophic earthquakes cause credibility problems in geoelectric field observations and short-impending predictions (Geller 1996; Huang 2006).

If the confirmation of the presence of background variation trends in the geoelectric fields of the site is possible before the occurrence of catastrophic earthquakes, then the implementation of corresponding short-impending geoelectric field information analysis will have a more credible basis. Geoelectric field observation data comprise spontaneous fields, telluric fields, and interference information, which determine the necessity of reliable data analysis. The VAN method (Varotsos and Alexopoulos 1984a, b) is a short-impending earthquake prediction method based on geoelectric field anomalies, which relies on the long and short polar distances in the same location to explore seismic electric signals (SESS) and initiate predictions thereof (Ma 2008). However, the VAN method is only used for short-impending earthquake prediction with obvious controversies (Geller 1996; Huang 2006), which is based on the criticality model that electric signals are emitted when in the future earthquake focal area the gradually increasing stress reaches a critical value so that the existing electric dipoles due to defects exhibit a cooperative orientation (Varotsos 2008). In the analysis of strong regional seismicities, it is a common method for the statistical analysis of seismic catalogs. To improve the reliability of precursory seismic anomaly statistics, Huang introduced a feasible RTL (region-time-length) statistical method (Huang 2006; Huang and Liu 2006). This approach requires a relatively stable data background. In a region with intense

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tectonic activities, frequent strong quakes, and poor data stability, such as the vicinity of the North–South seismic belt in recent years, prediction using the VAN method or surveying the precursory anomalies using the RTL method is very difficult.

In the North–South seismic zone, the time quasi-synchronization phenomena occurs in the turning trends of spontaneous fields at multiple sites near the same fault zone (Tan et al. 2014). Similar phenomena also occur near the Tan-Lu fault zone. This study introduces the correlating regional synchronization contrasts (CRSC) method for determining the reliability of spontaneous field anomaly trends. Time corresponding phenomena were found between the trends of dynamic spontaneous field anomalies and strong cluster earthquakes in the statistics of the trend variation of 25 stations on the North–South seismic belt and 70 earthquakes of M_S 5.0 and above from 2008 to 2013. In the Tan-Lu fault zone, correspondence existed between the trend anomalies in 2015 and increased tectonic activities in the region of Japan.

2 Characteristics of trend variation in the spontaneous field strength

Although the basic principle of geoelectric field observation devices is originated from the VAN method, their layout can be diverse. In general, the observation devices based on the VAN method comprise 2–3 pairs of electrodes, respectively, in the EW and NS directions. The polar distance ranges from tens to hundreds of meters. Moreover, 2–4 pairs of 1–10 km-long pole distance can be laid with appropriate configuration of their electrodes (Varotsos et al. 1991, 1993). In 1990, the Sino-French Electromagnetic Cooperation Project established the observing devices at the Songshan (SHN) station in Tianzhu, Gansu, as shown in Fig. 1a (polar distance of several kilometers was not laid). Japan Institute of Physical Chemistry's electrode layout models installed on the new isle of the Izu islands are as shown in Fig. 1b (Huang and

Liu 2006). The device comprises 8 pairs of mutually orthogonal long (several kilometers) and short (tens of meters) polar distances. Mainland China's devices are basically laid out in double-triangle shapes (also called L-shapes) as shown in Fig. 1c. The ratio of the long and short polar distances in the same direction is about 1.5, with the long distances mostly being 300–400 m.

Geoelectric field observation data usually includes spontaneous fields, telluric fields, and interference information. E_{SP} represents spontaneous field, E_T represents telluric field, and E_R represents the signal interference factor. The composition of the observed value of geoelectric field can be written as

$$E = E_{SP} + E_T + E_R. \quad (1)$$

When the conditions of the electromagnetic environments and the observation systems are ideal, the observed value of the i -th minute is set as E_i , and the daily mean value of the strength of E_{SP} calculated using the value data of minutes in one day can be expressed as formula (2). When formula (2) is applied for calculation, the relatively stable main composition of E_T , namely the effect of tidal geoelectric field, is eliminated (Tan et al. 2012):

$$E_{SP} \approx \frac{1}{1440} \cdot \sum_{i=0}^{1439} E_i. \quad (2)$$

The spontaneous field on day j is set as $E_{SP(j)}$, and the E_{SP} daily jump can be expressed by formula (3):

$$\Delta E_{SP(j)} = E_{SP(j+1)} - E_{SP(j)}. \quad (3)$$

In general, when the determination of the impact of electromagnetic environment and observation devices at the observation site is difficult, the reliability of results calculated via formulae (2) and (3) must be confirmed. When plotting the curves of E_{SP} and ΔE_{SP} , to show their long-impending trends, substantial kick data in a short duration (less than ten days) are deleted.

The observation environments and device systems of two stations in Shandan, Gansu, and Haian, Jiangsu, are favorable. Within the range of 100 km, no earthquake of

Fig. 1 Schematic of various geoelectric field orthogonal observation devices. **a** Orthogonal devices based on the VAN method, **b** orthogonal devices of Japan's new isle, and **c** China's orthogonal devices

M_S 5.0 or above occurred in the past 5 years. The E_{SP} patterns at these two sites are stable and their annual rangeability does not exceed 100 mV/km, with a slightly larger jump of ΔE_{SP} before and after the summer season, as shown in Fig. 2a, b. The locations of the two stations are shown in Fig. 2c. Figure 2a, b reflects that E_{SP} and ΔE_{SP} are relatively stable in the local areas where the earthquake activities are weak, thus showing the annual change pattern.

Figure 2d indicates the two regions studied here. Figure 2e, f is the trend curves of E_{SP} and ΔE_{SP} of the Lugu lake and Luo'ci stations on the southern section of the North–South seismic belt, respectively. The locations of these two stations are shown in Fig. 2c, wherein the E_{SP} and ΔE_{SP} curves show their significant range ability and violent jumps; however, the drastic changes in 2013–2014 showed better time corresponding phenomena. In recent years, strong seismicities violently occurred in the North–South seismic zone. The long-term E_{SP} stability of most stations in the vicinity was poor, with large magnitudes of changes and unclear cyclical annual changes, whereas phenomena like persistent fluctuation, leap, and bound existed at some E_{SP} stations. However, the inflection points of their trends exhibited time quasi-synchronization with similar stability during the same period. The E_{SP} patterns are irrelevant owing to site factors (Tan et al. 2014).

The southern section of the Tan-Lu fault zone mainly involves Shandong, Jiangsu, Anhui, and other provinces. The characteristics of E_{SP} trend anomalies of the North–

South seismic belt also appeared in the southern section of the Tan-Lu fault zone in correspondence to the E_{SP} changes of the stations in Jiashan, Anhui and Lingyang, Shandong, as shown in Fig. 3c.

3 The reliability of spontaneous field anomalies

3.1 Reliability analysis method for short-impending and trend anomalies of spontaneous field

At present, there are at least two methods for determining the reliability of short-impending anomalies of spontaneous fields E_{SP} . The first method is based on the principle of the VAN method for calculating the ratio of data variation of long-range and short-range polar distance at the same station in the same direction. If the ratio is close to one, the variation is considered to be a SES. Considering Changli station in Fig. 3a as an example, after zeroing treatment on the short polar distance data, the variation ranges of $E_{EW(L)}$, $E_{EW(S)}$, $E_{NS(L)}$, and $E_{NS(S)}$ during the time interval 15:54–16:13 were almost equal to each other. Such variations can be regarded as SESs (Guo et al. 2013). The second method is to conduct the correlating statistical analysis based on the seismic catalog. Figure 3b lists the main steps of the RTL statistic determination method for precursory seismic anomalies (Huang 2006; Huang and Liu 2006). This method can also be applied to the reliability analysis of spontaneous field changes.

Fig. 2 Trend variation curves of spontaneous fields E_{SP} and ΔE_{SP} . **a** Areas with weak seismicities (2012–2014), **b** distribution of analysis stations, and **c** areas with strong seismicities (2008–2014)

Fig. 3 Reliability analysis method for spontaneous field changes. **a** Application using the VAN method, **b** main procedures of the RTL statistical method, and **c** CRSC method

According to the VAN principle, all SESs at various sites originate from the seismic source. However, if it is assumed that the geoelectric field anomalies at each site are not from the seismic source but from the reflection of local site stress, strain, and underground fluid caused by intense local tectonic activities, then this reflection will be manifested through the geoelectric field E of the site in a large space. Moreover, there should be some differences in the anomalies of different sites in terms of E_{SP} or E_T patterns and time. For example, on the Qinghai–Tibet plateau, where tectonic activities are intense, various forms of short-impending anomalies could always be detected at more than ten remote E_{SP} or E_T stations before and after major earthquakes in recent years. The occurrence time of these anomalies exhibited quasi-synchronization (Tan et al. 2010, 2012). In recent years, studies have shown that morphological differences and time quasi-synchronization were also present in the regional trend anomalies of E_{SP} and ΔE_{SP} (Tan et al. 2014), as shown in Fig. 2e, f. In the southern section of the Tancheng–Lujiang fault zone, the E_{SP} anomalies at the Jiashan and Lingyang stations are also similar, as shown in Fig. 3c.

As a result, the significant E_{SP} trend and short-impending anomalies presented in this study do not have to be associated with a particular earthquake to determine their reliability. After excluding a wide range of interference factors (such as HVDC (high voltage direct current)), only the presence of the anomalies in the vicinity of the fault zone associated with the same fault zone or tectonic activities needs to be identified.

1) The E_{SP} leaps, jumps, or trend anomalies at numerous sites exhibited time quasi-synchronization without entirely consistent changing patterns;

2) The intense ΔE_{SP} jumps and relatively stable changes at numerous sites exhibited time quasi-synchronization;

3) The E_{SP} anomalies at certain sites and ΔE_{SP} anomalies at other sites exhibited time quasi-synchronization;

4) The E_{SP} and ΔE_{SP} trend anomalies at numerous sites exhibited rising and falling quasi-continuity.

When one of the above conditions is satisfied, the E_{SP} anomalies at these sites are deemed to have credibility. In this study, this approach is called the correlating regional synchronization comparison method of spontaneous field changes (CRSC method). The E_{SP} trend anomalies in Figs. 2e, 3c, f can be considered to possess reliability by applying the CRSC method. It is obvious that as the number of sites that satisfy the above conditions in one region increase, the reliability of the E_{SP} anomalies also increases.

It should be noted that: (1) Under the conditions of the CRSC method, the meaning of time quasi-synchronization possesses relativity. For analyzing the data of tens of days, the allowance of time quasi-synchronization can be several hours or days. For analyzing the trend variation on the year scale, the allowance of time quasi-synchronization can be tens of days. (2) The CRSC method can be applied to the reliability analysis of telluric field anomalies in principle.

3.2 Differences and mechanisms of reliability judgment results in different methods

Figure 2a illustrates the local regions with weak seismicities whose spontaneous fields E_{SP} and ΔE_{SP} are relatively stable in general. Figures 2e, f, and 3c show that in the vicinity of the fault zone where tectonic activities are intense, E_{SP} and ΔE_{SP} changes can be complex or without long-term stability. Since the origins of E_{SP} are complex, when focusing upon analyzing the effects of different field sources, there may be differences in established physical

models, analytical methods, and understanding of the reliability of data anomalies.

Figure 4a is the “point source” model diagram of the VAN method. According to the mechanism of the VAN method, SESs originate from remote seismic sources and near-field signals are an interference. The electric potential on various points around the “point electric source” is inversely proportional to the distance from the source. “Remote sources” may cause $\Delta E_{A_1B_1}$ and $\Delta E_{A_2B_2}$ at A_1B_1 and A_2B_2 in the figure to be almost equal. According to this principle, the geoelectric field anomalies in Fig. 3a can be regarded as SESs. However, these signals did not appear subsequently on March 6 when the M_L 4.7 earthquake occurred 56 km away from Luanxian. A possible explanation is that there were spectrum and other differences between the pre-seismic SESs and the contemporary seismic signals despite the lack of evidence. Thus, the application of long and short polar distances is mainly to explore the short-impending SESs from the seismic sources, near-field variation of geoelectric fields, tidal waves, and distortions, which can be regarded as “interference”, despite the existence of these variations (Huang and Liu 2006; Tan et al. 2010, 2011, 2012, 2014). Figure 2e shows that during 2008–2009, the EW and NE long polar distances at Yanyuan station exhibited distinctive diurnal waveforms. E_{SP} , E_T , and the adjacent Lugu lake station exhibited quasi-synchronization (Tan et al. 2010, 2011, 2012, 2014). However, the day correlation coefficients of long and short distances data in all directions were lower than 0.3. Based on the principle of the VAN method, such stations are considered to exhibit obvious near-field interference or system failure; however, the application of the CRSC law can identify that the data variations possess reliability.

In seismic case analysis, SES amplitudes mostly range from several mV to tens of mV (Ma 2008; Ma et al. 2009; Guo et al. 2013). In Fig. 3a, the amplitude of the SESs at Changli station is about 10 mV, and this lasts for about 20 min. In the regions and time periods with intense tectonic activities, such as the period of intense E_{SP} variation in Figs. 2e, f, and 3c, many large interferences can be seen based on the VAN principle, and it is difficult to find effective SESs. In fact, there are few applications of the VAN method and seismic case analyses on the North–South seismic belt with large and strong earthquakes.

Intense tectonic activities will lead to very complex stress and strain inside the plate. Seismogenic areas are stress-concentrated areas. Stress and strain variation will occur on other plates or near the fault. Microfractures of rocks at the site and abnormal fluid seepage at multiple sites may occur quasi-synchronously. Therefore, at various blocks inside the plate and its adjacent plates, there is a tectonic dynamic basis for the occurrence of E_{SP} and ΔE_{SP} corresponding trend changes at a number of sites (Chen et al. 2009). A study on the deep electrical structure of magnetotelluric observations (Zhao et al. 2009) indicated that the M_S 8.0 Wenchuan earthquake in 2010 was not a local tectonic event but stress accumulation in the Longmenshan fault zone caused by intense tectonic activities of various locations on the Qinghai–Tibet plateau. A study on selective numerical simulation of SES sites (Huang and Lin 2010) indicated that the electrical differences of surface media affected the distribution of geoelectric fields. Based on electrokinetic effects (Ren et al. 2012, 2015) and rock fissure water (charge) seepage model of tidal geoelectric fields, significant leaps or jumps in E_{SP} at the site may occur in rock mass shear fracture (Tan et al. 2014). On May

Fig. 4 Various principles for the reliability judgment methods of geoelectric field anomalies **a** principle of the VAN method, **b** tectonic plate and adjacent areas of the Qinghai–Tibet plateau, and **c** quasi-synchronous variation phenomena of geoelectric fields at different stations (2016-05-01–2016-05-17)

18, 2016, before the M_S 5.0 earthquake in Yunlong County, Dali Prefecture, Yunnan, multiple stations including Fengxiang, Chengdu, Tengchong, Yanyuan, and Ganzi stations were distributed on multiple blocks, as shown in Fig. 4b, and their geoelectric field changes are shown in Fig. 4c. The step changes, jumps, and waveform distortions of the geoelectric fields at these stations possessed different levels of quasi-synchronization. Therefore, the CRSC method can obtain the support of tectonic dynamics theory, deep electrical structure research results, geoelectric field mechanism, and seismic case analysis.

It can be seen that the purpose of applying the long and short polar distance theory of the VAN method is to explore the short-impending SESs from the seismic sources. Other geoelectric field variations are deemed as interferences. The application of the CRSC method focuses on determining the authenticity of short-impending or trend anomalies of E_{SP} (E_T) and not whether there is any direct association with earthquakes. Therefore, when analyzing

the reliability of E_{SP} variations with these two methods, the conclusions may be “conflicted”.

4 Correlation between the trend anomalies of spontaneous field strength and activities of strong earthquakes

After 2008, large and strong earthquakes in mainland China were mostly concentrated near the North–South seismic belt. On April 16, 2016, a M_S 7.3 earthquake occurred on Japan’s Kyushu island. Therefore, this section mainly analyzes the trend variation of the spontaneous field E_{SP} on the North–South seismic belt and the southern Tan–Lu fault zone.

4.1 North–South seismic belt

In the vicinity of the North–South seismic belt, the long-impending stability of the spontaneous field E_{SP} strength is affected by regions, sites, positions, tectonic activities, and other factors (Tan et al. 2014). Between 2008 and 2013, the statistics of the earthquakes of M_S 5.0 or above occurred in the regions at 99°E–107°E and 25°N–35°N are shown in Table 1. Based on the distribution of stations in the region, the Chengdu, Hanwang, and Lugu lake stations are selected for case analysis. It should be pointed out that the observing devices and electromagnetic environments at the three stations did not experience any significant changes simultaneously during this period.

Earthquake intensity and frequency in this section are represented by colored strips. The colors of the strips in Fig. 5a represent seismic magnitudes and the widths of the

Table 1 Statistics of strong earthquakes in the region at 99°E–107°E and 25°N–35°N in recent years

Year	$\geq M_S$ 8.0	$\geq M_S$ 7.0	$\geq M_S$ 6.0	$\geq M_S$ 5.0
2008	1	–	9	34
2009	–	–	1	6
2010	–	–	0	3
2011	–	–	0	1
2012	–	–	0	2
2013	–	1	1	11

The earthquake catalog obtained from China Earthquake Network Center

Fig. 5 Correlation between natural electrical field trend anomalies and strong regional cluster earthquakes at a typical station in the North–South seismic belt (2008–2013). **a** Seismicity colored strips, **b**, **c**, and **d** E_{SP} , ΔE_{SP} curves of Lugu lake, Chengdu, and Hanwang stations, respectively, and **e** distribution of epicenters and abnormal stations in the first period (2008-05–2008-12)

strips indicate seismic frequency. Earthquakes of M_S 5.0 or above that occurred once a month are indicated by a thin line, 2–4 times by a half-month breadth line, and 5 times and above by a full-month breadth line. Multiple quakes of various magnitudes that occurred in a month are represented by the strip color determined by the highest magnitude.

Figure 5a shows the strong earthquake clusters in the regions at 99°E – 107°E and 25°N – 35°N that occurred in three periods from 2008 to 2013. The first time period was from May 2008 to December 2008, the second was from June 2009 to May 2010, and the third was from September 2012 to August 2013. Figure 5a–c shows the presence of correlation between the intense changes and the relative calm of E_{SP} and ΔE_{SP} at the Lugu lake and Chengdu stations. The periods of violent changes responded to the time of strong earthquake clusters. Figure 5d shows no obvious abnormality of E_{SP} and ΔE_{SP} in the first and second periods at the Hanwang station. The drastic changes in the third period corresponded to the Lugu lake station and Chengdu counterparts. Therefore, the dynamic trends of E_{SP} and ΔE_{SP} at the three sites are correlated with the strong seismicities of the North–South seismic belt in different degrees. Figure 5e depicts the distribution of stations with

abnormal trends at each strong earthquake epicenter in the first period.

Table 2 shows the statistics of 25 stations in the three periods of strong earthquake clusters shown in Fig. 5e and the numbers and ratio of stations where E_{SP} and ΔE_{SP} show abnormal trends.

It can be observed that during the three strong earthquake cluster periods on the North–South seismic belt in 2008–2013, the lowest ratio of the stations with trend anomalies in E_{SP} and ΔE_{SP} was close to 30%. These trend anomalies generally exhibit quasi-synchronization similar to those in Fig. 5b–d. According to the CRSC method, the phenomenon is believed to have an acceptable reliability.

4.2 Southern segment of the Tan-Lu fault zone

The distribution of four main geoelectric observation stations in the southern section of the Tancheng-Lujiang fault zone is shown in Fig. 6a. From January 2012 to November 2016, no earthquake of M_S 5.0 or above occurred in Jiangsu, Shandong, Anhui or other places. A M_S 7.2 earthquake occurred in the East China Sea in November 2015. In April 2016, earthquakes having magnitudes of M_S 6.2, M_S 6.0, and M_S 7.3 occurred in succession in Kyushu, Japan. Table 3 shows the statistics of earthquakes having the magnitude of M_S 5.0 or above that occurred in the zones at 22°N – 38°N and 120°E – 136°E from January 2012 to November 2016. It can be seen that strong seismicities were clearly enhanced in 2015 and 2016.

During the period from January 2012 to November 2016, various strong earthquake epicenters occurred in the analysis areas and the locations of the geoelectric fields in Anqiu, Lingyang, Xinyi, and Jiashan stations are shown in

Table 2 Statistics of E_{SP} and ΔE_{SP} trend anomalies at 25 stations in the three periods of strong earthquake clusters (2008–2013)

Period	E_{SP}	Ratio (%)	ΔE_{SP}	Ratio (%)
May 2008–Dec 2008	8	32	9	36
June 2009–May 2010	7	28	9	36
September 2012–August 2013	16	64	16	64

Fig. 6 Spontaneous field trend anomalies of the 4th station in the southern segment of the Tan-Lu fault zone, and the contrast between the strong seismicities in the East China Sea and Kyushu island, Japan. (2012-01-01–2016-11-30). **a** Epicenter and station distribution, **b** Colored strips for strong seismicity, and **c** station E_{SP} curve

Table 3 Statistics of strong earthquakes in the regions at 120°E–136°E, 22°N–38°N in recent years

Year	$\geq M_S$ 8.0	$\geq M_S$ 7.0	$\geq M_S$ 6.0	$\geq M_S$ 5.0
2012	0	0	1	4
2013	0	0	4	6
2014	0	0	2	3
2015	0	1	4	12
2016	0	1	5	10

Seismic catalog obtained from China Earthquake Network Center, the deadline is November 30, 2016

Fig. 6a. Figure 6b shows the colored strips for strong earthquakes and their frequency in such regions, whose definitions are the same as in the previous section.

Figure 6c depicts the variation curve of the spontaneous field E_{SP} of the four stations in the southern section of the Tan-Lu fault zone. It can be seen that after June 2015, all four E_{SP} stations showed clear trend anomalies with time quasi-synchronization. According to the principle of the CRSC method, the E_{SP} trend anomalies of these four stations possess reliability.

Figure 6a shows that these four stations are remote from the epicenters of strong earthquakes, whose E_{SP} trend variation does not correlate with earthquakes at M_S 6.0 or below. However, Fig. 6b, c shows that E_{SP} trend variations have possible correlations with the major M_S 7.2 earthquake in the East China Sea in November 2015, and the M_S 7.3 earthquake on Kyushu island in April 2016.

5 Conclusions

1) The VAN method is more suitable for the blocks or sites with relatively stable tectonic activities. Its purpose is to explore the SES for short-impending predictions since this method can narrow the time window of the impending earthquake from a few days to one week or so (Varotsos et al. 2011). The CRSC method is used for multiple sites; it is more adaptable to the regions with complex electromagnetic environments and fault distributions as well as intense tectonic activities. Moreover, it confirms the authenticity of data anomalies. The RTL statistical method depends mainly on the selection of an appropriate model or algorithm that can be broadly applied in principle. So the selection of these methods may be affected by the factors such as regional, site, tectonic activities and others in the reliability analysis of spontaneous field variations.

2) In recent years, the trend variations of spontaneous fields on the North–South seismic belt and the southern Tan-Lu fault zone have alternated between relative stability and drastic fluctuation. Overall, the spontaneous field

strength of at least 30% of the stations exhibited trend anomalies during the strong earthquake cluster period on the North–South seismic belt. In the southern section of the Tan-Lu fault zone, the spontaneous field strength of four stations exhibited trend anomalies after June 2015, which might be correlated with the large earthquakes, respectively, occurred in the East China Sea in November 2015 and Kyushu island, Japan, in April 2016.

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