

# Electromagnetic Emissions Recorded by a Borehole TOA Installment before Four Huge Destructive $M_s \geq 8.0$ Earthquakes in Asia

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## Abstract

In this paper, electromagnetic emissions recorded by a borehole TOA installment with three observing channels of CH1 (0.01 - 0.1 Hz), CH2 (0.1 - 1.0 Hz) and CH3 (1 - 9 kHz) before four large earthquakes with magnitudes more than 8.0 have been depicted. These abnormalities present different fluctuating processes from one another. For the Wenchuan  $M_s$  8.0 earthquake on 12 May 2008, the nearest one among these four events and only 660 km from the TOA station, electromagnetic information appeared at least 5 months ago in two low frequency bands of CH1 and CH2 and it was subjected to an obvious fluctuating process with several developing stages: initial information, intensive anomaly and large amplitude signals. The typical pulse-like emissions in CH2 happened group by group with large various magnitudes, which can be of 10 mV in the climax period. While during this period, compatible wave-like information with little magnitudes also happened in CH1 channel and a few pulses in CH3. Anomalous emissions occurred about 4 months prior to the 25 April 2015 Nepal  $M_s$  8.1 event, 1560 km away from the TOA station. The abnormal information in CH2 also appeared group by group but with small various magnitudes, more than 2 mV during their climax. This process is also effective for the Sumatra  $M_s$  8.9 earthquake on 26 December 2004, 2500 km from the borehole TOA, only with a different duration of 2 months and less magnitudes of 0.1 mV in CH1 and 1 mV in CH2 in this case. However, there is no obvious fluctuation and only small constant amplitude signals being ~0.15 mV appeared during 2 weeks before the Japan  $M_s$  9.0 earthquake on 11 March 2011. It is the farthest one among these four events and beyond 4000 km from the observing station. So, we can make a conclusion that there is a near relationship between the properties of the abnormi-

ties associated with these four earthquakes, such as amplitudes, duration and signal types, and the distances from TOA station: on one hand, the amplitude and duration decreases as the distance increases; on the other hand, there is an evolution for emission properties from complex various magnitude signals to single equal magnitude ones as the distance changes to be far. However, one common feature of the anomalous information related to these four events is that almost electromagnetic emissions were collected in two low frequency bands of CH2 and CH1 instead of CH3 band, which means ULF band (0.01 - 1.0 Hz) is more sensitive than VLF band (1 - 9 kHz) at this TOA station.

### Keywords

TOA Borehole Observation, Huge Earthquake, Electromagnetic Emission, Coseismic Response

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## 1. Introduction

At present, short-term earthquake (EQ) prediction is still one of the most challenging targets worldwide [1]. Electromagnetic observation is one effective way to pursue precursors associated with seismic activities during the last several decades. Ground-based electromagnetic observation is broadly utilized and effective precursory data have been attained before many strong seismic events.

The ULF band is of particular interest because only EM signals in the ULF range and at lower frequencies can be effectively recorded at the Earth's surface without significant attenuation compared with "high" frequency band because most of the epicenter depths are at more than 10 km, even several hundreds of kilometers beneath the Earth's surface. Unusual ULF (0.01 - 10 Hz) magnetic signals were observed about two weeks before the Loma Prieta  $M_s$  7.1 EQ on 17 October 1989 [2] [3]; Anomalous electromagnetic emissions were also observed about one month and a few days before the 8 August 1993  $M_s$  8.0 Guam EQ ( $f = 0.02 - 0.05$  Hz) [4] [5] and before the great  $M_s$  8.2 Biak EQ in Indonesia, on February 17, 1996 ( $f = 0.005 - 0.03$  Hz) [6]. Li *et al.* [7] have reported that obvious ULF ( $f = 0.1 - 10$  Hz) electromagnetic abnormality had been observed for several months prior to the large Wenchuan  $M_s$  8.0 EQ on May 12, 2008 at Gaobeidian station, 1400 km away from the Wenchuan epicenter.

As the development of ionosphere-Earth integration observation, satellite-Earth observation has gradually displayed its application potential in fields of earthquake local mechanism investigation, earthquake monitoring and prediction, and defensive and rescue of seismic disasters because of its advantages on fast speed, large scale and high resolution, especially for areas with harsh natural conditions. Electromagnetic emissions associated with seismic activities have also been recorded by satellite-borne receivers [8]-[14]. The concept of lithosphere-atmosphere-ionosphere (LAI) coupling among the three involved

layers of the Earth system has been proposed due to the transfer of energy among these three layers during some last stages of the long-term process of preparation. At present, the coupling mechanism and coupling model in these three layers have been gained more and more attention [15]-[22].

Furthermore, as a segment of ionosphere-Earth stereoscopic observation system, the sub-surface measurements of electric and magnetic field emissions at frequencies between ULF and VLF (very low frequency) have also played an important role during some strong seismic activities due to its freedom of part disturbances outside of the Earth. VLF electromagnetic signals have been respectively recorded by borehole antennas before the  $M_s$  5.8 east Yamanashi Prefecture EQ [23] and the Chamoli  $M_s$  6.6 EQ on 29 March 1999 in India [24].

In this paper, a borehole electromagnetic observing installment named TOA is firstly introduced in Section 1. Then, in Section 2, the fluctuating processes of electrical emissions related to four huge EQs in Asia will be depicted in detail. Discussion and conclusions are in Section 3 and Section 4, respectively.

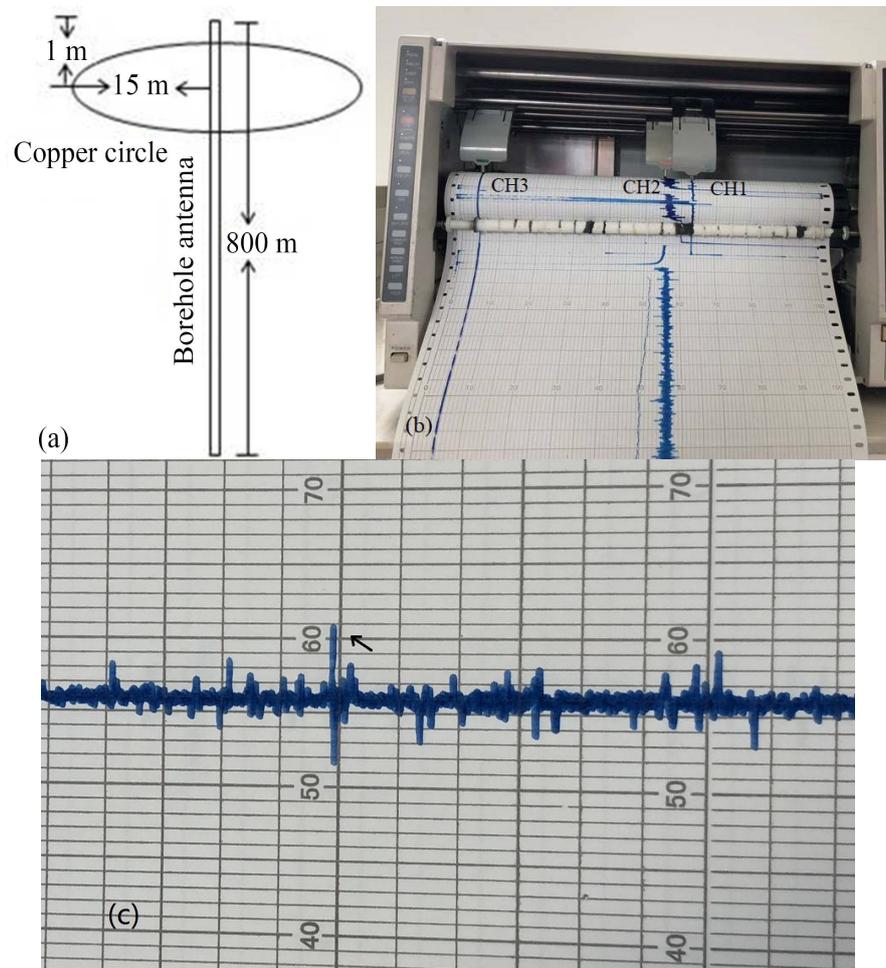
## 2. Experimental System

Benefitted from a cooperation with Japan Meteorology Agency (JMA), TOA electromagnetic measurement was put into service in November 1992 in Dali city in China. The observing system includes a sensor, a channel filter, a channel attenuator and a recorder. The sensor is comprised of a copper circle with 15 m radius, which is buried 1 m sub-surface, and an 800 m perpendicular borehole antenna in the casing pipes in an observing well (No. dian21), with a location of the geographical coordinates (100.2°E, 25.7°N). The depth of the observing well is 800.5 m and casing pipes with different diameters reach to 800 m underground (**Figure 1(a)**).

The system measures a potential difference between the borehole antenna and the copper circle and includes three observing channels: two ULF bands CH1 (0.01 - 0.1 Hz) and CH2 (0.1 - 1.0 Hz) and one VLF band CH3 (1 - 9 kHz). But the system is with a narrow channel bandwidth: 0.05 Hz, 0.5 Hz and 5 kHz for CH1, CH2 and CH3 when calibrated or there will be no output.

The measured potential difference is outputted by a drum recorder (see **Figure 1(b)**). The recording pen for each channel can record continuous analog signals as the drum is rotating automatically with a speed of 60 cm/h. In general, the amplitudes of background noises of the observation are usually less than 0.05 mV. What we need to notice is that there are different magnification coefficients for three channels CH1, CH2 and CH3 when a signal is output by the recorder; that is, it is 1 mV, 10 mV and 50 mV respectively for CH1 (0.01 - 0.1 Hz), CH2 (0.1 - 1 Hz) and CH3 (1 - 9 kHz) if the amplitude of a signal is full of all lattices of the recording paper (100 lattices in total). For example, **Figure 1(c)** shows a signal recorded by CH2 (0.1 - 1 Hz), which is labeled by a black arrow. This signal covers about 5 lattices in the recording paper and its amplitude is ~0.5 mV.

In fact, the system is still not free of all effects outside and it is affected mainly



**Figure 1.** TOA electromagnetic observing system. (a) Experimental setup monitoring electric fields associated with seismic activities using borehole antenna. (b) Real-time analog recorder with three observing channels CH1 (0.01 - 0.1 Hz), CH2 (0.1 - 1.0 Hz) and CH3 (1 - 9 kHz) labeled. (c) A real-time recorded electric field signal labeled by a black arrow and its amplitude is about 0.5 mV according to 0.1 mV per lattice for CH2 (0.1 - 1 Hz).

by thunder and lighting, strong magnetic storm when  $K_p > 7$ , AC/DC (AC, alternating current; DC, direct current) conversion, radio communication in measurement area and automobile engine. While the signals caused by these factors are short-period and single-shape transient pulses or discrete pulses. These emissions are of significant difference from relative long time, continuous and various-shape signals with big amplitudes during seismic activities [25]. More details about signal properties of disturbances outside the TOA measurement can be found in [26].

At the same time, Li *et al.* [25] have made an important statistical work on this TOA electromagnetic observation and summarized variation characters of electromagnetic emissions associated with 29  $M_s \geq 5.0$  EQs recorded in the ensuing decade after the installment coming into service. More details can also be found in [26].

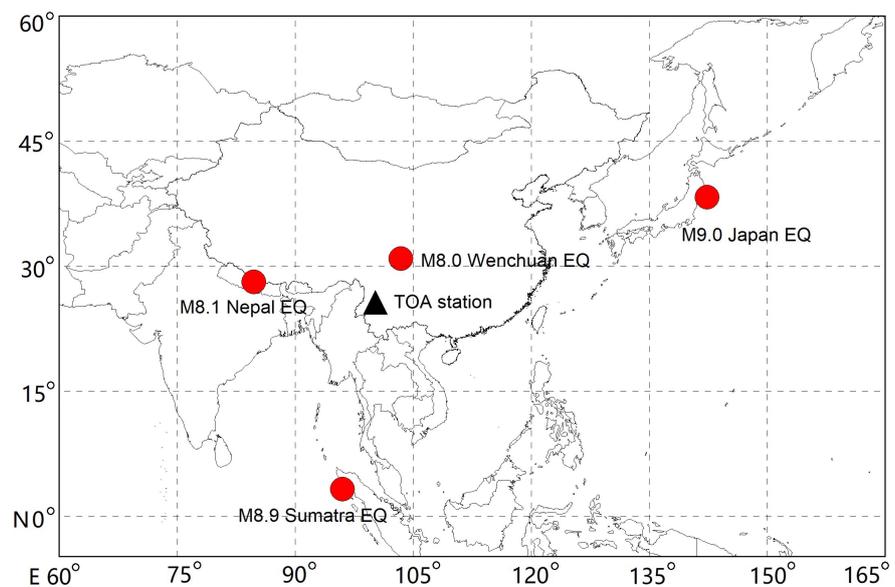
### 3. Electromagnetic Emissions Recorded by the Borehole TOA during Large EQs

Almost 40  $M \geq 8.0$  EQs have occurred since 2000 in the main global seismic zones, especially plate-boundary interfaces, Circum-Pacific seismic belt, and Chile seismic zone. During the last decade, four huge EQs took place one after another in Asia: the 26 December 2004  $M_s$  8.9 Sumatra EQ, the 12 May 2008  $M_s$  8.0 Wenchuan EQ, the 11 March 2011  $M_s$  9.0 Japan EQ and the 25 April 2015  $M_s$  8.1 Nepal EQ, which are located in the map as shown in **Figure 2**. These four events had been of huge destructiveness and led to a huge loss of life and property directly or indirectly because of caused tsunami, landslides, etc. Fortunately, these EQs had also been recorded effectively by the TOA and electrical emissions recorded prior to or during these events will be described in the following parts.

#### 3.1. Sumatra $M_s$ 8.9 EQ on 26 December 2004

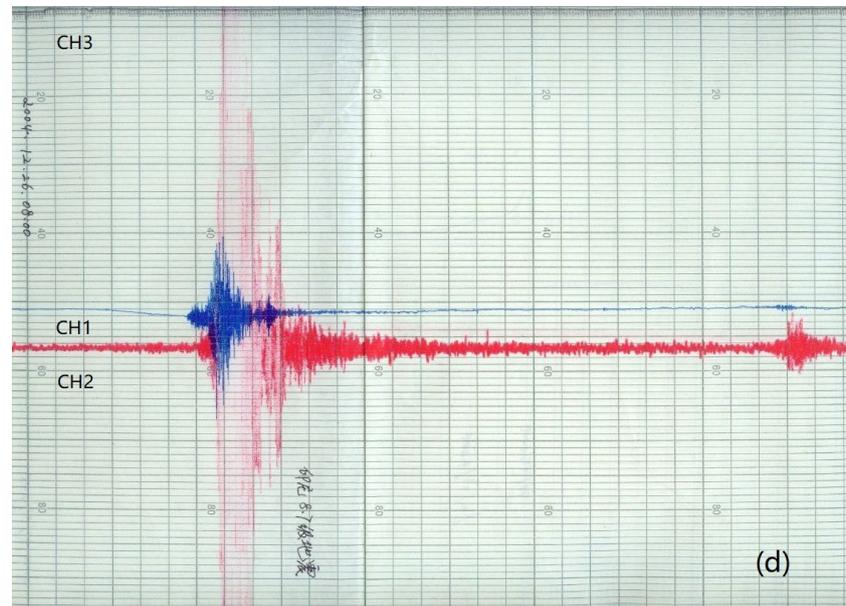
A huge EQ with a magnitude  $M_s$  8.9 occurred at 00:58:53 universal time (UT) on 26 December 2004 in Sumatra-Andaman Islands, with a location of the geographical coordinates (3.31°N, 95.95°E) (see **Figure 2**) and a depth of 30 km. It has been the fourth largest EQ in the world since 1900 and it is the largest since the 1964 Prince William Sound, Alaska EQ [27].

The electromagnetic emissions started at the beginning of November 2004 mainly in two low frequency CH1 (0.01 - 0.1 Hz) and CH2 (0.1 - 1.0 Hz) recording channels. The signals in CH1 are like waves with small amplitude pulses. Comparatively, signals in CH2 are continuous pulses with relative large magnitudes. **Figure 3(a)** shows part of real-time analog recordings on November 8 2004 and the magnitude of the signals is more than 2 mV sometimes (see **Figure 3(a)**). This condition was going on in the following days but with a little difference. The anomalous signals did not appear continuously but group by group



**Figure 2.** Locations of the four EQs happened in Asia and TOA borehole station.





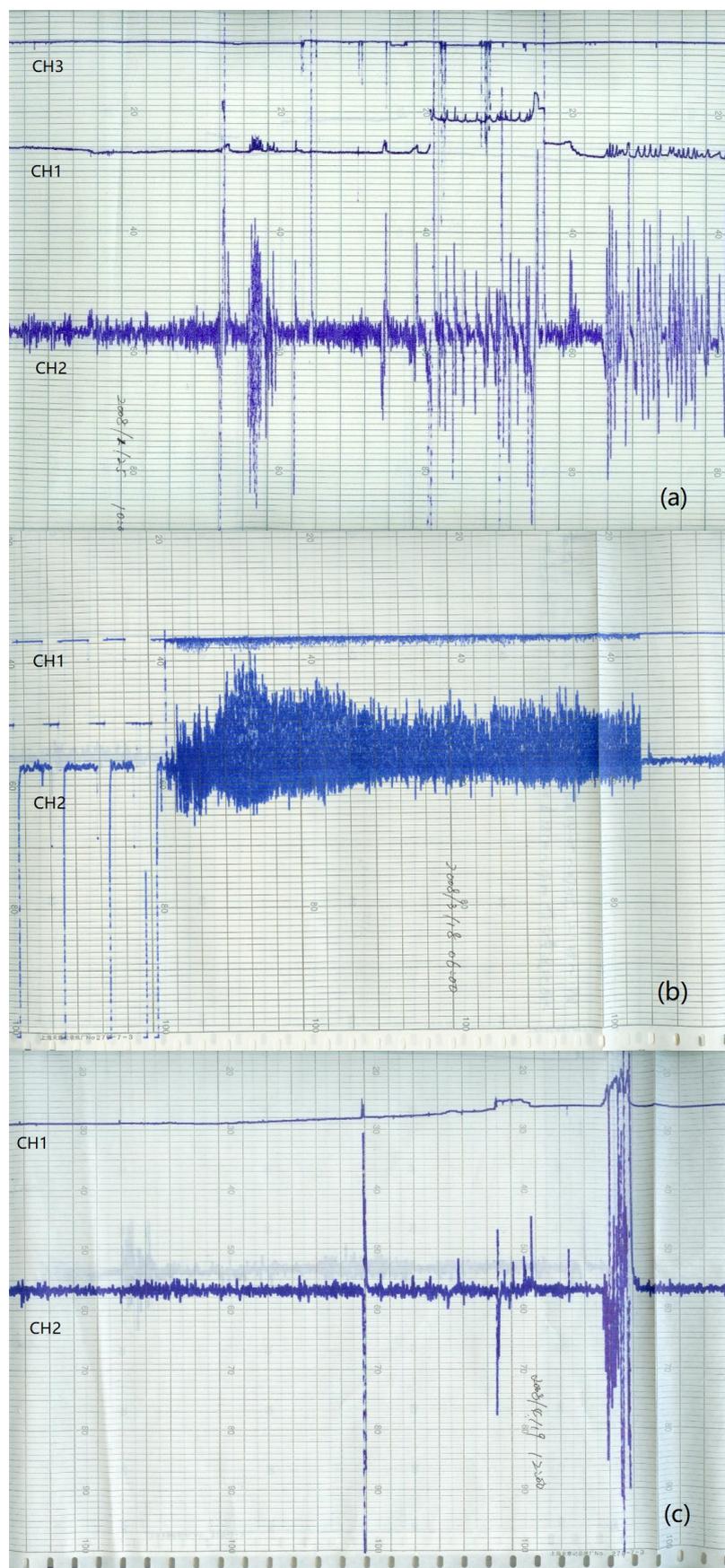
**Figure 3.** Electromagnetic emissions recorded by TOA during the 26 December 2004  $M_s$  8.9 Sumatra EQ. (a) Copy of a part real-time original recording on November 10, 2004. (b) Copy of a part real-time original recording on December 3, 2004. (c) Copy of a part real-time original recording on December 22, 2004. (d) Copy of a part real-time original recording on December 26, 2004.

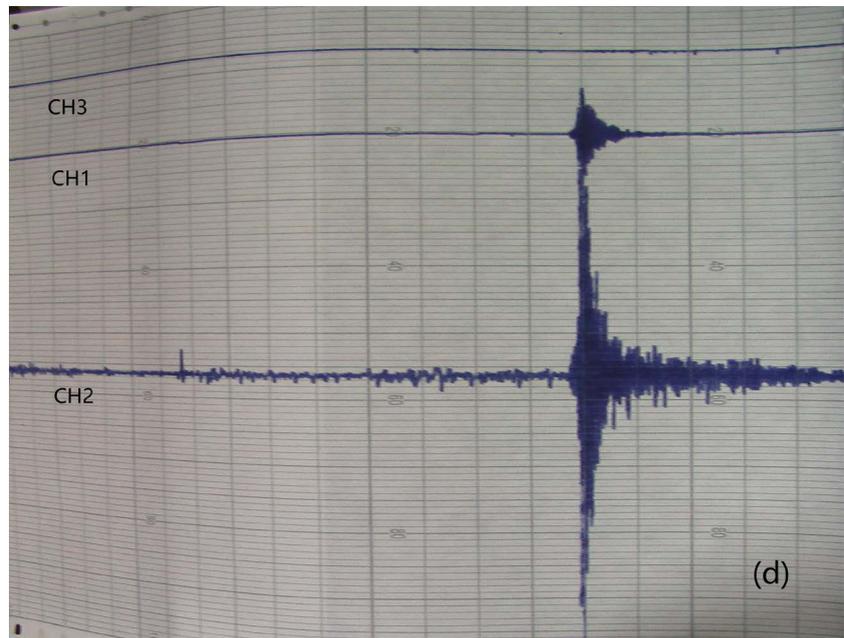
conformably both in CH1 and CH2 (see **Figure 3(b)** and **Figure 3(c)**). During this period, the magnitudes of the emissions are less than 0.1 mV in CH1 and 1 mV in CH2 (also see **Figure 3(b)** and **Figure 3(c)**) till the occurrence of the Sumatra  $M_s$  8.9 EQ on December 26 in Indonesia, 2500 km away from this TOA station. Here, obvious coseismic signals were recorded both in CH1 and CH2 and their magnitudes were full of all lattices of the recording paper shown in **Figure 3(d)**. No useful signals had been recorded during all the period in high frequency channel CH3 (1 - 9 kHz) but with civil-like disturbances with small equal magnitudes and equal gaps shown in **Figures 3(a)-(d)**.

### 3.2. Wenchuan $M_s$ 8.0 EQ on 12 May 2008

A large EQ with a magnitude of  $M_s = 8.0$  hit Wenchuan, Sichuan province at 14:28:01 CST (China Standard Time) on May 12, 2008 with an epicenter located at 103.4°E and 31.0°N and a depth of 19 km. This event is a typical terrestrial EQ lying in south-west China (**Figure 2**) and caused major extensive damage and 69,000 people lost their lives.

There seems to be a long run for the TOA station that recorded electromagnetic signals but the total developing process of these abnormalities can be divided into three stages. At the first stage, weak information started in October 2007. But the emissions became obvious in January 2008, more than five months prior to the Wenchuan EQ on May 12 2008. **Figure 4(a)** presents a part of original recordings on January 25 in this stage. From **Figure 4(a)**, one can see that the abnormalities were mainly recorded by CH2 recording channel with continuous





**Figure 4** Electromagnetic emissions recorded by TOA during the 12 May 2008  $M_s$  8.0 Wenchuan EQ. (a) Copy of a part real-time original recording on January 25, 2008. (b) Copy of a part real-time original recording on March 18, 2008. (c) Copy of a part real-time original recording on April 19, 2008. (d) Copy of a part real-time original recording on May 12, 2008.

pulses and various amplitudes. The amplitudes of some signals can be up to full lattices ( $\sim 10$  mV) of the recording paper occasionally. While there were also discrete signals happening in CH1 and CH3 channels during this period and their magnitudes were relatively small (see **Figure 4(a)**). However, during the second stage, the condition seems to change with a big difference when it came into the mid of March 2008. The emissions intensively appeared group by group in two low frequency channels CH1 and CH2 but with smaller magnitudes than before and each group of emissions last more than 3 hours. This phenomenon rarely happened in this TOA borehole observing history. **Figure 4(b)** shows a part of real-time recordings on 18 March 2008 and this group of emission was of small amplitudes less than 2 mV for CH2 and lasted more than 3 hours.

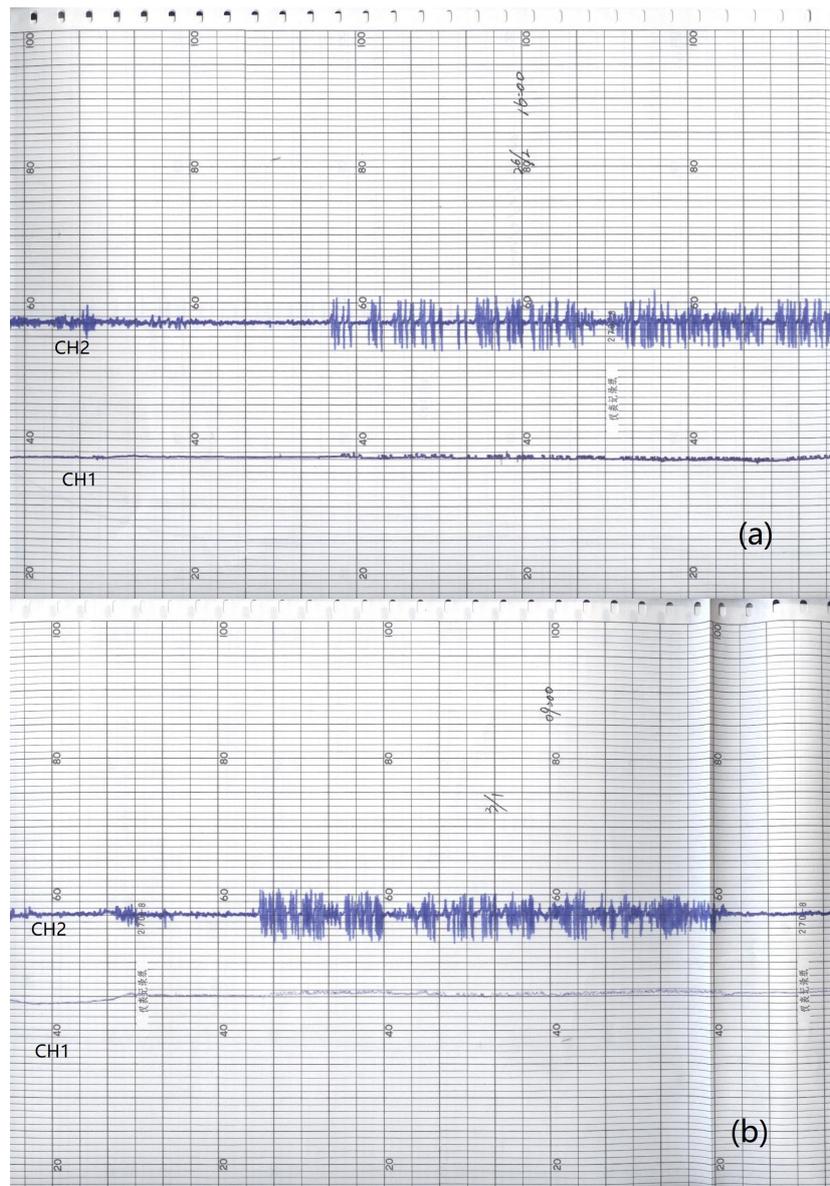
In the third stage, the characters of the signals in April 2008 are just like that of signals in January 2008. The electromagnetic emissions are characterized by continuous or discrete pulses with relative large magnitudes, like **Figure 4(c)**. Then, the abnormalities appeared less than ever till the Wenchuan  $M_s$  8.0 EQ took place on 12 May, when coseismic responses occurred at the same time both in CH1 and CH2 channels and decayed quickly (see **Figure 4(d)**). The distance between the Wenchuan epicenter and the TOA station is 660 km, the nearest one among these four events described in this paper.

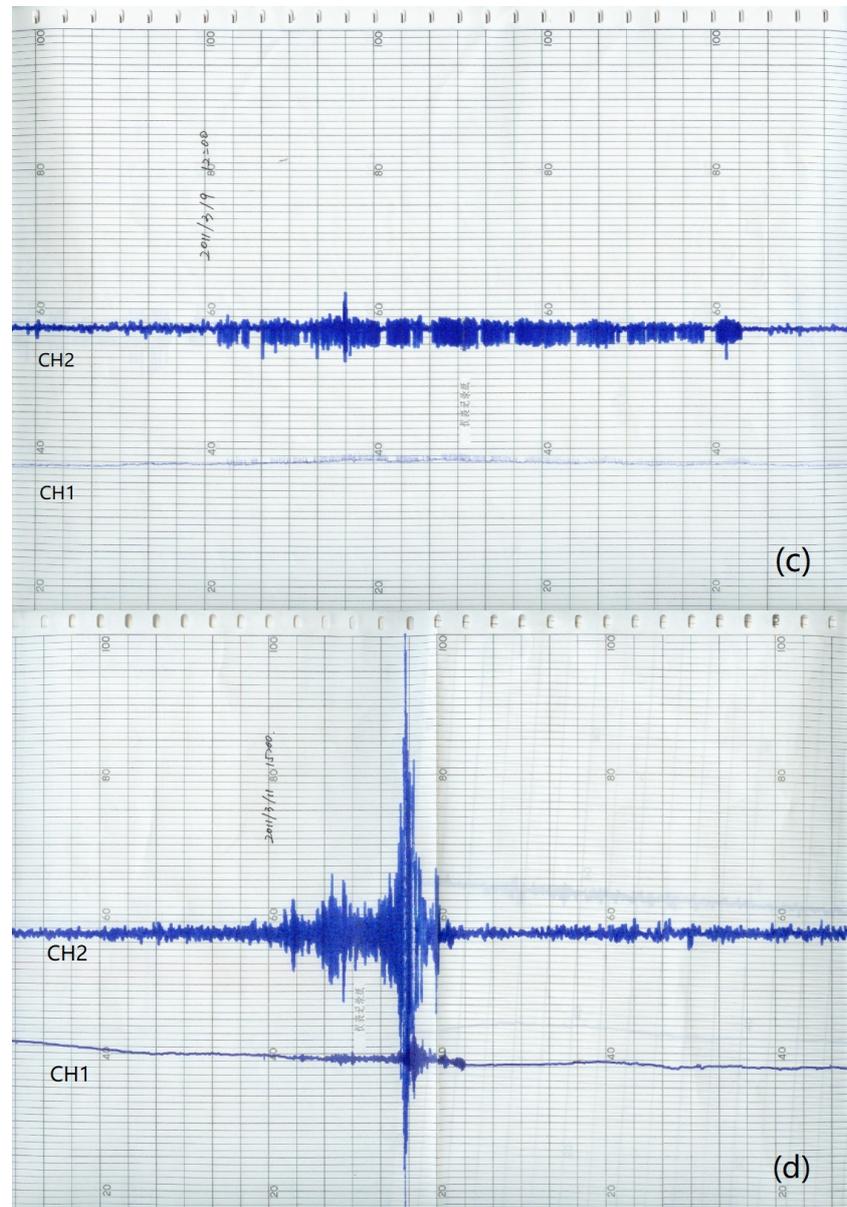
### 3.3. Japan $M$ 9.0 EQ on 11 March 2011

A disastrous EQ occurred in Japan on 11 March 2011, with an epicenter located

at  $142.6^{\circ}\text{E}$  and  $38.1^{\circ}\text{N}$  and a depth of 32 km. This  $M_s$  9.0 Tohoku-Oki EQ is officially referred to as the off the Pacific coast of Tohoku EQ by the JMA (**Figure 2**), which is the largest EQ in Japan since the start of instrumental observation in the late 19th century and the fifth one following the last Sumatra  $M_s$  8.9 EQ on 26 December 2004.

The anomalous information recorded this time at TOA station began from 26 February 2011, and it is characterized by discrete signals appeared group by group and with equal magnitudes in two low frequency bands of CH1 and CH2. **Figure 5(a)** & **Figure 5(b)** show parts of real-time analog recordings happened respectively on February 26 and March 1 at TOA station. From these two figures, one can see groups of weak continuous signals with the amplitudes being less than 0.15 mV in CH2 (0.1 - 1 Hz) (see **Figure 5(a)**, **Figure 5(b)**). This condition lasted but the electromagnetic emissions became intensive a little as the





**Figure 5.** Electromagnetic emissions recorded by TOA during the 11 March 2011  $M_s$  9.0 Japan EQ. (a) Copy of a part real-time original recording on February 26, 2011. (b) Copy of a part real-time original recording on March 1, 2011. (c) Copy of a part real-time original recording on March 9, 2011. (d) Copy of a part real-time original recording on March 11, 2011.

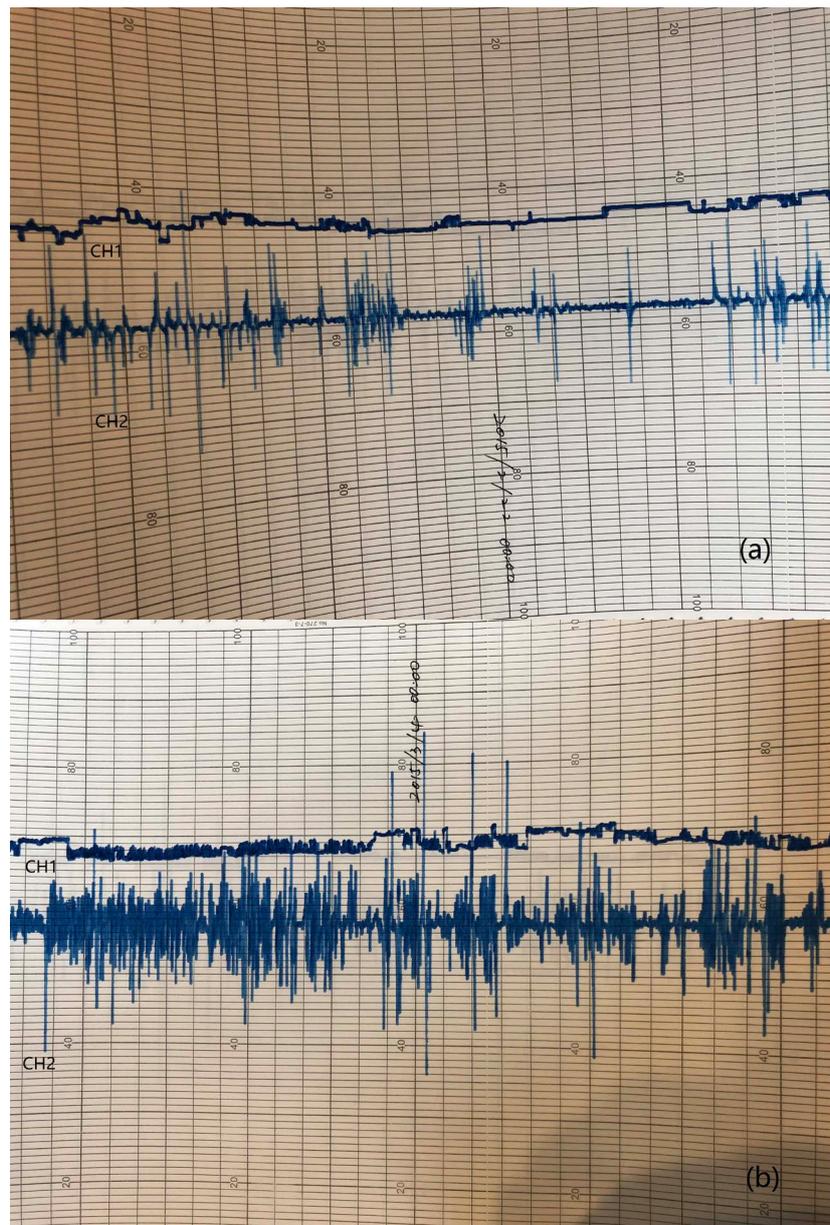
event approached (**Figure 5(c)**). Clear coseismic signals can be found both in CH1 and CH2 observing channels when the  $M_s$  9.0 Tohoku-Oki EQ took place on March 11, 2011 (**Figure 5(d)**). One point must be noted is that this EQ is beyond 4000 km away from the observing TOA station in Dali, Yunnan province, China.

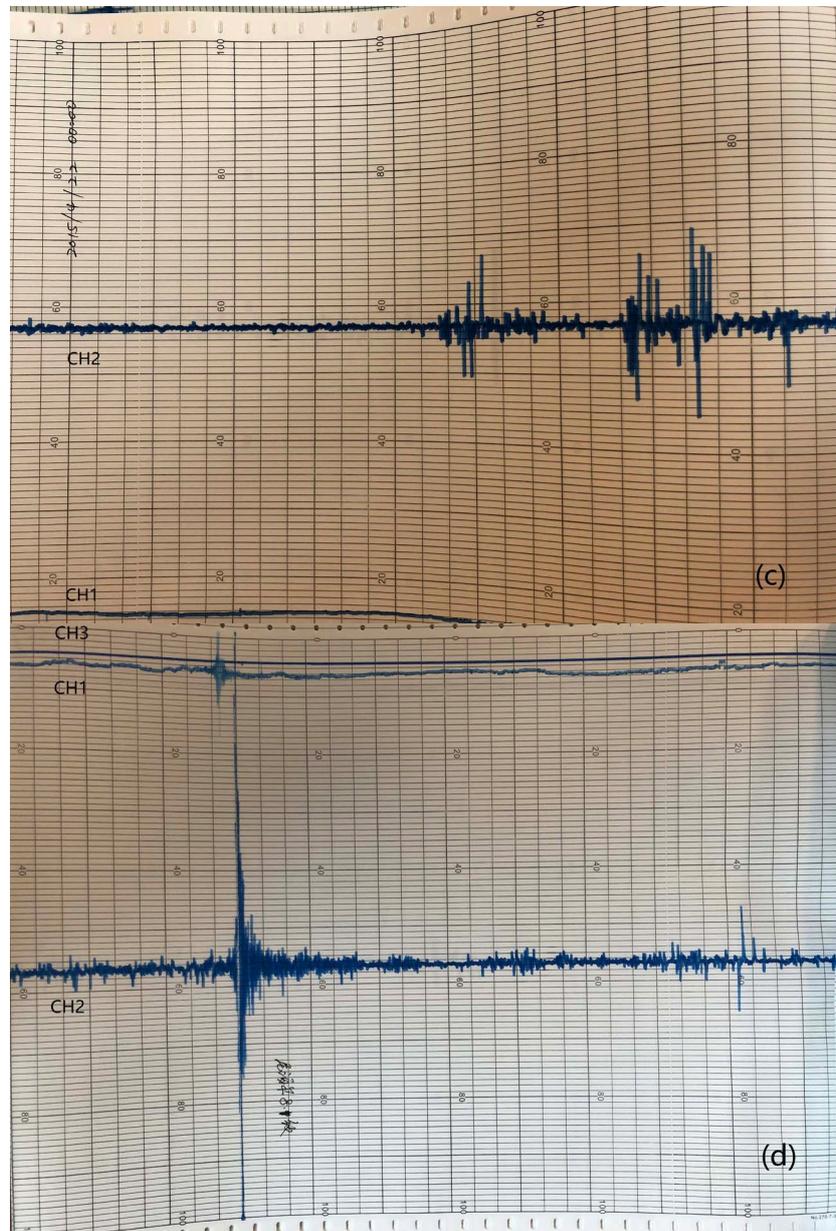
### 3.4. Nepal $M_s$ 8.1 EQ on 25 April 2015

The Nepal  $M_s$  8.1 EQ occurred on 25 April 2015 lies in the juncture of Nepal and

China and with a location of the geographical coordinates (28.1°N, 84.7°E) and a depth of 15 km (see **Figure 2**).

The electromagnetic variations started from the beginning of January 2015 and lasted more than four months till the occurrence of the Nipal event. During this period, it shows typical signal properties in each recording channel CH1, CH2 or CH3. Emissions in CH1 are wave-like with weak equal amplitude signals; emissions in CH2 were of group continuous pulses with various amplitudes, which tended to increase but generally less than 2 mV during last stage of the total process; relative long period wave appeared occasionally in CH3. Like the other three events illustrated above, coseismic responses had also been recorded in CH1 and CH2 but CH3 when the Nepal  $M_s$  8.1 EQ occurred on 25 April 2015, 1560 km away from the TOA station (**Figure 6**).





**Figure 6.** Electromagnetic emissions recorded by TOA during the 25 April 2015  $M_s$  8.1 Nepal EQ. (a) Copy of a part real-time original recording on February 22, 2015. (b) Copy of a part real-time original recording on March 4, 2015. (c) Copy of a part real-time original recording on April 22, 2015. (d) Copy of a part real-time original recording on April 25, 2015.

#### 4. Discussion

In this paper, electromagnetic emissions recorded by TOA before four large EQs with magnitudes more than 8.0 have been presented. These abnormalities present different fluctuating process from one another. While, one interesting point here is that the epicentral distances from 660 km to 4000 km for these four events are larger than usual, which are defined that the borehole TOA electromagnetic system can effectively record  $M_s > 5.0$  EQs within 200 km,  $M_s > 6.0$  events within

300 km, and  $M_s > 7.0$  events within 500 km [25]. However, Li *et al.* [7] have reported that ULF (0.1 - 10 Hz) electromagnetic emissions was recorded at 1400 km Gaobeidian station in north China before the Wenchuan EQ. Ohta *et al.* [27] have also reported that the seismogenic ULF emissions propagated from the Sumatra  $M 8.9$  EQ epicentre over about 5500 km.

The radius of seismic area where changes can be expected can be estimated using the Dobrovolsky formula  $R = 10^{0.43M}$ , where  $R$  is the radius of the EQ preparation zone, and  $M$  is the EQ magnitude [28]. It gives that the radius for the  $M_s 8.0$  event preparation zone is more than 2700 km and 7400 km for the  $M_s 9.0$  event. In order to estimate the magnetic field intensity expected on the ground, different mechanisms were proposed. When the seismogenic emissions are generated in the Earth's crust, electromagnetic emissions will be effectively recorded in the near distance used the empirical law by Hayakawa and Hattori [29]. However, the seismogenic ULF emissions might be generated near the Earth's surface or in the atmosphere when the depth of an EQ is very small (*i.e.*, 10 km). In this case, they seem to be able to propagate in the Earth-ionosphere waveguide over great distances as the quasi-TEM mode of propagation [30]. At the same time, in order to interpret a  $1.3 \text{ mV}\cdot\text{m}^{-1}$  electrical field recorded at 1400 km Gaobeidian station, Li *et al.* [31] have attained that the same value of  $1.3 \text{ mV}\cdot\text{m}^{-1}$  can be recorded at a 5800 km propagating distance in the Earth-ionosphere waveguide when the ionospheric influence is considered. However, a borehole antenna can still display its advantageous potential during EQ monitoring. On one hand, previous investigations have shown that it can effectively avoid most of disturbance signals outside; on the other hand, an antenna in deep boreholes can easily recorded seismogenic emissions from deep lithosphere and the Sumatra and Japan events here may be as examples.

Clear coseismic signals have been recorded both in CH1 and CH2 channels when these four large EQs took place. It is not the first time that coseismic phenomena have been mentioned at this TOA station. Li *et al.* [25] have shown clear coseismic signals appeared  $\sim 23$  s after the original time of Yongsheng  $M_s 5.4$  EQ on December 18, 1992. The epicentral distance is  $\sim 87$  km in this event. In the light of these, the average speed of coseismic information is of  $\sim 3.8 \text{ km}\cdot\text{s}^{-1}$ , which is in the speed range of seismic waves in lithosphere ( $\sim 3.2 - 7.0 \text{ km}\cdot\text{s}^{-1}$ ). At the same time, Li *et al.* [26] have also reported obvious coseismic information recorded in two low frequency bands at TOA station right after the last Mojiang  $M_s 5.9$  EQ on 8 September 2018.

Fortunately, Tang *et al.* [32] established two observation systems, including one MT (magnetotelluric) instalment produced by Metronix Canada and one ELF measurement produced by Russia in the Wenchuan  $M_s 8.0$  aftershock area on May 22, 2008, 10 days after the Wenchuan main shock occurred on May 12th, 2008. Their results confirmed that coseismic emissions were included in all components of electrical and magnetic fields and they arrived synchronously together with seismic waves. These results were consistent with those of Karake-

lian *et al.* [33], who observed that coseismic ULF signals exist on all components of the magnetic and electric fields and begin with the arrival of seismic waves. Mogi *et al.* [34] found coseismic changes in the electric field and inferred that these changes began at the arrival time of a seismic wave by examining the relationship between variations in the electric field and EQs in Sumatra, Indonesia. Similar results has also been attained by Nagao *et al.* [35], which concluded that electric field changes started at the arrival times of seismic waves, rather than the original times of EQs, and claimed that the generation mechanism of changes was related to the electrokinetic effect. On the other hand, Iyemori *et al.* [36] reported a possible mechanism associated with coseismic geomagnetic variations of an induction effect due to crustal dynamo mechanism. However, Matsushima *et al.* [37] considered that such an electromagnetic variation should propagate faster than the seismic wave itself. They also proposed seismo-dynamo effect of electromagnetic induction in the electrically conducting Earth caused by ground motion in the Earth's magnetic field [38].

However, it is not easy to distinguish the initial time of the coseismic response for each event because of different adjustments of three recording pens in different period and TOA instrument aging. However, we still consider that these coseismic signals arrived together with seismic waves based on the description by Li *et al.* [25].

## 5. Conclusions

In this paper, a borehole TOA electromagnetic experiment system from Japan has been introduced firstly. The system includes three observing channels: two ULF bands CH1 (0.01 - 0.1 Hz) and CH2 (0.1 - 1.0 Hz) and one VLF band CH3 (1 - 9 kHz). The sensor of this installment is comprised of a copper circle with 15 m radius buried 1 m sub-surface and an 800 m perpendicular borehole antenna in the casing pipes in an observing well. Potential difference between the borehole antenna and the copper circle is measured and output real time by three recording pens.

Almost 30 EQs with the magnitudes equal to or more than 5.0 have been recorded by this installment in the first decade since it was put into service in 1992 [25]. Li *et al.* [26] have proposed obvious electromagnetic emissions before the last Mojiang  $M_s$  5.9 EQ on 8 September 2018.

Then, as a review of this observation, electromagnetic emissions associated with four large EQs with  $M_s \geq 8.0$  occurring in the last decade in Asia have been described at this time. The electromagnetic emissions started at the beginning of November 2004 mainly in two low frequency CH1 (0.01 - 0.1 Hz) and CH2 (0.1 - 1.0 Hz) recording channels. The signals are wave-like with small amplitude less than 0.1 mV in CH1 and pulse-like with relative big magnitudes being up to 2 mV in CH2 but none in CH3. These emissions lasted near 2 months till the Sumatra  $M_s$  8.9 EQ took place on December 26 in Indonesia, 2500 km away from this TOA station.

For the Wenchuan  $M_s$  8.0 EQ on 12 May 2008, 660 km from the TOA station, electromagnetic information appeared more than 5 months ago in two low frequency bands of CH1 and CH2 channels and it displayed an obvious fluctuating process with several developing stages: initial information, intensive anomaly and large amplitude signals. The typical pulse-like emissions in CH2 appeared group by group with a maximum magnitude of 10 mV and compatible wave-like information with equal little magnitudes also happened in CH1 channel.

Anomalous emissions occurred about 4 months prior to the Nepal  $M_s$  8.1 event, 1560 km away from the TOA station. The abnormal emissions in CH2 appeared in groups but with small various magnitudes, more than 2 mV during their climax, and equal little magnitude appeared in CH1 during this period. However, there is no obvious fluctuation and only small constant amplitude signals being  $\sim 0.15$  mV in CH2 appeared during 2 weeks before the Japan  $M_s$  9.0 EQ on 11 March 2011, which is beyond 4000 km from the borehole station.

Though the abnormalities of these four events present different fluctuating processes from one another, on one hand, almost electromagnetic emissions were collected in two low frequency bands of CH2 and CH1 channels instead of VLF band of CH3 channel. At the same time, it seems that CH2 band is more sensitive to the seismic events at TOA station. On the other hand, for all these large EQs, both CH1 and CH2 bands had recorded obvious coseismic responses, which are thought to be induced by the arrival of seismic waves.

However, if these four huge EQs are considered in the light of their epicentral distances, we can conclude that there is a near relationship between the properties of the abnormalities, such as amplitudes, duration and signal types, and the distances from TOA station: on one hand, the amplitude and duration decreases as the distance increases; on the other hand, there is an evolution for emission properties from complex various magnitude signals to single equal magnitude ones as the distance changes to be far.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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