STUDIES ON THE PRECURSORS OF AN EARTHQUAKE AS THE VLF ELECTROMAGNETIC SFERICS

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Received October 29, 2010

The observation and analyses of pre-seismic VLF electromagnetic (EM) signals recorded by VLF receivers at frequencies 5, 7, 9 and 12 kHz on November 16, 2008 over Kolkata (Lat. 22.56º N, Long. 88.5º E) during the large earthquake at Minahasa, Sulawesi, under Indonesia (Lat. 1.27º N, Long. 122.09º E) will be presented. Spiky variations of signals are observed few days prior to the day of occurrence of the earthquake which continued several days more, then decayed gradually and eventually ceased. These signals are critically examined to delineate their correlation with earthquake. The time variability of natural EM signals in the VLF band is juxtaposed with the pre-seismic records.

Key words: Ionospheric perturbations, earthquake precursors, seismicity, seismo-electromagnetics.

1. INTRODUCTION

Both precursory and post-seismic variations in ELF-VLF amplitudes and in ionospheric parameters are well-known from ground-based, as well as satellite-based observations surrounding the earthquake zones (Pulinets, 1998; Shvets *et al.*, 2002; Molchanov and Hayakawa, 1998; Calais and Minster, 1995; Liu et al., 2004; Pulinets *et al.*, 2003; Molchanov *et al.*, 1993; Parrot, 1994).

During the occurrence of any strong earthquake, electric field is generated within the upper atmosphere due to seismo-ionospheric coupling phenomena (Hayakawa, 1999; Hayakawa *et al.*, 2004; Pulinets *et al.*, 2003). Underground gas discharges carry submicron aerosols with them which enhance the intensity of electric field close to the Earth’s surface in the earthquake preparation zone due to the drop in air conductivity created by aerosols (Chmyrev *et al.*, 1997; Krider and

Roble, 1986). Seismo-electromagnetic emissions have been observed in the ULF-ELF-VLF bands in the seismically active zones prior to the incidence of any large earthquake (Nagao *et al.*, 2002; Karakelian *et al.*, 2000; Fuzinawa and Takahashi, 1995). The propagation of electromagnetic waves in these frequency bands has been reported by many researchers (Gokhberg *et al.*, 1982; Fuzinawa and Takahashi, 1998). These emissions are different from lightning induced and technogenic emissions.

Some investigators inferred that the ionospheric perturbation as detected by VLF-LF propagation may be a significant tool for short-term earthquake prediction (Yamauchi *et al.*, 2007). In case of strong earthquakes, the atmospheric layer close to the Earth's surface becomes ionized and generates electric field which introduces particle acceleration thereby exciting local plasma instabilities. Several days before the occurrence of the earthquake, electron density of plasma in the upper ionosphere over the epicenter increases also abnormally (Utsunomiya, 2000). Moreover, an interrelation between the tectonic activity and the anomalous changes of the geophysical, geochemical and geohydrological parameters characterizing the Earth's lithosphere have been noticed (Moldovan *et al.*, 2009).

Electromagnetic anomalies (EA) preceding the destructive earthquakes in Greece covering a wide range of frequencies have been analyzed (Eftaxias *et al.*, 2003; Karakelian *et al.*, 2000). They are correlated with the fault model characteristics of the associated earthquake and with the degree of geotectonic heterogeneity within the focal zone. The time evolution of sequences in EA revealed striking similarities to the acoustic and electromagnetic emissions observed in the laboratory.

Ion cluster mass and plasma concentration during the process of lithosphere-ionosphere coupling vary with the earthquake size. As a result, the seismo-electromagnetic emissions would be expected to cover almost the whole of ULF-ELF-VLF band. During the process, there will be increase of thermal plasma noise along with other types of emissions, *e.g.*, Cerenkov, and Bremstrallung. This sort of plasma instability at the surface may be assumed to be simulated in dusty plasma (Kikuchi, 2001).

A devastating earthquake occurred on November 16, 2008 at Minahasa, Sulawesi (Indonesia): epicenter located at lat. 1.27º N, long. 122.09º E, magnitude M = 7.3. The depth of the hypocenter of the main shock (occurred at 22:32 IST) is about 30 km. 12 aftershocks have been reported on the first day after the initial shock with strength M~5.0.

In this paper, the results of some significant observations in the VLF sferics at frequencies 5, 7, 9 and 12 kHz recorded at Kolkata station (Lat. 22.56º N, Long. 88.5º E) during the Minahasa earthquake occurred on November 16, 2008 will be presented. The receiving station is about 2400 km away from the earthquake epicenter. Several discrete spike-type signals were observed first on November 9, 2008 and continued until November 23, 2008. On the day of occurrence of the earthquake, both number of spikes and their intensities as well as durations are found to be changed irregularly and reached the maximum value. The signatures ceased gradually and almost ended after November 23, 2008. These commencements may be considered to be precursory and post-seismic effects of this big earthquake (Calais and Minster, 1995).

2. EXPERIMENTAL ARRANGEMENT

The VLF sferics at different frequencies 5, 7, 9 and 12 kHz are regularly recorded over the last several years from Kolkata (Lat. 22.56º N, Long. 88.5º E). For the reception of these signals, a straight horizontal copper wire of 8 SWG having 120 m length is used in the form of an inverted L type antenna. The antenna installed 30 m above the ground, is capable of receiving vertically polarized sferics in the ELF-VLF bands from near and far sources of lightning discharges. The VLF sferics were recorded by a data acquisition system through a PCI 1050, 16 channel 12 bit DAS card. They are then processed and stored in a computer. The r.m.s. value of the filtered data are analyzed using Origin 5.0 software. The receiver system is presented by the block diagram in Fig. 1.

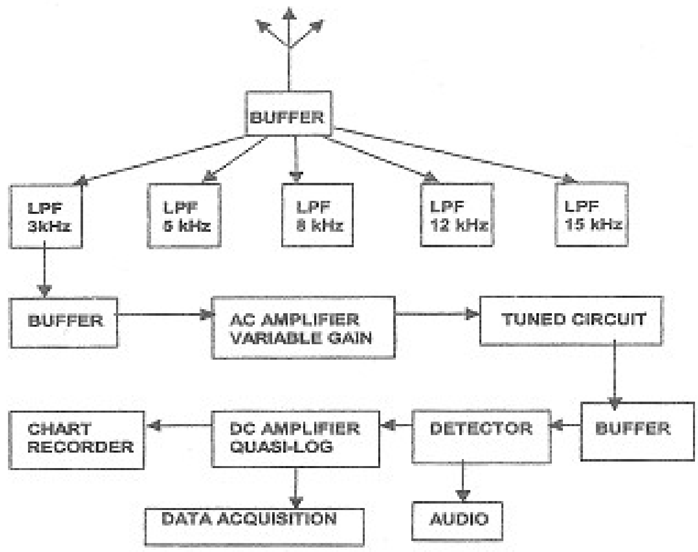

Fig. 1 – Diagram of the ELF-VLF receiving system at Kolkata station (lat: 22.56° N, long: 88.5° E).

3. OBSERVATIONS

Various features from the simultaneous records of VLF sferics at 5, 7, 9 and 12 kHz at Kolkata station have been observed. In the month of November, 2008, some days prior to the large earthquake (M 7.3) of Minahasa (Lat. 1.27º N, Long.

122.09º E), Sulawesi, Indonesia on November 16, 2008, remarkable spiky variations at 5, 7, 9 and 12 kHz records have been noticed. Figure 2 shows the raw data of sferics on February 28, 2008 at 5, 7, 9 and 12 kHz recorded at Kolkata in a meteorologically clear day where no spiky variations are observed. 15 month's data have been considered for a time interval from February, 2008 to April, 2009.

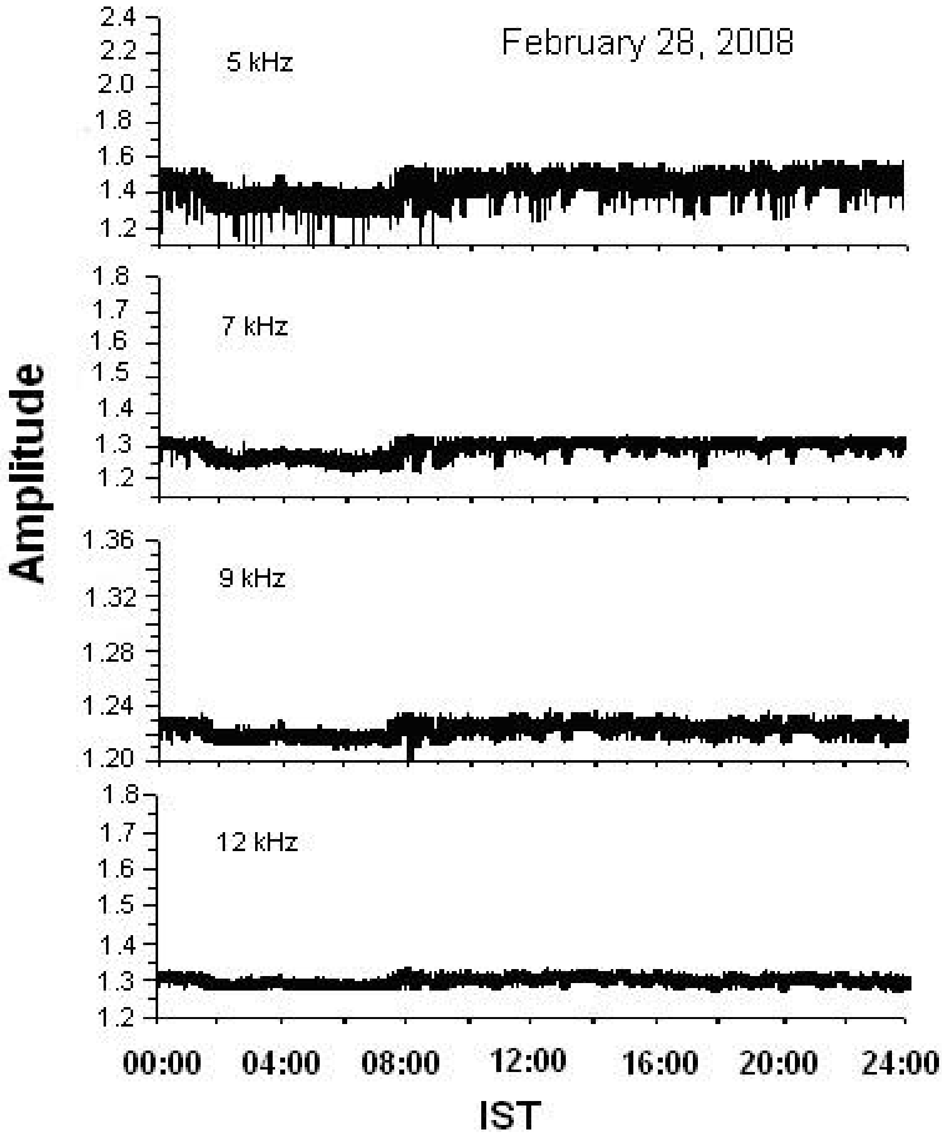

Fig. 2 – A normal day record of sferics at 5, 7, 9 and 12 kHz in a meteorologically clear day.

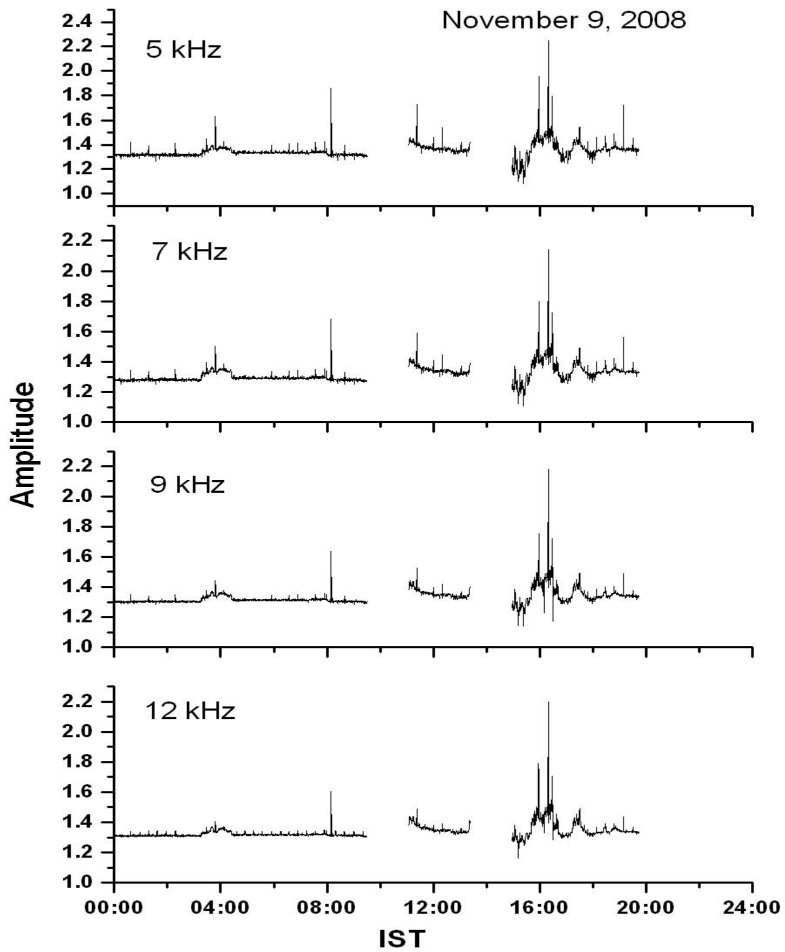

Fig. 3 – Diurnal variation of sferics observed over Kolkata. Date: November 9, 2008. The records show typical spikes beginning around midnight.

Some days prior to the main earthquake of Minahasa, Sulawesi, spikes of duration of the order of few minutes occur on sferic records. The nature of these spikes is completely different from any transient variation occurred due to thundershowers. The significant spiky variations appear first at the midnight on November 9, 2008 which is shown in Fig. 3. The spike heights are highly comparable to the ambient level of the sferics. The number of dominant spikes and their duration of occurrence increase gradually and showed maximum value on the day of occurrence of this major earthquake (Figs. 4 – 7). On the day of earthquake, the spike heights are remarkably higher than those observed on other days (Fig. 7). The appearance of the spikes was initially doubtful whether those are the signatures of geophysical phenomena or local noise. The experimental site is situated about

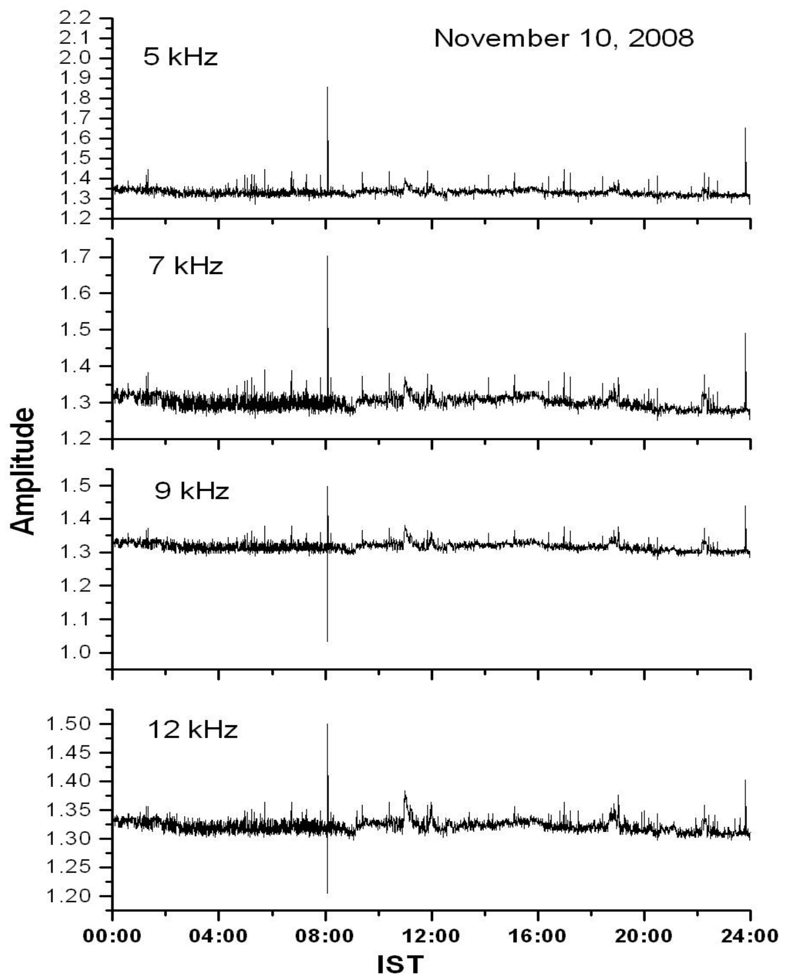

Fig. 4 – Diurnal variation of sferics observed at Kolkata. Date: November 10, 2008.

25 km away from the city in a remote village area. There is no question of man-made noise. We thoroughly checked up the concerned building to find out whether there is any electrical fault which may produce leakage giving spikes in the sferics records. There exists no such fault. We recorded mid-night spikes also which are even devoid of any man-made noise since the locality is a purely rural area, free from any small and large industries. Due to the fault in power supply, a distinguishable high spike occurred at 08:15 IST almost everyday as depicted in Figs. 3 – 5 and Figs. 9 – 11. Figure 8 shows the post-seismic spike variations as well as the variations of sferics due to Leonid meteor showers as indicated by the arrow marks. Here the ambient level shifted to a high value, confirmed by International Meteor Organization (IMO) report from website. The nature of spikes for the

earthquake and their characteristics are completely different from other known events, like solar flares, meteor showers, geomagnetic storms, etc. Between November 8

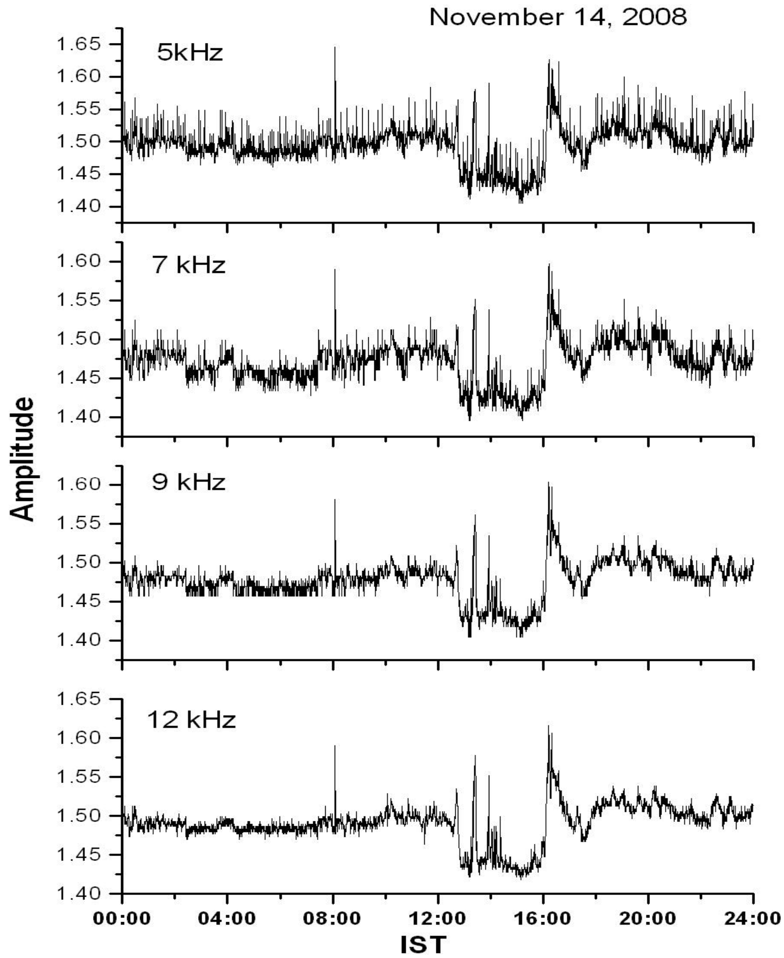

Fig. 5 – Diurnal variation of sferics observed at Kolkata. Date: November 14, 2008.

and 24, 2008, there were no thundershowers, cyclones and heavy rain on the path between Minahasa and Kolkata. This is confirmed by weather report from website. Figs. 9 – 11 show spiky variations of sferics at 5, 7, 9 and 12 kHz associated with the earthquake. Number of dominant spikes and their duration of occurrence decrease gradually to lowest ambient level. The spikes are found to occur at an average interval of 2 – 3 minutes. Earthquake related spikes are distinct from each other and their base-levels remain almost constant.

Statistical analyses of different parameters of the earthquake from the recorded data during November 8–24, 2008 are worked out which are shown in

Table 1. The spike intensity variations before and after the earthquake are shown by bar graphs through Figs. 12–14. On the earthquake day, the responses of 5 kHz and 7 kHz are much higher than 9 kHz and 12 kHz. From few days earlier, the spike intensity gradually increased up to the earthquake date. These may be the

Table 1

Statistical analyses of different characteristic parameters of the earthquake from the recorded data

Date	**Freq. (kHz)**	**Spike ambient level (mV); average height of spikes(mV)**	**Total no. of spikes**	**Total no. of spikes per hour**	**Average height of all spikes above spike ambient level (mV)**
08.11.08	5	1.50 ; 1.52	2	0.08	0.02
	7	1.30 ; 1.32	3	0.125	0.02
	9	1.50 ; 1.52	1	0.04	0.02
	12	1.30 ; 1.32	3	0.125	0.02
09.11.08	5	1.40 ; 1.60	50	3.125	0.20
	7	1.36 ; 1.51	46	2.875	0.15
	9	1.39 ; 1.50	20	1.25	0.11
	12	1.40 ; 1.55	9	0.56	0.15
10.11.08	5	1.45 ; 1.60	50	2.08	0.15
	7	1.39; 1.50	52	2.17	0.11
	9	1.40 ;1.45	38	1.58	0.05
	12	1.38 ; 1.40	30	1.25	0.02
11.11.08	5	1.37 ; 1.39	36	1.50	0.02
	7	1.33 ; 1.36	25	1.04	0.03
	9	1.34 ; 1.36	11	0.46	0.02
	12	1.34 ; 1.36	3	0.125	0.02
12.11.08	5	1.67 ; 1.69	36	1.50	0.02
	7	1.50 ; 1.53	32	1.33	0.03
	9	1.50 ; 1.55	5	0.21	0.05
	12	1.51 ; 1.52	4	0.17	0.01
13.11.08	5	1.47 ; 1.50	29	1.21	0.03
	7	1.42 ; 1.47	35	1.46	0.05
	9	1.42 ; 1.45	10	0.42	0.03
	12	1.425 ; 1.45	17	0.71	0.025
14.11.08	5	1.57 ; 1.60	47	1.96	0.03
	7	1.52 ; 1.58	36	1.50	0.06
	9	1.51 ; 1.57	28	1.17	0.06
	12	1.52 ; 1.57	29	1.21	0.05

Table 1 (continued)

15.11.08	5	1.70 ; 2.20	82	3.42	0.50
	7	1.68 ; 2.20	75	3.125	0.52
	9	1.73 ; 2.20	72	3.00	0.47
	12	1.80 ; 2.05	61	3.05	0.25
16.11.08	5	1.50 ; 2.19	192	8.00	0.69
	7	1.53 ; 2.12	182	7.58	0.59
	9	1.55 ; 2.05	134	5.58	0.50
	12	1.62 ; 1.81	106	4.42	0.19
17.11.08	5	1.49 ; 2.09	102	4.25	0.60
	7	1.54 ; 2.10	108	4.50	0.56
	9	1.58 ; 2.10	112	4.67	0.52
	12	1.68; 2.04	98	4.08	0.19
18.11.08	5	1.75 ; 2.10	47	3.35	0.35
	7	1.48 ; 2.05	42	3.00	0.57
	9	1.57 ; 2.07	40	2.86	0.50
	12	1.64 ; 1.96	41	2.93	0.32
19.11.08	5	1.74 ; 1.96	97	4.04	0.22
	7	1.65 ; 1.81	94	3.92	0.26
	9	1.64 ; 1.74	87	3.625	0.10
	12	1.63 ; 1.67	78	3.25	0.04
20.11.08	5	1.57 ; 1.75	86	3.58	0.18
	7	1.44 ; 1.50	66	2.75	0.06
	9	1.43 ; 1.46	51	2.125	0.03
	12	1.43 ; 1.45	23	0.96	0.02
21.11.08	5	1.40 ; 1.73	57	2.85	0.33
	7	1.35 ; 1.71	61	3.05	0.36
	9	1.38 ; 1.70	44	2.20	0.32
	12	1.40. 1.70	21	1.05	0.30
22.11.08	5	1.75 ; 1.85	17	1.13	0.10
	7	1.60 ; 1.72	23	1.53	0.12
	9	1.60 ; 1.70	18	1.20	0.10
	12	1.49 ; 1.60	17	1.13	0.11
23.11.08	5	1.61 ; 1.74	10	0.42	0.13
	7	1.46 ; 1.70	15	0.625	0.24
	9	1.47 ; 1.69	16	0.67	0.22
	12	1.46 ; 1.69	14	0.58	0.23
24.11.08	5	1.45 ; 1.47	3	0.18	0.02
	7	1.30 ; 1.33	2	0.12	0.03
	9	1.33 ; 1.34	3	0.18	0.01
	12	1.30 ; 1.32	2	0.12	0.02

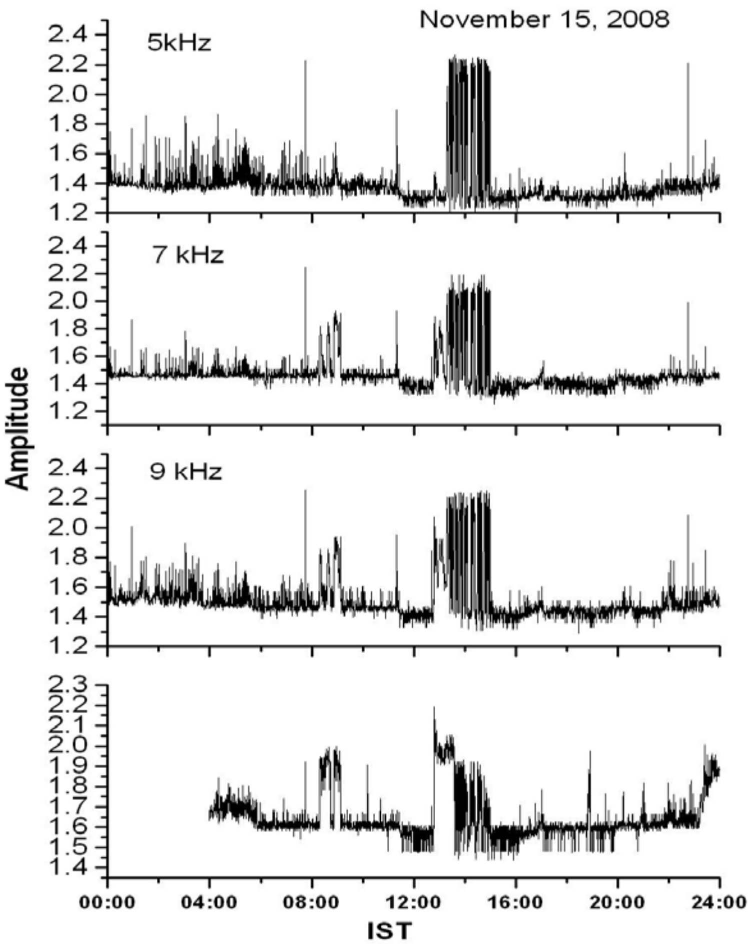

Fig. 6 – Diurnal variation of sferics observed at Kolkata. Date: November 15, 2008.

realization of the precursors of the earthquake. Post-earthquake effects have also been observed. Spike intensity gradually falls and almost ceased after November 23, 2008. Both precursory and post-earthquake effects are found to be different at these four frequencies.

4. CONCLUSION

In the study of ionospheric precursors of earthquake (M $\geq$ 6.0), the dependence of seismo-ionospheric effects on the distance from the hypocenter to the receiving station is to be considered. Exact statistical analysis is not generally possible because of its rareness. There are evidences of the increased value in signal amplitude at 81 kHz from minutes to hours prior to earthquakes and up to

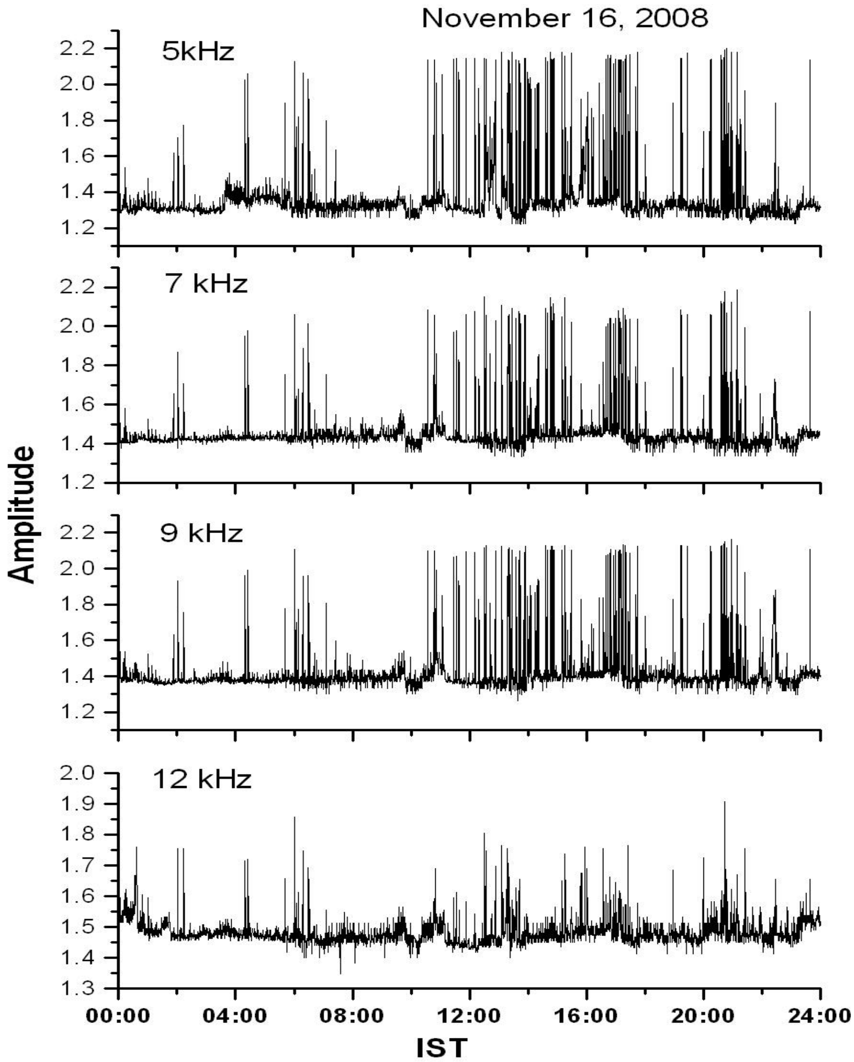

Fig. 7 – Diurnal variation of sferics observed at Kolkata. Date: November 16, 2008.

hundreds of kilometers away from epicenters. It is attributed to seismoelectric emissions (Gokhberg *et al.*, 1982; Yoshino, 1991). In the seismically active zones, thermal anomalies due to random irregularities generate internal gravity waves (IGW). From the viewpoint of energy coupling between the lower and upper atmosphere, IGW supplies a great amount of energy from troposphere to ionosphere influencing ionospheric parameters substantially (Mareev *et al.*, 2002) for which perturbations in VLF phase and amplitude occur (Hayakawa and Fuzinawa, 1994; Parrot, 1995; Parrot *et al.*, 1993). Thus, the study of the observations and analyses of pre-seismic VLF electromagnetic signals are of great significance in studying the earthquake preparation process (Kapiris *et al.*, 2002; Asada *et al.*, 2001). VLF sferics signals have been investigated here to point out their connection with the generation of a large earthquake in the Minahasa, Sulawesi seismic region.

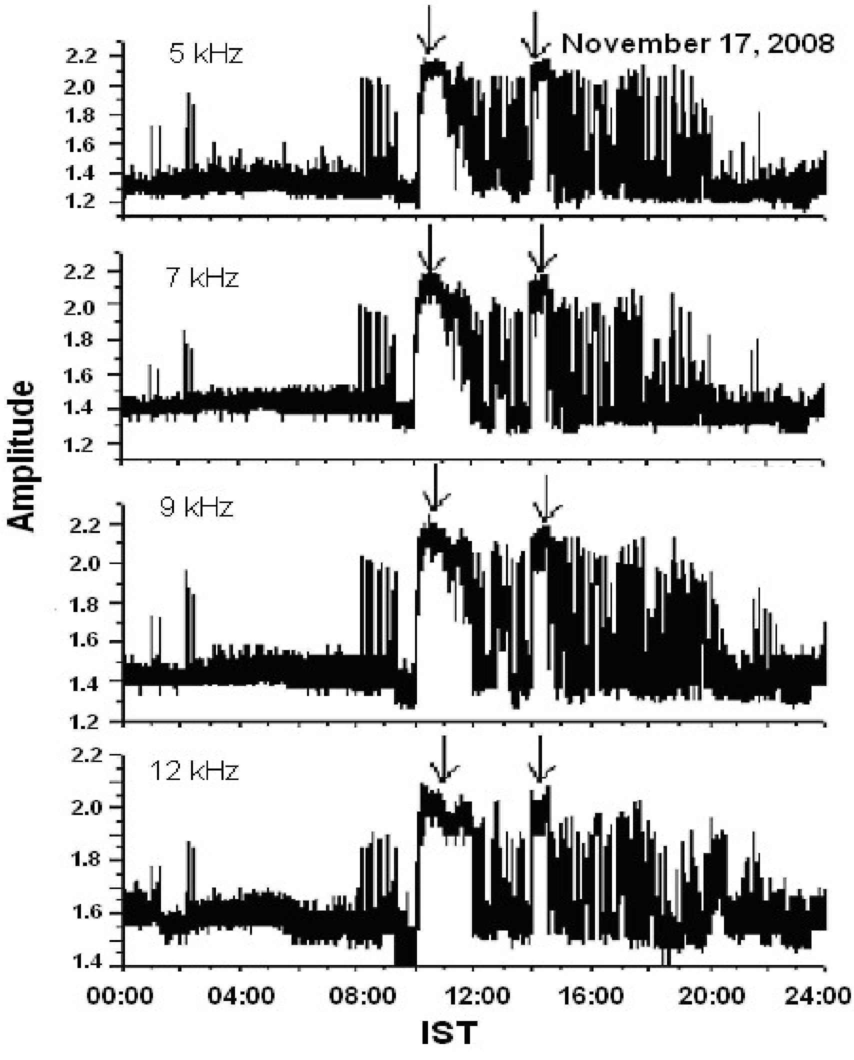

Fig. 8 – Diurnal variation of sferics observed over Kolkata. Date: November 17, 2008. The arrow marks indicate sferics changes due to Leonid meteor shower.

The earthquake at Minahasa, Indonesia (Lat. 1.27º N, Long. 122.09º E) occurred along with 12 after-shocks on the same day having M: 3.7 to 5.6. Two after-shocks having M>5 followed by 10 after-shocks with M<5. The records were taken near Kolkata which is about 2400 km away from the place of occurrence. Different quakes due to after-shocks are of various magnitudes and their hypocenters are located at different depths and regions. So, for various sources, the ponderomotive effects restrained the observed intensity which is depicted in Figs. 12–14 through uneven distribution of intensity of spikes.

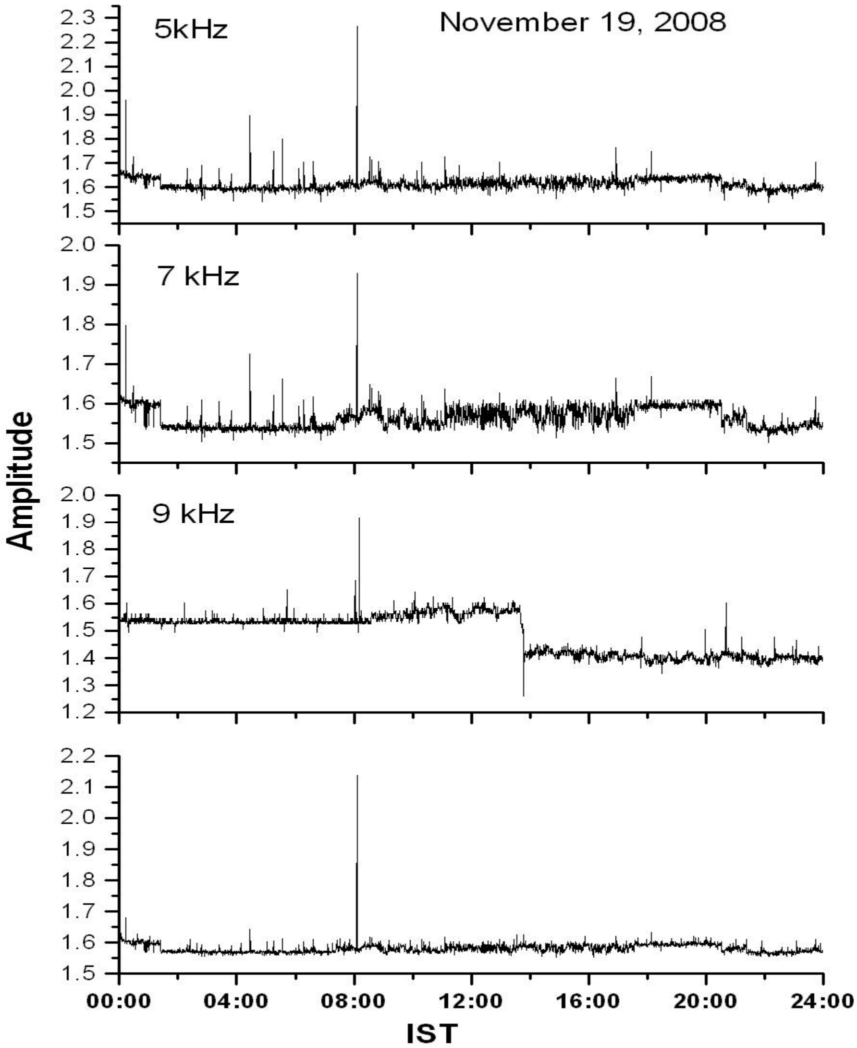

Fig. 9 – Diurnal variation of sferics observed over Kolkata. Date: November 19, 2008.

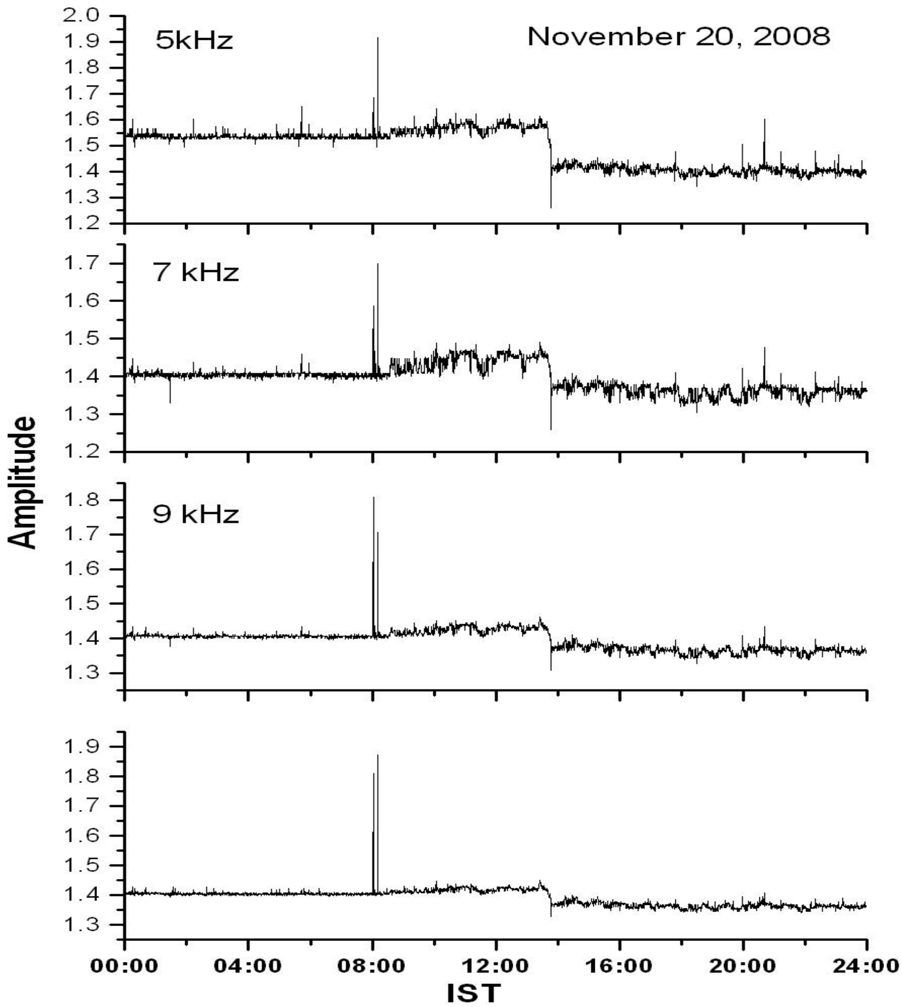

Fig. 10 – Diurnal variation of sferics observed over Kolkata. Date: November 20, 2008.

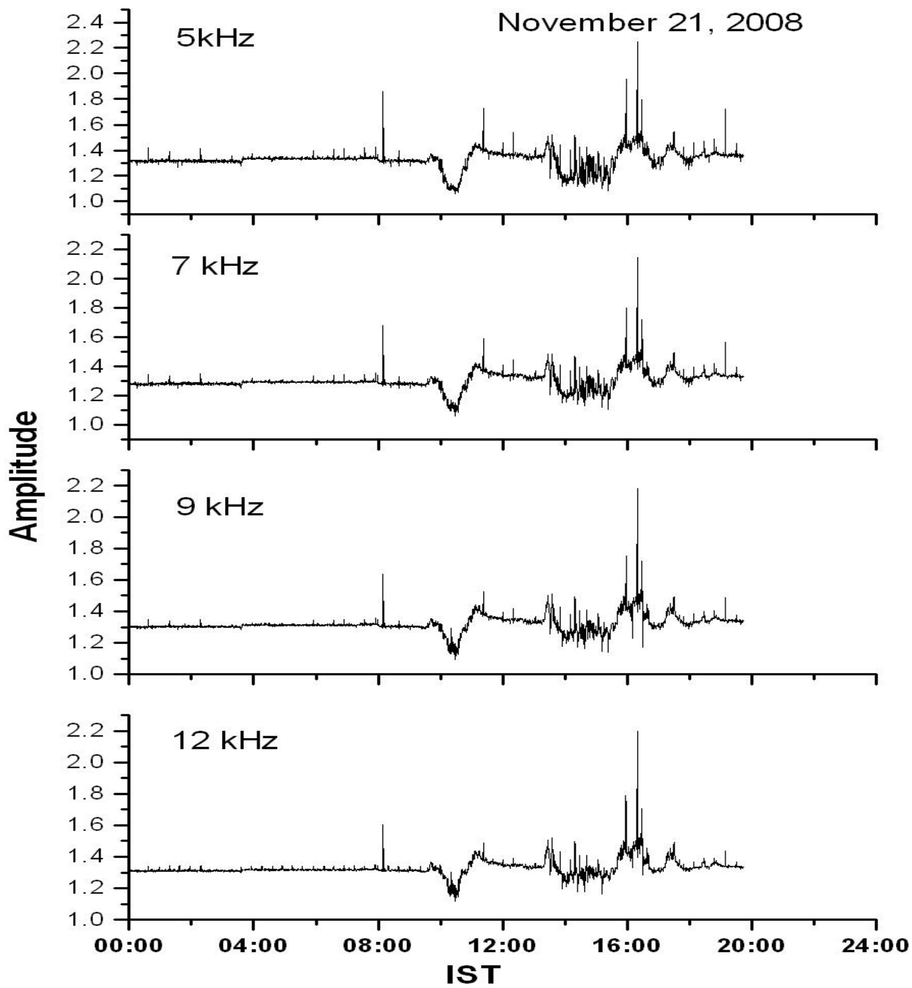

Fig. 11 – Diurnal variation of sferics observed over Kolkata. Date: November 21, 2008.

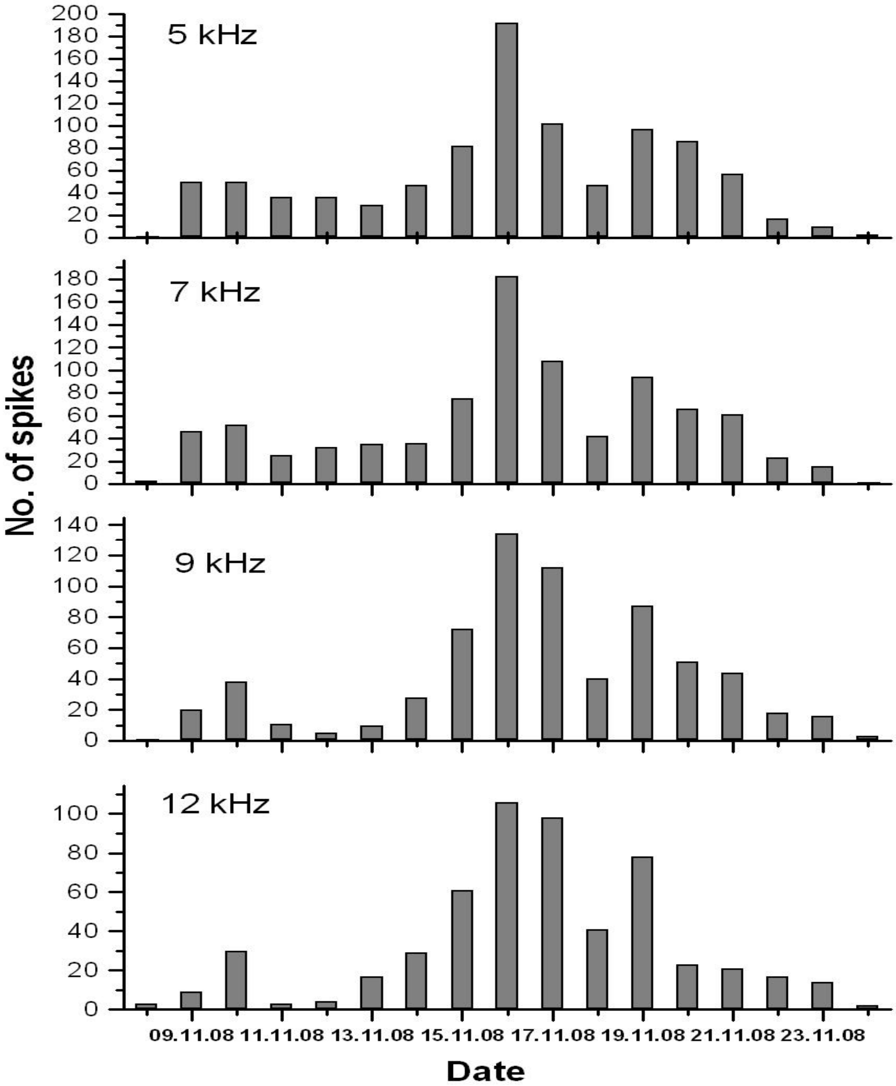

Fig. 12 – Variation of total no. of spikes before and after the earthquake.

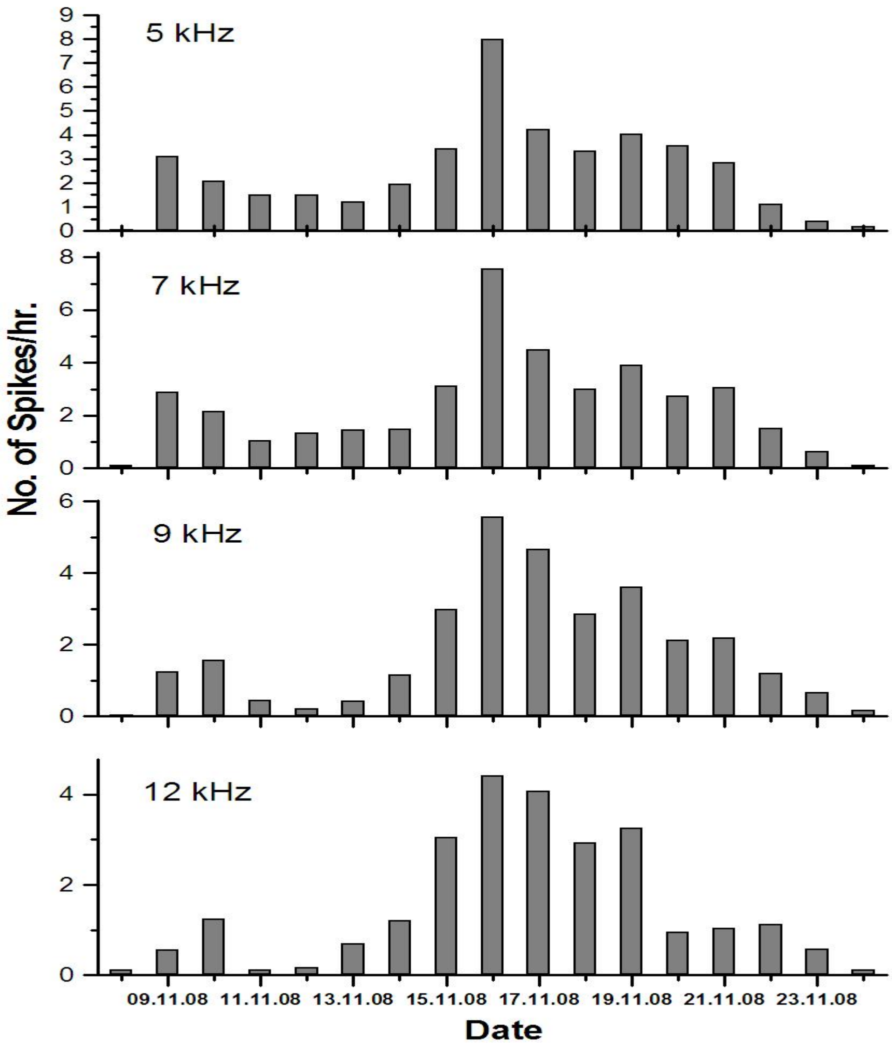

Fig. 13 – Variation of spike intensity per hour before and after the earthquake.

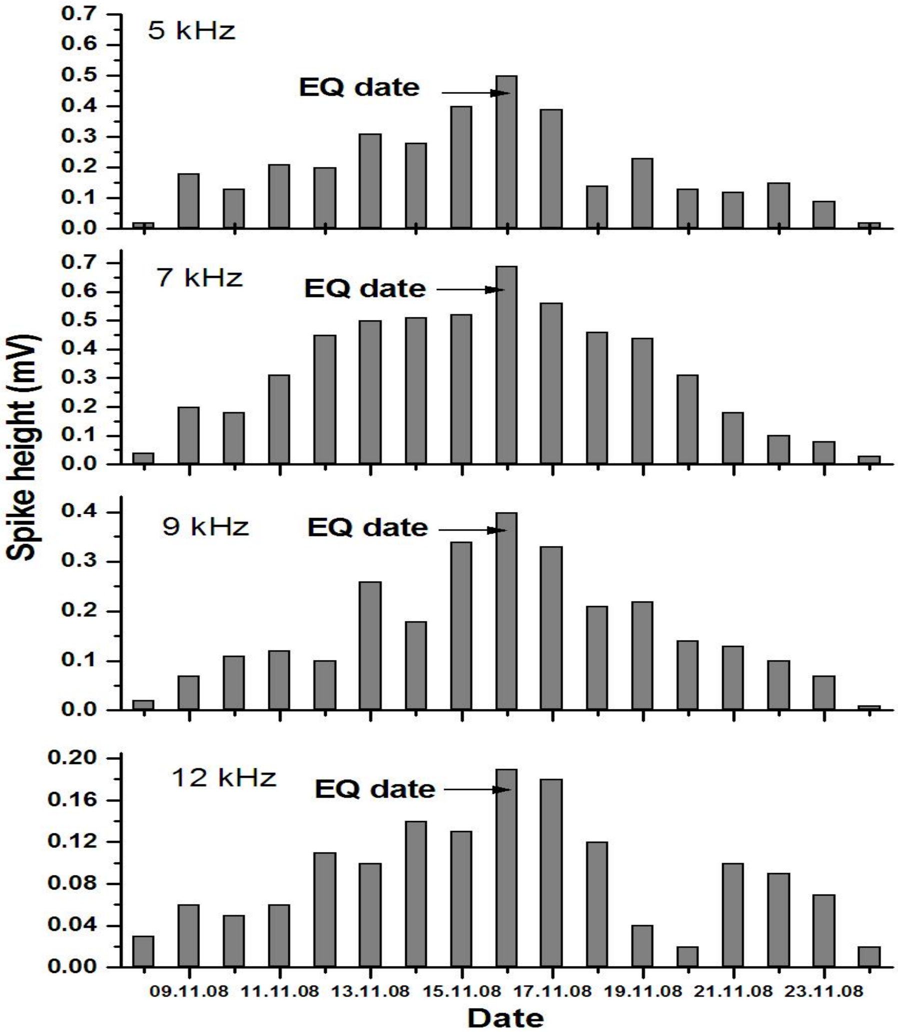

Fig. 14 – Variation of spike heights above the ambient level before and after the earthquake.

Acknowledgements. The authors acknowledge with thanks the financial support from Indian Space Research Organization (ISRO) through S K Mitra Centre for Research in Space Environment, University of Calcutta, Kolkata, India for carrying out the study.

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