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Fractal Analysis of Vertical Component of VLF Electric Field Related to Major Shallow Earthquakes (5.5 < M ≤ 5.9, depth < 10 km) occurred in Indian Ocean and China

Raj Pal Singh*

Abstract

Recording of amplitude of vertical component of VLF electric field is continued at Chaumuhan, Mathura (27.5° N, 77.68° E) at the frequency f = 3.012 kHz from 24 March 2011 with the help of vertical antenna. In this paper, fractal analysis of VLF data is carried out for the April 2012 and July 2013 months and the fractal dimension is computed using Higuchi's method to study the influence of three shallow and major seismic events (5.5 < M ≤ 5.9, depth<10 km) that happened in Indian ocean and China on the recorded data on it. Analysis of data yielded a decrease in fractal dimension, 6–14 days prior to onset of quakes considered. In addition to this, the effect of lightning activity, magnetic storms local building noises and power line emissions is examined on fractal dimension of VLF data. It is found that the said factors do not influence the fractal dimension of VLF data.

Keywords: Earthquakes, Terrestrial antenna, VLF data, Fractal analysis, Higuchi's method

INTRODUCTION

After the pioneering work of Gokhberg et al. [1] several workers have reported the presence of seismo-electromagnetic waves both in the atmosphere as well as in ionosphere employing satellite and ground based measurements in frequency band 0.01 Hz–30 MHz [2–4]. Experiments involving fracturing of rocks vindicate correlation of these radiations with earthquakes [5–6]. Recent researches carried in this directions can be found in the monographs [7–8].

Preparatory processes happening inside the earth's crust causes step like variation in it [9]. Such non-linear processes taking place in the earth's crust could be detected by the study of fractal dimension [10] and useful information regarding earthquake preparation processes occurring in focal zone of impending earthquakes can be gathered from the variation in fractal dimension of geophysical time series VLF data [11]. This technique was first used by Hayakawa et al. [12] and noticed significant variation in the spectral slop of the ULF data. Later on it was adopted by many other works for investigating the precursors of earthquakes [13–15].

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In the present paper, fractal dimension of the monitored VLF data is computed for each day using Higuchi's method for April 2012 and July 2013 for investigating the influence of three shallow and major seismic events (M = 5.6, 5.7, 5.9, depth < 10 km) of 25, 27 April 2012 and 22 July 2013 occurred in Indian ocean and China.

EXPERIMENTS SETUP

Continuous observations of vertical component of VLF electric field at the frequency of 3.012 kHz are going on at Chaumuhan, Mathura observatory (22.75°N, 77.68°E) from 24 March 2011 using the experimental set-up depicted in Figure 1. It comprises a terrestrial antenna of the length 18 m and diameter 2 mm which is made up of copper wire. The antenna is installed between two insulators vertically in air at the double storied building of Central Library, GLA University, Mathura. Another copper wire is buried 3 m in earth which works as a ground terminal. Vertical antenna is linked to a personal computer via amplifier with gain 26 dB, bandpass filter having bandwidth = 550 Hz and peak frequency 3.012 kHz, a notch filter of notch frequency = 50 Hz, and A/D converter and finally the output is recorded on a PC. The peak frequency of bandpass filter is selected 3.012 kHz because power line emissions generate spurious noises at lower frequencies while at the higher frequncies attenuation of these waves enhance severly. The signals filtered from the bandpass filter are passed across the notch filter to supress the effect of power line emissions on the vertical component of VLF electric field.

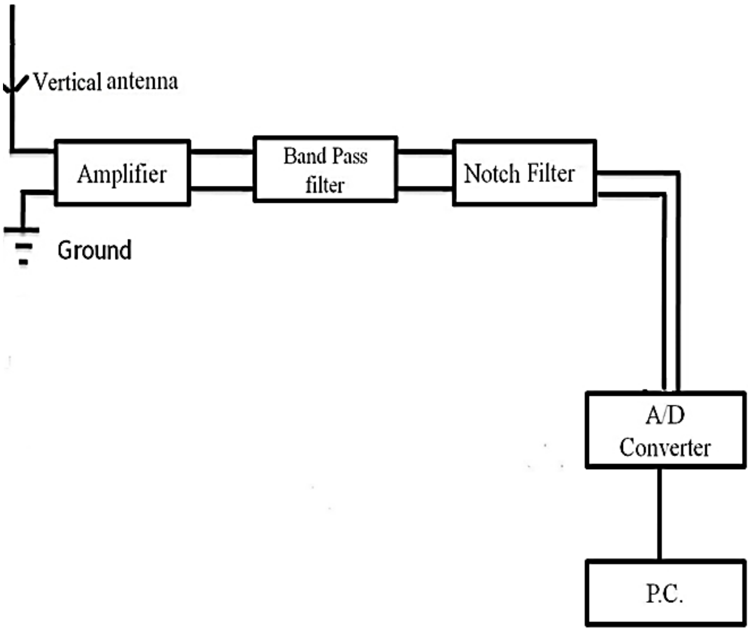

Figure 1. Block deagram of Experimental setup to observe vertical component of VLF electric field in Atmosphere

DESCRIPTIONS OF GEOGRAPHICAL POSITIONS OF OBSERVING STATION AND THE SEISMIC EVENTS CONSIDERED

In Figure 2, the map of India and its neighbouring nations are shown. Geographical positions of the three shallow major seismic events (shown by red color solid circles) happened in Indian ocean and China during April 2012 and July 2013 and the observing station Mathura (depicted by green color solid triangle) are shown in the said Figure 2. Rest of the details of the seismic events viz like magnitude, depth, latitude, longitude, date and time of happening and their distances from the Chaumuhan observatory are given in Table 1.

It is notable here that we have considered only those major shallow seismic events ($5.5 < M \leq 5.9$) whose focal point lie at depth < 10 km and have happened within the radius of 3300 km considering Mathura station as the centre (Table 1). The cause for this is that electromagnetic waves generated from earthquakes of large focal depth get attenuated on the way prior to their arrival at the Chaumuhan, Mathura observatory. Further, the earthquakes of low magnitude ($M \leq 5.5$) are not considered in the present analysis because mechano-electric conversion is less for such quakes [16] and hence feeble electromagnetic waves are supposed to be radiated from their focal zones which could not propagate up to the Mathura observatory though their epicenters are near the observing station.

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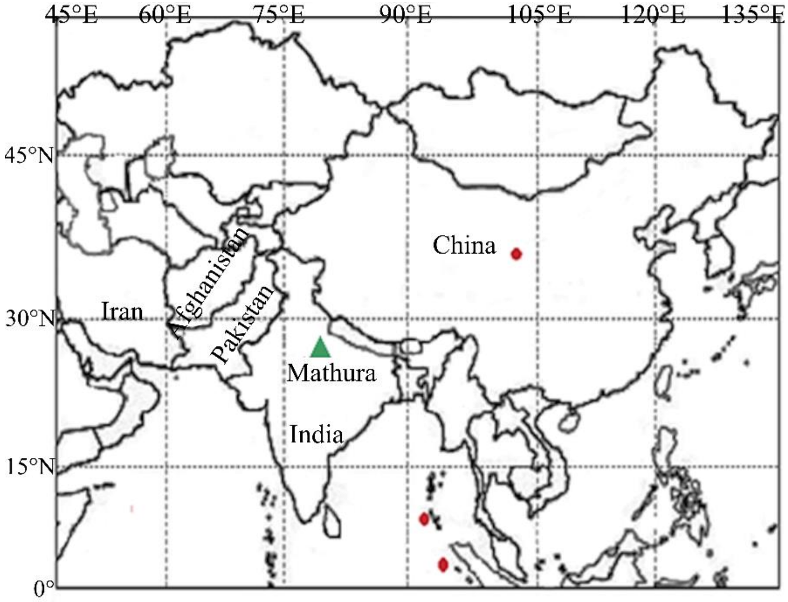

Figure 2. India's map and the states around it depecting Geographical locations of Mathura observastory (marked by solid green color triangle) and seismic events (depicted by solid red color circles).

Table 1. Details of major shallow seismic events (5.5 < M ≤ 5.9, depth < 10 km) happened in Indian ocean and China during April 2012 and July 2013.

Date of seismic events	Occurrence time of seismic events (LT)	Locations of seismic events		Magnitude of seismic events (M)	Depth (km)	Distance between Mathura observatory and epicentres of seismic events (km)
		Latitude	*Longitude*			
25/04/2012	13:12:23	9.01°N	93.94°E	5.7	9	2671
27/04/2012	0:51:42	2.69°N	94.45°E	5.6	7.9	3284
22/07/2013	5:15:56	34.51°N	104.26°E	5.9	8	2642

METHOD FOR ANALYSING THE VLF DATA

Continuous recording of vertical component of VLF electric field associated with earthquakes is going on at Mathura observatory from 24 March 2010 with the help of a vertical antenna. The data observed are analysed and important findings are obtained [17–19]. Sampling rate for logging the data is 1 Hz. To explore the effect of the major shallow earthquakes occurred in Indian ocean and China during April 2012 and July 2013 on the VLF data monitored in the vertical antenna, fractal dimension of each day data is computed using Higuchi's approach. This approach is robust for estimating stable fractal dimension. In this technique, original time series data Z(1), Z(2), Z(3),……….. Z(n) is subdivided in to k fresh series (Z_M^τ). Every new time series is specified as Z_M^τ= {Z(M), Z(M+τ), Z(M+2τ),……….Z(M+Nτ)}, M = 1, 2, 3 ……. τ, here τ and M are the integers showing time interval and initial time respectively. Length of each subtime series L(τ) is estimated for different values of time interval (τ) with the help of equation mentioned below;

$$L_M(\tau) = \left\{\left(\sum_{i=1}^{\left[\frac{N-M}{\tau}\right]} |Z(M+i\tau) - Z(M+(i-1)\tau)|\right) \frac{N-1}{\left[\frac{N-M}{\tau}\right]}\right\} / \tau \quad (1)$$

Using equation (1) length of time series is calculated for five different time intervals (τ = 1-5). Further, the length of each subtime series is related to its fractal dimension (D) as follows:

$$L(\tau) \propto \tau^{-D} \quad (2)$$

The log-log plot of equation (2) is obtained by dividing whole data of each day into five data sets. This plot is a straight line whose slope gives fractal dimension on a day. Same procedure is adopted for computing the fractal dimension on all the days. This method of estimating fractal dimension of ULF/VLF data is also used by earlier workers for detecting the irregularties in the time series of ULF/VLF data [20–21].

RESULTS AND DISCUSSION

To study the influence of the earthquakes happened on 25, 27 April 2012 and 22 July 2013 in Indian ocean and China on the VLF electric field data observed at Mathura obsevatory using terrestrial antenna variation of fractal dimension of each day for April 2012 and July 2013 is plotted (marked by solid blue color curve) in the first and third panels of Figure 3. It is noteworthy here that only the nighttime (19:00 hrs-05.00 hrs) VLF data is taken into accountability in this study for minimising influence of power line emissions and local building noises [22]. Cause for not choosing the day time data is that in daytime electromagnetic disturbances are prominent and hence may alter the VLF data. From a glance at these curves it clear that there is significant decrease in fractal dimension of VLF data on 11, 21 April 2012 and 12 July 2013. These significant reductions in fractal dimensions of VLF data may be attributed to magnetic storms, lightning activity, local building distubances, instrumental error, and seismic events. Now, we will explore the influence of these sources on the daily variation of fractal dimension of VLF data one by one.

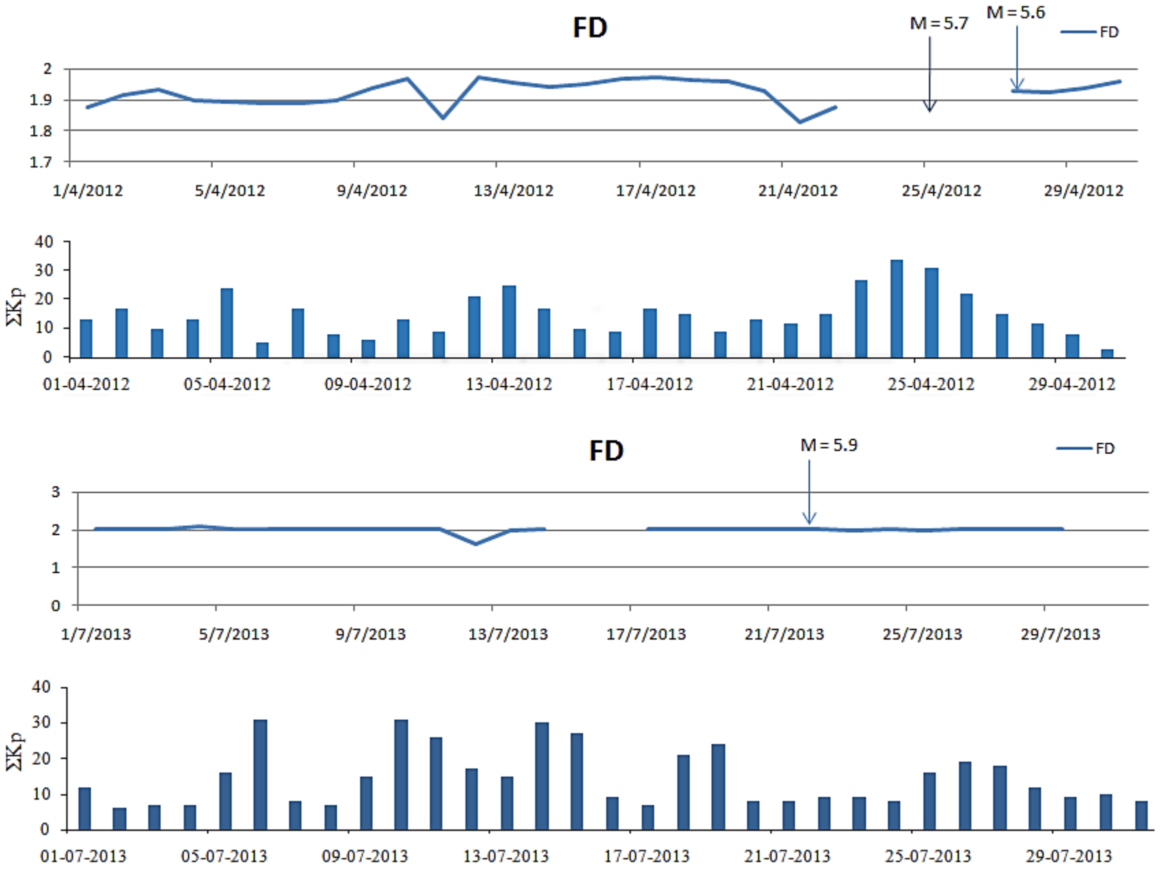

Figure 3. Daily variation of fractal dimension of the VLF electricc field data for April 2012 and July 2013.

Magnetic storms may perturb the observed VLF data. For studying the effect of magnetic storms on the VLF data, the variations of ∑Kp data are shown (by blue color histograms) beneath the daily variations of fractal dimensions of VLF data in Figure 3 for April 2012 and July 2013. It is notable here that the days on which $\sum Kp < 30$ are specified as magnetically quiet while those on which $\sum Kp \geq 30$ are known as "anomalous days" or "disturbed days". Looking at the histograms showing daily variation of ∑Kp data for the said months it is clear that the magnetic storms occurred on 24, 25 April

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2012 and 6, 10, 14 July 2013. The value of ∑Kp on these days were 34, 31, 31, 31, 30 respectively. But the reductions in fractal dimension are seen on 11, 21 April 2012 and 12 July 2013. As there is wide mismatch between the days of magnetic storms and the days of reduction in fractal dimension, observed significant reduction in fractal dimension of VLF data perhaps would not be attributed to magnetic storms happened on the aforesaid days.

Lightning activity that happens in atmosphere may also affect the fractal dimension of VLF data observed in vertical antenna because the electric field associated with the VLF emissions produced during lightning may alter the potential difference produced in it. Earlier researches [18, 23] have not shown any influence of lightning activity on the VLF data. Probable causes for this are: (i) it is a momentary phenomenon that occurs for the time span of 10^{-3} Sec. For recording the effect of such momentary events the sampling rate for monitoring of the data should be of the order of 10^3 Hz while it is 1 Hz only in our case (ii) other workers too have not noticed the effect of lightning activity on the VLF data [24]. In view of aforesaid reasons and findings of previous researchers in mind, effect of lightning activity on fractal dimension of VLF data are not examined. In the light of above, it can be concluded that the reduction found in fractal dimension of VLF data of terrestrial antenna may not be due to lightning activity.

Possibilities of influencing fractal dimensions of VLF electric field data from power line emissions electrical and electromagnetic disturbances of local building noises can be ignored because of use of notch filters and differential amplifiers in the experimental set-up and taking the nighttime VLF data into consideration for compution of fractal dimension. Further, the reductions seen on 11, 21 April 2012 and 12 July 2013 may not be due to instrumental error. If it were the case then reduction in fractal dimension would have appear on all the days of observations.

Now, since the reductions seen in fractal dimension on 11, 12 April 2012 and 10 July 2013 are not related to magnetic storms, lightning activity, building disturbances and power line emissions, these reductions may be attributed to the combined effect of earthquakes occurred on 25, 27 April 2012 and those observed on 10 July 2013 may be due to the quake occurred on 22 July 2013. It is noticeable here that precursory time for the seismic events enhance as their magnitude increase because for the earthquakes of higher magnitudes wave and other precursors much earlier than that of low magnitude seismic events [25]. In view of this, reduction in fractal dimension recorded on 11 April 2012 and those on 21 April 2012 may be attributed to the earthquakes of 25 April 2012 and 27 April 2012 respectively. The precursory time for these seismic events varies from 6 to 14 days.

CONCLUSION

Fractal dimension of the vertical component of VLF electric field data procured by using the terrestrial antenna is estimated for April 2012 and July 2013 using Higuchi's method. The results show a significant decrease in fractal dimension of the VLF data, 6–14 days prior the occurrence of three major shallow earthquakes happened in Indian ocean and China. Effect of lightning, magnetic storms and power line radiations and local buildings noises are also examined on the VLF electric field data and reductions are seen in fractal dimension of VLF data which are not related to the said non seismic sources.

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