

On the pre-seismic effects of VLF electric field anomalies on the atmosphere corresponding to major shallow seismic events ($M = 5.1 - 6.4$, depth < 29 km) occurring in India and nearby countries

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ABSTRACT

Observation of horizontal component of VLF electric field data are going on at 3.012 kHz frequency since 24 March 2011 at Mathura station (27.49° N, 77.67° E) by employing a horizontal antenna for investigating the effects of earthquakes. Bulk of the VLF data recorded is analysed using Quartile-based statistical analysis, covering the months of June–July 2015 and February, March and May 2016 in the light of 14 seismic events ($M = 5.1 - 6.4$, depth < 29 km) that took place in India and countries lying in a circular radius of 1270 km from Chaumuhan, Mathura observatory. Anomalous amplitude enhancements in VLF data were noticed, 1-27 days ahead the onset of the earthquakes that are considered in the present study. Moreover, pre-seismic anomalous amplitude enhancements were found to vary from 0.8 mV to 31.3 mV, and the percentage range of these enhancements varies from 0.95% to 86.22%. The unusual VLF amplitude intensifications are also explored in reference to spurious sources, which include geomagnetic and lightning activities, local building noises, radiations of power lines, and instrumental errors. It is found that the unusual amplitude enhancements are not connected with said sources, excluding the 4 cases of amplitude augmentations with the magnetic storms. To explore the association of VLF amplitude enhancements and their precursory times with earthquakes, probabilities for the pairs of magnitude with VLF amplitude enhancements and precursory time, and focal depth with VLF amplitude enhancements and precursory time, are calculated. Probable values for the aforesaid pairs comes to 84.96%, 88.61%, 81.94% and 92.33% respectively, which are significant and show a correlation of amplitude enhancements and their precursory time with the seismic events. Possible mechanisms for the origin of VLF electric field radiations and their propagation to long distances, are discussed briefly in terms of chemical and acoustic gravity wave channels. Further, following the model given by Sharma and Singh (2022), an attempt has been made to justify the observed VLF amplitude enhancements related to earthquakes using electromagnetic channel.

Keywords: VLF electric field, Horizontal antenna, Seismic events, Atmosphere, ΣKp data, Mathura observatory (India)

INTRODUCTION

Gokhberg et al. (1982) first recorded an unusual increase in the intensity of electromagnetic radiations approximately 1 hour prior to onset of the earthquake ($M = 6.1$) on 25 September 1980 in central Japan, employing a ground-based receiver of peak frequency 81 kHz. Subsequently, dedicated scientific efforts were initiated in many countries to detect electromagnetic effects of earthquakes, taking their precursory nature into account using ground and satellite-based methods (Zhao et al., 2020; Biswas et al., 2023; Calderon et al., 2025). Laboratory experiments involving fracturing of rock samples have provided several evidences for the association of electromagnetic waves with earthquakes (Panfilov, 2014; Gao et al., 2024). Studies by Hayakawa (2016), Pulinets and Ouzounov (2018), Arneva and Cordaro (2019), Conti et al. (2021), Pulinets et al. (2022), Zeigarnik et al. (2022), and Hayakawa (2025) provide a detailed account of recent findings obtained in the field of Seismo-electromagnetics.

Among many ground-based methods developed so far for the observation of electromagnetic effects of earthquakes, monitoring of VLF electric field on ground and in atmosphere has also drawn the attention of several researchers. Using this method, Zhang et al. (1988) observed the VLF pre-earthquake electromagnetic radiations using horizontal antenna at the Jiangsu station in China and they

found anomalous variations in it, a few days to several weeks before the Liyang earthquake ($M = 6.0$), Heze earthquake ($M = 5.9$), and South yellow sea earthquake ($M = 6.2$) that occurred on 9 July 1979, 7 November 1983 and 21 May 1984 respectively. Singh et al. (2003) noted unusual enhancements in VLF electric field (frequency, $f = 3$ kHz) data, 3 hours before the onset of the Chamoli earthquake ($M = 6.8$) in the Chamoli district of India, while Fujinawa et al. (2013) recorded pulse-like VLF signals with different waveforms, 6 days before the seismic event ($M = 9.0$) in Tohoku, Japan using almost similar type of borehole antenna in case of both the seismic events. Employing satellite-based VLF receiving antenna, several important findings in relation to precursory nature of seismo-electromagnetic radiations are reported in the recent past (Zhima et al., 2020; Salikhov et al., 2025).

Motivated by the findings of earlier researchers in the field of seismo-electromagnetics and precursory characteristics of electromagnetic radiations, observation of amplitude of horizontal component of seismogenic VLF electric field data at the frequency $f = 3.012$ kHz has started at Chaumuhan, Mathura since 24 March 2011 using a horizontal antenna of length 5.85 m for exploring the influence of these emissions in the atmosphere. In this paper, VLF electric field data monitored in horizontal antenna, are analysed using Quartile analysis for the periods of June and July 2015 and February, March, and May 2016 to explore the influence of 14