Precursory effects in the nighttime VLF signal amplitude for the 18th January, 2011 Pakistan earthquake

S Ray[1], S K Chakrabarti[1*,2] and S Sasmal[1]

[1]Indian Centre for Space Physics, 43 Chalantika, Garia Station Road, Kolkata 700084, India

[2]S N Bose National Centre for Basic Sciences, JD-Block, Salt Lake, Kolkata 700098, India

Abstract: We have presented the result of the analysis of the nighttime VLF signals transmitted from the Indian Navy station VTX (latitude 8.43°N, longitude 77.73°E) at 19.2 kHz and received at Kolkata (latitude 22.57°N, longitude 88.24°E). On 18th January, 2011 an earthquake of magnitude 7.4 occurred at Southwestern Pakistan (latitude 28.9°N, longitude 64°E). We have analyzed the nighttime VLF signals for 2 weeks around 18th of January, 2011 to see if there have been any precursory effects of this earthquake. We have found that the amplitude of the nighttime VLF signals anomalously fluctuated 4 days before the earthquake. This agrees well with our previous findings based on the analysis of 1 year of earthquake data.

Keywords: Waveguides; Radiowave; Ionospheric propagation; Earthquakes; Forecasting

1. Introduction

Earthquake is one of the greatest natural disasters. A prediction of the earthquake is still one of the most difficult tasks for the scientific community. It is already recognized that the ionospheric perturbations may be used as the short term earthquake prediction. The first paper regarding the earthquake prediction by ionospheric perturbation was published by Bolt and his group after the 'Alaskan earthquake' [1]. After that, several papers were published on the seismo-ionospheric correlations. In 1989, Gokhberg et al. [2] showed that the phase and amplitude of the nighttime VLF signal variations became anomalous before an earthquake. In 1996, after the 'Kobe earthquake', Hayakawa and coworkers [3] showed that the 'terminator time' (TT) of the VLF signals is shifted towards nighttime before the earthquake. In 2006, Maekawa et al. [4] used the nighttime fluctuation method and analyzed the 6 years data to find out the statistical correlation between the VLF propagation anomalies and earthquake and they found that the nighttime VLF signals are anomalously fluctuated before an earthquake. Horie et al. [5] also used this nighttime fluctuation method for the case study of Sumatra earthquake and they also found a correlation between nighttime VLF amplitude fluctuation and earthquake. Recently, Hayakawa et al. [6] introduced physical parameters namely (1) 'trend' (as the monthly average of nighttime amplitude), (2) 'dispersion' (D) (standard deviation of the signal amplitude from this average) and (3) nighttime fluctuation (NF) to analyze the VLF signals. They found for earthquakes with $M > 6$ a significant decrease in the 'trend' and significant increase in 'dispersion' (D) and 'nighttime fluctuation' (NF) few days before shallow earthquakes (with depth <40 km). Many other papers are published on the suitability of nighttime fluctuations for earthquake prediction (e.g., [7–9]. See, Sasmal et al. [10] and references therein), although the definition of nighttime fluctuation is not always unique. In the context of earlier Pakistan earthquakes, Kushwah et al. [11] employed 3-component search-coil magnetometer and found anomalies in the magnetic field components about 3–10 days before the earthquakes. Indian Centre for Space Physics (ICSP) has been monitoring the VLF signals for the last several years. The first paper on the seismo-ionospheric correlations from ICSP data was published by Chakrabarti and his group [12]. Apart from the seismic events Chakrabarti et al. [13] also used the VLF

*Corresponding author, E-mail: chakraba@bose.res.in

signals for the detections of the ionospheric disturbances due to Soft Gamma Ray Repeater SGR J1550-5418 and Gamma Ray Burst GRB 090424. In the year of 2009, using the VLF signals for VTX-Kolkata propagation path, Sasmal et al. [14] showed that the 'VLF day length' (defined as the time difference between the two terminator times) is correlated with the seismic activities. Chakrabarti et al. [15] showed that the 'D-layer preparation time' and 'D-layer disappearance time' become anomalous 1–2 days before the earthquake. Judging from the importance of monitoring of the VLF signals from a few places, ICSP is receiving the data at several receiving stations. Using the data of VTX-Malda propagation path, Ray et al. [16] showed that the anomalous behaviour of the 'VLF day length', 'D-layer preparation time' and also 'D-layer disappearance time' are correlated with the seismic activities. Recently, a full year's data was analyzed using a nighttime fluctuation (around a mean obtained each day) where we study the anomalous deviation of the amplitude at night. We report that this nighttime fluctuation of the VLF signal is correlated with the effective magnitudes of the earthquake [17]. In fact, in almost all the major earthquakes, we find that the highest deviation occurs 3 days prior to the event, though in general, the deviation between 2 and 5 days is significant. In the present paper, we analyzed the amplitude of the nighttime VLF signals, transmitted at 19.2 kHz from the Indian Navy station VTX and received at ICSP, Kolkata. We analyzed the nighttime VLF signals in the weeks around the 18th January (2011) earthquake of magnitude 7.4, which occurred at Southwestern Pakistan. Normally if one uses the Fresnel zone technique Hayakawa [18] one should have expected anomalies in the VTX-ICSP propagation path for a Pakistan based earthquake. However, the earthquake preparation zone for a 7.4 magnitude earthquake is around 1,500 km [19] and thus effects on our propagation path cannot be ruled out. Our major result is that the fluctuation of the nighttime VLF amplitude is anomalous 4 days before the earthquake. The plan of the paper is the following. In the next section, we discuss the transmitter and our receiving system. In Sect. 3, we present our result and analyzed the data. Finally, in Sect. 4, we draw our conclusions.

2. The transmitter and the receiver

Our receiving station is situated in Kolkata (latitude 22.57°N and longitude 88.24°E). We use the STANFORD/AWESOME receiver, which receives narrowband signals from several stations. For the present analysis we concentrate on the Indian Navy station VTX, located near Vijayanarayanam (latitude 8.43°N, longitude 77.73°E). This station transmits the VLF signal at 19.2 kHz. In an AWESOME receiver, the antenna has two cross-loops, which are capable of detecting fluctuating magnetic field components in the VLF signals. After receiving the data by this antenna, first it is pre-amplified and time stamped by a GPS unit. The data is automatically stored in the computer, which we analyze (Fig. 1).

3. Results

We have analyzed the nighttime VLF signals during 11th January 2011 to 25th January 2011 for the VTX-ICSP (Kolkata, India) propagation path. The distance between the VTX and Kolkata is 1,950 km. We have verified that there was no instrumental problem (power supply etc.) or other natural effects such as solar flares during the data acquisition period mentioned in this paper.

To analyze the nighttime VLF signals, we consider the data from 14:00 to 23:00 UT which corresponds to the local (IST = UT + 5:30 h) nighttime beginning at 19:30 h and ending at 04:30 h (23:00 UT) of the local next day. There is a 1-h gap just prior to the midnight for maintenance, data reduction etc. In Fig. 2 we plot the amplitude of the nighttime VLF signals for 13–14th January 2011. Note that the signal of 13th January 2011 is rather quiet but a very large fluctuation is present in the data of the 14th January 2011. We suspect that similar to our earlier study [17], this anomalous amplitude fluctuation may be the precursor effect of the earthquake occurred on the 18th January 2011.

To verify this, on each day, we calculate the difference between the maximum and minimum fluctuations of the

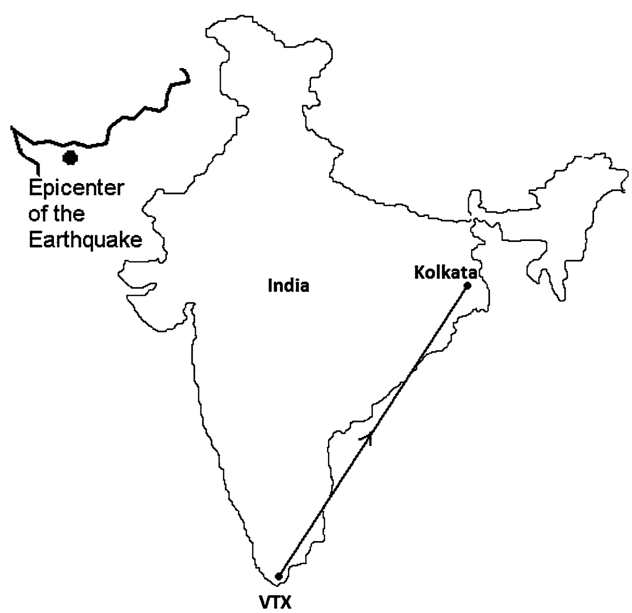


Fig. 1 The locations of the transmitter (VTX) and the receiver at ICSP, Kolkata, India which are connected by the great circle path. The epicenter of the earthquake is also indicated by a *filled circle* in Pakistan

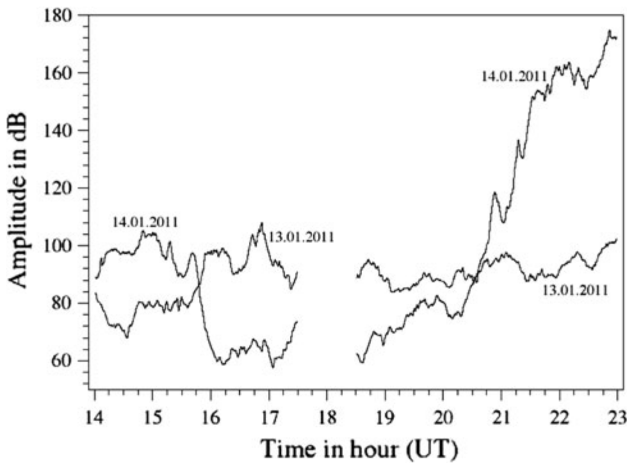


Fig. 2 The amplitude of the nighttime VLF signals is plotted as a function of time. The *dotted curve* is for 13th January 2011 and the solid curve is for 14th January 2011. Note that the amplitude of the signal of 13th January 2011 exhibits a low level of fluctuation but a very high fluctuation is present in the signal of 14th January 2011. This anomalous fluctuation in the nighttime VLF signal of 14th January 2011 could be the precursor effect for the earthquake ($M = 7.4$) occurred on 18th January 2011 in Pakistan

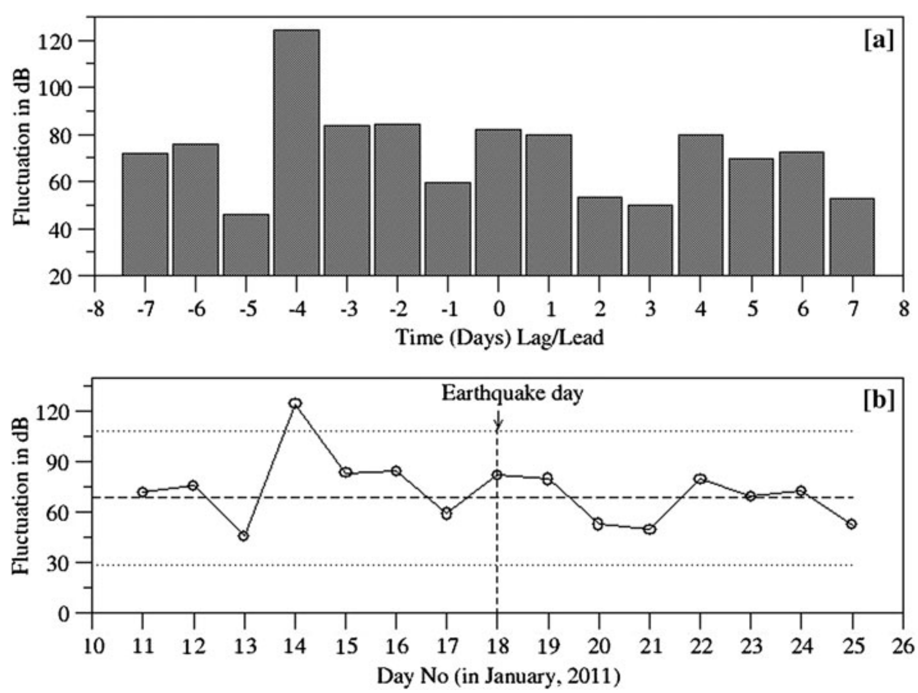
signal amplitude during the nighttime. In Fig. 3a, we plot this difference for 15 days centered on 18th January 2011, the earthquake day. Note that the peak appears 4 days before the event, i.e., the fluctuation of the nighttime VLF amplitude becomes anomalously high 4 days before the earthquake. In Fig. 3b we plot the nighttime VLF amplitude fluctuation (open circle) as a function of day number. Note that we compute the fluctuation based on each night's data and not with respect to 1 month's data as in [6]. The dashed curve represents the average nighttime VLF amplitude fluctuations while the dotted curves represent the average $\pm 3\ \sigma$ (σ is the standard deviation) line, computed on each night. The vertical dashed curve shows the earthquake day. From this plot, we can see that the fluctuation was above 3 σ level 4 days prior to the earthquake. This leads us to believe that this anomalous fluctuation could be the precursor effect of the earthquake occurred on 18th January 2011.

In a passing remark, we may note that the fluctuations mentioned here are non-trivial, namely, not due to lighting (duration < seconds) or magnetic storms. We found no solar events during this period.

4. Discussions and conclusions

In the last two decades, the effects of ionospheric perturbations on the seismic signals have been studied. However, there is no general consensus on how to quantify the so-called anomaly. In the literature, several ways to quantify the precursory effects, such as the shifting of the terminator times, D-layer preparation/disappearance times, the power density spectrum of the nighttime fluctuations, anomalous deviations of the nighttime amplitudes etc. have been discussed. In the present paper, we have shown that even the excursion of the nighttime signal amplitude measured on each day could be a good measure of the ionospheric

Fig. 3 **a** The nighttime VLF amplitude fluctuations for 2 weeks centered on 18th January 2011. Note that the peak appears 4 days before the event. **b** The amplitude of the nighttime VLF fluctuations (*open circles*) signals are plotted as a function of day no. The *dashed curve* represents the average nighttime fluctuations while the *dotted curves* represent the $\pm 3\ \sigma$ (σ is the standard deviation) lines. The *vertical line* is the earthquake day. The fluctuation 4 days before the event crossed the 3 σ line



perturbation. We have shown that this excursion 4 days prior to the event is beyond 3 σ level from the average nighttime excursion in the VTX-Kolkata propagation path. Already, using one full years data, it has been observed that the fluctuation peaks 3 days prior to the earthquakes [17]. Since we are considering the fluctuation on a daily basis, and not on the basis of specific number of hours prior to the earthquake, a difference of a day, i.e., 3-day for earlier studies and 4-day for the present study is expected. In any case, such an anomalous fluctuation could be considered to be a clear signature of a precursor. Due to negligible progress in the subject of lithosphere–ionosphere coupling, it is very difficult at this stage to specify real physical explanation for the fluctuations we have observed here. It is believed [20] that the deposition of ground seismic energy or radio-active decay of radon and other isotopes into the ionosphere can produce excessive ionization which may enhance the conductivity which in turn increases the chance of short discharges in the seismic regions much before the event. Heating by radon decay may produce slow expansion of the atmosphere which could eventually perturb the ionosphere itself. Similarly, large scale gravity waves may be responsible to spread the ionization around, as well. In a wave-hop model, ionization at the lower troposphere would also contribute to signal perturbation, especially when multiple hops are important. This is a subject of intense study and we will address in detail separately in future.

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