Anomalous behaviors of the VLF signals before earthquakes for VTX-Malda propagation path

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Abstract

We present the results of monitoring of four years (2005, 2007-09) of VLF signals collected in the Malda branch of ICSP, located in Malda, West Bengal and find the correlations, between the ionospheric activities and the earthquakes. Here we use that VLF signals which are transmitted from the VTX station (18.2 KHz). We first study the average signal throughout the year. We plot the so-called standardized calibration curve using the four years data. To establish the correlation between the ionospheric activities and the seismic events, we use the data of the year 2008 and we find that the deviations of the VLF day length (defined as the time difference between sunrise and sunset terminators) are correlated with the seismic event. We find that the highest deviation takes place one day prior to the seismic events. We also calculate the 'D-layer preparation time' (DLPT) and the 'D-layer disappearance time' (DLDT) for the data of 2008 and established the co-relation between the anomalous DLPT and DLDT with the seismic events. We find that the anomalous behaviour of the DLPT and DLDT are also correlated with the seismic events.

1 Introduction

The study of the behaviour of the ionosphere by monitoring the VLF signals is well known. In the last two decades, several attempts have been made for earthquake prediction by using the ionospheric perturbation (Gokhberg et al. 1989; Gufeld et al. 1992; Hayakawa et al. 1996; Molchanov & Hayakawa, 1998; Ray et al. 2010; Sasmal & Chakrabarti; 2009; Chakrabarti et al. 2010). Indian Centre for Space Physics has been monitoring VLF signals, specifically from VTX station (18.2kHz) for the last several years. Judging from the importance of monitoring from a few places, the data is received both at the Kolkata station and Malda station. So far, the Kolkata data has been analyzed to find a distinct correlation between the VLF day length and the seismicity (Sasmal & Chakrabarti, 2009) and between the D-layer preparation time (DLPT) or D-layer disappearance time (DLDT) with the magnitude of the earthquakes (Chakrabarti et al. 2010). Another procedure which we have adopted recently is to compute the night time fluctuations and relate that with the effective magnitude (Ray et al. 2011). In all these three methods, we found that the seismic events appear to have pre-cursors anywhere from 1 to 5 days before the earthquakes. In the present work, we show the results of the analysis of the data from the Malda (Lat 25° N, Long 88°08′ E) station (ICSP, Malda branch), which is 330km north of Kolkata and about 2290km away from VTX station (Lat. 08°26′ N and Long 77°44′ E). We used a Gyrator-III type receiver and a loop antenna made on a 1m ×1m frame. The preliminary result is in Ray et al. (2010) Analysis of multiple stations are required to improve the predictability. In this work, we use the four years data of 2005, 2007-2009 and plot the mean terminator times as a function of day. We defined this curve as 'Standardized Calibration Curve' (SCC) for VTX-Malda base line. Finally, we choose the data of 2008 and analyzed it to find the correlation of the seismic events with the anomalous 'VLF day length' and also with the anomalous DLPT and DLDT.

2 Standardized Calibration Curve

To study the average signals throughout the year first we plot the mean sunrise terminators (SRT) and the mean sunset terminators (SST) over the year in Fig. 1. We dene the SRT by the rst minimum which occurs just after the decrease of the signal amplitude during the formation of the D-layer in the morning

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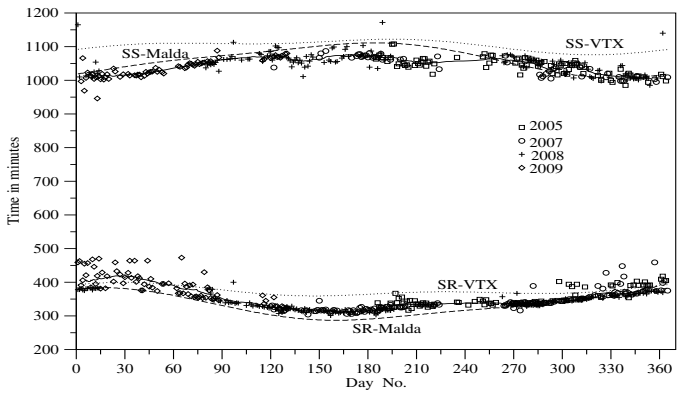

Figure 1: The Standardized Calibration Curve for VTX-Malda baseline (for detail see text).

and SST by the last weak minima just before the increase (recovery) of the signal amplitude during the disappearance of the D-layer in the evening. We plot in Fig. 1 the SRT and SSTs for the year of 2005, 2007, 2008 and 2009 by the Square, Circle, Plus and Diamond symbols respectively. The dashed curves represent the local sunrise and sunset of Malda, while the dotted curves represent the local sunrise and sunset of VTX. Solid thin curves are for the mean SRT and SSTs. We obtained this by taking the running mean of all observed four years data. We call this solid curves as 'Standardized Calibration Curve' (Sasmal & Chakrabarti, 2009) for VTX-Malda base line. In future, these curves will be used to quantify anomalous ionospheric behaviors.

3 The Correlations with the seismic activities:

We analyzed the whole year data of 2008 to find out the correlation of the seismic events with anomalous 'VLF day-length', anomalous 'DLPT' and also with the anomalous 'DLDT'. For this first we plot the 'VLF day-length' in Fig. 2(a) by 'plus' symbols. To obtain the mean variation of this 'VLF day-length' we first take the running mean of all calculated 'VLF day length' and calculate the standard deviation σ and eliminate those which are beyond σ level. After this we compute the mean and plot it in Fig. 2(a) by a solid thin curve. We compute the standard deviation σ and plotted curves which are σ and 1.5σ away from the mean (dashed and dotted respectively). We also plot the seismic activities, marked by the circles. This circles are plotted on the earthquake day, shifted vertically just to show the association with the observation. We calculate the deviation of the anomalous 'VLF day length' from this Figure.

To find out the correlations with the seismic activity we take the seismic events which occurred in the neighborhood of the great circle path between the transmitter and the receiver. For this purpose, we collect all the necessary information, i.e., the latitudes and the longitudes of the epicenter of the earthquakes, its magnitude, the depth of the epicenter from Indian Meteorological Department (http://www.imd.gov.in). We calculate the energy of the earthquake by using the equation $log_{10}E = 4.4 + 1.5M_s$, (for earthquake less than 5.0 magnitude) and $log_{10}E = 5.24 + 1.44M_s$ (for earthquake greater than 5.0 magnitude), where, E = Energy of the earthquake in Jules and M_s = Surface wave magnitude (Lowrie, 2007). We employ the relationship $M_s = -3.2 + 1.45M$ (Tobyas and Mittag, 1991) to convert from Richter scale magnitude to surface wave magnitude. In the days when more than one earthquake occurs, we calculate the total energy from the individual earthquakes and sum them up. To obtain the energy deposition by the earthquakes near the mid-point (i.e., the middle point between the transmitter and receiver), we divide the energies of the earthquakes by the GCP (great circle path) between the mid-point and the epicenter of the earthquakes. From this, by reverse process, we calculate the effective magnitude on each day. Thus we have the deviation of the anomalous 'VLF day length' from the mean and also the effective magnitude of each day. We then compute the correlation coefficient between these two quantities. In Fig. 2(b), we present this correlation coefficient. We find a sharp peak one day before the earthquake.

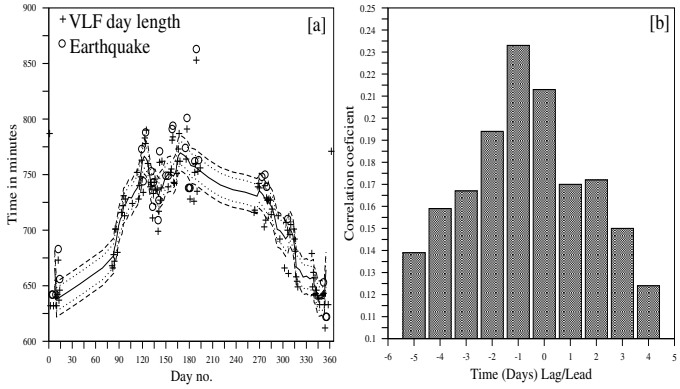

Figure 2: (a) Variation of the 'VLF day length' as a function of day no. for the year of 2008 (for details, see the text). (b) Correlation between the effective magnitude of earthquake at the mid-point between the transmitter and the receiver and the variation of the anomalous 'VLF day length'.

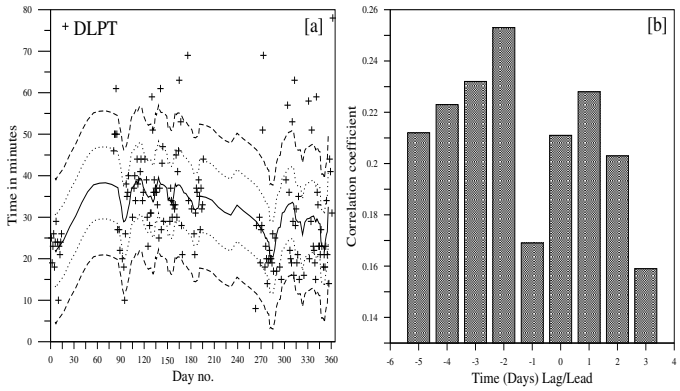

Figure 3: (a) The variation of 'DLPT' as a function of day no for the year of 2008 (for details, see the text) (b) Correlation between the effective magnitude of earthquake at the mid-point between the transmitter and the receiver and the variation of the anomalous 'DLPT'.

Similarly, in Fig. 3(a) and Fig. 4(a) we plot the variation of the DLPT and DLDT respectively and we calculate the deviation of the DLPT and DLDT from these two Figures respectively. In Fig. 3(b) and Fig. 4(b) we plot the correlation coefficient between DLPT and DLDT with the effective magnitude of earthquakes, respectively. We found that in case of DLPT, the peak of the correlation appears two days before the event day and in case of DLDT the peak appears on the event day.

4 Concluding Remarks

We obtained the 'Standardized Calibration Curve' for VTX-Malda base line both for sunrise and sunset. This curve, in future, can be used in a number of ways, particularly to quantify any deviation arising out of solar, extra-terrestrial and terrestrial activities. Clearly, for each baseline this curve is different. It has been recognized that the prediction of the earthquakes is one of the most difficult tasks faced by the scientific community throughout the world. In this paper, we showed that by VLF day-length and DLDT/DLPT methods, the seismic events could be predicted a few days before the events. We believe that the anomalous behaviour of the 'VLF day length' and also the anomalous behaviour of 'DLPT' and 'DLDT' are indications

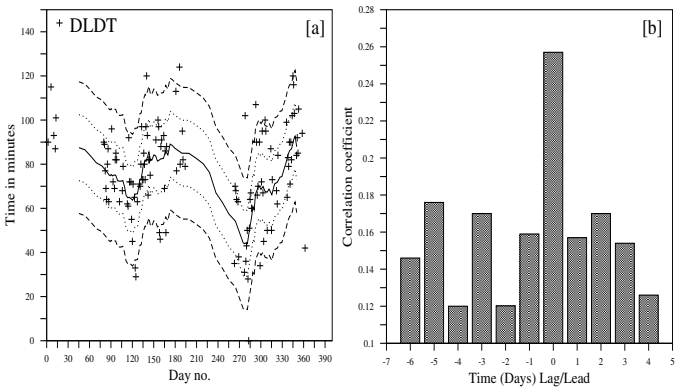

Figure 4: (a) The variation of the 'DLDT' as a function of day no. for the year of 2008 (for details, see the text) (b) Correlation between the effective magnitude of earthquake at the mid-point between the transmitter and the receiver and the variation of the anomalous 'DLDT'.

that the position and strengths of earthquakes may be predicted very accurately when correlations from multiple stations are combined together. The nighttime fluctuation method is yet another method which could be used together with these methods. The work is under way and would be reported elsewhere.

S. Ray thanks a RESPOND project of ISRO. Discussions with S. Sasmal is acknowledged.

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