Studies of the Correlation Between Ionospheric Anomalies and Seismic Activities in the Indian Subcontinent

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Abstract

It is long conjectured that the ionosphere is affected by the seismic activities and these effects can be detected in the VLF wave signal. We present the results of the sunrise and sunset terminators for the VTX 18.2 kHz signal received at Kolkata for a period of four years and draw a standardized calibration curve to study deviation from this curve which may be due to influences by terrestrial (such as earthquakes) and extra-terrestrial(such as solar activities and other high energy phenomena) events. We present examples of deviations of terminator shifts, D-Layer preparation time and disappearance time in several days of sixteen months of data and compute the correlations with seismic events. We found that correlation exists on 1-2 days prior to the events. We also discuss the effects of depths of the earthquakes on the correlation.

1 Introduction

The physical processes leading to seismic events are very complex. The occurrences of earthquake is connected to the earth's crustal dynamics. This generally involves in the movements of the tectonic plates, the microscopic processes such as friction, electric discharges and releases of various gases from the cracks. The physical mechanism of perturbation of the ionosphere due to the earthquakes is far more complicated. It has been reported that some electromagnetic phenomena are associated with seismic activities and thus can change the charge density profile in the ionosphere which may give rise to the changes in ELF/VLF. There are several publications regarding the seismo-ionosphere coupling by Bolt (1964), Gufeld et al., (1992) etc. An interesting result using VLF was obtained by Hayakawa et al. (1996) just before the Kobe earthquake (magnitude 7.3) on 17th January, 1995. Subsequently, several evidences of the shifting of the terminators during earthquakes followed: Clilverd, Rodger and Thomson (1999); Chakrabarti et al. (2005), Sasmal et al. (2009). We present the analysis of the data received at Indian Centre for Space Physics, Kolkata and using different methods show the correlations between seismic activities and the ionospheric perturbations really exist.

In left panel of Fig. 1 we present the transmitter VTX, receiving place Kolkata and wave path between them. We use Stanford AWESOME receiver for recording the data. In the middle panel of Fig. 1 we present a the diurnal amplitude variation of VTX. The SRT and SST are the sunrise and sunset terminators respectively. In order to obtain any correlation between the terminator shift and the seismic activities, we create a "standardized calibration curve" (SCC) for these terminators. Any deviation from the"mean" SCC may be associated with the seismic events. In the right panel of Fig. 1, we draw SCC using the four years of data. The open circles, closed circles, upper triangles and lower triangles are for the year 2005, 2006, 2007 and 2008 respectively. The solid curves are for sunrise time at Kolkata (SR-KOL) and sunset time at Kolkata (SS-KOL) and the dashed curves are for sunrise time at VTX (SR-VTX) and sunset time at VTX (SS-VTX). The thick curves which is the SCC for the VTX-Kolkata baseline are obtained by taking the running means of all the observed points.

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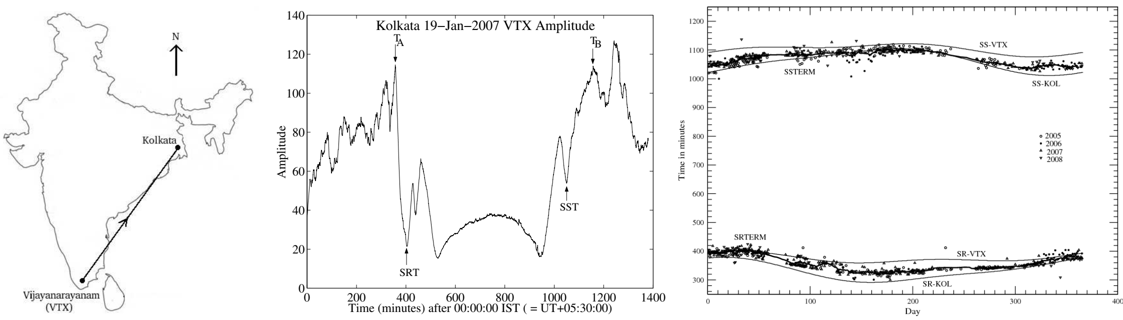

Figure 1: [Left] The position of the transmitter and receiver and the wave path between them (Sasmal et al., 2009). [Middle] Variation of the signal amplitude of VTX as a function of time (IST) in minutes (see, text for details). [Right] The superposition of the four years to a single plot to get the standardized calibration curve (SCC) (thick curves) Chakrabarti et al., (2009); Sasmal & Chakrabarti (2009).

2 Methodology of finding mean anomalies and correlations with seismic events

We first compute an effective magnitude of earthquake (M_{eff}) at the first reflection point between Kolkata and VTX by taking the energy of all the earthquakes of a single day. The earthquake data was obtained from web-page of the Indian Meteorological Department (www.imd.gov.in). Prior to earthquakes, the length of the VLF day which is the difference between the sunset and sunrise terminators is expected to lengthen. In the left panel of Fig. 2, we present the VLF day-length as a function of day using the data of sixteen months (November 2007 to February 2008) by filled circles. We took the running mean of only those days where SRT and SST are within $2\times\sigma_{whole}$ of the whole data. we compute the standard deviation σ and plotted curves which are 1σ, 2σ and 3σ away from the mean (solid, dotted and dash-dotted). We associated seismic activities with the anomalous days and marked the association by larger circles kept at a constant gap away from the observed points (filled circle). We computed the correlation coefficients between the earthquake magnitude and the anomaly. We calculate this for around 14 days of the earthquakes and after normalization obtain the correlation coefficient between the deviation of VLF day length and M_{eff}. In the right panel of Fig. 2 we show the correlation of the two quantities. The correlation peaks at two days before the earthquake. During the seismo-ionospheric coupling it is expected that the lower ionospheric

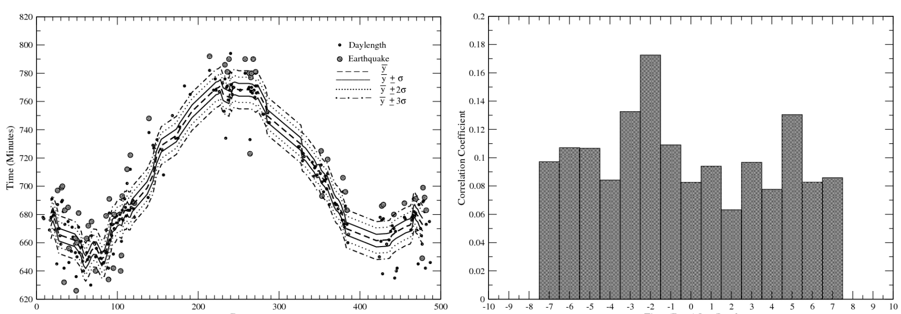

Figure 2: [Left] The Variation of the 'VLF-day length' as a function of days. [Right] The correlation between M_{eff} and the deviation of the VLF-day length from the mean (Sasmal at al., 2009).

boundary may be perturbed more which may change the characteristics, such as D-Layer Preparation Time (DLPT) and D-Layer Disappearance Time (DLDT) (Chakrabarti et al., 2007, Chakrabarti et al., 2010). We compute the DLPT and DLDT of the same data set used above, and in Fig. 3 plotted them as a function of days. Typically, the DLPT (left) varies between 30-50 minutes and the DLDT (right) varies between 50-70 minutes. However, in a number of days, these values are anomalous. The dark circles are observed values of DLPT and DLDT on a given day and the diamonds represents earthquakes 'associated' with the anomalous data. The thick solid curve is the average of the DLPT and DLDT values, computed by removing days which show anomalies of more than 3σ. The thin solid curves are drawn at 1σ, 2σ and 3σ apart. In left

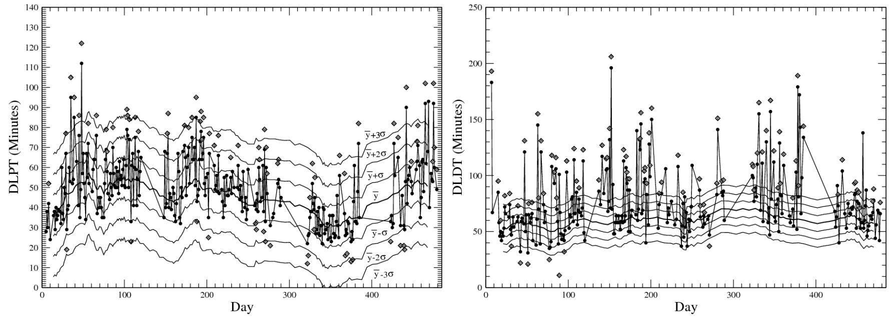

Figure 3: The variation of DLPT (left) and DLDT (right) as a function of days. (Chakrabarti et al, 2010).

panel of Fig. 4, we plot DLPT and DLDT in minutes for earthquakes having magnitude $M > 5$ (upper two panels) and we take averages of DLPT and DLDT (third panel) with error-bars as standard deviations. The average is maximum on two days prior for DLPT and one day prior for DLDT. In right panel of Fig. 4. We plot the cross-correlations between the (a) DLPT (left panel) or (b) DLDT (right panel) and M_{eff}. In (a), the peak occurred one day prior to the earthquake and in (b), a comparatively broader peak appears with the center one day prior to the event day. We compute the cross-correlation incorporating the depth of

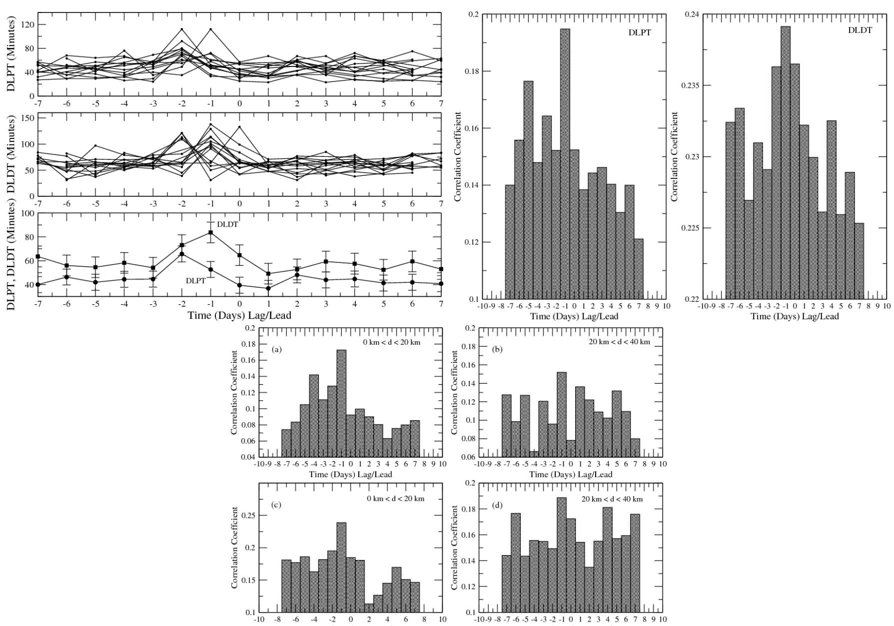

Figure 4: [Upper Left] Variation of the DLPT (upper panel) and DLDT (middle panel) as a function of days for a period of 15 days around the seismic events. [Upper Right] The cross-correlations between the DLPT (left histograms) or DLDT (right histograms) with M_{eff}. [Lower]The cross-correlations between the DLPT (a-b) or DLDT (c-d) with M_{eff} using the concept of depth.(Chakrabarti et. al., 2010).

the epicenter of the earthquakes. We choose the shallow earthquakes having depths $d < 20$km and deeper earthquakes having depth $d > 20$km. In the lower panel of Fig. 4, we present the cross-correlations between DLPT or DLDT and M_{eff}. In (a) and (c), we plot the correlation coefficients for $d < 20$ km and in (b) and (d) we plot for $d > 20$ km. For all the cases the peak is one day prior to the earthquake. We generally find that the peak is sharper for the shallow earthquakes.

3 Conclusions

Natural disasters such as Earthquakes take away thousands of lives and cause extensive damages. Their prediction is thus of great importance. At ICSP, we have been monitoring data and also trying to find various types of correlations between the anomalous ionospheric activities and the seismic activities. Unusual nighttime signal fluctuation during earthquakes have also been reported by our group (Ray et al., 2010). Thus, using three totally independent methods we find that there are indeed some correlations. So far, we obtained indications of earthquakes and not the positions of the earthquakes themselves. Our future goal would be to compare correlations from various stations and obtain the locations of possible future seismic activities.

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