Studies of Seismo-Ionospheric Correlations using Anomalies in Phase of Very Low Frequency Signal

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Abstract

It is long thought that the ionosphere is perturbed by seismic activities and these perturbations can be detected by probing the ionosphere with Very Low Frequency signal. We have analyzed the VLF phase data of NWC-IERC baseline in the year for 2011 and calculated the VLF day length using the sunrise and sunset terminator time in the phase. In this paper we present the cross correlation between VLF day-length and magnitude seismic activities. It is found that VLF day-length changed significantly before two days prior to the earthquakes.

1 Introduction

The physical process behind earthquake is in general very complex. It involves the movement of the tectonic plates, the electric discharge, anomalous heating, emission of gases etc. from the earths crust. The crustal dynamics are also equally complicated. It has been reported several times 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 Very Low Frequency (VLF) signal. There are several publications regarding the seismo-ionosphere coupling by Bolt (1964), Gufeld et.al.,(1992) etc. More 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), Ray et al. (2013) etc. In this paper we present the anomalous shifting of the sunrise and sunset terminator time calculated from the phase of the VLF signal. We present the analysis of the data received at Ionosphere and Earthquake Research Centre (IERC), Sitapur. The data has been taken by SoftPAL VLF receiver. We compute the effective magnitude of earthquakes occurred in the India and its sub-continent region and compute the correlations between effective magnitude of the earthquake and the anomalous fluctuation in the sunrise and sunset terminator time.

In left panel of Figure 1 we present the location of the NWC transmitter (19.8 kHz) and the receiving location IERC ($22°30'$N, $87°47'$E) and the wave path between them. In the right panel of Figure 1 we present the diurnal variation of VLF amplitude and phase data of NWC signal observed from IERC. The top panel is for the amplitude and the bottom is for the phase. The sunrise and sunset terminator times are indicated by SRT and SST.

In Figure 2, we present the seasonal variation of the phase data for six months period (July to December, 2011). We have chosen the data for 21st of every month and the data are stacked with an amplitude shift 10 dB for better viewing. This has been done to have a knowledge of the variation of the phase terminators in a quiet solar condition. Thus any kind of shifting in the terminators (if any) would be due to the seismic events as the solar activities are minimum.

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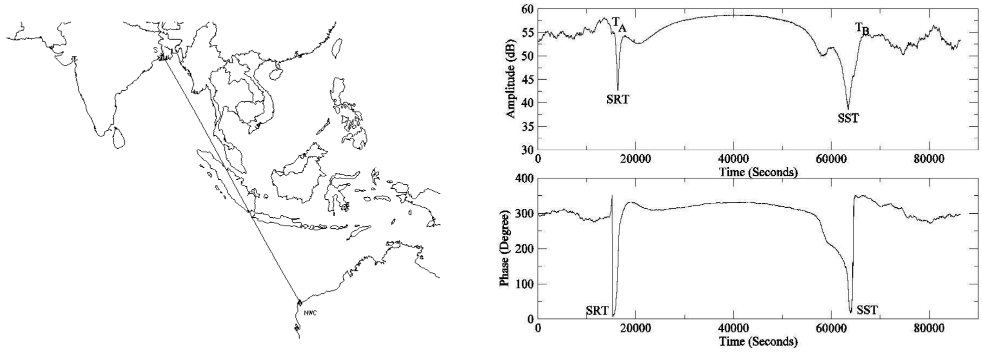

Figure 1: [Left] The position of the transmitter (NWC) and receiving location (IERC) and the wave path between them. [Right] The diurnal variation of VLF amplitude (top) and phase (bottom) transmitted from NWC.

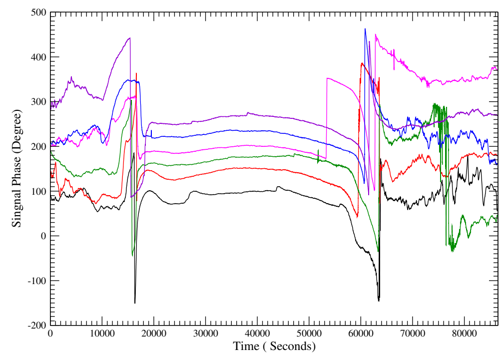

Figure 2: The seasonal variation of VLF phase data (see text for details).

2 Observations and Results

In the previous publications by ICSP (Sasmal et al., 2009), a quantity VLF day-length has been calculated by using the SRT and SST of the amplitude of the VLF data. The VLF day-length is the difference between the SST and SRT. In this paper we calculated the VLF day-length by using the SRT and SST for the phase data. So any unusual fluctuation from the mean value of VLF day-length an be treated as unusual fluctuation shift of the SRT and SST. We compute the effective magnitude of all the earthquakes for a single day by adding up the energies of all the earthquakes.

In Figure 3, we present the variation of the VLF phase day-length (open circles) as function of time for the entire year 2011. In some days the data are very noisy and there are so many fluctuations during the sunrise and sunset time. So we omit those days and take only clean signal. We calculate the mean (solid line) and the standard deviation σ for the seismically quiet days. This gives the basic idea of the variation of phase day-length during no seismic event. We put the $\pm 1\sigma$, $\pm 2\sigma$ and $\pm 3\sigma$ graphs (dashed, dotted and dotted-dashed) on it. Some of the days the value of day-length are more than 3-5σ level. We found (www.imd.gov.in, www.usgs.gov) that on those days there are strong earthquakes in the India and its sub-continent region. We associated those anomalous fluctuation with filled circles those are indication of earthquakes. The circles are kept at a constant distance just to indicate that during the anomalous fluctuation there are some earthquakes.

In Figure 4, we present the cross correlations between the anomalous fluctuations in the phase day-length with the effective magnitude of the earthquake. We compute the normalized correlation coefficients around

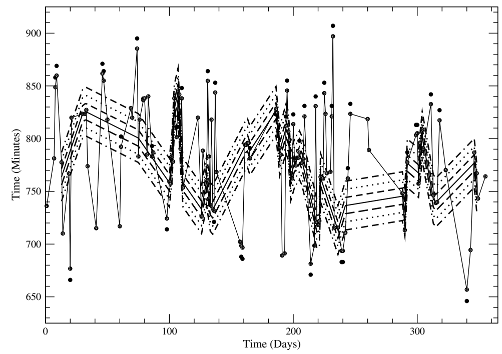

Figure 3: The variation of VLF phase day-length as a function of time for the year 2011 (see text for details).

±7 days of the earthquake. The zero in the histograms are the day of the earthquake. It is clear that the maximum fluctuation in the phase day-length is one two days prior to the earthquakes which is consistent with our previous results (see introduction).

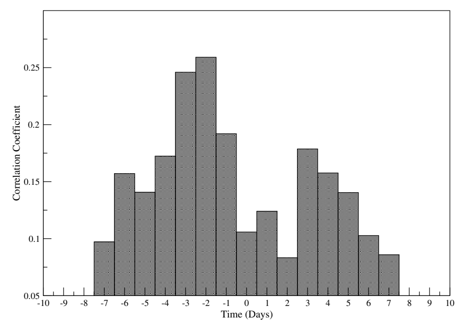

Figure 4: The cross correlations between fluctuations in the VLF day-length with effective magnitude of earthquake. The maximum anomaly occurs in the signal on two days prior to the earthquake.

3 Conclusions

The shifting of the sunrise and sunset terminators of the phase of the VLF data are well correlated with the seismic event. Tough the variation of the VLF phase day-length are not so regular like amplitude but the fluctuations and the anomaly during the seismic events are quite real. However long term statistical analysis using the phase data as well as the case wise study is needed for further understanding.

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