Unusual Shifts in Terminator Times of the VLF Signals before the Pakistan Earthquake (M=7.4), Occurred on 18th Jan., 2011.

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Abstract

On 18th Jan., 2011, at 20:23 UT, an earthquake of magnitude 7.4 occurred in Southwestern Pakistan (latitude $28°54'$ N, longitude $64°$ E). We present the results of the analysis of Very Low Frequency (VLF) radio signals, received at three receiving stations located in India. We analyze the VLF signal around this earthquake day for four different VLF propagation paths namely DHO-IERC(Sitapur), VTX-Pune, VTX-ICSP(Kolkata) and NWC-IERC. We observed significant shifts of the 'sunrise terminator time' (SRT) for DHO-IERC and VTX-Pune paths. We also observed the SRT-shift for VTX-Kolkata path, but here the shift is not so strong. We found no significant shifts of SRT for NWC-IERC propagation path. Higher deviation in the VTX-Pune path as compared to VTX-ICSP path could be due to the formers proximity to the epicentre. Similarly, DHO-IERC path is over the epicentre while that of NWC-IERC path is away from the epicenter. This could be the reason why the effect in DHO-IERC path is stronger than that in NWC-IERC path.

1 Introduction

It is postulated that the ionosphere could undergo changes well before earthquakes so that certain anomalies in the VLF signals may be used for short term earthquake prediction. In this regard, several papers have been published indicating seismo-ionospheric correlations (e.g., Bolt et al., 1964 etc.). In 1996, after the 'Kobe earthquake', Hayakawa et al. (1996, hereafter H96) introduced the 'Terminator time method' for earthquake prediction. They showed that both the sunrise and sunset terminators shifted towards the night-time few days before the earthquake. After that many papers have been published in support of 'Terminator time method' (Molchanov et al., 1998; Ray et al., 2010, etc.). One of the problems in the approaches given above is that while the precursors may have been observed, no inference could be drawn about the location of the epicentre, since only one receiving station was used. If multiple number of stations could be used, then there is a possibility to compare relative anomalies and perhaps some possible hints about the epicentre may be obtained. In the present paper, we use the 'Terminator time method' to analyze the same Pakisthan earthquake mentioned above. However, we consider the VLF signals for four different propagation paths to study if the shifts of the terminators closer to the epicentre are higher. In Fig. 1 we have shown the location of the epicentre of the earthquake and the four different VLF propagation paths for which we have analyzed the VLF signals. For the present analysis we mainly concentrate to the 'sunrise terminator time' (SRT), because the 'sunset terminator times' were not very prominent for all the paths.

2 Results

We analyze the amplitude variations of the VLF signals at the four propagation paths on days before, on and after 18th January, 2011 (UT) (hereafter E-day). At 20:23pm (UT), 18th of January, an earthquake of magnitude 7.4 occurred in the southwestern Pakistan. For convenience we shall present the data in Indian Standard Time or IST(=UT+5:30). This is because, since IST is ahead of UT by 5.5 hours and the time of sunrise at the receiving stations is also at around 5:30am, the diurnal variation of the data is roughly symmetric with respect to the local noon. In IST, the earthquake occurs on 19th January, 2011 at 1:53am and it will be marked as such in all the Figures.

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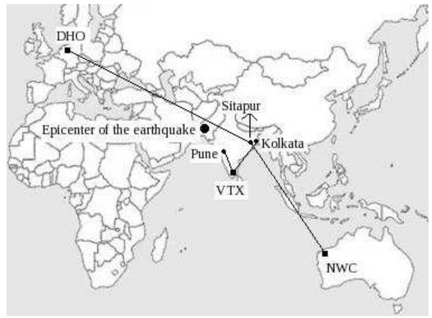

Figure 1: VLF propagation path and the epicentre of the earthquake

Let us first discuss the results for the DHO-IERC propagation path. The distance between the transmitting station (DHO) and the receiving station (IERC) is 7380 km. The Mid-point of this propagation path is situated 1865 km away from the epicenter of the earthquake. In left panel of Fig. 2 we plot the amplitude of the VLF signal as a function of time in minutes for a few days around the E-day. The sunrise terminators (SRT) of each day are marked by the 'arrow' symbol. We define the SRT by the first weak minimum which occurs after the weakening of the signal at dawn. We find that the SRT of the VLF signal of the data of 16th Jan, 2011 is shifted towards nighttime. This may be the precursor effect of the earthquake on the E-day. To elaborate this point, we have plotted the SRTs as a function of day number in the right panel of Fig. 2. In this Figure, the solid curve represents the average value of the terminator times while the dotted and dashed curves represent the 2σ and 3σ line, respectively. The vertical dashed line represents the earthquake day. The SRTs are marked by the circles connected by a solid line. We find that three days before the E-day, SRT crossed the 3σ line. We check that no solar flare or any other ionospheric disturbance event occur on that day. The shift is also towards night as was observed in several previoous occasions. This led us to believe that this terminator shift could be the precursor effect of the earthquake.

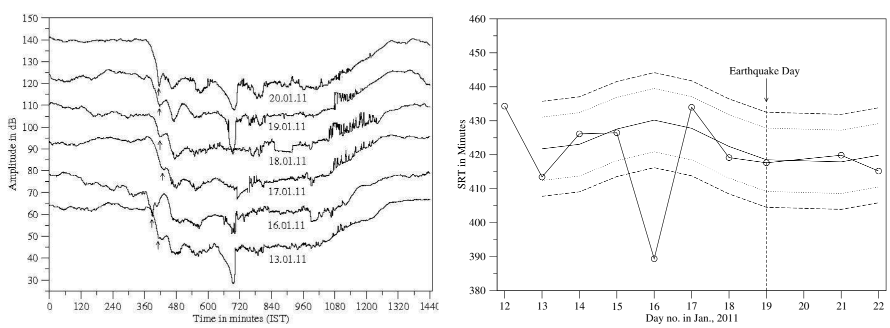

Figure 2: (a) The amplitude variation of the VLF signals for DHO-IERC propagation path are plotted around the E-day (left panel). (b) The SRTs of the VLF signals for DHO-IERC path are plotted as a function of day no around the E-day (right panel).

The distance of the VTX-Pune propagation path is 1203 km. The mid-point of this propagation path is situated 2107 km away from the epicenter of the earthquake. In left panel of Fig. 3, the amplitude of the signal is plotted as a function of time in minutes. In this case, the wave propagates from east to west and due to the attenuation the amplitude of the nighttime signal is very low. For this reason, the nature of the signal is quiet different. To be consistent with the earlier case, we define the SRT as the last minimum point in the morning after which the signal rises almost vertically. From left panel of Fig. 3 we see the significant shift of the SRT in the data of 18 Jan., 2011 (IST) which may be the precursor of the earthquake. In right panel of Fig. 3, we plot the SRT as a function of day no. The SRTs are indicated by the open circle, while the mean, 2σ and 3σ lines are represented by the solid, dotted and dashed curves, respectively. The vertical dashed curves represents the E-day. It is clear that the SRT one day before the earthquake crossed the 3σ line. The net shift of the SRT is about 100 minutes towards the night. Thus this anomalous shift may be the considered to be the precursor of the earthquake. Here also we check that no solar flare or any other event which may cause ionospheric disturbances occurred on that day.

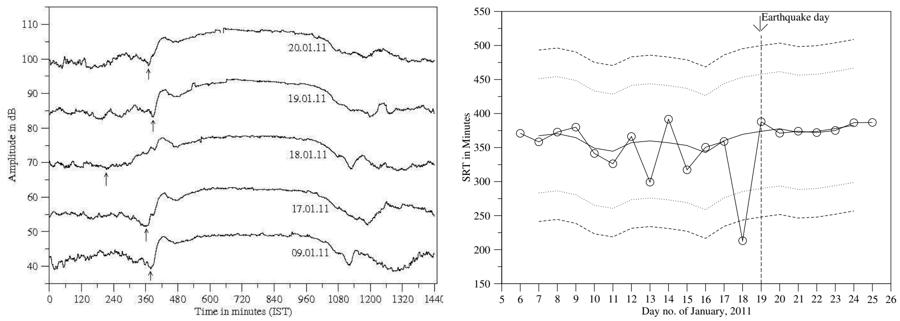

Figure 3: (a) The amplitude variation of the VLF signals for VTX-Pune propagation path are plotted around the E-day (left panel). (b) The SRTs of the VLF signals for VTX-Pune path are plotted as a function of day no around the E-day (right panel).

For VTX-Kolkata propagation path the effect is not so strong. The distance of this path is 1944 km and the mid-point of this path and is 2441 km away from the epicentre of the earthquake. This distance is comparatively longer than the previous two propagation paths. In left panel of Fig. 4, we plot the amplitude of the VLF signals of this propagation path as a function of time in minutes. From this plot, one can see a very small amount of shift (about 15 minutes) of the SRT (defined as the first weak minimum occur after the weakening of the signal at dawn) in the VLF signals four days before the earthquake. In the right panel of Fig. 4, these SRTs (marked by open circle connected by a solid line) are plotted as a function of day (IST) along with the mean, 2σ and 3σ lines, represented by solid, dotted and dashed curves, respectively. We find that the value of the SRT four days before the earthquake is just about 3σ level away from the expected mean value indicating a weak precursory effect. The reason of the absence of the strong precursor effect may be the long distance of the epicenter of the earthquake from the mid-point of this propagation path.

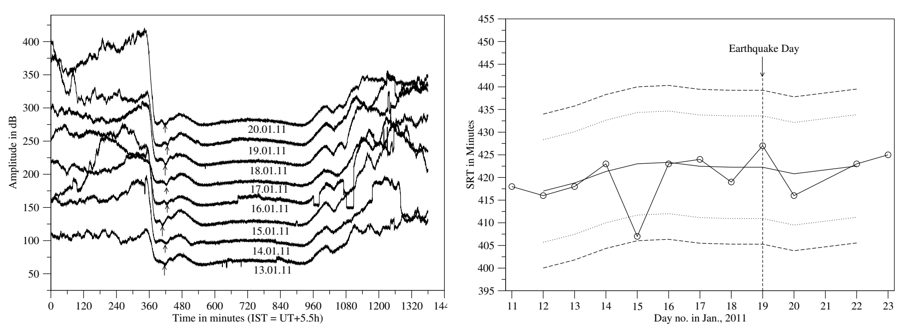

Figure 4: (a) The amplitude variation of the VLF signals for VTX-ICSP propagation path are plotted around the E-day (left panel). (b) The SRTs of the VLF signals for VTX-ICSP path are plotted as a function of day no around the E-day (right panel).

We have also analyzed the VLF signal for the NWC-IERC path. The distance between the NWC and IERC is 5698 km and the epicenter of the earthquake is situated 5049 km away from the mid point of this propagation path. We obtained the SRT from the VLF signal on each day and found no change of the value of SRT around the earthquake day. In the left panel of Fig. 5, we plot the amplitude of the VLF signals for a few days, as a function of time in minutes. It is clear that there is no change in the SRT around the E-day. To show this more clearly we plot the SRT as a function of day (IST) in the right panel of Fig. 5. We found that the SRT for each day is within the 2σ line, not significantly deviating. So the precursor effect is very weak in the data of NWC-IERC propagation path.

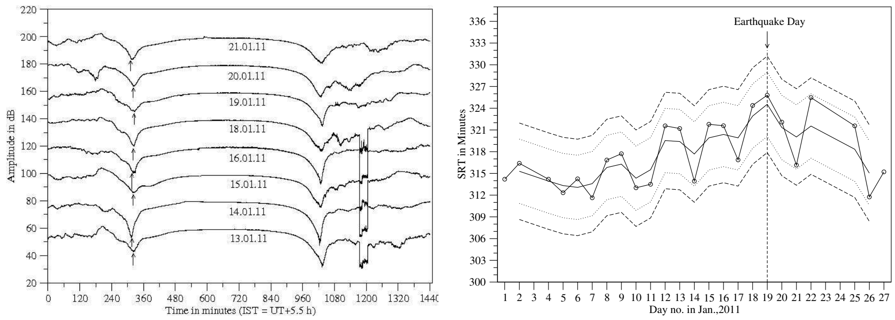

Figure 5: (a) The amplitude variation of the VLF signals for NWC-IERC propagation path are plotted around the E-day (left panel). (b) The SRTs of the VLF signals for NWC-IERC path are plotted as a function of day no around the E-day (right panel).

3 Conclusion

The search for the correlation between the seismic events and ionospheric signal anomaly is on for about half a century, and yet, a definite answer to this tantalizing problem is not in hand. The reason is that the problem is multi-parameteric and highly non-local. The effect is also non-linear. In these circumstances, the best goal would be analyze as many cases as possible and get a good amount of statistics of what we observe and what we do not observe. In previous analysis from our group, we presented the anomalies of terminator time shifts, formation/disappearance time of D-layer and the nighttime fluctuations from a given propagation path. However, in this paper, for the first time, we compared the effects of the same earthquake in four paths and found very exciting results. We find, in particular, that the anomalous terminator shifts are higher when the distance of the midpoint of the propagation path is lower. However, the relation is non-linear. The VTX-Pune path exhibited highest anomaly, even though the distance of the midpoint is more than that of DHO-IERC. Nevertheless, our study indicates that the effect is path dependent and with more observations one could look for a pattern which may lead to successful prediction of Earthquakes.

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4 References

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