Studies of Precursors of Earthquakes Using Anomalies in Very Low Frequency Signal

Sudipta Sasmal[1], ***Sandip K. Chakrabarti***[1,2], and ***Suman Ray***[1]

[1] Indian Centre for Space Physics, 43 Chalantika, Garia Station Road, Kolkata-700084, India (meet2ss25@gmail.com).

[2] S. N. Bose National Centre for Basic Sciences, J.D. Block, Sector-III, Salt Lake, Kolkata-700098, India (chakraba@bose.res.in).

Abstract

It is long conjectured that the ionosphere is affected by seismic activities and these effects can be detected in VLF signals. We present long term statistical studies for a quiet solar condition of three types of anomalies in the VLF signal amplitude and observed significant precursory effects in 1-5 days before major earthquakes. These are anomalies of (a) terminator shifts, (b) D-Layer preparation and disappearance times and (c) night time amplitude fluctuations. We compute correlations between earthquake magnitude and present feasible precursory effects in the signal before major earthquakes. We also present case by case studies for different earthquakes.

1 Introduction

Independent reports of observing ELF/VLF/LF signal anomalies several days prior to major earthquakes is well known for over two decades (e.g., Gokhberg et al., 1989; Hayakawa et al., 1996, 2003; Molchanov et al., 1998; Molchanov and Hayakawa, 1998; Clilverd et al., 1999; Hayakawa and Molchanov, 2000; Chakrabarti et al., 2005, 2010; Sasmal et al., 2009, 2010, 2014; Ray et al., 2011, 2012, 2013). Since a successful prediction of major seismic events would mean saving of hundreds or even thousands of lives any new approach in this direction should be tested out. Keeping in mind that India is an earthquake prone country, Indian Centre for Space Physics (ICSP) started monitoring VLF signals and several ways to quantify the signal anomalies have been found. Though there is no doubt that the anomalies are real which could lead to predictions of major disasters 15 days prior to an event, it has been so far impossible to predict the exact location of the epicenter or the magnitude of a seismic event. Fortunately, in some cases, it has been possible to show that when the signals are picked up from more than one station during an earthquake, anomalies in some directions are more than than those in other directions. From last couple of years ICSP developed an wing name Ionospheric & Earthquake Research Centre (IERC) at Sitapur, Midnapore(W) which is around 100 km away from ICSP solely for the earthquake research and presently all the analysis are based on the data received at IERC.

2 Observations and Results

In the left panel of Figure 1 we present the all the possible baselines for our study. The ICSP (22°34′N, 88°24′E) and IERC (22°30′N, 87°47 ′E) are denoted by K and S respectively. The four transmitter are denoted by their name as VTX (18.2 kHz), NWC (19.8 kHz), JJI (22.2kHz) and DHO (23.4kHz). There are three types of signal anomalies in VLF that were noticed by the ICSP group. These are mainly the anomalies in VLF day-length, the anomalies in the D-Layer Preparation Time and D-Layer Disappearance Time and finally the anomalies in the fluctuation of signal amplitudes at night. In the right panel of Figure 1, we present locations where the major earthquakes occurred around the VTX-ICSP propagation path. Circles are drawn with incremental radius of 500 km centered around the midpoint of the VTX-ICSP line, where, according to the wave-hop theory, the first reflection takes place in the ionosphere. The size of the circle is related to the strength of the earthquake as marked.

A VLF day may be defined as the time interval between the sunrise and sunset terminators. It has been reported that this day length gets bigger due to shifts in terminator time prior to an earthquake. One of the

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

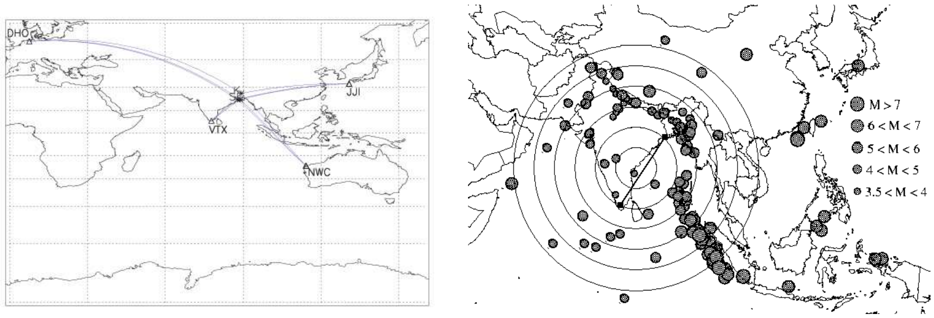

Figure 1: [Left] The position of the transmitter and receiving locations and the wave path between them. [Right] Epicenters of the earthquakes (shadowed circles) which occurred in sixteen months (Chakrabarti et al., 2010).

classic examples of terminator shifts in a single short range seismic event was reported by Hayakawa et al. (1996) where they showed that the terminators shifted towards night side several days before the earthquake. We have done the systematic scrutiny of four years of data (2005-2008) for VTX-ICSP baseline and one year (2011) data for NWC-IERC baseline and to calculate VLF day-length and DLPT/DLDT. We compute a quantity named effective magnitude of the earthquake by adding up the total energy of all the earthquakes for a single day.

In the left panel of Figure 2, we plot the VLF day-length as a function of day by filled circles and also plot the $\pm 1\sigma$, $\pm 2\sigma$ and $\pm 3\sigma$ away from the mean (solid, dotted and dash-dotted) where σ i the standard deviation calculated during seismically quiet condition. Some seismic events are generally found during the high value of VLF-day-length and we associated them by large circles.

We then obtained the correlation with the seismic activity by finding the correlation coefficients between the effective magnitude of earthquakes on a given day and the deviation in seconds. The normalized product is shown in middle panel of Figure 2. The peak is observed two days before the seismic event. For the IERC-NWC baseline we observed similar correlation but we observed that this baseline is less sensitive (right panel of Figure 2.)

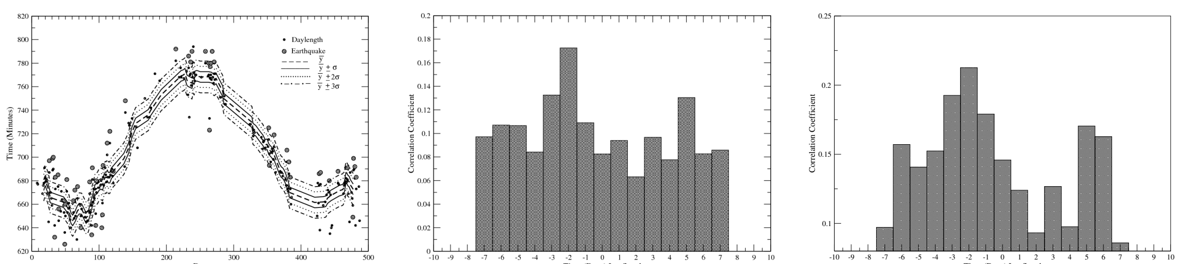

Figure 2: [Left] The variation of VLF day-length with time. [Middle] The cross-correlations between VLF day-length and effective magnitude of earthquake for VTX-ICSP baseline. [Right] Similar cross-correlations for NWC-IERC baseline. (see, text for details) (Sasmal et al., 2009, Chakrabarti et al., 2010, Sasmal et al., 2014)

.

In the second method we use DLPT and DLDT which are defined as time interval between the time when the final descent of the nighttime signal begins and the sunrise terminator and the time interval between the sunset terminator and the time at which the signal reaches the nighttime level respectively. We compute the DLPT and DLDT and using the same method as mentioned for VLF day-length we plot in first and second panel of Figure 3, the cross-correlations between the (a) DLPT or (b) DLDT and the effective magnitudes of the earthquakes which takes place on 0 day. For both DLPT and DLDT the peak is one day before the earthquake but the correlation is better for DLPT.

In the third method we compute the fluctuation in the night time signal amplitude. We generally compute the standard deviations of the fluctuations in the signal and compute similar cross correlations with fluctuation is standard deviation with effective magnitude of earthquake. We plot the cross-correlations in the third panel of Figure 3 and observed the fluctua quake.

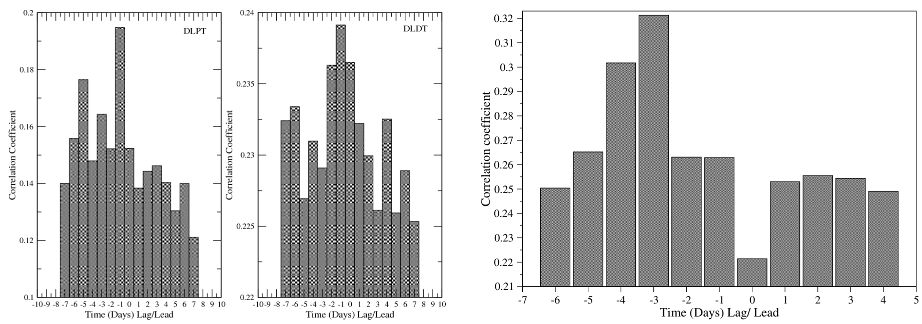

Figure 3: [Left] The cross-correlations between DLPT and effective magnitude of earthquake for VTX-ICSP baseline. [Middle] Similar cross-correlation for DLDT. [Right] The cross-correlations between night time amplitude fluctuation with effective magnitude of earthquake (see text for details) (Chakrabarti et al., 2010, Ray et al., 2011).

Apart from Statistical analysis we have also observed significant changes in the above three quantities for different earthquakes using for different baselines. In this paper we present effects on VLF signal for two earthquakes. One is for the historical Japan earthquake on 11th March, 2011 of magnitude 9.0 and another is the Pakistan earthquake on 18th January, 2011 of magnitude 7.4. We made simultaneous observations for different transmitting frequencies at IERC. For japan earthquake we observed strong shift in the sunrise terminator time (SRT) towards night and increase of DLDT on the day of the earthquake for IERC-JJI baseline. Similarly for Pakistan earthquake we observed anomalous nighttime fluctuation in VTX-ICSP baseline and

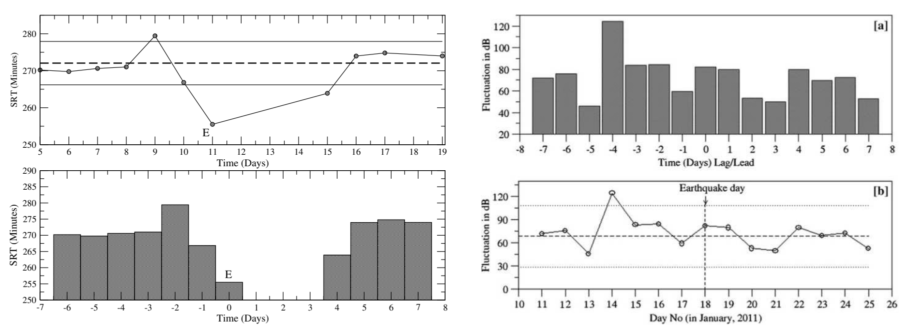

Figure 4: [Left] The variation of sunrise terminator time for IERC-JJI baseline during the earthquake on 11th March 2011 at Japan. [Right] The variation of nighttime fluctuation for ICSP-VTX during the earthquake on 18th January 2011 at Pakistan. (see text for details) (Sasmal et al., 2014, Ray et al., 2012).

In left panel of Figure 4, we present the variation of sunrise terminator time for IERC-JJI baseline for the 11th March earthquake, The zero is the earthquake day. It is clear that the value of SRT is minimum on the day of the earthquake. In the right panel we present the variation of night time fluctuation for ICSP-VTX baseline for frequency 19.2 kHz. It is clear that the signal fluctuation is maximum on four days before the earthquake.

We have a brief understanding of the location of the epicenter by observing that the signal affects maximum for the seismic events for which the propagation path is over the epicenter. For Japan earthquake only the JJI signal shows effects. Similarly for Pakistan earthquake (not presented in this paper) we observed significant changes in the DHO signal.

3 Conclusions

The VLF data analysis in ICSP and IERC suggested that there could be at least three different types of VLF signal anomalies prior to the seismic events. While the precise physical processes behind these anomalies are not yet known, but the effects seem to be convincing for both statistical and case wise studies. More works are needed to understand the cause of their origin.

S. Sasmal and S. Ray acknowledges MoES and ISRO RESPOND project for their financial support to carry out this work.

4 References

1. S. K. Chakrabarti, M. Saha, R. Khan, S. Mandal, K. Acharyya, R. Saha, "Unusual Sunset Terminator behaviour of VLF signals at 17kHz during the Earthquake episode of Dec., 2004" *Indian J. Radio and Space Phys., Volume 34*, 2005, pp. 314-317.
2. S. Chakrabarti, S. Sasmal, M. Saha, R. Khan, D. Bhowmik and S. K. Chakrabarti,"Unusual Behavior of D-region Ionization time at 18.2 kHz during Seismically Active Days"*IJP, Volume 81, (5 & 6*, 2007, pp. 531-538.
3. S. K. Chakrabarti, S. Sasmal, S. Chakrabarti, "Ionospheric Anomaly due to Seismic Activities -II: Possible Evidence from D-Layer Preparation and Disappearance times"*Nat. Hazards Earth Syst. Sci., Volume 10*, 2010, 1751-1757.
4. M. A. Clilverd, C. J. Rodger, N. R. Thomson, "Investigating seismoionospheric effects on a long subionospheric path", J. Geophys. Res., 104(A12), 28171-28179, 1999.
5. I. L. Gufeld, A. A. Rozhnoi, S. N. Tyumensev, S. V. Sherstuk and V. s. Yampolsky, "Radiowave disturbances in period to Rudber and Rachinsk earthquakes",*Phys. Solid Earth, Volume 28*, 1992, 267-270.
6. O. A. Molchanov, M. Hayakawa, T. Ondoh and E. Kawai, "Precursory effects in the subionospheric VLF signals for the Kobe earthquake", *.Phys. Earth Planet. Inter., Volume 105*, 1998, pp. 239-248.
7. M. Hayakawa, O. A. Molchanov, T. Ondoh and E. Kawai, "The precursory signature effect of the Kobe earthquake on VLF subionospheric signals.", *J. Comm. Res. Lab., Volume 43*, Tokyo, 1996, pp. 169-180.
8. S. Ray, S. K. Chakrabarti, S. K. Mondal and S. Sasmal, "Correlation between night time VLF amplitude fluctuations and effective magnitudes of earthquakes in Indian sub-continent", *Nat. Haz. Earth Syst. Sci.*, 11, 2011, pp. 26992707.
9. S. Ray, S. K. Chakrabarti and S. Sasmal, "Precursory effects in the nighttime VLF signal amplitude for the 18th January, 2011 Pakistan earthquake," *Ind. J. Phys.*, 86, 2012, pp. 8590.
10. S. Ray and S. K. Chakrabarti, "A study of the behavior of the terminator time shifts using multiple VLF propagation path during Pakistan earthquake (M=7.2) of 18 January 2011", *Nat. Hazards Earth Syst. Sci.,, 13, 2013, pp. 1501-1506.*
*11. S. Sasmal and S. K. Chakrabarti, Nat. Hazards Earth Syst. Sci., "Ionospheric Anomaly due to Seismic Activities -I: Calibration of the VLF signal of VTX 18.2KHz Station From Kolkata" ,*Nat. Hazards Earth Syst. Sci.*, 9*, 2009, pp. 1403-1408.
13. S. Sasmal, S. K. Chakrabarti and S. Ray, "Unusual behavior of VLF signal during the Earthquake at Honshu/Japan on 11 March, 2011", *Indian J. Phy.*, Communicated, 2014.
14. S. Sasmal, S. K. Mondal, S. K. Chakrabarti and S. Ray, "Ionospheric Anomaly due to Seismic Activities -IV: Calibration of Signal for NWC-IERC Baseline and Unusual Signal Behavior During Earthquakes", *J. Earth Sys. Sci*, Communicated, 2014.
15. S. Sasmal, S. K. Chakrabarti, S. Chakrabarti, "Propagation Effects of Very Low Frequency Radio Waves" *AIP*, 1286, July, 2010, pp. 270-290.