SUB-IONOSPHERIC VLF PROPAGATION ANOMALIES ASSOCIATED WITH THE EARTHQUAKE ON 25 MARCH 2013

Ashutosh K. Singh[1], Uma Pandey[2,3] O.P. Singh[1], Birbal Singh[1,2]

[1]Dept. of Physics, Faculty of Basic Science & Humanities;
[2]Dept of Electronics and Communication Engineering;
Raja Balwant Singh, F.E.T. Campus, Bichpuri, Agra-221005, India.

[3]Department of Physics, Bansthali University, Rajasthan, India
Email: ashutosh88singh@yahoo.com

Abstract

Ionospheric perturbations in possible association with the earthquake occurred on 25 March 2013 in India-Oceania region (magnitudes ≈ 6.0) is investigated on the basis of subionospheric propagation data from the NWC transmitter(19.8 kHz) on the North West Cape, Australia to a VLF receiving station at Agra, India. The local nighttime VLF amplitude data are extensively investigated during the period, ±15 days of the earthquake, in which the trend (nighttime average amplitude), dispersion and nighttime fluctuation are analyzed. It is found that a clear precursory ionosphere perturbation is detected, about 12 days before the main shock, which is characterised by the simultaneous decrease in the trend and increase in nighttime fluctuation. Possible seismo-ionospheric mechanisms to demonstrate the physics that how ionosphere starts to feel these earthquakes are discussed.

1. Introduction

Seismo-ionospheric effects possibly associated with the earthquakes (EQs) during the last two decades have been studied extensively [1,2,3]. Now it is widely accepted that the ionosphere gets perturbed prior to an EQ both in its lower part (D/E region) [2] and also in its upper region (F region) [4]. We have been working on collecting a lot of events on ionospheric perturbations in possible association with EQs using GPS-TEC as well as ULF anomaly using magnetometer signal [5] and also in subionospheric VLF/LF transmitter signals in recent years.

Hayakawa et al. [6] obtained a very convincing evidence of ionospheric perturbations for the Kobe EQ by means of shifts in terminator times using subionospheric VLF/LF propagation data. Since then there have been accumulated a substantial number of VLF/LF subionospheric evidences on seismo-ionospheric perturbations (see the recent reviews by Hayakawa et al [2], Hayakawa and Hobara [7]. These VLF/LF signals have been extensively utilized to investigate the perturbations in the lower ionosphere (i.e., D/E layers) due to seismic activities and there are two different ways in which investigations have been performed; (i) case studies (detailed studies for any particular huge EQ), and (ii) statistical studies on the correlation between the ionospheric perturbations and EQs. Individual earthquake having huge impact on society have been studied and discussed by many observers, Sumatra EQ [8-9,5], the 2008 Miyagi-oki EQ [10],. These case studies have enabled us to investigate extensively the spatial and temporal characteristics of seismo-ionospheric perturbations. Also very few statistical studies have been reported on the definitely significant correlation between VLF/LF propagation anomalies and EQs with magnitude greater than 6.0 [11]. A majority of above papers are based on the data over relatively short distance (distance is from 1Mm to a few Mm) propagation.

The purpose of this paper is to report on the detailed propagation anomalies in possible association with the reported EQ using a medium-distance propagation path (~6Mm path from North West Cape, Australia to Agra, India, (as shown in **Fig**. 1) occurring near the transmitter receiver great circle path (TRGCP). The spatial and temporal properties of seismo-ionospheric perturbations observed are discussed extensively in the context of previous case studies by different workers. Finally, some comments on the generation mechanism of seismo-ionospheric perturbations are given

2. VLF data analysis method

Namely two methods, terminator time (TT) method and nighttime fluctuation (NF) method are being used to investigate the seismo-ionospheric effects of the earthquakes using sub-ionospheric VLF propagation. TT method is more effective for VLF signals propagating in east-west meridian plane and short propagation path (Maekawa and Hayakawa, 2006).

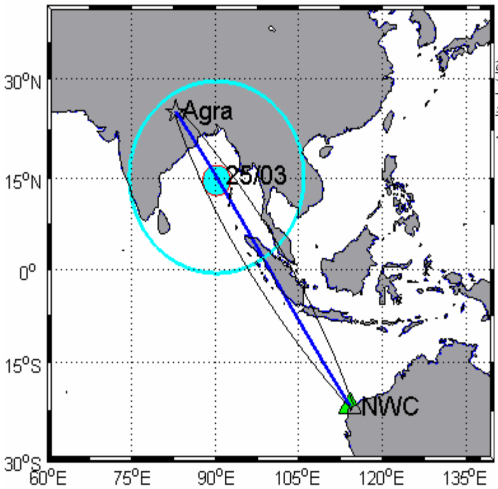

Figure 1: The location of NWC transmitter, receiver at Agra and great circle path to Agra. Earthquakes (EQs) are also plotted, with small filled circles where colour. Wave sensitive area (defined by fifth Fresnel zone) for NWC-Agra propagation path is also plotted.

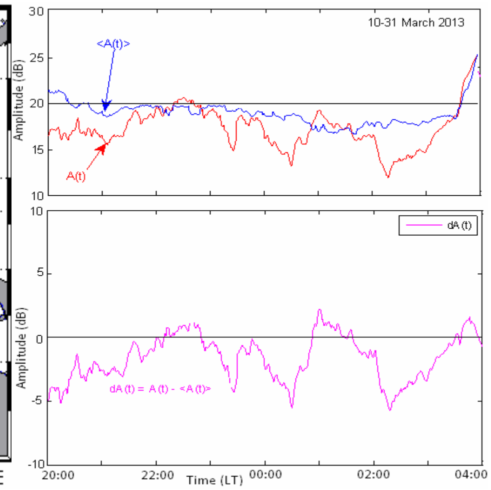

Figure 2: Explanation of analysis of VLF amplitude data. Top panel indicates the diurnal variation (in red) of signal intensity on a particular day (A(t)), and the variation (in blue) averaged over ± 15 days of the day(<A(t)>). The bottom panel shows the difference dA(t)=A(t)-<A(t)> (termed as residue).

Here we have used nighttime fluctuation method (Shvets et al., 2004; Hayakawa et al., 2010) to investigate the seismo-ionospheric effect on the sub-ionospheric VLF signals and hence the lower ionosphere. This method is more effective to study the effect of EQ over long propagation paths (>1000 km). We use the data during local nighttime (20:00-04:00 LT) at our receiving station when entire VLF path is in dark. We will use the two physical quantities for our analysis: nighttime average amplitude (trend), and nighttime fluctuation (NF) as described by Shvets et al. (2004). First, we estimate the value of dA(t)=A(t)−<A(t)> as shown in the upper panel of **Fig**. 2, where A(t) is the nighttime amplitude at a time t on a particular day (red curve) and <A(t)> is the amplitude at the same time averaged over ±15 days (blue curve). By using this residue dA(t) (lower panel of **Fig**. 2), we define the following two quantities.

1. Nighttime average amplitude (trend): Trend = [$\int_N dA(t)dt$]/[Nighttime period]
2. Nighttime fluctuation (NF): NF = $\int_N dA(t)^2 dt$ (only $dA(t) \leq 0$)

where N means the nighttime period (14:30h to 22:30 h UT), which gives one datum for each day. We have chosen the earthquakes occurring near the Agra-to-NWC transmitter receiver great circle path (TRGCP) during 2013. Total 3 earthquakes were found in this region with magnitude ≥6.0. Only the EQs occurred on 25 March 2013 have complete data set for analysis.

3. Earthquake Targeted

As mentioned above we have taken the earthquake occurred 25 March 2013 (magnitude ≈ 6.0 and depth = 20 km) to see the seismo-ionospheric effect on VLF signal and hence the ionosphere. **Fig**. 1 shows the epicenters of the earthquakes. The circle indicates the earthquake preparation zone. The fifth Fresnel zone (wave sensitive area) for Agra-NWC wave propagation path is also shown in Figure 1.

Fig. 2 **(**upper panel) shows the variation of average nighttime amplitude (blue) and on the day of earthquake (red), lower panel shows the residue (dA(t)). This residue is used to find trend and nighttime fluctuation. The nighttime average amplitude (or trend) and the nighttime fluctuation described in above section are evaluated for the reported earthquakes. These two physical quantities are dealt in **Fig.** 3, which shows the final results on the VLF/LF propagation anomalies during the observation period (~± 15 days).

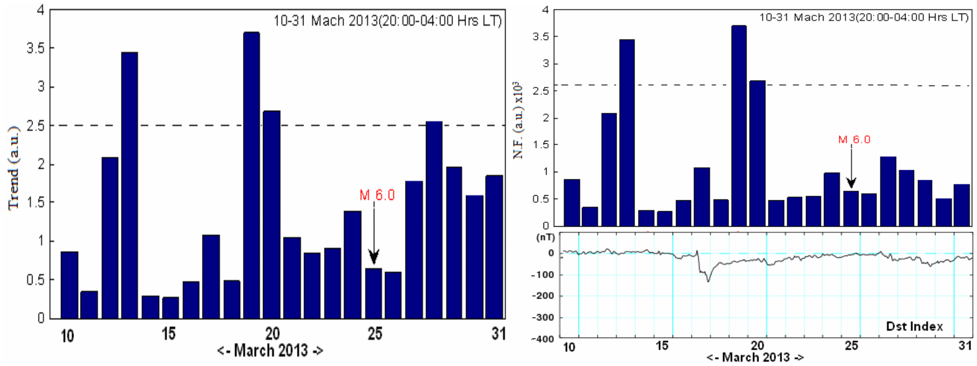

Figure 3: Temporal variation of VLF propagation anomalies (left panel: nighttime average amplitude (trend)); right panel (top): nighttime fluctuation (N.F); right panel (bottom): variation of Dst index and Kp index) before the EQ occurred on 25 March 2013. The horizontal dotted line in the figure indicates the 2σ criteria to define anomalous day.

In **Fig.** 3 the left panel refers to the average amplitude (or trend) at night (in dB). A horizontal light line indicates the mean (m) + 2σ (standard deviation) (both over the whole analysis period). Bar-diagram in right panel (top) of **Fig**. 3 illustrates the temporal evolution of nighttime fluctuation $[(dA(t))^2]$ during 10-31 March, 2013 and the right panel (bottom) shows corresponding Dst index. Again, the dotted horizontal line indicates the (m + 2σ) criteria. The EQ information is given at the top of the figure. It can be seen from the relative location of this big EQ with respect to the propagation path, we suppose that large anomalies are likely to appear in VLF data. The epicenter of this EQ is completely within the 5th Fresnel zone (as shown in **Fig**. 1) of the path from NWC to Agra, and also it is very close to the Agra-NWC TRGCP path. The wave sensitive area is defined by the fifth Fresnel zone, and we expect a propagation anomaly when the EQ epicenter lies within the sensitive area. As was shown by the recent statistical analysis by Maekawa et al. (2006), that the subionospheric VLF/LF signal exhibits an amplitude decrease (~3 dB for EQs with magnitude greater than 6.0) and enhanced nighttime fluctuation. For the case Agra-NWC, **Fig**. 3a indicates a very clear amplitude decrease (modulus of Trend is plotted) around this EQ (a few day before and a few days after the EQ) exceeding the value of (m + 2σ). Also the nighttime fluctuation is found to exceed the 2σ criterion a few days before the EQ. The absolute value of amplitude depletion reached -4 to -5 dB below the monthly average value. We need to comment on the anomaly 5-6 days before the EQ, which is found to be very pronounced. We have examined some possible effects, including the geomagnetic activity (Kp, Ap index), typhoon etc, and found that there occur a storm of -132 nT on 17 March 2013 (Sum Kp was 42) as shown in right panel (bottom) of **Fig**. 3. The perturbation observed on 19 and 20 March(5-6 days before the EQ) may be due to combined effect of the earthquake and storm, but the perturbation observed on 13 March is likely due to the earthquake occurred on 25 March.

The main cause of the propagation anomalies in the VLF signals is well explained by Pulinet et. al.[12] in terms of upward propagation of seismogenic electric field generated within the earthquake preparation zone few days before the main shock. The concept of earthquake preparation zone was introduced by Dobrovolsky et. al [13]. The size of earthquake preparation zone depends on the magnitude of earthquake. When this seismo-electric field penetrates into the ionosphere it causes the drifting of ions which results in the perturbations of electron density [14]. Parrot et al [15] explained that the nighttime field penetration is larger than the day time penetration. Therefore such ionospheric anomalies are better detected during the nighttime when ionospheric conditions are quiet. In some cases anomalies observed during day are also much better for earthquake prediction. In order to further elaborate the coupling mechanism, observations of other phenomena related to the EQ are needed.

4. Conclusion

Considering the recent earthquakes occurred in the vicinity of Agra-NWC TRGCP, we have studied the sub-ionospheric VLF propagation anomalies associated with 25 March 2013 earthquake. The most important conclusion from this study is that the lower ionosphere gets disturbed just around the earthquake having larger magnitude and larger depth. The reported earthquake has exhibited extremely clear propagation anomalies just around the EQ (both as an enhancement in the nighttime fluctuation and a decrease in average nighttime amplitude. Both of these two physical quantities are found to exceed the corresponding ($m + 2\sigma$) levels, a condition being sufficient for the events to be anomalous. The EQ magnitude is big enough ($M = 6.0$) and also the EQ epicentre is located within the fifth Fresnel zone of the Agra-NWC path for the reported EQ and close to the receiving station(lies within EQ preparation zone). Therefore these precursors appear to be reasonable. In order to elucidate the coupling mechanism, further studies related to the EQ are being carried out.

Acknowledgement

The authors are thankful to Ministry of Earth Sciences (MoES), Govt. of India New Delhi for providing research project under National Programme of Earthquake Precursors (NPEP) to carry out routine observation and analysis of the earthquake data.

References

1. Hayakawa, M. (Ed.), 1999. Terra Sci. Pub. Co., Tokyo, p. 996p..
2. Hayakawa, M., 2009: Transworld Research Network, Trivandrum India, 137-185
3. Molchanov, O.A., Hayakawa, M., 2008. TERRAPUB, Tokyo. 189.
4. Liu, J.Y., Chen, Y.I., Chuo, Y.J., Chen, C.S., 2006. J. Geophys. Res. 111, A05304. doi:10.1029/ 2005JA011333.
5. Chauhan, V. et al., 2012, Ind. J. Radio & Space Phys.,41, 543-556.
6. Hayakawa, M., Molchanov, O.A., Ondoh, T., Kawai, E., 1996, J. Commun. Res. Lab., Tokyo 43, 169–180.
7. Hayakawa, M. and Y. Hobara,, 2010, Geomatics, Nat. Hazards Risk, 1, 115-155, doi: 10.1080/19475705.2010.486933
8. Horie, T., Maekawa, S., Yamauchi, T., Hayakawa, M., 2007. Int. J. Remote Sens. 28, 3133–3139.
9. Horie, T., Yamauchi, T., Yoshida, M., Hayakawa, M., 2007. J. Atmos. Sol.-Terr. Phys. 69, 1021–1028.
10. Muto, F., Y. Kasahara, Y. Hobara, M. Hayakawa, A. Rozhnoi, M. Solovieva, and O. A. Molchanov, 2009, Nat. Hazards Earth Syst. Sci., 9, 1111-1118, doi: 10.5194/nhess-9-1111-2009
11. Kasahara, Y., F. Muto, T. Horie, M. Yoshida, M. Hayakawa, K. Ohta, A. Rozhnoi, M. Solovieva, and O. A. Molchanov, 2008, Nat. Hazards Earth Syst. Sci., 8, 653-656, doi: 10.5194/nhess-8-653-2008.
12. Pulinets, S. A. and K. Boyarchuk, 2004, Ionospheric Precursors of Earthquakes, Springer, Berlin, 215 pp.
13. Dobrovolsky, I. P., S. I. Zubkov, and V. I. Miachkin, 1979, Pure Appl. Geophys., 117, 1025-1044, doi: 10.1007/BF00876083
14. Kim V. P. and . Khegai, V. V, 1997, J. Earthq. Predict. Res. 6, 275-281.
15. Parrot, M., et al., 1993 Phys. Earth Planet. Inter. 77, 65.