Precursory Analysis of VLF Electromagnetic Signals as Terminator Time Shift during the Large (M≥6) Earthquake in Greece Region

[1*]Dr. Rahul Shrivastava and [2]Dr. Shailesh Raghuwanshi

[1]Department of Electronics, Barkatullah University, Bhopal, M.P., India,
[2]Department of Physics, Bhabha University, Bhopal, M.P., India.

Abstract: Enormous terminator time shift has been recorded in Very Low Frequency (VLF) electromagnetic signal during the large ($\boldsymbol{M \geq 6}$) Earthquake in Greece region. In this work VLF signal transmitted from famous Bafa (TBB) transmitter located in Turkey ($\boldsymbol{37°24' N}$ & $\boldsymbol{27°19' E}$) and recorded continuously at SID Monitoring receiving station ($\boldsymbol{46° N}$ & $\boldsymbol{2° E}$) have been analyze during the year 2013 for finding the short term Earthquake precursors. VLF electromagnetic signals are contaminated by various types of noises during the seismic activities. In the present work we reported the anomalous shift in terminator time of VLF signals few days prior to the Pirgos, Greece Earthquake ($\boldsymbol{M = 6.2}$) in the absence of any geomagnetic activity. These variations in VLF signals prior to seismic activity produced by an electromagnetic instability during the Earthquake preparation process in the Earth`s atmosphere up to the ionosphere triggered by charged aerosols or electromagnetic waves.

Index Terms **– Earthquake Precursors, Seismo-electromagnetic VLF Signals, Terminator Time Shift, Ionospheric Perturbations.**

I. INTRODUCTION

As far as the Earthquake prediction is concerned till no reliable precursor has been found and it has primary importance for human beings in order to alleviate the disasters from these seismic activities. From last few decades researchers have been investigated the data on the basis of observations done by satellites and ground based techniques and reported various electromagnetic phenomenon associated with seismic activities (Yamauchi et al., 2007; Hayakawa et al., 2010; De et al., 2012; Kumar et al., 2013; Hazra et al., 2014). The variations in electromagnetic waves ranges from Extremely Low Frequency (ELF) to Very Low Frequency (VLF) are well known tool for the investigation of Earthquake precursors (Molchanov and Hayakawa, 1998; Pulinets, 1998; Asada et al., 2001; Pulinets et al., 2003; Liu et al., 2004; Mullayarov et al., 2014). Firstly Gokhberg et al. (1989) reported an anomalous precursory behavior of Earthquakes upon sub-ionospheric VLF propagation and suggested that, it can be a possible method of Earthquake prediction. Molchanov et al. (1998) reported the sub ionospheric VLF perturbations in signal amplitude and terminator time prior to Kobe Earthquake. Similar disturbances also reported by Hayakawa (2007) and Horie et al. (2007) during the Sumatra Earthquake (26 December 2004, $M = 9.0$). Maurya et al. (2013) also reported the similar sub ionospheric VLF perturbations prior to Wenchuan Earthquake (12 May 2008, $M = 7.9$).

At the time of occurrence of any geomagnetic activity or solar event or any other meteorological activity, the electron density of the lower ionosphere does not affect (De et al., 2010). In the early stage of Earthquake preparation process electromagnetic radiations and aerosol particles emanations would cause ionospheric effects in D-region that modulate the electric charge distribution in the lower ionosphere. These seismic disturbances in the ionosphere are taken as the signatures of lithosphere-atmosphere-ionosphere coupling phenomenon which influence the conductivity, electron density fluctuations, changes in temperature and ionic composition of the lower atmosphere (Boskova et al., 1994). These Electromagnetic anomalies has been reported by various researchers (Yoshino, 1991; Karakelian et al., 2000; Kapiris et al., 2002; Eftaxias et al., 2003; Moldovan et al., 2009). They have analyzed wide range of frequencies prior to destructive Earthquakes in Greece region.

The prime objective of this study is to analyze the VLF signals during major Earthquake in Greece region. Here, we have analyzed the VLF signals during the Pirgos, Greece Earthquake ($M = 6.2$) occurred on June 15, 2013 at 16:11:02 (UTC). The geographical location of the main shock is 34.400 °N & 25.020 °E and the focal length of this event is about 10.0 km. These details have been taken from USGS website (http://www.usgs.gov). To minimize the effects of geomagnetic conditions on the analysis, we have checked Disturbance Storm Time (Dst) Index (Yao et. al., 2012; Le et. al., 2013) data during the period of Earthquake. The resulted precursor of this Earthquake has been found as huge time shift in morning terminator and evening terminator in VLF electromagnetic radio wave ranges.

II. DATA

To investigate the precursors of Earthquake a time window of 26 days (i.e. 20 days before and 05 days after the main shock) has been chosen. It is due to the fact that transient electromagnetic signals recorded on the ground occur during this time lapse (De et al., 2011). So during the Pirgos, Greece Earthquake which was occurred on June 15, 2013, the VLF amplitude data has been analyzed from May 26, 2013 to June 20, 2013. These datasets have been taken from Sudden Ionospheric Disturbances (SID) Monitoring Station, available online at website (http://sidstation.loudet.org/data-en.xhtml). These VLF signals are transmitted from famous Bafa (TBB) transmitter located at Turkey (37° N & 27° E) and recorded at SID Monitoring Receiver Station located at France (46° N & 2° E). The geomagnetic conditions during this time lapse have been observed with Disturbance Storm Time (Dst) Index and taken from OMNI Web server available online at website (http://omniweb.gsfc.nasa.gov).

III. METHODOLOGY

Firstly we have checked the diurnal behavior of VLF amplitude signal in 26 days along with the Dst level for the geomagnetic condition during this time lapse. Later than the morning terminator time (T_m) shift and Evening Terminator Time (T_e) shift has been calculated individually with statistical filtration of $\mu \pm 2\sigma$, where μ is the mean and σ is the standard deviation.

IV. RESULTS AND DISCUSSION

Various features from the simultaneous records of VLF electromagnetic signal at SID monitoring station have been recorded during the Pirgos, Greece Earthquake. In the month of June, 2013, some days prior to the main shock remarkable terminator time shift have been noticed on June 9, June 10 and June 11, 2013. The diurnal behavior of VLF amplitude signal during the seismic event is shown in Fig. 1 and Fig. 2.

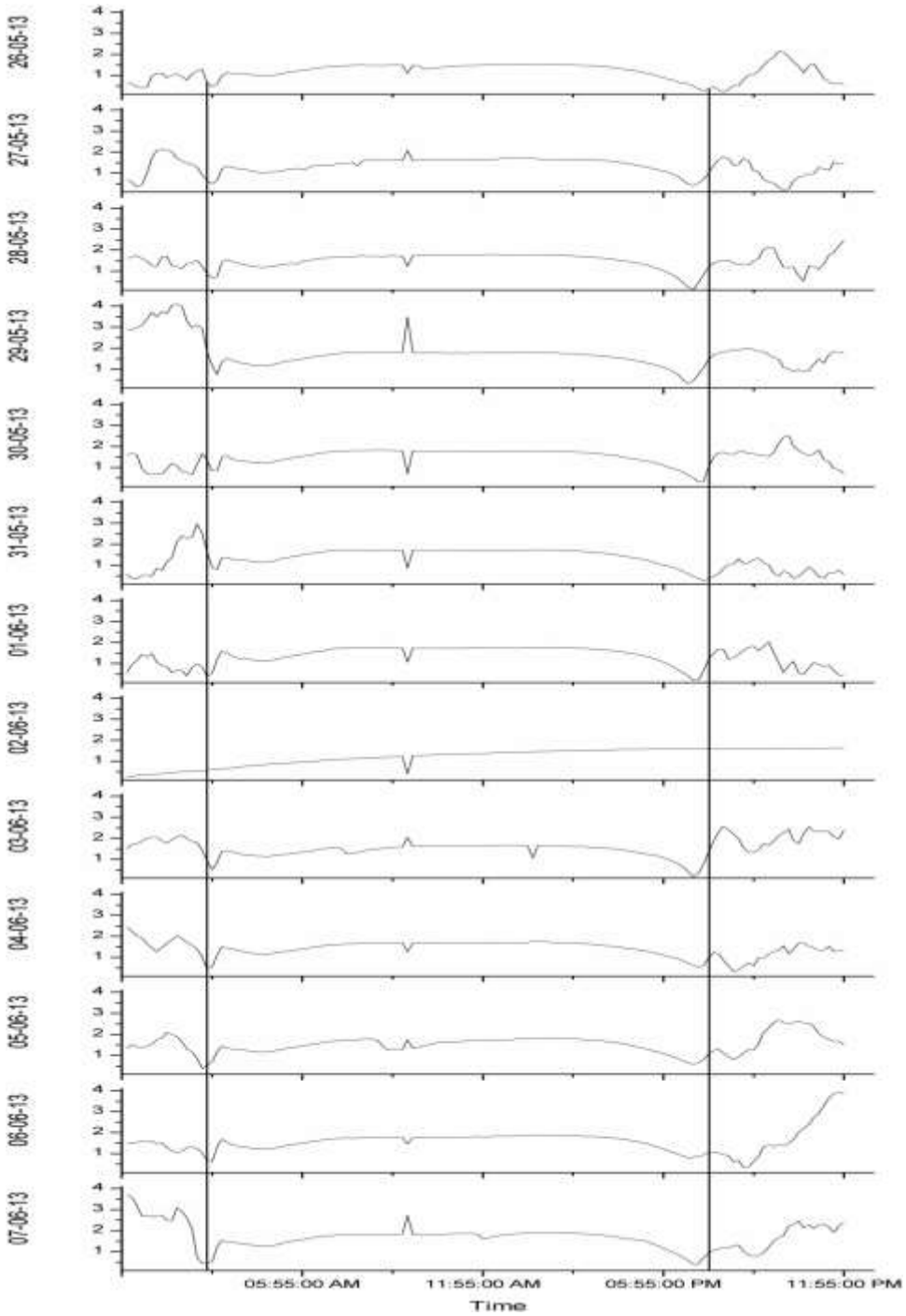

Fig. 1 – Diurnal behavior of VLF amplitude signal from May 26, 2013 to June 7, 2013 during the Pirgos, Greece Earthquake.

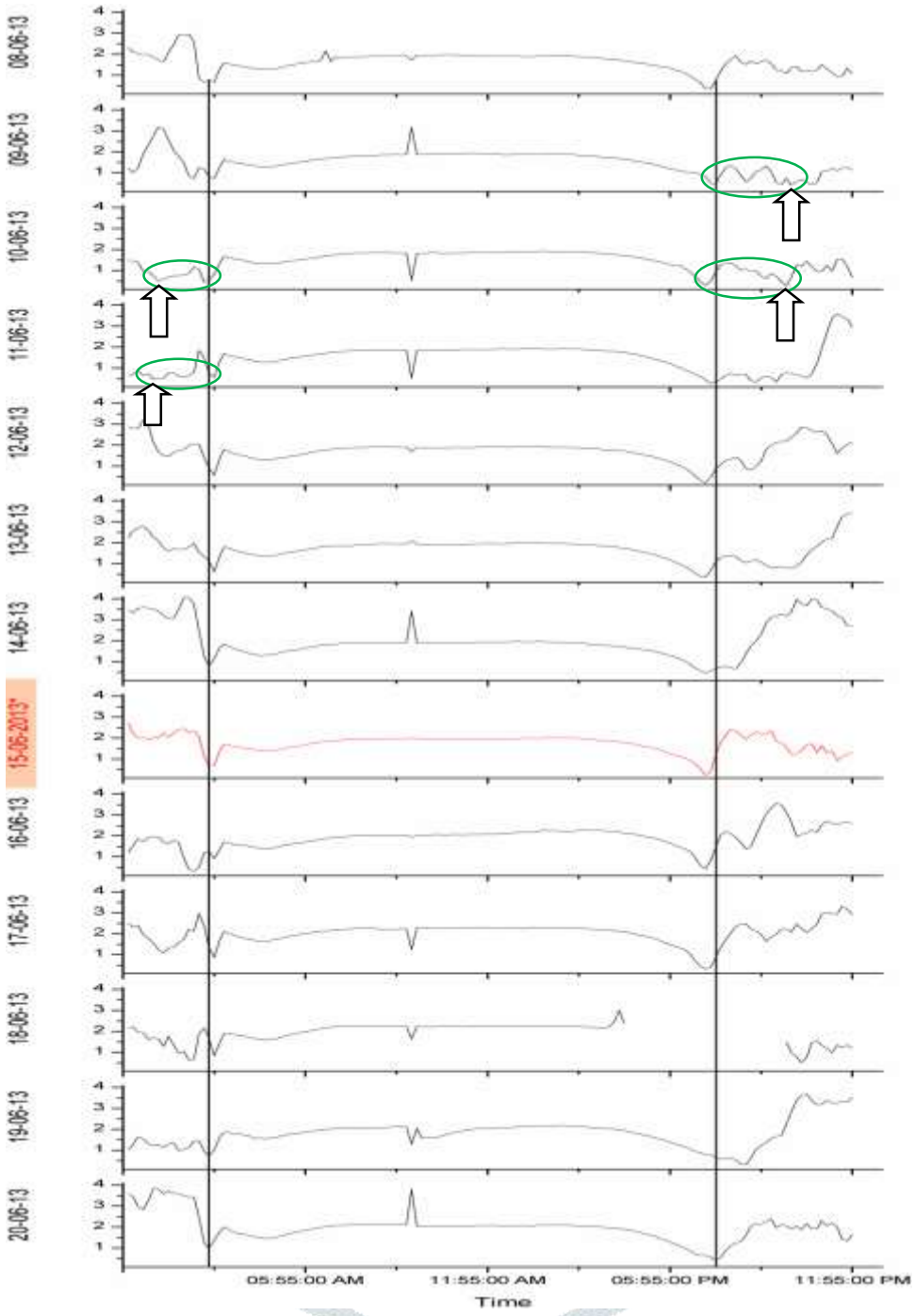

Fig. 2 – Diurnal behavior of VLF amplitude signal from June 8, 2013 to June 20, 2013 during the Pirgos, Greece Earthquake.

As illustrate in Fig. 1 there were not any presence of terminator time shift (T_m and T_e) and found as normal behavior of VLF electromagnetic signals. But some days prior to seismic activity there were presence of T_m shift on June 10 and June 11, 2013 and T_e shift on June 09 and June 10, 2013 as indicates with a circle in Fig. 2. The nature of these terminator time shifts is completely different from any transient variations. There was no geomagnetic activity notice during the analysis period as shown in Fig. 3.

Fig. 3 – Dst Index Value Plot from May 26, 2013 to June 20, 2013 during the Pirgos, Greece Earthquake.

As depicted in Fig. 3 there was not any presence of geomagnetic activity during these 26 days especially on June 9, June 10 and June 11, 2013 which are the precursory day for Pirgos, Greece Earthquake. These anomalous time shift in T_m and T_e values from the recorded data is shown in Table 1.

Table 1 – Statistics of Average T_m & Average T_e and Actual T_m and T_e from May 26, 2013 to June 20, 2013 during the Pirgos, Greece Earthquake.

S. No.	Date	Average T_m	T_m	Average T_e	T_e
1.	26-05-13	02:41:48	02:58:53	19:21:39	19:13:34
2.	27-05-13	02:41:48	02:57:45	19:21:39	18:54:56
3.	28-05-13	02:41:48	02:59:06	19:21:39	18:53:37
4.	29-05-13	02:41:48	03:02:58	19:21:39	18:43:49
5.	30-05-13	02:41:48	03:00:00	19:21:39	19:10:41
6.	31-05-13	02:41:48	02:59:41	19:21:39	19:17:02
7.	01-06-13	02:41:48	02:49:23	19:21:39	19:00:34
8.	02-06-13	02:41:48	02:54:54	19:21:39	19:07:55
9.	03-06-13	02:41:48	02:56:26	19:21:39	18:56:57
10.	04-06-13	02:41:48	02:49:37	19:21:39	19:06:08
11.	05-06-13	02:41:48	02:34:29	19:21:39	18:50:40
12.	06-06-13	02:41:48	02:52:11	19:21:39	18:46:02
13.	07-06-13	02:41:48	02:51:25	19:21:39	18:59:36
14.	08-06-13	02:41:48	02:50:36	19:21:39	19:09:38
15.	**09-06-13**	**02:41:48**	**02:12:08**	**19:21:39**	**21:55:29**
16.	**10-06-13**	**02:41:48**	**01:19:20**	**19:21:39**	**21:44:51**
17.	**11-06-13**	**02:41:48**	**01:09:31**	**19:21:39**	**20:43:22**
18.	12-06-13	02:41:48	02:53:03	19:21:39	19:03:54
19.	13-06-13	02:41:48	02:53:44	19:21:39	19:00:35
20.	14-06-13	02:41:48	02:42:56	19:21:39	19:06:37
21.	**15-06-13***	**02:41:48**	**02:51:17**	**19:21:39**	**19:08:09**
22.	16-06-13	02:41:48	02:16:29	19:21:39	19:03:40
23.	17-06-13	02:41:48	02:54:01	19:21:39	19:02:42
24.	18-06-13	02:41:48	02:54:22	19:21:39	Data Missing
25.	19-06-13	02:41:48	02:40:17	19:21:39	19:33:58
26.	20-06-13	02:41:48	02:42:08	19:21:39	19:27:00

The bold and * mark on **15/06/2013** shows the Earthquake day, while bold mark on **09/06/2013**, **10/06/2013** and **11/06/2013** shows the T_m and T_e time shift and can be consider as precursory days. The variations in T_m during the Earthquake are shown in Fig. 4.

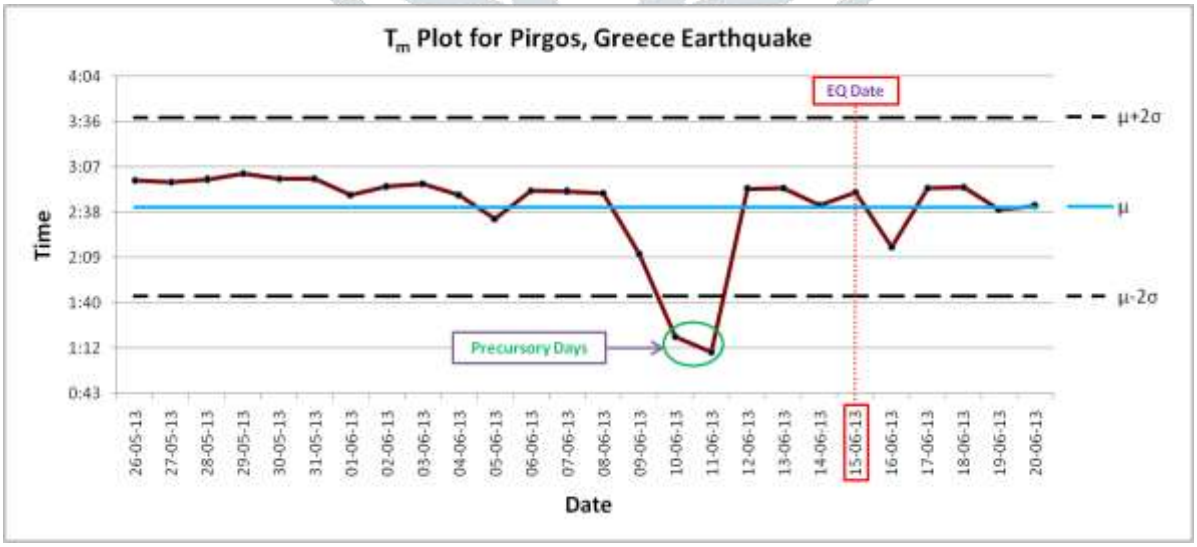

Fig. 4 – Morning terminator time shift (T_m) Plot from May 26, 2013 to June 20, 2013 during the Pirgos, Greece Earthquake.

As point up with a circle in Fig. 4 from few days earlier, the time shift gradually decreased in T_m and found the lowest times of terminator on 10/06/2013 and 11/06/2013 as filtered with $\mu - 2\sigma$ level. On these days the T_m occurs on 01:19:20 and 01:09:31 respectively. Similar variations have also been recorded in T_e during the Earthquake which is shown in Fig. 5.

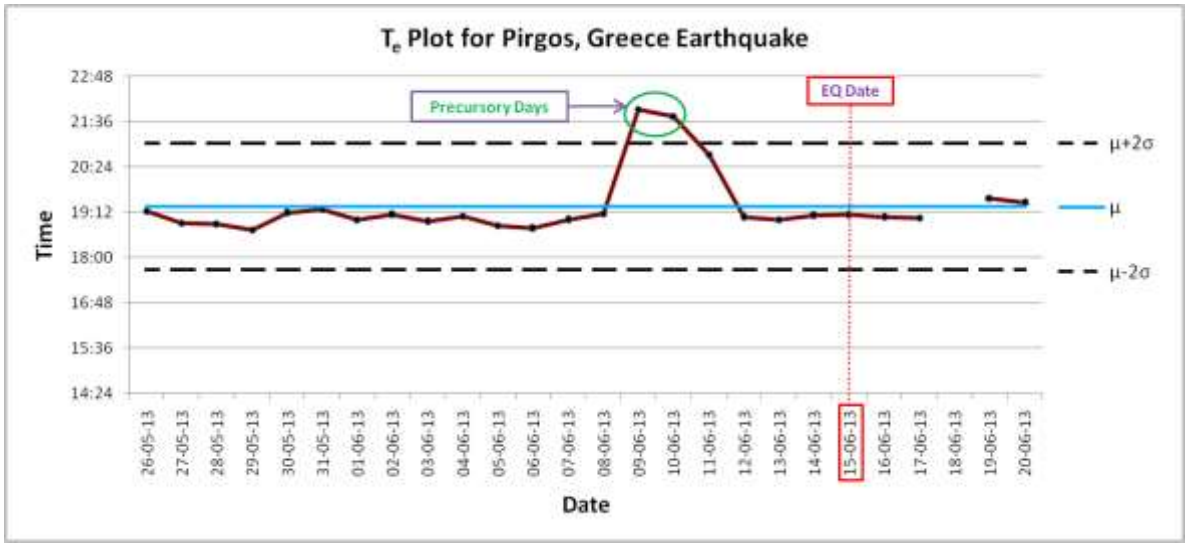

Fig. 5 – Evening terminator time shift (T_e) Plot from May 26, 2013 to June 20, 2013 during the Pirgos, Greece Earthquake.

The time shift gradually increased in T_e and found the highest times of terminator on 09/06/2013 and 10/06/2013 as filtered with $\mu + 2\sigma$ level. On these days the T_e occurs on 21:55:29 and 21:44:51 respectively. So these may be the realization of the precursors of the Earthquake.

V. Conclusions

In the present work terminator time shift in VLF electromagnetic signals have been investigated to find their possible connection with the generation of large ($M \geq 6$) and shallow ($Depth \leq 55\ km$) Earthquake. During the Pirgos, Greece Earthquake occurred on June 15, 2013, unusual behavior of VLF electromagnetic signals was observed on June 9, June 10 and June 11. On these days the terminator times (T_m & T_e) has been shifted before and after anomalously in the morning and evening respectively as filtered with $\mu \pm 2\sigma$. These analytical results have also been calculated by Molchanov et al. (1998) prior to Kobe Earthquake and by Maurya et al. (2013) prior to Wenchuan Earthquake.

The transmission of VLF electromagnetic signals is mainly depend on the electron density of the D-layer of the ionosphere, if transmitter frequency and receiver distance are fixed. The VLF signal method is very well known tool for the investigation of electron density variations in the lower ionosphere (Molchanov et al., 1998). During the Earthquake preparation process electric field is generated within the upper atmosphere due to phenomenon of seismo-ionospheric coupling (Parrot et al., 1993; Pulinets et al., 2003; Hayakawa et al., 2004). The underground radon gas discharges carry submicron aerosol particles with them in the Earthquake preparation zone, which enhance the intensity of electric field close to the Earth's surface due to the drop in air conductivity because of aerosols (Chmyrev et al., 1997). The atmospheric medium is further excited that move towards the ionosphere due to variations in temperature of Earth`s surface. So the electromagnetic emissions from lithosphere propagate upwards and modify the electron density of the lower ionosphere. The simplest idea for these anomalous changes in VLF electromagnetic signal might be connected with radon exhalation before an Earthquake, and the resultant increase in the electric field at the upper atmosphere Molchanov et al., 1998). The eruption of radon gas prior to seismic activities has been shown by many researchers (King, 1986; Singh et al., 2010). These electromagnetic emissions have been recorded in the ELF-VLF bands in the seismically active zones prior to the occurrence of any large Earthquake and reported by many researchers (Fuzinawa and Takahashi, 1998; Karakelian et al. 2000).

VI. Acknowledgements

The authors are thankful to USGS for providing the details of Earthquake event, OMNIWeb for providing the data sets of Dst values and also very much grateful to SID monitoring for providing the datasets of VLF electromagnetic signals.

VII. References

- Asada T., Baba H., Kawazoe M. and Sugiura M., (2001) "An attempt to delineate very low frequency electromagnetic signals associated with earthquakes", Earth Planets Space, Vol.: 53, PP: 55-62.
- Boskova J., Smilauer J., Triska P. and Kudela K., (1994) "Anomalous behavior of plasma parameters as observed by the INTERCOSMOS-24-SATELLITE prior to the Iranian Earthquake of 20 June 1990", Studia Geophysica et Geodaetica, Vol.: 38, PP: 213-220.
- Chmyrev V.M., Isaev N.V., Serebryakova O.N., Sorokin V.M. and Sobolev Y.P., (1997) "Small-scale plasma in-homogeneities and correlated ELF emissions in the ionosphere over an earthquake region", Journal of Atmospheric and Solar Terrestrial Physics, Vol.: 59, PP: 967-974.
- De S.S., De B.K., Bandyopadhyay B., Paul S., Haldar D.K., Bhowmick A., Barui S. and Ali R., (2010) "Effects on atmospherics at 6 kHz and 9 kHz recorded at Tripura during the India-Pakistan Border earthquake", Natural Hazards and Earth System Sciences, Vol.: 10, PP: 843-855.
- De S.S., De B.K., Bandyopadhyay B., Paul Suman, De D., Barui S., Sanfui Minu, Pal Pinaki and Das T.K., (2011) "Studies on the precursors of an earthquake as the VLF electromagnetic sferics", Romanian Journal of Physics, Vol.: 56, Issue: 9-10, PP: 1208-1227.

- De S.S., Paul Suman, Haldar D.K., De D., Kundu A.K., Chattopadhyay S. and Barui S., (2012) "Analyses of the effects of several earthquakes on the sub-ionospheric VLF-LF signal propagation", Journal of Atmospheric and Solar-Terrestrial Physics Vol.: 74, PP: 20-26.
- Eftaxias K., Kapiris P., Polygiannakis J., Peratzakis A., Kopanas J., Antonopoulos G. and Rigas D., (2003) "Experience of short term earthquake precursor with VLF-VHF electromagnetic emissions", Natural Hazards Earth System Sciences, Vol.: 3, PP: 217-228.
- Fuzinawa Y. and Takahashi K., (1998) "Electromagnetic radiations associated with major earthquakes", Physics of the Earth and Planetary Interiors, Vol.: 105, PP: 249-259.
- Gokhberg M.B., Gufeld I.L., Rozhnoy A.A., Marenko V.F., Yampolsky V.S. and Ponomarev E.A., (1989) "Study of seismic influence on the ionosphere by super long-wave probing of the Earth-ionosphere waveguide", Physics of the Earth and Planetary Interiors, Vol.: 57, Issue: 1-2, PP: 64-67.
- Hayakawa M., Molchanov O.A. and NASDA/UEC team, (2004) "Achievements of NASDA's earthquake remote sensing frontier project", Terrestrial Atmospheric and Oceanic Sciences, Vol. :15, PP: 311-327.
- Hayakawa M., (2007) "VLF/LF radio sounding of ionospheric perturbations associated with earthquakes", Sensors, Vol.: 7, PP: 1141-1158.
- Hayakawa M., Horie T., Muto F., Kasahara Y., Ohta K., Liu J.Y. and Hobara Y., (2010) "Subionospheric VLF/LF probing of ionospheric perturbations associated with earthquakes: a possibility of earthquake prediction", SICE Journal of Control, Measurement, and System Integration, Vol.: 3, Issue: 1, PP: 10-14.
- Hazra Pranab and Islam Tamanna, (2014) "A Search for Precursors of Earthquake from 9 kHz Sferic Signal observation Recorded at Kolkata", International Journal of Emerging Technology and Advanced Engineering, Vol.: 4, PP: 144-148.
- Horie T., Yamauchi T., Yoshida M. and Hayakawa M., (2007) "The wave-like structures of ionospheric perturbation associated with Sumatra earthquake of 26 December 2004, as revealed from VLF observation in Japan of NWC signals", Journal of Atmospheric and Solar Terrestrial Physics, Vol.: 69, PP: 1021-1028.
- Kapiris P., Polygiannakis J., Peratzakis A., Nomicos K. and Eftaxias K., (2002) "VHF-electromagnetic evidence of the underlying pre-seismic critical stage", Earth Planets Space, Vol.: 54, PP: 1237-1246.
- Karakelian D., Klemperer S.L., Fraser-Smith A.C. and Beroza G.C., (2000) "A transportable system for monitoring ultra low frequency electromagnetic signals associated with earthquakes", Seismological Research Letters, Vol.: 71, PP: 423-436.
- King C.Y., (1986) "Gas geochemistry applied to earthquake prediction: An overview", Journal of Geophysical Research, Vol.: 91, PP: 12269-12281.
- Kumar A., Kumar S., Hayakawa M. and Menk F. (2013) "Subionospheric VLF perturbations observed at low latitude associated with earthquake from Indonesia region", Journal of Atmospheric and Solar Terrestrial Physics, Vol.: 102, PP: 71-80.
- Manishaben Jaiswal, "COMPUTER VIRUSES: PRINCIPLES OF EXERTION, OCCURRENCE AND AWARENESS ", International Journal of Creative Research Thoughts (IJCRT), ISSN:2320-2882, Volume.5, Issue 4, pp.648-651, December 2017, http://doi.one/10.1729/Journal.23273 Available at http://www.ijcrt.org/viewfull.php?&p_id=IJCRT1133396
- Le Huijun, Liu Libo, Liu Jann-Yeng, Zhao Biqiang, Chen Yiding and Wan Weixing, (2013) "The ionospheric anomalies prior to the M9.0 Tohoku-Oki earthquake", Journal of Asian Earth Sciences, Vol.: 62, PP: 476-484.
- Liu J.Y., Chuo Y.J., Shan S.J., Tsai Y.B., Pulinets S.A. and Yu S.B., (2004) "Pre-earthquake ionospheric anomalies registered by continuous GPS TEC measurement", Annales Geophysicae, Vol.: 22, PP: 1585-1593.
- Maurya A.K., Singh R., Veenadhari B., Kumar S. and Singh A.K., (2013) "Sub-ionospheric very low frequency perturbations associated with the 12 May 2008 M = 7.9 Wenchuan earthquake", Natural Hazards and Earth System Sciences, Vol.: 13, PP: 2331-2336.
- .H. Darji, B. Shah & M.K. Jaiswal. "CONCEPTS OF DISTRIBUTED AND PARALLEL DATABASE", International Journal of Computer Science and Information Technology & Security (IJCSITS), ISSN:2249-9555 vol. 2, no. 6, Dec. 2012, No;224, pg. no: 1150 available at https://www.academia.edu/42308519/CONCEPTS_OF_DISTRIBUTED_AND_PARALLEL_DATABASE
- Molchanov O.A., Hayakawa M., Oudoh T. and Kawai E., (1998) "Precursory effects in the subionospheric VLF signals for the Kobe earthquake", Physics of the Earth and Planetary Interiors, Vol.: 105, PP: 239-248.
- Molchanov O.A. and Hayakawa M., (1998) "Subionospheric VLF signal perturbations possibly related to earthquakes", Journal of Geophysical Research, Vol.: 103, PP: 17489-17504.
- Moldovan I.A., Moldovan A.S., Panaiotu C.G., Placinta A.O. and Marmureanu Gh., (2009) "The geomagnetic method on precursory phenomena associated with 2004 significant intermediate-depth Vrancea seismic activity", Romanian Journal of Physics, Vol.: 54, PP: 249-261.
- Mullayarov Viktor A., Druzhin Gennady I., Argunov Vyacheslav V., Abzaletdinova Larisa M. and Mel'nikov Aleksander N., (2014) "Variations of VLF radio signals and atmospherics during the deep earthquake with M = 8.2 occurred on 24 May 2013 near Kamchatka peninsula", Natural Science, Vol.: 6, PP: 144-149.
- Parrot M., Achache J., Berthelier J. J., Blanc E., Deschamps A., Lefeuvre F., Menvielle M., Planet J.L., Tarits P. and Villain J.P., (1993) "High-frequency seismo-electromagnetic effects", Physics of the Earth and Planetary Interiors, Vol.: 77, PP: 65-83.

- Pulinets S.A., (1998) "Seismic activity as a source of the ionospheric variability", Advances in Space Research, Vol.: 22, PP: 903-906.
- Pulinets S.A., Legen'ka A.D., Gaivoronskaya T.V. and Depuev V.Kh., (2003) "Main phenomenological features of ionospheric precursors of strong earthquakes", Journal of Atmospheric and Solar Terrestrial Physics, Vol.: 65, PP: 1337-1347.
- Singh Surinder, Kumar Arvind, Bajwa Bikramjit Singh, Mahajan Sandeep, Kumar Vinod and Dhar Sunil, (2010) "Radon Monitoring in Soil Gas and Ground Water for Earthquake Prediction Studies in North West Himalayas, India", Terrestrial Atmospheric and Oceanic Sciences, Vol.: 21, PP: 685-695.
- Yamauchi T., Maekawa S., Horie T., Hayakawa M. and Soloviev O., (2007) "Subionospheric VLF/LF monitoring of ionospheric perturbations for the 2004 Mid-Niigata earthquake and their structure and dynamics", Journal of Atmospheric and Solar Terrestrial Physics, Vol.: 69, Issue: 7, PP: 793-802.
- Yao Y.B., Chen P., Zhang S., Chen J.J., Yan F. and Peng W.F., (2012) "Analysis of pre-earthquake ionospheric anomalies before the global M = 7.0+ earthquakes in 2010", Natural Hazards and Earth System Sciences, Vol.: 12, PP: 575-585.
- Yoshino T., (1991) "Low frequency seismogenic electromagnetic emissions as precursors to earthquakes and volcanic eruptions in Japan", Journal of Scientific Exploration, Vol.: 5, PP: 121-144.