THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

Investigations of Anomalous Spiky Variations in VLF Electromagnetic Signals Associated with Western Mediterranean Sea Earthquake

Rahul Shrivastava
Research Scholar, Space Science Laboratory, Department of Electronics,
Barkatullah University, Bhopal, M. P., India
Monu Raghuwanshi
Assistant Professor, TIT College, Bhopal, M. P., India
Dr. Shailesh Raghuwanshi
Professor, KNP College, Bhopal, M. P., India
Dr. Deepak Kumar Sondhiya
Assistant Professor, LNCT College, Bhopal, M. P., India
A. K. Gwal
Professor (Retd.), Space Science Laboratory, Department of Electronics,
Barkatullah University, Bhopal, M. P., India

Abstract:
In the present work electromagnetic signals have been critically examined to delineate their correlation with Western Mediterranean Sea Earthquake occurred on July 07, 2011 (M=5.3). Anomalous variations in electromagnetic signals in VLF range may be considered as most promising tools for short term Earthquake precursor. To investigate the precursors of Earthquake, VLF signal observed by Sudden Ionospheric Disturbances (SID) monitoring station are used and it was found that the amplitude and number of spikes of VLF signals are increased anomalously on June 21 and June 29 before the preceding Earthquake. Another peak was also observed on July 12, 2011 which may be consider as post seismic activity for these signals. The variations in VLF electromagnetic signals prior to seismic activity may be produced by an electromagnetic instability process in the Earth`s atmosphere up to the ionosphere triggered by charged aerosols or electromagnetic waves induced in the preparatory stage of shallow (Depth≤55 km) Earthquakes.

Keywords: *Earthquake Precursors, Seismo-electromagnetic Signals, VLF, Ionospheric Perturbations.*

1. Introduction

The Earthquake prediction has primary importance for human beings in order to alleviate the Earthquake disasters. From the last few decades there is a considerable interest in radio wave propagation ranges from Extremely Low Frequency (ELF) to Very Low Frequency (VLF) bands due to their importance in short term (i.e. from few days to weeks) Earthquake precursors. Analysis of electromagnetic signals observed from Earth-orbiting satellites and ground based techniques reported anomalous variation in signals associated with seismic activities (Molchanov et al., 1998; Yamauchi et al. 2007; Hayakawa et al., 2010; Kumar et al., 2013). These anomalous variations in electromagnetic signals are most promising tool for the finding of Earthquake precursors (Yoshino T., 1991; Molchanov and Hayakawa, 1998; Pulinets, 1998; Asada et al., 2001; Liu et al., 2004). Maurya et al. (2013) reported the sub ionospheric VLF perturbations prior to Wenchuan Earthquake (12 May 2008, M=7.9). They showed the VLF amplitude variations and terminator time shift prior to seismic activity. Similar anomalous variations also reported by Hayakawa (2007) and Horie et al. (2007) during the Sumatra Earthquake (26 December 2004, M=9.0). These electromagnetic anomalies in wide range of frequencies prior to destructive Earthquakes in Greece region have been reported by various researchers (Kapiris et al., 2002; Eftaxias et al., 2003; Moldovan et al., 2009).

The ionosphere is sensitive to seismic activities and the variations in signal amplitude and number of the spikes and their characteristic separations are completely different from the local thunderstorm transient variations or from any other effects, e.g., solar flare, meteor shower, geomagnetic storms etc. (De et al., 2010). During the Earthquake preparation process electromagnetic radiations and aerosol particles emanations would cause ionospheric effects that modulate the electric charge distribution in the ionosphere. These seismic disturbances in the ionosphere are taken as the signatures of lithosphere-atmosphere-ionosphere coupling which influence the conductivity, electron density fluctuations, changes in temperature and ionic composition of the lower atmosphere (Boskova et.al., 1994).

The objective of this study is to analyze the VLF electromagnetic signals during the major Earthquake. Here, we have analyzed the VLF signals during the Western Mediterranean Sea Earthquake (M=6.1) occurred on July 7, 2011 at 19:21:46 (UTC). The geographical location of the main shock is 41.948°N & 7.698°E and focal length of the event is about 10.9 km. These details have been taken from USGS website (http://www.usgs.gov). The geomagnetic conditions during this time lapse have been observed with Disturbance Storm Time (Dst) index from OMNI Web (http://omniweb.gsfc.nasa.gov). The resulted precursors of this Earthquake have been found as spiky variations in VLF electromagnetic radio wave ranges.

2. Data and Methodology

To investigate the precursors of Earthquake a time window of 41 days (i.e. 30 days before and 10 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). During Western Mediterranean Sea Earthquake, the VLF signal (20.27 kHz) transmitted form ICV transmitter located at Italy has been analyzed from June 7, 2011 to July 17, 2011. The data are available online at website (http://sidstation.loudet.org/data-en.xhtml).

Daily average values of all 41 days calculated individually and plotted these values with statistical filtration of $\mu \pm \sigma$, where $\mu$is the mean and$\sigma$are the standard deviation. The recorded VLF data is for 10 second interval having 8640 data values in a day. To investigate the number of spikes, 10 minutes' average of data have been calculated and filtered with certain cut of amplitude value. Then these spiky values now plotted for all 41 days with the statistical filtration of $\mu + 3\sigma$.

3. Results and Discussion

Various features from the simultaneous records of VLF electromagnetic signal at SID monitoring station have been recorded during the Western Mediterranean Sea Earthquake. In the month of June, 2011, some days prior to the main shock remarkable spiky variations have been noticed and peaked on June 21 and June 29, 2011. The disturbances in VLF signals continued several days more, then decayed gradually and recorded highest values on July 12, 2011. The daily average value plot of 41 days during the seismic event is shown in Fig. 1 as:

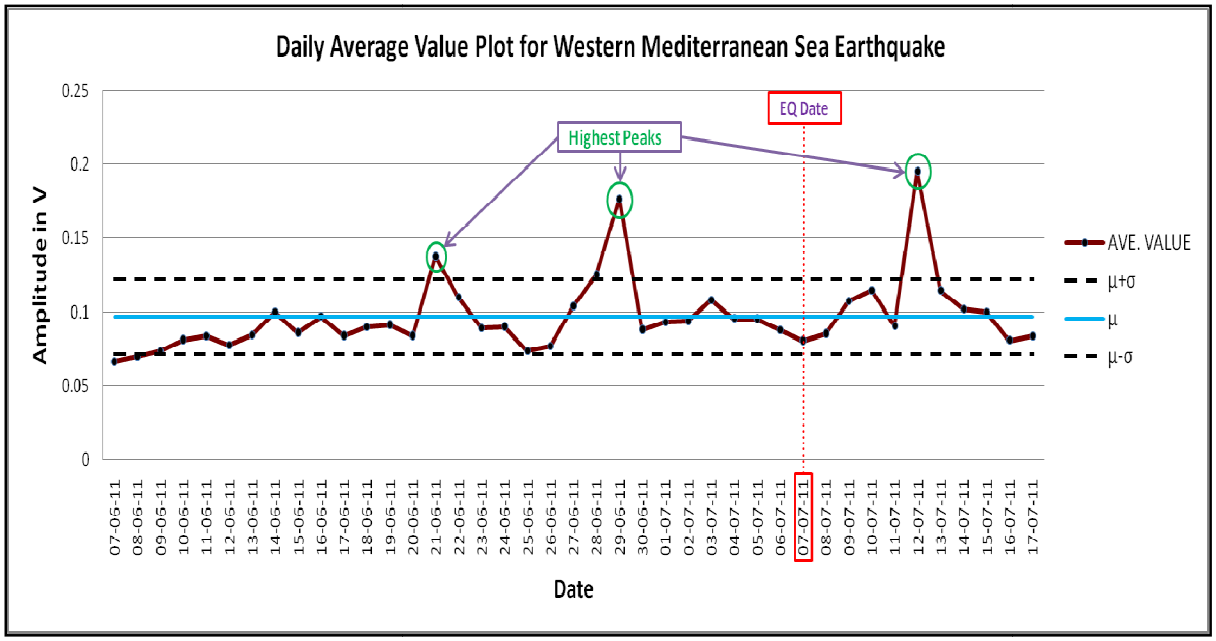

Figure 1: Daily Average Value Plot from June 7, 2011 to July 17, 2011 during the Western Mediterranean Sea Earthquake.

The highest daily average values were observed on June 21, June 29 and July 12, 2011 as compare to the rest values and clearly observed with $\mu \pm \sigma(\mu + \sigma = 0.1215488$ V and $\mu - \sigma = 0.0716506$ V) filter level as shown in Fig. 1. There is also a presence of post seismic peak value of daily average on July 12, 2011. Prior to main seismic event, the duration of spikes is found in the order of few minutes in signals records. The nature of these spikes is completely different from any transient variations. The geomagnetic conditions during this time lapse observed normal in behavior, which is shown in Fig. 2 as:

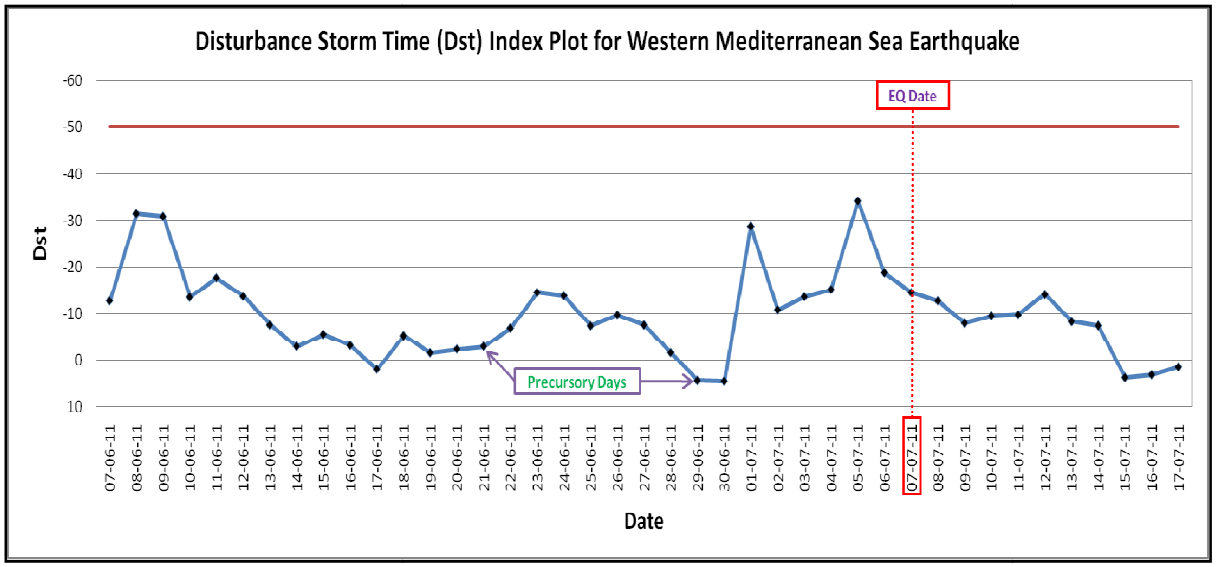

Figure 2: Dst Index Value Plot from June 7, 2011 to July 17, 2011 during the Western Mediterranean Sea Earthquake.

As illustrate in Fig. 2 there were not any presence of geomagnetic activity during these 41 days especially on June 21 and June 29, 2011 which may be the precursory days for Western Mediterranean Sea Earthquake. For the calculation of number of spikes per day cut off amplitude value has been taken as $0.15\ V$ and $\mu + 3\sigma$filter level is 44.9495663. The total number of spikes more than $\mu + 3\sigma$ level in a single day will be considered as a precursory day prior to seismic activity. The statistical analysis of different parameters of the Earthquake from recorded data is shown as:

S. No.	Date	Average Height	Dst	Total No. of Spikes
1.	07-06-11	0.066066204	-12.70833333	1
2.	08-06-11	0.069211343	-31.54166667	1
3.	09-06-11	0.073227804	-30.95833333	1
4.	10-06-11	0.081070602	-13.5	1
5.	11-06-11	0.083410532	-17.625	1
6.	12-06-11	0.077526505	-13.66666667	2
7.	13-06-11	0.084283796	-7.458333333	1
8.	14-06-11	0.09965625	-2.875	1
9.	15-06-11	0.085850909	-5.458333333	1
10.	16-06-11	0.096734228	-3.083333333	1
11.	17-06-11	0.083827083	2.083333333	1
12.	18-06-11	0.089516088	-5.166666667	1
13.	19-06-11	0.091146875	-1.5	2
14.	20-06-11	0.083777405	-2.291666667	3
15.	**21-06-11**	**0.137574306**	**-2.875**	**51**
16.	22-06-11	0.109944792	-6.791666667	23
17.	23-06-11	0.088926157	-14.5	0
18.	24-06-11	0.089952199	-13.79166667	1
19.	25-06-11	0.073311458	-7.291666667	2
20.	26-06-11	0.076843963	-9.666666667	3
21.	27-06-11	0.10386088	-7.458333333	16
22.	28-06-11	0.124971875	-1.541666667	12
23.	**29-06-11**	**0.176630093**	**4.458333333**	**22**
24.	30-06-11	0.087841088	4.583333333	10
25.	01-07-11	0.092939808	-28.70833333	0
26.	02-07-11	0.093805787	-10.79166667	4
27.	03-07-11	0.107646991	-13.58333333	20
28.	04-07-11	0.095445255	-15.16666667	11
29.	05-07-11	0.09536088	-34.16666667	3
30.	06-07-11	0.087532523	-18.70833333	1
31.	***07-07-11****	***0.080359227***	***-14.5***	***1***
32.	08-07-11	0.085116551	-12.70833333	1

33.	09-07-11	0.107262079	-7.875	16
34.	10-07-11	0.114582542	-9.458333333	9
35.	11-07-11	0.090221322	-9.708333333	1
36.	**12-07-11**	**0.195182892**	**-14.04166667**	**56**
37.	13-07-11	0.114377634	-8.208333333	22
38.	14-07-11	0.101705058	-7.333333333	9
39.	15-07-11	0.09968758	3.833333333	1
40.	16-07-11	0.080549832	3.25	0
41.	17-07-11	0.083652003	1.625	3

Table 1: Statistics of Average Value, Dst and Number of Spikes from June 7, 2011 to July 17, 2011 during theWestern Mediterranean Sea Earthquake.

In Table 1, the bold and * mark on 07/07/2011 shows the Earthquake day, while bold mark on 21/06/2011 and 12/07/2011 show the highest number of spikes days. The variations in number of dominant spikes and their duration before and after the Earthquake are shown in Fig. 3 as:

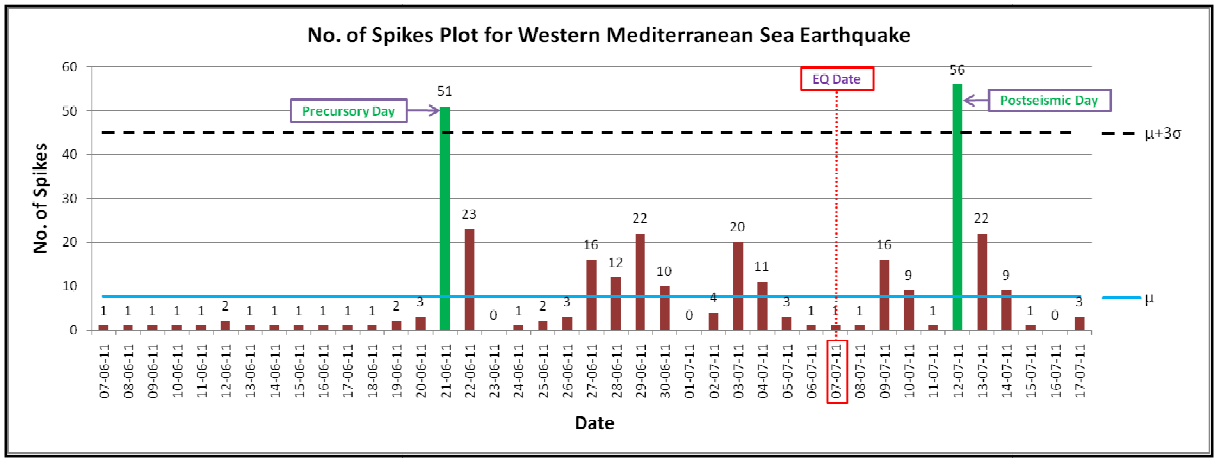

Figure 3: Number of Spikes Plot from June 7, 2011 to July 17, 2011 during the Western Mediterranean Sea Earthquake.

As shown in Fig. 3 during the seismic activity, number spikes gradually increased and found the highest values on 21/06/2011 and 12/07/2011 as filtered with $\mu + 3\sigma$level. On 21/06/2011 number of spikes are found more than $\mu + 3\sigma$level $(44.9495663)$with 51 spikes and this may be the realization of the precursor of the Earthquake. On 12/07/2011 the number of spikes are 56 spikes and these are found as post seismic effects for the seismic activity.

4. Conclusions

In the present work VLF electromagnetic signals have been investigated to find out their connection with the generation of Earthquakes. During the Western Mediterranean Sea Earthquake occurred on July 7, 2011, unusual behavior of VLF electromagnetic signals was observed on June 21 and June 29, 2011. On these days the highest intensity of VLF electromagnetic signals recorded and number of spikes reached up to 51. There is also a presence of post seismic activity on July 12, 2011. After the main shock anomalous variations in the VLF electromagnetic signals occur because of acoustic gravity waves (Lognonne et al. 2006). These are the evidences of increased value in signal amplitude of daily average value of 41 days as filtered with $\mu \pm \sigma$ in the absence of any geomagnetic activity as shown with Dst values. Also our study shows the increase in number of spikes as filtered with $\mu + 3\sigma$. These analytical results of spiky variations in VLF electromagnetic signals have also been calculated by De et al. (2011). The Molchanov et al. (1998) reported the similar kind of signal amplitude variations prior to Kobe Earthquake.

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 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 aerosol particles (Chmyrev et al., 1997). Then the atmospheric medium is further excited that move towards the ionosphere due to the temperature variations on Earth`s surface. So the electromagnetic emissions from lithosphere propagate upwards and modify the ionosphere. These electromagnetic emissions have been observed in the ELF-VLF bands in the seismically active zones prior to the incidence of any large Earthquake and reported by many researchers (Fuzinawa and Takahashi, 1998; Karakelian et al. 2000).

5. Acknowledgement

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

6. References

i. 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, 53, 55-62.

ii. 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, 38, 213-220.

iii. 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, 59, 967-974.

iv. 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, 10, 843-855.

v. 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, 56, 9-10, 1208-1227.

vi. 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, 3, 217-228.

vii. Fuzinawa Y. and Takahashi K., (1998) "Electromagnetic radiations associated with major earthquakes", Physics of the Earth and Planetary Interiors, 105, 249-259.

viii. Hayakawa M., Molchanov O.A. and NASDA/UEC team, (2004) "Achievements of NASDA's earthquake remote sensing frontier project", Terrestrial Atmospheric and Oceanic Sciences, 15, 311-327.

ix. Hayakawa M., (2007) "VLF/LF radio sounding of ionospheric perturbations associated with earthquakes", Sensors, 7, 1141-1158.

x. 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, 3, 1, 10-14.

xi. 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, 69, 1021-1028.

xii. 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, 54, 1237-1246.

xiii. 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, 71, 423-436.

xiv. 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, 102, 71-80.

xv. 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, 22, 1585-1593.

xvi. Lognonne P., Artru J., Garcia R., Crespon F., Ducic V., Jeansou E., Occhipinti G., Helbert J., Moreaux G. and Godet P.E., (2006) "Ground-based GPS imaging of ionospheric post-seismic signal", Planetary and Space Science, 54, 528-540.

xvii. 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, 13, 2331-2336.

xviii. 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, 105, 239-248.

xix. Molchanov O.A. and Hayakawa M., (1998) "Subionospheric VLF signal perturbations possibly related to earthquakes", Journal of Geophysical Research, 103, 17489-17504.

xx. 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,54, 249-261.

xxi. 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,77, 65-83.

xxii. Pulinets S.A., (1998) "Seismic activity as a source of the ionospheric variability", Advances in Space Research, 22, 903-906.

xxiii. 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, 65, 1337-1347.

xxiv. 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, 69, 7, 793-802.

xxv. Yoshino T., (1991) "Low frequency seismogenic electromagnetic emissions as precursors to earthquakes and volcanic eruptions in Japan", Journal of Scientific Exploration, 5, 121-144.