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Ionospheric precursors observed during some earthquakes

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ABSTRACT

Ionospheric anomalies in association with earthquakes were derived using foF2 records from ionospheric stations. The present study reports the ionospheric perturbations, if any, observed over the related ionospheric station prior to occurrences of five earthquakes during last three years at various locations. Initially, foF2 data were analyzed with upper and lower bound and the observed anomalous changes related to geomagnetic disturbances were filtered out. Then the remaining perturbations were analyzed in relation to the occurrence of seismic activities. Hence period considered in this study comes under the quiet geomagnetic conditions. The results of the study showed some unusual perturbations. These anomalies are strongly time dependent and appeared some days before the main shock. The possible mechanism to explain these anomalies is the effect of seismogenic electric field generated just above the surface of the earth within the earthquake preparation zone well before the earthquake.

INTRODUCTION

The ionosphere is known to undergo many kinds of disturbances connected with solar and geomagnetic activities.The ionospheric parameters are mainly related to the control of solar geophysical conditions and it is greatly affected by geomagnetic storms. If there is no solar or geomagnetic activity but disturbances occur in the ionosphere then it can be originated from earthquake and volcanoes. In this connection the large number of publications made during last 20 years (Blanc 1985; Liperovsky et al., 2000; Liu et al., 2000; Boyarchuk, Lemonosov & Pulinets 2001; Dutta et al., 2007; Dabas et al., 2007).Some physicist (Pulinets et al., 2003; Pulinets & Liu 2004 and Dutta et al., 2007) worked on ionospheric perturbation and showed earthquake precursors in the F- region ionosphere well before the main shock. A physical mechanism between seismology and ionospheric perturbations was reported by Pulinets & Liu (2004). Pulinets et al. (2003) used a statistical method to obtain a reliable precursor of earthquake.The perturbations occur just after the shock and are due to acoustic waves, which are amplified through the atmosphere because of decreasing atmospheric density with increasing height. Furthermore,it has been shown that electric and magnetic modifications could occur between a few hours and a few days before earthquake in the seismic zone.Ionospheric perturbations had also been observed few days before earthquake. How ever it must be noted that not all earthquakes produce such phenomenon. Experiment close to some earthquakes has not recorded perturbations.

This is a common factor of all precursors due to the complex nature of earthquakes.Some examples of these perturbations can be found in the monographs edited by Hayakawa & Fujinawa (1994) and Hayakawa et al. (2000). Such Ionospheric anomalies are better detected in the night when the ionosphere is quiet (Parrot et al., 1993). Increases as well as decreases of the critical frequencies are observed in the F-regions before earthquakes. Mechanism of these perturbations could be related to a redistribution of the electric charges at the surface of the earth and then the earth's atmosphere system. Other hypotheses concerning the mechanism of these perturbations are given in Parrot et al. (1985), Parrot et al. (1993), Molchanov (1993) and Pulinets et al. (2003). Ionospheric effects may be occurrence of metallic ions emitted in the atmosphere above seismic regions is considered in Pulinets & Legenka 1994; Pulinets 1998 and Pulinets & Benson 1999 and Pulinets et al. (2000) calculated the electric field generation on the earth's surface and in the atmosphere. Pulinets et al. (2002) found that the nighttime field penetration efficiency is larger than during the daytime and that it depends upon the size of the vertical field localization layer. It was shown that seismic ionospheric disturbances are strongly time dependent before the beginning of the main shock (Pulinets et al., 2003). Seismic ionospheric disturbances are generated weekly, several days before the first shock, but at that moment the displaced region is not located above the epicenter, but rather displaced from it.These disturbances can be transferred along magnetic field lines in to the conjugate regions in the opposite hemisphere.

Variations of the critical frequencies of the ionospheric layers were mainly observed with ground-based ionospheric sounders, but measurements of Total Electron Content (TEC) by satellites can also be used.The TEC gives the sum of electron density between the altitude of the satellite and the ground. Therefore this parameter is mainly related to the density in the F- layer. Clais & Minster (1995) have used this parameter to detect perturbations due to an earthquake. Liu et al. (2002) also used this method for ionospheric precursors. The recent publication of Liu et al. (2004), where a statistical analysis of TEC anomalies has been performed before strong earthquakes at Tiawan, claims a leading time of five days before the seismic shock for the ionospheric precursors.

Present study is focused on the seismogenic variations in the ionospheric foF2 data recorded from NOAA Space Environment Center, related to earthquake. We studied five cases of earthquakes of last three years and got ionospheric precursory results. The study of results is in accordance with previous observations reported by various researchers.

CHARACTERISTICS OF EARTHQUAKES

The characteristics of earthquakes considered in the present study were summarized in Table (1) with their onset date and time, epicenter latitude/longitude, focal depth and the distance from concerning observing station. The magnitude of each earthquake is > 5 and the focal depth varied from 10 to 40 km. Our study includes five earthquake events. The radius of earthquake preparation zone was calculated for each earthquake by using the following formula given by Dobrovolsky, Zubkov & Myachkin (1979)

$$\rho = 10^{0.43M} \text{ km}, \qquad (1)$$

Where ρ is the radius of the earthquake preparation zone in km. and M is the observed magnitude in Richter scale.

METHOD AND ANALYSIS

The manually scaled foF2 data, obtained from NOAA Space Environment Center from Digital Ionosonde installed at different locations of earth for the period December 2005 - December 2007 were analyzed. In

Table 1. Characteristics of earthquakes.

S.N.	Location Name	Epicenter	Date of earthquake	Time of earthquake (UTC)	Intensity	Foc. Dep in km.	Nearest Ionosonde station	Location of station	Distance from epicenter km
1	GREECE-SOUTHERN	36^0N & 23^0E (Northern Hemisphere)	08-01-2006	11:34:55	6.7	66	ATHENS	38 N & 24E	200
2	RUSSIA:KORY AKAKSKIY	60^0N & 167^0E (Northern Hemisphere)	20-04-2006	23:25:2	7.6	22	MAGADON	60N & 151E	888
3	INDONESIA - SERAM	3.5^0 S&127^0E (Near Equator)	14-03-2006	6:57:33	6.7	30	VANIMO	3S & 141E	1556
4	NEW-ZEALAND	49^0S & 163^0E (Southern Hemisphere)	30-09-2007	5:23:34	7.4	10	CHRISTCH URCH	43S & 172 E	963
5	NEWZEALAN D NORTH	39^0S&178^0E (Southern Hemisphere)	20-12-2007	7:55:15	6.6	20	CHRISTCH URCH	43S & 172 E	672

the present study we have considered five earthquakes occurred during the above period.

For earthquake precursors, we have calculated median value of data and the standard deviation of time series data. The upper bound and lower bound were calculated by using the following formulae (Liu et al., 2004):

Upper bound = foF2 (Mean) + 1.96 σ (2)
Lower bound = foF2 (Mean) - 1.96 σ (3)

Where foF2 (Mean) is the median value of foF2 time series data and σ is the standard deviation. To study the day-to-day variations in hourly foF2 values, a deviation analysis method was used to detect percentage increase and decrease from upper and lower bound with the help of following equations:

Percentage Deviation Increase
= [{(foF2 – Upper bound)/Upper bound}*100] 4)

Percentage Deviation Decrease
= [{(Lower bound- foF2)/Lower bound}*100] (5)

The observed foF2 data were analyzed with the help of above equations.We observed anomalous variations in foF2 which seems to be associated with earthquake before and after its occurrence. We know that anomalous variation in foF2 values is also related with geomagnetic conditions. To filter the geomagnetic effect from anomalous foF2 variations, the observed anomalous variations in the foF2 values were again filtered by setting a threshold value ± 15 nT for Dst index. To show the clear view of seismic anomaly, the observed anomalous variations drawn at a logarithmic scale.

RESULTS

In this study, ionospheric variations were examined before all the five earthquakes that occurred during December 2005 to December 2007. The results related to these earthquakes are described below:

Major Earthquake of January 08, 2006 that occurred at Greece - Southern

The major earthquake of magnitude 6.7 occurred January 8, 2006 in Greece – Southern [36^{0}N, 23^{0}E]. The observed results were presented in Fig (1) to Fig (6).This earthquake was much severe and destructive. For this event the observed foF2 data for the entire period of December 05 and January 2006, were analyzed using equations (1) to (4). In the Fig (1) variation of foF2 is shown. Fig (2) shows the logarithmic variation of foF2. Fig (3) shows the percentage deviation of foF2 data. Fig (4) shows the logarithmic variation of percentage deviation of foF2 when there was no filter. Fig (5) shows the percentage deviation of foF2 using a filter of Dst ± 15 nT to remove the geomagnetic effect. This shows some major variations of 3 -26 % in upper bound which are not correlated with normal day-to-day variability in foF2.That means the above- observed anomalous variation in foF2 might be caused by some other sources like earthquake through lithosphere-ionosphere coupling suggested by various researchers described above. Fig (6) shows the logarithmic variation of percentage deviation of foF2. In these figures E mark the time of occurrence of main shock of earthquakes and P mark the precursory phenomenon.

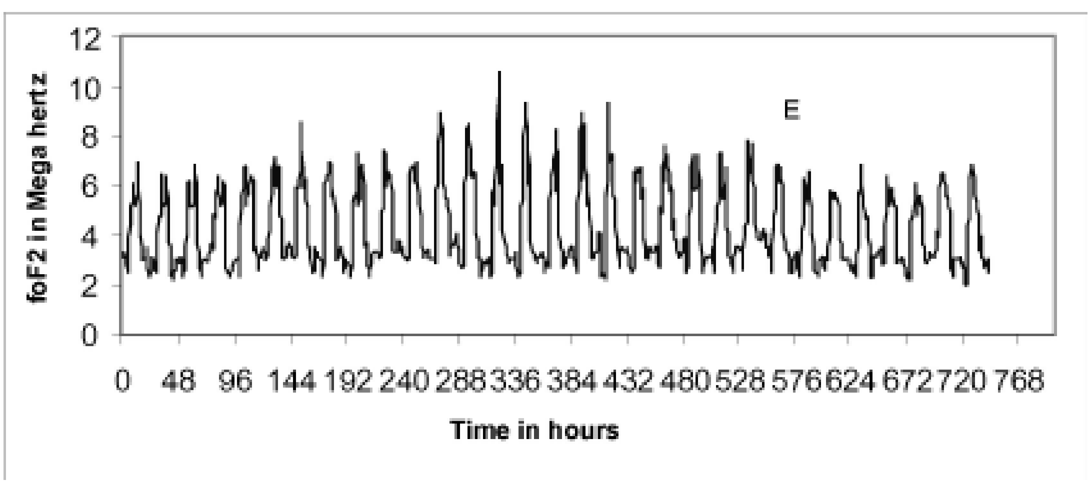

Figure 1. Study of variation of foF2 [data used from 16 December 2005 to 15 January 2006] Earthquake occurred on Jan 08, 2006.

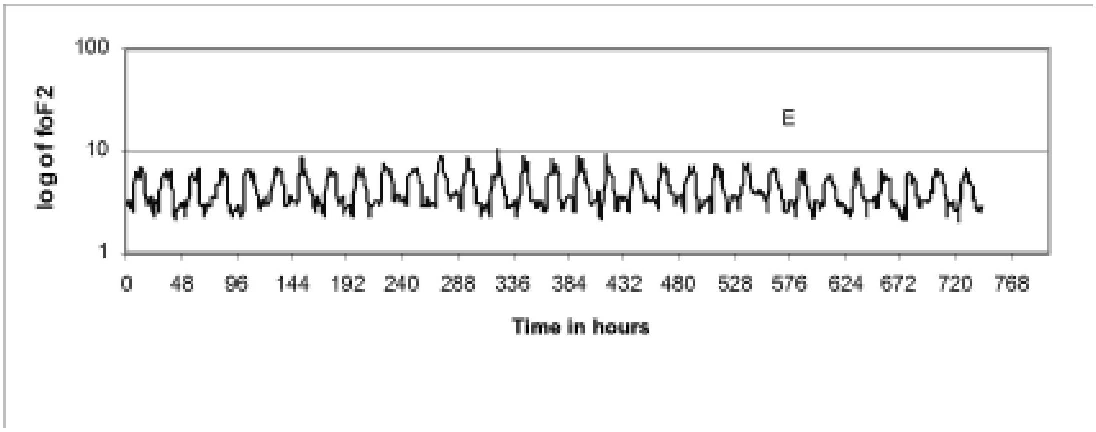

Figure 2. Study of logarithmic variation of foF2 [Earthquake occurred on Jan 08, 2006.

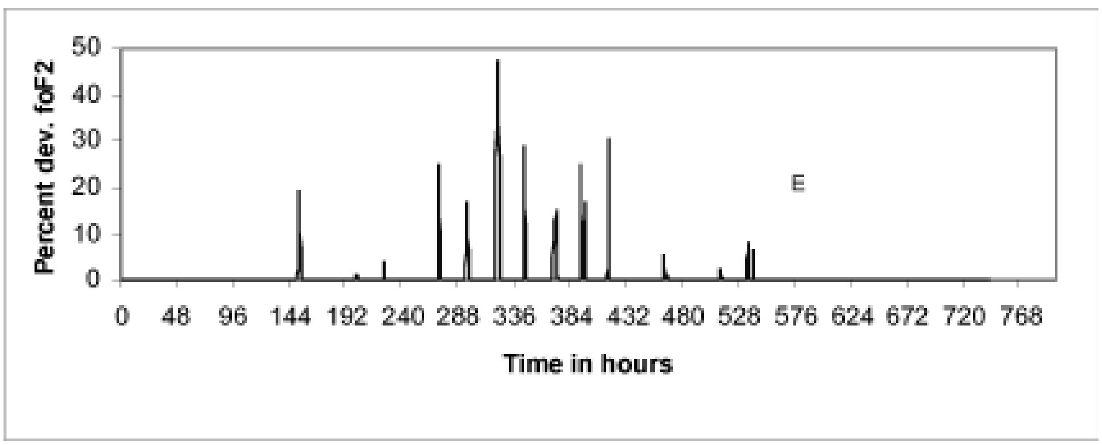

Figure 3. Study of percentage deviation of foF2 [with out filter] Earthquake occurred on Jan 08, 2006.

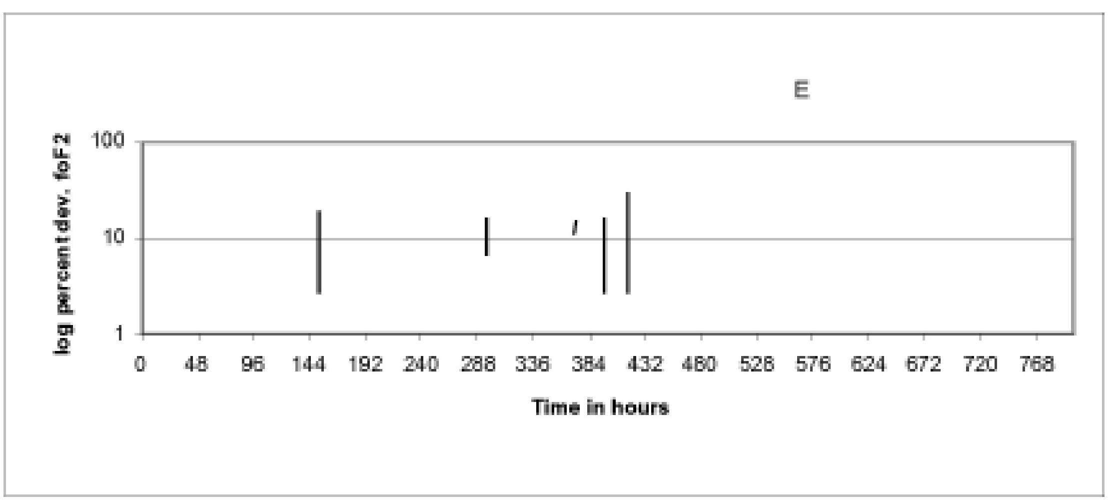

Figure 4. Study of logarithmic variation of percentage deviation of foF2 [with out filter] Earthquake occurred on Jan, 08, 2006.

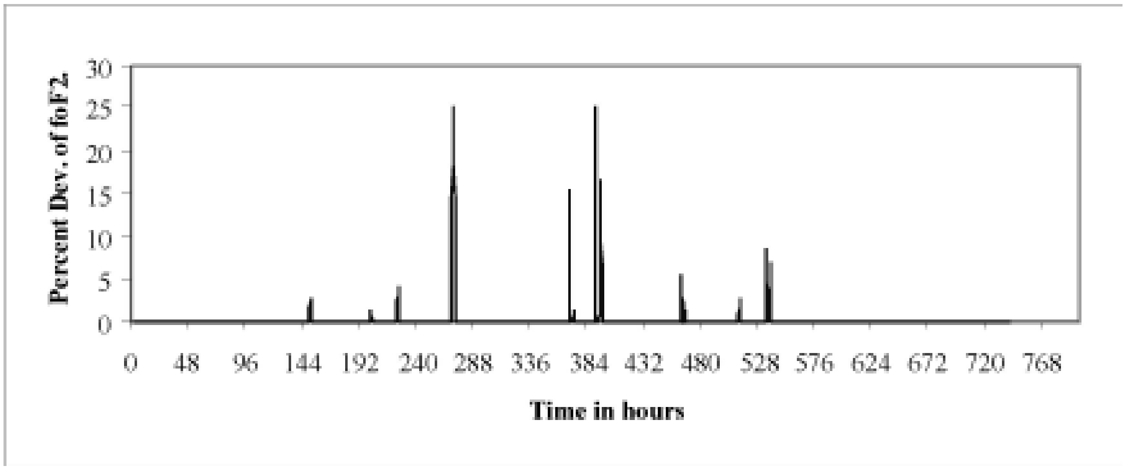

Figure 6. Study of logarithmic variation of percentage deviation of foF2 [with filter] Earthquake occurred on Jan 08, 2006.

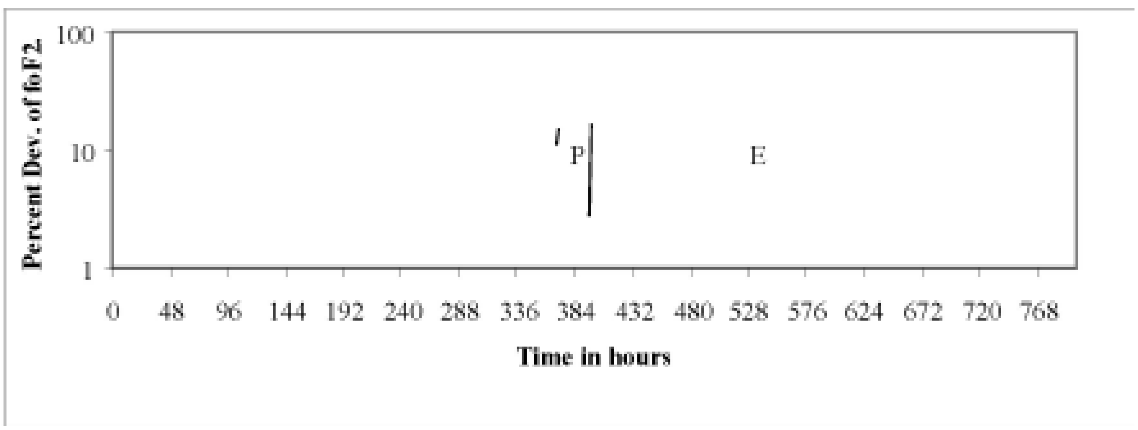

Figure 5. Study of variation of percentage deviation of foF2 [with filter] Earthquake occurred on Jan 08, 2006.

Major Earthquake of September 30, 2007 that occurred at New- Zealand

Another major earthquake of magnitude 7.4 occurred on September 30, 2007 in New-Zealand. To study the Ionospheric perturbations in this case, Christchurch ionosonde data during September – October 2007 were analyzed as above and results were plotted in Fig .7 to Fig.12. Fig (7) shows the variation of foF2. Fig (8) shows the logarithmic variation of foF2. Fig (9) shows the percentage deviation of foF2 when there was no filter. Fig (10) shows the logarithmic percentage deviation of foF2. Fig (11) shows the percentage deviation of foF2 when a filter was used. It shows some major variation in foF2 values of around 16% from the upper bound before five days before the main shock. Some continuous enhancements of 5-10% higher than upper bound are also observed 2-10 days prior to earthquake. As in the case of other earthquakes discussed above, these enhancements might be related to the earthquake. Fig (12) shows logarithmic percentage deviation of foF2, when a filter was used. This shows the existence of earthquake precursor which occur five days before the main shock.

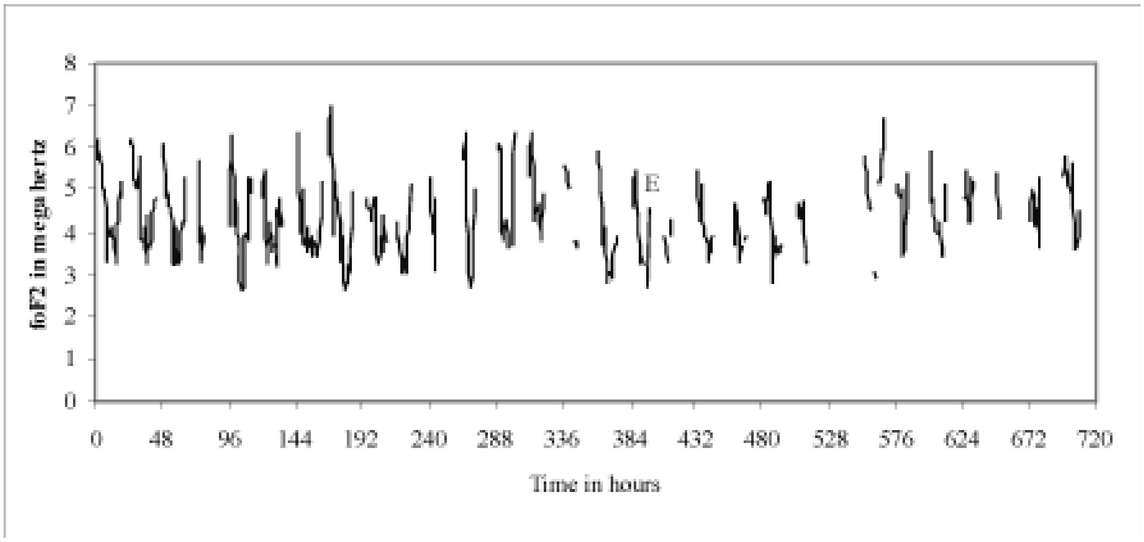

Figure7. Study of variation of foF2 [Data used from September 14, 2007 to October 13, 2007] Earthquake occurred on September 30, 2007.

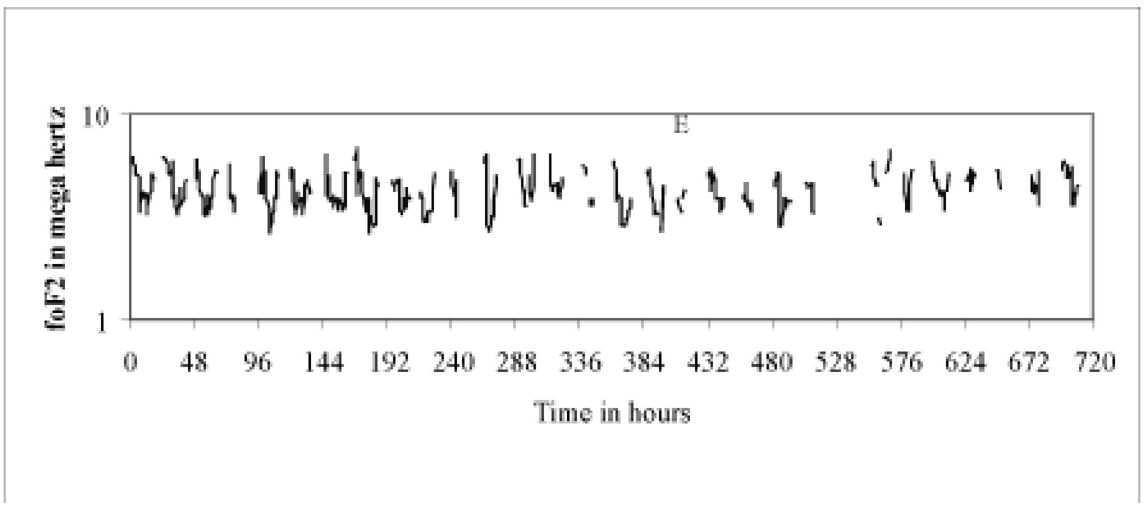

Figure 8. Study of logarithmic variation of foF2 [Earthquake occurred on September 30, 2007].

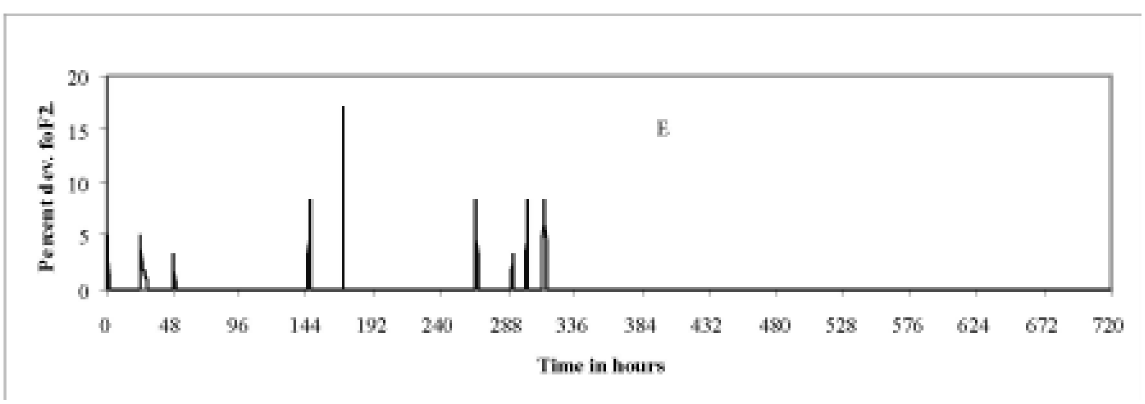

Figure 9. Study of percentage deviation of foF2 [with out filter] Earthquake occurred on September 30, 2007.

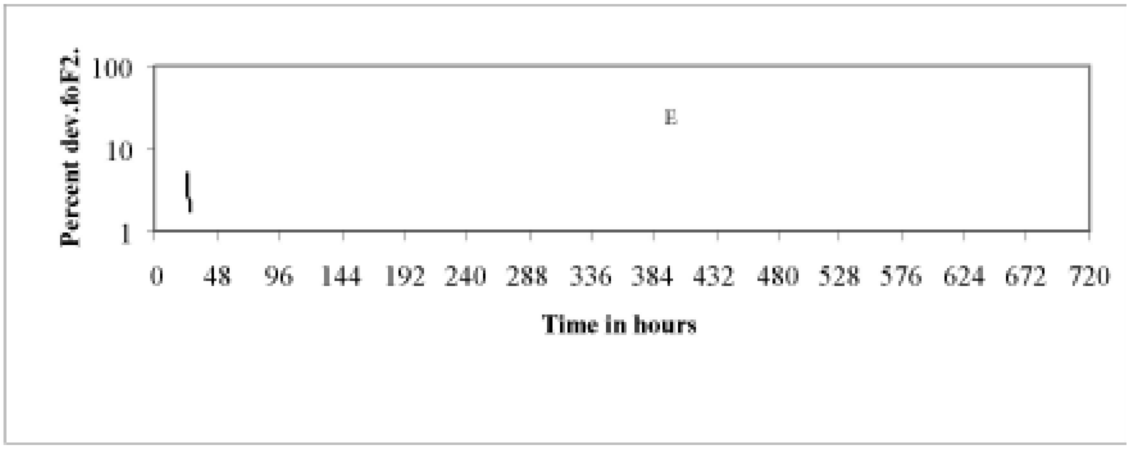

Figure 10. Study of log. Percentage deviation of foF2 [with out filter] Earthquake occurred on September 30, 2007.

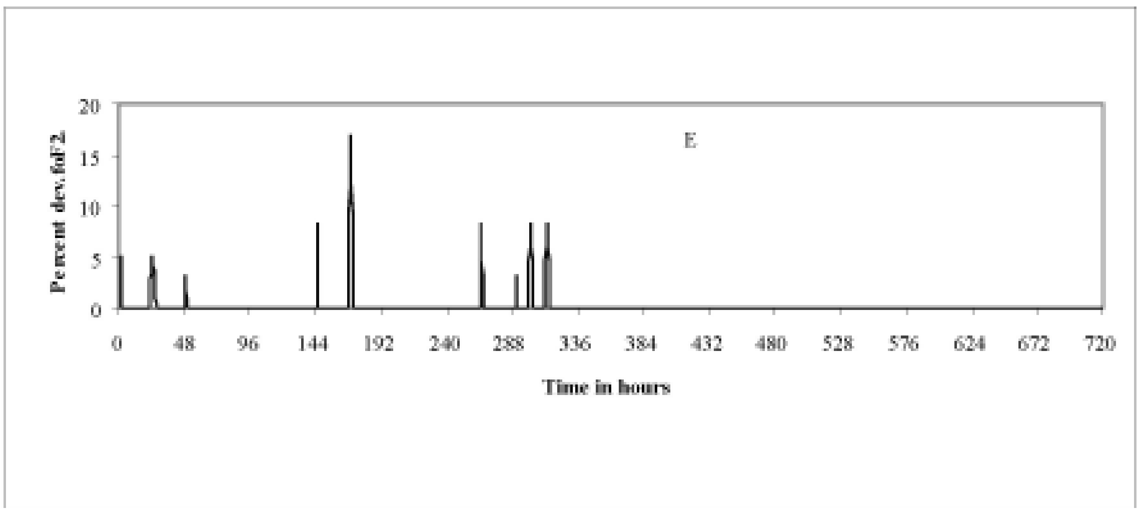

Figure 11. Study of percentage deviation of foF2 [with filter] Earthquake occurred on September 30, 2007.

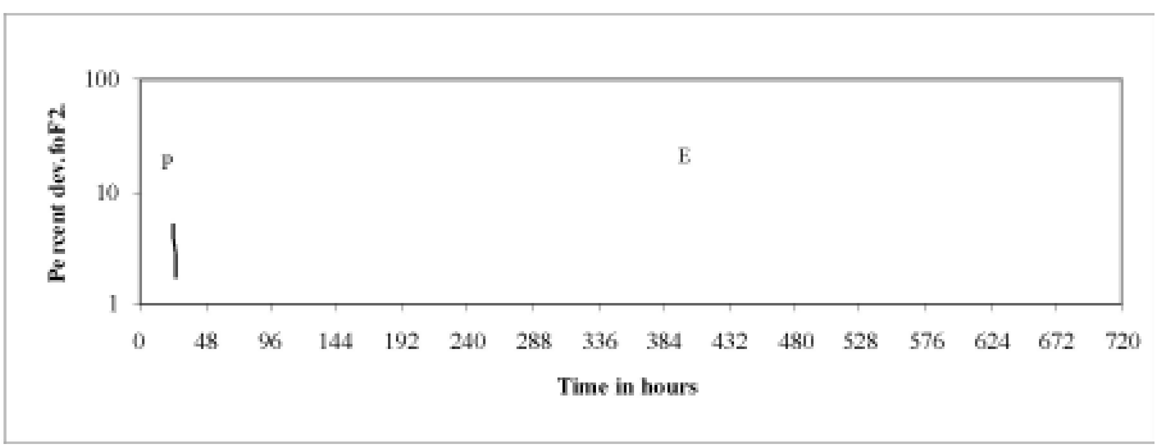

Figure 12. Study of log.percentage deviation of foF2 [with filter] Earthquake occurred on September 30, 2007.

Earthquake of December 20, 2007 that occurred in New-Zealand North

Earthquake of magnitude 6.6 was occurred in New-Zealand-North, on December 20, 2007. For analysis the foF2 data of the month of December 2007 analyzed. The results of foF2 variations for this case were shown in Fig.13 to Fig.18. Fig (13) shows the variation of foF2. Fig (14) showed logarithmic variation of foF2. Fig (15) showed percentage deviation of foF2 when there was no filter. Fig (16) showed logarithmic percentage deviation of foF2 when there was no filter. Fig (17) showed percentage deviation of foF2 when a filter was used. It shows some major variations in foF2 values of around 13% from the upper bound which was recorded about 11 days before the main shock of earthquake. Some continuous enhancement of 2-10% also observed before 3-7 days before the main shock.

Fig (18) showed logarithmic percentage deviation of foF2 when a filter was used. This shows the existence of earthquake precursor which occur before 15 days from the main seismic shock.

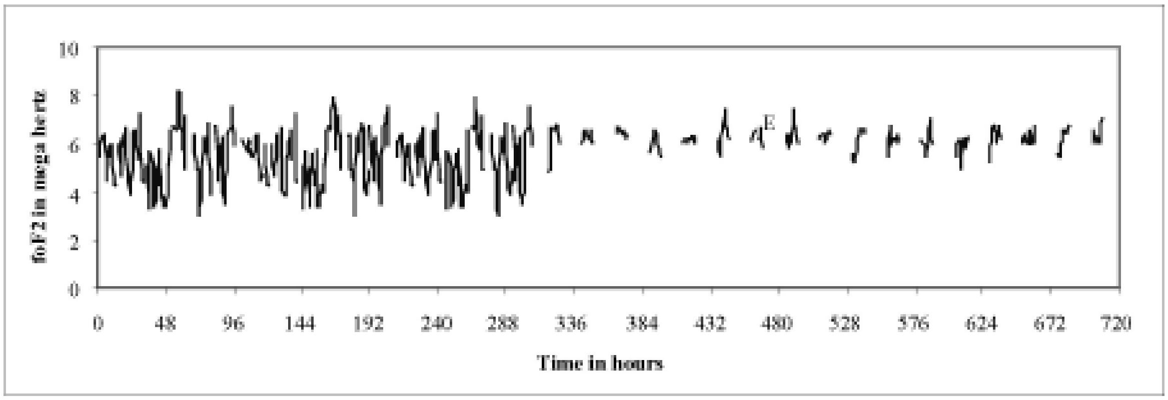

Figure 13. Study of variation of foF2 [Data used from December 01, 2007 to December 30, 2007] Earthquake occurred on December 20, 2007.

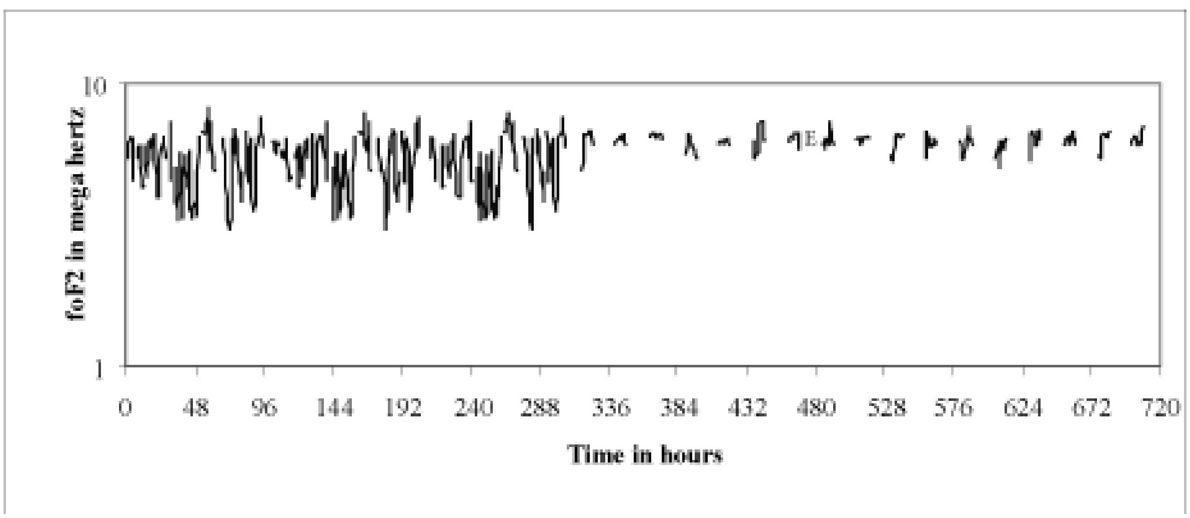

Figure 14. Study of log. variation of foF2 [Data used from December 01, 2007 to December 30, 2007] Earthquake occurred on December 20, 2007.

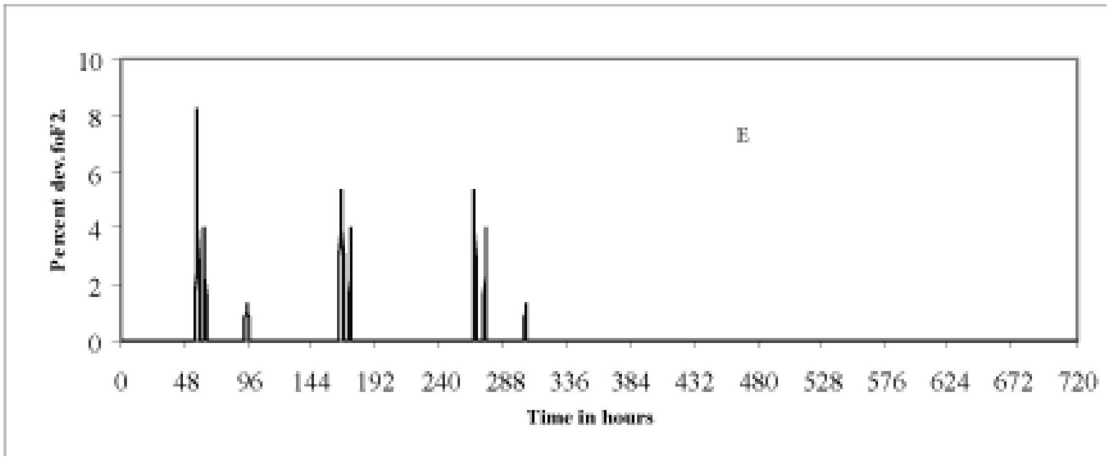

Figure 15. Study of percentage deviation of foF2 [with out filter] Earthquake occurred on December 20, 2007.

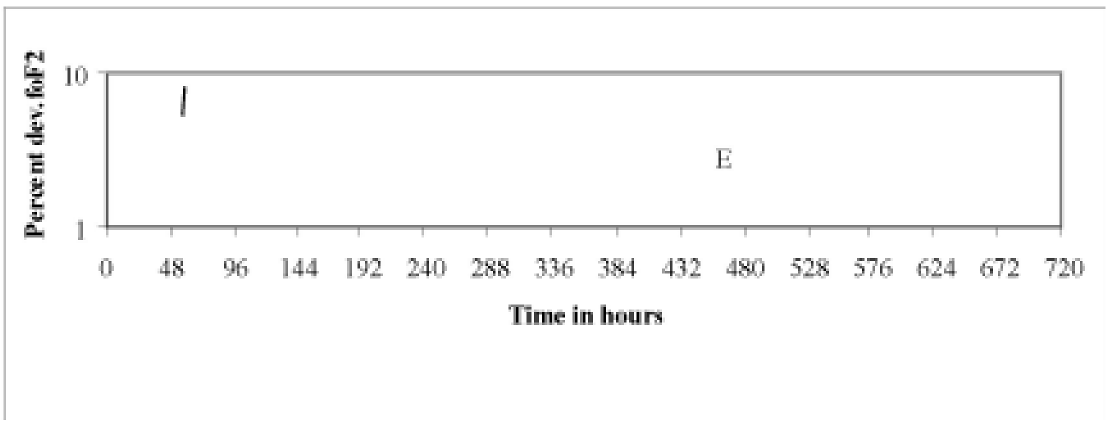

Figure 16. Study of log. Percentage deviation of foF2 [with out filter] Earthquake occurred on December 20, 2007.

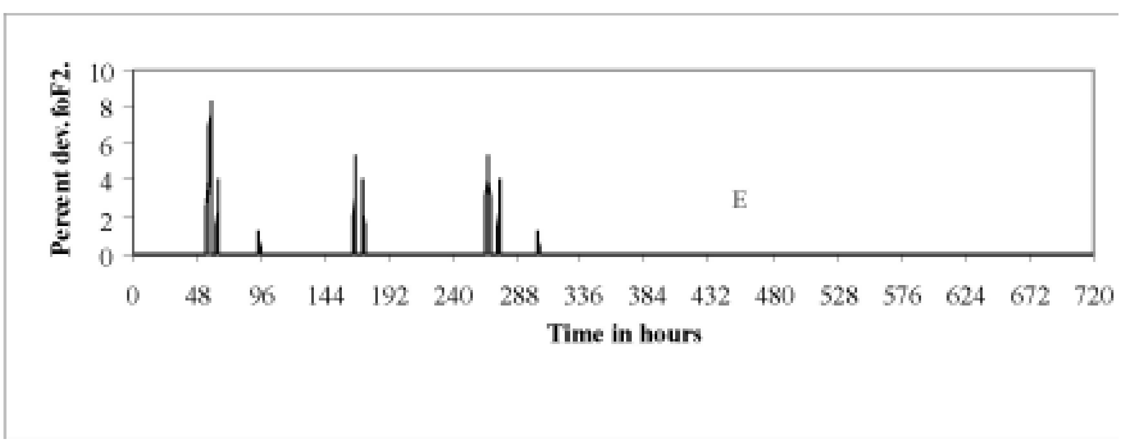

Figure 17. Study of percentage deviation of foF2 [with filter] Earthquake occurred on December 20, 2007.

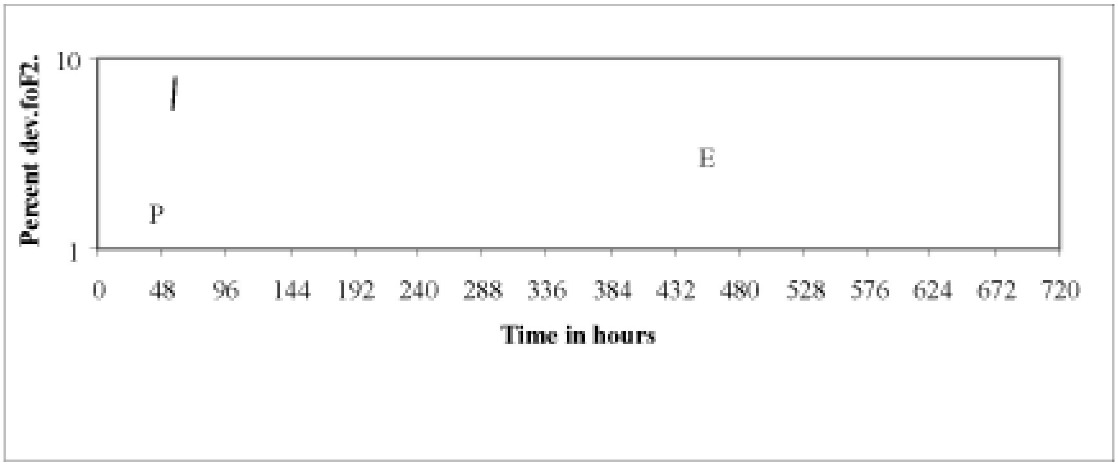

Figure 18. Study of log. Percentage deviation of foF2 [with filter] Earthquake occurred on December 20, 2007.

Major Earthquake of April 20, 2006 that occurred at Russia-Koryakaskky

The major earthquake of magnitude 7.6 occurred April 20, 2006 in Russia-Koryakaskky. This earthquake was much severe and destructive. For this event the observed foF2 data for the entire period of April 2006, were analyzed using equation (1) to (4) and results plotted were shown in Fig.19 to Fig.24. In the Fig (19) variation of foF2 was shown. Fig (20) showed the logarithmic variation of foF2. Fig (21) showed the percentage deviation of foF2 data. Fig (22) showed the logarithmic percentage deviation of foF2 when there was no filter. Fig (23) showed the percentage deviation of foF2 using a filter of Dst ± 15 nT to remove the geomagnetic effect. The result shows some major variations of 25% from upper bound, which was not correlated with normal day-to-day variability in foF2. That means the above observed anomalous variation in foF2. It also shows post earthquake effect in foF2 variations. The foF2 variations were very high (about 40% higher than upper bound) and continue for several days after the main shock. Fig (24) shows the logarithmic variation of percentage deviation of foF2. This shows the precursory phenomena before seven days from the main seismic activity.

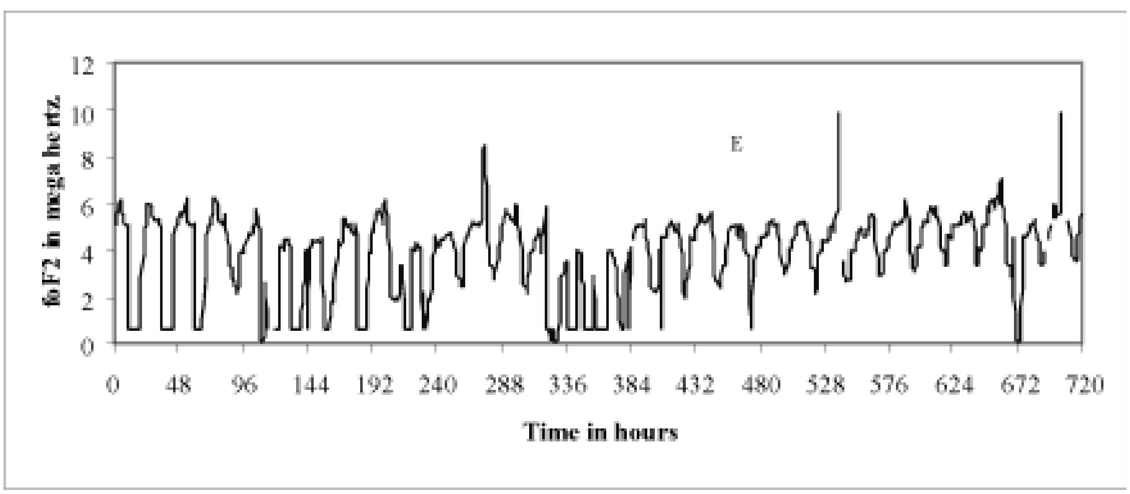

Figure 19. Study of variation of foF2 [Data used from April 01, 2006 to April 30, 2006] Earthquake occurred on April 20, 2006.

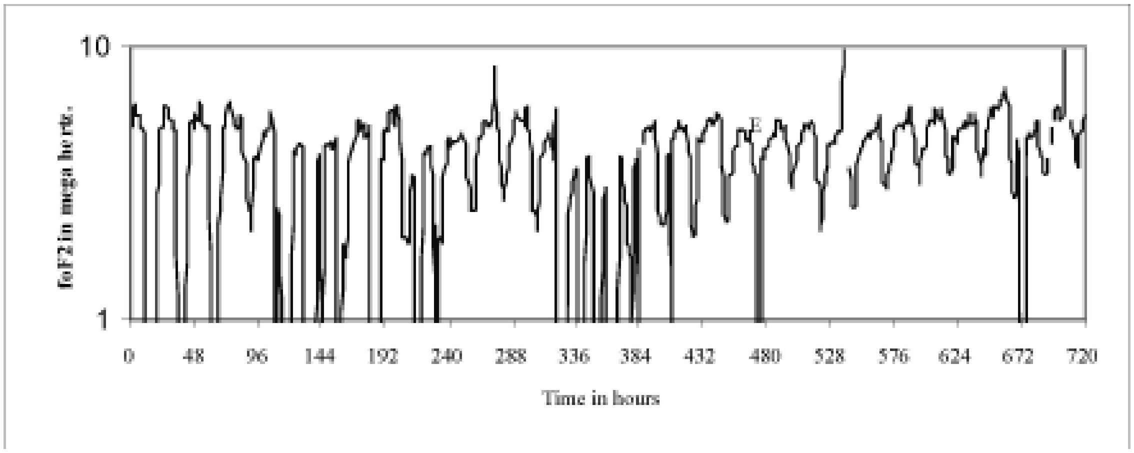

Figure 20. Study of log. variation of foF2 [Data used from April 01, 2006 to April 30, 2006] Earthquake occurred on April 20, 2006.

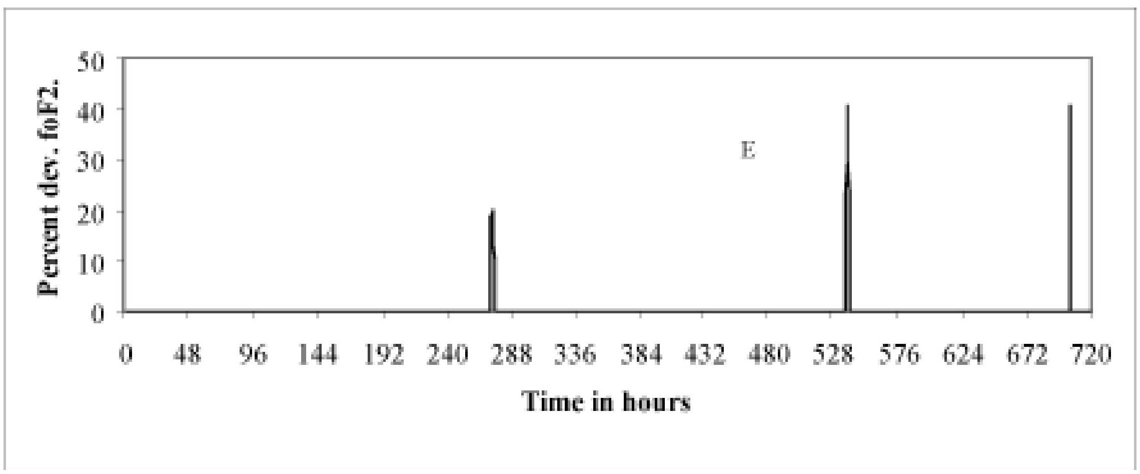

Figure 21. Study of Percentage deviation of foF2 [with out filter] Earthquake occurred on April 20, 2006.

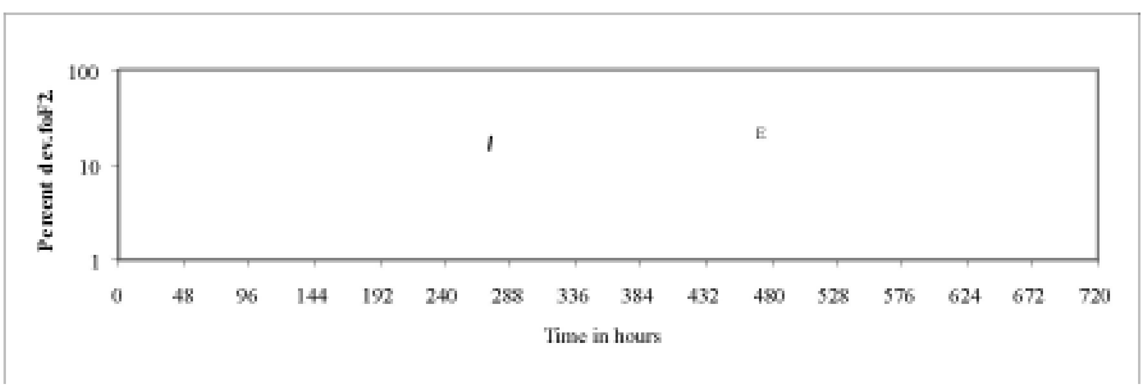

Figure 22. Study of log Percentage deviation of foF2 [with out filter] Earthquake occurred on April 20, 2006.

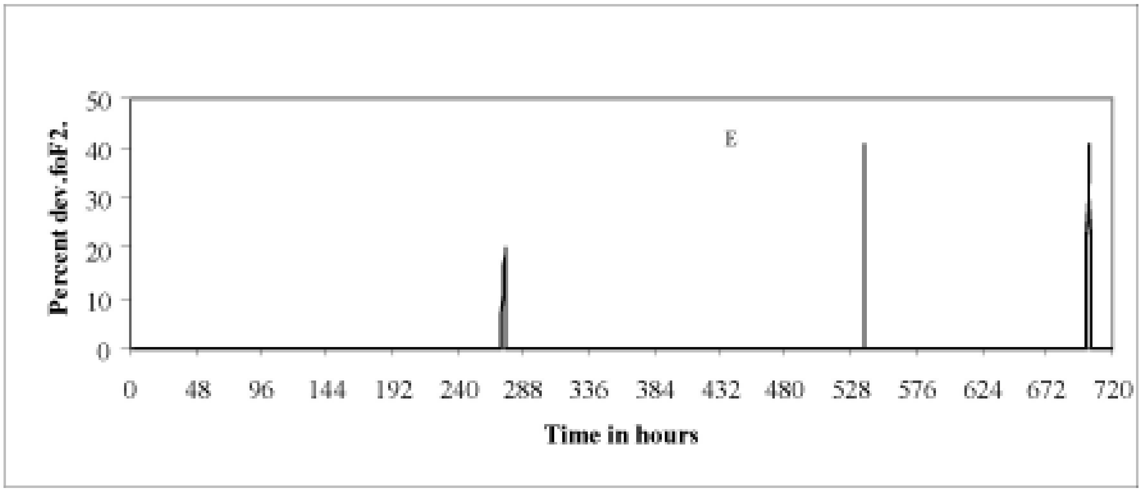

Figure 23. Study of Percentage deviation of foF2 [with filter] Earthquake occurred on April 20, 2006.

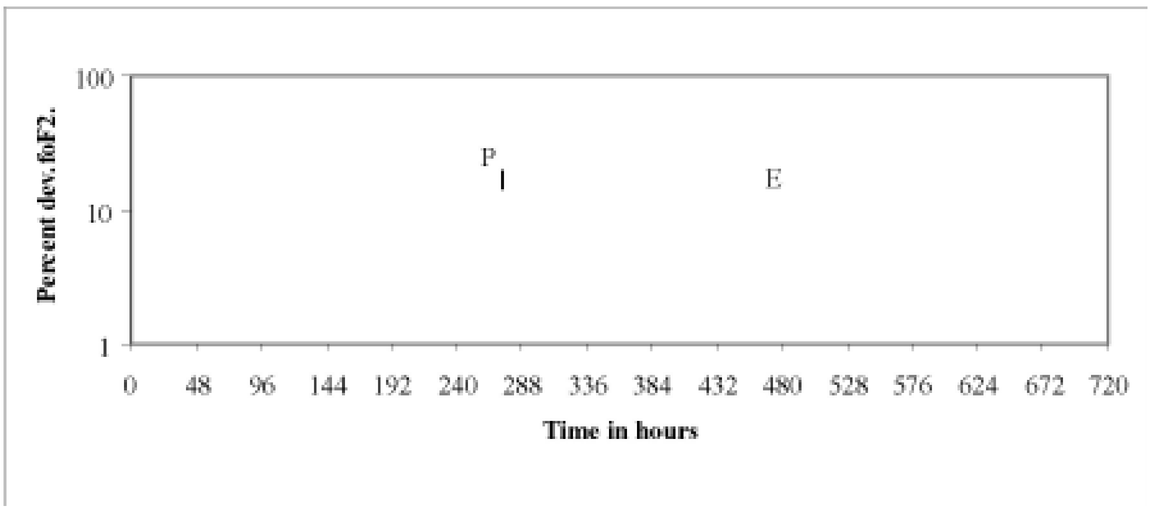

Figure 24. Study of log Percentage deviation of foF2 [with filter] Earthquake occurred on April 20, 2006.

Earthquake of March 14, 2006 that occurred at Indonesia- Seram

Another major earthquake of magnitude 6.7 was occurred on March 14, 2006 in Indonesia- Seram. To study the ionospheric perturbations in this case, Vanimo ionosonde data during March 2006 were analyzed as above and results were plotted in Fig.25 to Fig.30. Fig (25) showed variation of foF2. Fig (26) showed the logarithmic variation of foF2. Fig (27) showed percentage deviation of foF2 ,when there was no filter. Fig (28) showed the logarithmic percentage deviation of foF2. Fig (29) showed the percentage deviation of foF2 when a filter was used. It shows some major variation in foF2 values of around 9% from the upper bound before four days before the main shock of earthquake. Some continuous enhancements of 2-6 % higher than upper bound were also observed 2-8 days prior to earthquake. Fig (30) showed the logarithmic percentage deviation of foF2. It shows the existence of precursor before four days from the main shock.

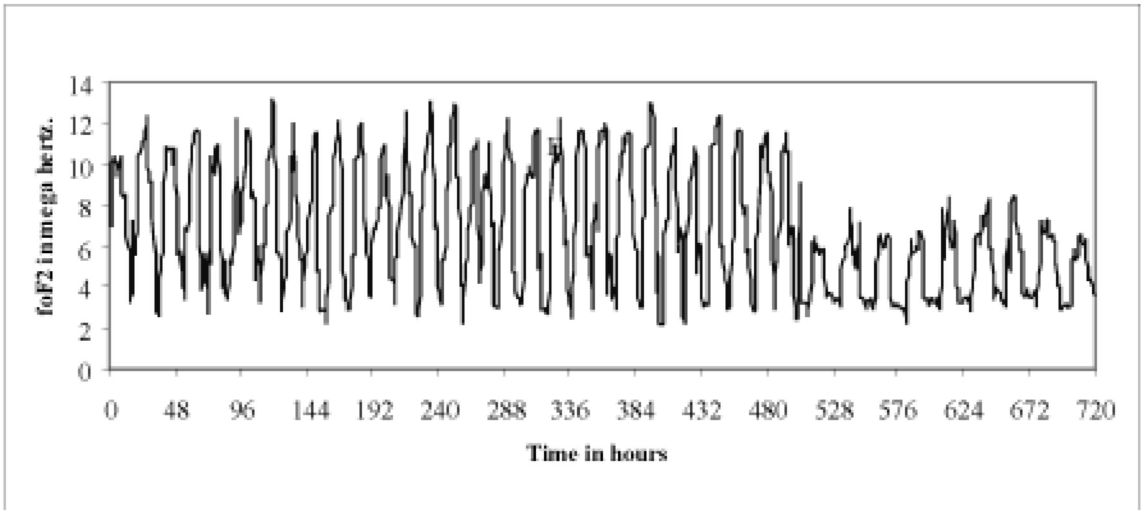

Figure 25. Study of variation of foF2 [Data used from March 01, 2006 to March 30, 2006] Earthquake occurred on March 14, 2006.

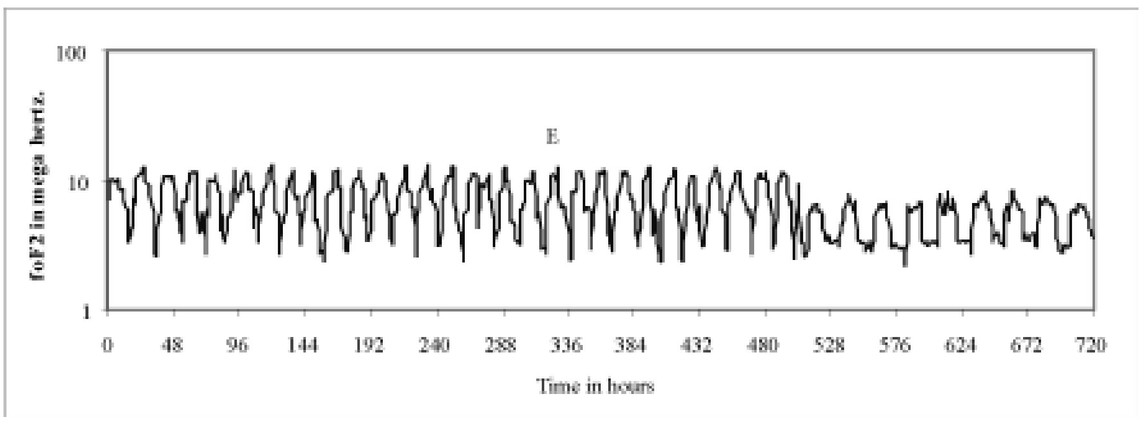

Figure 26. Study of log. variation of foF2 [Data used from March 01, 2006 to March 30, 2006] Earthquake occurred on March 14, 2006.

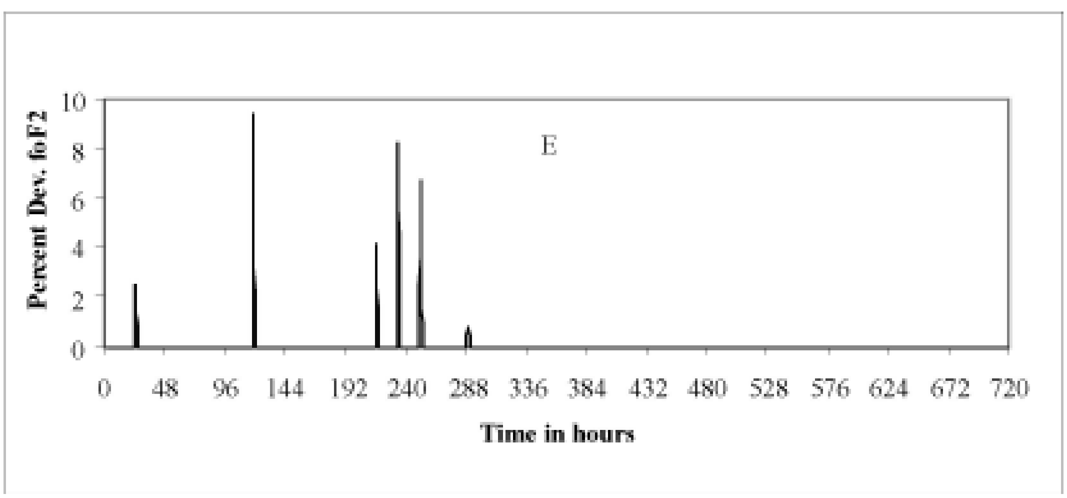

Figure 27. Study of Percentage deviation of foF2 [with out filter] Earthquake occurred on March 14, 2006.

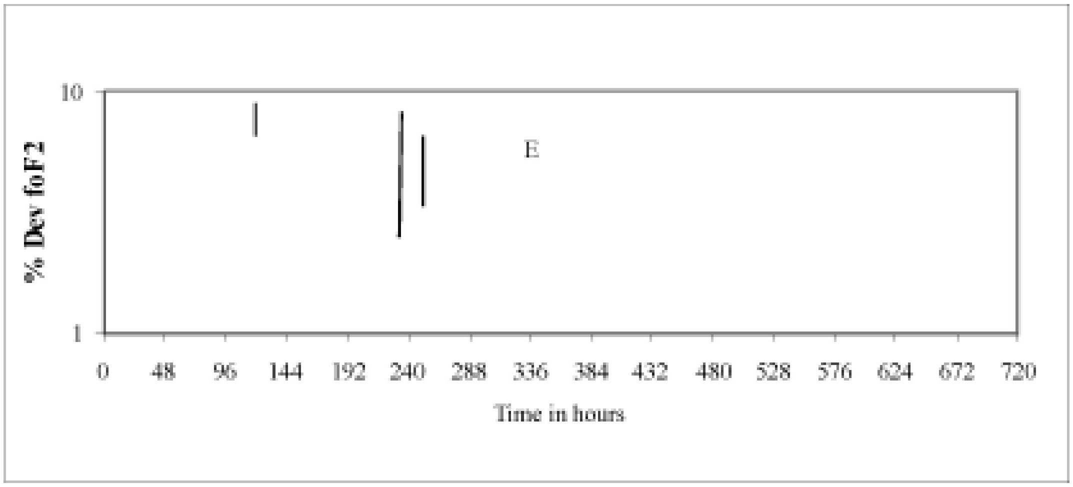

Figure 28. Study of log Percentage deviation of foF2 [with out filter] Earthquake occurred on March 14, 2006.

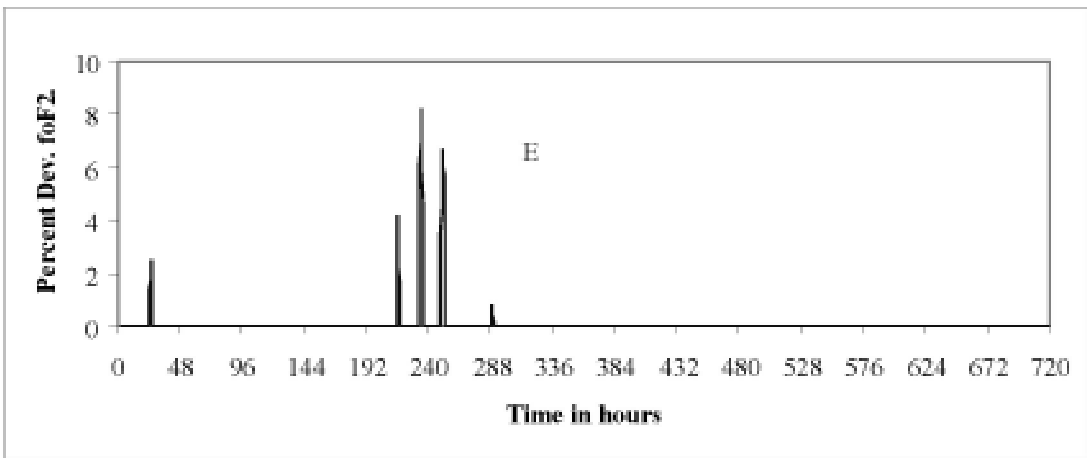

Figure 29. Study of Percentage deviation of foF2 [with filter] Earthquake occurred on March 14, 2006.

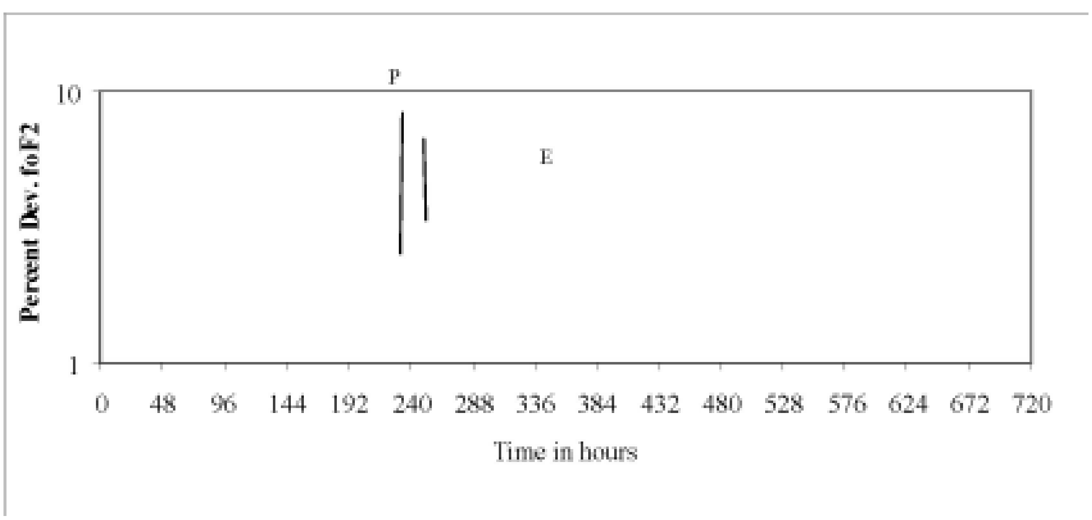

Figure 30. Study of log. Percentage deviation of foF2 [with filter] Earthquake occurred on March 14, 2006.

Table 2. Earthquake precursor study.

S.N.	Location Name	Epicenter	Date of earthquake	Time of earthquake (UTC)	Intensity	Focal depth in km.	Nearest Ionosonde station	Location of station	Distance from epicenter km	Precursor found
1	GREECE-SOUTHERN	36^0N,23^0E (Northern Hemisphere)	08-01-2006	11:34:55	6.7	66	ATHENS	38 N & 24E	200	Before 5 Days
2	RUSSIA;KORYA KAKSKIY	60^0N&167^0E Northern Hemisphere	20-04-2006	23:25:2	7.6	22	MAGADON	60N & 151E	888	Before 7 Days
3	INDONESIA-SERAM	3.5^0S&127^0E (Near Equator)	14-03-2006	6:57:33	6.7	30	VANIMO	3S & 141E	1556	Before 4 Days
4	NEW-ZEALAND	49^0S&163^0E Southern Hemisphere	30-09-2007	5:23:34	7.4	10	CHRISTCH URCH	43S&172E	963	Before 13 Days
5	NEWZELAND NORTH	39^0S&178^0E Southern Hemisphere	20-12-2007	7:55:15	6.6	20	CHRISTCH URCH	43S&172E	672	Before 15 Days

DISCUSSION AND CONCLUSIONS

From the above observations it was found that the pre earthquake ionospheric disturbances were observed for each earthquake. Summary of the anomalous ionospheric perturbations enhancement or depletion in foF2, not related to magnetic disturbances, before the main shock of each of the five earthquakes as discussed above, is shown in Table 2.

The results presented above showed a very strong coupling between lithosphere and ionosphere well before the earthquake. For better understanding the foF2 data of five ionosonde stations were used. The main goal of this study is the detection of significant precursors. It is well known that on short-term basis, i.e., day- to -day or hour -to-hour basis, the earth's ionosphere is strongly dependent on magnetic influences, which originated from the Sun. Hence, during magnetic disturbances, it is very difficult to separate significant changes in ionosphere related to earthquake. But if any abnormal ionospheric perturbation is observed under quiet magnetic condition, we can say that it may be related to earthquake or any other activity from below. In present study, all ionospheric perturbations related to magnetic activity are filtered out by setting a threshold value ± 15 nT for Dst index. Observations showed a good agreement with previous results (Liu et al., 2000, 2001; Pulinets & Liu 2004) and other workers.

The main cause of the above observed ionospheric anomalies might be due to the upward propagation of seismogenic electric fields, which initially generated near the surface of the earth during the earthquake preparation period as reported by many other workers (Hayakawa & Fujinawa 1994; Hayakawa, 1999 and Pulinets et al., 2000). The seismogenic electric field is generated due to the emission of radioactive particles like radon and other charged particles into the atmosphere before the earthquake within the area of earthquake preparation zone. This dynamical process modifies the height distribution of electric conductivity and induced the additional electromotive force in the lower ionosphere (Sorokin, Chmyrev & Yaschenko 2001). Due to this the global closed electric circuit in the earth-ionosphere system is modified. This modification leads to perturbations of the ionosphere well before the main shock of earthquake. Pulinets & Benson (1999) showed by using the topside sounder data that strong vertical atmospheric electric field significantly affects the electron density in the ionosphere during the earthquake period.

In this paper, we have shown the variation in foF2 data prior to earthquake. These ionospheric foF2 data recorded from nearby ionosonde station from earthquake epicenter. The result discussed in the above section shows significant ionospheric perturbations over the related ionosonde station several days before and after the main shock of earthquake. The observed anomalous variation might be correlated with the seismic effect due to isolation from any known solar or magnetic activities. We have concluded here that ionospheric behavior changes, a few days before a major seismic shock within or far from the earthquake preparation zone.

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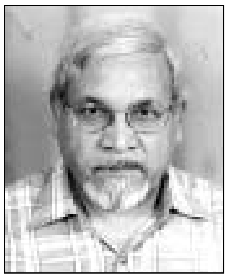

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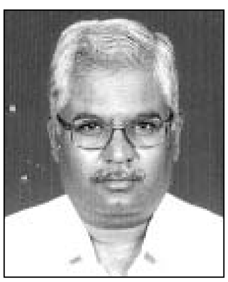

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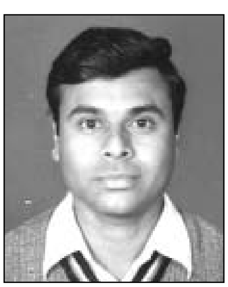

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