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Study of Seismic Precursors Using Ionospheric Maximum Usable Frequency Factor

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Abstract

Ionospheric perturbations in connection with seismic event were analyzed by Maximum Usable Frequency Factor, M (3000) F2, time series data records, from ionospheric stations. This work describes the ionospheric anomaly, if any, found over the associated ionospheric stations prior to occurrence of four earthquakes during last seven years at different locations of earth. We analyzed Maximum Usable Frequency Factor M(3000)F2 data records, by lower and upper bound, and the observed perturbations associated to geomagnetic disorder were filtered out. After filtration, the remaining anomalies were analyzed in association to the occurrence of earthquake. Thus the time interval taken in this analysis comes under the calm geomagnetic activities. The results of the analysis found a few remarkable anomalies in Maximum Usable Frequency Factor. These perturbations are solidly time dependent and seen few days prior to the seismic event. It may be due to the generation of seismogenic electric field on the surface of the earth well before the seismic event. This study may be give us important precursory results.

Keywords: Ionospheric perturbations, earthquake, M (3000)F2, geomagnetic disturbances, seismic electric field.

Introduction

Earth crust and part of upper mental is made-up of different rigid slab known as tectonic plate. These plate moves independently and collide caused earthquake. It is a natural disaster, which destroy human being and property. So the researchers are trying to get a reliable precursor of earthquake. The traditional study of earthquake prediction was based on the theory of seismic rotation implying the periodical storing and discharge of the seismic pressure taking into explanation of the regularly plate movement. On the basis of elasticity theory, Turcotte and Spense[1] prepared the calculations of periodicity for a uniform medium. But it is difficult to expect from the Earth's crust the ideal homogenous structure but sometimes the earthquake sequence has a strikingly regular periodicity. There are number of methods studied by researchers to get success in earthquake prediction. The ionosphere is acknowledged to experience many kinds of disorder associated with astrophysical and geomagnetic performance. The variation in ionospheric parameters are mainly connected to the control of solar geophysical situation and it is greatly affected by geomagnetic storms. If there is no solar or geomagnetic activity but perturbations still found in the ionosphere then it may be originated due to volcanoes and earthquake. During last 20 years, large number of articles written by researchers in relation to ionospheric - seismic perturbation[2-7]. Some researchers[8-10] worked on ionospheric perturbation and report earthquake precursors in the F- region ionosphere. A physical mechanism between seismology and ionospheric perturbations was reported by Pulinets and Liu[11,12] used a statistical method to obtain a reliable precursor of earthquake. The disturbances occur just before and after the seismic shock and are due to acoustic gravity waves, which are amplified through the atmosphere because of decreasing atmospheric density with increasing height. Moreover, it has been exposed that electric and magnetic modifications could occur between a few days and a few hours prior to earthquake in the earthquake preparation zone. But it must be renowned that not all earthquakes produce ionospheric anomalies. This is a general factor of all precursors due to the complex nature of earthquakes. Few examples of these disturbances may be found in the monographs written by Hayakawa and Fujinawa[13]. Such Ionospheric anomalies are better detected in the night when the ionosphere is calm[14]. Increases as well as decreases of the critical frequency (foF2) 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 work[14-17]. Ionospheric effects may be considered as occurrence of metallic ions emitted in the atmosphere above seismic regions[18]. Pulinets[19] calculated the electric field generation on the earth's surface and in the atmosphere. Pulinets[20] 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[21]. 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. Calais and Minster[22] have used this parameter to detect perturbations due to an earthquake. Liu[23] also used this method for ionospheric precursors. The recent publication of Liu[24], where a statistical analysis of TEC anomalies has been performed before strong earthquakes at Tiawan, claims the ionospheric precursor of earthquake before five days from the main seismic shock.

Present study is focused on the seismic variations in the ionospheric Maximum Usable frequency Factor data obtained from NOAA Space Environment Centre. We studied four cases of earthquakes of last seven years and got ionospheric precursory results. The study of results is in accordance with previous observations reported by various researchers.

Description of earthquakes: Description of earthquakes considered in this study were written in table 1 with their occurrence of date, time, epicentre, latitude, longitude, distance from ionospheric station and focal depth. The focal depth of earthquakes varied from 10 to 66 km. and magnitude of each earthquake is > 5. We analyzed four cases of earthquake. includes four earthquake events. The radius of earthquake preparation zone was calculated for each earthquake by using the following formula given by Dobrovolsky[25]

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

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

Material and Methods

Method of Analysis: The scaled foF2 data and MUF data obtained from NOAA Space Environment Centre, of Digital Ionosonde installed at different locations of earth, for the period January 2006 to May 2009 were analyzed. All the 04 earthquakes considered in the present study occurred during the above period.

We calculate Maximum usable frequency factor by following formulae using MS Excel software:

$$M(3000)F2 = MUF(3000)/ foF2$$

In the present study for earthquake precursors, we 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)

$$\text{Upper-bound}=M(3000)F2(\text{Mean})+1.96\sigma \quad (2)$$

$$\text{Lower-bound}=M(3000)F2(\text{Mean})-1.96\sigma \quad (3)$$

Where M(3000)F2 (Mean) is the median value of M(3000)F2 time series data and σ is the standard deviation. To study the day-to-day variations in hourly M(3000)F2 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

$$= [\{(M(3000)F2 – \text{Upper bound})/\text{Upper bound}\}*100] \quad (4)$$

Percentage Deviation Decrease

$$= [\{(\text{Lower bound}- M(3000)F2)/\text{Lower bound}\}*100] \quad (5)$$

The observed M(3000)F2 values were analyzed with the help of above or view of anomalous variations of ionospheric M(3000)F2 and seems to be associated with earthquake before and after its occurrence. We know that anomalous variation in M(3000)F2 values is also related with geomagnetic conditions. To filter the geomagnetic effect from anomalous M(3000)F2 variations, the observed anomalous variations in the M(3000)F2 values were again filtered by setting a threshold value ± 15 nT of Dst index.

Table-1
Description of earthquakes used in this study

Location Name	Epicenter	Date of earthquake	Time of earthquake (UTC)	Intensity	Focal depth in km.	Nearest Ionosonde station	Location of observing station	Distance from epicentre km
GREECE-SOUTHERN	36N& 23E	08-01-2006	11:34:55	6.7	66	ATHENS	38 N & 24E	200
GREECE-ARGOSTOLION	38N & 20E	25-03-2007	13:57:58	5.8	15	ATHENS	38N & 24E	315
TURKEY-ANKARA	39N&33E	26-12-2007	23:47:10	5.6	8	ATHENS	38N&24E	791
BALKANS Nw: Macedonia	41N&20E	24-05-2009	16:17:50	5.5	10	ATHENS	38N&24E	375

The Data: The Ionosonde data has been used for the study of precursors of earthquake. In this study the foF2 data and MUF (3000) data obtained from NGDC. To filter the influence of geomagnetic activity, Dst data obtained from World Data Center of Geomagnetism Kyoto University, Japan and OMINI web data server. We obtained raw data of foF2 of 15-minute interval and related data of MUF(3000) and derived M(3000)F2, further change these data in hourly interval data records using MS Excel software.

Results and Discussion

In this work, ionospheric disorders are examined prior to all four cases of earthquakes that occurred January 2006 to May 2009. Results related to these earthquakes are described below:

An earthquake that occurred on January 08, 2006: Earthquake of magnitude 6.7 occurred on January 08, 2006 at Greece-Southern [36^0N, 23^0E]. It was a severe and destructive earthquake. For this event we analyzed M(3000)F2 data for the period of December 2005 and January 2006 by using equations 2 to 5 and results are shown from figures 1 to 9. Figure 1 shows the variation of foF2. Figure 2 shows the variation of MUF(3000) Maximum usable frequency data. Figure 3 shows the variation of M(3000)F2 data. Figure 4 shows the percentage deviation of M(3000)F2 data when there was no filter. This shows some major variations of 9-43% in upper bound which are not correlated with normal day to day variability in M(3000)F2, this type of variation may be used as seismic precursor. Figure 5 shows the percentage deviation of M(3000)F2 using a filter of Dst ± 15 nT to remove the geomagnetic effect. This shows some major variations of 43% in upper bound which are not correlated with normal day-to-day variability in M(3000)F2, Hence figure 5 clearly indicates that the observed anomalous variation in M(3000)F2 might be caused by any other sources like earthquake through lithosphere - ionosphere coupling suggested by various researchers described above. In these figures arrow marks the time of occurrence of main shock of earthquake and 'P' marks the precursory phenomenon. Figure 6 shows the logarithmic variation M(3000)F2 parameter. Figure 7 shows the variation in Dst index. Figure 8 shows the variation in Ap index and figure 9 shows the variation in Kp index.

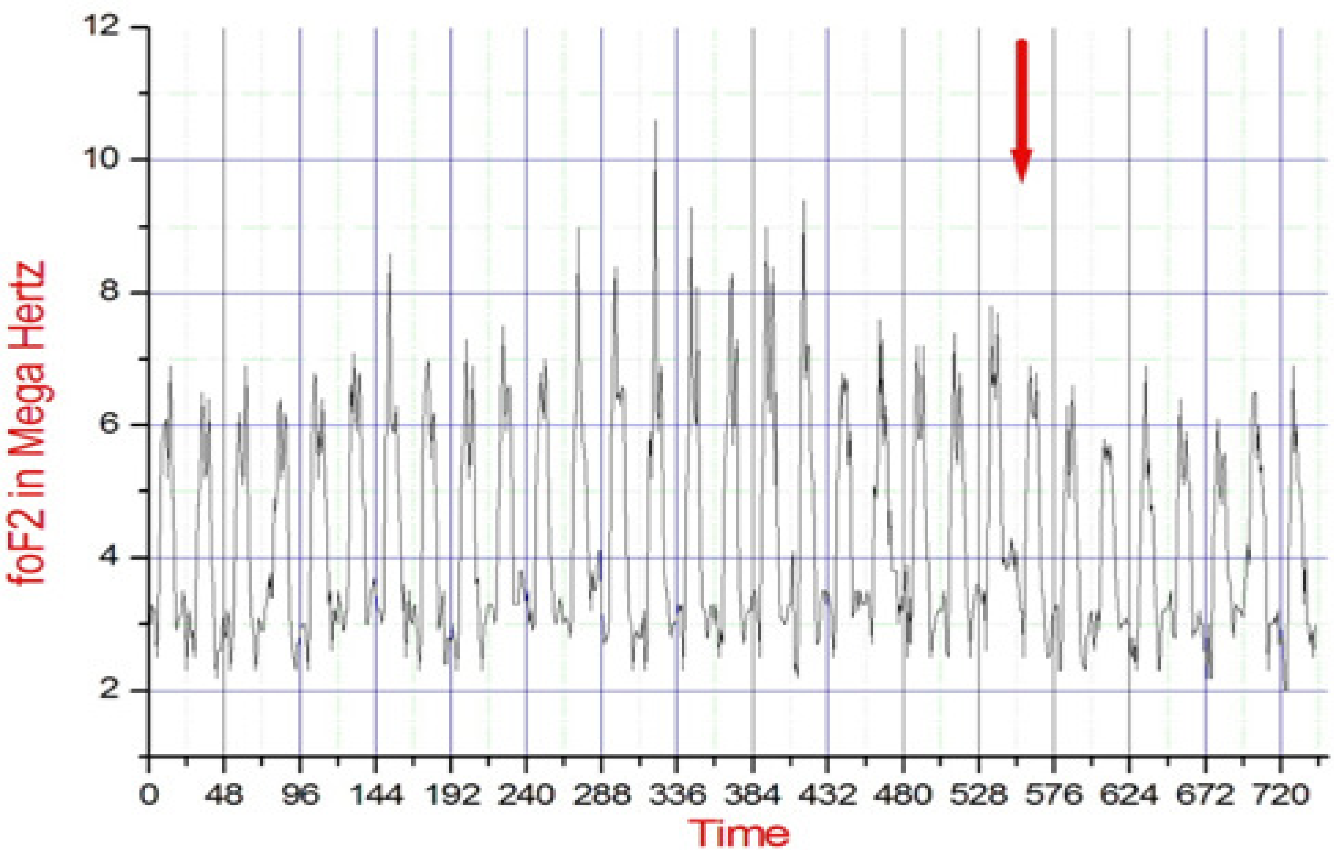

Figure-1
Variation of foF2 for earthquake of January 08, 2006

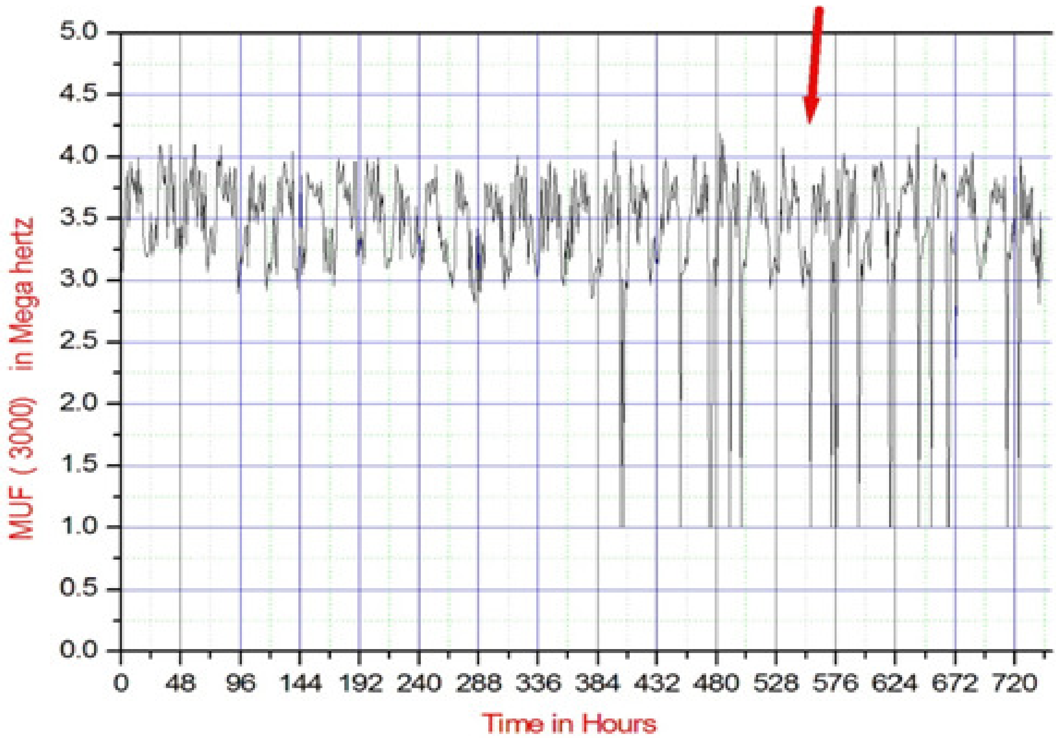

Figure-2
Variation of MUF (3000) for earthquake of January 08, 2006

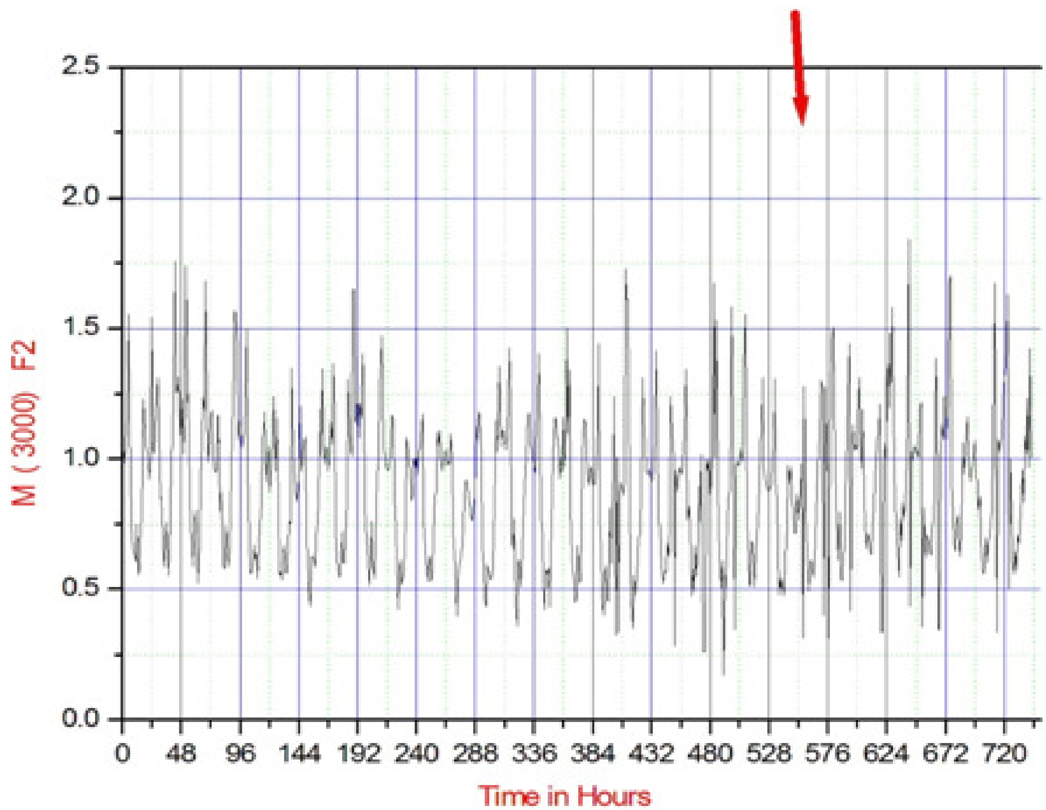

Figure-3
Variation of M (3000) F2 for earthquake of January 08, 2006

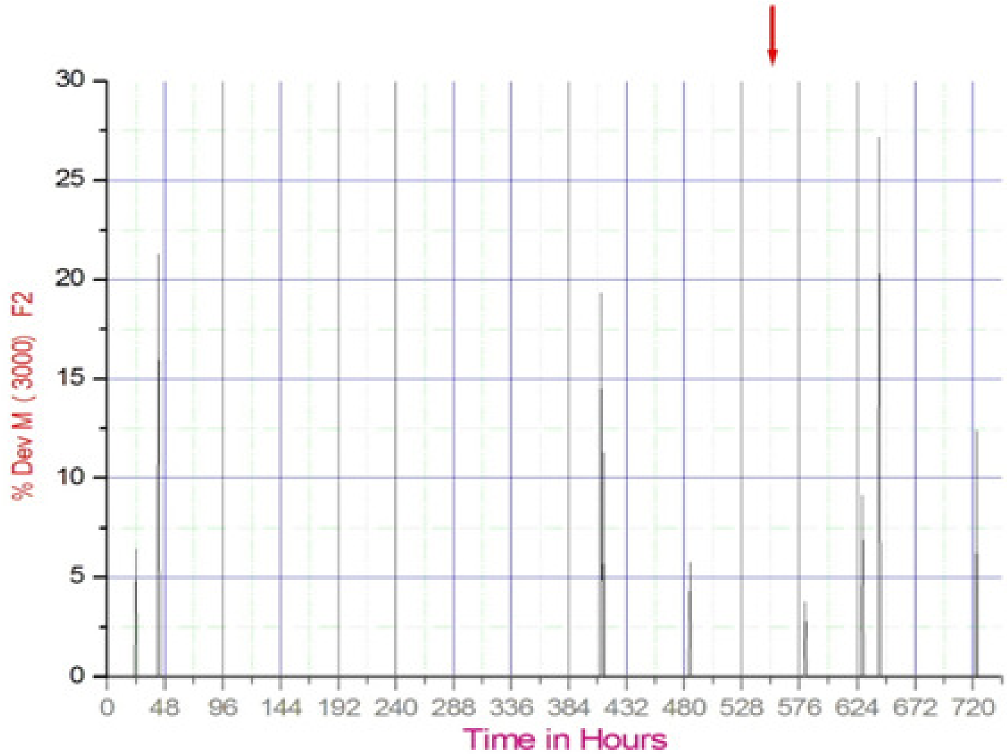

Figure-4
Variation of % Dev. of M (3000) F2 for earthquake of January 08, 2006 [Without filter]

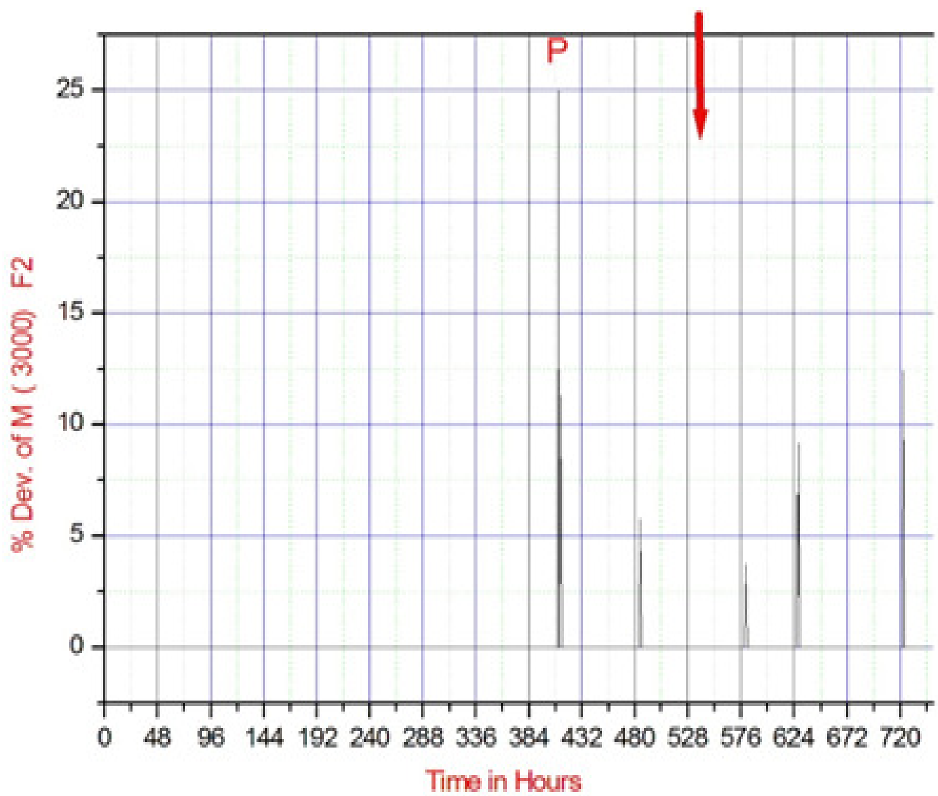

Figure-5
Variation of % Dev. of M (3000) F2 for earthquake of January 08, 2006 [With filter]

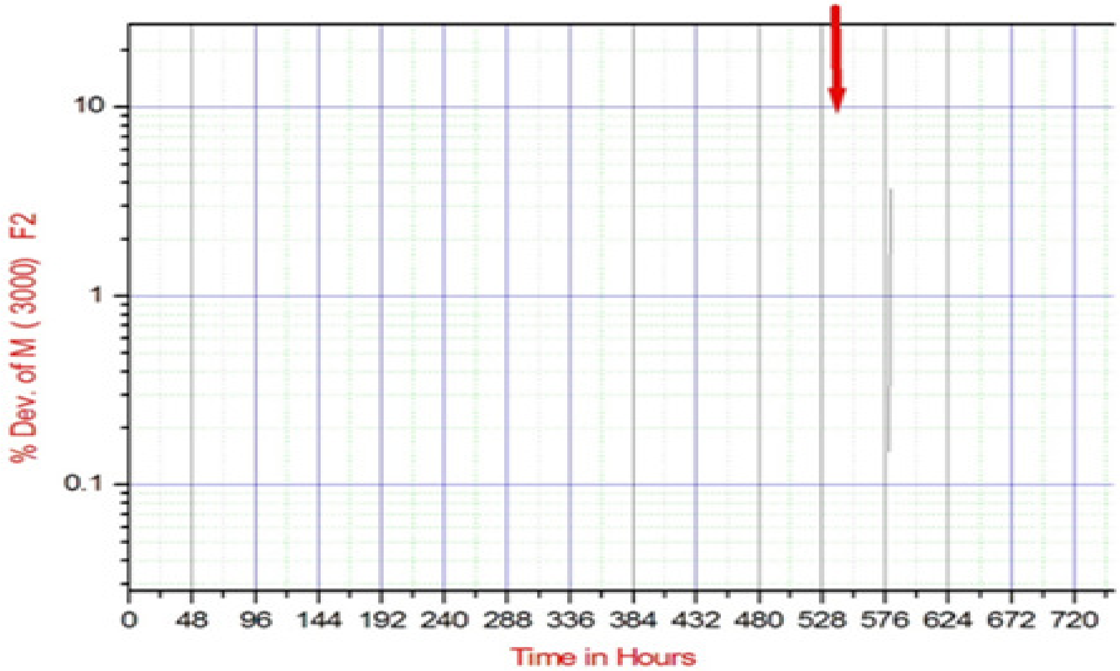

Figure-6
Variation of log % Dev. of M (3000) F2 for earthquake of January 08, 2006 [With filter]

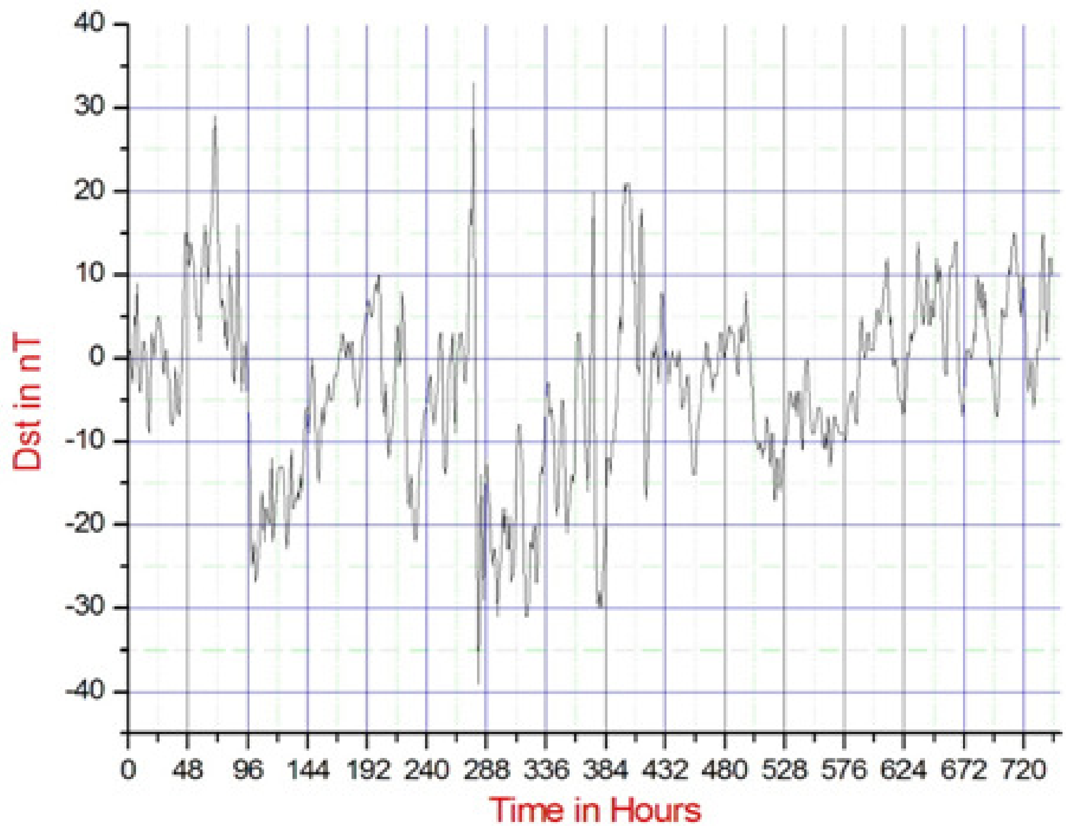

Figure-7
Variation of Dst index [16 January 2005 to 15 January 2006]

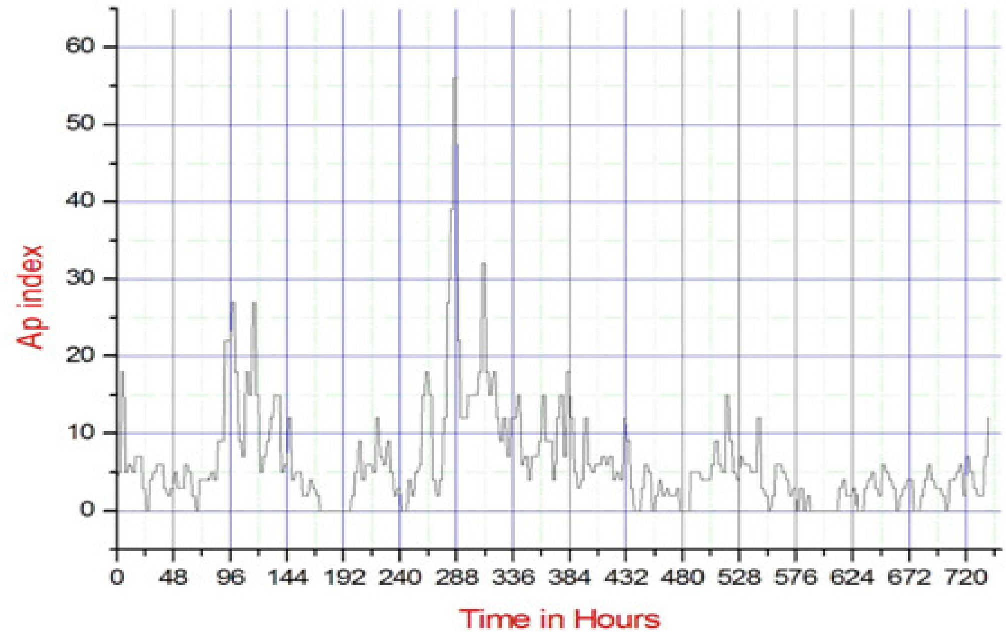

Figure-8
Variation of Ap index [16, December 2005 to 15, January 2006]

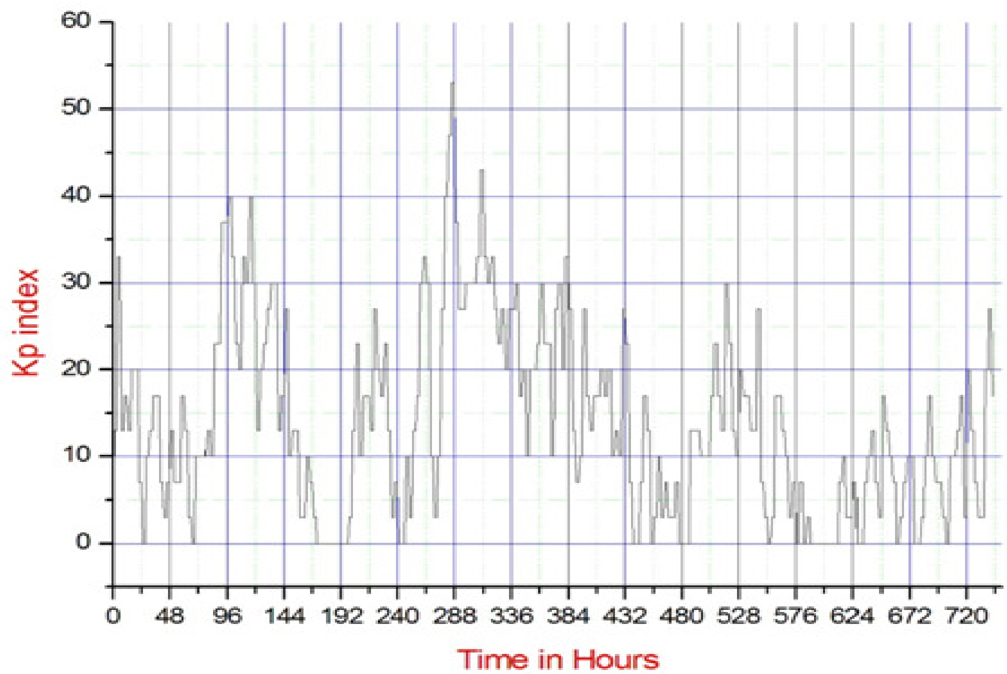

Figure-9
Variation of Kp index [16, December 2005 to 15, January 2006]

Earthquake of March 25, 2007: On March 25, 2007 an earthquake occurred in Greece - Argostolion [38^0N, 20^0E]. The results of M(3000)F2 variations for this case are shown in Figure 10 to 17. Figure 10 shows the variation of foF2. Figure 11 shows the variation of MUF(3000). Figure 12 shows the variation of M(3000)F2. Figure 13 shows the variation of percentage deviation of M(3000)F2 , while there was no filter. Figure 14 shows the percentage deviation M(3000)F2 while solar and geomagnetic disturbances are filtered out by threshold value ±15 nT of Dst index. In this case a significant increase 14 % in M(3000)F2 variations is observed 03 days before the main shock. Figure 15 shows the variation of Ap index. Figure 16 shows the variation of Kp index during seismic event. Figure 17 shows the variation of Dst index during seismic event.

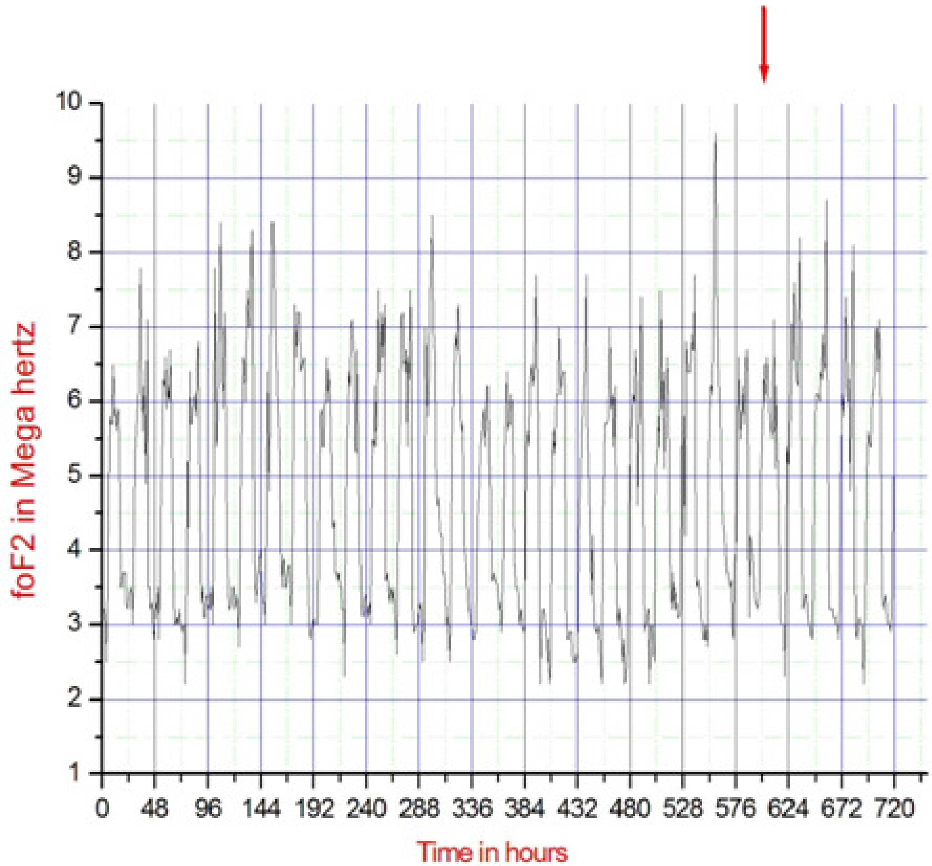

Figure-10
Variation of foF2 for the earthquake of March 25, 2007

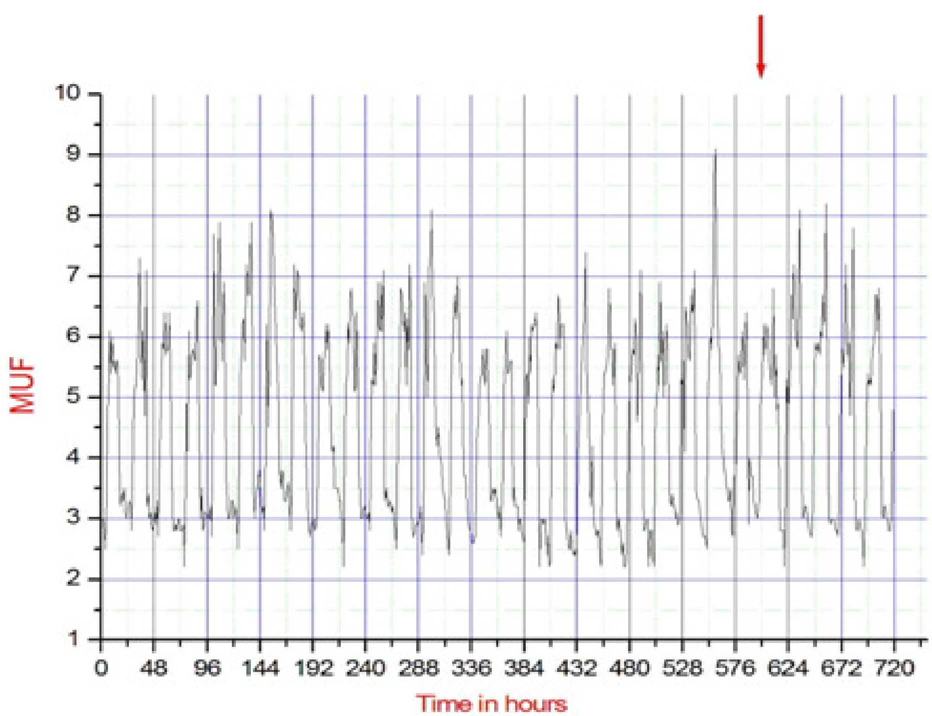

Figure-11
Variation of MUF (3000) for the earthquake of March 25, 2007

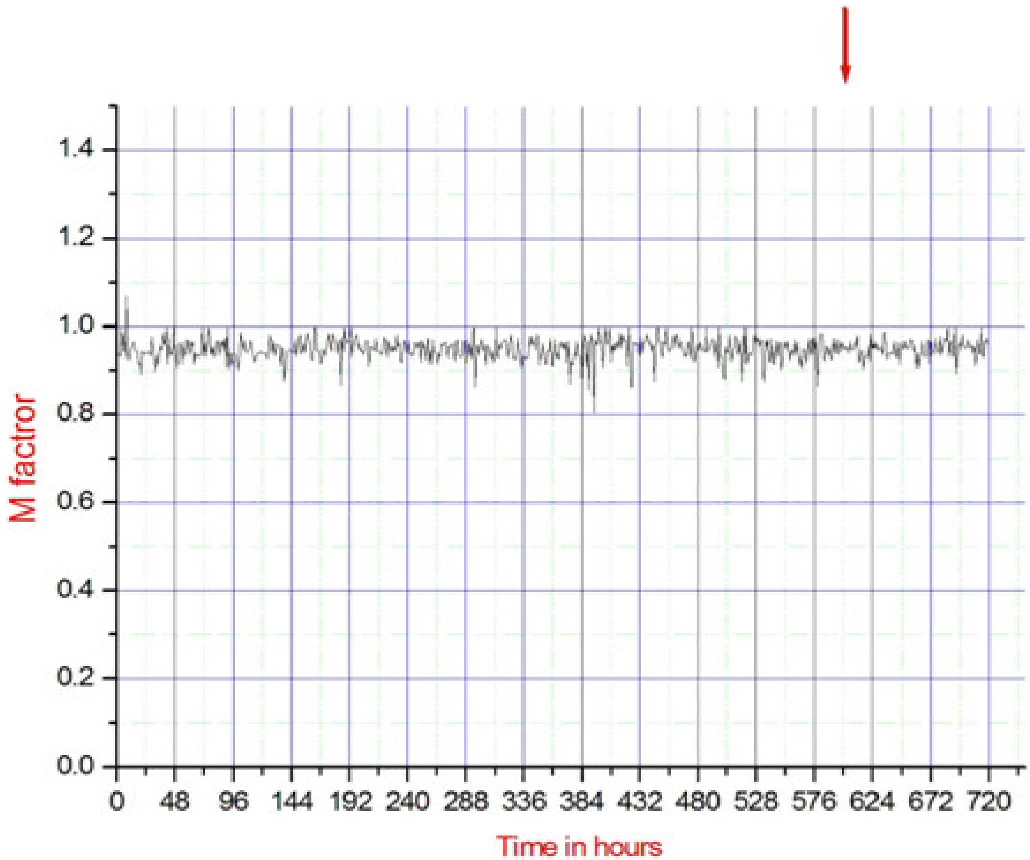

Figure-12
Variation of M (3000) F2 Factor for the earthquake of March 25, 2007

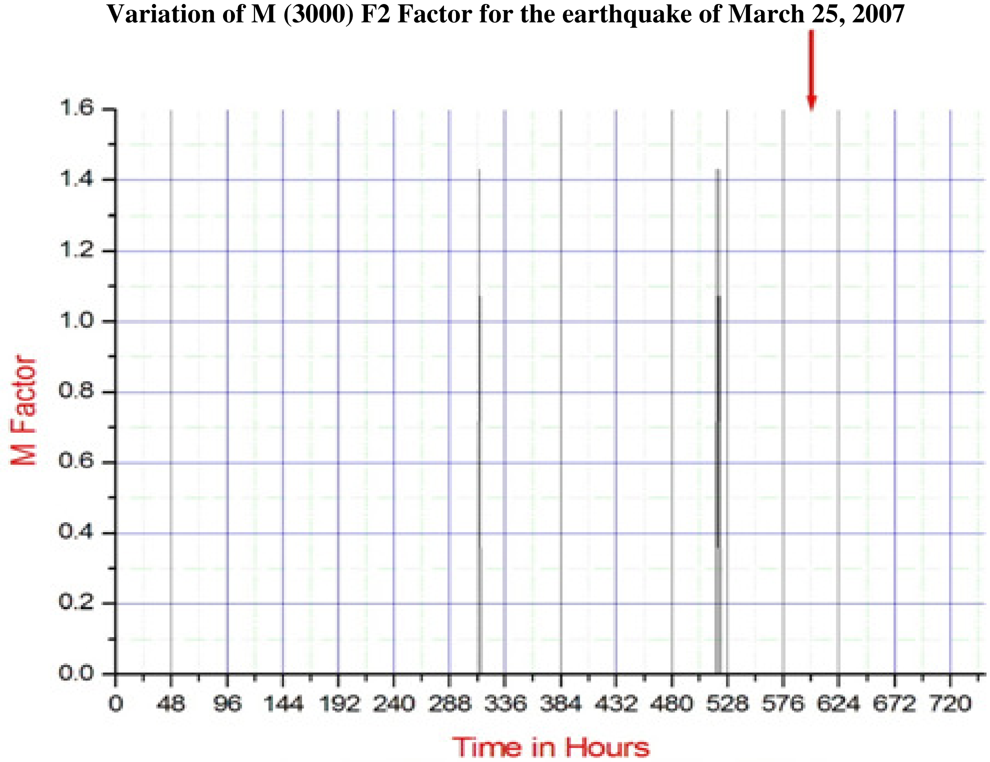

Figure-13
Variation of % Deviation of M(3000) F2 Factor [Without filter]

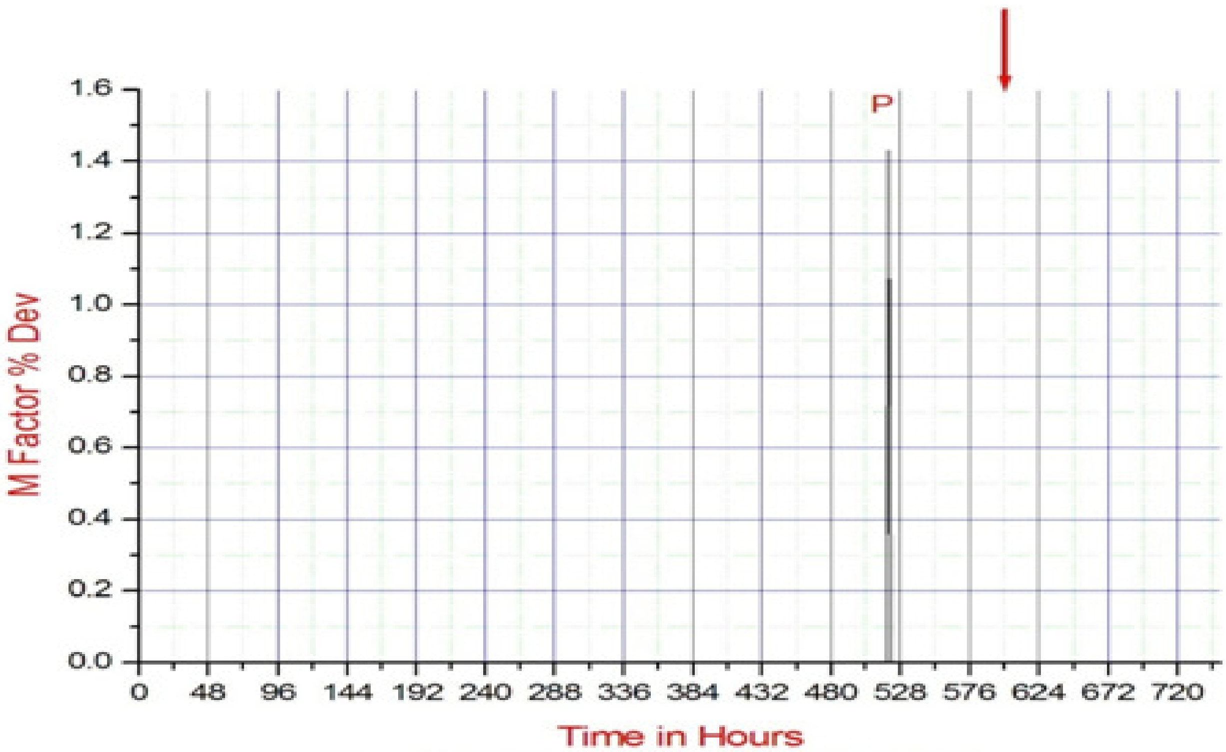

Figure-14
Variation of % Deviation of M(3000)F2 Factor [With filter]

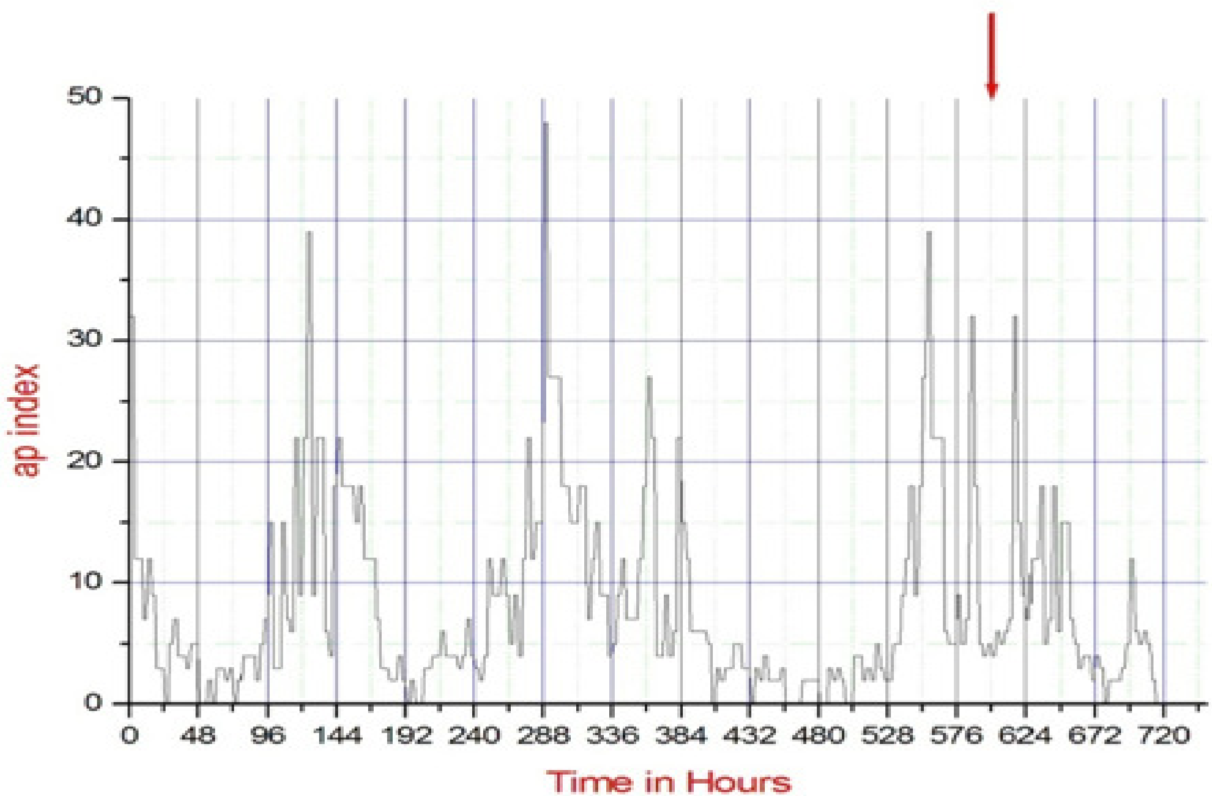

Figure-15
Variation of ap index earthquake of March 25,2007

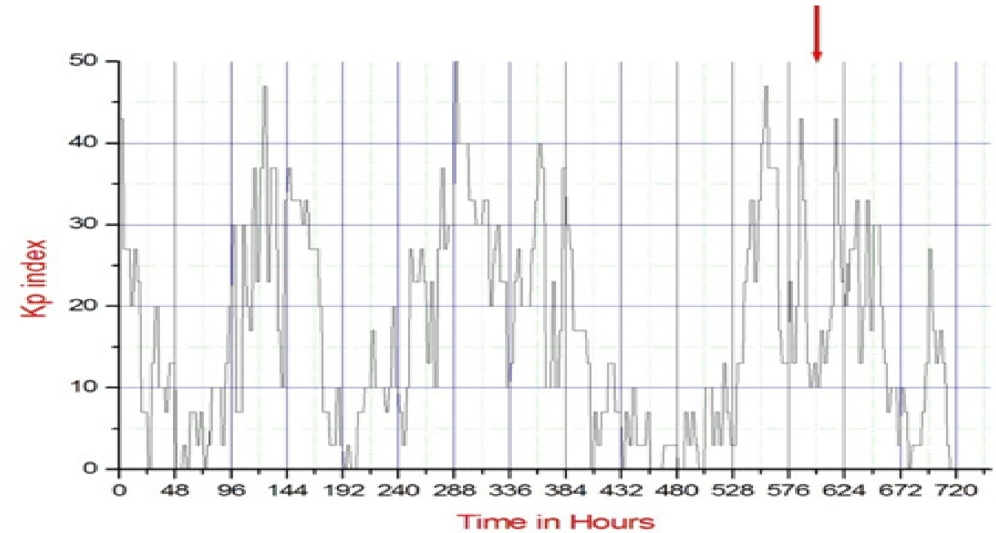

Figure-16
Variation of Kp index for earthquake of March 25, 2007

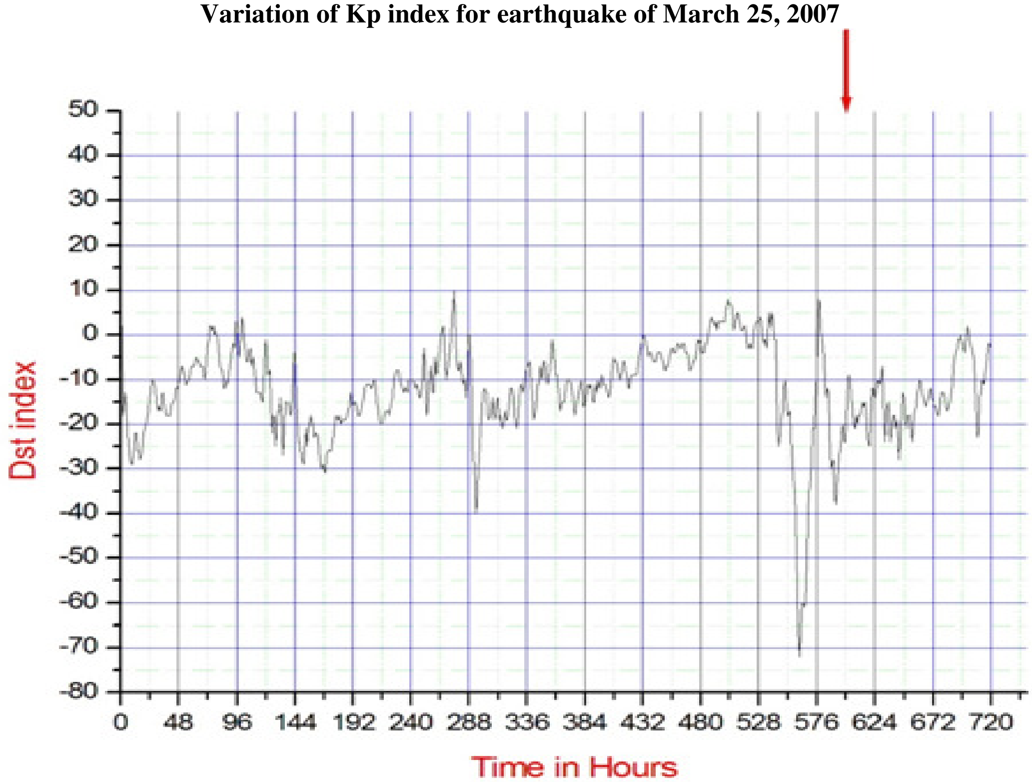

Figure-17
Variation of Dst index for earthquake of March 25,2007

Earthquake of December 26, 2007: On December 26, 2007 an earthquake occurred in Turkey – Central Ankara [39^0N, 33^0E]. The results of M(3000)F2 variations for this case are shown in figure 18 to 25. Figure 18 shows the variation of foF2. Figure 19 shows the variation of MUF(3000). Figure 20 shows the variation of M(3000)F2. Figure 21 shows the variation of percentage deviation of foF2 while solar and geomagnetic disturbances are not filtered. Figure 22 shows the variation of percentage deviation of M(3000)F2 while solar and geomagnetic disturbances are filtered out by threshold value ±15 nT of Dst index. In this case a significant increase 27 % in M(3000)F2 variations is observed 03 days before the main shock and 14 % increase in M(3000)F2 recorded before 23 days. It shows the existence of precursor before 23 days from the main shock. Figure 23 shows the variation in Ap index. Figure 24 shows the variation of Kp index during seismic event. Figure 25 shows the variation of Dst index during seismic event.

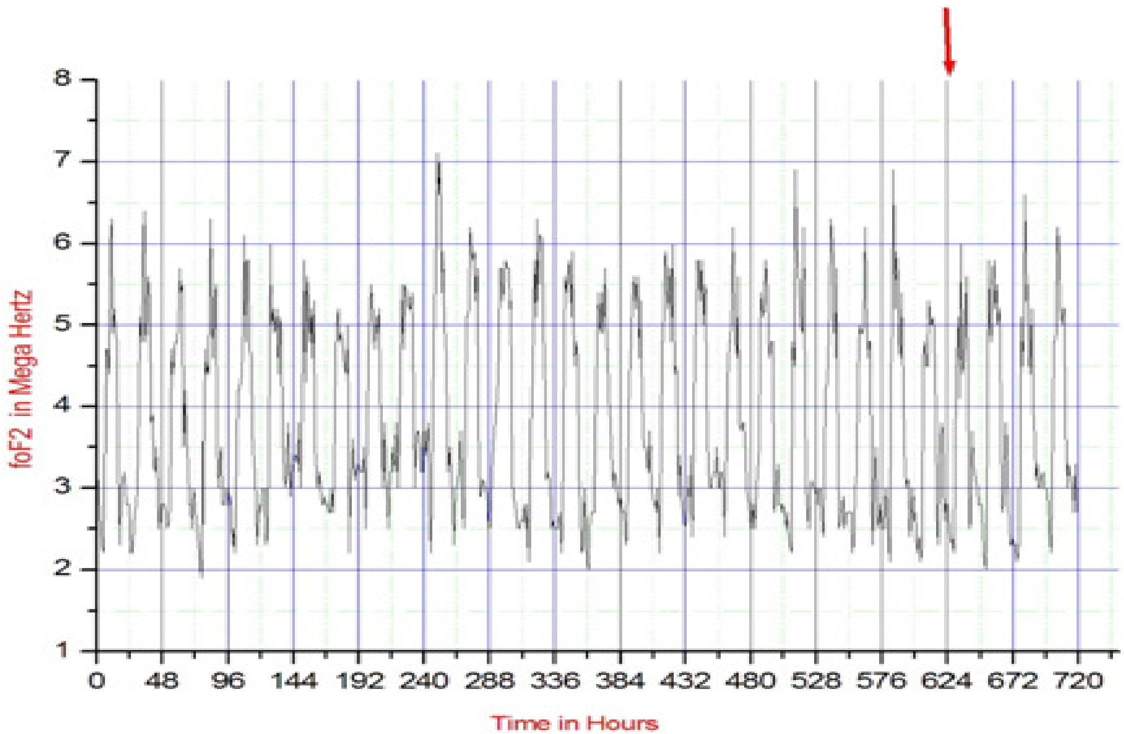

Figure-18
Variation of foF2 earthquake of December 26, 2007

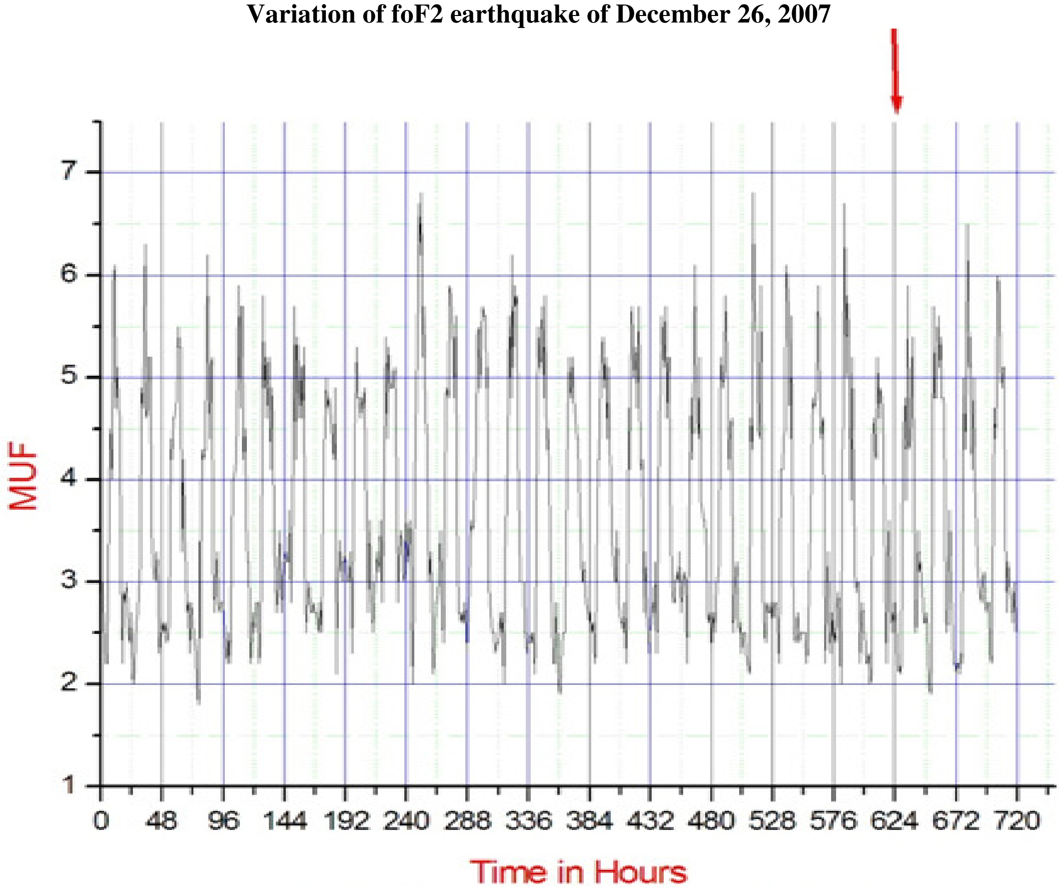

Figure-19
Variation of MUF (3000) Earthquake of December 26, 2007

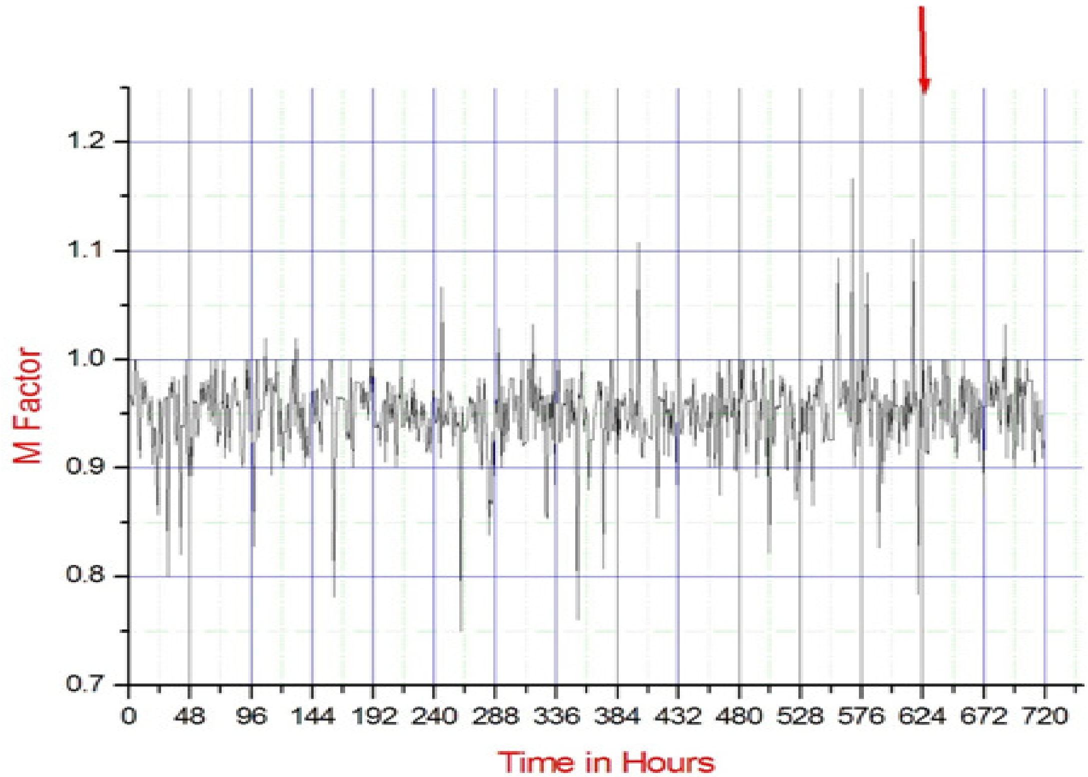

Figure-20
Variation of M(3000)F2 Factor for earthquake of December 26, 2007

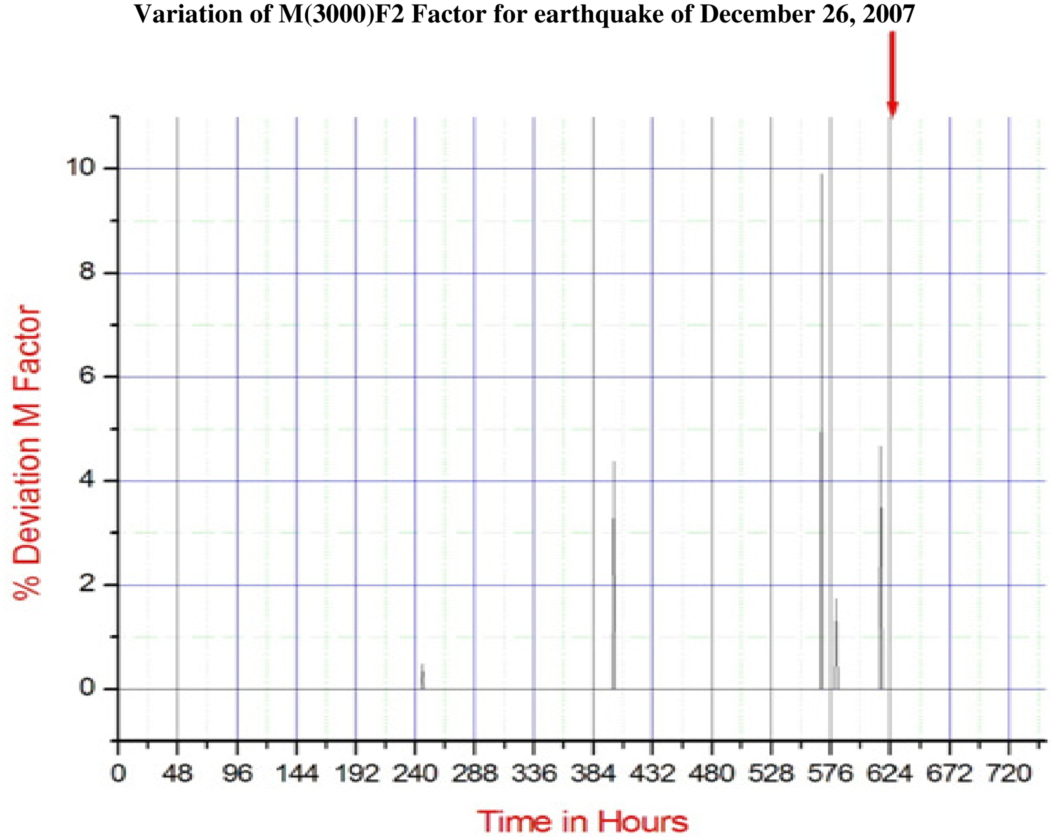

Figure-21
Variation of % Deviation of M(3000)F2 Factor [Without Filter]

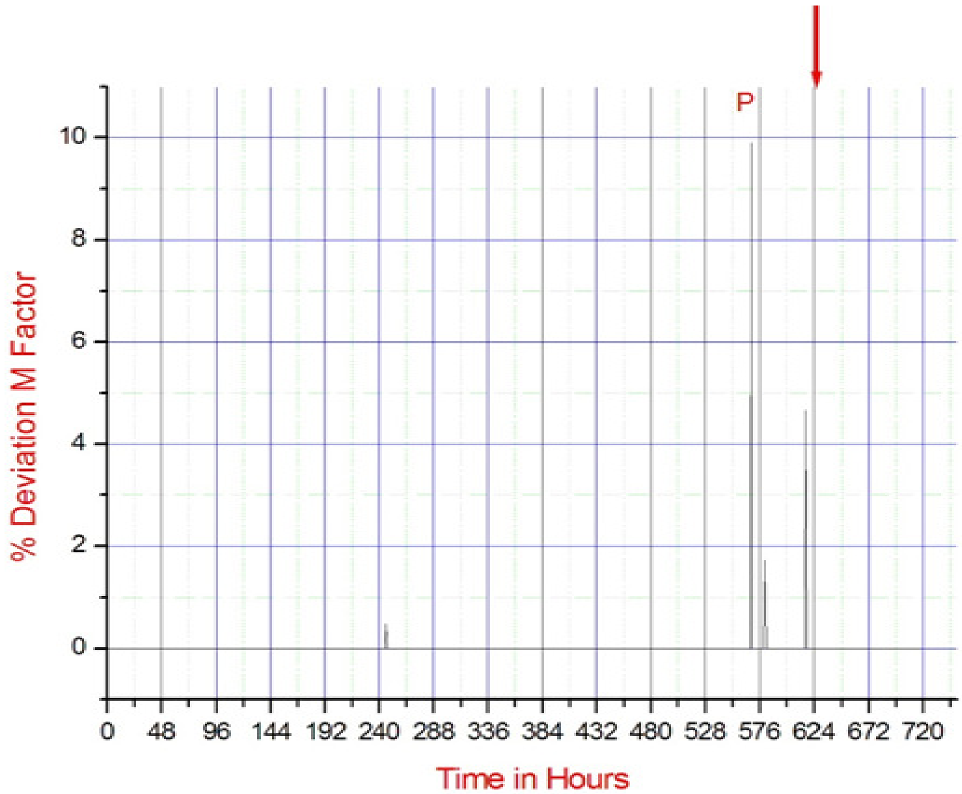

Figure-22
Variation of % Deviation of M(3000)F2 Factor [With Filter]

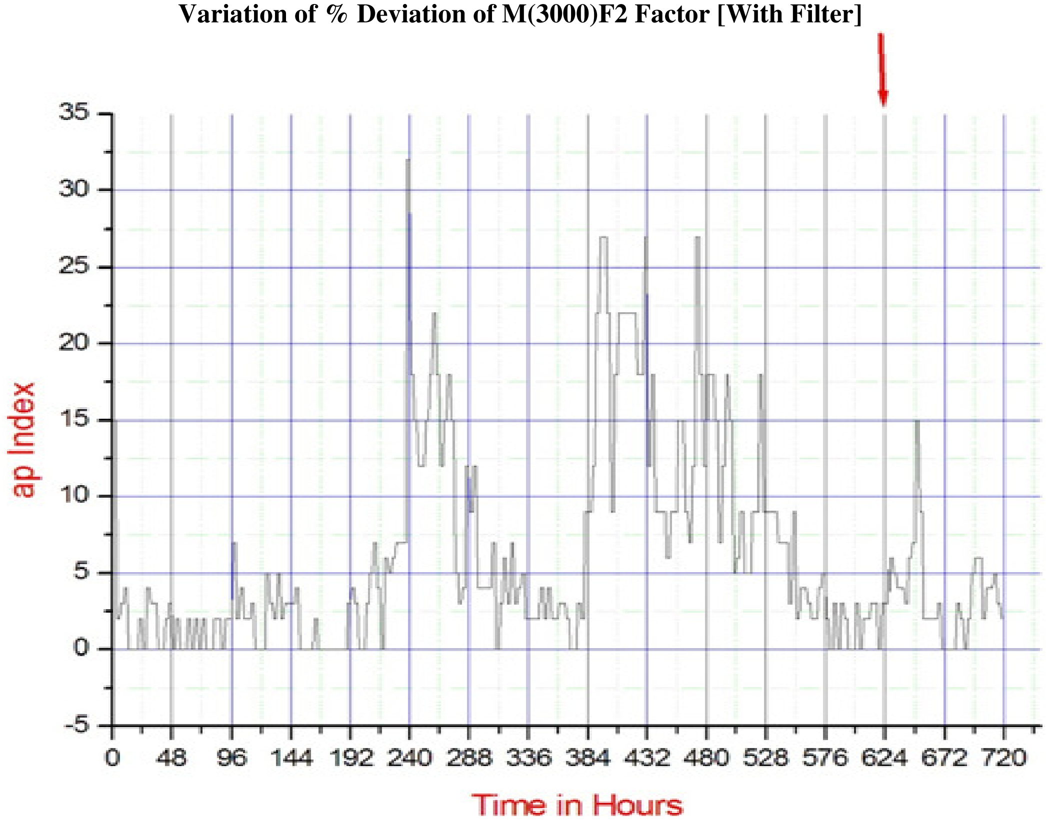

Figure-23
Variation of ap index for Earthquake of December 26, 2007

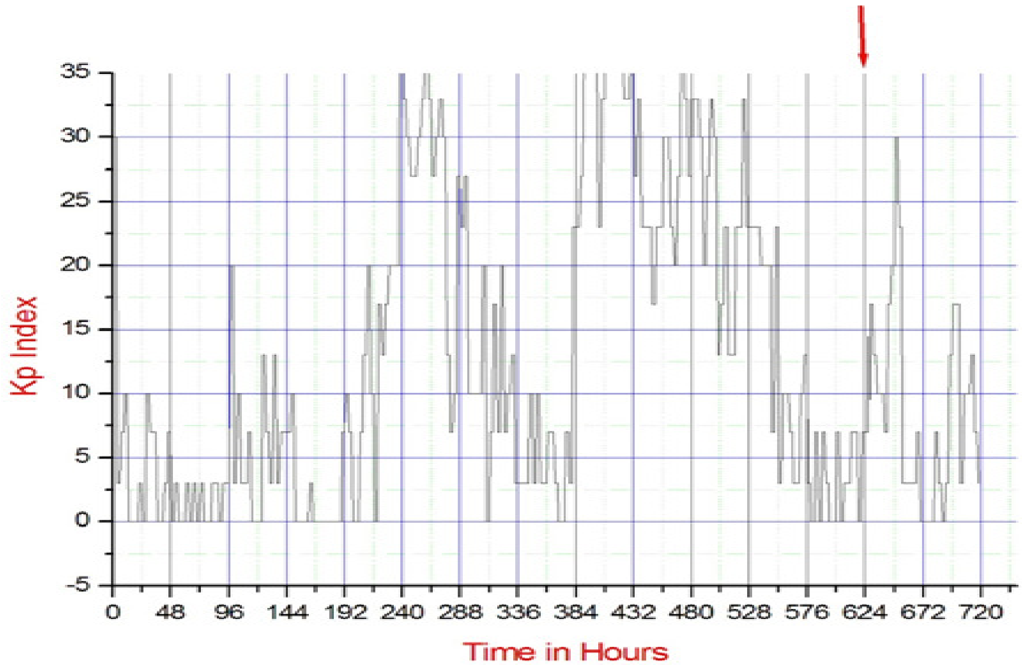

Figure-24
Variation of Kp index Earthquake of December 26,2007

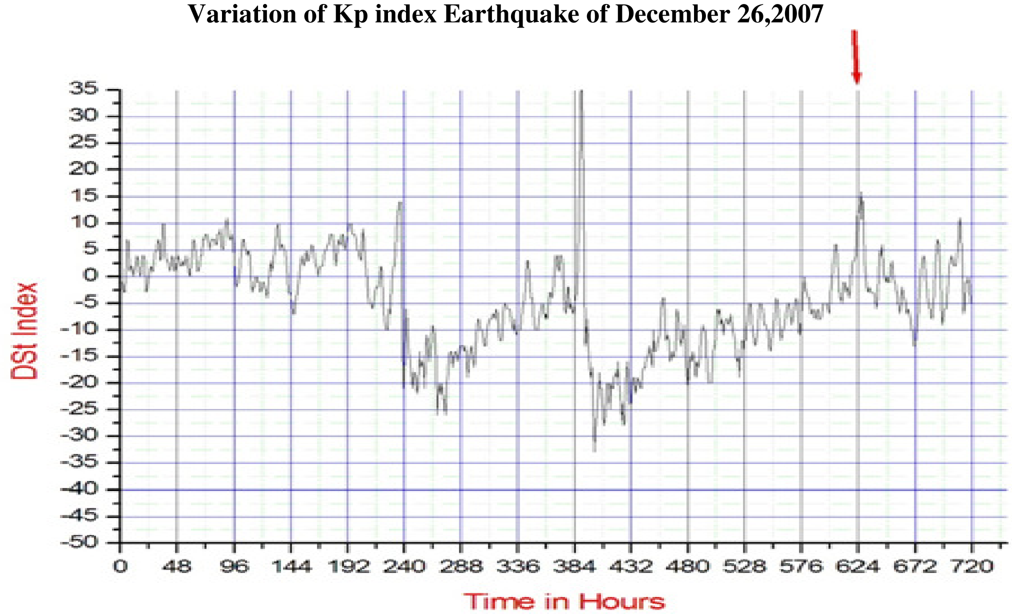

Figure-25
Variation of Dst index

Earthquake of May 24, 2009 that occurred at Balkans: Nw: Macedonia: During the month of May 2009, an earthquake of magnitude 6.1 (on Richter Scale) occurred at Balkans : Nw : Macedone on May 24, 2009. For analysis the M(3000)F2 data of the month of May 2009 analyzed. The bound technique analysis results of M(3000)F2 variations for this case are shown in Figure 26 to 33. Figure 26 shows the variation of foF2 for Athens Station. In the Figure 27 shows the variation of MUF(3000). Figure 28 shows the variation of M(3000)F2. Figure 29 shows the variation of percentage deviation of foF2 while solar and geomagnetic disturbances are not filtered.. Figure 30 shows the variation of percentage deviation of M(3000)F2 while solar and geomagnetic disturbances are filtered out by threshold value ±15 nT of Dst index. In this case a significant increase 27 % in M(3000)F2 variations is observed 02 days before the main shock and 14 % increase in M(3000)F2 recorded before 07 days. It shows the existence of precursor before 22 days prior to the main shock. Figure 31 shows the variation in Ap index. Figure 32 shows the variation of Kp index during seismic event. Figure 33 shows the variation of Dst index during seismic event.

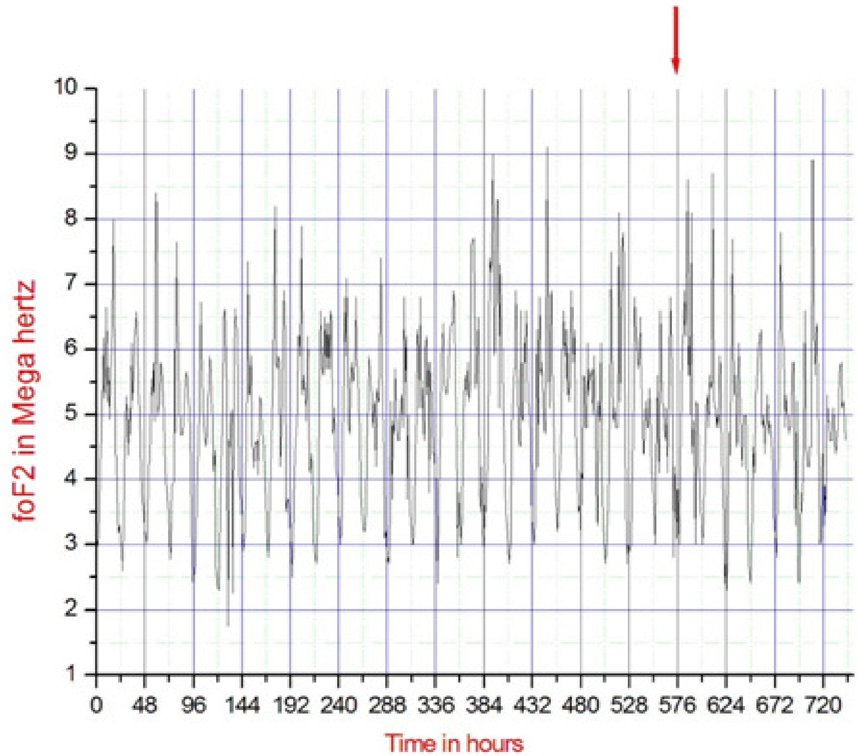

Figure-26
Variation of foF2 for earthquake of May 24,2009

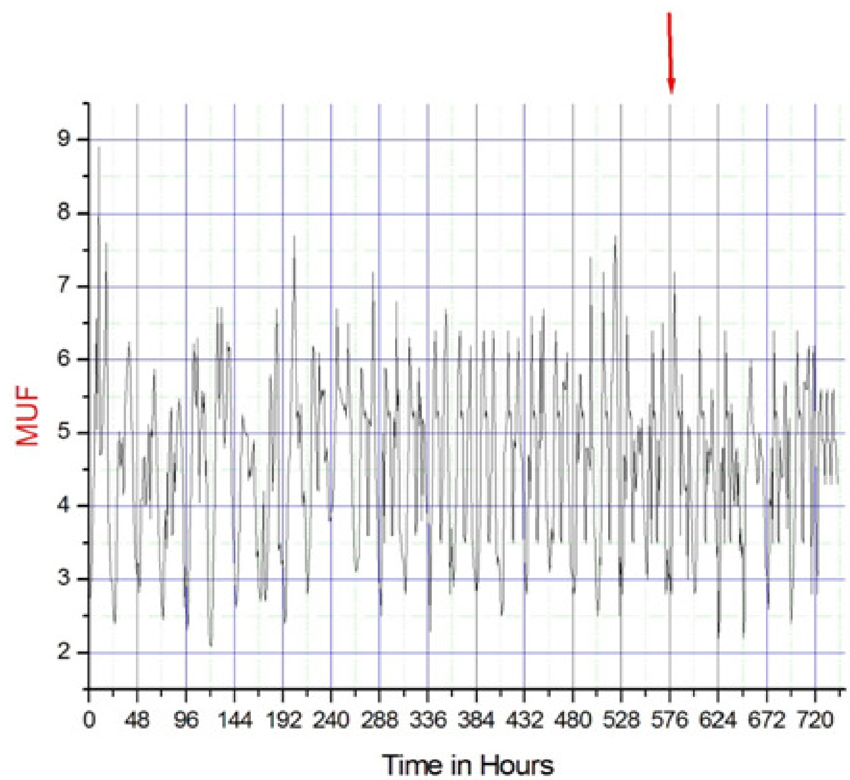

Figure-27
Variation of MUF(3000) for earthquake of May 24, 2009

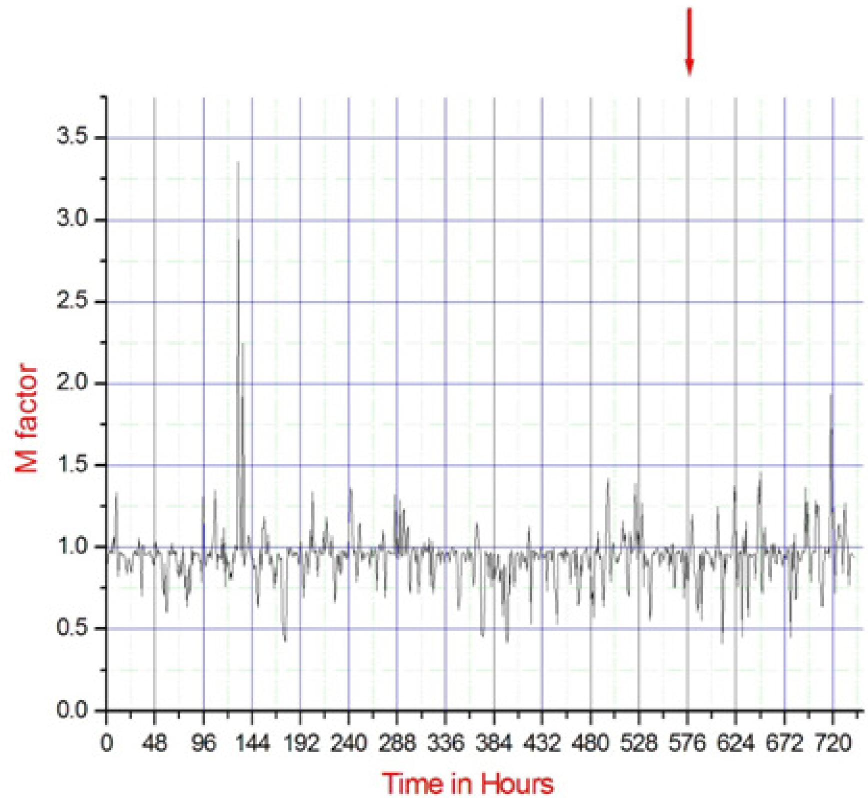

Figure-28
Variation of M(3000) F2 Factor for earthquake of May 24, 2009

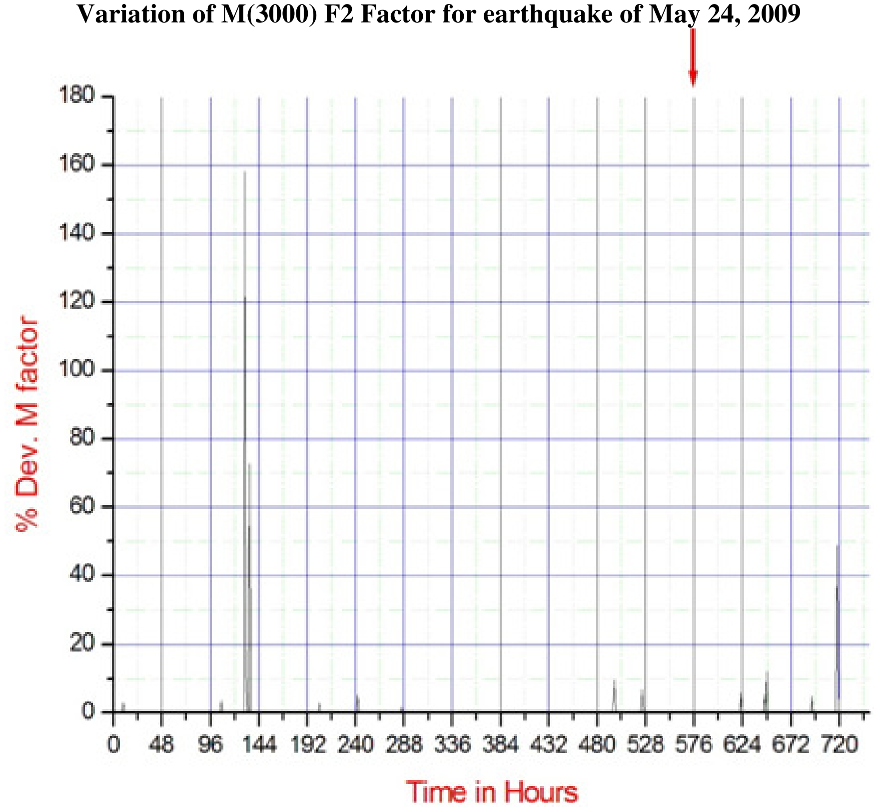

Figure-29
Variation % Dev.of M(3000) F2 Factor for earthquake of May 24, 2009[Without filter]

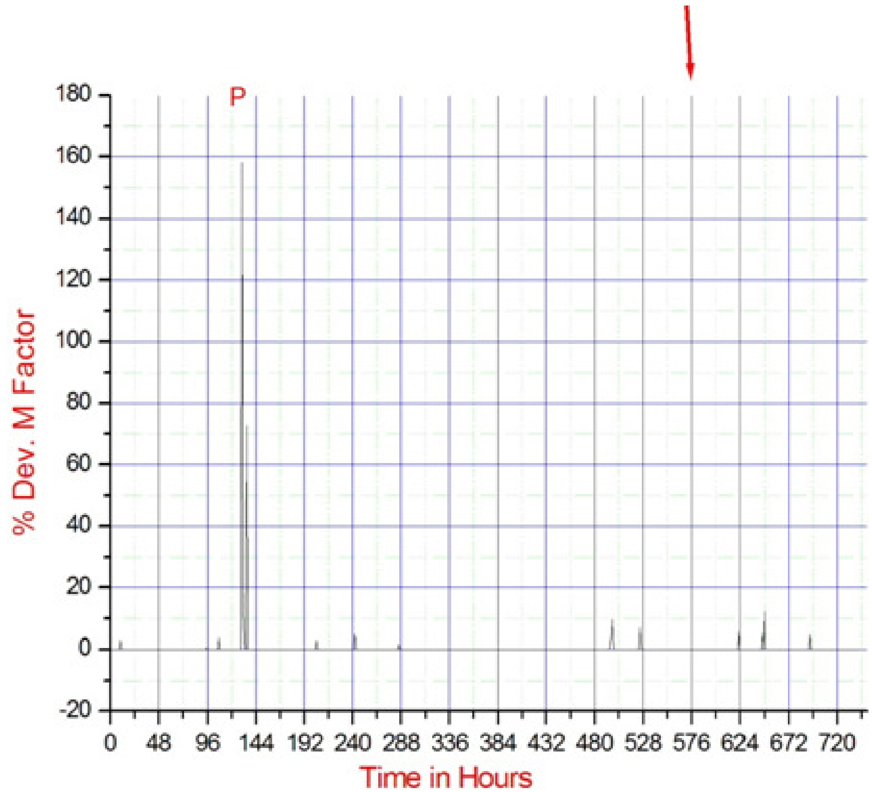

Figure-30
Variation % Dev.of M(3000) F2 Factor for earthquake of May 24, 2009[With filter]

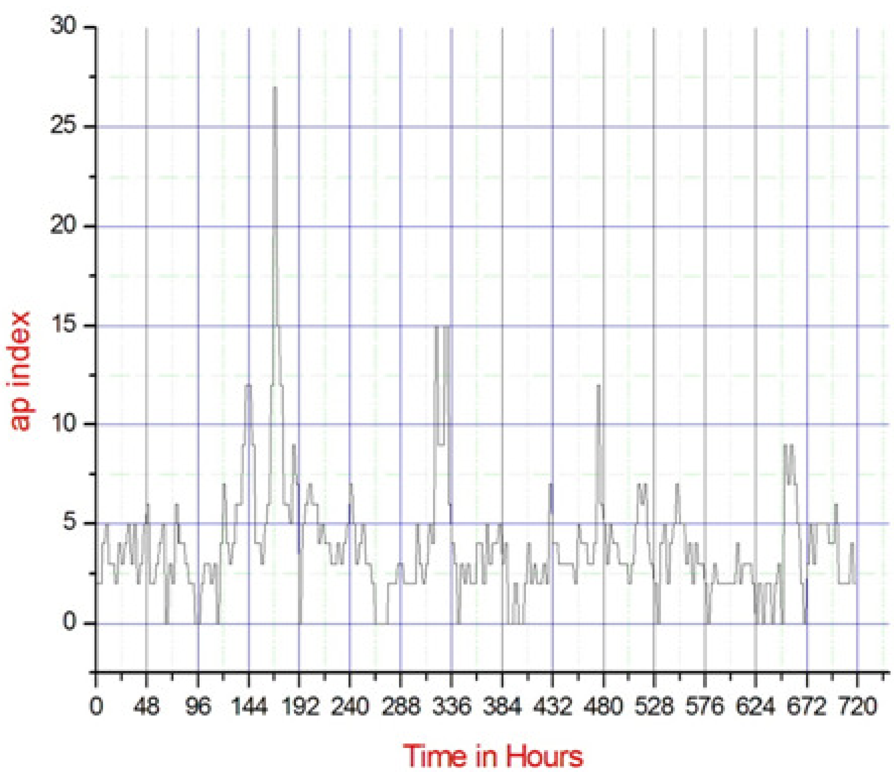

Figure-31
Variation of ap index for earthquake of May 24, 2007

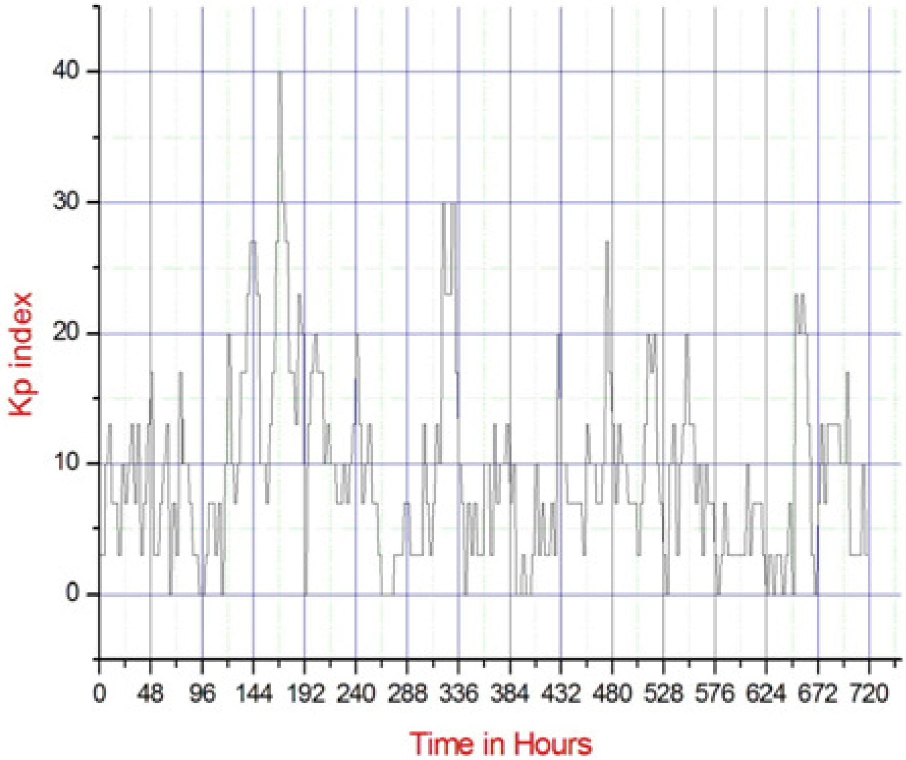

Figure-32
Variation of Kp index for earthquake of May 24, 2007

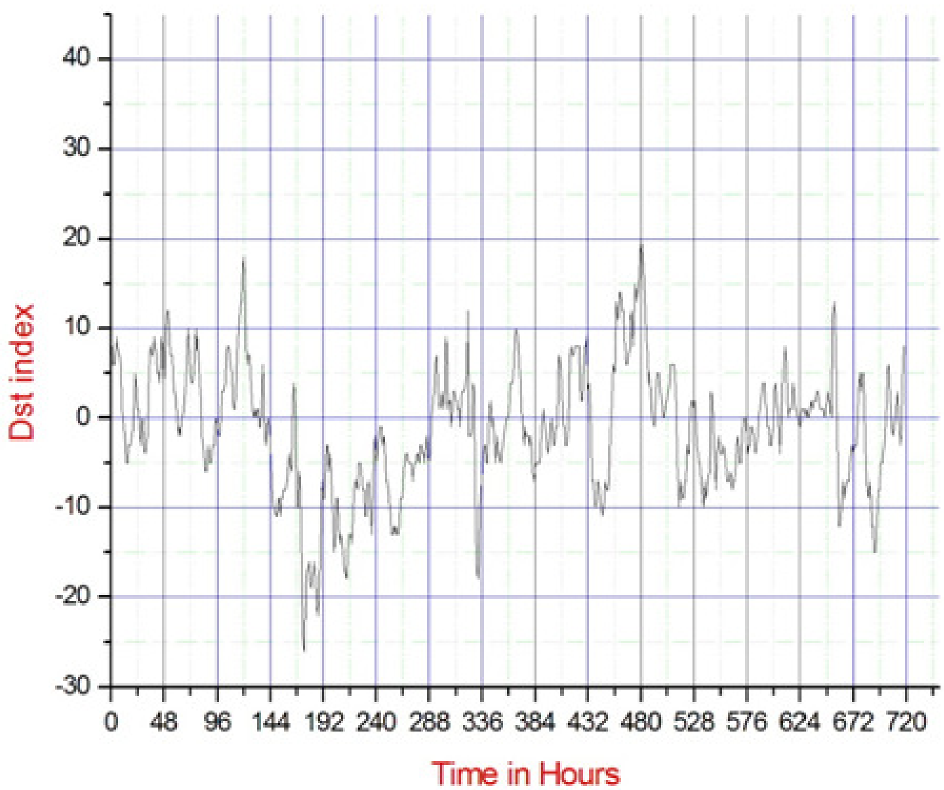

Figure-33
Variation of Dst index for earthquake of May 24, 2007

Discussion: In this article ionospheric data were analyzed using statistical method to find out meaningful ionospheric anomalies related to seismic activities. Results of the analysis shows pre earthquake ionospheric disturbances in ionospheric data. These results shows the strong coupling in ionosphere and lithosphere well before the occurrence of seismic shock. The M(3000)F2 data of four ionospheric stations analyzed for accuracy of results. Our aim of this study is to obtain significant seismic precursor. We know that earth's ionosphere is also affected by the energy coming from the sun, which strike the magnetic field of the earth. Thus during the period of geomagnetic disturbances, it is extremely complex to resolve meaningful perturbation in the ionosphere associated to earthquake. But if we find any perturbation in calm geomagnetic period, than we can declare that it may be due to earthquake or the energy coming from below. In our analysis, we filtered the perturbations related to geomagnetic activity by setting the threshold value of 'Disturbance storm time index' (Dst) ± 15. Our results are in the line of in agreement by other workers [4,23,24,26-28]. The most important reason of these observed ionospheric anomalies might be due to the generation of seismogenic field just above the surface of the earth during the earthquake preparation period as reported by other workers [29,30,33,34]. The generation of seismogenic electric field is due to the emission of radioactive particles into the atmosphere prior to seismic activity within the area of earthquake preparation zone. The process of emission of Radon like particles modifies the height distribution of electric conductivity and induced the supplementary electromotive force in the inferior ionosphere [31]. Thus, the earth-ionosphere system is modified due to this global closed circuit. This type of modification in global closed circuit leads to perturbation of the ionoshere well before the main shock of earthquake. Similarly Pulinets and Benson[32] 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.

Conclusion

In this work, we have shown significant perturbations in ionospheric Maximum Usable Frequency Factor M(3000)F2 parameter prior to seismic event. These perturbations were recorded in all four cases of earthquake. These results may be beneficial in seismic precursor study.

Acknowledgement

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