

## Study of Ionospheric Perturbations during Strong Seismic Activity by Correlation Technique using NmF2 Data

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### Abstract

Present paper deals the variation in NmF2 (Maximum electron density of F2 layer) parameter by correlation technique at the time of strong seismic activity. We used Ionosonde data which installed at different locations for analysis purpose. We used two ionosonde receivers, where one is in the earthquake preparation zone and the other is out side of it. By correlation technique we calculate Auto Correlation Coefficient and Cross-Correlation Coefficient. Results of the study showed the anomaly in Correlation Coefficients related to NmF2 parameter few days before the seismic event. This fact can be regarded as precursory phenomena. The anomaly in the F-layer density may be interpreted as a result of associated seismic electric field generated by internal gravity waves. It may be due to the inflow of energy from the earth and then propagated upward, which perturb the F-region of ionosphere. This study may be beneficial for prediction of earthquake.

**Keywords:** NmF2, ionosphere, earthquake, ionospheric precursors.

### Introduction

Ionospheric disturbances by seismic activity, such as volcanic eruptions and earthquakes, have been studied since 1965. Measurements made from the ground based instrument, show a change of the critical frequency (foF2) of F2 layer before and after the seismic event. Pulnests and Legen'ka<sup>1</sup> have shown seismic ionospheric variations are strongly time dependent before the beginning of the main shock. Ionospheric disturbances related to seismicity are generated, some days before the main seismic shock, but at that moment the displaced region is not located above the epicentre, but rather displaced from it. These kinds of perturbations can be transferred along magnetic field lines into the conjugate regions in the opposite hemisphere. By the help of ground based ionospheric sounders variations of the critical frequencies of the ionospheric layers were mainly observed, but measurements of the Total Electron Content (TEC) by satellites can also be used<sup>2</sup>. The total electron content gives the sum of the electron density between the altitude of the satellite and the ground. Hence TEC parameter is mainly related to the density in the F-layer which is larger than in the others. This method has been used to detect perturbations due to an earthquake by Calais and Minster<sup>3</sup>. Zaslavski<sup>4</sup> have used a statistical method with TEC data from TOPEX – POSEIDON to check correlations between ionospheric perturbations and seismic event. Liu<sup>5</sup> also used a statistical method to derive the ionospheric TEC from data recorded by a network of the Global Positioning System (GPS) in Tiawan. It based on the network data the latitude time – TEC plots are constructed and showed that 1-4 days prior the three earthquakes on sets, TEC values decreases and

anomaly crusts move toward the equator. Further, the simultaneously deduced overhead TEC and the foF2 observed at Chung – Li during the three earthquakes are compared and examined. In a publication of Liu<sup>6</sup> a statistical analysis of TEC anomalies has been performed before strong earthquake. With the help of top sound sounder installed onboard the intercosmos-19 satellite, strong variations in the vertical structure of the ionosphere over the region of preparing earthquake was discovered by Pulnests . These include variations of electron density in F- layer maximum manifested in critical frequency variations. The density height distribution variations imply a change of the positive ion composition within the F-layer of the ionosphere. The ionosphere rises over the seismo - active region forming a dome of density depletion. These variations are most intensive for specific intervals of local time i.e. before the sun rise and in afternoon hours. In this chapter we studied the data of maximum electron density in F-region of the ionosphere. We studied four cases of earthquake at different locations and find anomaly in electron density data before the seismic event.

**Data:** In this study data of NmF2 were obtained from NOAA space environment centre. We used ionospheric data base of 2005 to 2009. We used SWPC Anonymous FTS for downloading ionospheric data base. These ionospheric data base was prepared by the U.S. Department of Commerce NOAA, space weather prediction centre. For earthquake data characteristics we used NGDC acquiesces, processes which disseminates the data in many usable format. We used the global significant earthquake data base from 2005 to 2009.

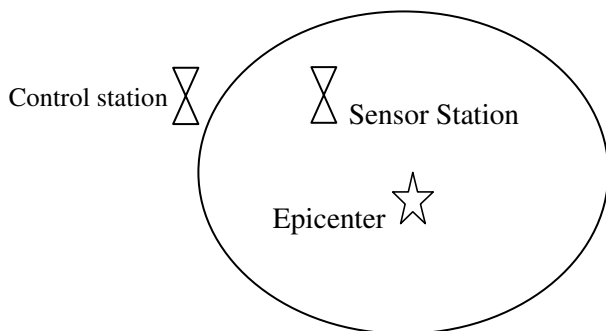
## Material and Methods

The ionospheric variability given by maximum electron density of F2 layer (NmF2) is studied in relation to the major earthquakes occurred on January 08, 2006 and March 25, 2007. The idea to use the correlation between the neighbor ionospheric stations to reveal the seismogenic variations in F2 layer of ionosphere was studied. In this study we measure the maximum electron density of two different ionospheric stations. In this technique we use an idea of earthquake preparation zone and correlation radius. To determine the radius of correlation associated with the seismic activity the conception of the earthquake preparation area was used. It is supposed that ionospheric variability associated with seismic activity will be observed over the earthquake preparation area. The radius of earthquake preparation area is given by the following formula:

$$R = 10^{.43M} \quad (1)$$

Where R is the radius of earthquake preparation area and M is the earthquake magnitude.

In this method two measuring points are used: one (Sensor station) is located in side of earthquake preparation zone, and second station (Control station) is located outside of earthquake preparation area.



**Configuration of the measurement of earthquake preparation area:** Above figure shows the radius of earthquake preparation zone, epicenter and sensor station and control station. In general, it is not obligatory to put the “Control Station” outside the earthquake preparation zone but it is sufficient if it will be quite far from the epicenter. We calculated the daily cross – correlation coefficient by the following formula:

$$C = [\Sigma \{(NmF2_{1i} - \langle NmF2_{1i} \rangle) * (NmF2_{2i} - \langle NmF2_{2i} \rangle)\} / (k \sigma_1 \sigma_2)] \quad (2)$$

Here indices 1 and 2 correspond to the “Sensor” and “Control” ionosonde stations respectively, NmF2 (Maximum electron density of F<sub>2</sub> layer) is represented by time series, the NmF2 values are calculated from the ionosonde measurements, k = 24 (or 96 or 144) points is the number of samples per day (traditionally k = 24 for t = one hour sampling interval is used for ionospheric soundings, k = 96 for 15 minute interval is used), the mean value  $\langle NmF2 \rangle$  and standard deviation  $\sigma$  are determined by the following expression:

$$\langle NmF2 \rangle = [\Sigma \{(NmF2)_i / k\}] \quad (3)$$

$$\sigma^2 = \Sigma [(NmF2)_i - \langle NmF2 \rangle]^2 / k \quad (4)$$

Where  $\langle NmF2 \rangle$  is the daily mean value of the critical frequency and  $\sigma$  is the standard deviation. We applied this method on the series of earthquakes in the different areas of earth. As an example we will consider the data of two stations: Athens (38° N and 24° E) and San-Vito (40° N & 17° E). The first one is inside the main seismo - active area.

## Results and Discussion

**Case I – Earthquake of January 08, 2006:** In this study ionospheric variations are examined before the two earthquakes that occurred during December 2005 to June 2009. The results related to these earthquakes are described below:

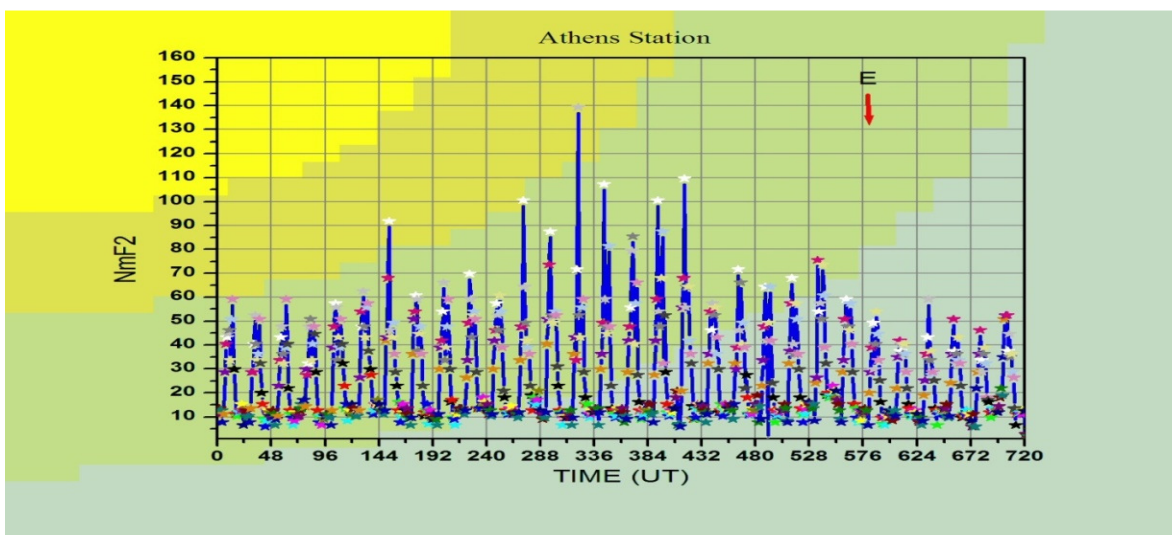
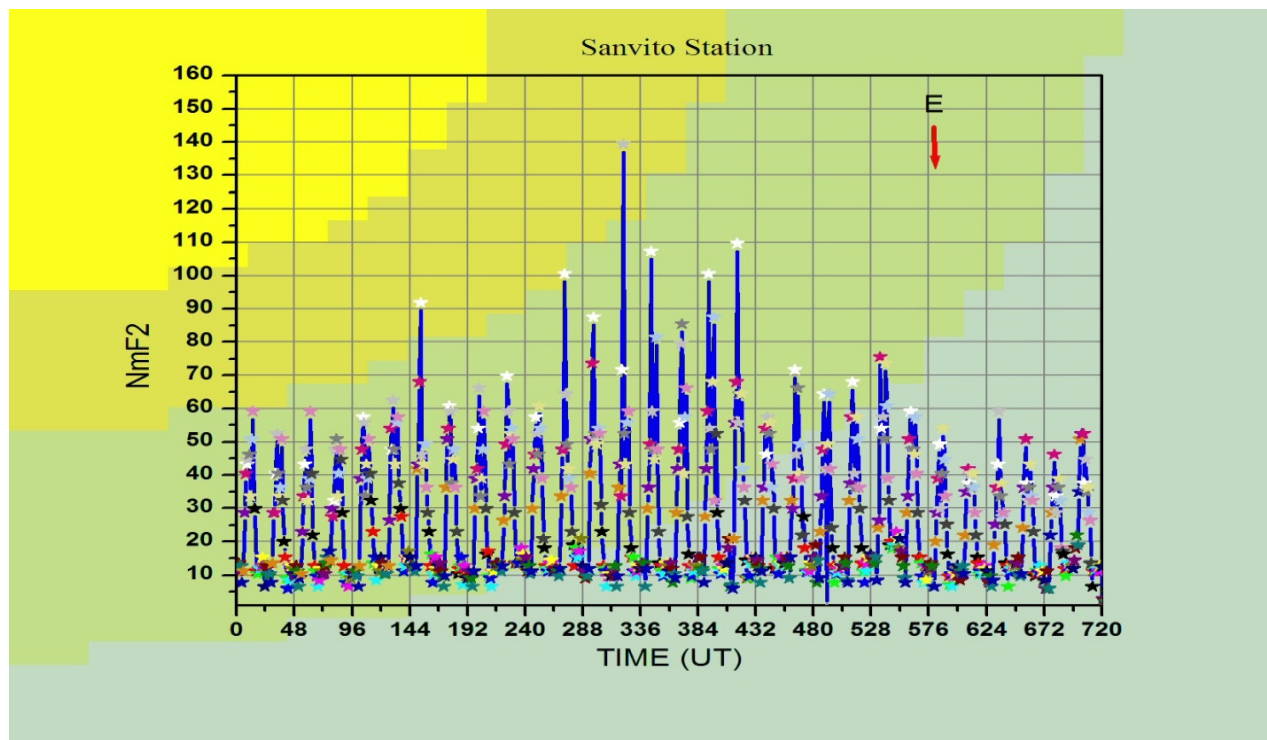
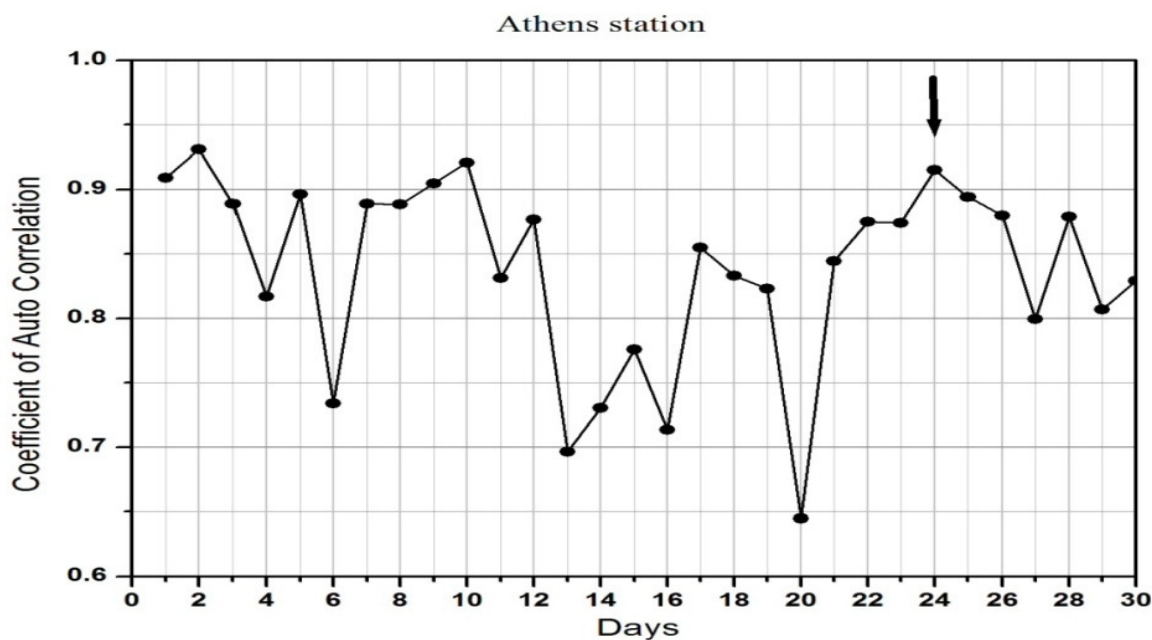


Figure-1

Study of Variation of NmF2 [Data used from 16 Dec. 2005 to 15 Jan. 2006] Earthquake occurred on Jan. 08, 2006



**Figure-2**  
 Study of Variation of NmF2 [Data used from 16 Dec. 2005 to 15 Jan. 2006] Earthquake occurred on Jan. 08, 2006



**Figure-3**  
 Auto Correlation Coefficient

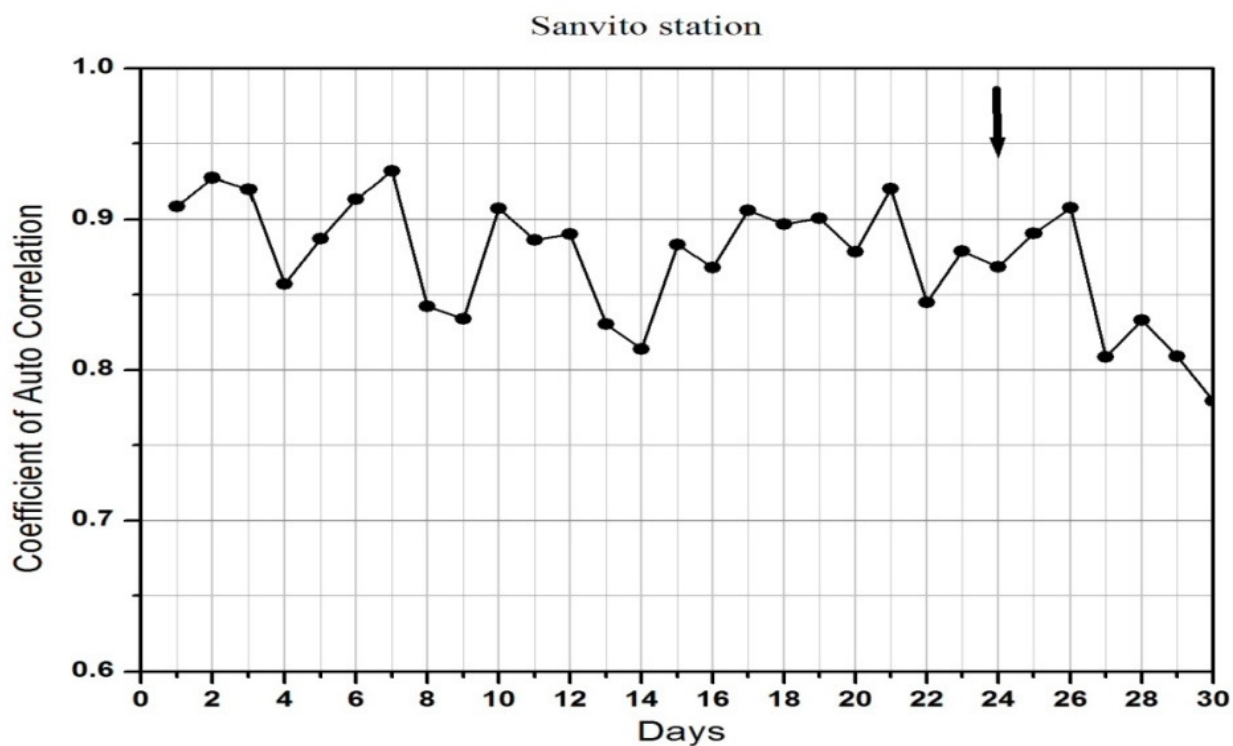


Figure-4  
Auto Correlation Coefficient

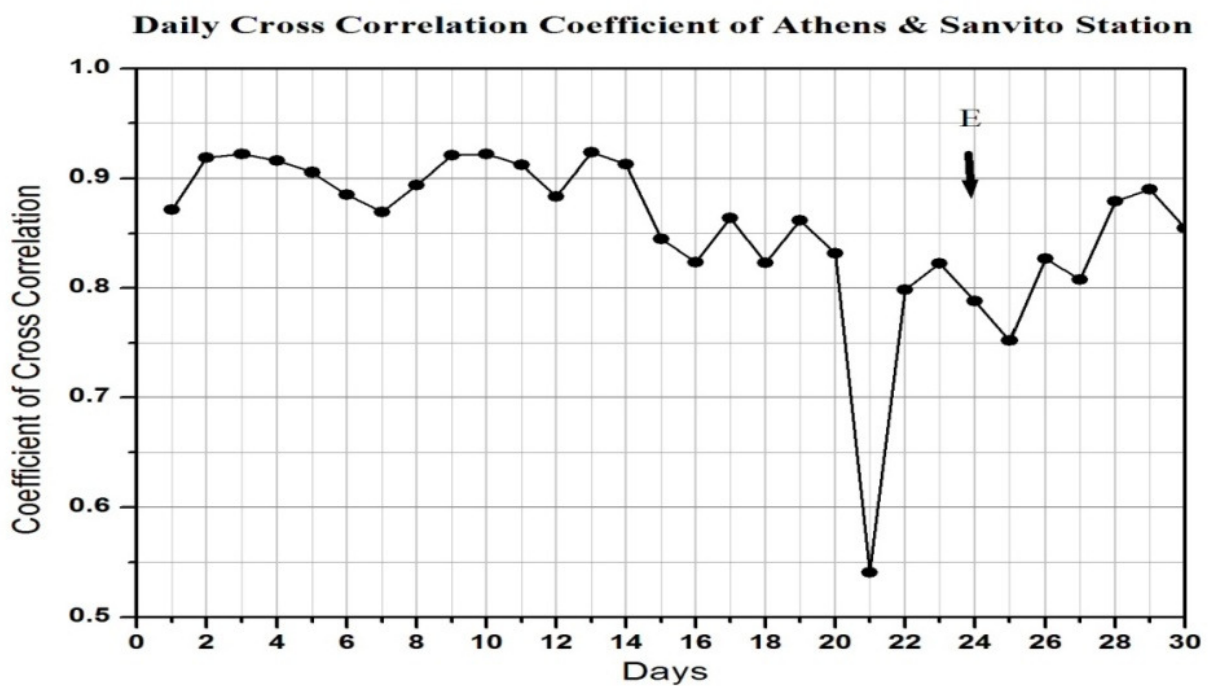
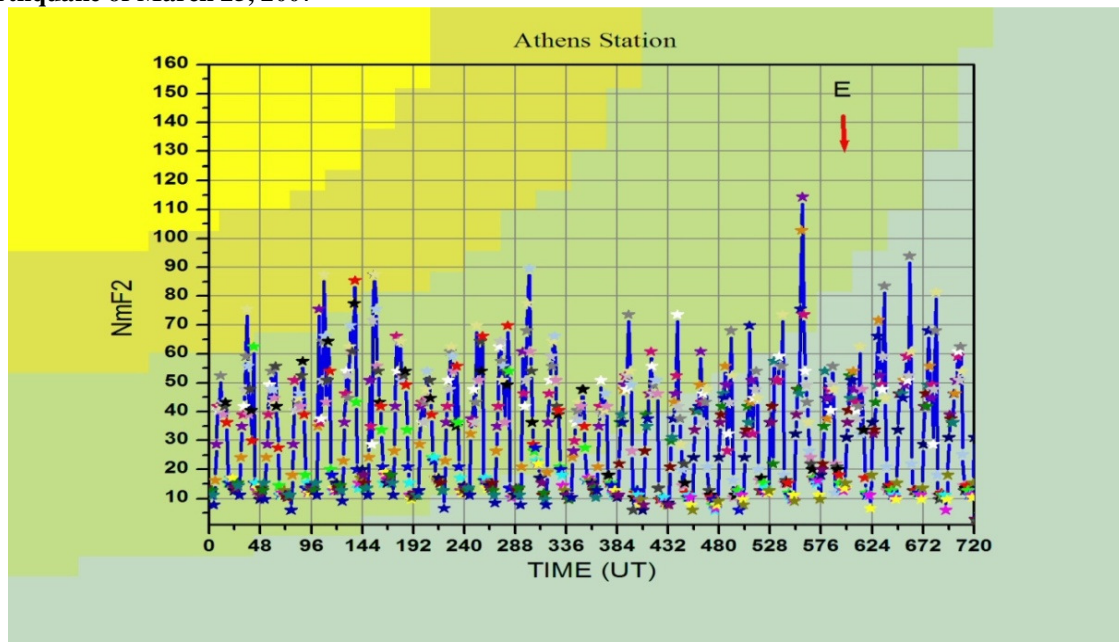


Figure-5  
Daily Cross Correlation Coefficient

The epicenter of this earthquake was located at  $36^{\circ}\text{N}$  and  $23^{\circ}\text{E}$ . The magnitude of the event was 6.2 on Richter scale and focal depth 66 kms. The distance from Athens station was 239 km and distance from Sanvioto station 689 kms. Using equation 1, the earthquake preparation area is calculated as 463 kms, and therefore Athens is expected to pick up the ionospheric precursors. Athens is the nearby ionosonde station which is inside of the earthquake preparation area. Figure 1 shows the variation of NmF2 for

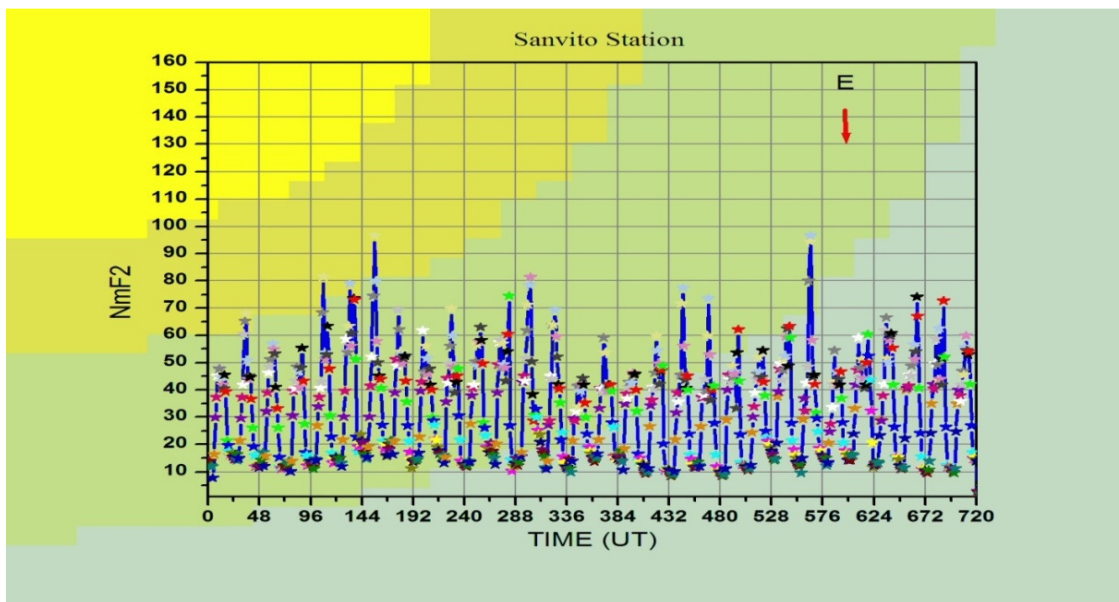
Athens station. Figure 2 shows NmF2 variation for San-vioto station. Figure 3 and 4 shows auto correlation study for Athens and Sanvioto station respectively. The cross correlation study of NmF2 parameter for Athens and Sanvioto station is shown in figure 5. As shown the cross correlation coefficient drops 3 days prior to earthquake on 5 January 2011. The drop in daily cross correlation coefficient may be used as precursor.

**Case II - Earthquake of March 25, 2007**



**Figure-6**

Study of Variation of NmF2 [Data used from 1 March 2007 to 30 March 2007] Earthquake occurred on March 25, 2007



**Figure-7**

Study of Variation of NmF2 [Data used from 01 March 2007 to 30 March 2007] Earthquake occurred on March 25, 2007

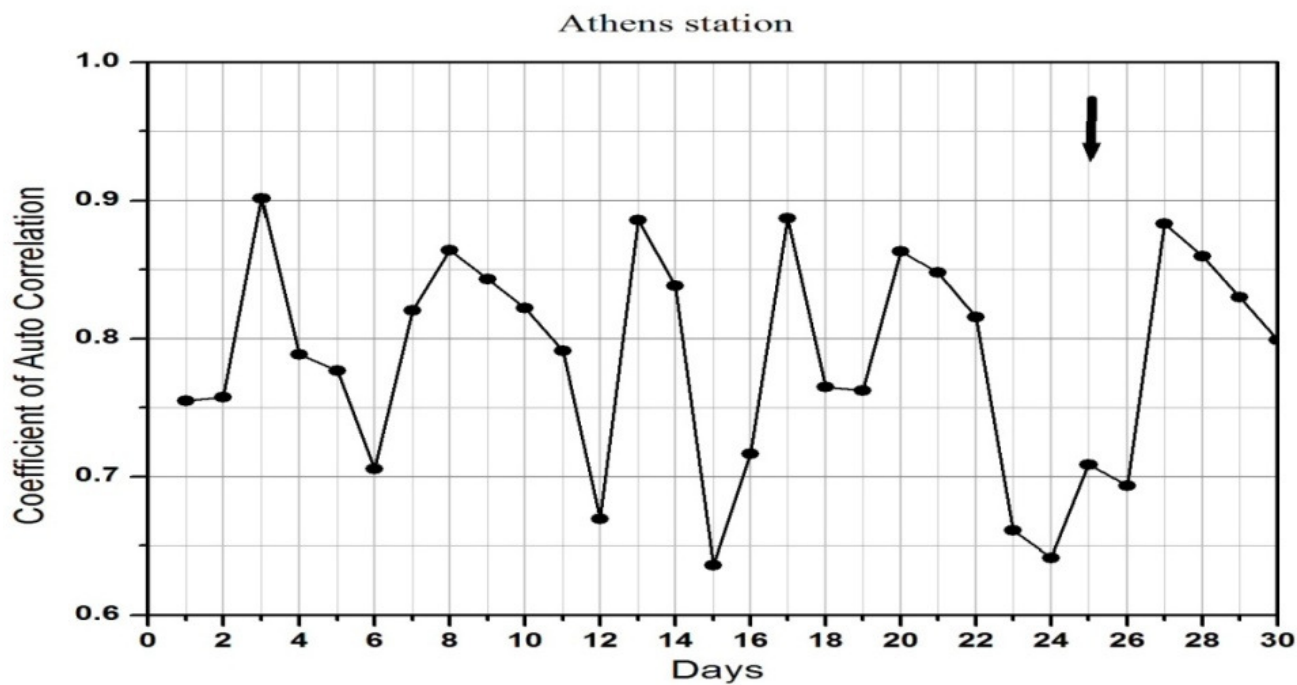


Figure-8  
Auto Correlation Coefficient

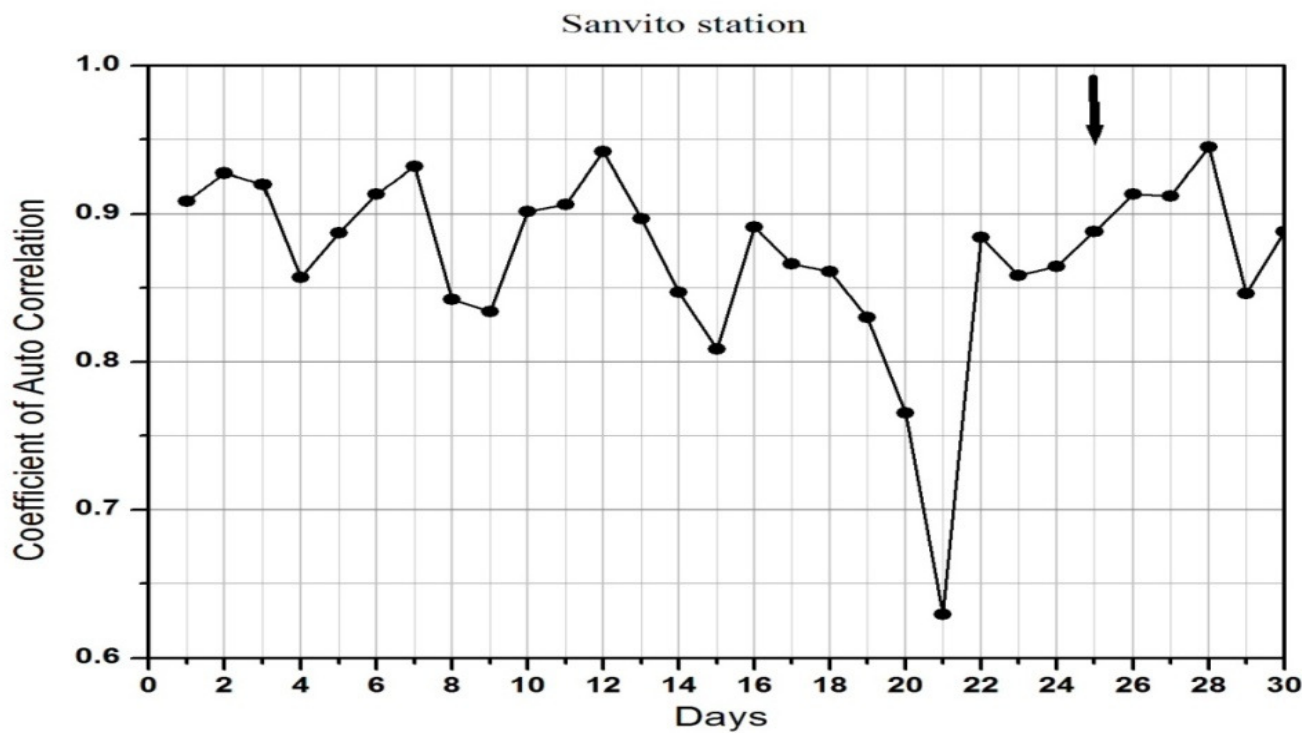
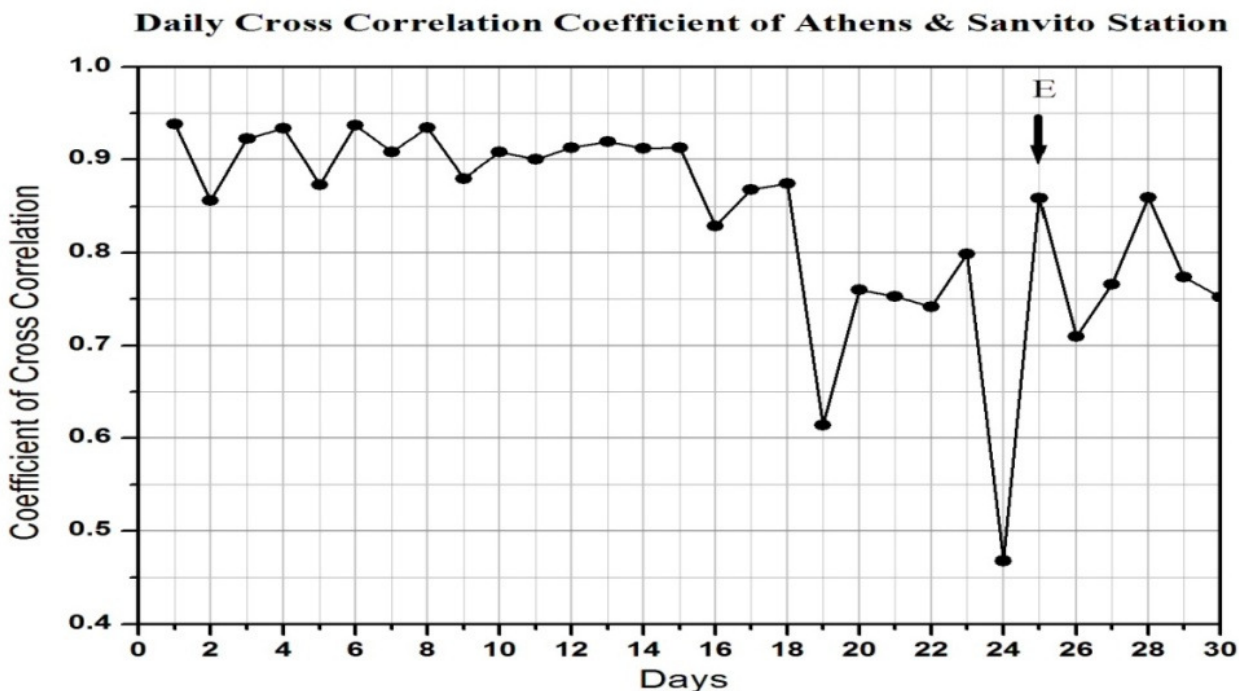


Figure-9  
Auto Correlation Coefficient



**Figure-10**  
**Daily Cross Correlation Coefficient**

This event occurred 341 kms South of Athens at 38°N and 20°E, in depth 15 kilometers and its magnitude was 5.9 at Richter scale. Here the correlation coefficient is calculated for the noised NmF2 signals from March 01, 2007 to March 31, 2007. Athens station is inside of earthquake preparation area. Figure 10 there is a severe drop in the cross correlation coefficient 3 days before the earthquake, on 22 March 2004.

### Conclusion

In this chapter we have applied the autocorrelation and cross correlation coefficient method. The main advantage of the Cross-Correlation coefficient method is that it ensures cancelation of disturbances in the ionosphere caused by geomagnetic storms, and thus weaker variations caused by earthquake events can be revealed. For this we use data for two different stations, both inside and outside of the earthquake location of the sensor preparation area namely Athens and Sanvito respectively. Some limitation of the proposed technique is connected with the fact that an arbitrary location of the sensor station may not give the positive result. This fact is connected with the complex configuration of anomalous variations within the ionosphere. The ionospheric irregularities may be shifted along the geomagnetic field lines equatorward against the vertical projection of the epicentre of the impending earthquake on the ionosphere. In such a situation the sensor station becomes blind and cannot feel the anomalous variations. This situation

may be avoided by an accurate selection of the position of the sensor and control stations. In addition, since ionospheric variability is a result of various parameters, including geophysical noise. We treated the NmF2 measurements collected by Sanvito and Athens stations. The results are very promising confirming the existence of ionospheric precursors before strong seismic events. Specifically we found that the correlation coefficient of the denoised NmF2 signals drop 1 to 5 days before earthquake, which is accordance with the results of previous seismo-ionospheric studies.

In the all four cases presented in this chapter one can observe the sudden drop in correlation coefficient for ionospheric NmF2 data before 1 to 5 days from the seismic event. Correlation method used in this chapter is a simple and useful technique. Some limitation of the proposed technique is connected with the fact that an arbitrary location of the sensor station may not give the positive result. This fact is related with the complex configuration of anomalous variations within the ionosphere. The ionospheric abnormality may be shifted along the geomagnetic field lines equatorward against the vertical projection of the epicentre of the impending earthquake on the ionosphere. In such a situation the sensor station becomes unsighted and cannot feel the inconsistent variations. This position may be avoided by an exact selection of the position of the sensor and control stations. It requires the additional investigations within the

particular zone of seismic activity. Nevertheless the proposed technique permits a low cost monitoring of ionospheric precursors of earthquakes avoiding the use of costly satellite technologies.

### Acknowledgement

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### References

1. Pulinets S.A. and Legen'ka A.D., Spatial – temporal characteristics of the large scale disturbances of electron concentration observed in the F-region of the ionosphere before strong earthquakes. *Kosmicheskie issledovaniya (Cosmic Research)*, **41(3)**, 1-10 (2003)
2. Evans J.V., Satellite beacon contributions to the structure of the ionosphere, *Rev. Geophys. Space Phys.*, **15**, 325-350
3. Calais E. and Minster J.B., GPS detection of ionospheric perturbations following the January 17, 1964, Northridge earthquake, *Geophys. Res. Lett.*, **22**, 1045-1048 (1995)
4. Zaslavski Y., Parrot M. and Blanc E., Analysis of TEC measurements above active seismic regions, *Physics of the earth and Planetary Interiors*, **105**, 219-228 (1998)
5. Liu J.Y., Chuo Y.J., Pulinets S.A., Tsai H.F. and Zeng X., A study on the TEC perturbations prior to the Rei-Li, Chi-Chi and Chai-Yi earthquakes, In “Seismo-Electromagnetics: Lithosphere-Atmosphere-Ionosphere Coupling”, Eds Hayakawa, M. and Molchanov O.A., TERRAPUB, Tokyo, 297-301 (2002)
6. Liu J.Y., Chuo Y.J., Shan S.J., Tsai Y.B. and Pulinets S.A., Pre- earthquake ionospheric anomalies monitored by GPS TEC, *Ann., Geophys.*, **22**, 1585-1593 (2004)