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Study of Ionospheric Perturbations during Strong Seismic Activity by Correlation Analysis Method

A.K. Gwal, Santosh Kumar Jain, Gopal Panda and Y.S. Gujar
Space Science Laboratory, Department of Physics Barkatullah University, Bhopal 462026, India

Corresponding Author: Santosh Kumar Jain, Space Science Laboratory, Department of Physics Barkatullah University, Bhopal 462026, India Tel: +919993154997

ABSTRACT

In this study, we report the variation in foF2 (critical frequency of F2 layer) parameter by correlation method at the time of strong seismic event. Ionosonde data installed at different locations were used for analysis purpose of four cases of earthquakes. Considering two ionosonde recorders, where one ionosonde is in the earthquake preparation zone and the other is out side of it. By correlation analysis method Karl's Pearson coefficients have been calculated. Results of the study showed the anomaly in the Karl's Pearson coefficient related to foF2 parameter, few days before the seismic activity. This fact can be regarded as precursory phenomena. The changes 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. Hence, E×B drift in the ionospheric region get changed. This study may be beneficial for prediction of earthquake.

Key words: Earthquake, foF2, ionosphere, ionospheric precursors, Karl's Pearson coefficient

INTRODUCTION

The responses of the ionosphere to seismic activity have been studied by many workers (Pulinets *et al.*, 2002; Liu *et al.*, 2004; Chen *et al.*, 2004). Earthquakes are capable of inducing large scale perturbations in the global ionospheric dynamics and related parameters. Day-to-day ionospheric variability still remains the subject of the ionospheric physics related to seismic activity which are not studied thoroughly enough. Attempts to classify the terminology of ionospheric variability can be found in the review (Davies and Baker, 1965; Depuev and Zelenova, 1989; Chuo *et al.*, 2002). Usually the variability is expressed as a deviation (in percent) from the mean or median value. The quantitative estimations of the ionospheric variability are given in the papers (Kim and Hegai, 1997; Pulinets *et al.*, 2003; Forbes *et al.*, 2000; Rishbeth and Mendillo, 2001) Showing that day-to-day variability of the critical frequency foF2 lies within the limits 10-30%. The effect on the ionosphere from below is regarded as a main source of the day to day variability and it is demonstrated in the reviews of Pulinets (1998) and Pulinets *et al.* (2004a, 2005) who proposed the effects of seismic activity through the electromagnetic coupling with the ionosphere which is one of the sources of the ionospheric variability. The detailed aspects of the physical mechanism and main morphological features of the ionospheric variability associated with seismic activity are described (Pulinets and Boyarchuk, 2004; Pulinets *et al.*, 2005).

Table 1: Characteristics of earthquakes

Location name	Epicenter	Date of earthquake	Time of earthquake (UTC)	Focal depth in km	Station located inside the earthquake pre. zone
Greece-Southern	36° N and 23°E	8-01-2006	11:34:55	66	Athens 38°N and 24°E
Greece-Argostolion	38°N and 20°E	25-03-2007	13:57:58	15	Athens 38°N and 24°E
Turkey:Central:Ankara	39°N and 33°E	26-12-2007	23:47:10	8	Athens 38°N and 24°E
Balkans:New:Macedonia	41°N and 22°E	24-05-2009	16:17:50	10	Athens 38°N and 24°E

Station located outside the pre. zone	Radius of earthquake pre. zone (km)	Distance between epi center and I Stat. (km)	Distance between epi center and II Stat. (km)	Precursor observed
San-Vito 40°N and 17° E	463	239	689	03 Days before the main shock
San-Vito 40°N and 17°E	345	350	341	01 Days before the main shock
San-Vito 40°N and 17°E	926	791	1376	02 Days before the main shock
San-Vito 40°N and 17°E	419	375	437	02 Days before the main shock

In present applications, the correlation radius of the ionosphere is a very important parameter (Tronin *et al*., 2002). But the correlation technique developed does not take into account the nature of the ionosphere variability source. In present study, one of the most important things which is associated with earthquake precursor is their local character. There are numbers of methods by which we can prove the localness of seismo-ionospheric variations. Three important methods to demonstrate the ionospheric variability in the earthquake preparation area: regional variability index, regional mapping and correlation method. In these three methods correlation method is more reliable; so, we are using here correlation method.

The characteristics of earthquakes considered in the present study are summarized in Table 1 with their onset date and time, epicenter latitude/longitude, focal depth and the distance from concerned observing station. The magnitude of all earthquakes are >5 and the focal depth varied from 10 to 40 km. This study includes four earthquake events. The radius of earthquake preparation zone is calculated for each earthquake by using the formula given by Dobrovolsky *et al*. (1979).

MATERIALS AND METHODS

To get precursors two measuring points are used in very simple arrangements, first receiver that is located inside the earthquake preparation zone is called receiver ionosonde. The second receiver which is located out side the earthquake preparation zone is control receiver. To localize the receivers generally two things must be taken care of, first is to get similar reaction to geomagnetic disturbances receiver ionosonde must be posted in the same geomagnetic latitude, and second is as the local time dependence of the ionospheric reaction to the geomagnetic storm, there should not be much difference in the longitude of the receiver ionosonde.

The idea to use the correlation between the neighboring ionospheric stations to review the seismo-genic variations in sporadic E-layer of the ionosphere was proposed by Liperovskaya *et al*. (1994) and reviewed in Liperovsky *et al*. (2000). Similar technique for the F-layer parameters of the ionosphere was developed by Gaivoronskaya and Pulinets (2002). This technique was extended for the GPS TEC measurements (Pulinets *et al*., 2004b). To determine the radius of correlation associated with the seismic activity the conception of the earthquake preparation zone was used (Dobrovolsky *et al*., 1979):

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

Table 2: Values of earthquake preparation zone radius

Magnitude	3	4	5	6	7	8	9
Earthquake preparation zone radius (km)	19.6	52	141	380	1022	2754	7413

where, ρ is the radius of the earthquake preparation zone and M is the earthquake magnitude on Richter scale. The value of earthquake preparation zone radius in accordance with Eq. 1 is shown in Table 2. It is supposed that ionospheric variability associated with seismic activity will be observed over the earthquake preparation zone (Dobrovolsky *et al.*, 1979). According to the earthquake preparation zone conception the character of the ionospheric variability is different within the earthquake preparation area in comparison with the variability out side of it. In general case, it is not obligatory to put the "control" station out side the earthquake preparation zone, it is sufficient if it will be quite far from the epicenter. The daily Karl's Pearson coefficient of correlation calculated for these two stations in the form:

$$C = [\Sigma \{(foF2_1 - <foF2_1>) * (foF2_2-<foF2_2>)\}/ (k\, \sigma_1\, \sigma_2)] \quad (2)$$

Here, indices 1 and 2 correspond to the first and second ionosonde stations, respectively, foF2 (Critical frequency of F_2 layer) is represented by time series, the foF2 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 min interval is used), the mean value <foF2> and standard deviation σ are determined by the following expression:

$$< foF2 > = [\Sigma \{(foF2)_i/k\}] \quad (3)$$

$$\sigma^2 = \Sigma [(foF2)_I - <foF2>]^2/k \quad (4)$$

where, <foF2> is the daily mean value of the critical frequency and σ 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 and 17°E). The first one is inside the main seismo-active area. Cross-correlation study for these stations is shown in Fig. 3. Similar pattern is applied for other earthquakes.

RESULTS

In this study, ionospheric variations are examined before the all four earthquakes that occurred during December 2005 to June 2009. 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 6.2 (on Richter scale) occurred January 08, 2006 at Greece-Southern [36°N, 23°E]. The observed results are presented in Fig. 1-3. This earthquake was much severe and destructive. For this event the observed foF2 data for the entire period of December 2005 and January 2006 are analyzed using Eq. 1-4 and results plotted are shown in Fig. 1-3. In the Fig. 1 variation of foF2 for Athens station is shown. Athens station is a receiver station which is very close to epicenter. Figure 2 shows the variation of foF2 for San-Vito station [40°N and 17°E] which is

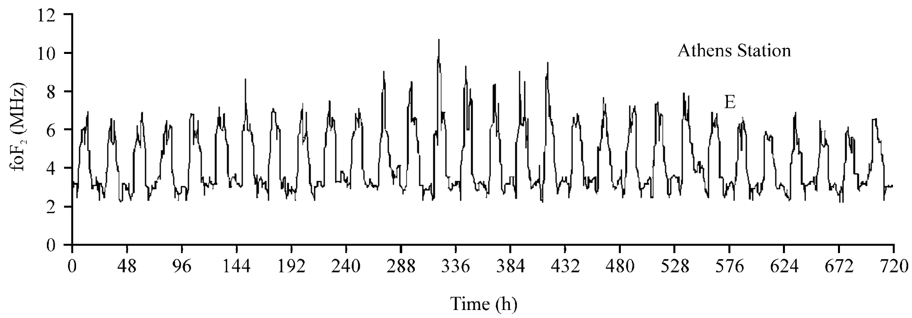

Fig. 1: Study of variation of foF2 (earthquake occurred on January 08,2006)

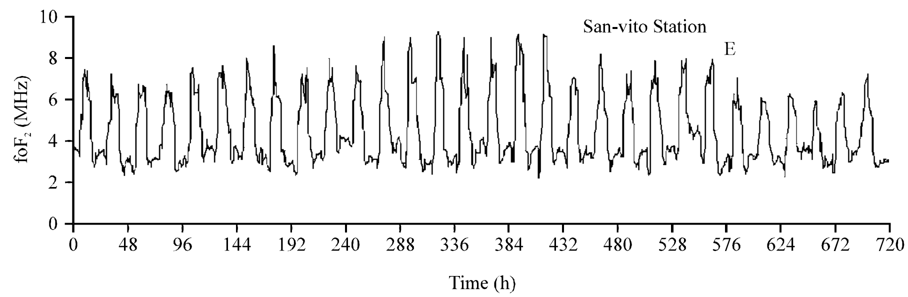

Fig. 2: Study of variation of foF2 (earthquake occurred on Janunary 08,2006)

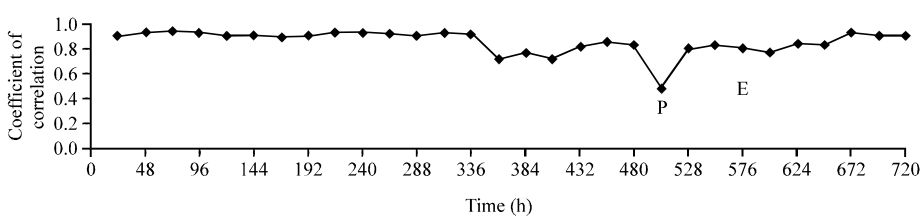

Fig. 3: Cross-correlation study for Athens and San-Vito station

control station and far from epicenter of earthquake. Figure 3 shows the cross-correlation study for Athens and San-Vito station. It shows that the cross correlation-coefficient decreases three days before the main shock of earthquake. Which shows the precursory phenomena. In Fig. 1-3 'E' mark the time of occurrence of main shock of earthquake and 'P' marks the precursory phenomena.

Earthquake March 25, 2007 that occurred at Greece-Argostolion: During the month of March 2007, an earthquake of magnitude 5.9 (on Richter scale) occurred at Greece-Argostolion on March 25. For correlation analysis the foF2 data of the month of March 2007 analyzed. The correlation results of foF2 variations for this case are shown in Fig. 4-6. In the Fig. 4, some major variations in foF2 values recorded prior to one day from the main shock of earthquake.

Earthquake of December 26, 2007 that occurred at Turkey-Ankara: The major earthquake of magnitude 6.9 (on Richter Scale) occurred on December 26, 2007 at Turkey-Central-Ankara

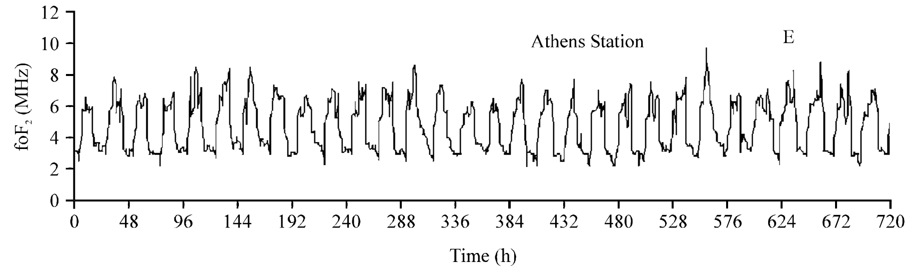

Fig. 4: Study of variation of foF2, earthquake occurred on March 25, 2007 data used from March 1, 2007 to March 30, 2007

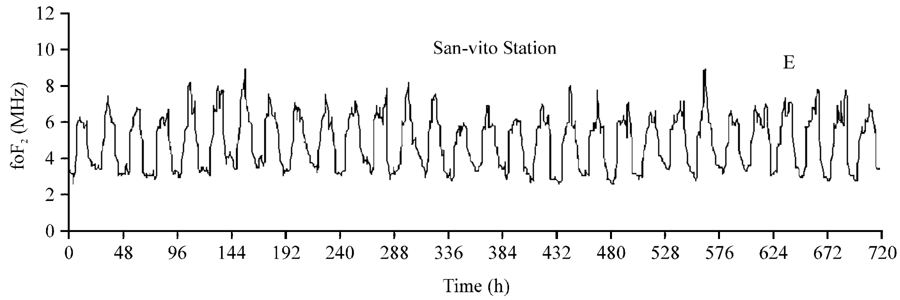

Fig. 5: Study of variation of foF2 earthquake occurred on March 25, 2007

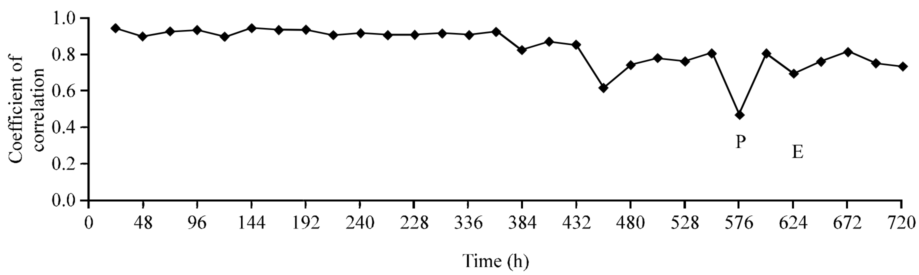

Fig. 6: Correlation study for Athens and San-Vito station earthquake occurred on March 25, 2007

[39°N, 33°E]. The observed results are presented in Fig. 7-9. This earthquake was much severe and destructive. For this event the observed foF2 data for the entire period of December 2007 are analyzed using Eq. 1-4 and results plotted are shown in Fig. 7-9. In the Fig. 7 variation of foF2 for Athens [38°N, 24°E] station is shown. Athens station is a receiver station which is very close to epicenter. Figure 8 shows the variation of foF2 for San-Vito [39°N and 33°E] station.

San-Vito [39°N and 33°E] is the control station which is so far from epicenter of earthquake. Figure 9 shows the cross-correlation study for Athens [38°N, 24°E] and San-Vito [39°N and 33°E] station. It shows that the cross correlation-coefficient decreases before two days from the main shock of earthquake.

Earthquake 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:Macedonia on May 24. For correlation analysis the foF2 data of the month of May 2009 analyzed. The

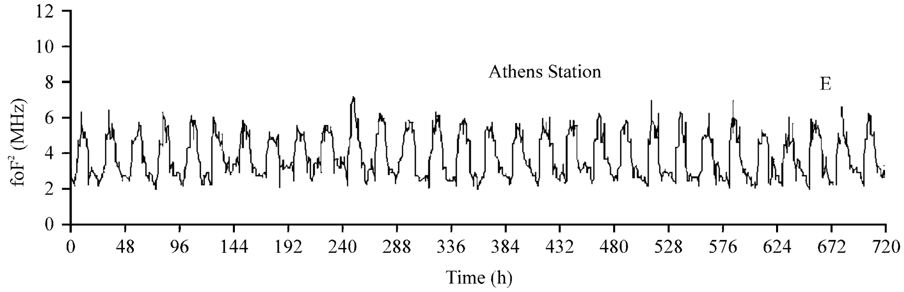

Fig. 7: Study of variation of foF2, earthquake occurred on December 26, 2007

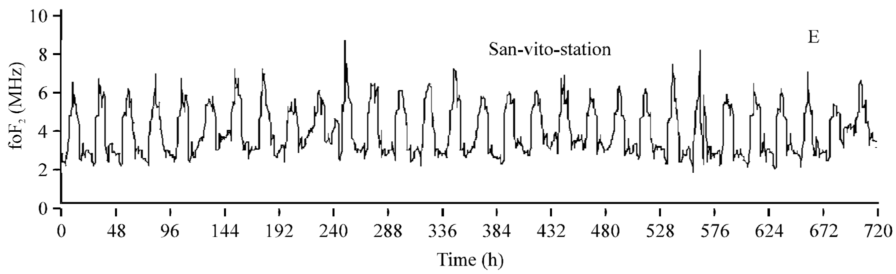

Fig. 8: Study of variation of foF2, earthquake occurred on Dec. 26, 2007 data used from December 1, 2007 to Dec. 30, 2007

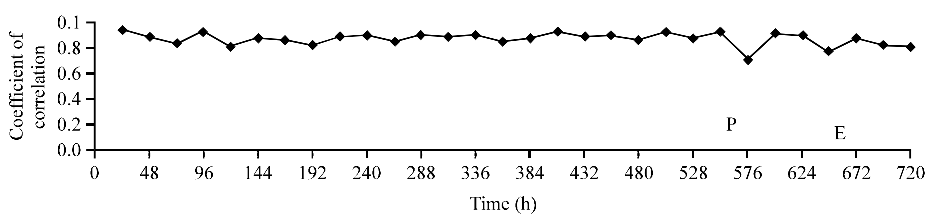

Fig. 9: Correlation study for Athens and San-Vito station earthquake occurred on Dec. 26, 2007

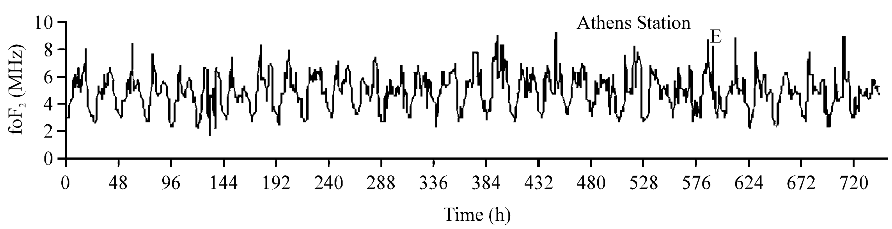

Fig. 10: Study of variation of foF2, for Athens station earthquake occurred on May 24, 2009

correlation results of foF2 variations for this case are shown in Fig. 10-12. Figure 11 shows the variation of foF2 for San-Vito Station. In the Fig. 12 some major variations in foF2 values recorded prior to two days from the main shock of earthquake. This Fig. 12 also indicates the breaking of mutual correlation after one day from the main shock.

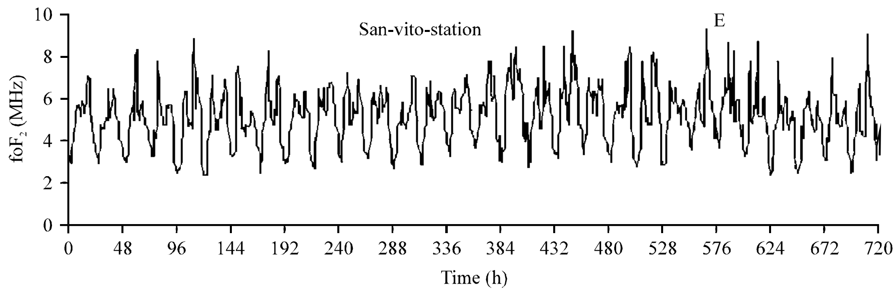

Fig. 11: Study of variation of foF2, for San-vito station

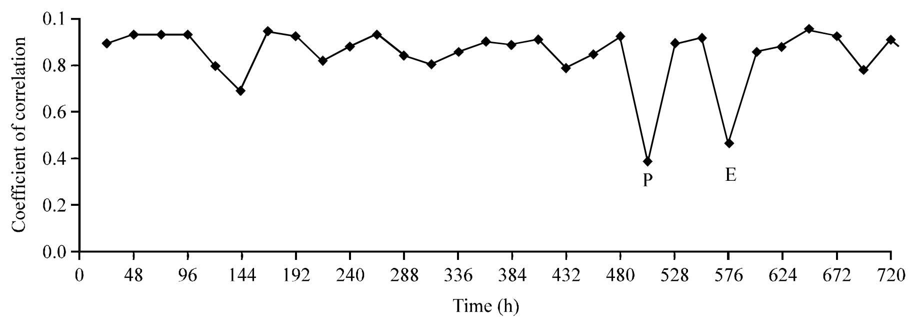

Fig. 12: Study of variation of cross-correlation coefficient (earthquake occurred on May 24, 2009)

DISCUSSION

The observed perturbations in the ionosphere during seismic activity reveal a coupling between the lithosphere and the ionosphere. The changes in the F layer density may be interpreted as a result of associated seismic electric field generated by internal gravity waves (Boyarchuk, 1999; Bolt, 1964; Calais and Minster, 1995). Such field can penetrate the F region of the ionosphere and move the layer up or down due to E×B drift and bring out the changes in plasma density. The enhancement in density may be the result of earthquake associated E×B drift when the density can increase if an electric field of sufficient magnitude develops at ionospheric height. The main goal of this study is the detection of significant precursors. In all four cases presented in the paper one can observe the decrease of correlation coefficient of the related ionospheric stations before the seismic shock. The index demonstrates the spread of the ITEC over the area few hundred kilometers in diameter. If we look at the problem from the position of the physical mechanism, the variability intensity will depend on the extend of the atmospheric changes. The modification of these parameters is provided by the air ionization produced by energy released from the active tectonic fault before the earthquake. In this study technique of cross- correlation index applied for determination of the ionospheric variability over the earthquake preparation area. 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 are originated from the Sun. Hence, during magnetic disturbances, it is very difficult to separate significance changes in ionosphere related to earthquake. In this study, we choose the position of receiver station and control station hence, perturbations related to magnetic activity filtered out.

In this study, we have shown the variation in foF2 data prior to earthquake. The result discussed in the above section shows significant ionospheric perturbations over the related ionosonde stations several days before 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. From the above observations it is found that the pre-earthquake ionospheric disturbances are observed for each earthquake. Summary of the ionospheric perturbations depletion in correlation index, before the main shock of the four earthquakes discussed above, is shown in Table 1. The results presented above shows a very strong coupling between receiver ionosonde station and control ionosonde station. For better understanding the foF2 data of two ionosonde stations used.

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REFERENCES

Bolt, B.A., 1964. Seismic air waves from the great 1964 Alaskan earthquake. Nature, 202: 1094-1095.

Boyarchuk, K.A., 1999. Kinetics of elementary ions in the lower atmosphere acted upon by ionization radiation. Izv. Atmos. Ocean. Phys., 33: 236-240.

Calais, E. and J.B. Minster, 1995. GPS detection of ionospheric TEC perturbations following the January 17, 1994, Northirdge Earthquake. Geophys. Res. Lett., 22: 1045-1048.

Chen, Y.I., J.Y. Liu, Y.B. Tsai and C.S. Chen, 2004. Statistical tests for pre-earthquake ionospheric anomaly. Terr. Atm. Ocean Sci., 15: 385-396.

Chuo, Y.J., J.Y. Liu, M. Komogawa and Y.I. Chen, 2002. The Anomalies in the foEs Prior to M 6.0 Taiwan Earthquakes. In: Seismo Electromagnetics: Lithosphere-Atmosphere-Ionosphere Coupling, Hayakawa, M. and O.A. Molchanov (Ed.). TERRAPUB, Tokyo, pp: 309-312.

Davies, K. and D.M. Baker, 1965. Ionospheric effects observed around the time of the Alaskan earthquake of March 28, 1964. J. Geophys. Res., 70: 2251-2253.

Depuev, V. and T. Zelenova, 1989. Electron density profile changes in a pre earthquake period. Adv. Space Res., 18: 115-118.

Dobrovolsky, I.R., S.I. Zubkov and V.I. Myachkin, 1979. Estimation size of earthquake preparation zones. Pure Applied Geophys., 117: 1025-1044.

Forbes, J.M., S.E. Palo and X., Zhang, 2000. Variability of the ionosphere. J. Atm. Sol. -Ter. Phys., 62: 685-693.

Gaivoronskaya, T.V. and S.A. Pulinets, 2002.. Analysis of the F2-layer variability in the areas of the seismic activity. Preprint IZMIRAN No. 2 (1145), Moscow, 20.

Kim, V.P. and V.V., Hegai, 1997. On possible changes in the mid latitude upper ionosphere before strong earthquakes. J. Earthquake Pre. Res., 6: 275-280.

Liperovskaya, E.A., N. Christakis, V.A. Liperovsky and M.A. Oleinik, 1994. Seismic and anthropogenic activity effects in the night time sporadic E layer of the ionosphere. Geomag. Aeron., 34: 311-314.

Liperovsky, V.A., O.A. Pokhotelov, E.V. Liperovskaya, M. Parrot, C.V. Meister and A. Alimov, 2000. Modification of sporadic E- layers caused by seismic activity. Surveys Geophys., 21: 449-486.

Liu, J.Y., Y.J. Chuo, S.J. Shan, Y.B. Tsai and S.A. Pulinets, 2004. Pre- earthquake ionospheric anomalies monitored by GPS TEC. Ann. Geophys., 22: 1585-1593.

Pulinets, S.A., 1998. Seismic activity as a source of the ionosphere variability. Adv. Space Res., 22: 903-906.

Pulinets, S.A., K.A. Boyarchuk, A.M. Lomonosov, V.V. Khegai and J.Y. Liu, 2002. Ionospheric precursors to earthquake: A preliminary analysis of the foF2 critical frequencies at Chung-Li ground based station for the vertical sounding of the ionosphere (Taiwan Island). Geomag. Aeron., 42: 508-513.

Pulinets, S.A., K.A. Boyarchuk, V.V. Hegai, V.P. Kim and A.M. Lomonosov, 2003. Quasielectrostatic model of atmosphere-thermosphere-ionosphere coupling. Adv. Space Res., 26: 1209-1218.

Pulinets, S.A. and K.A. Boyarchuk, 2004. Ionospheric Precursors of Earthquakes. Springer-Verlag, Berlin, Germany, pages: 315.

Pulinets, S.A., J.Y. Liu and I.A. Safronova, 2004a. Interpretation of a statistical analysis of variations in the foF2 critical frequency before earthquakes based on data from Chung-Li ionospheric station (Taiwan). Geomag. Aeron., 44: 102-106.

Pulinets, S.A., T.B. Gaivoronska, A.L. Contreas and L. Ciraolo, 2004b. Correlation analysis technique revealing ionospheric precursors of earthquakes. Nat. Hazard. Earth Syst. Sci., 4: 697-702.

Pulinets, S.A., A. Leyva and L. Ciraolo, 2005. GPS TEC variations around the time of the Colima, earthquake of 21 January 2003. Geofis. Int., 44: 369-377.

Rishbeth, H. and M., Mendillo, 2001. Patterns of ionospheric variability. J. Atm. Sol.-Ter. Phys., 63: 1661-1680.

Tronin, A.A., M. Hayuakawa and O.A. Molchanov, 2002. Thermal IR satellite data application for earthquake research in Japan and China. J. Geodyn., 33: 519-534.