Cross Correlation Analysis of Ionospheric foF2 Parameter during the Seismic Activities in Japan Region

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Abstract : Anomalous variations in ionospheric parameters associated with large (M ≥ 6) earthquakes can be considered as short term earthquake precursors. The main concern of this study is to analyze the foF2 datasets by using the cross correlation method to find a reliable precursor for the seismic activities in Japan region. Further we also filtered our data by using wavelet transform based matching pursuit MATLAB technique to denoise data and find out approximation value. These seismic activities took place on 14-03-2012 and 07-12-2012 and we analyzed the datasets of foF2 for a certain time lapse. The results show that the pre-earthquake ionospheric anomalies appear during 5 to 8 days prior to main shock and they are showing strong agreement with seismic activity in the absence of any geomagnetic activity. The changes in the F layer density may be interpreted as a result of associated seismic electric field generated by internal gravity waves and also the radon gas plays the major role.

Index Terms – Earthquakes, Seismic Activities, Ionosphere, Critical Frequency, Cross Correlation Analysis.

I. INTRODUCTION

Recently pre-seismic ionospheric anomalies have drawn intensive attention and it is considered that seismo-ionospheric coupling phenomena is a local event i.e. only a certain area over the ground is affected by the earthquake and its size is a function of the magnitude of the event. When Earth's lithosphere relate with the atmosphere before strong seismic event which generate an anomalous electric field and that affects the electron content of the ionosphere. Due to complex and non linear nature of ionosphere, in addition to the fact that there are large numbers of parameters contributing to its variability due to which many type of harmonic noises are generated in geophysical process. The interference of harmonic noise in geophysical data has long been a nuisance problem for geophysicists. Therefore the real problem is distinguishing the variations caused by earthquake activity from those stimulated by other sources.

By using Ionosonde we studied the variability of ionosphere with the help of electron density of ionospheric plasma or the integral of the electron density known as Ionospheric Total Electron Content (ITEC). Ground based ionosonde measure the most interesting parameter is the critical frequency of the F2-layer (foF2). This parameter shows the chaotic and nonlinear behavior of the ionosphere. It is very difficult to distinguish between the seismic-generated foF2 fluctuations and the fluctuations attributed to various noises. This problem becomes even more complicated when other smaller magnitude disturbances of undefined origin appear in the foF2 signal, which are known as geophysical or ionospheric noise (Davies, 1990 and Ismaguilov et al., 2001). To find a signal in a noisy environment creates a classic problem in signal processing. The goal of any signal denoising method is to effectively reduce noise level in order for retrieve a useful signal to emerge, while minimizing the information loss (Kopytenko et al., 2006).

There are two principle approaches in short-term earthquake prediction and can be separated. First one the deterministic approach which studies the temporal and spatial distribution behavior of some precursor, for example, the radon emanation (King et al., 1993). Other one is the statistical patterns processing on the purpose to find some regularity in the behavior of statistical characteristics of the given parameter. At present self organized criticality is one of the main streams of statistical earthquake prediction. It was established recently that seismic activity is one of the sources of the day-to-day ionospheric variability (Pulinets et al., 1998; Pulinets and Boyarchuk, 2004; Pulinets et al., 2004; Liu et al., 2004).

The coupling phenomenon of the ground, the surface and the ionosphere is due to the generation of irregular electric field in the earthquake preparation area (Pulinets et al., 2000). This preparation area of an earthquake event was introduced by Dobrovolsky et al. (1979) by using the elastic deformation calculations. The size of the earthquake preparation zone depends on the earthquake magnitude. The same (or very similar) dependencies were obtained not only in the case of the elastic deformations, but also in that of the spatial distribution of different types of precursors in the seismic activation zone (Bowman et al., 1998; Kostoglodov et al., 2003) including geochemical ones and local seismicity. These penetrations in the ionosphere generate anomalous electric field which causes the ion drift and that results in the formation of electron density irregularities (Kim and Hegai, 1997). These anomalies that appear in the ionosphere before the main seismic shock can be considered as ionospheric precursors (Pulinets et al., 2005).

The subsistence of the ionospheric anomalies or ionospheric precursors is well established not only by physical modeling but statistically as well (Pulinets et al., 2002; Chen et al., 2004; Liu et al., 2006). For the ionospheric precursors of earthquakes, mainly two approaches are used. First is to trace the specific ionospheric parameters and try to detect the anomalies by the measurements of recently revealed main features of the ionospheric precursor (Pulinets et al., 2003). The other way is to use the statistically established behavior of some parameter (for example, the critical frequency foF2) as a signature of the impending earthquake (Pulinets et al., 2002).

II. DATA AND METHODOLOGY

In this study the data were obtained from NOAA Space Environment Centre which was prepared by the U.S. Department of Commerce NOAA, Space Weather Prediction Centre. We had taken 41 days ionospheric data for various earthquakes for these studies. For earthquake data characteristics we used USGS acquiesces which gives global significant earthquake data base. The ionospheric variability given by critical frequency of F2 layer (foF2) is studied in relation to the major earthquakes. In this work the basic idea to employ the correlation between the neighboring ionospheric stations is to show the seismogenic disturbances in F2 layer of ionosphere. In this study we consider the maximum critical frequency of two different ionospheric stations one inside the preparation zone while other is outside of the radius of preparation zone. In this study we use the techniques of earthquake preparation area and correlation radius and the determination of this radius of correlation associated with the seismic activity the earthquake preparation area method was used. It is believed that the ionospheric variability attached with seismic activity will be determined over the earthquake preparation area. The radius of earthquake preparation zone is given by the following formula given by Dobrovolsky et al. (1979):

$$\rho = 10^{0.43\mathrm{M}}\ \mathrm{km} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where the radius of earthquake preparation zone represented by ρ as radius in km and the magnitude for the same earthquake define by M in Richter scale.

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 zone. 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. Daily cross-correlation coefficient (C) is given by (Liu et al., 2004).

$$C = \frac{\Sigma\{(foF2_1 - < foF2_1 >) \times (foF2_2 - < foF2_2 >)\}}{(k.\sigma_1.\sigma_2)} \ldots (2)$$

Here indices 1 and 2 correspond to the "Sensor" and "Control" ionosonde stations respectively, foF2 (Maximum electron density of F2 layer) is represented by time series. The foF2 values of ionosphere are calculated from the ionosonde measurements for $k = 24$ (or 96 or 144) points are 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 $< foF2 >$ and standard deviation σ are determined by the following expression:

$$< foF2 > = \left[\Sigma\left\{\frac{(foF2)i}{k}\right\}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\sigma^2 = \Sigma\frac{[(foF2)I - <foF2>]2}{k} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

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. After calculating the cross correlation coefficient we had represented these coefficients in graphs and filtered with Upper Bound and Lower Bound techniques which gives clear indication that given two Ionosondes data has negative correlation at certain point. To ensure these results we had also filtered our data by using wavelet transform based matching pursuit MATLAB technique to denoise data and find out approximation value which also give us the same cross correlation relation.

III. RESULTS AND DISCUSSION

Analysis of ionospheric F2 layer critical frequency (foF2) for strong earthquakes in Japan region revealed the common feature of ionospheric anomalies observed before earthquakes. These anomalies are expressed in the form of sharp changes of foF2 few days before the seismic shock. We present two cases of earthquakes:

- **Case 1: Japan: Hokkaido Earthquake (40°N & 144°E)**

The major earthquake of magnitude 6.9 (on Richter scale) occurred on March 14, 2012 at Japan: Hokkaido. The epicenter of this earthquake was located at 40°N and 144°E. The Figure 1 shows the sensor (Kokubunji) and control (Yamakawa) ionosonde station and epicenter for Japan: Hokkaido earthquake. The Kokubunji ionosonde station is well inside the earthquake preparation area and the Yamakawa ionosonde is outside the earthquake preparation area of Japan: Hokkaido earthquake. So these might be considering as sensor station and control station respectively. The next Figure 2 illustrates the variations in cross correlation coefficient of foF2 for 41 days time interval (February 13, 2012 to March 24, 2012). The cross correlation coefficient of foF2 shows the sudden drops five days prior to Japan: Hokkaido earthquake as illustrated in Figure 2. The geomagnetic conditions for this time lapse are shown in Figure 3 and there were not any presences of geomagnetic activity at the time of precursory day. So this result may be due to the seismic activity in Japan: Hokkaido region.

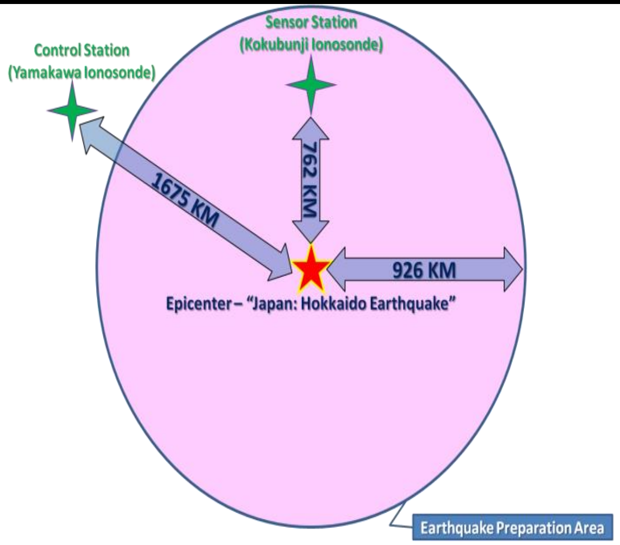

Fig. 1 – Epicenter of the Japan: Hokkaido Earthquake and the Sensor Station (Kokubunji Ionosonde) and Control Station (Yamakawa Ionosonde).

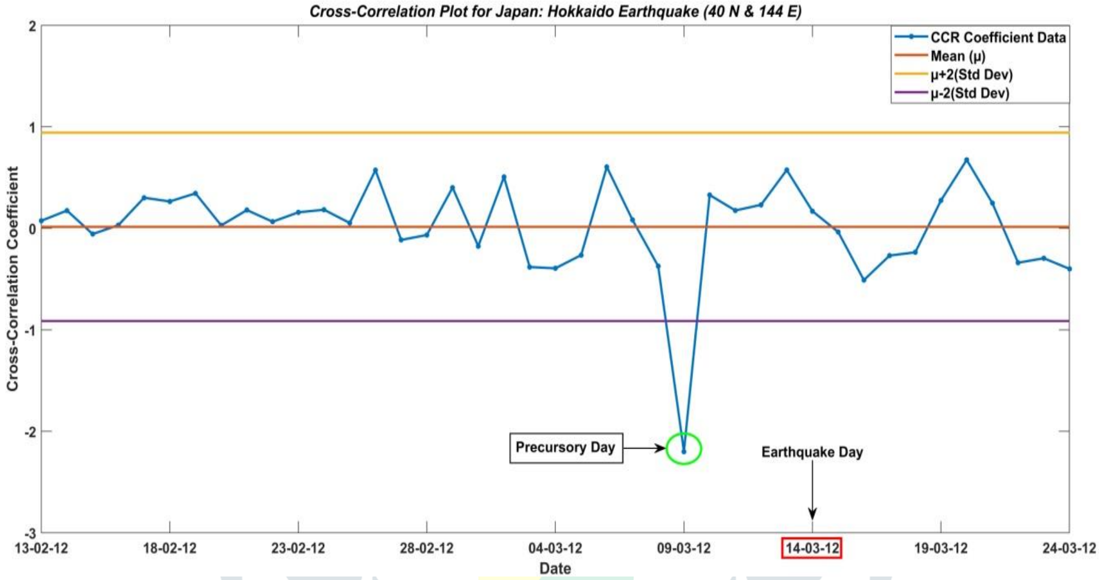

Fig. 2 – Diurnal Cross-Correlation Coefficient Plot from February 13, 2012 to March 24, 2012 during the Japan: Hokkaido Earthquake.

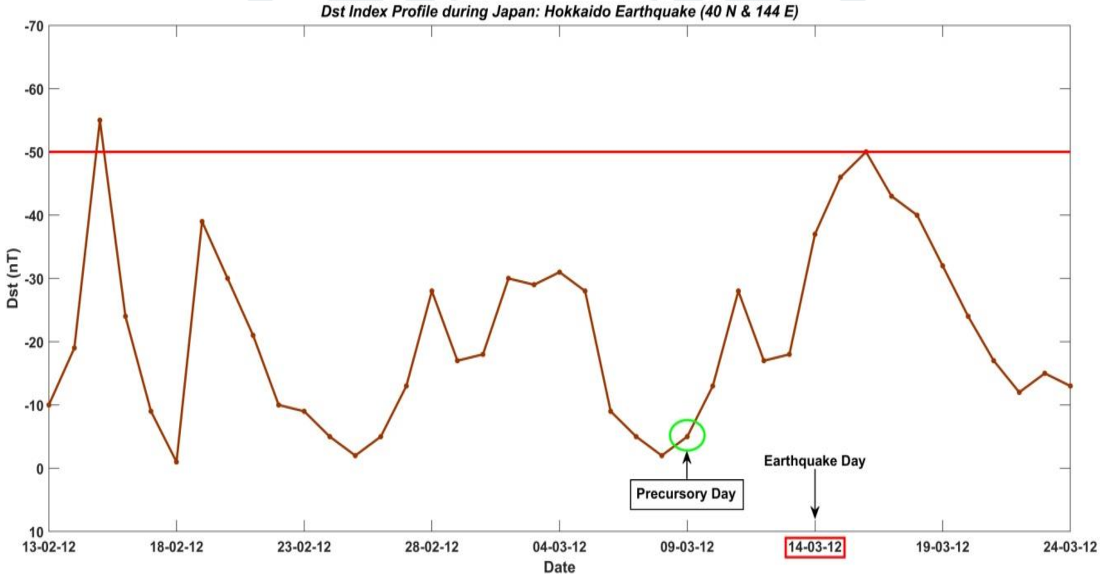

Fig. 3 – Dst Index Value Plot from February 13, 2012 to March 24, 2012 during the Japan: Hokkaido Earthquake.

We also calculated this behavior with wavelet transformation based approximation analysis and found the similar behavior of cross correlation coefficient shown in Figure 4. The approximation value is also shows sudden drop five days before the Japan: Hokkaido earthquake.

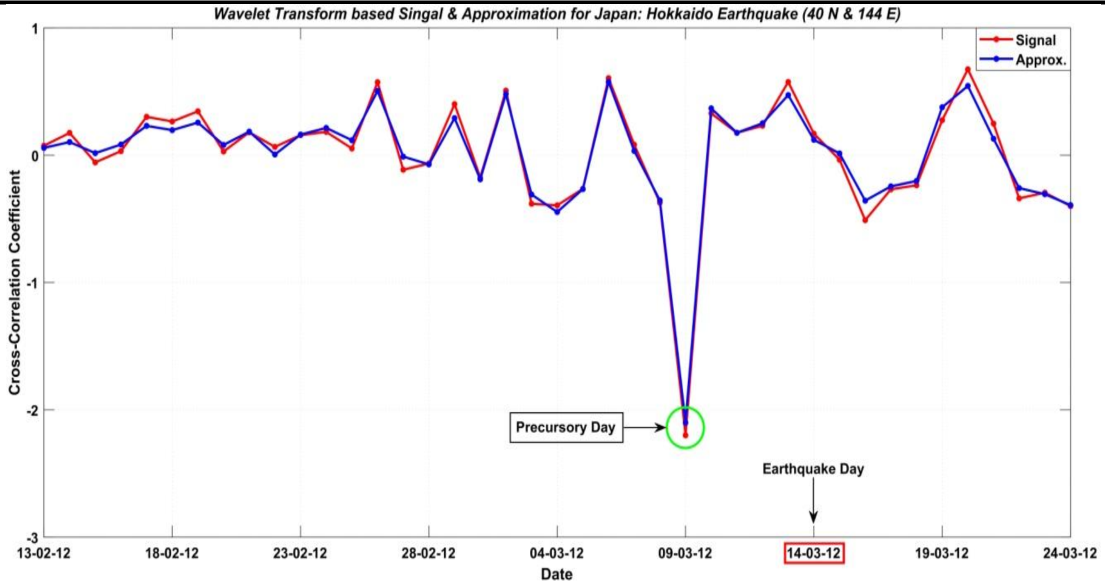

Fig. 4 – Wavelet Transform based Signal and Approximation Plot from February 13, 2012 to March 24, 2012 during the Japan: Hokkaido Earthquake.

- **Case 2: Japan: Honshu Earthquake (37°N & 143°E)**

The major earthquake of magnitude 7.2 (on Richter scale) occurred on December 07, 2012 at Japan: Honshu. The epicenter of this earthquake was located at 37°N and 143°E. The Figure 5 shows the sensor (Kokubunji) and control (Yamakawa) ionosonde station and epicenter for Japan: Honshu earthquake. The Kokubunji ionosonde station is well inside the earthquake preparation area and the Yamakawa ionosonde is outside the earthquake preparation area of Japan: Honshu earthquake. So these might be considering as sensor station and control station respectively. The next Figure 6 illustrates the variations in cross correlation coefficient of foF2 for 41 days time interval (November 07, 2012 to December 17, 2012).

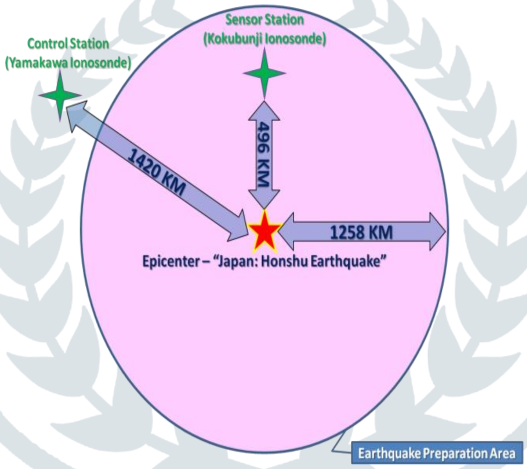

Fig. 5 – Epicenter of the Japan: Honshu Earthquake and the Sensor Station (Kokubunji Ionosonde) and Control Station (Yamakawa Ionosonde).

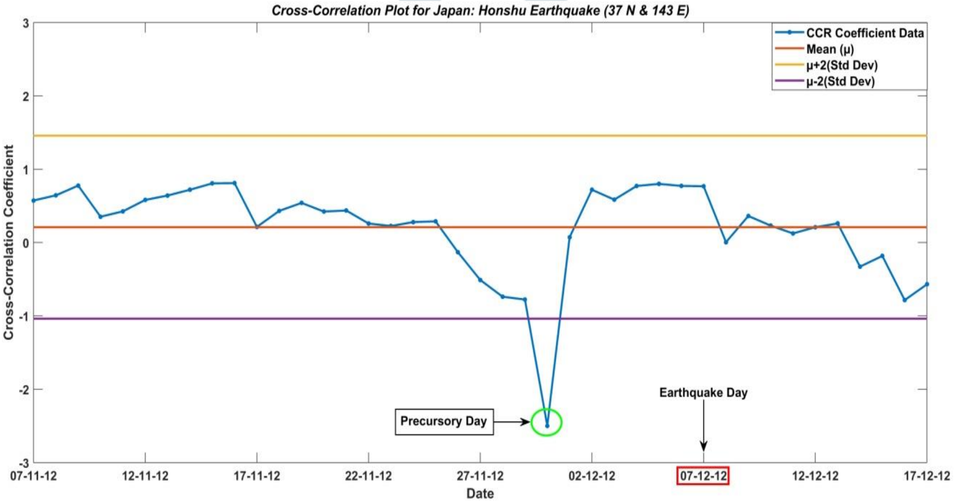

Fig. 6 – Diurnal Cross-Correlation Coefficient Plot from November 07, 2012 to December 17, 2012 during the Japan: Honshu Earthquake.

The cross correlation coefficient of foF2 shows the sudden drops eight days prior to Japan: Honshu earthquake. The geomagnetic conditions for this time lapse are shown in Figure 7 and there were not any presences of geomagnetic activity at the time of precursory day. So this result may be due to the seismic activity in Japan: Honshu region.

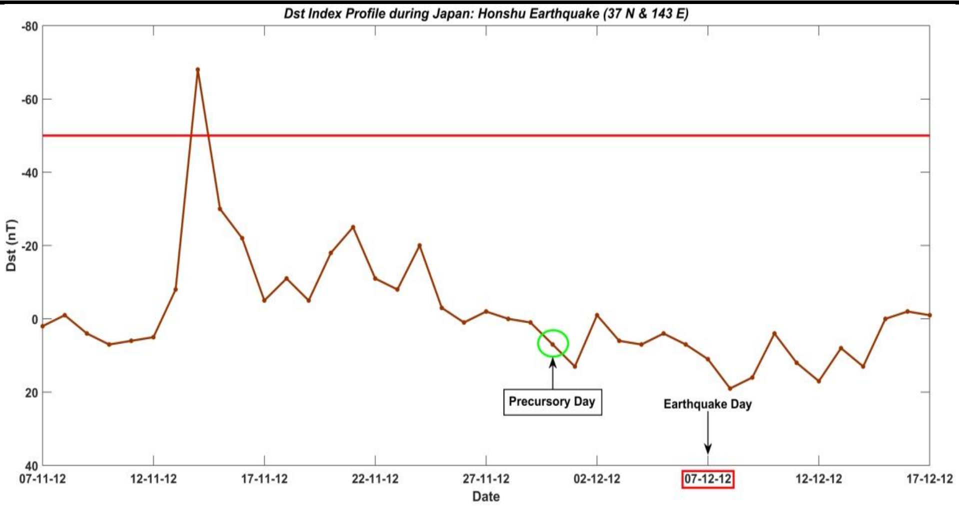

Fig. 7 – Dst Index Value Plot from November 07, 2012 to December 17, 2012 during the Japan: Honshu Earthquake.

We also calculated this behavior with wavelet transformation based approximation analysis and found the similar behavior of cross correlation coefficient shown in Figure 8. The approximation value is also shows sudden drop eight days before the Japan: Honshu earthquake.

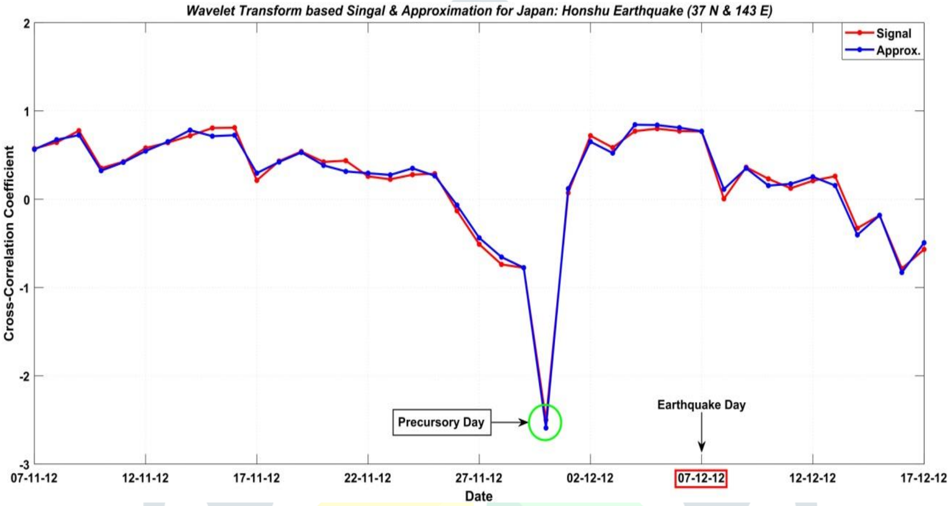

Fig. 8 – Wavelet Transform based Signal and Approximation Plot from November 07, 2012 to December 17, 2012 during the Japan: Honshu Earthquake.

IV. CONCLUSIONS

In this paper we used the cross-correlation coefficient method. The main advantage of this 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. Some restriction of the proposed method is connected with the information that a random location of the sensor station may not give the optimistic result. This is actuality associated with the complex configuration of abnormal variations within the ionosphere. The ionospheric irregularities may be shifted along the geomagnetic field lines equator ward against the vertical projection of the epicenter of the impending earthquake on the ionosphere. In such circumstances the sensor station becomes unsighted and cannot sense 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. 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 foF2 signals drop 5 to 8 days before earthquake, which is in accordance with the results of previous seismo ionospheric studies.

The changes in the F layer density may be interpreted as a result of associated seismic electric field generated by internal gravity waves (Bolt, et al., 1964; Calais, et al., 1995). Such field can penetrate the F region of the ionosphere and move the layer up or down due to $E \times B$ drift and bring out the changes in plasma density. The enhancement in density may be the result of earthquake associated with $E \times B$ drift when the density increases. The main goal of this study is the detection of significant precursors. If we look at the problem from the position of the physical mechanism, the intensity of variation will depend on the extent 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.

V. ACKNOWLEDGMENT

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