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Analysis of Seismo-ionospheric Perturbations using Correlation Method

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ABSTRACT

The aim of this paper is to examine the anomalous variations of the critical frequency (foF2), Total Electron content (TEC) and critical frequency of sporadic E layer (foEs) before earthquake occurred on 01 April 2014 Iquique Chile (M=8.2) and on 25 October 2013 Japan(M=7.1). Using the Correlation technique we analyzed the foF2, TEC and foEs parameters. A sudden drop in cross correlation coefficient of foF2 observed 02 days before, drop for TEC observed 12 days before and drop for foEs parameter observed 03 days before Chile event While drop in correlation coefficients for foF2 and foEs were observed 05 days and 01 day before Japan event.

Introduction

The earthquake is a sudden and rapid shaking of the earth caused by the breaking and shifting of fault lines under the earth's surface [1]. An earthquake is the sudden movement of the earth's surface. But were there any marks or symptoms about such approaching destructing causality? What happened in the days before those earthquake events? The earlier research tells that nature gives some signs of approaching earthquakes. Thus it requires searching for reliable precursor of seismic event. The precursor gives us prior intimation of approaching earthquake.

It has been reported by researchers that the ionosphere suffers specific changes prior to earthquake events. A relationship between seismic activity and changes in ionospheric properties has been monitored by various researchers. Researchers have observed anomalous changes in the ionospheric total electron content (TEC), Critical frequency of F2 layer (foF2) of ionosphere few days prior to the earthquake. If we can keep record of these ionospheric changes then we can predict earthquake events. A precursor provides a prior, earlier indication of these approaching disasters. Thus detection of precursor can lead to forecasting of upcoming earthquakes. This would minimize loss of lives and property damage and may help in recovery from the effect of earthquakes.

Ionosphere lies between 60Km and 1000Km above earth's surface. The F2 layer is a layer where the peak of the electron concentration is situated [2]. The ionospheric parameters which may be used to investigate seismic impact in the ionosphere are Critical frequencies of the F2 region (foF2), Critical frequencies of the E-region (foEs) and Total electron content (TEC). foF2 is the greatest (critical) plasma frequency of ionosphere. TEC is a measure of the total electron content of the ionosphere along a particular line of sight [2].

Cross-correlation coefficients were obtained for two Italian ionospheric stations Roma & Gibilmanna for the period April-May 1984. In this case a strong drop of the cross-correlation coefficient was observed one day before the earthquake of 29 April 1984 [M=6.1, 43.3^0 N, 12.6^0 E] which occurred 126 km from the Roma station [2]. [3] Made a quantitative evaluation of the ionospheric variability at heights of the F2 layer maximum for the pairs of ionospheric stations which were more or less in the same geophysical conditions but were at different distances from the epicentre. They considered the data of two Russian stations Petropavlovsk-na-Kamchatka [53^0 N, 158.7^0 E] & Megadan [60^0 N, 151^0 E]. They worked on Magadan-Petropavlovsk-na-Kamchatka stations for the three month period January -April 1974. The Petropavlovsk-na-Kamchatka station was inside the seismically active zone and Magadan was situated outside of seismically active area. They calculated the day-to-day correlation of daily variations of critical frequencies foF2 between two stations. A sharp drop of the cross-correlation coefficient 3-7 days before seismic shock was observed. Also a drop of autocorrelation coefficient appeared only on the record of Petropavlovsk station because of its location inside the earthquake preparation area. The drop of cross-correlation coefficient means the ionospheric precursor registration. A correlation technique was used for the San Simeon earthquake in central California in December 2003 [M=6.5, 35.7^0 N, 121.11^0 W] on 22 December 2003. The results obtained indicates the gradual drop of the cross-correlation coefficient starting from 15 of December i.e. 7 days before the shock with absolute minima registered one day and three days before the shock respectively [3]. [4] Calculated the cross-correlation coefficient for two pairs of GPS receivers around the time of the Colima earthquake (M=7.8) of January 21, 2003. Colima receiver was in the epicentre and Toluca receiver was to the east of it by 300 km. Toluca receiver was used as Sensor. Colima & Toluca receivers were closer to the epicentre. The Aguascalientes receiver was 400 km to north of epicentre. The daily cross-correlation coefficients calculated for the different

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pairs of GPS receiver presented a drop within an interval of one to five days before the seismic shock. A drop in the correlation coefficient 5 days before the seismic shock was observed. [5] Calculated correlation between the variations of the ionospheric peak electron density NmF2 & GPS TEC. The Correlation technique works for GPS TEC data as well. [6] For M9 Tohoku Japan earthquake of March 11, 2011 calculated the foF2 data cross-correlation coefficients between daily variations at Kokubunji and Yamagawa stations. A maximum drop in cross-correlation coefficients was observed on 8 March.

Event Selection & Data

In the present paper we have taken two earthquake events for analysis one occurred near Chile and the other one occurred near Ishinomaki Japan. Event (i): A major earthquake of magnitude M=8.2 occurred on April 01, 2014 near Iquique Chile at 23:46:47 UTC [18:46:47 UTC-05.00] at epicentre. The epicentre of this earthquake was located at 94 km NW of Iquique Chile [19.61^{0}S, 70.769^{0}W]. The magnitude of the event was 8.2 on Richter scale and focal depth 25 km. Event (ii): The major earthquake of magnitude M=7.1 occurred on October 25, 2013 near Ishinomaki of Japan. The epicentre of this earthquake was located at 325 km SE of Ishinomaki Japan [38^{0}25'N, 141^{0}18'E] and 475 Km ENE of Tokyo Japan. The magnitude of the event was 7.1 on Richter scale and focal depth was 35 km.

We used the Correlation method and analysed the ionospheres abnormalities prior to these events. For event (i) we obtained the Ionosondes data foF2 and foEs from Jicamarca Ionosondes station [-120°N,-76.8°E] located in Peru and from station Port Stanley [-51.7^0 N,-57.8^{0}E] situated in Falkland Island and GPS data (TEC) from GPS receiver stations Iquique Chile [20^{0}10'S, 70^{0}7'W] and Punta Arenas [-53^{0}10'S, 70^{0}56'W]. For second event the Ionosondes data were obtained from stations Kokubunji [35.7^{0}N, 139.5^{0}E] and Okinawa [26.30^{0}N, 127.80^0 E] situated in Japan. We retrieved the hourly values of TEC from Ionolab and the hourly values of foF2 were retrieved from NOAA Space Environment Centre Weather Prediction centre from the website URL:http://spidr.ngdc.noaa.gov/spidr/.

Methodology

In this paper the Correlation analysis method is used to explain the effects of seismic activities on ionosphere layers. It is a method which is based on the correlation of records of two receiving stations (Ionosondes or GPS receiver). The concept of earthquake preparation area was introduced by Dobrovolsky et al. (1979) [7]. According to Dobrovolsky the size (radius) of the earthquake preparation area depends on the earthquake magnitude M. The radius of this earthquake preparation area is given by

$$R=10^{0.43M} \qquad (1)$$

Where,

R is the radius of the earthquake preparation zone in km.

M is the magnitude of earthquake in Richter scale.

The radius of earthquake preparation zone (area) is estimated for these earthquake events by using the above formula. Putting the value of M in above equation the radius of earthquake preparation zone is estimated as 3357.3 Km for first event and it is estimated as 1129.796 Km for second event.

In the present analysis for Chile event for foF2 & foEs analysis we choose two Ionosondes stations. One station Jicamarca (known as sensor was situated in earthquake preparation zone and the other one station Port Stanley (known as control station) was situated outside of this area. For TEC data analysis we choose two GPS receiver stations. One station Iquique Chile was situated inside earthquake preparation zone and the other one station Punta Arenas was situated outside of it. Similarly for second event of Japan earthquake we choose two Ionosondes stations. One station Kokubunji was situated inside earthquake preparation zone and the other one station Okinawa was situated outside of it. It is based on the theory that around the time of seismic shock the nature of the ionospheric change is different in the ionosphere over the epicentre than over the distant station which leads to the drops in the cross-correlation coefficient between them [8].

Cross Correlation analysis method gives a correlation between two time series or two waveforms. The observations of one series of (foF2 or TEC) parameters are related with those of another series of (foF2 or TEC) [9]. Using the Correlation method we analysed the ionospheric data of period prior to earthquake event. Using the formula given below firstly we calculated the autocorrelation coefficient then calculated the daily Cross-correlation Coefficient of two stations. The autocorrelation coefficient characterizes the day-to-day variability of the ionosphere. The daily cross-correlation coefficient is calculated by the following formula:

The formulae used for Correlation Coefficients is

$$r =\Sigma_i [(x (i)-m_x). (y (i)-m_y)] / \sqrt{} \Sigma_i (x (i) – m_x)^2.\sqrt{} \Sigma_i(y (i)-m_y)^2 \qquad (2)$$

Where m_x and m_y are the means of the corresponding series. Here x (i) and y (i) corresponds to Sensor and Control Ionosondes/GPS stations respectively and i= k where k = 24 (or 96 or 144) points is the number of samples per day. k =24 for t = one hour sampling interval is used, k = 96 for 15 minute interval is used. The hourly values of foF2, TEC and foEs were used.

For detection of any anomalous variation the values of correlation coefficients were examined. The geomagnetic activity also affects the ionospheres parameters and causes perturbations in it. We also checked the geomagnetic factors influencing ionosphere. For investigating the ionosphere variations prior to only seismic event, we also checked the geomagnetic factor that is the geomagnetic indices Kp index and Dst index. The values of Kp and Dst were checked during the considered time period. We obtained the Kp index and Dst index data from World Data Centre (WDC) Kyoto Japan. For Chile event the variations in the Dst index were within normal limit values. The Dst index value was Dst >-20nT and value of Kp index was also below 4. This shows that the space environment and the geomagnetic activity were quiet during the analysis period. Similarly for Japan event the variations in the values of Dst index were within normal limit values. The Dst index value was Dst >-20nT and value of Kp index was also below 4. This shows that the geomagnetic activity were relatively quiet during the analysis period of second event.

Results

Event-I :Earthquake event of magnitude M=8.2 occurred on April 01, 2014 Near Chile

The major earthquake of magnitude M=8.2 occurred on April 01, 2014 in Iquique Chile at 23:46:47 UTC [18:46:47 UTC-05.00] at epicentre. The epicentre of this earthquake was located at 94 km NW of Iquique [19.61^0 S, 70.769^{0}W]. The focal depth was 25 km. In our study ionospheric variations were examined during the period 15 March – 01 April 2014 prior to Iquique Chile earthquake of April 01, 2014. We have examined the anomalous variations of ionospheric foF2

(Critical frequency of F2 layer), foEs (Critical frequency of Es layer), and TEC (Total electron content) by analyzing foF2, foEs and TEC data. The results related to these earthquakes are plotted as shown in Figure 1 to Figure 6.

f_OF2 (Critical Frequency) Analysis

We examined the anomalous variation of ionospheric foF2 (critical frequency of F2 layer) prior to this event by analyzing foF2 data of period 15 March - 01 April 2014. The results related to these earthquakes are plotted as shown in Figure 1 and Figure 2. Figure 1 shows autocorrelation coefficient of foF2 for Jicamarca Station. Figure 2 shows the cross correlation coefficient of foF2 for both Jicamraca & Port-Stanley Stations. From Figure 1 a sudden drop of auto correlation coefficient of foF2 for Jicamarca Station observed about 09 days before the earthquake on 22 March 2014. From Figure 2 a sudden drop of cross- correlation coefficient of foF2 for Jicamarca and Port-Stanley Stations observed 02 days before the earthquake on 29 March 2014.

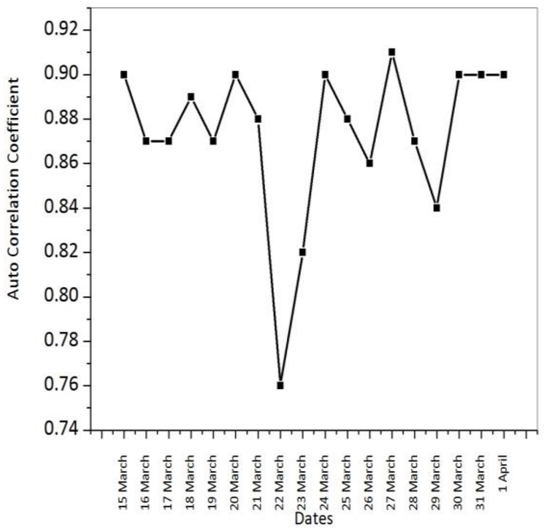

Figure 1. Auto Correlation Coefficient of foF2 for Jicarmarca Station

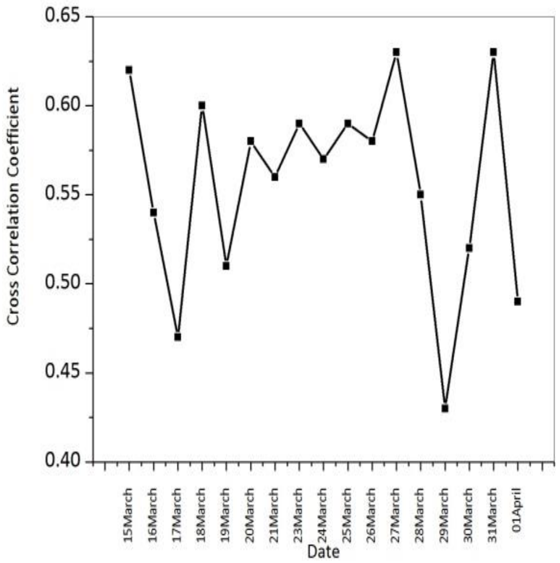

Figure 2. Cross Correlation Coefficient of foF2 for Jicamarca and Port Stanley Stations

Total Electron Content (TEC) Analysis

We examined the anomalous variation of TEC (Total electron content) prior to this event by analyzing TEC data of period 15 March - 01 April 2014. The results related to these earthquakes are plotted as shown in Figure 3 and Figure 4. Figure 3 shows autocorrelation coefficient of TEC for Iquique Chile Station. Figure 4 shows cross correlation coefficient of TEC for both Iquique Chile Station & Punta Arenas Stations. From Figure 3 a sudden drop of auto correlation coefficient of TEC for Iquique Chile Station is observed about 02 days before the earthquake on 29 March 2014. From Figure 4 a sudden drop of cross- correlation coefficient of TEC for Iquique Chile and Punta Arenas Stations observed 02 days before earthquake on 29 March and maximum drop observed 12 days before earthquake on 19 March 2014.

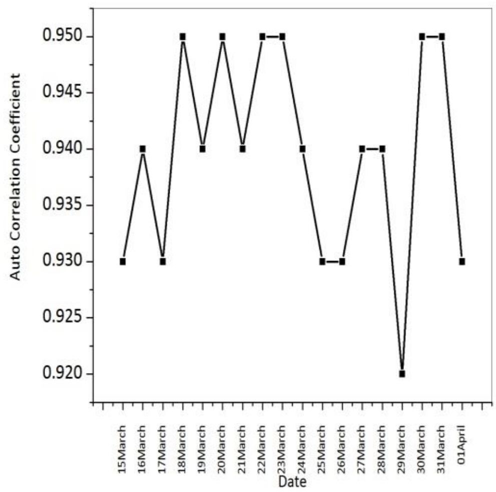

Figure 3. Auto Correlation Coefficient of TEC of Iquique Chile Station

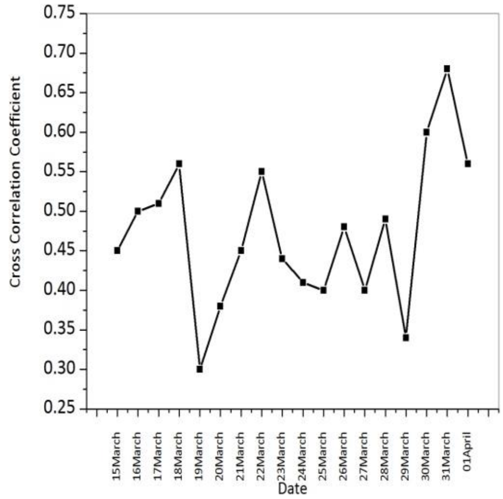

Figure 4. Cross Correlation Coefficient of TEC for Iquique Chile and Punta Arenas Station

f_OEs (Critical frequency of Es layer) Analysis

We examined the anomalous variation of foEs (Critical frequency of Es layer) prior to this earthquake event by analyzing the foEs data of period 25 March - 02 April 2014. The results related to these earthquakes are plotted as shown in Figure 5 and Figure 6. Figure 5 shows autocorrelation coefficient of foEs for Jicamarca Station. Figure 6 shows cross correlation coefficient of foEs for Jicamraca and Port-Stanley Stations. From Figure 5 a sudden drop of auto correlation coefficient of foEs for Jicamarca Station is observed about 04 days before the earthquake on 27 March 2014. From Figure 6 a drop of cross- correlation coefficient of foEs for Jicamarca and Port Stanley Stations observed before earthquake on 30 March and maximum drop observed 03 days before the earthquake on 28 March 2014.

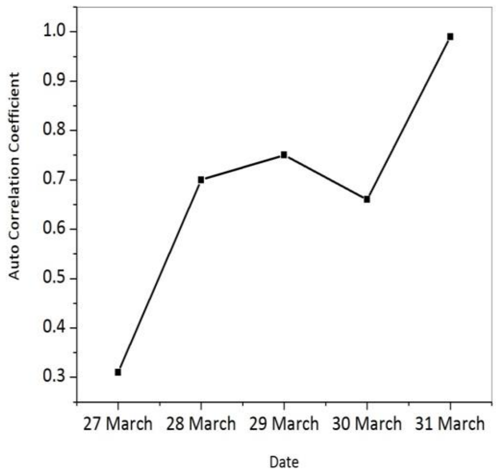

Figure 5. Auto Correlation Coefficient of foEs of Jicarmarca Station

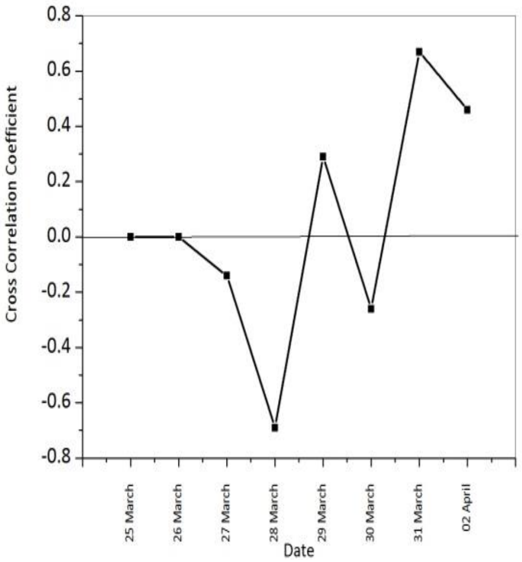

Figure 6. Cross Correlation Coefficient of foEs of Jicamarca and Port Stanley Stations

Event-II :Earthquake event of magnitude M=7.1 occurred on October 25, 2013 Near Ishinomaki of Japan

The major earthquake of magnitude M=7.1 occurred on October 25, 2013 near Ishinomaki of Japan. The epicentre of this earthquake was located at 325 km SE of Ishinomaki Japan [$38^0$25'N, $141^0$18'E]. The focal depth was 35 km. In our study ionospheric variations were examined during the period 18 October - 25 October 2013 prior to October 25, 2013 Japan Earthquake. We examined the anomalous variation of ionospheric foF2 and foEs by analyzing foF2 and foEs data. The results related to these earthquakes are plotted as shown in Figure 7 to Figure 10.

foF2 (Critical Frequency) Analysis

We examined the anomalous variations of foF2 prior to this event by analyzing foF2 data of period 18 October-25 October 2013. The results related to these earthquakes are plotted as shown in Figure 7 and Figure 8. Figure 7 shows autocorrelation coefficient of foF2 for Kokubunji Station. Figure 8 shows cross correlation coefficient of foF2 for both Kokubunji & Okinawa Stations. From Figure 7 a sudden drop of auto correlation coefficient of foF2 for Kokubunji Station is observed 01 day before event on 24 October 2013. From Figure 8 a sudden drop of cross- correlation coefficient of foF2 for Kokubunji & Okinawa Stations observed 05 days before the earthquake on 19 October 2013.

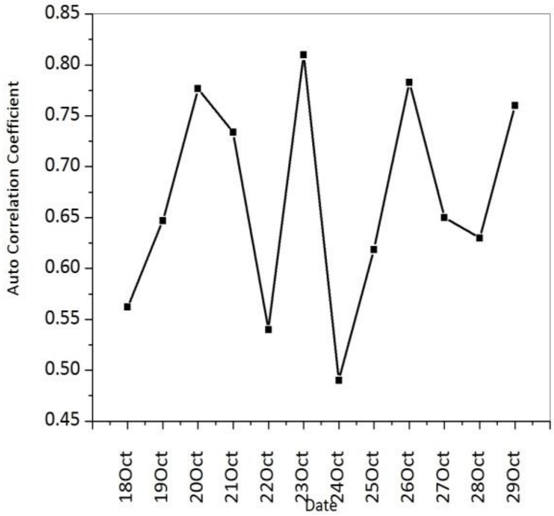

Figure 7. Auto Correlation Coefficient of foF2 of Kokubunji Station

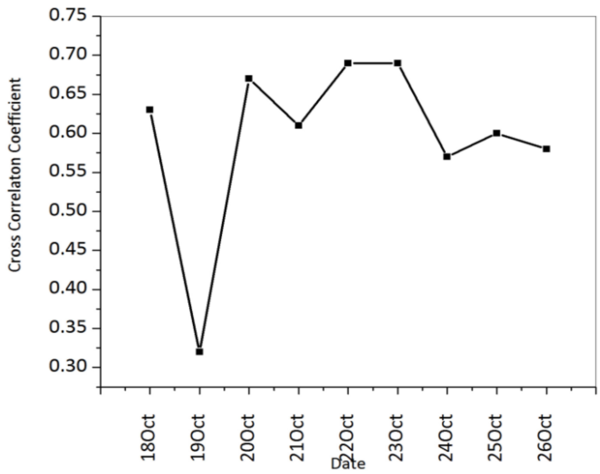

Figure 8. Cross Correlation Coefficient of foF2 of Kokubunji & Okinawa Station

foEs (Critical frequency of Es layer) Analysis

We examined the anomalous variation of foEs (Critical frequency of Es layer) prior to this earthquake event by analyzing the foEs data of period 18 October - 25 October 2013. The results related to this earthquake are plotted as shown in Figure 9 and Figure 10. Figure 9 shows autocorrelation coefficient of foEs for Kokubunji Station. Figure 10 shows cross correlation coefficient of foEs for Kokubunji & Okinawa Stations. From Figure 9 a sudden drop of auto correlation coefficient of foEs for Kokubunji Station is observed about 01 day before the earthquake on 24 October 2013 and 05 days before on 19 October 2013. A sudden fall in cross- correlation coefficient of foEs for Kokubunji & Okinawa Stations observed 01 day before shock on 24 October and maximum drop observed on earthquake day as shown in Figure 10.

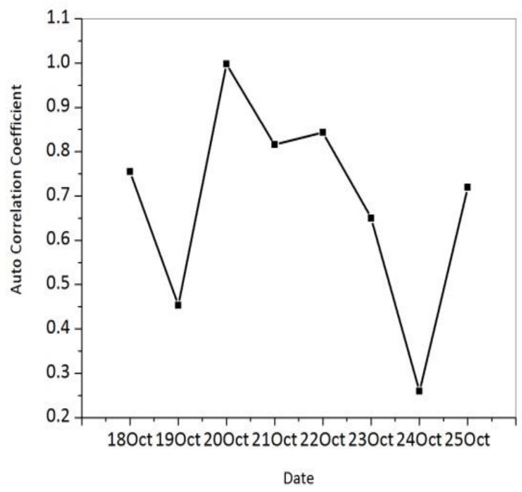

Figure 9. Auto Correlation Coefficient of foEs of Kokubunji Station

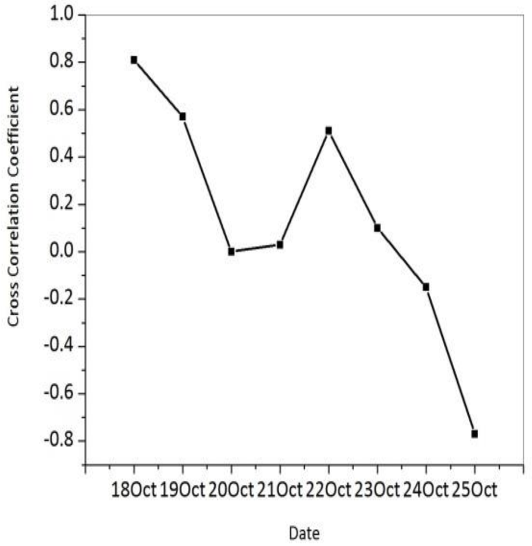

Figure 10. Cross Correlation Coefficient of foEs of Kokubunji & Okinawa Station

Discussion

In our study ionospheric variations were investigated during the period of 15 days prior to Iquique Chile earthquake of April 01,2014 and during the period of 07 days prior to (M=7.1) Japan earthquake occurred on 25 October 2013 near Ishinomaki of Japan. We investigated the variations of ionospheric foF2, foEs and TEC by analyzing foF2, foEs and TEC data using correlation method. The results related to these earthquakes are as shown in Figure (1) to Figure (6). For Chile event a drop of auto correlation coefficient of foF2 for Jicamarca Station was observed about 09 days before shock on 22 March 2014. A sudden drop of cross- correlation coefficient of foF2 for Jicamarca and Port Stanley stations was observed 02 days before the earthquake on 29 March. A drop of auto correlation coefficient of TEC for Iquique Chile station was observed about 02 days prior to event on 29 March. A sudden drop of cross- correlation coefficient of TEC for both Stations Iquique Chile and Punta Arenas was observed 02 days before shock on 29 March 2014. The maximum drop was observed 12 days before the earthquake on 19 March. Similarly drop of auto correlation coefficients of foEs for Jicamarca Station observed about 04 days prior to event on 27 March. A drop of cross- correlation coefficient of foEs for Jicamarca and Port Stanley Station observed 03 days before the earthquake on 28 March 2014. Thus for Chile event 19 March, 28 March and 29 March are the anomalous days prior to earthquake event. Thus 19 March, 28 and 29 March may be considered as precursor days prior to earthquake event. Thus precursors were obtained which was on 12 days, 03 days and 02 days before Chile event. For Chile event the values of the Dst index and Kp index were within normal limit values. This shows that the geomagnetic activity were quiet during the analysis period. Therefore the ionospheres anomaly was probably linked to the earthquake event. Similarly for earthquake event of Japan a drop of auto correlation coefficient of foF2 for Kokubunji was observed about 01 day prior to event on 24 October 2013. A sudden drop of cross-correlation coefficient of foF2 for Kokubunji and Okinawa Stations was observed 05 days before the earthquake on 19 October. A drop of auto correlation coefficient of foEs for Kokubunji Station was observed about 01 day prior to event on 24 October. A sudden fall in cross- correlation coefficient of foEs for Kokubunji and Okinawa Stations observed 01 day before shock on 24 October and maximum drop observed on earthquake day. For Japan event also the variations in the Dst index and Kp index were within normal limit values. It means the geomagnetic activity was quiet during analysis period. Therefore the ionospheres anomaly was probably related to the earthquake event. Thus 19 October and 24 October are the anomalous days which may be considered as precursor days prior to earthquake event. Thus precursors were obtained 05 days and 01 day before Japan earthquake event. The drop in daily cross correlation coefficient may be used as precursor. The above results of anomalous ionospheric variations seem to be linked with earthquakes.

Conclusion

For Chile event 19 March, 28 March and 29 March were observed as anomalous days prior to earthquake event. Thus these days may be regarded as precursor days prior to earthquake event. Thus precursors were obtained 12 days, 03 days and 02 days before Chile earthquake event. Similarly for Japan earthquake event the 19 and 24 October were observed as anomalous days which may be regarded as precursor days prior to earthquake event. Thus precursors were obtained 05 days and 01 day before Japan earthquake event. The above results of anomalous ionospheric variations seem to be linked with earthquakes.

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