EARTHQUAKE ANALYSIS OVER THE EQUATORIAL REGION BY USING THE CRITICAL FREQUENCY DATA AND GEOMAGNETIC INDEX

Karthigesu Nagarajoo[1]

[1]Faculty of Electrical and Electronics Engineering,
Universiti Tun Hussein Onn Malaysia,
86400 Parit Raja, Batu Pahat, Johor

Email: [1]karthi@uthm.edu.my

ABSTRACT

This paper focuses on the variation of the ionosphere in the F_2 layer over the equatorial region during seismic event. The critical frequency of the F_2 layer, f_cF_2, shows that there is relationship between the variation of the ionosphere and the occurrence of an earthquake. This f_cF_2 was obtained from the ground-based ionosonde that has been stationed in Wireless and Radio Science Centre, UTHM. Two statistical techniques, which are the median and mean based techniques, were used to examine the possible relationship between the occurrence of the earthquake with the variations of the f_cF_2. For this research, two strong earthquakes phenomena occurred in Indonesia were chosen. The results obtained shows that there is strong relationship between the f_cF_2 and the occurrence of earthquake. Then, fitting method from Matlab was applied to the respective f_cF_2 data some days before and after the earthquake in order to obtain an analytical equation which can be used as a precursor for the occurrence of an earthquake. However, 2 different earthquakes gave 2 different equations though. Other than ionospheric disturbances, the earthquake also affects the Earth's magnetic field, which can be measured using geomagnetic index, K_p. However, the K_p does not correlate very well with the variation of the f_cF_2 during an earthquake.

***KEYWORDS**: ionosphere, earthquake, critical frequency, geomagnetic index.*

1.0 INTRODUCTION

Ionosphere is one of the Earth's atmospheric layer which is formed when extreme ultraviolet (EUV) light from the Sun strip electrons from the neutral atoms of the Earth's atmosphere (McNamara, 1994). The ionosphere approximately extends from a height of 70 to 2000 km above the Earth's surface. The degree of ionization and the heights of the ionized layers fluctuate on a daily and a seasonal basis. It is also varies latitudinaly and altitudinaly. On top of that, the variation of the ionosphere is very much dependent on the solar activity.

The ionosphere can be divided into 3 main layers; D, E, and F, referring to the level of ionization (Ioannides, 2002). The F layer can be divided further into F_1 (only present at day time) and F_2 (present at day and night time) layers. The F_2 layer is the most important ionospheric layer for the High Frequency (HF) propagation (3 and 30 MHz) to take place. The composition of the electron density in each layer depends on the solar activity and also on the geographical location.

From the Earth, the critical frequency (f_c) of the F_2 layer can be measured by using an equipment called ionosonde. The f_c is the maximum frequency that a radio wave can be transmitted vertically and be reflected to the Earth. Figure 1 shows the relationship between the HF propagation and the fc of the ionosphere.

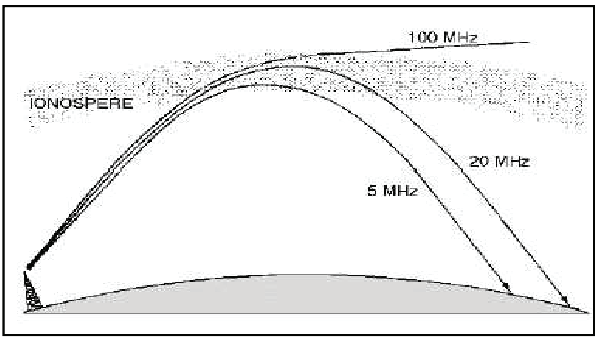

Figure 1 Illustration of the HF propagation and its relation with f_c (Pulinet and Boyarchuk, 2004)

Each of the ionospheric layers has its own value of f_c. It depends on the maximum electron density, N_{max} on the ionospheric layer which varies with time of a day, altitude, season and location. Equation (1) shows this relationship.

$$f_c = 9\sqrt{N_{\max}} \tag{1}$$

An ionosonde is a special radar to measure the f_c of the F_2 layer at a frequency range that varies from 1 to 20 MHz. It is a shortwave transmitter tunable through the whole shortwave range, which transmits on various shortwave frequencies pulses, whose echo are analyzed by the means of radar.

An ionogram is the output of an ionosonde receiver, which is the plot of the tracings of high frequency ionospheric reflected radio pulses. Sample of ionogram from an ionosonde is shown in Figure 2. The f_c of each layer is scaled from the highest point of an ionogram.

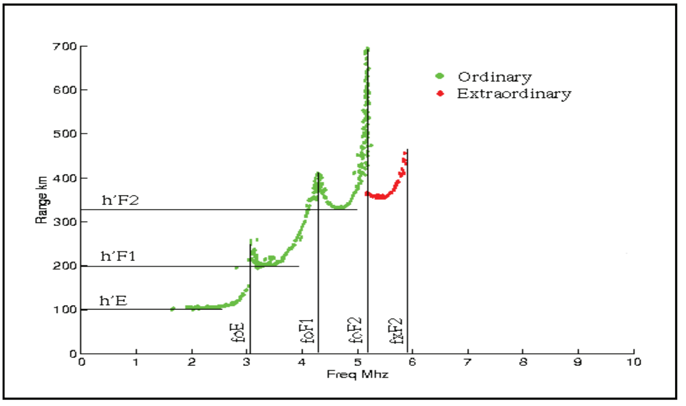

Figure 2 Sample of an ionogram from ionosonde

Earthquake is the sudden movement of the Earth's crust caused by the release of stress accumulated along geologic faults or by volcanic activity that can create seismic waves (Dabas *et.al.*, 2007). Earthquakes are recorded with a seismometer, also known as a seismograph. The magnitude of an earthquake is measured in absolute Richter scale. When the Ritcher scale is 3 or lower, earthquakes normally imperceptible. At the value of 5, it is still moderate. However, when the Richter scale is 6 and above, it can cause serious damages over large areas (Pulinet *et.al.*, 2003).

Predicting when the quake will strike the Earth is the hardest part. It is impossible to predict a specific earthquake (Pulinet and Boyarchuk, 2004). However, in this project, a research has been carried out to determine any possible relationship between the f_cF_2 and the Earth movement. Then, those results will be used to see if there is any possibility to develop an analytical mathematical model which can act as a precursor for an earthquake occurrence.

Another parameter that can be used to determine the disturbance in the ionosphere is the geomagnetic indices. Geomagnetic indices are daily regular magnetic field variations arise from current systems caused by regular solar radiation changes. So, magnetic activity indices were designed to describe the variation in the geomagnetic field caused by these irregular current systems. They are termed as K_p and A_p indices. However, in this research, only K_p index will be considered.

K_p variations are all irregular disturbances of the geomagnetic field caused by solar particle radiation within 3 hour interval concerned. K_p index ranges from 0 (no disturbances) to 9 (very disturbed). The index was obtained from the National Geophysical Data Centre (NGDC) monitored by National Oceanic and Atmospheric Administration (NOAA) online services.

2.0 METHODS

To do the fitting, the median-based and average-based statistical techniques were applied to the f_cF_2 variations. Median-based statistical technique is a technique where the median is the number in the middle of a sample after sorting the list into increasing order. Whereas, the average-based statistical technique is a technique where the mean is calculated by adding up together all the numbers of a sample and then divide them by the sum of the number of the given sample.

In this research, the f_cF_2 was obtained and analyzed at every 30 minutes by using those statistical methods mentioned above. The data was taken on the days when the earthquakes occurred in Indonesia, as shown in the Table 1 below. Two earthquake occasions were chosen just to see if there is any difference in the f_cF_2 analysis done at two different tremor levels of earthquake.

Table 1 The location and time earthquakes took place in the region of Indonesia

No	Date	Region	Ritcher Scale	Time (UTC)	Location
1.	26.12.2004	Off West Coast of Northern Sumatra	9.1	00:58:53	3.316°N, 95.854°E
2.	08.08.2007	Java	7.5	17:04:58	5.968°S, 107.66°E

3.0 DATA

First of all, the f_cF_2 data that was obtained from the ionosonde was plotted. This plot was done to show the diurnal f_cF_2 observation over a day. Plots for two consecutive days are shown in Figure 3 below.

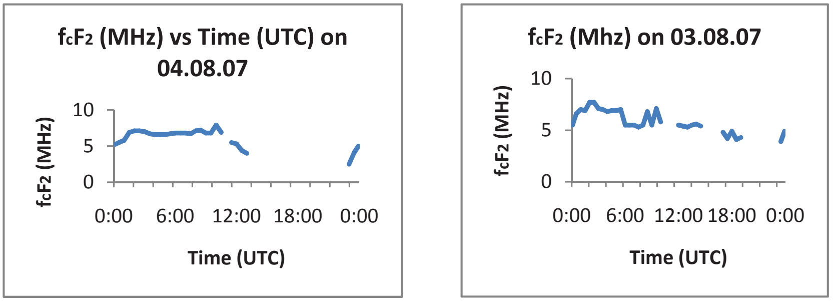

Figure 3 The diurnal variation of the fcF2 on 3rd and 4th August 2007

As can be seen, from about 00:00 UTC (08:00 LT) to 06:00 UTC (14:00 LT), the f_cF_2 is keep increasing. This is due to the photoionization process. However, after about 14:00 UTC (22:00 LT), the f_cF_2 is decreasing and at some point, there is no observation. This is due to the recombination process. So, from the figure above, it is proven that the f_cF_2 observation data from ionosonde can be used to represent the diurnal variation of the ionosphere.

4.0 RESULTS AND ANALYSIS

As for the earthquake that occurred on 26th December 2004, the variation of the f_cF_2 for the whole month of December 2004 was studied. The f_cF_2 data that was taken for a day (a sample of 48 sets of fcF2 data) was averaged-out using both statistic techniques as was mentioned above to determine the f_cF_2 data for a day. Then, the same method was used to obtain the average f_cF_2 for each day of the month of December 2004. The plot that was obtained is as shown in the Figures 4 and 5 below.

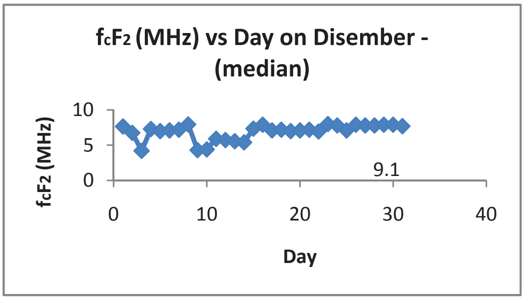

Figure 4 Observation of f_cF_2 using median based statistical method for the whole month of December 2004

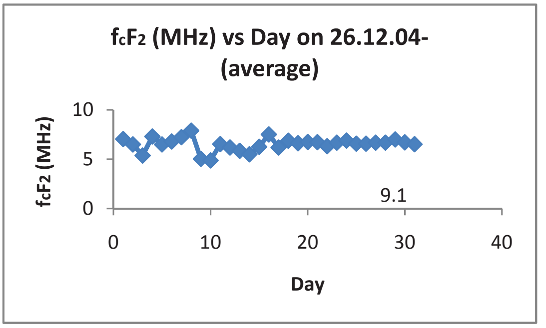

Figure 5 Observation of f_cF_2 using average based statistical method for the whole month of December 2004

As can be seen from those figures, it was found out that the variation of f_cF_2 is about the same though two different techniques have been used. The plot from both techniques is shown in Figure 6 below.

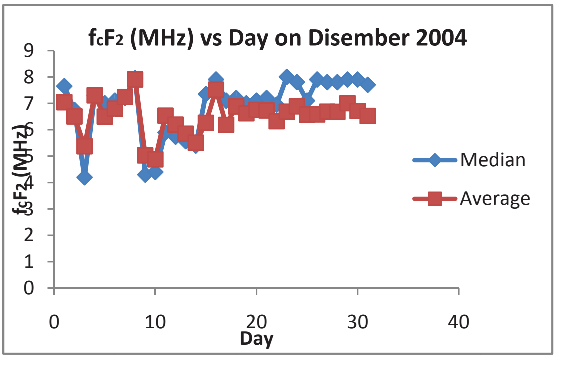

Figure 6 Observation of f_cF_2 using both median and average based statistical methods for the whole month of December 2004

From here, it has been proved that any of those techniques above can be used to plot the variation of f_cF_2 for a period of time.

At the same time, it is also can be seen that there is a fluctuation in the variation of the f_cF_2 before the earthquake day. The deepest fluctuation can be seen on 3rd, 9th, 10th and 15th of December 2004 prior to the earthquake day (26th December 2004). However, after 15th of December 2004, there is no very deep fluctuation in the f_cF_2. This tremendous drop and uncertainty in f_cF_2 can be used as an indicator or as a precursor to the earthquake.

To enhance the results that had been obtained, the plot was done for the f_2F_c data averaged at only local noon time, which is from about 04:00 to 06:00 UTC (12:00 to 14:00 LT). It is shown in Figure 7 below.

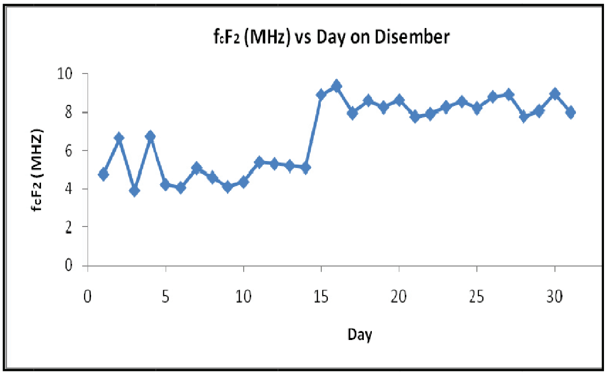

Figure 7 Observation of f_cF_2 at local noon time for the whole month of December 2004

From the figure, it can be seen that there is significant drop in the f_cF_2 value around 4 to 5.4 MHz from about 5th to 14th December 2004. This indication can be a potential precursor for the occurrence of earthquake on 26th December 2004.

Then, the Matlab fitting method was used to fit the f^cF^2 in order to obtain an approximate analytical mathematical model that can be used as a precursor for an earthquake. Figure 8 shows the fitting and approximated polynomial equations in two different orders together with their residuals.

From the figure, it can be seen that the approximation is better when the polynomial order of the equation is higher. The residuals for the 5th polynomial order is also less than 4th order of the fittings. Though the fitting is not highly accurate, however this result could have been used as the precursor for the earthquake that occurred on 26th December 2004, that caused the deadly tsunami.

As for comparison purpose, another analysis was done for another occurrence of earthquake. This time the f_cF_2 was analysed on 8th of August 2007, the day earthquake occurred at Java, Indonesia.

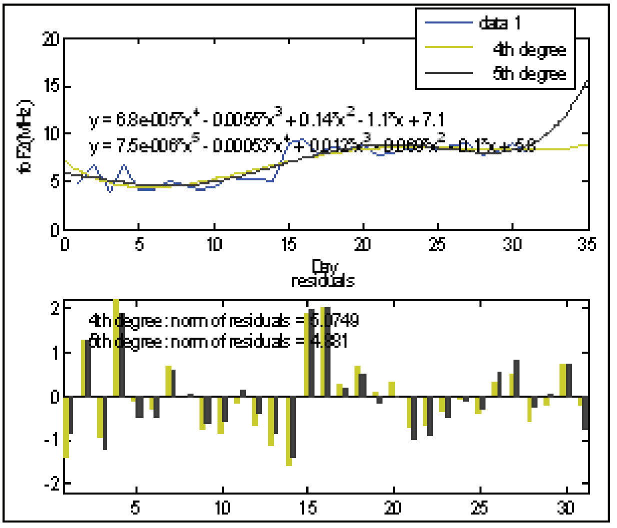

Figure 8 Fitting of f_cF_2 (for the month of December 2004) using 4th and 5th order polynomial and their residuals

By using both statistic techniques as was mentioned above, the plot of f_cF_2 was done for the first 17 days of the month of August 2007 at local noon time. The variation of f_cF_2 is shown in Figure 9 below.

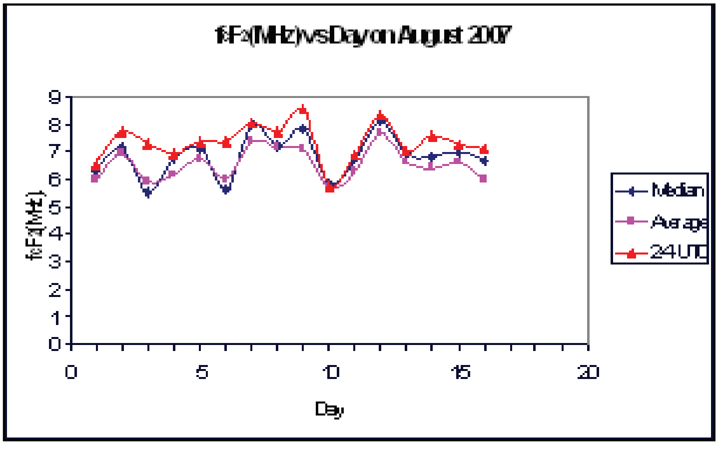

Figure 9 Observation of f_cF_2 using both median and average based statistical methods for the first 17 days of August 2007

As of the previous case, there is a drop in the value of f_cF_2 (about 2 to 3 MHz) on 3rd and 6th of August 2007. This drop in the f_cF_2 could have been used as the precursor for the occurrence of the earthquake on 8th of August 2007. However, for this scenario, there is still a drop in the value of fcF_2 after the earthquake. As can be seen, there is a huge drop in the value of f_cF2 on 10th of August 2007, which is 2 days after the earthquake.

Then, the Matlab fitting was done as of the previous case. As expected, the 5th order polynomial fitting is better than the 4th order fitting. The residual of the 5th order is 2.5387, which is very much less than the the 4th order. The fitting done is shown in Figure 10 below.

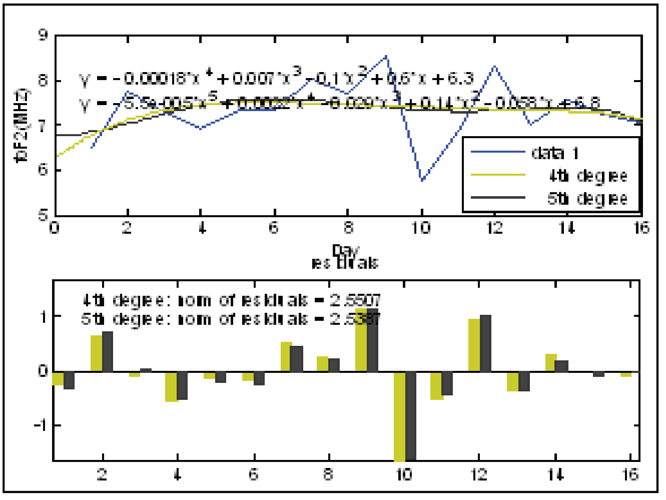

Figure 10 Fitting of f_cF_2 (for the month of August 2007) in the 4th and 5th order polynomial and their residuals

From the results obtained, it can be seen that there is a relationship between the variation of f_cF_2 and the earthquake occurrence. However, the polynomial equations that were obtained from both the fittings are not the same. It shows that though mathematic equation could be derived from the f_cF_2 variation due to an earthquake, it could not be used as a precursor for the occurrence of any earthquake.

The K_p index that was obtained from NOAA was averaged by using both statistical methods for the whole days of the month of December 2004. The correlation of the K_p index using both methods was really good. It is shown in figure 11 below. It has been proved that any statistical method can be used to plot the K_p index.

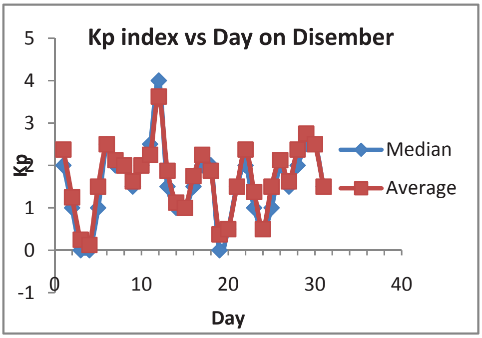

Figure 11 K_p index variation using both median and average based statistical methods for the whole month of December 2004

However, there is no correlation between the variation of f_cF_2 and K_p index. It can be seen in Figure 12 below. In fact, the f_cF_2 is inversely proportional to the K_p index.

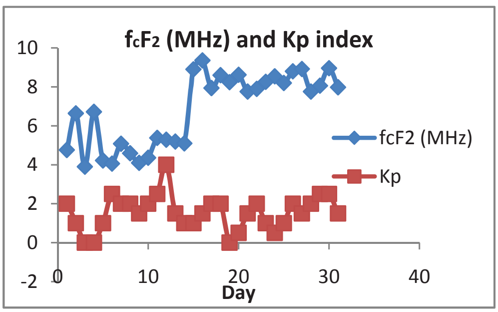

Figure 12 Variation of f_cF_2 and K_p index using median based statistical method for the whole month of December 2004

To enhance the finding above, the variations between f_cF_2 and K_p index also was obtained for the earthquake that occurred on 8^{th} of August 2007. The same scenario as for the year 2004 was also obtained, where there is no correlation at all between the f_cF_2 and K_p index, which is shown in Figure 13 below.

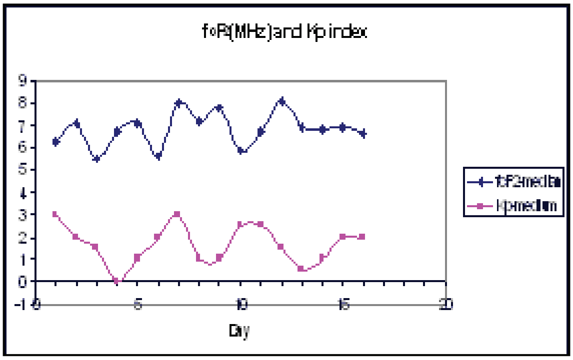

Figure 13 Variation of f_cF_2 and K_p index using median based statistical method for the first 17 days of August 2007

From here, it can be seen that the K_p index cannot be used as an indicator to be the precursor for the earthquake occurrence.

5.0 CONCLUSION

This research was focused to identify the relationship between the variations of the f_cF_2 and the earthquake. It is also an idea to come up with an analytical mathematical model that can be used as a precursor for any earthquake occurrence. Two earthquake events were chosen for this purpose. For both cases, it was found out that there were fluctuations in the f_cF_2 of the ionosphere few days before and after the earthquake. This is a good indication to show that there is a relationship between the variation of the f_cF_2 and the occurrence of the earthquake. Then, f_cF_2 data was used to do the fitting and to obtain an analytical mathematical model that can be used to be the precursor for any earthquake occurrence. Though the 5th order polynomial equation fits very well the f_cF_2, the fitting equations are different for two different earthquakes. Due to that, the equation obtained cannot be used as a precursor for any earthquake occurrence. On top that, the Earth's magnetic field (measured in K_p index) was also analyzed since it is also gets 'disturbed' due to occurrence of an earthquake. The correlation between the K_p index and the f_cF_2 was evaluated before any further analysis. However, there was no any correlation at all between the K_p index and f_cF_2 in order to relate them with the occurrence of an earthquake. In the future, more observation data such as the Total Electron Content (TEC) data from Global Positioning System (GPS) can be used to determine the relationship between the TEC and f_cF_2 variation, which might represent well as a precursor for any earthquake occurrence.

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