Analysis of the Earth Movement over the Equatorial Region by using the Ionosonde Observation Data

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Abstract

This paper focuses on the ionospheric variability observed in the F2 layer during a seismic event at equatorial region. The analysis using critical frequency, fc, shows that there is relationship between the ionospheric variations and the occurrence of earthquake. The fc of the F2 layer (fcF2) and the minimum virtual height (h'F2) data were measured using ground-based ionosonde that has been stationed in Wireless and Radio Science Centre (WARAS), UTHM (1.860 N, 103.080 E). Two statistical techniques, which are the median and mean based techniques, were used to examine the possible relationship between the Earth movement and the variation of the fcF2 in the ionosphere. In this research, five cases of strong earthquakes in Indonesia with Ritcher scale from 6.4 to 9.1 for the year 2004 and 2007 were chosen. However, only two cases are in good agreement with the results obtained from the previous research that was done in India. Both earthquakes occurred at off west coast of Northern Sumatra (M=9.1) and Java (M=7.5). The results showed that fcF2 are reducing 23 to 26 days prior to the earthquake occurred at the off west coast of Northern Sumatra and within 5 days prior to the Java earthquake. Data fitting was done to the ionospheric perturbations (i.e. fc) before and after the earthquake by using the mathematical equations from Matlab. The fittings show better approximation with the mathematical equations in the 5th order. Nevertheless, those equations were not good enough to be an analytical mathematical model to represent the precursor for any earthquake event because the ionosphere varies diurnally.

Keywords: analytical mathematical model, critical frequency, earthquake, Ionospheric variability.

1. 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 [1]. The ionosphere approximately extends from a height of 70 to 400 km above the Earth's surface [2]. The degree of ionization and the heights of the ionized layers fluctuate on a daily and a seasonal basis. It also varies latitudinaly and altitudinaly.

The ionosphere can be divided into 3 main layers; D, E, and F, referring to the level of ionization. The F layer can be divided further into F1 (only present at day time) and F2 (present at day and night time) layers. The F2 layer is the most important ionospheric layer for the High Frequency (HF) propagation (3 and 30 MHz) to take place.

From the Earth, the critical frequency (fc) of the F2 layer can be measured by using equipment called Ionosonde. The fc is the maximum frequency that a radio wave can be transmitted vertically and be reflected to the Earth. Fig. 1 shows the relationship between the HF propagation and the fc of the ionosphere. Each of the ionospheric layers has its own value of fc. It depends on the maximum electron density, Nmax on the ionospheric layer which varies with time of a day, altitude, season and location as shown in equation (1);

$$f_c = 9\sqrt{N_{max}} \text{ Hz}$$

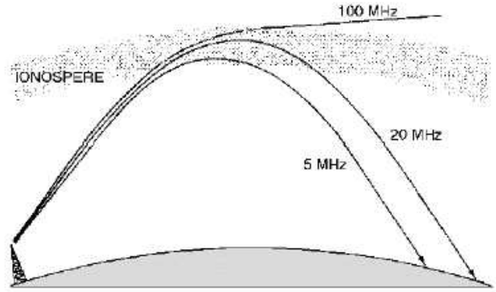


Fig. 1 Scenario that shows the HF propagation and its relation with fc [3].

An Ionosonde is a special radar to measure the fc of the F2 layer at a frequency range that varies from 1 to 20 MHz. An ionosonde is a shortwave tunable transmitter through the whole shortwave range, which transmits on various shortwave frequencies pulses, whose echo are analyzed by the means of radar [4]. So, an Ionosonde is used to find the best frequency in the shortwave range.

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 Fig. 2. The fc of each layer is scaled from the highest point and the virtual height of each layer is scaled from the lowest point on each curve.

It can be seen that the virtual height increases for each layer. There are two distinct traces that present in an ionogram; the lower penetration frequency for F2 which is termed as ordinary wave trace and the higher penetration frequency fxF2 which is termed as extraordinary wave trace.

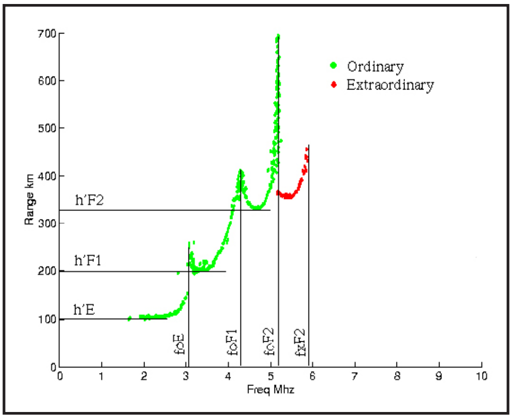


Fig. 2 Sample of an ionogram from ionosonde [5].

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. It is also known as seism, temblor [6]. Earthquakes have various effects such as changes in geologic features, damage to man-made structures and severe impact to human and animal life. One of the most dangerous effects of an earthquake is tsunami. Tsunamis are giant waves that can rise as high as 100 meters tall and can cause massive flood which is enough to give tremendous drawback to human nature.

Earthquakes are recorded with a seismometer, also known as a seismograph. The magnitude of an earthquake is reported conventionally, mostly in absolute Richter scale [7]. 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 to people, animal and things over large areas.

Predicting when the quake will strike the Earth is the hardest part. However, in this project, a research has been carried out to determine if there is any possible relationship between the fc and the Earth movement. The results that are obtained from this research can then be used as an earthquake indicator (or as an early warning) to help the public to make an early preparation if there is any possibility of earthquake occurring in order to minimize the loss of life and property damage.

However, first of all, the behaviour of the ionospheric layer (especially the F2 layer) over the equatorial region will be studied. Then, the relationship between the Earth movement and the fc of the ionospheric layer at this region will be analyzed. Basically, large earthquakes can generate acoustic gravity waves, which lead to disturbances in the atmosphere. However the amount of disturbance is related to the magnitude of the Ritcher scale which can be used to determine the strength of the earthquake. The electron density in the F-layer will fluctuate depending on the strength of the seismic activity. On top of that, the strong electric fields build up prior to strong earthquakes at the surface of the Earth can also modify the electron density of the F-layer. Many scientific papers have reported on the drop in fc before the onset of an earthquake for Ritcher scale greater than 6 and this can be described as 'calm' before the storm happens.

Analysis in order to determine the relationship between the Earth movement and the fc of the ionospheric layer was carried out using the ionosonde observation data for the year 2004 and 2007 which was obtained from the ionosonde that has been stationed in WARAS Centre, UTHM.

2. RESULTS AND ANALYSIS

The fc data were obtained from the ionosonde which is located at WARAS Centre, UTHM, Johor (1.860 N, 103.080 E). The critical frequency of the F2 layer, fcF2, and the virtual reflection height of the F2 layer, h'F2, that were obtained at every 30 minutes from the ionogram were analyzed. Four different earthquakes that occurred at equatorial region (Indonesia) in the year 2007 and one earthquake in the year 2004 were chosen for this study as shown in Table 1.

TABLE 1: The location and time of earthquakes that took place in the region of Indonesia [8].

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.	06.03.2007	Southern Sumatra	6.4	03:49:39	0.512°S, 100.53°E
3.	08.08.2007	Java	7.5	17:04:58	5.968°S, 107.66°E
4.	12.09.2007	Southern Sumatra	8.4	11:10:26	4.520°S, 101.37°E
5.	20.09.2007	Kepulauan Mentawai Region	6.7	08:31:14	2.025°S, 100.14°E

3. OBSERVATION AND DATA ANALYSIS

3.1 Diurnal variations of the fcF2

The diurnal variation of fcF2 is often rather complicated. It reaches its lowest value just before dawn, which is termed as recombination. When the sun rises, fcF2 rises rapidly as photoionization starts to create the free electrons again [1]. So, the drastic diurnal variation in the ionosphere is due to the rapid changes in the solar activity. Referring to Fig. 3 and Fig. 4, on both 3rd and 4th August 2007, the ionosonde data shows that the value of fcF2 increases at sunrise, which is from about 06:00 UTC, as a result of the photoionization. However, during the noon time, which is from about 12:00 to 14:00 UTC, the fcF2 reaches its maximum when the sun is right on top of the equatorial region. After the sun set, it can be seen that the fcF2 is very low. This could be due to the recombination process. It can also be seen that the pattern of both h'F2 and fcF2 are quite similar.

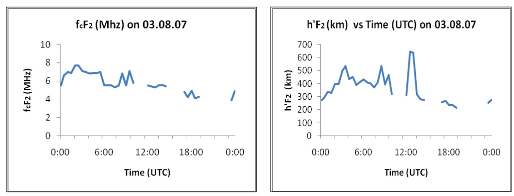


Fig. 3 The Diurnal Variation of the fcF2 and h'F2 on 03.08.2007

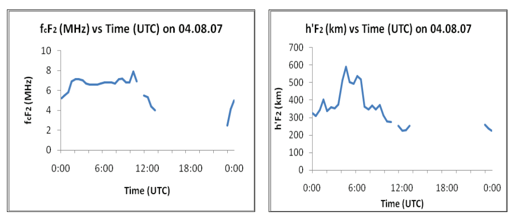


Fig. 4 The Diurnal Variation of the fcF2 and h'F2 on 04.08.2007

3.2 Anomalous ionospheric variations observed before and after the main shock of the earthquake

3.2.1 Earthquake on 26.12.2004

As the first case for this research purpose, the earthquake occurred at Off West Coast of Northern Sumatra (3.316°N, 95.854°E) at 00:58:53 UTC on 26.12.2004 was chosen. The ritcher scale was 9.1, which is classified as rare great earthquake that can destroy anything that is on the surface of the Earth in areas of several thousands of km across.

In order to identify the ionospheric precursor, the median-based and average-based statistical techniques were applied on fcF2 variations. Median-based statistical technique is a technique where in a sample of number, the median is taken after sort the list of numbers in that sample in increasing order [9]. 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.

Fig. 5 and Fig. 6 show the results obtained by the median and average statistical techniques respectively. The results for both techniques are quite similar as can be seen in Fig. 7 (overlap of fcF2 from both Fig. 5 and Fig. 6).

As shown in Fig. 7, it can be seen that lower and abnormal fcF2 were detected on 3rd, 9th and 10.12.2004, which indicates an early warning of an earthquake. However, there is no rapid drop or fluctuation in fc from 15th to 31.12.2004.

The analysis using only the noon time observation is another alternative method to observe the variation of fcF2 more clearly compared to median or average-based statistical technique in a day. It is because the value of fcF2 always maximum during noon time from about 12:00 to 14.00 UTC. However, there is significant decrease in the fcF2 around 4 to 5.4 MHz from 5th to 14.12.2004 as can be seen in Fig. 8. This indication can be a potential precursor for the occurrence of earthquake on 26.12.2004. Fig. 9 is similar to Fig. 8 whereby the plot was done using the h'F2 data instead of fcF2. It can be seen that the variation of h'F2 is about the same as fcF2.

The data fitting using Matlab was used to fit the fc data in order to get approximate analytical mathematical model that can be used as a precursor for an earthquake. In the upper panel of Fig. 10 (a), (b) and (c), the fitting and approximated equations in different orders are shown. In the lower panel of those Fig., the residuals from the fitting are shown. From Fig. 10(c), it can be seen that the approximation is better when the order of the equation is higher, i.e.; the norm of residual is 4.881 for 5th order fitting compared to 5.0749 for 4th order fitting. Although the fitting is not accurate, this result could have been used as the precursor for the earthquake that occurred on 26.12.2004 that caused the deadly tsunami.

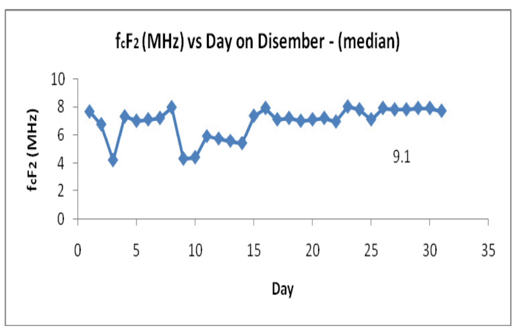


Fig. 5 Observation of fcF2 using median based statistical method for earthquake occurred on 26.12.2004

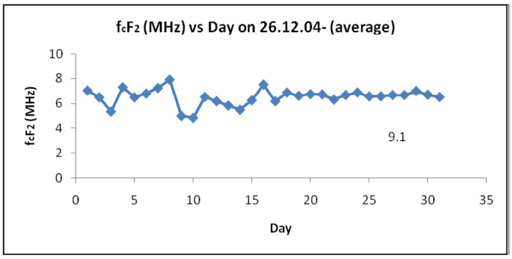


Fig. 6: Observation of fcF2 using average based statistical method for earthquake occurred on 26.12.2004

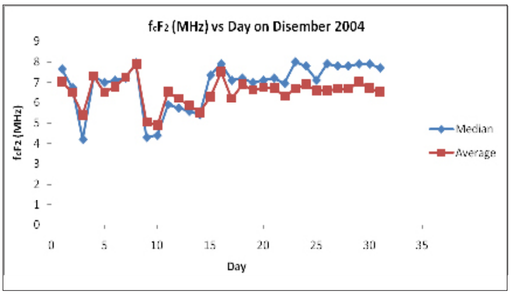


Fig. 7 Observation of fcF2 using both median and average based statistical method for earthquake occurred on 26.12.2004

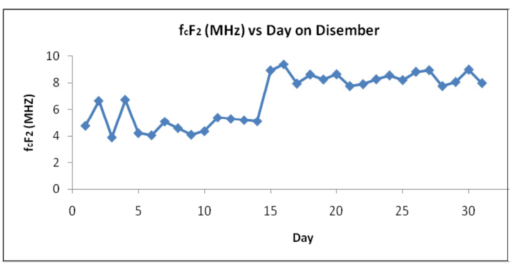


Fig. 8 Observation of fcF2 at sunrise time for earthquake occurred on 26.12.2004

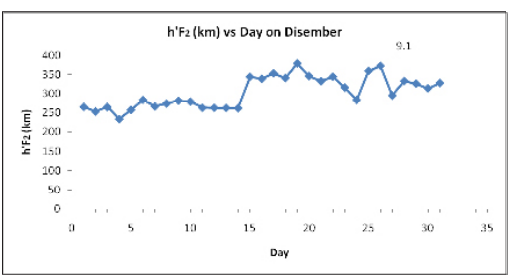
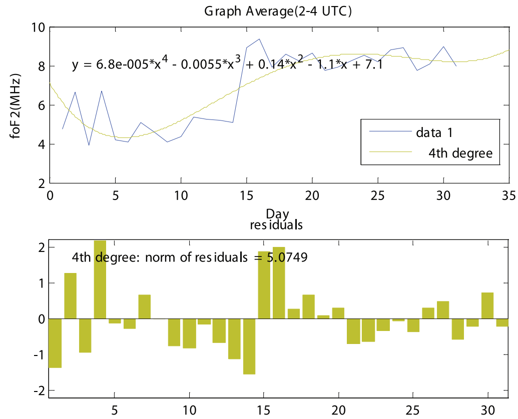
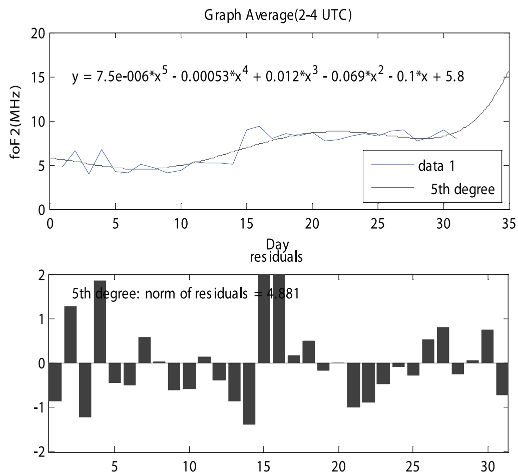


Fig. 9 Observation of h'F2 at sunrise time for earthquake occurred on 26.12.2004

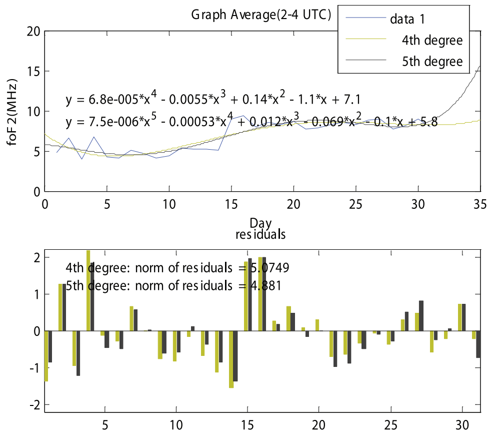


(a)



(b)

Fig. 10 (a) fc fitting using mathematical equation in the 4th order and its residual. (b) fc fitting using mathematical equation in the 5th order and its residual. (c) Combination of fc fitting using mathematical equations both in the 4th and 5th order and their residuals.



(c)

3.2.2 Earthquake on 08.08.2007

On 08.08.2007 at 17:04:58 UTC, another earthquake with Ritcher scale of about 7.5 strokes Java, Indonesia (5.968°S, 107.655°E). For this phenomenon, the fluctuations in the fc could be seen very much earlier than 08.08.2007, which were on 3rd and 06.08.2007. The fluctuations are shown in Fig. 11 (median-based statistical technique) and 12 (average-based statistical technique). The results, as depicted in Fig. 11 and 12, can be a good precursor for the occurrence of an earthquake because the fluctuations were observed just few days before the quake. On top of that, there is still drop in the value of fcF2 on 10.08.2007, which was after the earthquake.

Since a pattern of precursor could be seen, the fitting was done to the ionospheric perturbations by using the MATLAB fitting toolbox as shown in Fig. 13(a), (b) and (c). For this case, the fitting was better that the previous case because the norm of residuals for the 5th order is only 2.5387.

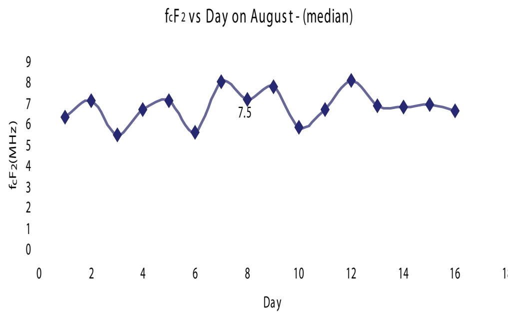


Fig. 11 Observation of fcF2 using median based statistical method for earthquake occurred on 08.08.2007

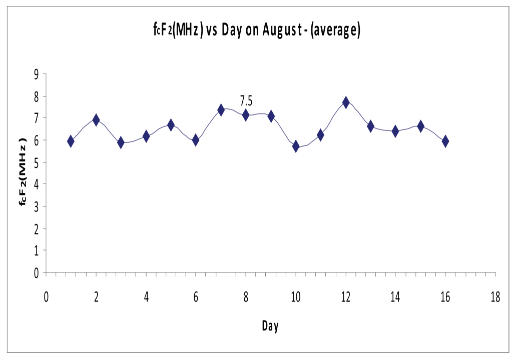
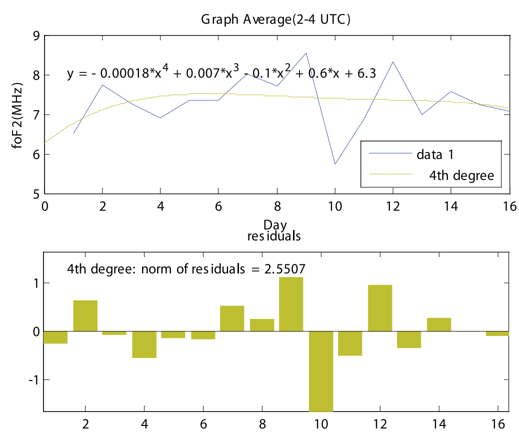
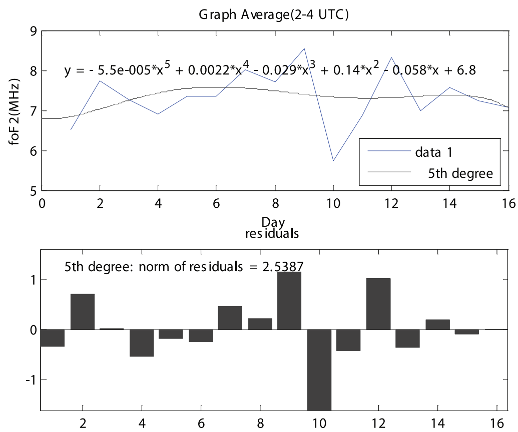


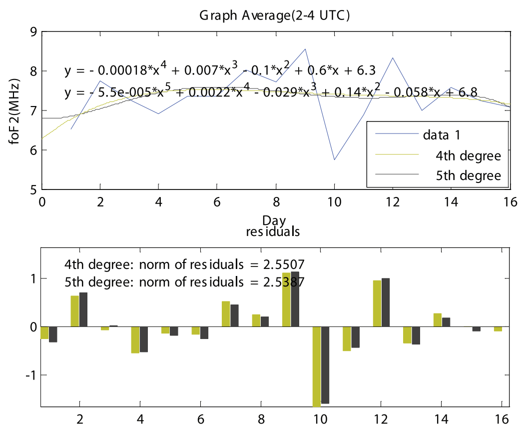
Fig. 12 Observation of fcF2 using average based statistical method for earthquake occurred on 08.08.2007



(a)



(b)



(c)

Fig. 13 (a) fc fitting using mathematical equation in the 4th order and its residual. (b) fc fitting using mathematical equation in the 5th order and its residual. (c) Combination of fc fitting using mathematical equations both in the 4th and 5th order and their residuals.

4. CONCLUSIONS

This research was carried out mainly to identify the relationship between the variations of the fcF2 in the ionosphere and the earthquake. The results that have been obtained in this research showed that there are significant ionospheric perturbations several days before and after an earthquake. Normally, the variation of fcF2 can be linked with the earthquake phenomena. By using the data fitting method in Matlab and the fc data from Ionosonde, an analytical mathematical model can be developed. However, the mathematical equations that were obtained in this research are not good enough to be used as a precursor for the occurrence of an earthquake. This is because for each case, the fitting method produced different mathematical equation. On top of that, by using just two sets of Ionosonde data, it is not enough to prove that the fc variation can be considered as a precursor for the occurrence of an earthquake. More observation data such as variation of Total Electron Content (TEC), sunspot number, solar cycle, magnetic indices such as Kp and Ap indices need to be looked into and analyzed in order to get the best relationship between the ionospheric variation and the occurrence of earthquake and to come up with an analytical mathematical model which can act as a precursor for the earthquake occurrence.

ACKNOWLEDGMENT

The author is grateful to WARAS Research Centre, UTHM, for making available Ionosonde data to carry out this research.

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