MODELLING OF IONOSPHERE BEHAVIOUR PRIOR TO LARGE EARTHQUAKES

By

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ABSTRACT

This project examines the behavior of pre-earthquake ionospheric parameters by the variation in foF2 (critical frequency of F2 layer) and TEC (total electron content) from the ionosondes stations. The data from a week before and after the main shock of an earthquake is analyzed to observe and model the behavior of the foF2 and TEC before the earthquakes (EQs). Monitoring these parameters is one of the methods of recent study to aim in reducing the damage of the natural hazards. Normally, a precursor alone is not enough to give an accurate and precise prediction of the earthquake. Therefore, it is important to exploit more on this study. Besides, the region of the study (Sumatra region) is a region that where the earthquake happened quite frequent. So, this study basically, to help and study whether the Sumatra's earthquake gave the same anomalies like other studies. This study involving all of the Sumatra's earthquake with a large magnitude (M> 6) in a range of 20 years from the year 1996 until 2016. The behavior of the chosen parameters will be discussed in the next chapter based on the listed earthquake within the year, and region of the study.

PEMODELAN IONOSFERA TERHADAP PERLAKUAN SEBELUM GEMPA BUMI BESAR

ABSTRAK

Projek ini mengkaji tingkah laku pra-gempa bumi parameter ionosfera oleh variasi dalam foF2 (frekuensi kritikal lapisan F2) dan TEC (jumlah kandungan elektron) dari stesen ionosondes. Data dari seminggu sebelum dan selepas kejutan utama gempa bumi dianalisis untuk memerhati dan model tingkah laku foF2 dan TEC sebelum gempa bumi (EQs). Pemantauan parameter ini adalah salah satu kaedah kajian baru-baru untuk matlamat dalam mengurangkan kerosakan daripada bencana alam. Biasanya, pelopor sahaja tidak cukup untuk memberi ramalan yang tepat dan tepat gempa bumi. Oleh itu, adalah penting untuk mengeksploitasi lanjut mengenai kajian ini. Selain itu, kawasan kajian (wilayah Sumatra) ialah sebuah kawasan yang di mana gempa bumi itu berlaku agak kerap. Jadi, kajian ini pada dasarnya, untuk membantu dan mengkaji sama ada gempa bumi Sumatera memberikan anomali sama seperti kajian lain. Kajian ini melibatkan semua gempa bumi Sumatera dengan magnitud yang besar (M> 6) dalam julat 20 tahun dari tahun 1996 sehingga 2016. Kelakuan parameter dipilih akan dibincangkan dalam bab yang akan datang berdasarkan kepada gempa bumi yang disenaraikan dalam tahun, dan kawasan kajian.

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Finally, I thank my family, fellow friends and staff of School of Aerospace Engineering for their continuous moral support and confidence in my effort.

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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EQ	Earthquake
foF2	Electron density
TEC	Total Electron Content

NOMENCLATURE

M_w	:	Magnitude of the Earthquake
º	:	Degree of the coordinate
º N	:	Degree of North
º E	:	Degree of East
º S	:	Degree of South
º W	:	Degree of West

CHAPTER 1

INTRODUCTION

1.1 Seismic wave

Earth is a place that have a lot of secrets and mystery. There are too many things that we as human being do not know if we do not have the desire to study about it. One of the interesting thing is that the moving of ground of the earth. It actually happen every day without we noticed the movements. By this movement, the seismic waves are formed. The waves of energy that caused by the breaking of rock or ground of the earth or also the energy that travels around the earth are called as Seismic Wave.

There is so many theory involves in this study. One of this is the seismic wave theory. Seismic waves consists of many different types and it can move in various kind of movement. There are two types of waves. First, Body Waves. Body waves have two kind of waves which are P wave and S wave shapes. Next, Surface Waves. For the surface waves also have two kind of waves Love wave and Rayleigh wave shapes. All of these waves shows the different of the particles motion.

Since seismic wave is a wave that happen if there are movements of the ground of the earth, it also directly involving with the earthquakes. Earthquakes happen when two blocks of the earth suddenly slip past by one another. During earthquakes, the seismic wave that formed is more than usually. With the higher wave of the seismic wave it give

effects to the ionosphere of the earth. The particle at the ionosphere also effected form this waves.

1.2 Ionosphere

The study of earthquake prediction is still a difficult task. Many recent studies have shown that many geophysical and geochemical parameters can be used to monitor the activity on the earth. The ionospheric anomalies mostly happen in D-layer, E-layer and F-layer and it can be observed about 10 days before the event day. There are many parameters can used to get the precursor data such as electron and ion density, electron temperature, land surface temperature and electric and magnetic fields. Most of the recent study used total electron content (TEC) and the electron density (foF2) in the research as the precursor of the prior to the strong earthquake.

1.3 Lithosphere-Atmosphere-Ionosphere Coupling (LAIC)

Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) is one of the way to explain the relation between ground surface, atmosphere and directly to the ionosphere. Since, the earthquake is a dynamic phenomenon or phenomena that involved with a movement, the energy of the movement will be transferred. These changes that occur prior to the earthquake or during the earthquake may have the effect on the lithosphere, atmosphere, and ionosphere in terms of the different physical and chemical effects. The changes that happen at lithosphere, atmosphere and ionosphere parameters prior to the large earthquake are considered as the earthquake precursor.

So, in this project, the precursor selected to be analyzed are total electron content (TEC) and the electron density (foF2). The total number of electrons that present between a radio transmitter and receiver is known as Total Electron Content (TEC). The presence of these electron affect the radio waves. More radio signal will be affected if there is more electron along the radio wave path. TEC is measured in electrons per square meter;

$$1\ TEC\ Unit\ (TECU) = \ 10^{16}\ electrons/m^2$$

The TEC in the ionosphere is being modified and propagate up from the lower atmosphere of the earth. The TEC is depended on the specific time, latitude, longitude, season, geomagnetic conditions, solar activity, and troposphere conditions.

The travel of the radio waves is caused by the ionosphere. The velocity of the radio waves changes when the waves pass through the electrons in the ionosphere. A radio wave that propagates through the ionosphere suffered a total delay and it depends on both of the frequency of the radio wave and the TEC between the transmitter and the receiver. The radio waves can be pass through the ionosphere or been reflected by the ionosphere at different frequencies. From the ground station to the satellite, TEC is a good parameter to monitor for space weather impacts.

Besides, the foF2 (frequency of the Ordinary wave reflected from F2 layer) which is also known as the Critical frequency of the F2 layer of the ionosphere. It is measured as the highest frequency of radio signal that reflects directly back from the peak of the F2 layer

to the transmission location. The foF2 is depended on the intensity of the ultra-violet (UV) radiation from the sun. If the UV is increasing, it will cause radiation of the F-layer to be increased. The foF2 is also one of the parameters that seen to be consistent and therefore will also provide a good comparison.

The behavior of ionosphere profile due to the total electron content (TEC) and the peak density (foF2) will be studied further with the specific cover area around Sumatra. There will be a comparison and possibility of anomaly in ionosphere caused by EQs. The data analysis will be covered on what happened 20 years before until recently.

1.4 Region of the study

Figure 1: Region of the study (Sumatra)

Figure 1, shows the region of the earthquake study for this project. The coordinate of the study is with a range of longitude within 90° ~ 120° while the latitude is in the range within 10° ~ -10°. By choosing this region of study, the study can be conducted widely since Sumatra is one of the countries that earthquake happens almost frequently. With these data, the ionosphere profile behavior prior to large earthquake can be observed more.

1.5 Problem Statement

Recently, our country also involved in the earthquake area. The recent strong earthquake that happens at Malaysia was on 2015. It happens at Ranau, Sabah. Many victims that did not survive during this large earthquake. Furthermore, the earthquake that is happening at Ranau, Sabah, is frequently. The differences are only the scale of the earthquakes. Besides, Malaysia also once affected by the Sumatra's large earthquake in Dec 2004. Why is it important for Malaysia? Once Malaysia involves or affected by the earthquake, it will give side effect in many ways for the country. When an earthquake happens, the place or the affected region will experience a huge damage just like the Dec 2004 tragedy. Besides, there are many people dead, a lot of house destroyed, many things were damaged and the city will be dispersed everywhere. So, it will need a lot of money and many works in order to recover back all the damage. Hence, in order to reduce these damage, this study should be held to prevent the same thing happen again.

The study about earthquake at Malaysia is narrow. Basically, this research is conducted because at Malaysia, we have lacking data to study and implemented it to the country.

This is due to none of satellites that from Malaysia that can produced large amount of data and more specific into only around Malaysia area. So, due this lacking data, in order to study further about the space environment, we need to request the data from other country's satellites or the free opened worldwide database. The data will be a little bit difficult to study because it is from other's satellite and the data provided also may not the same as what are needed to do the study. Besides, Malaysia also still not too interested in this field of study because Malaysia do not have any causes that will produce an earthquake. Malaysia's earthquake usually happen due to the affected by others country such as Indonesia.

1.6 Objectives of Research

The research work described in this thesis is performed based on the following objectives:

(i) To identify the behavior in ionosphere parameters, TEC and foF2 in Sumatra region.

(ii) To perform the data analysis about the ionosphere parameter that occur in ionosphere from database since 20 years before until recent.

(iii) To make a validation of the ionospheric parameter from EQs epicenter in Sumatra that gain from the Jicamarca station.

1.7 Thesis Layout

This thesis consists of 5 chapters. Chapter 1 gives a general overview of what is seismic wave and ionosphere actually. Besides, there also will be a general review of the

relationship between the ionosphere and earthquake. Finally, the objectives of the research are defined.

Chapter 2 reviews all the literature reviews that related to this work. The focus is on the recent study of the earthquakes. Besides, the parameters and the sources of the data that were used along all of the studies also will be discussed in this chapter. Last, a general overview on the earthquake precursor is included.

Chapter 3 briefly describes all the method that been used for this study. The flow of the study is described more detail in this chapter. From the beginning on how to determine the objective of the study, what tool or instrument that are used to gain the data of the study. Finally, the analysis part in this study is explained.

Chapter 4 will be divided into 3 part. In the first part, will show all the result of the data collected. It will show the true behavior of the foF2 and TEC for every earthquake with the different station that is available. Next, the discussion about the data analysis of foF2 and TEC that occur in ionosphere from the database since 20 years before which from the year 1996 until the year 2016. For the last part, it will be the part to validate all the gain data with the quiet condition data.

Chapter 5 is the last chapter that will be focusing on the conclusion of the project and the recommendation for the future work of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Study of the earthquake

The group of study of earthquake has been formed in order to study about what happen at the atmosphere during and before the earthquake. The research on ionospheric precursor earthquakes began few years ago. The study start about three decades ago, which is start around year of 1971. [4] There was also a first investigation started during the Alaska earthquake 1964. [3] However, the study of the earthquakes not only stop there. The study become more intensive as through the years, there were many developing systems and methods to study about what happened before the earthquakes. [3, 4] For this new era, still have groups that was supported to do further study on this disaster. [1]

There are many ways used to study the ionospheric anomalies. Some of the study examine the TEC derived from the ground-based receiver of Global Positioning System (GPS). [11] Besides, some of the study report the variation of foF2 by the correlation method at the strong seismic event time. The data of the ionosonde installed at the different place used for the analysis of the study. [10] There also a study being held up with a method in finding the relation or interconnection of the Ionospheric Earthquake Parameter (IEP) between the major ($M>6.0$) and the medium ($4.0<M<6.0$) earthquakes. [9]

2.2 Parameter and Database

There are several geophysical parameters that been used in this fields in order to study about the anomalous behavior before large earthquakes (EQs). For example, VLF propagation, infrared emission and particle precipitation. [4, 9] Besides, there were also some that used magnetic field and solar activity as the source to study about earthquakes. [5] Electron temperature also been used as one of the parameters to study about the earthquakes. [7, 8] However, the main data sources that been used today are total electron content (TEC) and electron peak density (NmF2). [1, 2, 3, 4, 5, 8]

In order to study this fields, the data from various and available satellite have been collected. The data from the satellite such as TEC and electron density could be collected from the satellites. The satellites like DMSP, CHAMP, DEMTER, and Formosat-3/Cosmic have been transmit to the ground to analysis the behavior of the electron. [1, 4, 7, 9] Besides, there is a popular instrument that probing the ionospheric parameters which known as ionosondes and been used for a long time. [10, 11]

2.3 Earthquake precursor

Several of study had been performed previous, and it shows that earthquake actually can be detected several weeks before the earthquake. [1, 4, 5, 7, 8, 10, 11] By using TEC, the result can be detected about a week before the (EQs). While, data studied from electron density, the (EQs) can be detected a few hours or days before the events. Both of them took place and gave more reaction during the daytime. So, the study of this two parameters is important and it does give a good result in forthcoming earthquakes. [4]

Based on study, total electron content (TEC) is one of the occurrence of positive and negative anomalies detected before earthquakes. [4, 7, 8] The study about TEC were handled to see its reaction towards the space environment. The study shows that TEC also react towards the space weather. [5] However, TEC and electron density are still the best method to see the changes of behavior of electron during or before the earthquake.

CHAPTER 3

METHODOLOGY

This chapter presents all the method that been used for this study. The flow of the study is described more detail in this chapter. From the beginning on how to determine the objective of the study, what tool or instrument that are used to retrieve the data of the study.

3.1 Parameter to used

Phase 1 of this study is to understand all the parameters that used in the research. The parameter that will be used for the further Data Analysis will be chosen. Study the behavior of the electron and other reactions towards it that will be involve. Study the pattern of graphs from the previous journal. Based on the research, there are many parameters that been used to study the behavior of the ionosphere prior to large earthquake. In this research, the Critical frequency of the F2 (foF2) and Total Electron Content (TEC) is chose as the parameters to model the behavior of the ionosphere.

3.2 Data collecting

The next phase is the data collecting phase. The data that will be collect will be used to perform the analysis. The detail of the data that will be collected;

(i) Date/Time

(ii) Location (Latitude and Longitude)

(iii)Magnitude of the earthquake

(iv)TEC

(v) foF_2

The data that will be collected is from 20 years before. All the data collected are saved in Excel software. After that, all of the data will be convert into graphs in order to see the anomalies before and after the earthquake. The data collected is from many stations. This is because not every station can provide the needed data. Some of the data will come only in a half of the data, not the full set of data.

Besides, the stations also need to be chose precisely because not every station are working from the range of 20 years of the study which is from the year of 1996 until 2016. Some of the station also are not in the equatorial, so the data might be not too accurate since it is already far from the study region. So, the station that can be used is the one that in the line of the equatorial. Table 1 shows the stations been used to get the data of foF2 and TEC.

STATION	CODE	LATITUDE	LONGITUDE	COUNTRY
Trivandrum	TM	8.54	76.87	India
Sanya	SA	18.34	109.42	China
Hainan	HA	19.40	109.00	China
Guam	GU	13.62	144.86	United State
Kwajalein	KJ	9.00	167.20	United State
Fortaleza	FZ	-3.90	321.60	Brazil
Sao Luis	SL	-2.60	315.80	Brazil
Boa Vista	BV	2.80	299.30	Brazil
Jicamarca	JI	-12.00	283.20	Peru

Table 1: Station used for the study

Digital Ionogram Data Base (DIDBase) is the software that was used in this research to gather the values of foF2 and TEC. Figure 2 illustrates the steps that should be taken to gain the data.

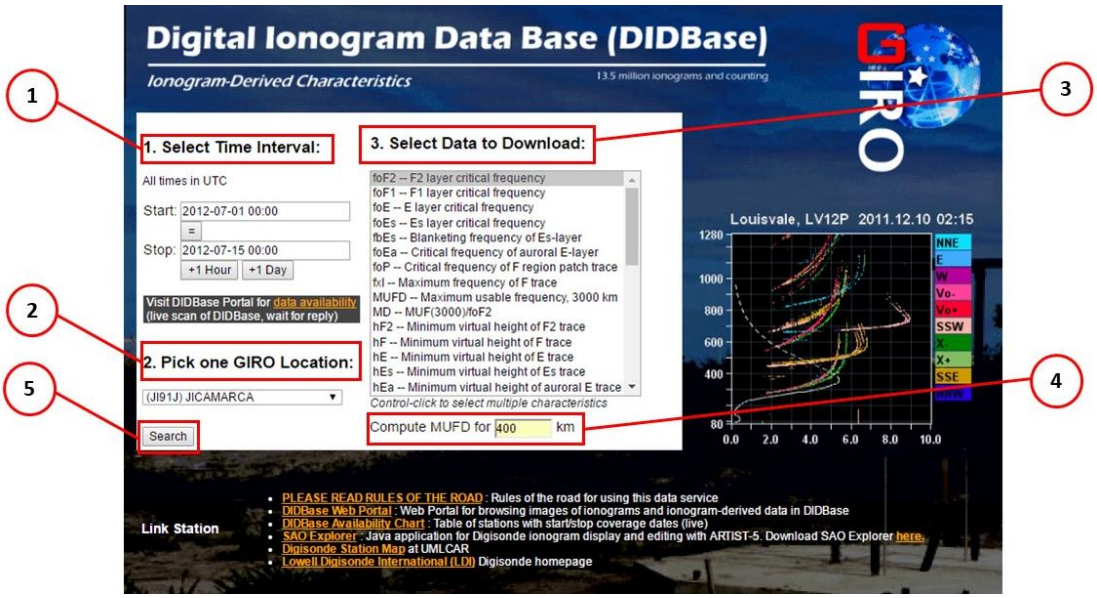


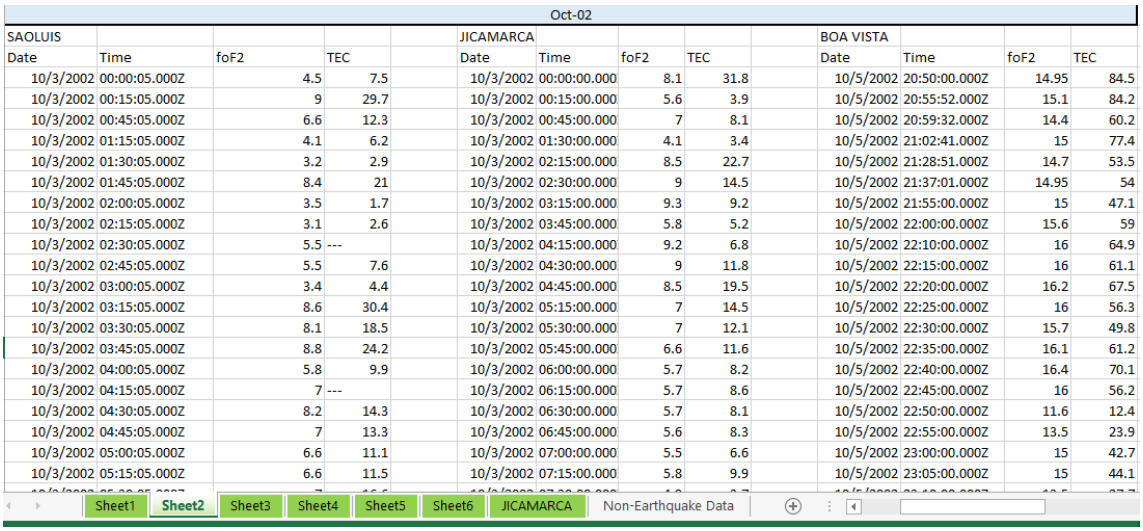
Figure 2: DID Ionogram Data Base (DIDBase) website

First, input the selected time interval of the needed data which is one week before until one week after the Earthquake. The second step is to choose the station that available and will be used for the data collecting. Next, select the parameter that will be downloaded as the data. In this case, the foF2- F2 layer critical frequency and TEC- Total Electron Content are selected. After that, input the value of the Compute MUFD to 400 km. This is the altitude chosen for this research. Lastly, click the 'Search' button to start the process of gaining the data.

```
# Global Ionospheric Radio Observatory
# GIRO Tabulated Ionospheric Characteristics, Version 1.0 Revision B
# Generated by DIDBGetValues on 2017-06-18T22:01:33.994Z
#
# Location: GEO -12.0N 283.2E, URSI-Code JI91J JICAMARCA
# Instrument: Ionosonde, Model: DPS-4
#
# Query for measurement intervals of time:
# 2012-07-01T00:00:00.000Z - 2012-07-15T00:00:00.000Z
#
# Data Selection:
# CS is Autoscaling Confidence Score (from 0 to 100, 999 if manual scaling, -1 if unknown)
# foF2 [MHz] - F2 layer critical frequency
# TEC [10^16 m^-2] - Total electron content
#
#Time                      CS   foF2 QD   TEC QD
2012-07-01T00:00:00.000Z 100  6.500 /_  21.5 /_
2012-07-01T00:15:00.000Z   0  6.400 /_  14.2 /_
2012-07-01T00:30:00.000Z 100  6.400 /_  14.7 /_
2012-07-01T00:45:00.000Z 100  6.600 /_  16.9 /_
2012-07-01T01:00:00.000Z 100  6.300 /_  13.6 /_
2012-07-01T01:15:00.000Z 100  6.400 /_  15.8 /_
2012-07-01T01:30:00.000Z 100  6.100 /_  10.6 /_
2012-07-01T01:45:00.000Z 100  6.000 /_  13.6 /_
2012-07-01T02:00:00.000Z 100  6.200 /_  11.2 /_
2012-07-01T02:15:00.000Z 100  5.800 /_   9.7 /_
2012-07-01T02:30:00.000Z 100  5.500 /_   8.2 /_
2012-07-01T02:45:00.000Z 100  5.300 /_   8.6 /_
2012-07-01T03:00:00.000Z 100  4.900 /_   7.2 /_
2012-07-01T03:15:00.000Z 100  5.400 /_  11.4 /_
2012-07-01T03:30:00.000Z 100  5.200 /_   8.4 /_
2012-07-01T03:45:00.000Z 100  5.300 /_   9.6 /_
2012-07-01T04:00:00.000Z 100  5.400 /_   5.9 /_
2012-07-01T04:15:00.000Z 100  5.300 /_   8.3 /_
2012-07-01T04:30:00.000Z 100  5.600 /_   8.8 /_
2012-07-01T04:45:00.000Z 100  5.400 /_   3.5 /_
2012-07-01T05:00:00.000Z 100  5.300 /_   6.4 /_
2012-07-01T05:15:00.000Z 100  5.600 /_   9.1 /_
2012-07-01T05:30:00.000Z 100  5.600 /_   8.3 /_
2012-07-01T05:45:00.000Z 100  4.800 /_   7.6 /_
2012-07-01T06:00:00.000Z 100  4.900 /_   6.9 /_
2012-07-01T06:15:00.000Z 100  4.900 /    4.2 /
```

Figure 3: Some of the raw data of the foF2 and TEC

Figure 3 above shows the result of the searching from above steps. The data then, been copied and save into another excel folder as Figure 4 below.



Oct-02

SAOLUIS				JICAMARCA				BOA VISTA			
Date	Time	foF2	TEC	Date	Time	foF2	TEC	Date	Time	foF2	TEC
10/3/2002	00:00:05.000Z	4.5	7.5	10/3/2002	00:00:00.000	8.1	31.8	10/5/2002	20:50:00.000Z	14.95	84.5
10/3/2002	00:15:05.000Z	9	29.7	10/3/2002	00:15:00.000	5.6	3.9	10/5/2002	20:55:52.000Z	15.1	84.2
10/3/2002	00:45:05.000Z	6.6	12.3	10/3/2002	00:45:00.000	7	8.1	10/5/2002	20:59:32.000Z	14.4	60.2
10/3/2002	01:15:05.000Z	4.1	6.2	10/3/2002	01:30:00.000	4.1	3.4	10/5/2002	21:02:41.000Z	15	77.4
10/3/2002	01:30:05.000Z	3.2	2.9	10/3/2002	02:15:00.000	8.5	22.7	10/5/2002	21:28:51.000Z	14.7	53.5
10/3/2002	01:45:05.000Z	8.4	21	10/3/2002	02:30:00.000	9	14.5	10/5/2002	21:37:01.000Z	14.95	54
10/3/2002	02:00:05.000Z	3.5	1.7	10/3/2002	03:15:00.000	9.3	9.2	10/5/2002	21:55:00.000Z	15	47.1
10/3/2002	02:15:05.000Z	3.1	2.6	10/3/2002	03:45:00.000	5.8	5.2	10/5/2002	22:00:00.000Z	15.6	59
10/3/2002	02:30:05.000Z	5.5	---	10/3/2002	04:15:00.000	9.2	6.8	10/5/2002	22:10:00.000Z	16	64.9
10/3/2002	02:45:05.000Z	5.5	7.6	10/3/2002	04:30:00.000	9	11.8	10/5/2002	22:15:00.000Z	16	61.1
10/3/2002	03:00:05.000Z	3.4	4.4	10/3/2002	04:45:00.000	8.5	19.5	10/5/2002	22:20:00.000Z	16.2	67.5
10/3/2002	03:15:05.000Z	8.6	30.4	10/3/2002	05:15:00.000	7	14.5	10/5/2002	22:25:00.000Z	16	56.3
10/3/2002	03:30:05.000Z	8.1	18.5	10/3/2002	05:30:00.000	7	12.1	10/5/2002	22:30:00.000Z	15.7	49.8
10/3/2002	03:45:05.000Z	8.8	24.2	10/3/2002	05:45:00.000	6.6	11.6	10/5/2002	22:35:00.000Z	16.1	61.2
10/3/2002	04:00:05.000Z	5.8	9.9	10/3/2002	06:00:00.000	5.7	8.2	10/5/2002	22:40:00.000Z	16.4	70.1
10/3/2002	04:15:05.000Z	7	---	10/3/2002	06:15:00.000	5.7	8.6	10/5/2002	22:45:00.000Z	16	56.2
10/3/2002	04:30:05.000Z	8.2	14.3	10/3/2002	06:30:00.000	5.7	8.1	10/5/2002	22:50:00.000Z	11.6	12.4
10/3/2002	04:45:05.000Z	7	13.3	10/3/2002	06:45:00.000	5.6	8.3	10/5/2002	22:55:00.000Z	13.5	23.9
10/3/2002	05:00:05.000Z	6.6	11.1	10/3/2002	07:00:00.000	5.5	6.6	10/5/2002	23:00:00.000Z	15	42.7
10/3/2002	05:15:05.000Z	6.6	11.5	10/3/2002	07:15:00.000	5.8	9.9	10/5/2002	23:05:00.000Z	15	44.1

Figure 4: Sample of the data in Excel

3.3 Data analysis

The last phase of this project is the comparison of the data analysis. The behavior of the data that had been processed is discussed. More precise ionosphere behavior prior to large earthquakes is concluded. In order to validate the numerous data, a small study of Jicamarca earthquake's are studied. The data then being compared with the quiet condition which in other meaning where there is no earthquake happen at that time. The validation process is also involving with all of the stations chosen for this study.

3.4 Project Flow Chart

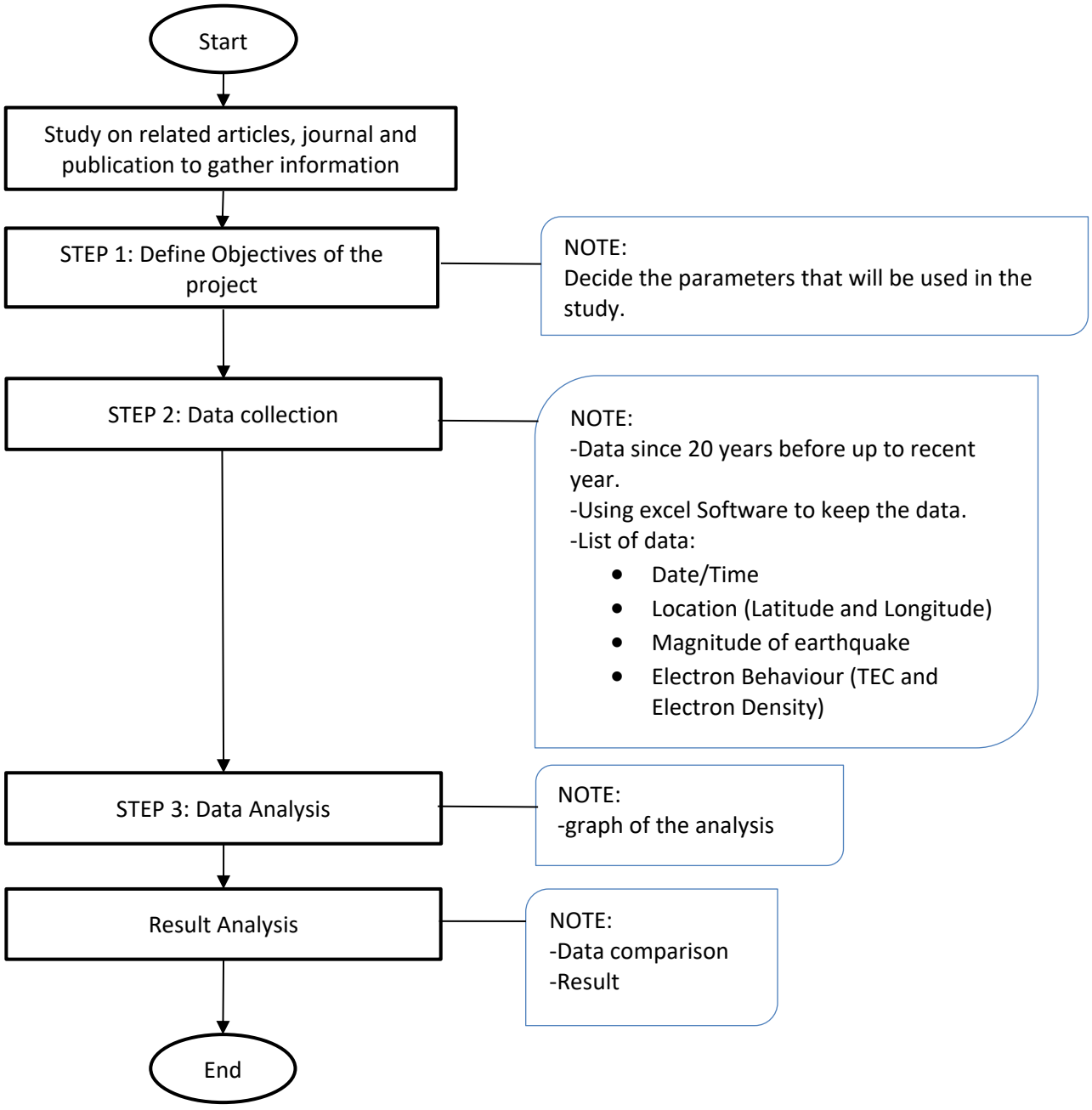


Figure 5: Flow chart of the study

CHAPTER 4

RESULTS AND DISCUSSION

In this study of the behavior of ionospheric are observed before and after all of the recorded earthquakes with magnitude more than 6 that occurred within 20 years, from January 1996 to December 2016. The data taken is from various station. In order to have clearer understanding about the relationship of the seismo-ionospheric parameter with the earthquake with Magnitude higher than 6, the observation of a week before and after the event day (Earthquake) are plotted into graphs. In this study, the diurnal TEC and foF2 variations are analyzed. The behavior that related to the earthquakes are showed below.

4.1 List of Earthquake

Figure 6 below shows the number of the large earthquake that happens throughout the 20 years of the study years. From the year of 1996 to 2016. The total number of the strong earthquake is about 21 earthquake. In the year of 2007, 2008, and 2009 shows the largest number of the earthquake that happened in the respectively year. The data were collected is based on the number of the earthquake in this graph.

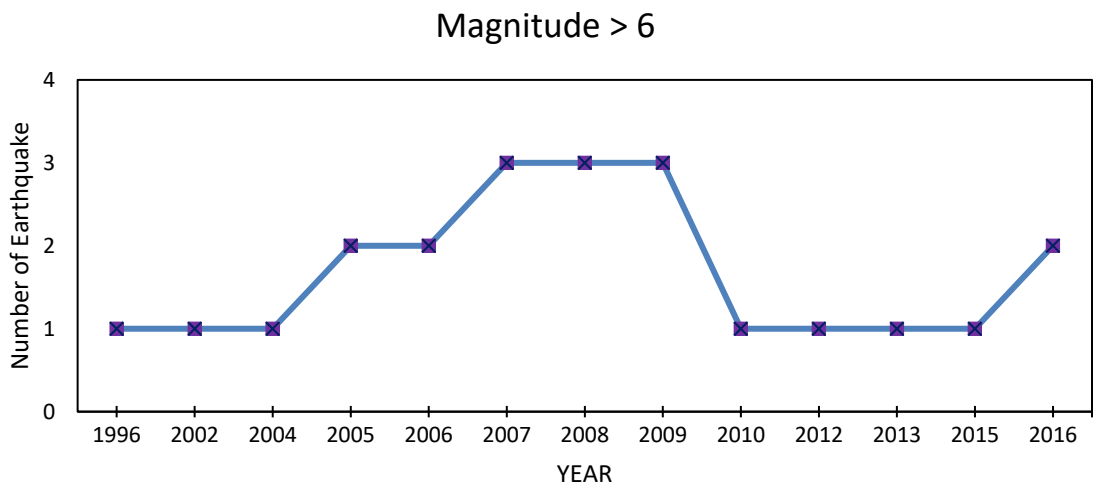


Figure 6: Graph for the number of large earthquake in 20 years

YEAR	DATE	TIME (UTC)	LOCATION	LATITUDE	LONGITUDE	MAGNITUDE	DEPTH (km)	STATION
1996	1-Jan-96	16:05:00	Sulawesi	0.6 N	119.92 E	7.9	39	JI
2002	2-Nov-02	01:26:11	Northern Sumatra	2.824N	96.085E	7.3	30	SL, BV, JI
2004	26-Dec-04	00:58:50	W Coast of Northern Sumatra	3.30N	95.78E	8.5	10	SL, JI
2005	28-Mar-05	16:09:36	Northern Sumatra	2.08N	97.01E	8.7	30	KJ, JI
	5-Jul-05	01:52:04	Nias	1.85N	97.05E	6.7	30	KJ, JI
2006	26-May-06	22:54:03	Java	7.97S	110.31E	6.3	35	KJ, JI
	17-Jul-06	08:19:25	South of Java	9.31S	107.28E	7.7	10	KJ, JI
2007	6-Mar-07	03:49:39	Southern Sumatra	0.51S	100.52E	6.4	19	KJ, JI
	6-Mar-07	05:49:29	Southern Sumatra	0.49S	100.52E	6.3	30	KJ, JI
	8-Aug-07	17:04:58	Java	5.96S	107.65E	7.5	289	KJ, JI
	12-Sep-07	11:10:26	Southern Sumatra	4.51S	101.38E	8.4	30	FZ, KJ, JI
	12-Sep-07	23:49:01	Kepulauan Mentawai	2.52S	100.96E	7.8	10	FZ, KJ, JI
2008	20-Feb-08	08:08:32	Simeulue	2.77N	95.97E	7.4	35	HA, KJ, JI
	25-Feb-08	08:36:35	Kepulauan Mentawai	2.35S	100.01E	7	35	HA, KJ, JI
	22-Nov-08	16:01:00	Southern Sumatra	4.34S	101.24E	6.3	10	KJ, JI
2009	16-Aug-09	07:38:00	Siberut, Mentawi Islands	1.397S	99.473E	6.7	45	KJ
	2-Sep-09	07:55:00	West Java	7.778S	107.328E	7	5	KJ
	30-Sep-09	10:16:10	Sumatra	0.71N	99.97E	7.6	90	KJ
2010	25-Oct-10	14:42:22	Mentawai	3.464S	100.084E	7.7	13	KJ
2012	11-Apr-12	08:38:00	Northern Sumatra	2.311N	93.063E	8.6	14	FZ, JI
	11-Apr-12	10:43:00	Northern Sumatra	2.311N	93.063E	8.2	10	FZ, JI
2013	2-Jul-13	07:37:02	Acheh	4.698N	96.687E	6.1	10	GU, KJ
2015	5-Jun-15	00:15:43	Ranau, Sabah	5.980N	116.525E	6	10	SA, GU
2016	2-Mar-16	12:49:00	Sumatra	4.908S	94.275E	7.8	24	SA, GU
	7-Dec-16	22:04:36	Aceh, Indonesia	5.283N	96.168E	6.5	13	SA, GU

Table 2 : List of detail information about the earthquakes

Table 2 gives a catalog of the earthquakes, which summarizes the date, origin time location, specific coordinate of latitude and longitude, magnitude of the earthquake, the depth of the earthquake and all the availability station for the data of the foF2 and TEC for the event day.

4.2 Behavior of Ionosphere parameter in Sumatra region

Behavior of ionospheric parameter for Earthquake year 1996.

Figure 7, illustrates the data of foF2. The single straight dotted line in every graph shows the event day (Earthquake). The data that only available for this year is the foF2 data. The only station that working and provide this data is Jicamarca station. The magnitude of this earthquake is 7.9. It is quite larger. It occur at Sulawesi around 16:05:00 at Universal Time. The anomaly of the foF2 3 days prior the earthquake shows some perturbation happen. The value of foF2 suddenly become peak up to 13 on the Day 5. Based on Figure 7, it can be seen that there is 3 phase of profiles of the anomaly for foF2. The first phase is starting with Day 1 until Day 5. The next identical profile is on the Day 6 up to Day 9. The profile suddenly shows a slightly increasing from the phase before and the graph shows an unsteady pattern. The EQ occur at this phase on the Day 8. Last, Day 10 to Day 13 profile show the pattern become a little bit steady than the previous phase.

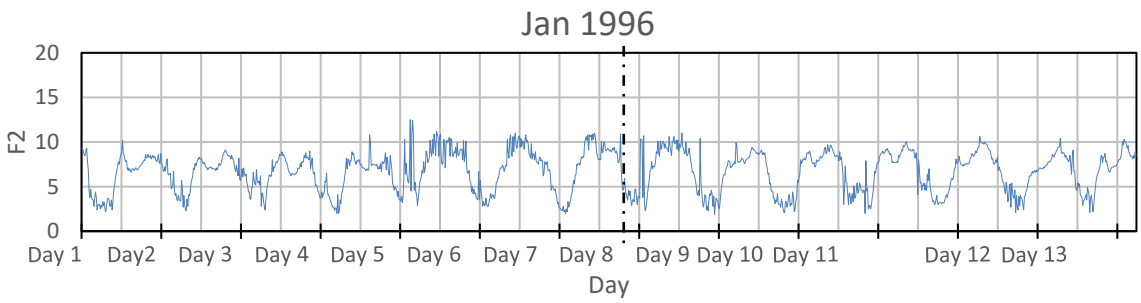


Figure 7: Earthquake year 1996

Behavior of ionospheric parameter for Earthquake year 2002.

After the 1996's earthquake, there are eventually a lot of earthquakes occur throughout the years but all of the earthquakes were below the studied magnitude. Until the year of 2002, an earthquake with magnitude higher than 6 which is with magnitude of 7.3 are recorded happen at Southern Sumatra. During this year, a lot of station are already functions but the function stations are still far away from the earthquake locations. However, the data of foF2 and TEC are still recorded and plotted into graphs. Figure 8 shows the anomalies of the behavior of the foF2 for earthquake year 2002.

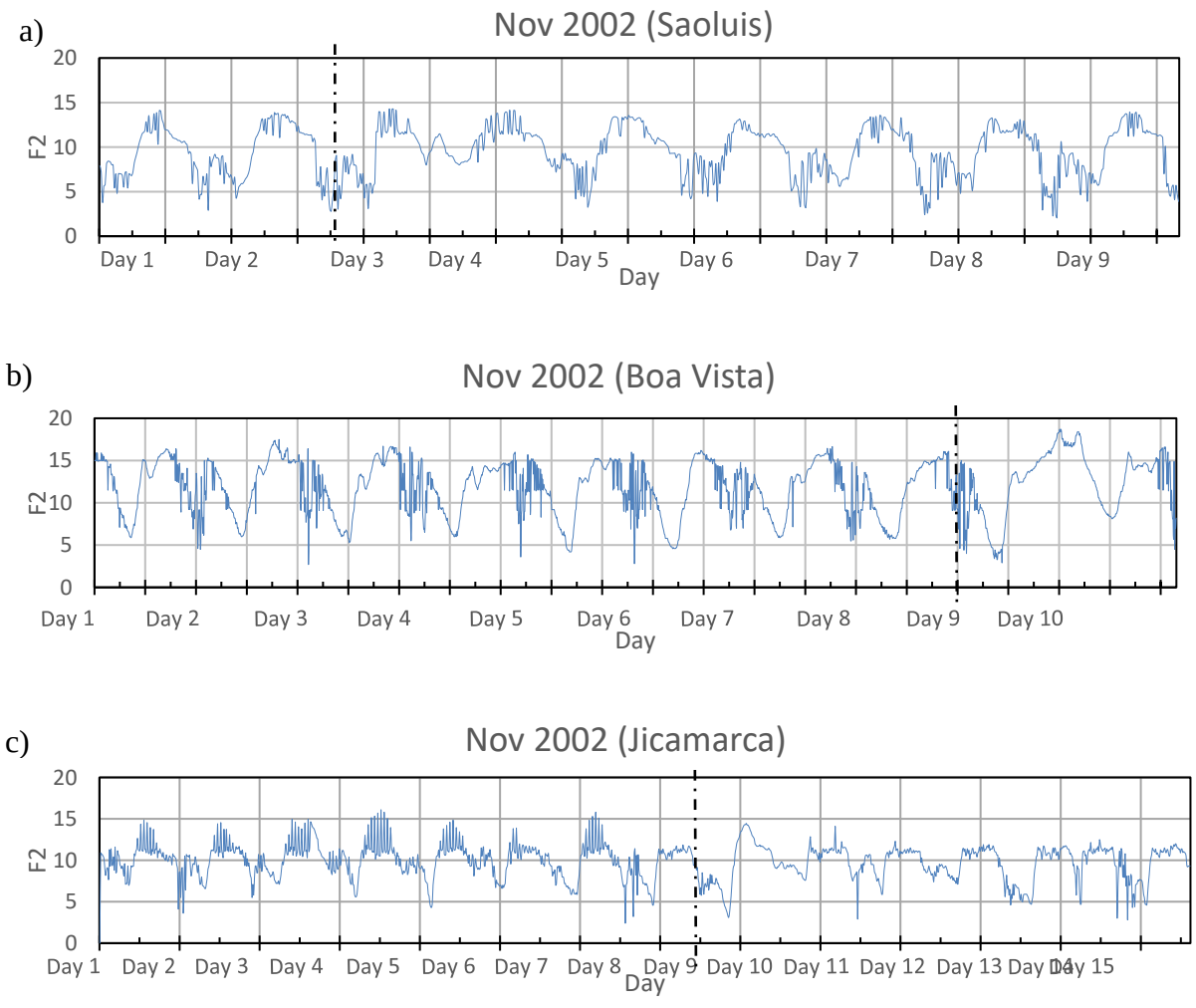


Figure 8: Anomalies of foF2 for earthquake year 2002

Figure 9 shows the anomalies of the behavior of the TEC for earthquake year 2002.

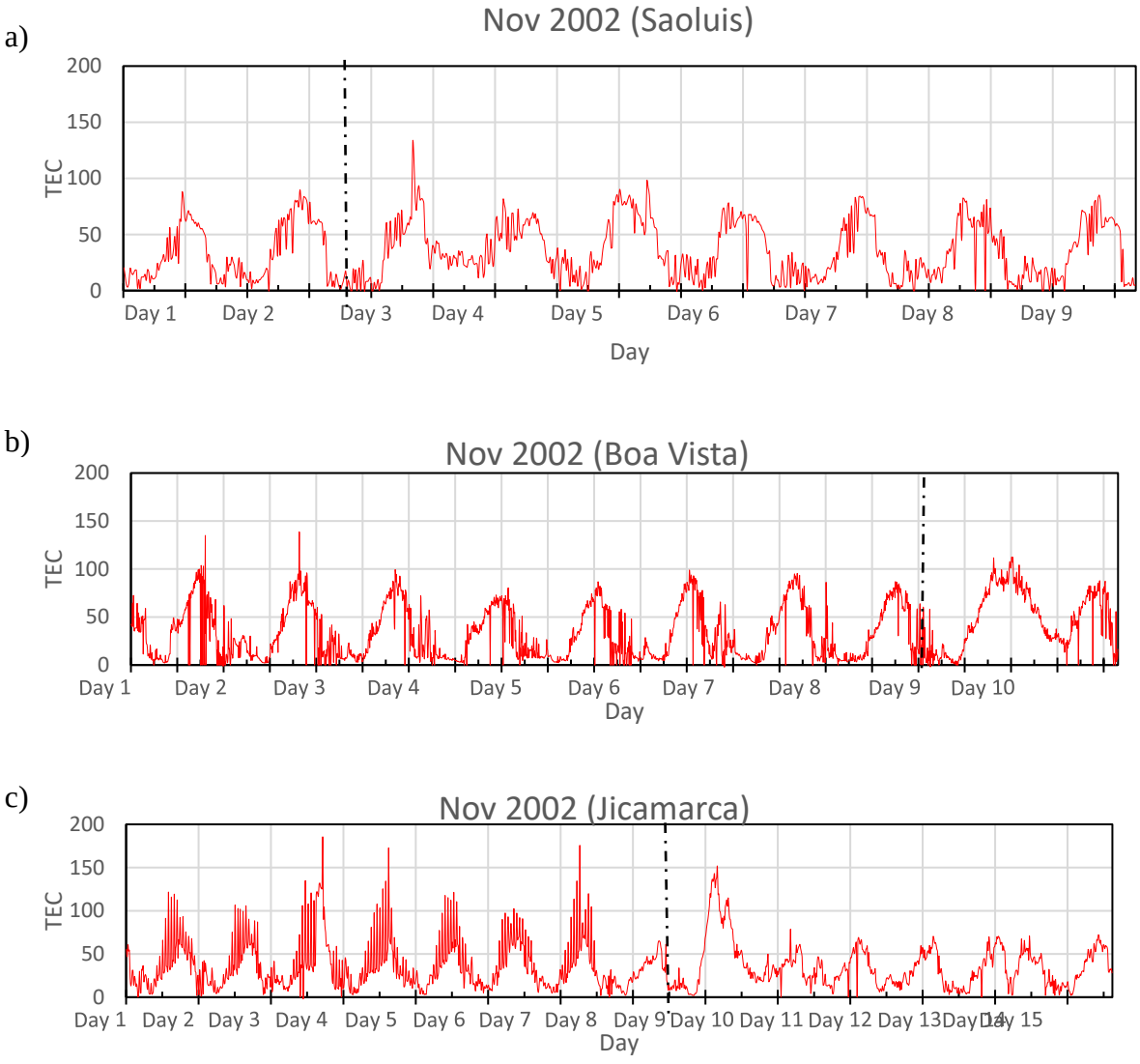


Figure 9: Anomalies of TEC for earthquake year 2002

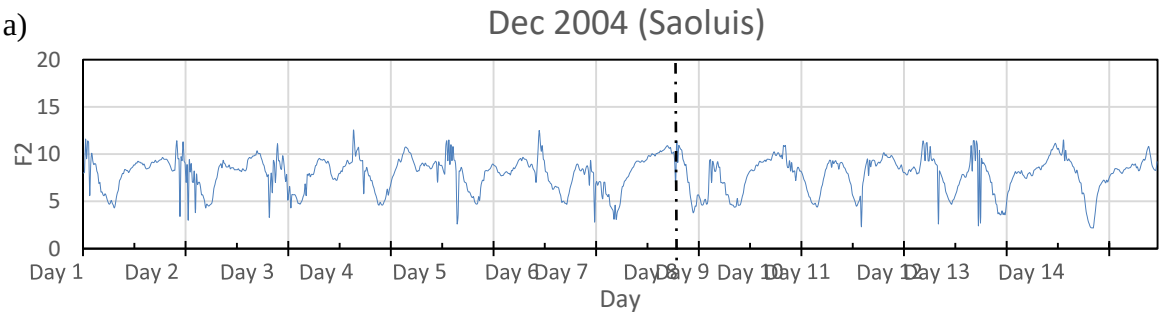
Based on these three stations, Sao Luis station is the station that is closer which is located at the east to the event coordinate and followed by the station that far away towards the west of region study, Boa Vista and Jicamarca respectively. For the value of foF2 from Figure 8, it shows that few days prior to the event day, the foF2 value suddenly approaching the peak with the value of foF2 approximately approach to 20 and unusual

from others time. The same behavior is showed with the TEC's behaviors from all of these three stations which the value of TEC almost reach to the range of 150-200. The graphs also showed that there are differences between before and after the earthquake happen. Data from Jicamarca station, Figure 8(c) and Figure 9(c), shows the most abnormal disturbance occurred a week before the event day which can be determined from the profile of the graph before the straight dotted line. And for the aftershock event, the data of the foF2 and TEC definitely different to the prior of earthquake day. The disturbances suddenly become normal and steady. For Boa Vista graph, Figure 8(b) shows that the profile before the EQ (dotted straight line) different than the after the main shock. While, data from Sao Luis station does not show an obvious change of the pattern for both foF2 and TEC, Figure 8(a) and Figure 9(a).

Behavior of ionospheric parameter for Earthquake year 2004.

The earthquake that occurred on this year is one of the large earthquake that happen at the Sumatra region. Malaysia also affected by this earthquake. The earthquake happen on 26 December 2004. It is became the most tragedy and historical earthquake because many are died due to this earthquake. The magnitude reach about 8.5 (scale Richter). And the impact of this earthquake is larger. This earthquake was much destructive and severe.

a)



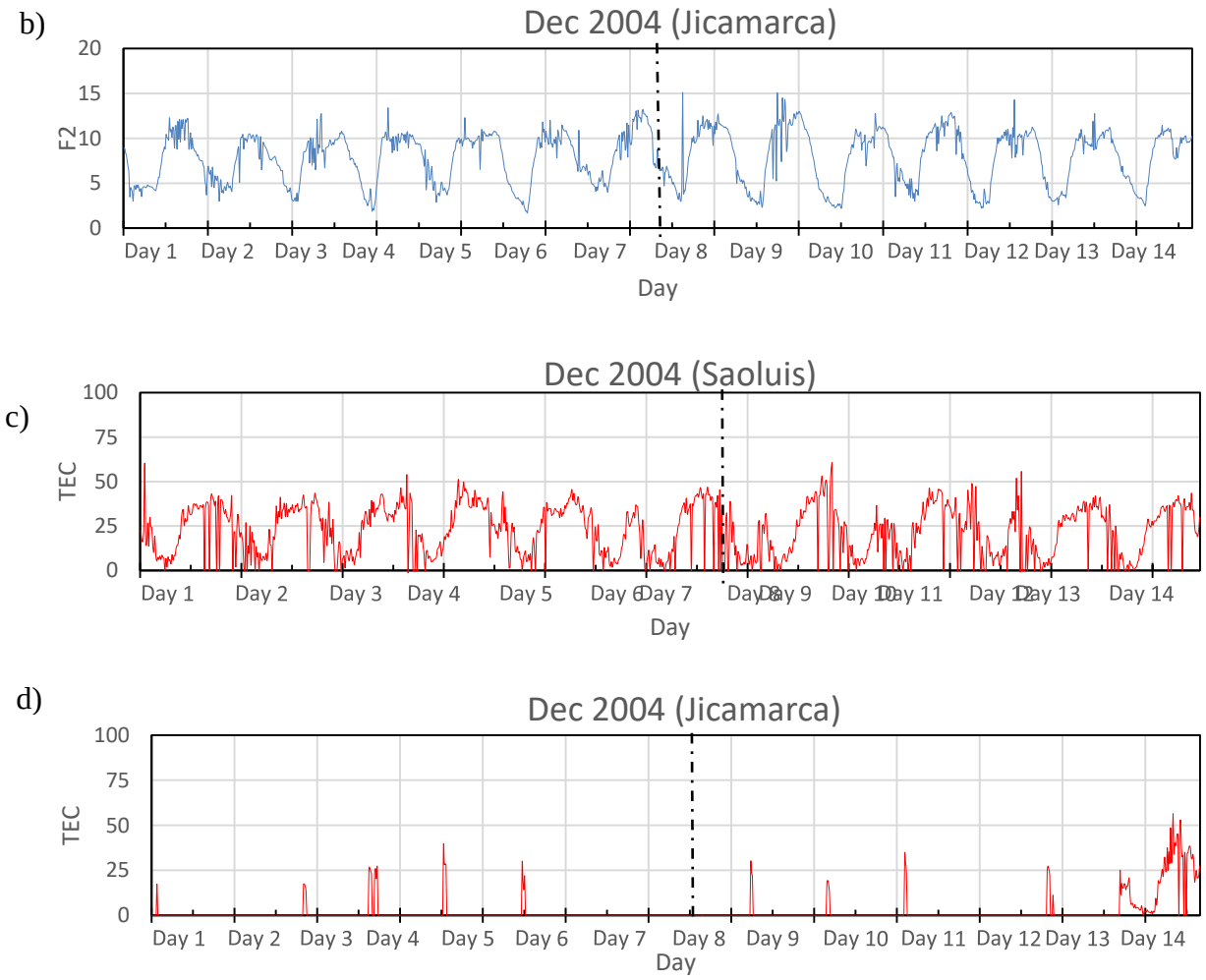


Figure 10: Earthquake year 2004

Based on Figure 10, the data of this earthquake is retrieved from two stations which are Sao Luis and Jicamarca. For the graph, Figure 10(a) and Figure 10(c) shows that 1 to 2 days before the EQ, the graph drop differently from other days. It can be seen that the profile also suddenly shifted to lower than the usual days before the EQ. The graph before the event day also gives a strange fluctuate than the aftershock profile. However, Figure 10(b) and 10(d) does not show any obvious changes of the profile for both foF2 and TEC graph.

Behavior of ionospheric parameter for Earthquake year 2005.

In this year, there were two earthquake with larger magnitude occur. The first one is on 28 March 2005 which is the largest magnitude of earthquake ever happen throughout this 20 years of study. The earthquake took place at the Northern Sumatra with magnitude of 8.7. Next, the second earthquake for this year occur at Nias on the 5 July 2005 with the magnitude of 6.7.

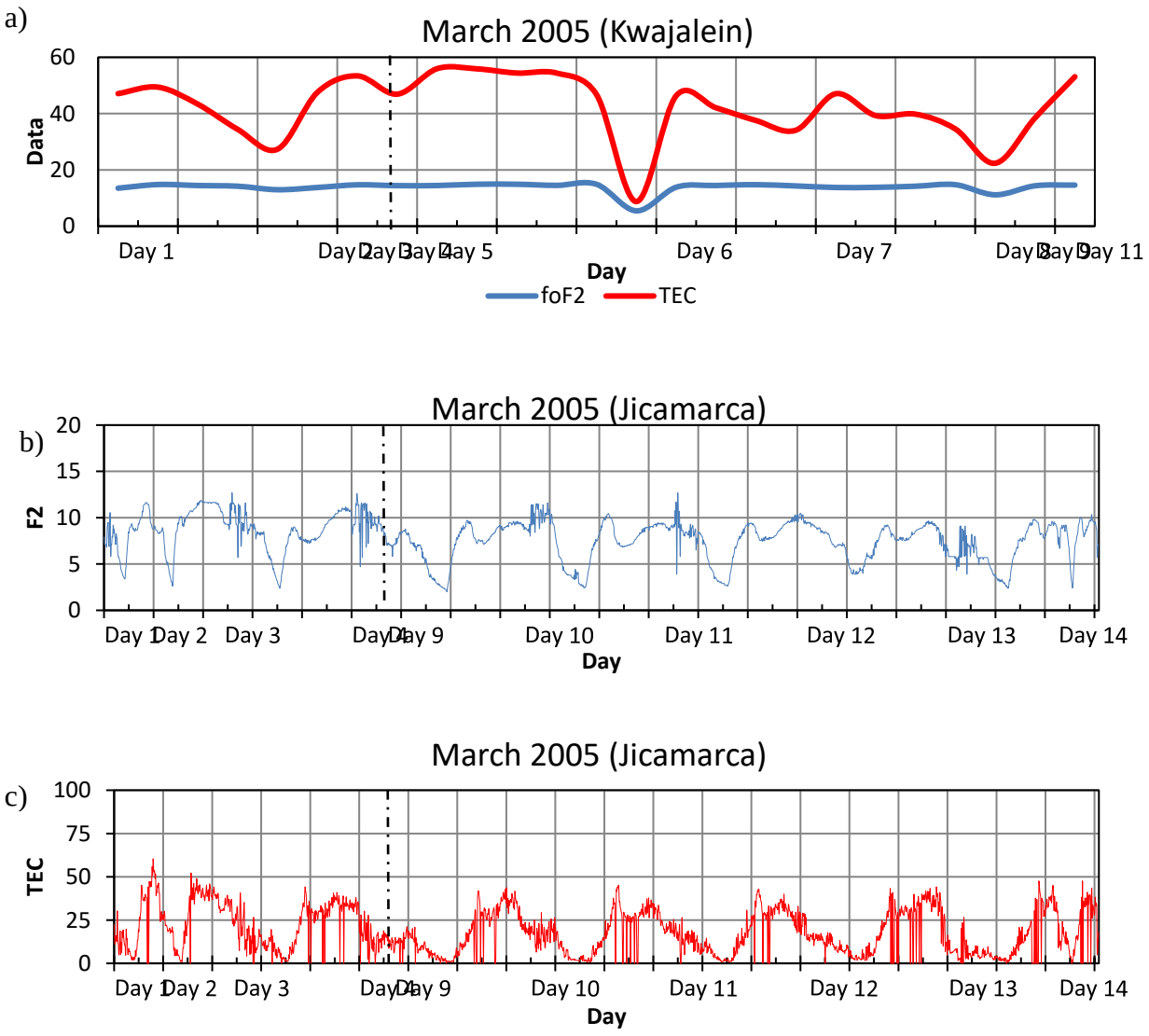


Figure 11: March 2005 earthquake