IONOSPHERIC AND GEOMAGNETIC DISTURBANCE STUDY DURING SEISMIC ACTIVITY IN SOUTHEAST ASIA USING SPACE BORNE AND GROUND SENSOR

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by

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LIST OF SYMBOLS

nT	NanoTesla
km	Kilometre

LIST OF ABBREVIATIONS

CHAMP	Challenging Minisatellite Payload
MAGDAS	Magnetic Data Acquisition System
AGW	Acoustic Gravity Wave
CDF	Common Data File
EQ	Earthquake
LAIC	Lithosphere-Atmosphere-Ionosphere Coupling
M	Magnitude
SAT	Satellite
SEA	Southeast Asia

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GANGGUAN GEOMAGNETIK DAN IONOSFERIK KETIKA AKTIVITI GEMPA DI ASIA TENGGARA MENGGUNAKAN PENDERIA ANGKASA DAN BUMI

ABSTRAK

Banyak kajian mengenai pra-gempa bumi yang melibatkan pelbagai kaedah telah dilakukan untuk memahami aktiviti gempa bumi. Kesan Gabungan Litosfera-Atmosfera-Ionosfera (LAIC) digunakan untuk menggambarkan proses fizikal yang terlibat sebelum gempa bumi berlaku. Asia Tenggara adalah kawasan kerap berlakunya gempa bumi dan kajian terhadap gempa bumi di kawasan ini masih kurang dan kurang difahami. Oleh itu, kajian ini bertujuan untuk memahami tingkah laku pra-gempa bumi dengan menyiasat apa yang berlaku pada tingkah laku geomagnetic dan komponen sebelum gempa bumi. Data geomagnetik dikumpul oleh sensor satelit dan bumi. Data satelit dikumpul dari satelit CHAMP dan Swarm, manakala MAGDAS digunakan untuk mengumpul data sensor bumi. Kajian ini berdasarkan gempa bumi besar (M>6.5) yang berlaku di Asia Tenggara pada sebelas tahun, dari 2008 sehingga 2018. Data dua minggu sebelum setiap gempa bumi yang disenaraikan, akan dikumpul dan dibezakan dari sebarang anomali geomagnetik yang tidak berkaitan seperti aktiviti solar dan ribut magnet. Berdasarkan hasilnya, sekurang-kurangnya satu profil yang terganggu akan muncul sebelum gempa bumi besar berlaku. Komponen dominan yang menunjukkan anomali paling ketara pada setiap profil yang terganggu adalah komponen-y dan komponen-N untuk data satelit dan MAGDAS, masing-masingnya. Akhir sekali, pengumpulan data yang banyak dari sensor satelit dan bumi ini diharapkan dapat membantu menambahbaik dalam pemantauan terhadap pra-gempa bumi secara langsung terutama bagi kawasan di Asia Tenggara.

IONOSPHERIC AND GEOMAGNETIC DISTURBANCE STUDY DURING SEISMIC ACTIVITY IN SOUTHEAST ASIA USING SPACE BORNE AND GROUND SENSOR

ABSTRACT

Many studies on the pre-earthquake involving various methods have been conducted to understand the earthquake activity. The Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) effect describes what physical processes are involved prior to an earthquake. Southeast Asia is a region where earthquakes have a high frequency to occur, and the earthquake's studies in this region still lack and poorly understood. Therefore, this study aims to understand the pre-earthquake behaviour by investigating the behaviour of the geomagnetic field and the components before an earthquake. The geomagnetic field data is collected using space borne sensors and ground sensors. Satellite data will be collected by the CHAMP and Swarm satellites, while MAGDAS will collect ground sensor data. This study is based on the major earthquakes (M>6.5) that happened in Southeast Asia for eleven years, from 2008 to 2018. Two weeks prior to every listed earthquake, the data was collected, filtered, and distinguished from any unrelated geomagnetic anomalies such as solar activities and magnetic storms. Based on the result, at least one disturbed profile would appear before a major earthquake. The dominant component that showed the most significant anomalies on every disturbed profile was the y-component and N-component for satellites and MAGDAS data, respectively. Lastly, the mass collecting data from both satellite and ground sensors hopefully will be helpful to the improvement for the future real-time earthquake precursor in the Southeast Asia region.

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter presents a general overview of the research. The research background explains the earthquake phenomenon in the Southeast Asia region, the problem statements, objectives, and the research scope and presented in Sections 1.3 to Section 1.5. The final part of this chapter is the thesis outline that presents every chapter's description in this thesis.

1.2 Research Background

1.2.1 Location of the study

The Southeast Asia region is an area where earthquakes occur most frequently because of its location in the Pacific Ring of Fire. The geographical plate of this region is on the unstable tectonic plates, and earthquakes occur frequently. The study coordinate is in longitude range of 95°E - 125°E and latitude range is 8°S - 21°N as shown in Figure 1.1. The Southeast Asia region is also located in the equatorial.

Figure 1.1 Map of country in Southeast Asia

(Page URL: https://www.britannica.com/place/Southeast-Asia/Plant-life, downloaded on 5th October 2021)

Table 1.1 shows the indicator for the class of the magnitude level of the earthquake magnitude. From the year 2008 until 2018, 37 earthquakes with a magnitude mora than 6 occurred in the Southeast Asia region. Magnitude more than 6 is categorized as a strong earthquake. Figure 1.2 shows that 2010 has recorded the largest number of earthquakes with the frequency of 6 earthquakes (M>6) this year. While the year 2014 was recorded, only one earthquake occurred with a magnitude of 6.1.

Table 1.1 Richter scale of earthquake magnitude

Magnitude level	Category	Effects
< 1.0 to 2.9	Micro	Generally not felt by people, though recorded on local instruments
3.0–3.9	Minor	Felt by many people; no damage
4.0–4.9	Light	Felt by all; minor breakage of objects
5.0–5.9	Moderate	Some damage to weak structures
6.0–6.9	Strong	Moderate damage in populated areas
7.0–7.9	Major	Serious damage over large areas; loss of life
8.0 <	Great	Severe destruction and loss of life over large areas

(Page URL: https://www.britannica.com/science/earthquake-geology/Earthquake-magnitude, downloaded on 5th October 2021)

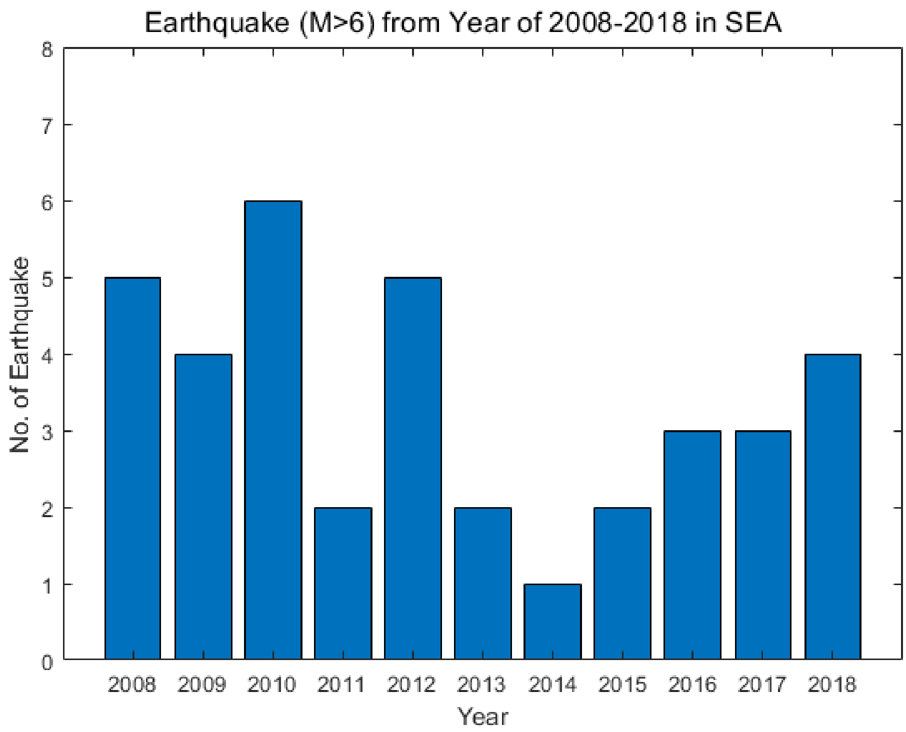

Figure 1.2 Frequency of earthquakes from the year 2008-2018

(Page URL: https://earthquaketrack.com/p/malaysia/recent, referred on 9th July 2020)

Figure 1.3 show the scattered place for the location of the earthquake epicentre. It shows most of the earthquakes in Southeast Asia occurred in Indonesia.

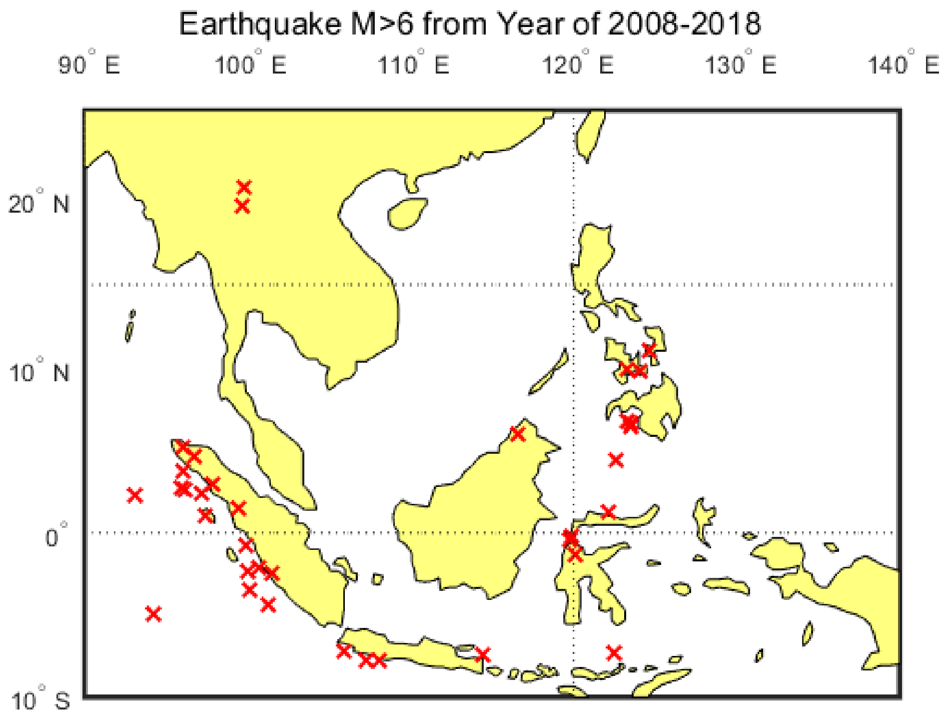

Figure 1.3 Epicentre of the earthquake of the year 2008-2018

(Page URL: https://earthquaketrack.com/p/malaysia/recent, referred on 9th July 2020)

A variety of studies have been carried out to understand earthquake precursor-related issues. The previous research is beneficial in terms of improving and adding to understand earthquakes. The region of the study, the precursor, and the time range for the precursor to detect an earthquake are all variables that have been used for each research.

1.2.2 Lithosphere-Atmosphere-Ionosphere Coupling (LAIC)

Figure 1.4 shows the LAIC approach based on the principles of the movement of the Earth's tectonic plates. The tectonic plates' movement has a few types; divergent, convergent, and transform plates. The movement of the plates produced significant types of waves and caused many other effects such as earthquakes, tsunamis, and volcanoes.

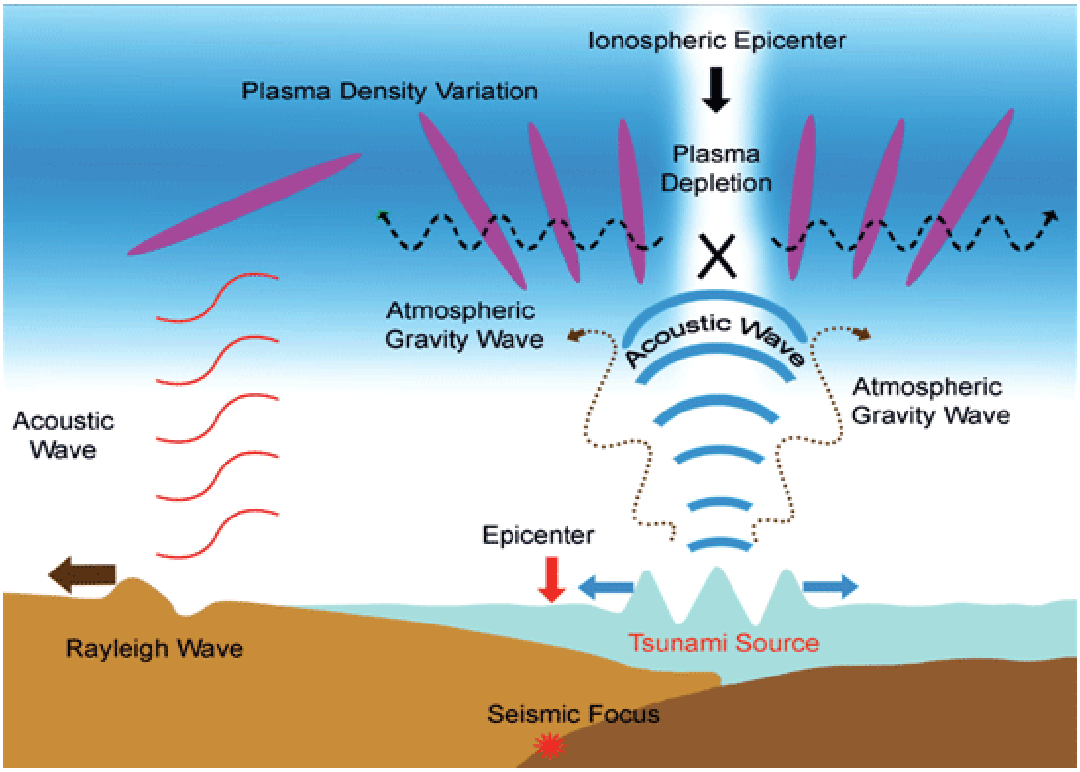

Figure 1.4 Lithosphere Atmosphere Ionosphere Coupling phenomenon

(Page URL: http://www.iigm.res.in/content/claims, downloaded on 3rd October 2021)

A seismic wave is one of the theories that shows what exactly happens as the Earth's crust moves. Earthquakes occur as two blocks of the Earth unexpectedly slide past each other. When earthquakes occur, a few waves are produced, and one of them is an acoustic gravity wave. Acoustic gravity wave (AGW) usually gets excited and propagate through the atmosphere into the ionosphere layer. AGW is a type of sound wave that can travel through the speed of sound and will be generated by earthquakes, landslides or surface waves that occur.

In this study, both data taken from the ground sensor (lithosphere) and in-situ measurement of the satellite data (ionosphere) are used to identify the geomagnetic profile before the seismic activity occurred.

1.2.3 Earth Magnetic Field

Earth magnetic field, called a geomagnetic field, consists of a magnetic dipole, North poles, and South poles. The magnetic field is radiated from the core of the Earth into space. The magnetic field of both the Earth and the Sun affect the particles in the ionosphere. The particles detected in Earth's magnetic field are located at the ionosphere that overlaps with Earth's magnetosphere.

1.2.3(a) Magnetic Field Concept

Various studies of the geomagnetic field have been conducted using different methods for different purposes. Earth's magnetic field observations are one of the studies that have been growing throughout the year. This study is an opportunity to observe and investigate the magnetic field produced from both sources, upper sources (satellites) and lower sources (ground sensor-MAGDAS).

Earth's magnetic field consists of at least three components. First, the Earth's main magnetic field is related to the Earth's liquid core currents. Second, the remnant magnetic field will drastically change its magnetic properties and become solidified together with the crust. As a result, the magnetic field temperature will drop until below the Curie temperature (Thébault et al. 2010). Third, the current flow in the Earth's ionosphere and the crust is produced due to the fluctuation of the main field formed by charged particles between the solar wind and the Earth's main magnetic field.

1.2.3(b) Magnetic Field Element

The magnetic element of the Earth consists of three orthogonal components (X, Y, and Z), total field strength (F) and two angles; declination angles (d), inclination angles (i), and horizontal (H) and vertical component (Z) as showed in Figure 1.5.

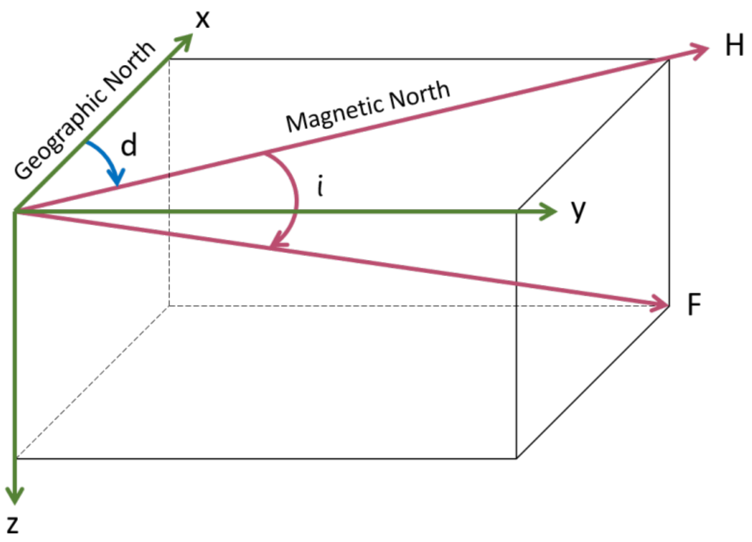

Figure 1.5 Magnetic field element (vector component)

(Page URL: https://www.ngdc.noaa.gov/geomag/geomaginfo.shtml, referred on 5th October 2021)

The Magnetic Northward, Magnetic Eastward, and vertical components were examined to obtain the diurnal variations of the geomagnetic data. Usually, satellite data will use 'NEC' as the component of the magnetic field with N (northward-southward), E (eastward-westward), C (towards the centre of the Earth or also known as z-component). For MAGDAS, the Magnetic Northward component is also called H or N. Magnetic eastward, usually known as D or E, and the vertical component is Z.

This study observes the geomagnetic disturbance prior to the large earthquake using geomagnetic field data from the lithosphere and ionosphere. Data from the ground sensor will be taken from the MAGDAS in the Southeast Asia region. For the satellite data, in-situ measurements from CHAMP and Swarm satellites will be analysed to study the magnetic field behaviour before the earthquake.

1.3 Problem Statement

Southeast Asia is one of the regions that have the most significant possible threat to earthquakes to happen. From the year 2008 until the year 2018, about 37 of the large earthquake of Southeast Asia’s earthquakes with a magnitude of more than 6 are recorded. Many study studies have been conducted to understand the chosen parameters' exact profile before an earthquake happens. However, the number of observations on the exact profile of Southeast Asia's earthquake behaviour has not been studied.

The study using magnetic field data from ground sensor and satellite was conducted separately without analyzing the reliability of both data. Most of the research on the earthquake used either the satellite sensor or the ground sensor to study the choosing parameter's behaviour. By the approach of this study, the Lithosphere-Atmosphere-Ionosphere Coupling fundamental can be observed more apparent if there is an identified profile of the disturbance of the geomagnetic field from both ground sensors and space borne sensors.

1.4 Research Objective (s)

The objectives of this project are listed below:

1. To characterise the behaviour of geomagnetic profile using satellite data from 2008 until 2018 for Southeast Asia's earthquake.
2. To analyse the geomagnetic component's behaviour using two sources from satellite data and the ground sensor prior to and during seismic activity (earthquake).

1.5 Research Scope

In this study, satellite data's geomagnetic profile will be observed fourteen days before the earthquake happens for 27 shortlisted large earthquakes with a magnitude more than 6.5 from 2008 until 2018. The profile of the geomagnetic field prior earthquakes is observed if there are any anomalous showed.

The most reaction component of the geomagnetic field will be observed from both satellite sensor and ground sensor. The components in the geomagnetic field from satellite data are N (north-south), E (east-west), and C (toward the centre or vertical), while the geomagnetic field components using by the ground sensor are N(north-south), E(east-west) and Z(vertical). The qualitative analysis of the geomagnetic field variation from satellite data and ground sensor (MAGDAS) will be observed.

1.6 Thesis Outline

This thesis consists of five chapters. Chapter 1 gives a general overview of the fundamentals of how earthquakes happen. Then, the overview of the earthquakes in the Southeast Asia region, LAIC and geomagnetic field are explained. Finally, the problem statement and the objectives of the research are defined.

Chapter 2 reviews all the review of the literature relating to this study. The first part will be focused on the previous study on the earthquake that been conducted. The next part will be elaborate more on the magnetic field itself as the parameter to study the behaviour prior to the earthquake.

Chapter 3 will briefly describe the method used in this study. The process of gathering the data, decrypting the data, filtering the data, processing the data, and analysing the data are elaborated in this chapter.

The result of this study will be divided into two chapters. Chapter 4 will discuss the result of the first objective, which is the behaviour of the geomagnetic field profile from the satellite data. The plotted graph from the satellite data for the selected earthquakes will be presented in this part. In addition, it will show the behaviour of the geomagnetic field profile for the three components fourteen days prior to the selected earthquake.

Chapter 5 will present the geomagnetic field from the ground sensor. This chapter will analyse and compare geomagnetic components' behaviour using both sources, satellite data, and ground sensors. The qualitative analysis will be used to observe the variation of the geomagnetic field from both sources.

Chapter 6 is the final chapter for the conclusion and the future recommendation for the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter presents the previous work regarding the study related to earthquake's, specifically in Southeast Asia. The earthquake study's relevance is presented in section 2.2 that explain how the earthquake is related from lithosphere to ionosphere. The following section will discuss the previous research on the study region, the precursor used and the range of time of the earthquake events. At the end of this chapter, the parameter used for this study, the magnetic field, are discussed. The concept of the magnetic field, the relationship of the magnetic field and earthquake, and the brief history of the satellite and ground sensor used to collect the magnetic field data are discussed in this chapter.

2.2 Earthquake studies

The lithosphere consists of tectonic plates, and the boundary of these plates is known as the earthquake's active place or hotspot. Earthquakes will lead to a great deal of destruction and the loss of many lives. Therefore, many earthquake studies have been conducted to understand nature and find solutions to minimise the loss. Work on earthquakes precursor started decades ago (Hasbi et al. 2011; Ghosh and Midya 2014; Jusoh et al. 2008; Pulinets 2004).

Lithosphere Atmosphere Ionosphere Coupling (LAIC) is a model that can explain how the crust of the Earth-related to the atmosphere layer towards to ionosphere layer. As previously mentioned in Chapter 1, when an earthquake happens, the energy produced from the lithosphere propagates to the atmosphere. The LAIC model acts as a catalyst in the study of the earthquake. A lot of studies involving earthquake studies have been conducted using different regions, precursors, parameters, and methods widely to illustrate and prove this phenomenon (Akhoondzadeh et al. 2018; Klimenko et al. 2012; De Santis et al. 2017; Ouzounov et al. 2015; Yuliatmoko et al. 2021; Banyunegoro 2021).

2.2.1 Region of study

There have been several earthquakes research around the world. Most of the studies conducted on earthquakes that occurred in specific areas as listed in the earthquake study's Table 2.1.

Table 2.1 Earthquake's study

Earthquake	Location	Years	Reference
Acheh, Sumatra	Indonesia	2004	(Uyeda et al., 2009)
Java	Indonesia	2006	(Ammon et al., 2006)
Mentawai Island	West Sumatra	2010	(Satake et al., 2013)
Mindanao	Philippines	2010	(Li et al., 2020)
Sulawesi	Indonesia	2018	(Song et al., 2019)
Kumamoto	Japan	2016	(Potirakis et al., 2018)
Nepal	Nepal	2015	(Zhou et al., 2017)
L'Aquila	Italy	2009	(Masci et al., 2017)
Tohoku	Japan	2011	(Takla et al., 2013)
Wenchuan	China	2008	(Yu et al., 2009)

All these selected earthquakes are major earthquakes that are causing a lot of destruction. Therefore, a variety of studies have been performed on one earthquake to determine the best way to resolve pre-earthquake behaviour. For example, more than 38,000 and 54,000 studies were conducted based on the Acheh, Sumatra Earthquake in 2004 and Tohoku Earthquake in 2011, respectively (Wiseman et al. 2015; Saraf et al. 2005; Okal and Stein 2009; Gunawan et al. 2014; Ouzounov et al. 2011; Potirakis et al.2017). These studies use differential parameters and precursors to study the precise method for predicting earthquakes.

Studies about earthquakes have also been performed in Pakistan, Tohoku and Hokkaido regions (Pundhir et al. 2015; Astafyeva and Heki 2011). Typically, the region analysis would pick a set of earthquakes in the same region over a given period of the year. Therefore, this study selected regions in the equatorial, specifically the Southeast Asia region. All the large earthquakes M>6.5 and located in the Southeast Asia region are collected and analysed in this study.

2.2.2 Earthquake precursor

A variety type of precursors was used to study the behaviour of the pre-earthquake. The methods for earthquake precursors are different based on the device to do the measurement and the choosing parameter to do the analysis. Based on, Robert D. Cicerone, these precursors have the general characteristic that has been observed such as the amplitude and the number of the precursory anomalies (Cicerone et al. 2009).

For example, the earthquake with the largest magnitude tends to occur when the largest amplitude precursor anomaly is detected. Besides, the closer the earthquake, it tends to show the increase in the number of precursor anomaly. The precursor anomaly also seems to occur near the epicentre of the Earthquake (Hayakawa 2016; Cicerone et al. 2009).

The phrase "Earthquake Precursor" refers to the physical phenomena that were detected happen prior to an earthquake. The detected physical phenomena are temperature change, gas emission, induced electric field, and magnetic field (Bellaoui et al. 2017; Riggio and Santulin 2015; Zhao et al. 2014; Zhu et al. 2021). The precursor is not the same as the instruments. For example, to observe the geomagnetic field, a magnetometer can collect data on the Earth's magnetic field.

2.2.3 Range of precursor

Several previous studies have been conducted to indicate the range of the precursor that can be detected before the earthquake happens. Based on these studies, a few methods have been used to find the best time range to predict and monitor the pre-seismic activity (Kamiyama et al. 2016).

One of the methods is using long-term variations. Generally, long term variation is a method used throughout several years of study before the selected event of seismic activity. The study could even take up to 10 years before the seismic event occurs. Research on long-term precursors primarily based on the previous seismic recorded and the geology properties such as the Earth's crustal movement (Hayakawa 2016; Uyeda et al. 2009; De Santis et al. 2019).

Next, the medium-term precursor is a study that monitors any apparent changes that occurred in a year. The medium-term earthquake study or any seismic activity can also be detected a few months prior to an earthquake (Kamiyama et al. 2016). A random study has been conducted to investigate the behaviour of the magnetic field observed by Swarm satellites during quiet geomagnetic conditions (Marchetti et al. 2019; Akhoondzadeh 2019). A significant rise of the anomalies occurs approximately forty days before the Earthquake (Hayakawa 2016; Akhoondzadeh 2012; Kamiyama et al. 2016).

The short-term precursor is a period of observations, from a few days to a few weeks. Most of the is performed detect significant changes in the parameter used only a few days or a few weeks before the mainshock occurs (Hattori et al. 2004; Stanica et al. 2018; Parrot et al. 2006; Pritchard et al. 2020).

The imminent precursor is the shortest time for detecting anomaly perturbation. This precursor senses less than one day typically before the mainshock occurs. The observed disturbance can occur hours or minutes before Earthquake (Mavrodiev et al. 2008; Mavrodiev 2016; Marchetti et al. 2019).

2.3 Magnetic field relation to earthquake

Often researches are conducted using various types of parameters such as Total Electron Content (TEC), Electron Density (Ne), Peak Frequency (FoF2), and magnetic field to study the behaviour of the magnetic field (Alcay 2016; He et al. 2011; Rizal et al. 2020; Gwal et al. 2011; Hasbi et al. 2009). The magnetic field data was collected using a different type of precursor or sensor such as for ionospheric magnetic field (Swarm, CHAMP, DEMETER, Orsted) and for the lithospheric magnetic field (INTERMAGNET, MAGDAS, SKO(Skopje)) (Strachimir Chterev Mavrodiev et al. 2008; Bhattacharya et al. 2009; Marchetti et al. 2020; Zhima et al. 2020).

2.3.1 Magnetic field data from Satellite

Many satellites have been developed to observe the Earth's magnetic field at the ionosphere layer. The first satellite that been designed to measure the magnetic field was the POGO satellite in 1965. POGO satellite mission is to measure the scalar field, also known as the magnetic intensity at the ionosphere layer (Thébault et al. 2010; Olsen et al. 2010; Francisco 2013). After the POGO satellite, Magsat is launched to continue studying the Earth's magnetic field. Magsat is the revised version of the POGO satellite. Magsat's mission is successful but with only a short-lived mission, approximately eight months of life. Magsat is also the first satellite to measure the vector field of the magnetic field (Francisco 2013; Hulot et al. 2010). A few missions come after the

POGO satellite and Magsat has been modified and improved to collect the magnetic field data (Hulot et al. 2010; N. Olsen et al. 2010).

The mission of the POGO satellite was continuing by the Swarm satellite and the most recent China Seismo-Electromagnetic Satellite (CSES). Swarm satellites are constellations of three satellites that orbit at different altitudes and latitudes. CSES also will be manufactured and launched as a constellation. However, the CSES had just been launched in 2018, so it is still only a single satellite. Swarm and CSES have the same mission to monitor the geomagnetic fields (Christodoulou et al. 2019; Olsen et al. 2013; Marchetti et al. 2020).

2.3.2 The magnetic field from the ground sensor

The magnetic field observations using the ground station or ground sensor have been conducted early since the 12th century before satellite observatory started. The magnetic field has been observed from time to time. The Earth's magnetic field measurement began with measuring field components of Declination and Inclination of the Magnetic field maps (Thébault et al. 2010; Mavrodiev et al. 2008). Afterwards, the method for the measurement of the magnetic field continues to evolve the changes in time of all magnetic components (H, D, Z, F(intensity)) (Thébault et al. 2010; Mavrodiev et al. 2008; Piersanti et al. 2020).

Based on the ground-based measurements, for the last few decades, more evidence happens to have appeared on the precursor of electromagnetic precursors related to earthquakes. Several ground-based are available and have been used for this study, such as MAGDAS, INTERMAGNET, International Geomagnetic Reference Field (IGRF) and many more (Rabiu et al. 2009; Yusof et al. 2021; Vervelidou et al. 2018; Chen et al. 2004). Most of this ground-based is open source, and the data desired for any study can be requested. INTERMAGNET and MAGDAS are ground sensors with many stations located around the world, with INTERMAGNET approximately 150 stations, while MAGDAS approximate 79 stations. Compared to IGRF, IGRF is a combination of data from satellites and ground observatories, and the data for IGRF are calculated data for every five years (Reay et al. 2011; Yumoto et al. 2006; Alken et al. 2021; Finlay et al. 2010).

Earthquake is a phenomenon that is difficult to understand when and where it will happen in time and place, respectively. Typically, the ground sensor will have a few numbers and be placed in various locations. Maintaining these data from every station is already a challenging task. However, it still gives an advantage in terms of monitoring if the epicentre of the earthquake occurs near the ground sensor stations.

2.4 Summary of literature review

In the literature, studies using different methods have been conducted to explain the earthquake phenomenon. Hence, LAIC is the best model to describe what happened during the earthquake phenomenon. Regardless of the previous research work, many studies have been conducted; however, there is still a lack of studies that mainly focused on Southeast Asia's earthquake. Therefore, this study will focus on the Southeast's Asia earthquakes regions, with magnitude more than 6.5. In addition, various earthquake precursor has been used to investigate the earthquake either from space borne or ground sensor but have been conducted separately without a correlation analysis on the reliability of both data. Therefore, this study is performed to observe the behaviour of a chosen parameter (Earth's magnetic field) that are available at both ionosphere and lithosphere layer, using the method of short-term precursor (14 days prior to an earthquake) analysis for Southeast Asia's earthquakes from 2008 until 2018.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter presents the methodology for this study. The methodology of this study will be described briefly using the flowchart, and the detail of every process will be divided and explained based on four phases. First, how the preliminary study has been conducted is discussed. Second, the data collection process will be described step by step. The third phase explains how the data will be processed by phasing the three-step of the process; Decrypt>>Filter>>Process. Finally, the analysis phase of the chosen parameter's plotted behaviour will be described in the last part of this chapter.

3.2 Project flowchart

This study will undergo a few processes to achieve the objectives of this study. From Figure 3.1, the preliminary study is conducted to find the parameter and sensor that will be used throughout the study. The second will be the process for data collecting. Data collecting will be conducted separately for the satellite data and the ground sensor data. The data will be filtered and need to meet the requirement for this study, such as the year of the earthquake, the magnitude of the earthquake, and the epicentre's location.

Next, the crucial part of this study is data processing. Data processing will require the phase to process all the collected data as the expected outcome for this study. The collected data will undergo every process as shown in the 'Data Processing' box in Figure 3.1 below. The final phase will be the data analysing process. The result will be selected in this process by distinguishing the disturbing result from other anomalies related to geomagnetic activities. The selected result will be analysed and discussed one by one and will be presented in Chapter 4 and Chapter 5. The detailed process for every phase will be discussed in this chapter.

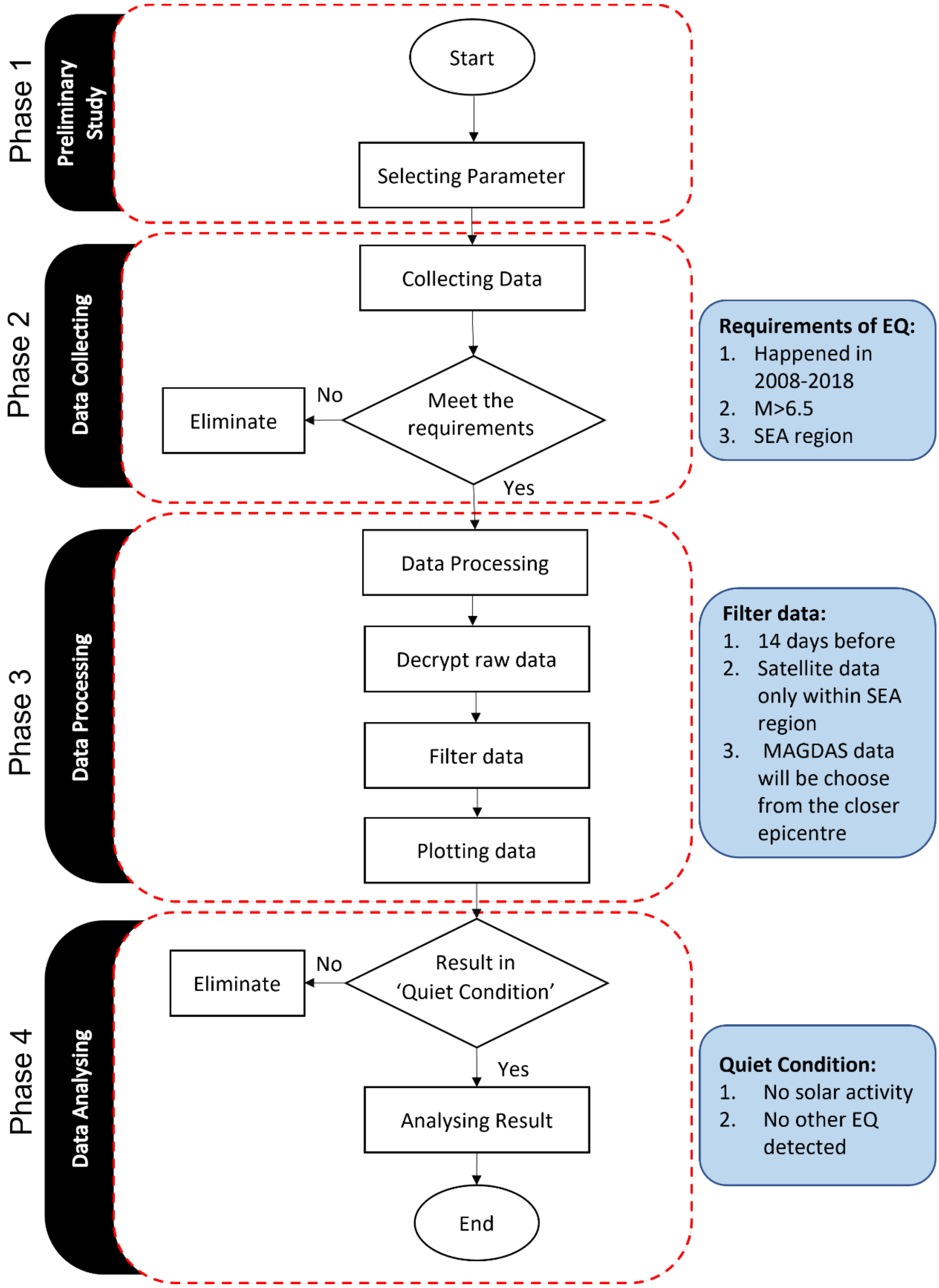

Figure 3.1 Flowchart of the study

3.3 Phase 1: Preliminary study

The preliminary study is conducted to find the best parameter that can be used to observe the behaviour of the magnetic field from both Earth's sensor and satellite sensor, respectively. Furthermore, to synchronise the observation of the Earth's magnetic field from both geo and satellite sensor; the same parameter is chosen to study the disturbance occurred prior to the large earthquake.

This method is also used to observe and relate to the Lithosphere-Atmosphere-Ionosphere Coupling (LAIC) phenomenon. Therefore, both sensors detected the anomaly before, during, and after any seismic activity within the radius.

Magnetic fields collected from the satellite usually used Bx, By and Bz or N(X), E(Y), and C(Z) as the component. For the ground station sensor, the common components used to study the disturbance before the earthquake are H(north-south), D(east-west), and Z. All of these components are observed to characterise the geomagnetic behaviour before the seismic activity.

3.4 Phase 2: Data collecting

Data collecting is a phase where all the data from satellite and ground sensors been collecting. Before the data collecting process begins, a few requirements are justified according to the location, magnitude, and year of the earthquake occurrence. A chosen list of earthquakes for this research is the earthquakes with a magnitude higher than 6.5, which occurred in ten years from 2008 until 2018, with the earthquake's epicentre placed in the Southeast Asia region. Therefore, the listed earthquakes are in the Southeast Asia region, with latitude from -8^{o} to 21^{o} and longitude from 95^{o} to 125^{o}. The data will be collected from two approaches in this phase, using satellite sensors and ground sensors.

Table 3.1 List of earthquakes with M>6.5 from 2008-2018 in SEA region

ID No.	Date	Time (UTC)	Place	Latitude	Longitude	Magnitude
EQ01	20th February 2008	08:08	Simeulue, Indonesia	2.778	95.978	7.4
EQ02	25th February 2008	08:36	Mentawai Islands region, Indonesia	-2.352	100.018	7.2
EQ03	16th November 2008	17:02	Minahasa, Sulawesi, Indonesia	1.290	122.100	7.4
EQ04	16th August 2009	07:38	Mentawai Islands region	1.497	99.473	6.7
EQ05	2nd September 2009	07:55	Java, Indonesia	-7.809	107.259	7.0
EQ06	30th September 2009	10:16	Southern Sumatra, Indonesia	-0.725	99.856	7.6
EQ07	1st October 2009	01:52	Sumatra earthquakes	-2.508	101.484	6.6
EQ08	6th April 2010	22:15	Northern Sumatra, Indonesia	2.360	97.132	7.8
EQ09	9th May 2010	05:59	Northern Sumatra, Indonesia	3.747	96.013	7.2
EQ10	23rd July 2010	22:08	Moro Gulf, Mindanao, Philippines	6.699	123.475	7.3
EQ11	23rd July 2010	22:51	Moro Gulf, Mindanao, Philippines	6.470	123.532	7.6
EQ12	23rd July 2010	23:15	Moro Gulf, Mindanao, Philippines	6.792	123.282	7.4
EQ13	25th October 2010	14:42	Mentawai Islands region, Indonesia	-3.484	100.114	7.7
EQ14	24th March 2011	13:55	Myanmar	20.687	99.822	6.9
EQ15	5th September 2011	17:55	Northern Sumatra, Indonesia	2.958	97.916	6.6
EQ16	6th February 2012	03:49	Negros–Cebu region, Philippines	9.964	123.246	6.7
EQ17	11th April 2012	08:38	Northern Sumatra	2.311	93.063	8.6
EQ18	11th April 2012	10:43	Northern Sumatra	2.311	93.063	8.2
EQ19	15th October 2013	00:12	Bohol, Philippines	9.880	124.117	7.1
EQ20	27th February 2015	13:45	Flores Sea	-7.288	122.532	7.0
EQ21	2nd March 2016	12:49	Sumatra	-4.908	94.275	7.8
EQ22	1st June 2016	22:56	Mentawai Islands region, Indonesia	-2.097	100.665	6.6
EQ23	6th December 2016	22:03	Northern Sumatra, Indonesia	5.281	96.108	6.5
EQ24	10th January 2017	06:13	Celebes Sea	4.463	122.575	7.3
EQ25	6th July 2017	08:03	Leyte, Philippines	11.114	124.633	6.5
EQ26	15th December 2017	16:47	Java, Indonesia	-7.734	108.023	6.5
EQ27	28th September 2018	10:02	Minahasa, Sulawesi, Indonesia	-0.178	119.840	7.5

(Page URL: https://earthquaketrack.com/p/malaysia/recent, referred on 9th July 2020)

3.4.1 Satellite data

Magnetic field anomalies from the ionosphere will be analysed from the collected data using satellite. The chosen satellite for this study is CHAMP and Swarm satellites.

3.4.1(a) CHAMP satellite

The Challenging Minisatellite Payload, also known as the CHAMP satellite, was a satellite developed by the German space industry. With the main mission to investigate the atmospheric and ionospheric surroundings, the CHAMP Satellite was launched on 15^{th} July 2000 with an initial altitude of 454 km. The total mass for the CHAMP satellite was 522 kg (including the mass of the propellant, 30 kg). The mission lifetime for CHAMP Satellite is five years. However, the satellite sustained about ten years and decayed on 19^{th} September 2010. CHAMP satellite has three science objectives, and one of them is collecting the global earth magnetic field.

The flowchart in Figure 3.2 shows the procedure of obtaining the CHAMP data. CHAMP satellite data can be accessed and get at the POTSDAM GFZ website, as shown in Figure 3.3. Before choosing the data, the first step is to know the data and sensor used to collect the required data.

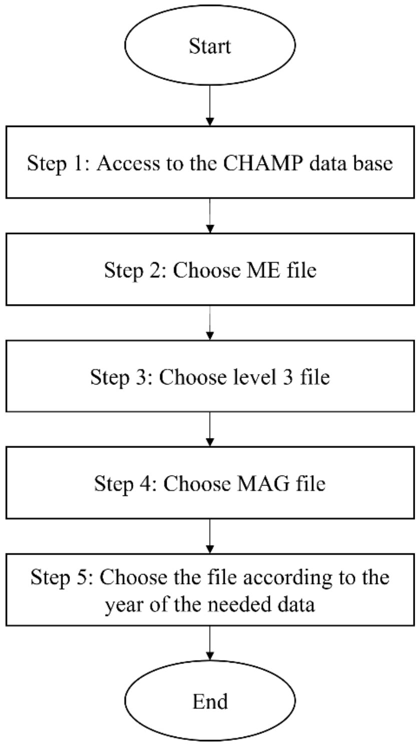

Figure 3.2 Flowchart in collecting CHAMP data

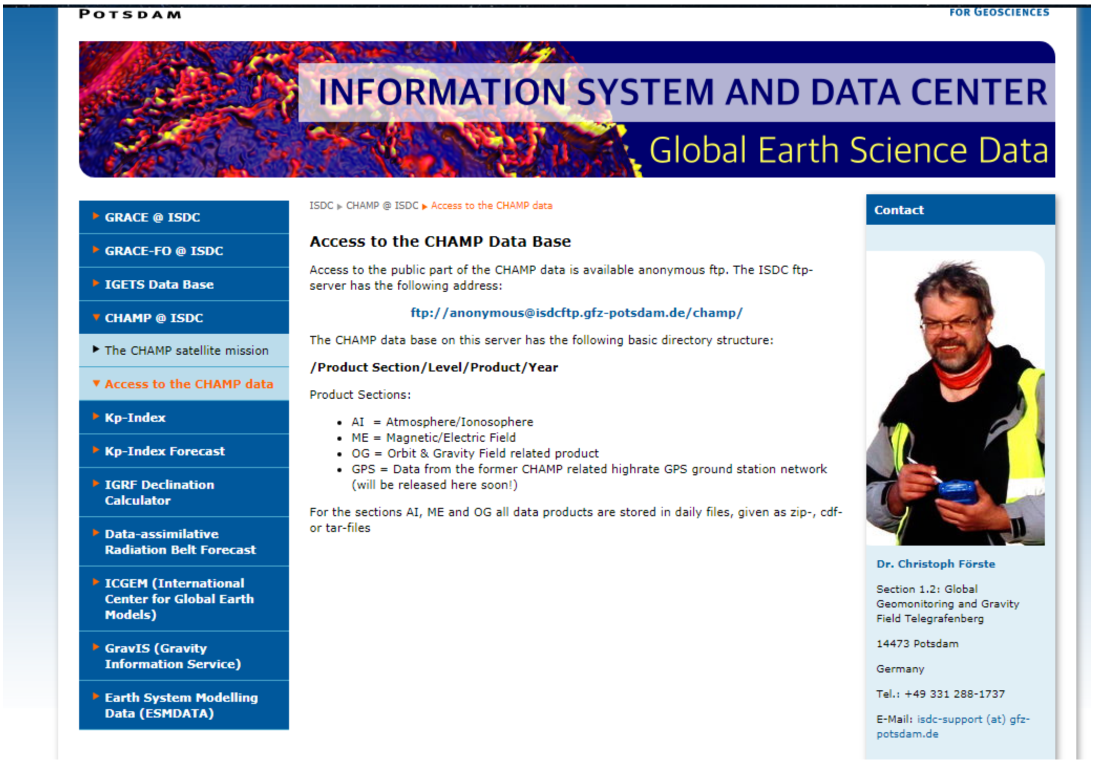

Figure 3.3 POSTDAM GFZ website

The ME is referred to as magnetic or electric field data. In this case, 'ME' is chosen. There are two files in the Level 3 file, ASC-BOOM and MAG files. MAG file is the data from the magnetometer sensor; thus, the file type is selected. Magnetic field data that will be used in this research are received from the satellite's magnetometer. The data are sort according to the year.

3.4.1(b) Swarm satellite

European Space Agency have sent Swarm satellite as the first constellation to carry a mission to explore the Earth's magnetic field. The Swarm satellite operated from 22^{nd} November 2013 and have three identical satellites, Satellite Alpha (Sat A), Satellite Beta (Sat B) and Satellite Charlie (Sat C), with the same mass (468kg), sensors, and frequency. Sat A and Sat C are almost side-by-side at the same altitude. The initial orbit of Sat A and Sat C is about 460 km and descending to around 300 km over the life of the mission. At the lower altitude of the satellites, the measurement of the magnetic features in the crust is more sensitive. The third satellite, Sat B, remains in a higher orbit, with the initial orbit at 530 km and a slightly different inclination.

Swarm satellite data can be accessed from the website, as shown in Figure 3.8. A few sets and types of data can be retrieved from this database based on using the data. For this research, data that will be used to study the disturbance before the large earthquake is the magnetic field data.