

DESIGN AND DEVELOPMENT OF AN IAGA  
COMPLIANT MAGNETIC OBSERVATORY

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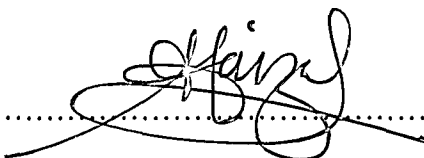
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DESIGN AND DEVELOPMENT OF AN IAGA COMPLIANT MAGNETIC  
OBSERVATORY

MOHD KHAIR BIN OTHMAN

A thesis submitted in  
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## ABSTRACT

The first attempt to construct a magnetic observatory station was initiated in 2002 at Kolej Universiti Teknologi Tun Hussein Onn, presently known as Universiti Tun Hussein Onn Malaysia (Lat.  $1.51^{\circ}$  N , Long.  $103.55^{\circ}$  E), as a scientific facility equipped to detect and record daily scientific phenomena of the earth's magnetic field variations. Preliminary activities such as magnetic surveys, construction of non-magnetic station and coding a new data logger software were carried out. The proton overhauser and fluxgate magnetometers were used to measure the daily magnetic field variations. Daily field variables of the horizontal ( $H$ ), declination ( $D$ ) and vertical ( $Z$ ) components were recorded every second and the total intensity ( $F$ ) component was observed every 5 seconds daily. One-minute digital gaussian filter was applied to the data to minimise the effect of aliasing to produce the values of  $dH$ ,  $dD$  and  $dZ$ . Between the months of June to December 2005, three geomagnetic phenomena were observed namely the magnetic field variations, magnetic storms and pulsations. Daily average variations of the  $dH$  ( $-0.5039$  nT) component shows that it is low at night and maximises around local noon. The average  $dZ$  ( $0.2817$  nT) shows an opposite variation to the  $dH$ , minimising at local noon. This is due to the east-west ionospheric current enhancement by solar radiation which is a maximum at local noon. The average  $dD$  ( $0.3741$  nT) follows a similar variation to  $dH$ . However, the  $dD$  does not always follow the trend, due to very strong north-south components of the equatorial electrojet (EEJ) current. The day-to-day variation of  $dD$  is influenced by the dawn to dusk effect and the EEJ current. Nine geomagnetic storms were detected during this period, with the most intense observed on 24 August 2005 with  $Dst = -216$  and  $Kp = 9-$ . Eighty-five Pi 2 ( $f = 2$  to  $30$  mHz) pulsations were also observed during magnetically quiet periods ( $Kp \leq 2+$ ). The successful detection of these phenomena shows that quality magnetic data which comply with international measurement standards based on IAGA specifications can be observed.

## ABSTRAK

Percubaan awal untuk membangunkan balai cerap magnet bumi telah di mulakan di Kolej Universiti Teknologi Tun Hussein Onn pada tahun 2002, yang kini dikenali dengan nama Universiti Tun Hussein Onn Malaysia (Lat.  $1.51^{\circ}$  N, Long.  $103.55^{\circ}$  E), sebagai sebuah pusat penyelidikan saintifik untuk mengesan dan mencatat perubahan harian magnet bumi. Kerja-kerja pembangunan merangkumi aktiviti tinjauan magnet, membina balai bebas magnet dan merekacipta perisian pengkalan data. Dua alat iaitu 'proton overhauser' dan 'fluxgate' digunakan di balai cerap untuk mengesan perubahan harian magnet bumi. Tiga komponen magnet bumi iaitu komponen mendatar ( $H$ ), sudut pugak ( $D$ ), menegak ( $Z$ ) dikesan dan direkodkan setiap saat, manakala jumlah medan magnet  $F$  direkodkan setiap lima saat. Data-data dituras menggunakan penapis digital gaussian 1-minit untuk mengurangkan kesan pengalisan isyarat dan mengira nilai perubahan kecil komponen  $dH$ ,  $dD$  dan  $dZ$ . Tiga fenomena magnet bumi yang dikesan di antara bulan Jun hingga Disember 2005 ialah, perubahan harian magnet bumi, ribut magnet dan getaran. Pemerhatian harian menunjukkan, komponen  $dH$  ( $-0.5039$  nT) akan mencapai nilai maksima pada tengahari dan terendah pada tengah malam. Komponen  $dZ$  ( $0.2817$  nT) pula, berubah berlawanan arah dengan komponen  $dH$  dan mencapai nilai minima di waktu tengahari. Perubahan ini di sebabkan oleh pertambahan nilai arus ionosferik timur-barat akibat dari sinaran matahari yang maksima. Bentuk perubahan nilai  $dD$  ( $0.3741$  nT) pula hampir sama dengan perubahan  $dH$ , walau bagaimanapun kerap kali perubahan nilai  $dD$  dipengaruhi oleh arus komponen utara-selatan yang dihasilkan oleh fenomena arus elektrojet (EEJ). Perubahan harian nilai  $dD$  dipengaruhi oleh kitaran pagi dan petang, dan arus EEJ. Sembilan ribut geomagnet berlaku dalam tempoh pemantauan dan ribut terbesar terjadi pada 24 Ogos 2005 dengan nilai indeks  $Dst = -216$  dan  $Kp = 9-$ . Dalam tempoh yang sama, lapan puluh lima fenomena getaran Pi 2 ( $f = 2 - 30$  mHz) dikesan semasa magnet bumi dalam keadaan tenang ( $Kp \leq 2+$ ). Kejayaan pengesanan fenomena-fenomena ini menunjukkan data magnet berkualiti yang menepati piawaian pengukuran antarabangsa berdasarkan spesifikasi IAGA boleh di cerap.



I dedicated this thesis to all my parents, my family and my friend.

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## LIST OF SYMBOLS

|              |                                     |
|--------------|-------------------------------------|
| $Dst$        | Disturbance storm time index        |
| E            | East                                |
| elf          | Extremely low frequency             |
| $f$          | Frequency                           |
| Hz           | Hertz or cycle per second           |
| kg           | kilogram                            |
| $Kp$         | Planetary three-hour-range index    |
| L            | Entropy rate or Reconstruction rate |
| $m$          | Magnetic dipole axis                |
| mA           | mili Ampere                         |
| mdnt         | Midnight                            |
| mrاد         | miliradian                          |
| nT           | nanoTesla                           |
| N            | North                               |
| $N$          | Number of coil turns                |
| Pc           | Pulsation continuous                |
| Pi           | Pulsation irregular                 |
| $R_{\oplus}$ | Radius of the Earth                 |
| S            | South                               |

|          |                               |
|----------|-------------------------------|
| $T$      | Time                          |
| $V$      | Voltage                       |
| $W$      | West                          |
| $\gamma$ | Gamma                         |
| $\mu$    | Permeability of core material |
| $\mu_0$  | Permeability of free space    |



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## LIST OF ABBREVIATIONS

|        |   |
|--------|---|
| A/D    | Analogue to Digital                         |
| AC     | Alternating Current                         |
| AE     | Auroral Electroject                         |
| ADC    | Analogue-Digital Converter                  |
| ANSI   | American National Standards Institute       |
| USA    | United State of America                     |
| AU     | Astronomical Unit                           |
| BGS    | British Geological Survey                   |
| CANMOS | Canadian Magnetic Observatory System        |
| CME    | Coronal Mass Ejections                      |
| DC     | Direct Current                              |
| DGRF   | Definitive Geomagnetic Reference Field      |
| DMI    | Danish Meteorolgical Institute              |
| EEJ    | Equatorial Electroject                      |
| FE     | Fluxgate Magnetometer                       |
| FFT    | Fast Fourier Transform                      |
| G-DAS  | British Geomagnetic Data Acquisition System |
| GeoDAS | Geomagnetic Data Acquisition System         |
| GIC    | Geomagnetically Induced Current             |



|             |   |
|-------------|---|
| GPS         | Global Positing System  |
| GSM         | Group Special Mobile  |
| GUI         | Graphical User Interface  |
| HF          | High Frequency  |
| IAGA        | International Associated of Geomagnetism and<br>Areonomy                    |
| ICSU        | International Council of Scientific Unions                                  |
| IGRF        | International Geomagnetic Reference Field                                   |
| IUGG        | International Union of Geodesy and Geophysics                               |
| IMF         | Interplanetary Magnetic Field   |
| INTERMAGNET | International Real-time Magnetic Observatory<br>Network                     |
| IQD         | International Quiet Days  |
| KUITTHO     | Kolej Universiti Teknologi Tun Hussein Onn                                  |
| LAN         | Local Area Network  |
| LT          | Local Time  |
| MagTerm     | Magnetic Observatory Terminal   |
| NGDC        | National Geomagnetic Data Center  |
| NMEA        | National Marine Electronics Association                                     |
| NOAA        | National Oceanic and Atmospheric<br>Administration, United State of America |
| PC          | Personal Computer   |
| POM         | Proton Overhauser Magnetometer  |
| PPM         | Proton Precession Magnetometer  |
| PPS         | Pulse Per Second  |

|       |   |
|-------|---|
| PSD   | Power Spectrum Density                      |
| PVC   | Polyvinyl Chloride                          |
| SQUID | Superconducting Quantum Interference Device |
| STFT  | Short Time Fourier Transform                |
| SCW   | Substorm Current Wedge                      |
| SSC   | Storm Sudden Commencements                  |
| ULF   | Ultra Low Frequency                         |
| UPS   | Uninterrupted Power Supply                  |
| USB   | Universal Serial Bus                        |
| UT    | Universal Time                              |
| UTC   | Coordinated Universal Time                  |
| UTHM  | Universiti Tun Hussein Onn Malaysia         |
| WARAS | Wireless and Radio Science Center           |
| WDC   | World Data Center                           |
| WMM   | World Magnetic Model                        |
| TNB   | Tenaga Nasional Berhad                      |
| TFT   | Thin-Film Transistor                        |
| VGA   | Video Graphics Array                        |
| VAC   | Voltage Alternating Current                 |

## LIST OF GLOSSARYS

**Auroral Electroject (AE)** : A current that flows in the ionosphere at a height of ~100 km in the auroral zone.

**Astronomical Unit (AU)** : The mean radius of the Earth's orbit,  $1.496 \times 10^{13}$  cm.

**Base-line value** : The value to be added to the recorded value to obtain the final component value. This value is almost constant, where a straight-line for scaling exists at magnetograms.

**Bow shock** : A collisionless shock wave in front of the magnetosphere arising from the interaction of the supersonic solar wind with the Earth's magnetic field.

**Cusp region** : The cusp region is located on the antisolar side of the Earth's and is the area where the geomagnetic field lines are first transformed into the magnetotail. This region occurs at a distance of 8 to 16 Earth Radii at geomagnetic latitudes of  $\pm 25^\circ$ .

**Coronal Mass Ejection (CME)** : A transient outflow of plasma from or through the solar corona. CMEs are often but not always associated with erupting prominences, disappearing solar filaments, and flares.

**Cyclotron** : Circular accelerator in which the particle is bent in traveling through a magnetic field, and an oscillating potential difference causes the particles to gain energy .

**DI Fluxgate** : The fluxgate theodolite magnetometer for measuring declination and inclination.

**Flare** : A sudden eruption of energy in the solar atmosphere lasting minutes to hours, from which radiation and energetic charged particles are emitted.

**Geophysical technique** : the scientific study of the Earth's using methods of physics.

**Gyration** : The circular motion of a charged particle in a magnetic field.

**High Frequency (HF)** : That portion of the radio frequency spectrum between 3 and 30 Mhz.

**Hydromagnetic** : see Magnetohydrodynamic.

**Ionosphere** : The region of the Earth's upper atmosphere containing free electrons and ions. This ionization is produced from the neutral atmosphere by solar ultraviolet radiation at very short wavelength and also by precipitating energetic particles.

**keV** : 1000 electron Volts.

**Magnetogram** : The magnetogram is synthetic images constructed by measuring the magnetic field.

**Magnetosheath** : The region between the bow shock and the magnetopause, characterized by very turbulent plasma. This plasma has been heated and slowed as it passed through the bow shock.

**Magnetosphere** : The magnetic cavity surrounding a magnetised planet, carved out of the passing solar wind by virtue of the planetary magnetic field, which prevents the direct entry of the solar wind plasma into the cavity.

**Magnetotail** : The extension of the magnetosphere in the antisunward direction as a result of interaction with the solar wind.

**Magnetopause** : The boundary surface between the solar wind and the magnetosphere, where the pressure of the magnetic field of the object effectively equals the ram pressure of the solar wind plasma.

**Magnetic susceptibility** : The magnetic susceptibility is the degree of magnetisation of a material in response to an applied magnetic field or in an external magnetic field.

**Magnetic anomaly** : Small deviations in the observed magnetic field strength relative to values predicted by a reference or model.

**Magnetisable material** : The ferromagnetic minerals, paramagnetic minerals, canated antiferromagnetic materials, and diamagnetism materials. The ferromagnetic material is strongly magnetisation follow by paramagnetic. The weak magnetisation material is canted antiferromagnetic and weaker is diamagnetism material.

**Magnetisation** - A property of some materials that describes to what extent they are affected by magnetic fields, and also determines the magnetic field that the material itself creates. Magnetisation is not always homogeneous within a body, but rather a function of position. In some materials magnetisation can exist even without an external magnetic field. In other types of materials, magnetisation is induced only when an external magnetic field is present.

**Magnetospheric convection** : The bulk transport of plasma from one place to another, in response to mechanical forces or electromagnetic forces. Thermal convection, due to heating from below and the gravitational field, is what drives convection inside the sun. The magnetospheric convection is driven by the dragging of the Earth's magnetic field and plasma together by the solar wind when the geomagnetic field becomes attached to the magnetic field in the solar wind.

**Magnetohydrodynamic** : The study of the interaction that exists between a magnetic field and an electrically conducting fluid. Also called magnetoplasmadynamics, magnetogasdynamics, hydromagnetics.

**Magnetohydrodynamic wave** : A transverse wave in magnetised plasma characterised by a change of direction of the magnetic field with no change in either the intensity of the field or the plasma density.



**Ring Current** : In the magnetosphere, a region of current that flows near the geomagnetic equator in the outer belt of the two Van Allen radiation belts. This current is produced by the gradient and curvature drift of the trapped charged particles of energies of 10 to 300 keV. The ring current is greatly augmented during magnetic storms because of the hot plasma injected from the magnetotails and upwelling oxygen ions from the ionosphere. The ring current causes a world depression of the horizontal geomagnetic field during a magnetic storm.

**Scintillation** : Describing a degraded condition of radio propagation characterized by a rapid variation in wave amplitude and/or phase caused by variations in electron density anywhere along the signal path.

**Secular Variation** : The first derivative of the normal field, usually expressed as the annual change of a particular field element.

**Shock front** : A shock front exists at the boundary between the solar wind and the geomagnetic field. This shock is similar to a sonic boom and occurs because the solar wind is moving faster than the magnetic field can respond. The magnetic field experiences oscillations with large amplitudes at this location.

**Solar activity** : Transient perturbations of the solar atmosphere as measured by enhanced x-ray emission, typically associated with flares.

**Solar cycle** : The approximately 11 year quasi-periodic variation in the sunspot number.

**Solar Maximum** : The month during the sunspot cycle when the smoothed sunspot number reaches a maximum.

**Solar Minimum** : The month during the sunspot cycle when the smoothed sunspot number reaches a minimum.

**Solar Wind** : The outward flow of solar particles and magnetic fields from the Sun. Typically at 1 AU, solar wind velocities are 300-800 km/s and proton and electron densities of 3-7 per cubic centimeter.

**Substorm** : A substorm corresponds to an injection of charged particles from the magnetotail into the nightside magnetosphere.

**Substorm Current Wedge** : The Substorm Current Wedge is a current system that forms in Earth's magnetotail during periods of magnetic activity called substorms. A portion of the cross tail current that flows across the center of the magnetosphere is diverted into the ionosphere along the magnetic field, where it flows horizontally (to the ground), then returns along the magnetic field to the magnetotail.

**Sunspot** : An area seen as a dark spot, in contrast with its surroundings, on the photosphere of the Sun. They appear dark because they are cooler than the surrounding photosphere.

**Supersonic** : Above the sound speed.

**Variometer** : A magnetometer which is used to record variations of the magnetic field.

**Variometer house** : An installation where one or more elements of the geomagnetic field are measured continuously.



**LIST OF APPENDICES**

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PT TAAUTHIM  
PERPUSTAKAAN TUNKU TUN AMINAH

## CHAPTER I

### INTRODUCTION

#### 1.1 The Importance of the Earth's Magnetic Field



The Earth's magnetic field is important in daily life. It is believed to originate from the dynamo process in the Earth's liquid outer core [1]. It is used in many applications and forms the basis for navigation, geophysical exploration, surveying and prediction of weather forecasting. The discovery of the directive property of the magnet and its development to full precision by measurement of the magnetic declination was the beginning of the new subsience of geomagnetism. According to Campbell [2] it has been 400 years since William Gilbert published "De Magnete", the book that put magnetism on a firm scientific basis and he was the first to note that the Earth behaved like a large magnet. Many advances in the field of the Earth's magnetism have been made in the last 400 years, but the past behaviour of the past geomagnetic field and its evolution, at scales from seconds to millions of years, is still largely unknown. The past behaviour of the geomagnetic field is therefore essential for a better understanding of the physical processes in the Earth's present magnetic field.

Unfortunately, the geomagnetic disturbances phenomena due to space weather caused by the interplanetary space, solar influence and energy particles which vary, affect spacecraft, ground-based technology and human health [3, 4, 5]. Figure 1.1 graphically illustrates the various space weather phenomena. Prediction of the geomagnetic distribution does not always happen, and occasionally unforeseen activity occurs. Physical processes driving the space weather is linked to the chain connections starting from processes on the sun.

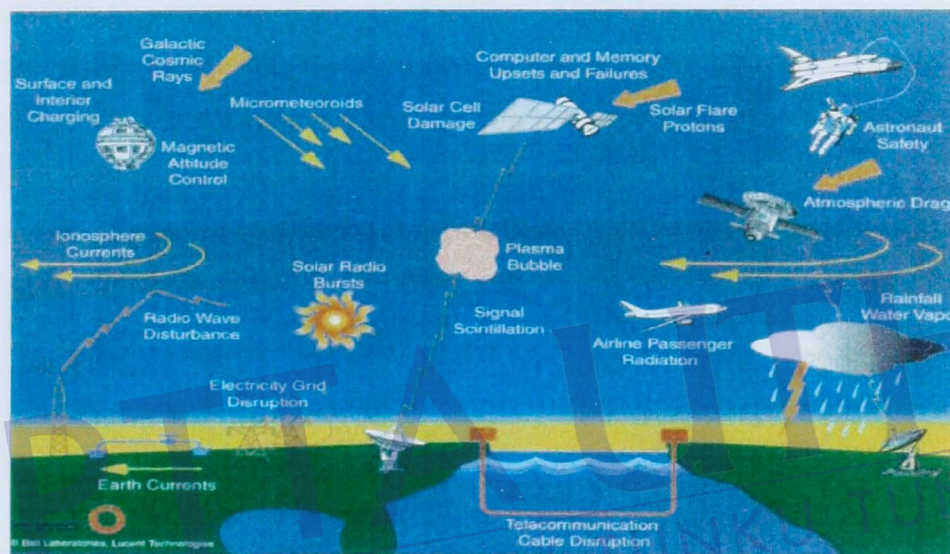


Figure 1.1: Illustration some of the effects of space weather on technical systems, adapted from Lanzerotti [6]

The ability to observe, monitor and forecast space weather is becoming increasingly important. A growing number of sophisticated and expensive spacecrafts are being deployed in near-Earth orbits where effects attributed to energetic particle fluxes impair satellite operations and damage satellite systems. Energetic particles precipitation also presents a serious danger for the health of crews of high-altitude jets, including commercial transcontinental aircrafts flying over high-latitude zones. Sudden changes in ionospheric parameters attributed to magnetospheric and solar processes can disrupt radio communications [6, 7]. Analysis of these observations will allow the development of improved models of the processes, which will provide the foundation for future predictions and related policies to be made.



Due to the great complexity of the problems, this thesis focused on initial attempts to develop a ground-based magnetic observatory, that is World Data Center (WDC) compliant to observe the daily variations of the magnetic field in Malaysia, particularly in the Parit Raja area. Regular geomagnetic recording is necessary for radio communications research, particularly recording of the geomagnetic disturbances, ionospheric disturbances [8], pulsation phenomena [9], generation of scientific reference fields [10], field survey corrections [11], comparison of magnetic anomaly surveys [12] and generation of the global geomagnetic models DGRF (Definitive Geomagnetic Reference Field) and IGRF (International Geomagnetic Reference Field). Modelling of the magnetic field and its secular variation over long periods of time depends greatly upon the network of geomagnetic observatories which continuously record the field variations. One of the major problems [13] in generating the global models and in their evaluation is the uneven distribution of the geomagnetic observatories around the globe.

## 1.2

### Overview of Magnetic Observatories

A geomagnetic observatory is a facility where vector observations of the Earth's magnetic field are recorded accurately and continuously, with a time resolution of one minute or less, over a long period of time [13]. Historically, magnetic observatories were established to monitor the secular change of the Earth's magnetic field, and this remain one of their most important functions. The roles of magnetic observatories are essential for scientific, commercial and government use. Thus, there are global, regional and local needs for magnetic observatories to serve different functions [14].

The goals of the observatory are the continuous measurement of the geomagnetic field elements and establishment of the base-line values. The development of the geomagnetic observation for acquiring data in near real-time is necessary for effective research on the processes of monitoring space weather conditions [14]. The geomagnetic data collected in real time will be used to make quantitative estimates of the geomagnetic variations parameters, so as to extract qualitative information.

Over more than 70 countries currently operate more than 200 observatories throughout the world, as shown in Figure 1.2. The locations of the observatories are unevenly distributed, with highest concentration in the developed world compared with developing nations, with the bulk being in industrialised nations and very few in the developing world and oceanic areas. Satellite observatories such as POGO (Polar Orbiting Geophysical Observatories) from 1965 to 1971 and Ørsted (Danish Ørsted Satellite) from 1999 to 2001 are also used to monitor the Earth's magnetic field and provide an excellent global distribution of the data, but this only lasts for short periods of time [2].

### **1.3 International Association of Geomagnetism and Aeronomy (IAGA)**

The International Association of Geomagnetism and Aeronomy (IAGA) is the international scientific association promoting the study of terrestrial and planetary magnetism and space physics. It was formerly known as the International Association of Terrestrial Magnetism and Atmospheric Electricity (IATMAE). It is one of the seven geophysical associations under the International Union of Geodesy and Geophysics (IUGG), which is one of the scientific unions of the International Council of Scientific Unions (ICSU). Most of scientific disciplines are represented by the ICSU. The IAGA is a non-governmental body funded through the subscriptions paid to IAGA by its Member Countries. It is also the main coordinator of all geomagnetic work and the

collection of geomagnetic data for the World Data Center (WDC). The IAGA has five divisions, namely

- Group I - Internal Magnetic Field
- Group II - Aeronomomic Phenomena
- Group III - Magnetospheric Phenomena
- Group IV - Solar Wind and Interplanetary Magnetic Field
- Group V - Observatories, Instruments, Surveys and Analyses

Every two years, the IAGA is responsible for carrying out quality control of data measured by the observatory operators, through the participation in the IAGA scientific and observatory workshop. It is also responsible for persuading observatory operators to adopt modern standard specifications for measuring and recording equipment, to facilitate data exchange and production of geomagnetic data in close to real time. Therefore, the IAGA published two guidebooks in 1996 to provide comprehensive information for first time users on how to organise a magnetic observatory station and make magnetic measurements at the observatory.

#### **1.4 Problem Statements**

As the years pass, scientists have continued to study the origin of the Earth's magnetic field as one of the great unsolved problem in physics. The geomagnetic field behaviour is notoriously nonlinear, making predictions even a few years forward in time inaccurate. It is now ranked amongst the major technical challenges that need to be solved to achieve higher civilisation standards. A clue to understanding geomagnetic behaviour is the self-excited dynamo in the liquid iron core of the Earth.

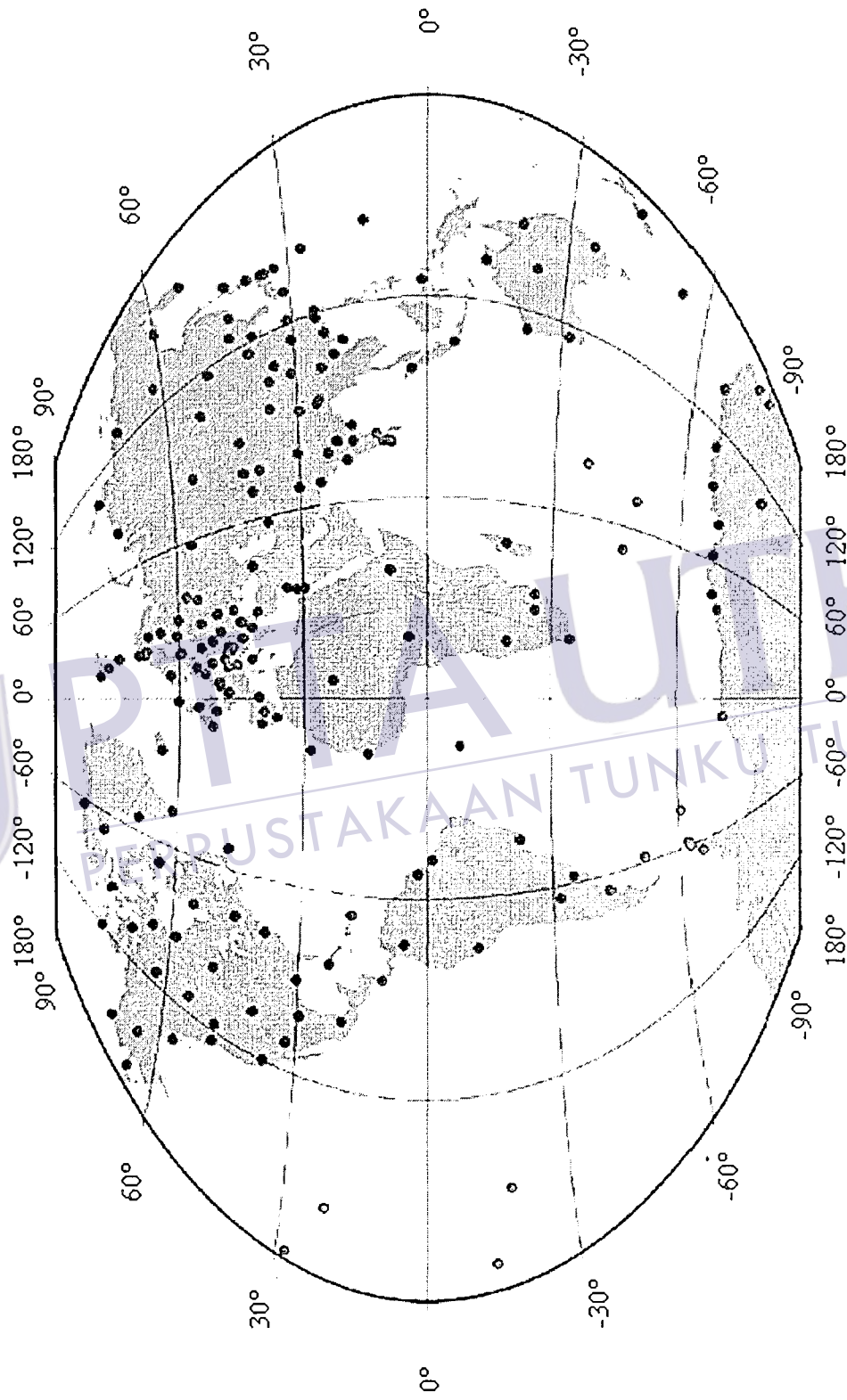


Figure 1.2: Locations of the geomagnetic observatories, adapted from Macmillan and Quinn [13]

Over the past 10 years, the international scientific community has been trying to develop an accurate World Magnetic Model (WMM) [10], with the projection of increasing the number of observatories on land and in space to cover uneven distribution around the globe [13]. Two reasons are typically cited as why the goal has not been achieved [2]: firstly, the inadequate coverage of the magnetic observatories in the Southern Hemisphere, Asia and oceanic areas; secondly, a lack of awareness and priorities given to determine site location of observatories in the developing countries, due to significant geological, political, educational and economic factors. Figure 1.3 shows the trend of the growth of observatories.

There are many reasons why the need for a geomagnetic observatory is of ever-increasing importance in Malaysia. One of the most critical reasons is that the lack of a permanent, continuously recording geomagnetic station in Malaysia creates a major problem for accurate geophysical surveys [11, 12, 15] and special projects focused on monitoring of the geomagnetic changes. The magnetic observatory would be a complement to the ionospheric monitoring station that currently operates at the main campus of Kolej Universiti Teknologi Tun Hussein Onn.

Secondly, the first geomagnetic activities on record were carried out in 1956-1959 by the Government of the Federation of Malaya, under the Colombo Plan, during the International Geophysical Year (IGY) 1957-1958 [16]. The development of this magnetic observatory station will allow us to participate in the International Heliophysical Year (IHY) 2007 with more than 60,000 scientists and engineers from 67 nations at thousands of research stations around the world. The main objective of IHY 2007 is to improve scientists' ability to address the Sun's influence on the terrestrial climate and the near-Earth space environment, on the 50th anniversary of the IGY [17] to coincide with the high point of the 11-year sunspot cycle. The importance of the magnetic observatory station in Malaysia was further recognized, when Pulau Langkawi at about 6.30° N, 99.78° E geographic coordinate (GC) and 2.32° S, 171.29° E geomagnetic coordinate (GmC) was selected as one of the MAGDAS (Magnetic Data Acquisition System) stations of the magnetometer network sponsored by the Space Environment Research Center



(SERC), Kyushu University [18]. This station was inaugurated on 8 September 2006, as part of the IHY program.

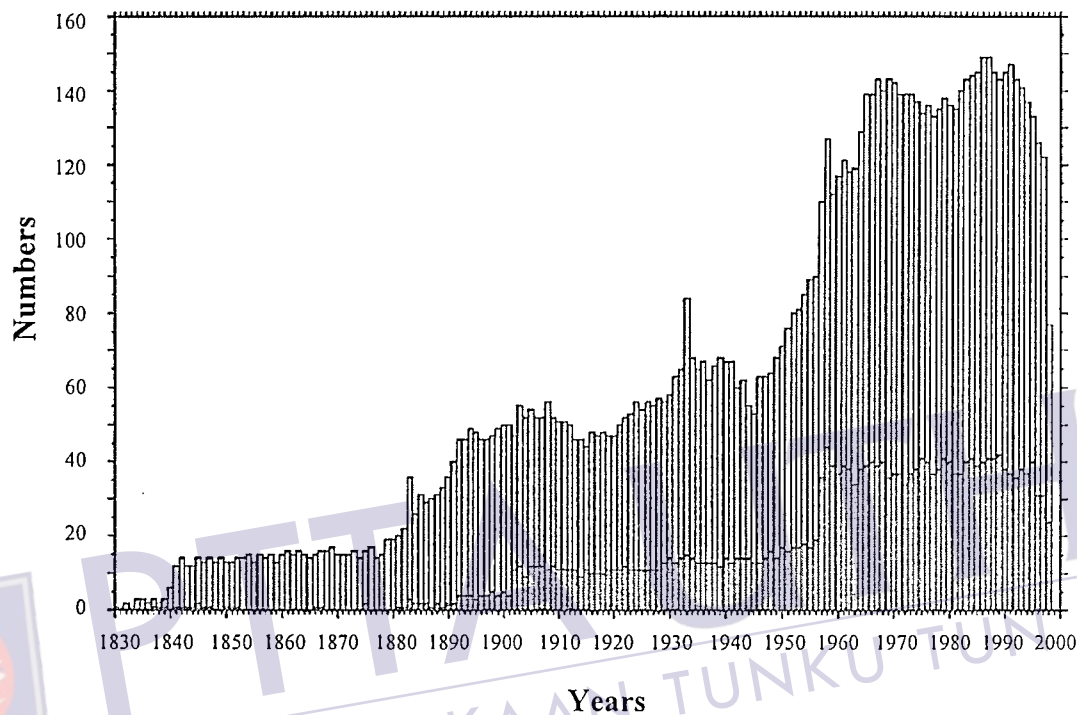


Figure 1.3: Number of observatories provided annual means - North (gray) and South (black) hemispheres, adapted from Macmillan and Quinn [13]

Thirdly, over the years, there has been very little effort to enrich the knowledge and awareness of the Malaysian public and scientific community on the importance of the Earth's magnetic field that directly or indirectly affects life and society in Malaysia. The increasing dependence on space-based systems with the launch of three of Malaysia's satellites MEASAT-1, MEASAT-2 and MEASAT-3 (Malaysia East Asia Satellite) allows broadcasting and telecommunications operators in Malaysia to redefine the limits of performance, functionality and reliability. Temporary service outages of the satellite communications, caused by ionospheric interference originating from the solar events such as geomagnetic storms, can lead to

loss of revenue for the satellite operators [2], impact on client businesses through loss of services, and in cases satellite being declared lost completely and hence subject to insurance claims [19].

In the need for better understanding of the physical geomagnetic processes, the initial research into the development of the first magnetic observatory station at Parit Raja was launched at Kolej Universiti Teknologi Tun Hussein Onn under the Wireless and Radio Science Center (WARAS) as a preliminary step to support the nation's vision of becoming a developed country by the year 2020. This study will contribute significantly to the long-term goal of developing a permanent observatory and will support ongoing study on ionospheric investigation related to radio and wireless communications.

Historically, the incidents of geomagnetic disturbance (Figure 1.4) have contributed to the social and economic losses [7] described below:

1. Rostagi et al. [20] and Banola et al. [21] analysed the effect of the geomagnetic storms on equatorial VHF amplitude scintillations at 137 to 244 Mhz. The study reveals that the effects of geomagnetic storm on ionospheric irregularities depends on the local time of the recovering phase of the magnetic storms.
2. Lanzerotti, MacLennan and Thomson [7], examined the problem of solar radio noise and bursts during the sunspot maximum of the 22nd cycle with average 6 dB to 12 dB levels above thermal noise of  $168.2 \text{ dBW/m}^2$  (4kHz). This was due to the disturbance by the magnetic field on satellite downlinks.

3. Anderson, Lanzerotti and MacLennan [22], analysed the nearly hourly-long outage of a major continental telecommunications cable that stretched from outside Chicago to the west coast and was disrupted between its Illinois and Iowa power stations by the magnetic storm of August 1972.
4. Campbell [23], discussed the electric currents induced in the Earth during magnetic storms which resulted in the corrosion of buried conductors. The conductors required a special protective coatings and applied electrical voltages alongside them.
5. Albertson, Thorson and Miske [24], discussed electric currents induced in powerlines during magnetic storms that caused the damage of power relays at the Quebec station and even caused a power grid failure.

The geomagnetic disturbance impacts of solar-terrestrial process on various technologies is summarised in Table 1.1.

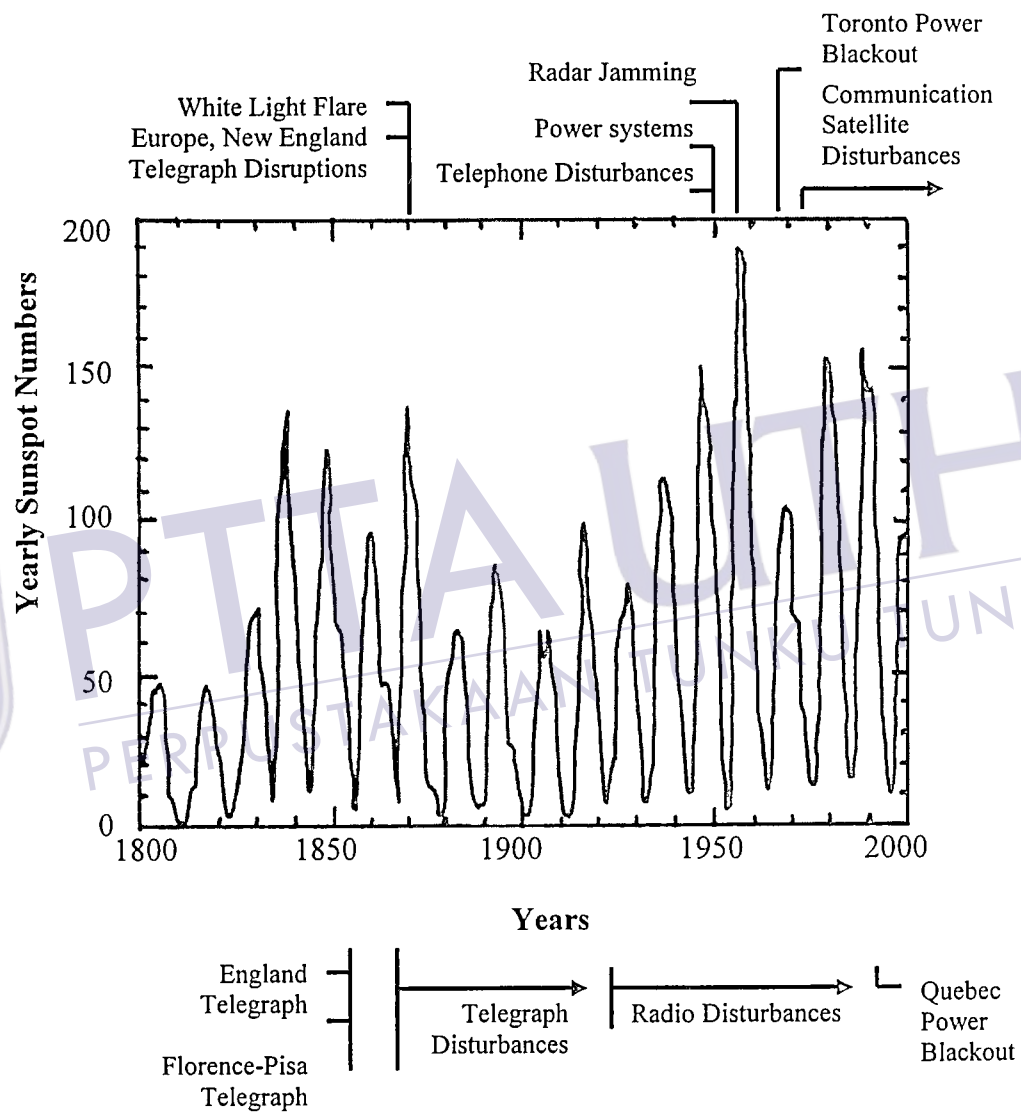


Figure 1.4: Yearly sunspot numbers with indicated time of selected major impact of the solar-terrestrial environment, adapted from Lanzerotti [6]

Table 1.1: Impacts of Solar-Terrestrial Processes on Technologies, adapted from  
Lanzerotti [6]

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Ionosphere Variation

Induction of electrical currents in the Earth

Power distribution systems

Long communications cables

Pipelines

Interference with geophysical prospecting

Source for geophysical prospecting

Wireless signal reflection, propagation,  
attenuation Communication satellite signal  
interference

Scintillation

Magnetic Field Variations

Attitude control of spacecraft

Compasses

Solar Radio Bursts

Excess noise in wireless communication systems

---

## 1.5 Research Scope and Objectives

The scope of this thesis is the design and development of a magnetic observatory station, according to the IAGA specifications to observe the Earth's magnetic phenomena at Parit Raja, Pahat Batu. The preliminary requirement for the observatory is to minimise the magnetic interference surrounding the area. The observatory is developed using non-magnetic materials, as are the existing operational observatories around the globe. The experience and knowledge gathered from the development of this observatory will minimise costs and also the need for foreign expertise for the future development of observatories in Malaysia. An automatic data acquisition system with real-time continuous data recording and processing has been developed to fully utilise the capability of the observatory. Real-time and continuous data recording design of the observatory requires analytical approach to ensure that the design goals are achieved. On this basis, the objective of this research effort includes the following goals:

- To develop a magnetically clean observatory using non-magnetic materials for recording geomagnetic data,
- To develop and implement an automatic data acquisition system for the observatory in terms of software, hardware and a network for the remote sensing of the data logger, and
- To produce scientific data and develop a mathematical model of the geomagnetic field variations at Parit Raja, in the Batu Pahat area.

In order to achieve these goals, five steps were implemented. First, a comprehensive study on geomagnetic theory and practice was conducted to develop a small-scale observatory. Next, a new data logger software was developed to consolidate the real-time data input received from the instruments. The simulation results of the data logger were then validated by comparing the input and output data. Thirdly, magnetic gradient surveys were performed at selected sites to determine the lowest



local gradient profile for the proposed observatory location. Then, a magnetically clean observatory was constructed using non-magnetic materials to start the data recording. Finally, daily geomagnetic variation analysis was performed to determine the equatorial phenomena of various events recorded from the observatory and to develop a mathematical model of field variation.

## 1.6 Thesis Outline

This thesis consists of seven Chapters; including necessary background, scope and the objectives of the research are presented in Chapter 1. Chapter 2 provides some related information and describes previous research done by other researchers in the same area. It includes a review of recent literature on of the geomagnetic fields, its origins, characteristics and coordinates. Description of the observatory practice, instruments and the site selection for the observatory station are presented in Chapters 3. This Chapters which also describes the technologies that have been used to developed the instruments, and the advantage and disadvantage of their use at observatories. The geomagnetic indices that are commonly used in geomagnetic study are also discussed here.

Chapter 4 covers the experimental set up for the magnetic survey and the construction of the observatory. The results of magnetic surveys are discussed and compared to the specifications in order to validate the method. Three-integrated strategies were employed to optimise the development and construction of the observatory house. The non-magnetic materials were tested during construction of the observatory. An analytical study on air ventilation and pillar structure was also discussed for minimising the room's temperature variation and further stabilising the pillars. In Chapter 5 has a detailed description of an automatic data logger system design, including software, hardware and network. An approach to the development of current measurement processes was also discussed in this chapter. Chapter 6

## CHAPTER II

### THEORETICAL BACKGROUND

#### 2.1 The Earth's Magnetic Field

The geomagnetic field is described in detail in the textbook written by Campbell [2], as well as those by Jacobs [25] and Parkinson [26]. The description of the geomagnetic field coordinates, its characteristics, and origins are described in the sections below.

##### 2.1.1 Coordinate Systems

The magnetic field can be described in a variety of ways, each requiring three numbers detailed in Figure 2.1. One way is with an angular relationship. This relationship uses the intensity of the field  $F$ , the inclination angle  $I$ , and the declination angle  $D$ .

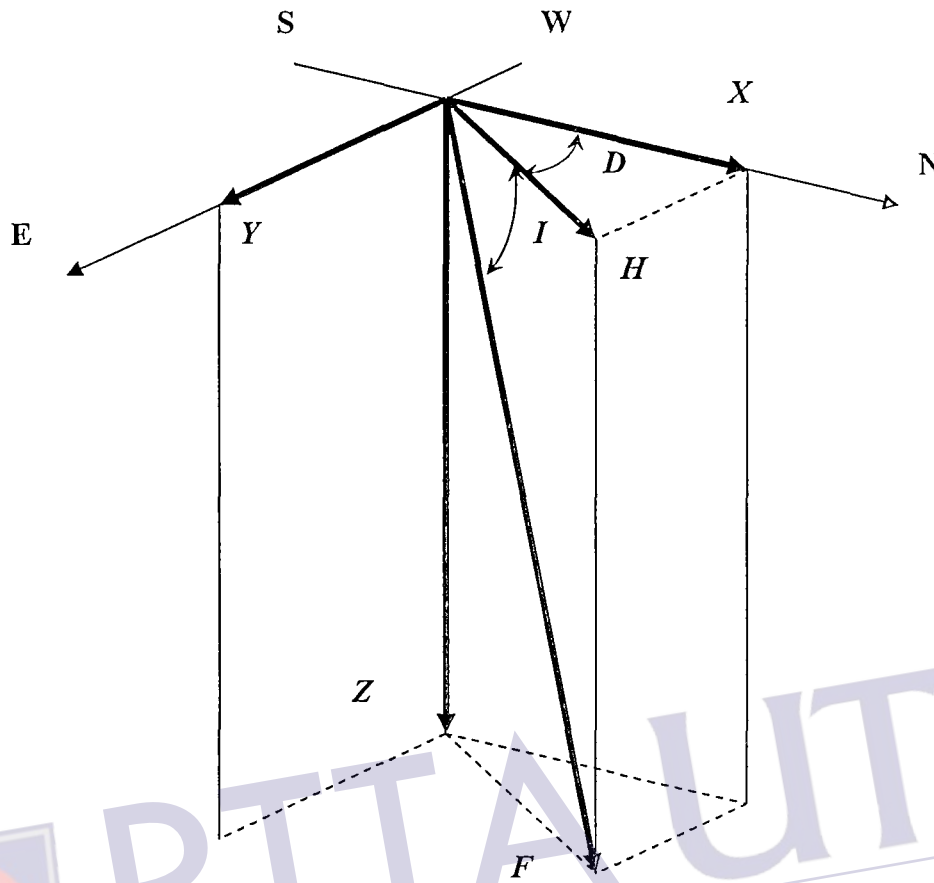


Figure 2.1: Earth's magnetic components, adapted from INTERMAGNET (27)

The second method is to use the cartesian coordinates,  $X$  northward,  $Y$  eastward and  $Z$  downward and the last is  $H$  horizontal,  $D$  declination and  $Z$  downward. The  $F$ ,  $X$ ,  $Y$ ,  $Z$  and  $H$  are measured in Tesla. The  $D$  and  $I$  angles are measured in degrees or minutes of arc. These components are related by the following equations:

$$H = F \cos I \quad (2.1)$$

$$Z = F \sin I \quad (2.2)$$

$$\tan I = Z / H \quad (2.3)$$

$$X = H \cos D \quad (2.4)$$

$$Y = H \sin D \quad (2.5)$$

$$\tan D = Y / X \quad (2.6)$$

Where

$$\begin{aligned} F^2 &= H^2 + Z^2 \\ &= X^2 + Y^2 + Z^2 \end{aligned} \quad (2.7)$$

### 2.1.2 The Earth's Geomagnetic Field

The magnetic field around the Earth resembles that of a uniformly magnetised sphere, or a dipole, which is tilted, as shown in Figure 2.2. Gellibrand [1] was the first to show in 1635 that the geomagnetic field is both time and position dependent. The strength of the magnetic field is approximately 30,000 nT at the equator and 60,000 nT at the poles on the surface of the Earth [14]. The magnetic dipole axis, designated as  $m$  in Figure 2.2, was located at latitude 80.8° N and longitude 109.4° W geographical coordinate, as at the year 2000 [10].

The magnetic dipole axis is currently at an inclination angle of 11.5 degrees to the equatorial plane [14, 28]. Paleomagnetic studies that show the axis is drifting westward at about 0.2 degrees per year, and its strength is decreasing by 0.05 percents per year, called the secular change or secular variation [1, 2]. The magnetic field is weakest at the magnetic equator, or the plane perpendicular to the magnetic dipole. The geomagnetic coordinates compared with geographical coordinates are shown in Figure 2.3.

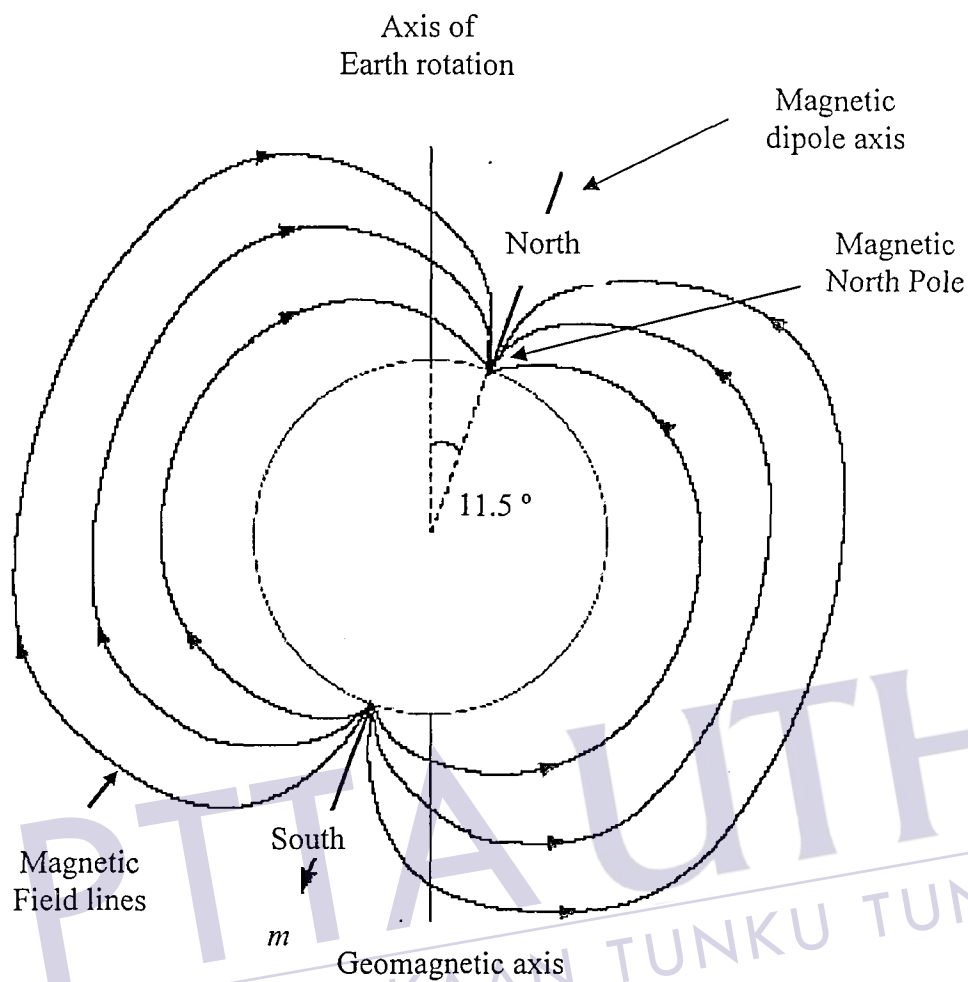


Figure 2.2: The magnetic field and its geographical axis

At various locations on the Earth's surface, a magnetic dipole model is not closely followed due to influences of the ferromagnetic materials at the Earth's crust. However, as the altitude increases, the contours of the field strength begin to become regular and resemble a dipole field. There is a low in magnetic intensity at about  $25^\circ$  S,  $45^\circ$  W GC ( $16^\circ$  S,  $25^\circ$  E GmC), called the Brazilian Anomaly, and a high at  $10^\circ$  N,  $100^\circ$  E GC ( $1^\circ$  N,  $172^\circ$  E GmC). These anomalies imply that the centre of the dipole is offset from the centre of the Earth.

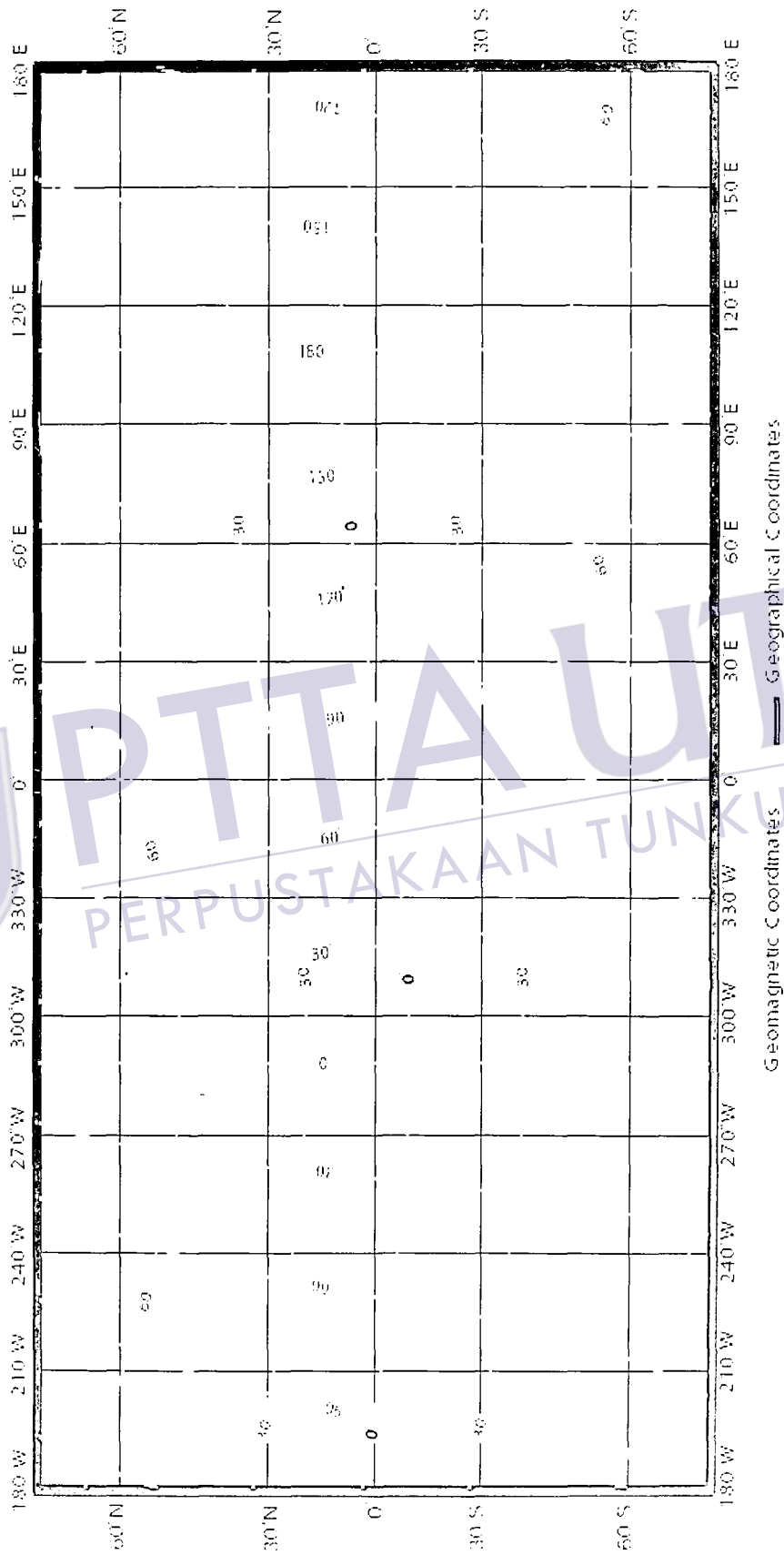


Figure 2.3: Geomagnetic coordinates in the year 1995, adapted from Campbell [2]



The intensity of the magnetic field measurements at any location on the Earth's surface consists of three central components, the main field, the external field and that due to magnetisable materials within the Earth's crust [25]. The main field, which accounts for over 97 percent of the Earth's total magnetic field strength, varies slowly with time [2]. The crustal field originates in the crust and provides information about the properties of the rock complexes. The external field is varying, which is related to the rotation and/or orbital movements of the Earth, the sun and the moon. The result is that the solar radiation that ionises the higher atmosphere and the ionised gas in the ionosphere moves in the magnetic field to the Earth that causes the external field to vary. This process creates electric currents which are seen as the daily variations in magnetic recordings [2, 26].

Campbell [2], Jacobs [25], Parkinson [26] and Merrill [1] have provided basic information on aspects of the geomagnetic field, including the strength, orientation and layout of the magnetosphere. At locations far from the Earth, the effect of the magnetosphere is more dominant than at the dipole. This effect is shown in Figure 2.4 [29]. The magnetosphere is created from the interaction of the solar plasma flow, or solar wind, and the geomagnetic field. The two areas have a great effect on each other, with the solar wind acting to compress the Earth's magnetic field, while particles of the solar wind are deflected and trapped by the geomagnetic field. This effect causes the structure of the geomagnetic field to be complex and consisting of a number of regions, the Shock Front, Magnetosheath, Magnetopause, Magnetotail, Neutral Sheet and Cusp Region.

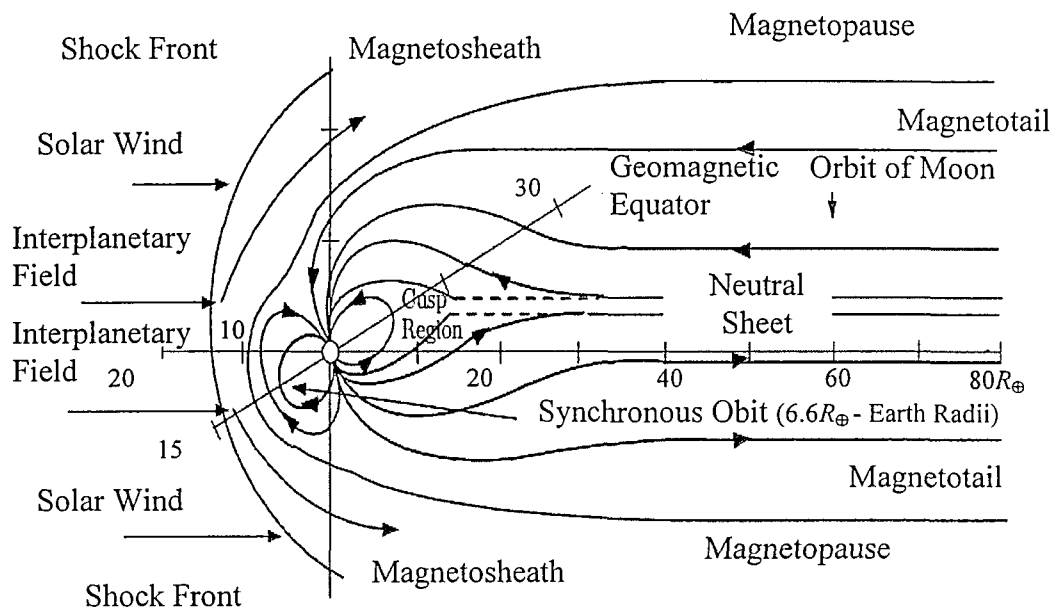


Figure 2.4: The magnetosphere, adapted from NASA SP-8017 (Ed.) [29]

### 2.1.3

#### Origin of the Geomagnetic Field

The origin of the geomagnetic field is a self-exciting dynamo that results from the interactions of the magnetic field with the flow of electric currents arising from fluid motion of the Earth's core. In the core, fluid motions across an existing magnetic field will produce their own magnetic fields and induced electric currents. Therefore, the motion of the fluid acts to reinforce and maintain the geomagnetic field by way of a self-exciting dynamo.

The energy source for the dynamo is thought to be either the radioactive decay of elements in the core, or gravitational energy released by sinking of heavy materials in the outer core. This energy forms the convection currents and drives the dynamo with magnetohydrodynamic actions. There are still objections to the dynamo

theory, although it has been generally accepted. The detail theories on the origin of the magnetic field are discussed by Rikitake [30] and Rikitake and Honkura [31].

## **2.2 Variations of the Earth's Magnetic Field**

The Earth's magnetic field is not constant over time [32, 33], as observed at the Earth's surface. It exhibits a remarkable spectrum with periods ranging from less than a second to tens of millions of years as in Figure 2.5. Various changes occur in the intensity and direction, including daily variations due to the influence of the sun. The intensity and direction return to their initial states after a while, and are known as temporal variations. The magnetic field also undergoes drifts over long periods of time, or secular variations, which can eventually result in a reversal of the field. These variations in the magnetic field are discussed by Jacobs, [25] Parkinson [26] and Campbell [2].

### **2.2.1 Temporal Variations**

Temporal variations are described as disturbances in the geomagnetic field which result from the changing positions of the Earth and sun. These variations usually only last for a short time, ranging from a few seconds to a few days. The occurrence of the temporal variations is based on the rotation rates of the Earth and the sun. Every 27 days, the sun's rotation causes an active solar area to face the Earth. The magnitude of the temporal variations increases during the periods from March-April and September-October when the Earth is near the equinoxes. The intensity of the variations is linked to the number of sunspots. This number varies over an 11-year cycle. In addition, different types of the temporal variations have different effects on the field intensity.

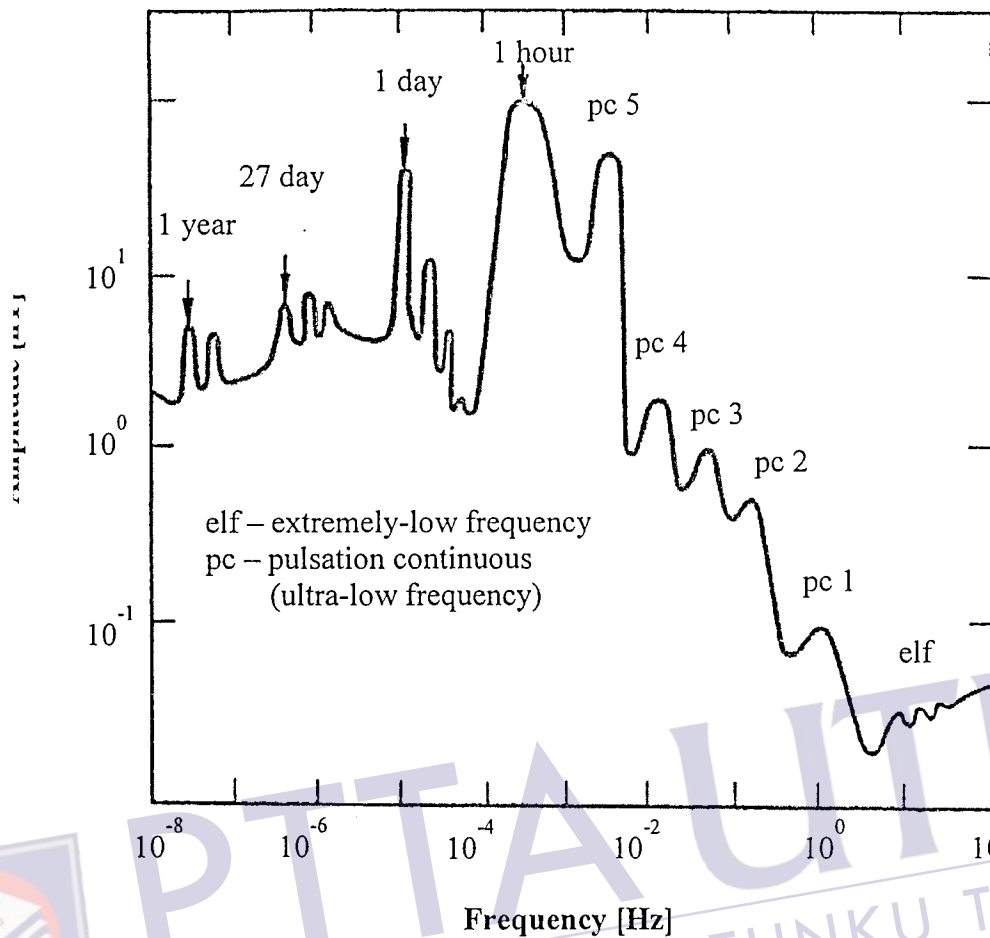


Figure 2.5: Amplitude of natural variations of the horizontal components  $H$ , adapted from Jankowski and Sucksdorff [14]

**Diurnal Variations** - Diurnal variations are one type of temporal variation shown in Figure 2.6. These variations occur in the day-to-night transition of the magnetic field intensity. The main causes of diurnal variations are changes in ionospheric currents resulting from systems of charged particles moving between 50 and 600 kilometres. These effects are not prevalent in the geomagnetic field more than a few Earth radii away from Earth's surface, since the intensity of the magnetic fields resulting from the current decreases with increasing distance.

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