VARIATION OF GEOMAGNETIC STORM AS OBSERVED DURING SOLAR CYCLE 24.

By

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Abstract

The sun activity governs the interaction of magnetosphere with solar wind and Earth magnetic field, this influence of magnetosphere is called Geomagnetic storm. The main point to study Geomagnetic storm is used to understand the current passing through the ionosphere. The Geomagnetic Storms occurred during the whole solar cycle 24 were analyzed using southward Interplanetary magnetic field (IMF(Bz)), Interplanetary electric field of the ring current (IEF), the solar wind velocity (SW) and the Dst index from OMNI data explorer. As the results reveal at the high solar activity CME driven geomagnetic storms are more prominent than CIR driven Geomagnetic Storms. On the Other hand, these solar activity starts declining solar maximum events derived from CIR-driven storms. Moreover that it is clear from the observations of geomagnetic storm events that the occurrence of Geomagnetic Storms is highly correlated with the southward turning of Bz, the z component of IMF. The magnitude of turning of Bz into southward direction from northward direction depends highly upon the severity of the storm.

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Chapter 1

INTRODUCTION

The Earth's atmosphere is the mixture of different gases and small particles, and defined as the region from sea level to about 1000 km altitude around the Earth. Where neutral gases can be detected, although traces of atmosphere gases have been detected far in to space. Observations show that 99 percent of the mass of atmosphere lies below 30 km altitude. Above 80 km altitude the atmosphere contains ionized and free electrons.

The Earth's atmosphere can be in to several layers based on different characteristic such as temperature, ionization and their propagation. These are troposphere (sea level to 10 km), stratosphere (10 km to 50 km), mesosphere (50 km to 80 km), thermosphere (80 km to 400 km) and exosphere (400 km to 1000 km). The region of the Earth's upper atmosphere is called ionosphere, from about 60 km (37 mi) to 1000 km (620 mi) altitude [1]. The ionosphere includes mesosphere, thermosphere and exosphere. It is ionized by solar radiation and plays an important role in the electrifying the atmosphere and forming the inner edge of the magnetosphere, and also influencing the radio propagation to distinct region on Earth. The layers of ionosphere can be classified in to D-region (60 km to 90 km), E-region (90 km to 150 km) and F-region (150 km to 600 km), during day time F-region splits in to F1 and F2 [8].

It is well known that the magnetosphere-ionosphere system and their interaction is strongly governed by the activity of the Sun. The region is directly influenced by solar wind parameters and by the strength and direction of interplanetary magnetic field (IMF). These influence of the ionosphere can be existence due to X-ray and ultraviolet radiation emitted by the sun, is principally determined by the level of both solar activity and geomagnetic perturbations. It is reported that Equatorial Ionization Anomaly (EIA) can undergo enhancement due to the magnetospheric disturbance electric fields which penetrate to low latitudes during the growth phase of a storm(substorm), whereas EIA inhibition occurs more often under a disturbance dynamo (DD) electric field [7].

The response of the ionosphere to magnetic storms is important for understanding the energy coupling process between the Sun and the Earth, and for forecasting space weather changes. Intensive magnetospheric and ionospheric currents during geomagnetic storms disturb the quiet ionosphere and cause the observed shortterm variations of the ionospheric characteristics. The ionospheric wind dynamo is considered as an important and the main mechanism in generating the electric currents and fields. The disturbed ionospheric wind dynamo can be the generator of the equatorial ionospheric electric currents during Geomagnetic Storms in the after math of strong auroral heating. The magnetospheric Electric field directly penetrating into the lowlatitude ionosphere can be another source of electric field. During disturbed space weather conditions magnetospheric electric fields disturb the auroral ionosphere forming auroral electrojets and by the highlatitude electric field and thermosphere disturbances can penetrate to the equatorial ionosphere. That is the reason the equatorial ionospheric electric field variations, like geomagnetic variations they are complex in nature and caused by superposition of different disturbing agents. The critical frequency (foF2) at low latitudes were very different in periods when the Bz component turns to north (the quiet day conditions) and when Bz component turns on south (the main phase of magnetic storms). It is also evident that the solar wind controls not only the auroral ionosphere but also the equatorial ionosphere [2, 10].

Geomagnetic storm is a temporary disturbance of the Earth's magnetosphere caused by a solar wind shock wave and cloud of magnetic field that interacts with the Earth's magnetic field. The increase in the solar wind pressure initially compresses the magnetosphere. But when the solar wind's magnetic field interacts with the Earth's magnetic field, transfers an increased energy in to magnetosphere.

The occurrence of geomagnetic storm can be verified using different indicators such as Dst index, AE index, KP index and k index. The Dst index estimates the globally average change of the horizontal component of the Earth's magnetic field at the equator based on measurement from a few magneto-meter stations or it is the measure of the magnetic field variation due to equatorial ring currents. The Auroral Electrojet (AE)index is designed to provide a global, quantitative measure of auroral zone magnetic activity produced by enhanced ionospheric currents flowing below and within the aurora. The kp index is an indicator of planetary scope derive from k-parameter. The k index is the quantitative assessment of magnetic disturbance and calculated with magnet grams[3, 8].

The equatorial Dst index computed from low-latitude geomagnetic data and traditionally used to study magnetic storms, shows that storms which develop either suddenly or gradually. The former category of storms start with a sharp increase of magnetic field, referred to as the storm sudden commencement (SSC or SC) which is observed throughout the magnetospheric cavity. The SC is not just a timing signal of the impending magnetic storm but a noteworthy large-scale geophysical phenomenon by itself. It arises because of the impact of shocks and discontinuities in solar wind on the day side magnetopause that leads to sudden magnetospheric compression and consequent enhancement of magnetopause currents, the net result being a sharp increase of ground level magnetic field all over the globe. It is established from experimental studies that the actual physical situation however is far from being benign, and the SC waveform exhibits temporal structure with a complex dependence on latitude and local time clearly indicating a role of not only distant currents but near-Earth ionospheric currents as well.

The effect of sudden magnetospheric compression is cleanly seen at low latitudes away from the influence of the intense auroral and equatorial electrojet currents. But even here, the sensitivity response to sudden increases in solar wind dynamic pressure is found to depend on local time and the orientation of the IMF [2, 13].

1.0.1 Why we study Geomagnetic storm?

It is important to understand the complicated current system in magnetosphere and ionosphere during the storm.

Because the solar wind has huge amount of charged particle, so those charged particle interact to Earth magnetic field affect life on the Earth.

To know the source of the storm and what facilities the storm?

Chapter 2

THE EARTH’S ATMOSPHERE AND IONOSPHERE

2.1 The Earth’s Atmosphere

The Earth’s atmosphere is the layer of gases, commonly known as ’air’ that surrounds the plant Earth and is retained by Earth’s gravity. The atmosphere protects life on Earth by absorbing ultraviolet solar radiation, warming the surface through heat retention green house effect and reducing temperature extremes between day and night (Michael C. Kelley (2009)). The dry air contains 78.09 of nitrogen, 20.95 of oxygen, 0.93 of argon, 0.039 of carbon dioxide and small amount of other gases [1, 9].

2.2 Layer of Earth’s Atmosphere

The region of the neutral Atmosphere are named according to various schemes. The most important classification was based on the temperature altitude profile which can be describe as follows.

Troposphere is the lowest major atmospheric layer, extending from the Earth’s surface up to 10 km. In troposphere all the Earth’s weather occurs, it contains 80 percent of total mass of atmosphere. It is characterized by decreases in a temperature with height.

According to free encyclopedia troposphere is the lowest portion of Earth's atmosphere and contains 75 percent of the atmosphere's mass and 99 percent of water vapor. The end of troposphere is tropopause [9, 11].

Stratosphere is the second major atmospheric layer above troposphere and extend up to 50 km. The stratosphere characterized by having no weather, increase in temperature with altitude and contains over 15 percent of the mass of the atmosphere, ozone layer also occur in this layer of atmosphere. The upper boundary of stratosphere is stratopause [11].

Mesosphere is the third major atmospheric layer and the middle layer of atmosphere and it extend 80-85 km. Mesosphere is characterized by decreasing temperature with increase altitude, this is due to decrease in solar heating and increase in cooling by carbon dioxide radiative emission. It's upper boundary is mesopause which is the coldest naturally occurring place on the Earth [5].

Thermosphere is the fourth major layer of the atmosphere and extends about 400-500 km from mesosphere. It is characterized by increasing temperature with altitude, with low air density and in this layer much of x-ray and Uv-radiation from the sun is absorbed and aurora (southern and northern light) occur as well as charged particles(electron, proton and ions)from the space collide with atoms and molecules in this layer. The upper boundary is called thermopause found at an altitude between 500-1000 km [5].

Exosphere is the upper most region of Earth's atmosphere as it gradually fades in to vacuum of space. The air on the exosphere is extremely thin and there is no clear upper boundary of the layer because its boundary depends on the solar activity [5]. Fig.(2.1) indicates the vertical structurer of Earth's Atmosphere with a temperature versus altitude relation. As the figure show in troposphere the temperature decrease as the altitude increase, but in stratosphere temperature increase when altitude increase again temperature decrease as the altitude increase in the mesosphere. Finally above mesosphere the temperature increase when altitude increase both in thermosphere and exosphere.

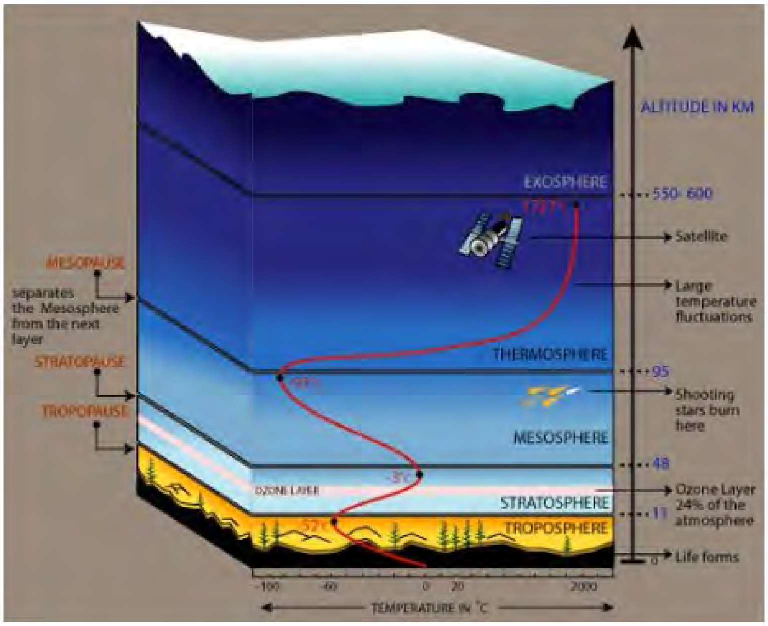

Figure 2.1: Layer of Earth's Atmosphere

2.3 The Earth's Ionosphere

The ionosphere is the part of the atmosphere that contains ionized gases, called plasma, and that affects radio propagation. It corresponds to altitudes from 50 to 500 miles at which the atmosphere is so thin that free electrons can exist. The ionization process originates from UV solar radiation and X-Ray wavelengths. These photons are energetic enough to dislodge electrons from gases atoms. Simultaneously, those free electrons can be captured by positive ions. This is called recombination. The ratio between ionization and recombination determines on overall electron density. It depends on gases density (at lower altitudes, the recombination process accelerates) and on the amount of radiation received from space (Sun mainly, but also GRBs). Thus, the ionosphere exhibits is a diurnal effect (day/night), a seasonal effect (summer/winter) and strong relationship with solar activity (11-years sunspot level and solar flares).

Due to the availability of different atoms and molecules with changing rates of absorption, the ionosphere at all latitudes has a tendency to stratify as group of regions. However, a series of distinct regions or layers of electron density occurred in the daytime ionosphere at mid- latitudes. These layers are denoted by the letters D, E,F(F1,F2). Each layer is generally characterized by a density maximum at a certain altitude and a density decrease with altitude on both side of the maximum [12].

D-Region is the inner most layers from 60 km (37 mi) to 90 km (56 mi) above the surface of the Earth. Ionization here is due to layman series alpha hydrogen radiation at a wavelength of 121.5 nm ionizing nitric oxide (NO). In addition high solar activity can generate hard x-ray(wavelength < 1nm) that ionize N_2 and O_2. Recombination is high in the D-region, net ionization is low and high frequency (HF) radio waves are significantly damped within the D-region by collision with electrons(about 10 collision every mill second). This is the main reason for the absorption of HF radio waves, Particularly at 10 MHz and below, on the other hand their is progressively smaller absorption at higher frequencies gets high. This effect peaks around noon and is reduced at night due to a decrease in the D-layer's thickness, only a small part remains due to cosmic rays. A common example of the D-layer inaction is the disappearance of distant AM broadcast band stations in the daytime [6, 12].

E-Region is the middle layer of ionosphere from 90 km (56 mi) to 150 km (93 mi) above the surface of the Earth. Ionization is due to the soft x-ray (1-10 nm) and far ultraviolet (UV) solar radiation of ionization of molecular oxygen normally at oblique incidence, and also this layer can only reflect radio waves having frequency lower than about 10 MHz, and may contribute only a little absorption on high frequency. However, during intense Sporadic E events, the Es layer can reflect frequencies up to 50 MHz and higher. The vertical structure of the E layer is primarily determined by the competing effects of ionization and recombination. At night the E layer weakens because the primary source of ionization is no longer available. After sunset, an increase in the height of the E layer maximum, increases the range to which radio waves can propagate by reflection from the layer [6, 12].

F-Region also known as the AppletonBarnett layer, extends from about 150 km to more than 500 km above the surface of Earth [6]. It is the densest layer of the ionosphere, which implies signals penetrating this layer will have a charge of escaping into space. At higher altitudes, the number density of oxygen ions decreases and lighter ions such as hydrogen and helium become dominant. It is the topside layer of ionosphere. There is an extreme ultraviolet (UV, 10-100 nm) solar radiation which ionizes the atomic oxygen. The F layer consists of one layer at night, but during the day there is F_1 and F_2 layers. The F_2 layer remains by day and night responsible for most sky wave propagation of radio waves, facilitating high frequency (HF, or shortwave) radio communications over long distances [6]. Fig.(2.2) show the layer of ionosphere from low to higher with different atom and molecule absorbtion, due to this the lower ionosphere is D-region, the next layer of the ionosphere is E-region and the Upper layer of ionosphere is called the F-region.

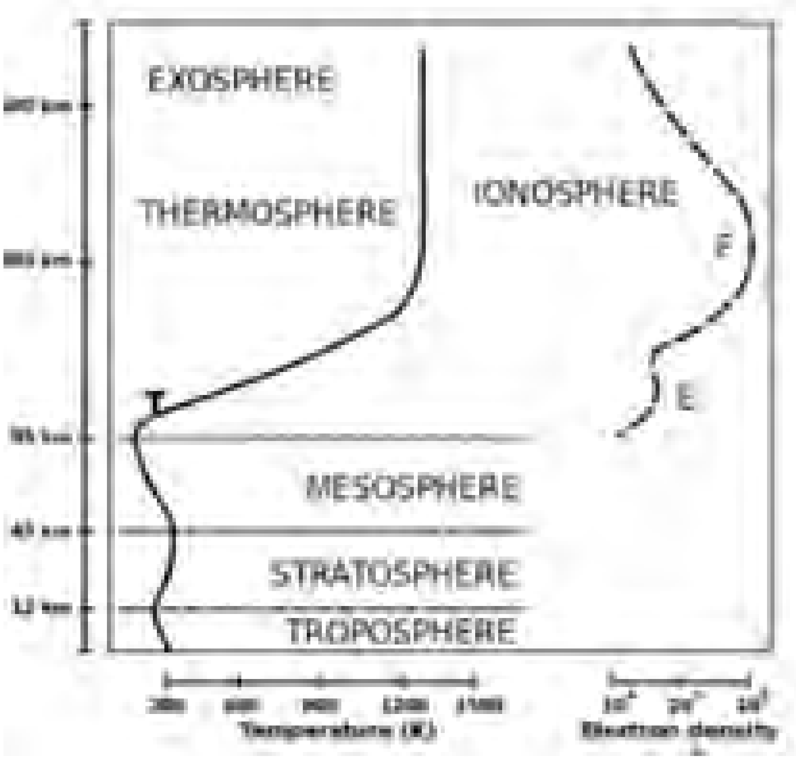

Figure 2.2: Layer of ionosphere from lower to higher height

Fig.(2.3) show the relation of the ionosphere and atmosphere, which indicates some

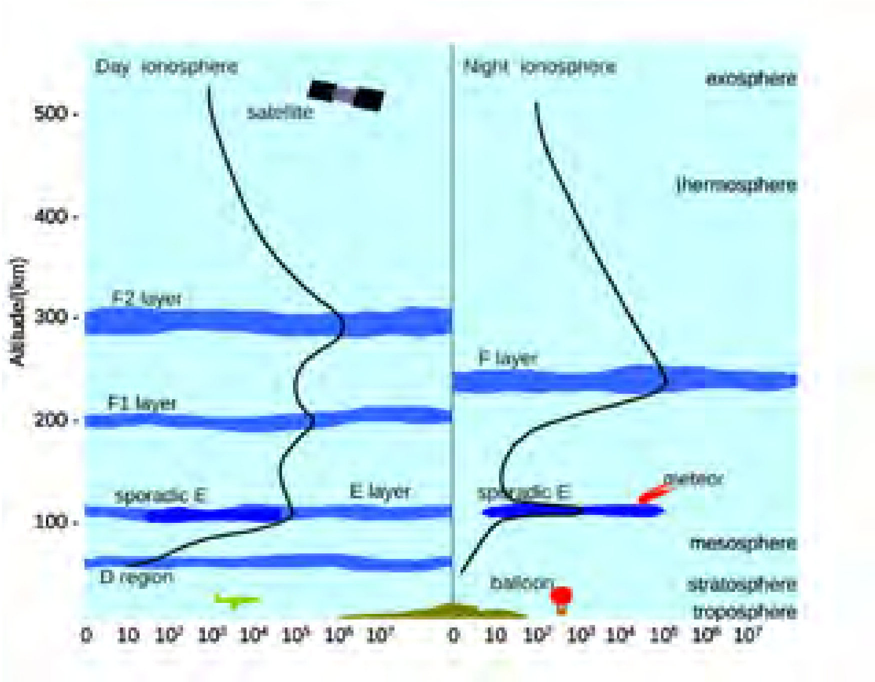

Figure 2.3: Relation between layer of Earth's Atmosphere and Ionosphere

layer of the atmosphere can also consider as the layer of the ionosphere such as mesosphere, thermosphere and exosphere.

2.4 Ionospheric model

Is a mathematical description of the ionosphere as a function of location, altitude, day of the year, phase of the sunspot cycle and geomagnetic activity. Geophysically, the state of the ionospheric plasma may be described by four parameters. Electron density, electron, ion and temperature. Since several species of ions are present, ionic composition and radio propagation depends uniquely on electron density. Models are usually expressed as computer programs, the model based on basic physics of interactions of the ions and electron with the neutral atmosphere and sunlight or it may be a statistical description based on a large number of observations. One of the most widely used model is the so called international reference ionospheric (IRI) [12]. This is based on data and specifics the four parameters just mention in the above. The IRI is an international project sponsored by the committee on space research (COSPAR) and international union of radio science(URSI) [12].

Chapter 3

EARTH'S MAGNETIC FIELD

Earth's magnetic field, also known as the geomagnetic field, is the magnetic field that extends from the Earth's interior out into space, where it meets the solar wind, a stream of charged particles emanating from the Sun. Its magnitude at the Earth's surface ranges from 25 to 65 micro-tesla (0.25 to 0.65 gauss). Roughly speaking it is the field of a magnetic dipole currently tilted at an angle of about 10 degrees with respect to Earth's rotational axis, if there were a bar magnet placed at that angle at the center of the Earth [15]. The North geomagnetic pole, located near Greenland in the northern hemisphere, is actually the south pole of the Earth's magnetic field, and the South geomagnetic pole is the north pole. Unlike a bar magnet, Earth's magnetic field changes over time because it is generated by a Geodynamo (in Earth's case, the motion of molten iron alloys in its outer core) [15]. While the North and South magnetic poles are usually located near the geographic poles, they can wander widely over geological time scales, but sufficiently slowly for ordinary compasses to remain useful for navigation. However, at irregular intervals averaging several hundred (thousand) years, the Earth's field reverses and the North and South Magnetic Poles relatively abruptly switch places. These reversals of the geomagnetic poles leave a record in rocks that are of value to paleomagnetists in calculating geomagnetic fields in the past. Such information in turn is helpful in studying the motions of continents and ocean floors in the process of plate tectonics.[8, 15]

3.0.1 Importance of Earth's Magnetic Field

The study of Earth's magnetic field has long history because of its important for navigation. The geomagnetic field and its variation over time are our most direct way to study the dynamic of the core. The Earth magnetic field was first exploited by Chinese, it was not until 1600 AD that Gilbert postulated that the Earth was in fact a Gigantic magnet [14]. The Earth's magnetic field serves to deflect most of the solar wind, whose charged particles would otherwise strip away the ozone layer that protects the Earth from harmful ultraviolet radiation. One stripping mechanism is for gas to be caught in bubbles of magnetic field, which are ripped off by solar winds.[14] The study of past magnetic field of the Earth is known as palaeomagnetism. The polarity of the Earth's magnetic field is recorded in igneous rocks, and reversals of the field are thus detectable as "stripes" centered on mid-ocean ridges where the sea floor is spreading, while the stability of the geomagnetic poles between reversals has allowed paleomagnetists to track the past motion of continents. Reversals also provide the basis for magnetocardiography, a way of dating rocks and sediments. The field also magnetizes the crust, and magnetic anomalies can be used to search for deposits of metal ores [15]. Humans have used compasses for direction finding since the 11^{th} century A.D and for navigation since the 12^{th} century. Although the magnetic declination does shift with time, this wandering is slow enough that a simple compass remains useful for navigation. Using magnetoception various other organisms, ranging from some types of bacteria to pigeons, use the Earth's magnetic field for orientation and navigation [18].

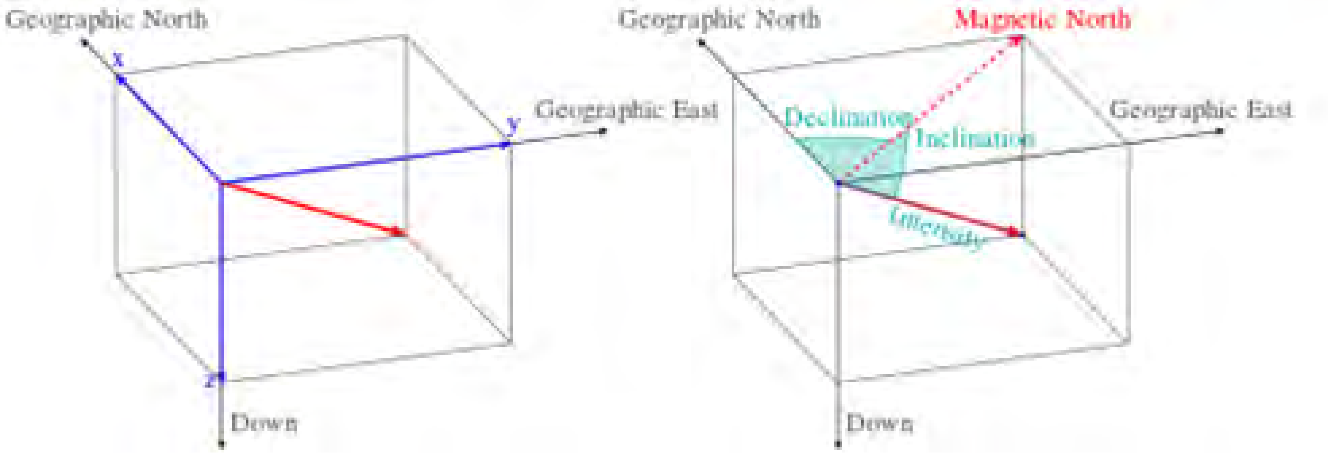

Figure 3.1: Common coordinate systems used for representing the Earth's magnetic field.

Fig.(3.1) show the Earth magnetic field and it is characteristics,how it related and form with the true north direction as observed in the graph.

Main characteristics

Description at any location, the Earth's magnetic field can be represented by a three-dimensional vector. A typical procedure for measuring its direction is to use a compass to determine the direction of magnetic North. Its angle relative to true North is the declination (D) or variation. Facing magnetic North, the angle the field makes with the horizontal is the inclination (I) or magnetic dip. The intensity (F) of the field is proportional to the force it exerts on a magnet. Another common representation is in X (North), Y (East) and Z (Down) coordinates.

Intensity, the intensity of the field is often measured in gauss (G), but is generally reported in nT, with 1 G = 100,000 nT. A nanotesla is also referred to as a gamma, tesla is the SI unit of the Magnetic field (B). The Earth's field ranges between approximately 25,000 and 65,000 nT (0.25-0.65 G). By comparison, a strong refrigerator magnet has a field of about 10,000,000 nT (100 G). A map of intensity contours is called an isodynamic chart. As the World Magnetic Model shows, the intensity tends to decrease from the poles to the equator. A minimum intensity occurs in the South Atlantic Anomaly over South America while there are maxima over Northern Canada, Siberia, and the coast of Antarctica south of Australia [17].

Inclination (Magnetic dip), the inclination is given by an angle that can assume values between -90 (up) to 90(down). In the northern hemisphere, the field points downwards. It is straight down at the North Magnetic Pole and rotates upwards as the latitude decreases until it is horizontal (0) at the magnetic equator. It continues to rotate upwards until it is straight up at the South Magnetic Pole. Inclination can be measured with a dip circle.

Magnetic declination, declination is positive for an eastward deviation of the field relative to true north. It can be estimated by comparing the magnetic north/south heading on a compass with the direction of a celestial pole. Maps typically include information on the declination as an angle or a small diagram showing the relationship between magnetic north and true north. Information on declination for a region can be represented by a chart with isogonic lines (contour lines with each line representing a fixed declination) [15].

3.0.2 The Difference and Similarity between Earth Magnetic Field and Gravity field

Similarity:

Both are potential field, Both field dominated by a simple geometry, but the higher degree components are required to get a complete picture of the field. For Gravity the major components of the field is that of the point of mass in the center of the Earth, but in Geomagnetism the field is dominated by that of an axial dipole in the center of Earth and aligned along the rotational axis.

Difference:

In Gravity the attracting mass 'M' is positive, no negative mass but for magnetism there are positive and negative poles [12].

3.1 The Earth's magnetic field and Solar wind

Earth is largely protected from the solar wind, a stream of energetic charged particles emanating from the Sun, by its magnetic field, which deflects most of the charged particles. Some of the charged particles from the solar wind are trapped in the Van Allen radiation belt. A smaller number of particles from the solar wind manage to travel, as though on an electromagnetic energy transmission line, to the Earth's upper atmosphere and ionosphere in the auroral zones. The only time the solar wind is observable on the Earth is when it is strong enough to produce phenomena such as the aurora and geomagnetic storms. Bright auroras strongly heat the ionosphere, causing its plasma to expand into the magnetosphere, increasing the size of the plasma geosphere, and causing escape of atmospheric matter into the solar wind. Geomagnetic storms result when the pressure of plasmas contained inside the magnetosphere is sufficiently large to inflate and thereby distort the geomagnetic field [3]. The solar wind is responsible for the overall shape of Earth's magnetosphere, and fluctuations in its speed, density, direction and entrained magnetic field strongly affect Earth's local space environment. For example, the levels of ionizing radiation and radio interference can vary by factors of hundreds to thousands. The shape and location of the magnetopause and bow shock wave upstream of it can change by several Earth radii, exposing geosynchronous satellites to the direct solar wind. These phenomena are collectively called space weather. The mechanism of atmospheric stripping is caused by gas being caught in bubbles of magnetic field, which are ripped off by solar winds Variations in the magnetic field strength have been correlated to rainfall variation within the tropics [19].

3.2 The Earth's Magnetic Field and Coronal Mass Ejection

A coronal mass ejection (CME) is an unusually large release of plasma from the solar corona. They often follow solar flares and are normally present during a solar prominence eruption. The plasma is released into the solar wind and can be observed in coronagraph imagery. Coronal mass ejections are often associated with other forms of solar activity, but a broadly accepted theoretical understanding of these relationships has not been established. CMEs most often originate from active regions on the Sun's surface, such as groupings of sunspots associated with frequent flares. Coronal mass ejections release huge quantities of matter and electromagnetic radiation into space above the Sun's surface, either near the corona (sometimes called a solar prominence), or farther into the planetary system, or beyond (interplanetary CME). The ejected material is a plasma consisting primarily of electrons and protons. While solar flares are very fast, CMEs are relatively slow. The CME are associated with enormous changes and disturbances in the coronal magnetic field. They are usually observed with a white-light coronagraph [21].

3.2.1 The impact of coronal mass ejection on Earth

When the ejection is directed towards Earth and reaches as an interplanetary coronal mass ejection (ICME), the shock wave of the traveling mass of solar energetic particles causes a Geomagnetic storm that may disrupt Earth's magnetosphere, compressing it on the day side and extending the night-side magnetic tail. When the magnetosphere reconnects on the night side, it releases power on the order of tera watt scale, which is directed back toward Earth's upper atmosphere [28]. Solar energetic particles can cause particularly strong aurora in large regions around Earth's magnetic poles. These are also known as the Northern Lights (aurora borealis) in the northern hemisphere and the Southern Lights (aurora Australias) in the southern hemisphere. Coronal mass ejections, along with solar flares of other origin, can disrupt radio transmissions and cause damage to satellites and electrical transmission line facilities, resulting in potentially massive and long-lasting power outages. Energetic protons released by a CME can cause an increase in the number of free electrons in the ionosphere, especially in the high-latitude polar regions. The increase in free electrons can enhance radio wave absorption, especially within the D-region of the ionosphere, leading to Polar Cap Absorption (PCA) events. Humans at high altitudes, as in airplanes or space stations, risk exposure to relatively intense cosmic rays. The energy absorbed by astronauts is not reduced by a typical spacecraft shield design and, if any protection is provided, it would result from changes in the microscopic inhomogeneity of the energy absorption events [29].

3.3 The Earth's Magnetic Field and Co-rotating Interaction Region

Co-rotating interaction region (CIR) occurred when the fast solar wind streams emanate from coronal holes interact with the slow solar wind streams i.e the intense magnetic field can be produced at the interface between the fast and slow streams in the solar wind. Then as the CIR interacts with the Earth magnetic field it produce Geomagnetic storm [15]. Co-rotating interaction regions are not always bounded by shocks. The reason is that shock formation occurs due to the nonlinear steepening of waves, thereby requiring several nonlinear steepening times to elapse before a shock is formed. Since most CIRs do not have shocks at 1 AU but have steepened into shocks by 2 AU, empirically the nonlinear steepening time must be of order 4 days. The reason why two shocks are eventually formed at a CIR is due to symmetry about the pressure enhancement caused by compression and entraining of the slow wind ahead of the fast stream [16].

Chapter 4

GEOMAGNETIC STORM

A Geomagnetic storm is a temporary disturbance of the Earth's magnetosphere caused by a solar wind shock wave and cloud of the magnetic field that interacts with the Earth's magnetic field. The increase in the solar wind pressure initially compressed the magnetosphere. The solar wind's magnetic field interacts with the Earth's magnetic field and transfer increase energy to the magnetosphere [26]. Both interactions cause an increase in the plasma movement through the magnetosphere (driven by increased electric fields in the magnetosphere) and increase in the electric current in the magnetosphere and ionosphere. Several space weather phenomena tend to be associated with geometric storm or caused by geomagnetic storm. This include solar energetic particle (SEP) events, Geomagnetically induced current (GIC), ionospheric disturbance that cause radio and radar scintillation, disruption of navigation by magnetic compass and auroral displays at much lower latitude than normal [17]. Geomagnetic storm is also defined by change in the disturbance storm time index (Dst). The Dst index estimates the globally averaged change of the horizontal component of the earth's magnetic field at the magnetic equator based on measurements from a few magnetometery station. Dst is computed once per hour and reported in near real time, during quiet time the Dst is between -20 and +20 nT [7, 13].

4.1 Phase of Geomagnetic Storm

There are three phase of Geomagnetic storms, namely initial, main and recovery phase.

Initialphase is characterized by Dst (it is one minute component SYm-H) increasing by 20 to 50 nT in tens of minute. It is referred to as a storm sudden commencement (SSC). However, not all Geomagnetic storms have an initial phase and not all sudden increases in Dst or SYm-H are followed by Geomagnetic storm [17].

The main phase of Geomagnetic storm defined by Dst decreasing to less than(< -50 nT) to define a storm is somewhat arbitrary, the minimum value during a storm will be between -50 and approximately -600 nT. The duration of the main phase is typically 2-8 hours. During the main phase of Geomagnetic storm electric current in the magnetosphere creates a magnetic force that pushes out the magnetosphere and solar wind [17].

The recovery phase is defined by Dst-index, it changes from minimum value to the quite time value. The recovery phase may last as short as 8 hours or as long as 7 days [17].

4.2 Formation and Measurement of Geomagnetic Storm

Geomagnetic storms are triggered by an increase in the plasma density and the speed of the solar wind after a solar flare or an Earthwards-directed CME [20]. These increases raise the pressure of the solar wind in the magnetopause and deform the magnetosphere. On the daytime side, the magnetopause approaches our planet along the Sun-Earth line, moving in from 11 Earth radii to only 4-5. At the same time the region corresponding to the night-time hemisphere stretches out in a very complex manner, similar to a tube of toothpaste squeezed in the middle. This intensifies the Earth's magnetic field and increases its bow-wave pressure against the solar wind, reaching a new equilibrium position. All these phenomena give rise to the geomagnetic storm, which affects, to a lesser or greater extent, the whole planet. Depending on the speed of the disturbed solar wind, it will occur between one and four days after the violent event on the surface of the Sun. Not all CME produce magnetic storms on the Earth [20].

In General, the three conditions required for the existence of Geomagnetic storm are the following.

(1) the solar storm has to be energetic enough, reaching either class X or high values of class M.

(2) the CME has to be directed Earthwards, i.es the sunspot cluster or active region initiating the whole process must be on the visible side of the Sun away from its limbs.

(3) the Bz component of the IMF dragged by the solar wind must be negative so that the lines of this field can join up with those of the Earth (reconnection of the IMF with the terrestrial field). It has recently been shown that IMF fluctuations, before their encounter with the magnetopause, are an important factor, little understood as yet, in whether the solar wind disturbance will trigger a geomagnetic storm [18].

4.3 Types of Geomagnetic Storm

There are two main types of geomagnetic storms. These are Recurrent and Nonrecurrent storms.

Recurrent storms are caused by features on the Sun called coronal holes that live for several months and generate co-rotating interaction regions (disturbances in the solar wind where the fast solar wind from the coronal holes catches up with the slow solar wind) that repeat on the 27-day solar rotation period [21].

Nonrecurrent storms occur sporadically throughout the solar rotation but are primarily driven by CMEs. Co-rotating interaction regions are most commonly observed during the declining phase of the solar cycle (the few years after solar maximum) into solar minimum, whereas CMEs are seen most often during solar maximum [21].

4.4 Historical occurrence of Geomagnetic Storm

The first observation of the effects of Geomagnetic storm occur early in 19th century, from May 1806 until June 1807 in Germany (Alexander vone Humboldt) recorded the bearing of a magnetic compass in Berlin (Russell and Randy 2010) [20]. The second geomagnetic storm occurred on September 1 to 2, 1859. From August 28 until September 2, 1859, numerous sunspots and solar flares observed on the sun, with largest flare on September 1. It can be assumed that a massive CME was launched from the sun and reached to the Earth within 18 hours. That takes normally 3 to 4 days. The horizontal field was reduced by 1600 nT as recorded coolabah observatory and it is estimated to be approximately -1760 nT [2, 20]. The disruption of telegraph service and initiation of fires was observed, an aurora of November 17, 1882 and May 1921 and 1960, when widespread radio disruption was reported. The March 1989

Geomagnetic storm caused the collapse of the hydro-Quebec power grid in seconds as equipment protection relays tripped in a cascading sequence. Six million people were left without power for nine hours. The storm causing this event was the result of a coronal mass ejected from the sun(Extreme space weather events national Geophysics data center). The minimum of the Dst-index value was -589 nT. On July 14, 2000, an x5- class flare erupted known as the Bastille day event and coronal mass was launched directly at Earth. A typically super Geomagnetic storm occurred on July 15-17, the minimum of Dst index was -301 nT. Despite the storm's strength, no power distribution failures were reported. It can be observed the Bastille day event by voyager1 and voyager2. Generally during a Geomagnetic storm the ionosphere's F2 layer becomes unstable, fragment and may disappear. In the north and southern pole regions of the Earth, auroras are observable [20].

4.5 Effect's of Geomagnetic Storm

There are many effect of geomagnetic storm these include effects in radiation hazards to humans, disruption of electrical system, communications, navigation system, satellite hard ware damage, mains electrical grid, geologic exploration and pipe lines etc.

Radiation hazards to humans, this effect of geomagnetic storm exist when an intense solar flares release very high energy particles that have tendency to produce radiation which will poison to humans and other mammals, this effect general similar to low energy radiation from nuclear blast. The Earth's atmosphere and magnetosphere allow adequate protection at ground level but Astronauts are subjects to potentially lethal doses of radiation. The penetration of high energy particles into living cells can cause chromosome damage, cancer and other health problems. Extreme exposers are usually fatal. Solar protons with energies greater than 30 MeV are particularly hazardless. Solar proton events can also produce elevated radiation abroad air craft flying at high altitudes. Although these risks are small monitoring of solar proton events by satellite instrumentation allows the occasion are exposure to be monitored evaluated and eventually flight paths and altitudes adjusted in order to lower the absorbed dose of the flight [3, 26].

Disruption of Electrical system, it has been suggested that a geomagnetic storm on the scale of the solar storm of 1859 today would causes billions of dollars of damage to satellite, power grids and radio communications could cause electrical blackout on a massive scale that might not be repaired for weeks [27].

Communication, many communications system use the ionosphere to reflect radio signals over long distance. Ionospheric storms can affect radio communication at all latitudes. Some frequencies are absorbed and others are reflected, leading to rapidly fluctuating signals and unexpected propagation paths. TV and commercial radio stations are little affected by solar activity, but ground to air, ship to shore, short wave broadcast and amateur radio (mostly the bands below 30 MHz) are frequently disrupted. Radio operators using HF bands rely upon solar and geomagnetic alerts to keep their communication circuits up and running. Some military detection or early warning systems are affected by solar activity. The over horizon radar bounces signals off the ionosphere to monitor the launch of air craft and missiles from long distances. During geomagnetic storm, this system can be severally hammered by radio clutter. Some submarine detection systems use the magnetic signatures of submarines as one input to their locating schemes [24]. Geomagnetic storms can mask and distort these signals and also telegraph lines in the past were affected by the Geomagnetic storms. Telegraph used a single long wire for the data line, stretching for many miles, using the ground as the return wire and fed with DC power from a battery, this made them together with the power lines mentioned below susceptible to being influenced by the fluctuations caused by the Geomagnetic ring current, Voltage, current induced by the Geomagnetic storm could have diminished the signal, when subtracted from the battery polarity, or to overly strong and spurious signals when added to it. Geomagnetic storms affect also long-haul telephone lines, including undersea cables unless they are fiber optic. Damage to communications satellite can disrupt non-terrestrial telephone, television, radio and internet links. The national academy of sciences reported in 2008 on possible scenarios of wide spread disruption in the 2012-2013 solar peak [21, 24].

Navigation, Systems such as GPS (global postioning systems) , LoRAN (long range navigation) and the new defunct OMEGA are adversely affected when solar activity disrupts their signal propagation. The OMEGA system consists of eight transmitters located throughout the world. Airplanes and ship used the very low frequency signals from these transmitters to determine their positions. During solar events and geomagnetic storms, the system gave navigators information that was in accurate by as much as several miles. If navigators had been alerted that a proton event or geomagnetic storm was in progress, they could have switched a backup system. GPS signals are affected when solar activity causes sudden variations in the density of the ionosphere causing the GPS signals scintillate [26].

Satellite hard ware damage, the Geomagnetic storm and an increase in the solar ultraviolet emission heat Earth's upper atmosphere, causing it to expand. The heated air rises and the density at the orbit of the satellite up to about 1000 km (621 mi) increase significantly. This result increased drag, causing satellite to slow and change orbit slightly. Another problem for satellite operators is differential charging, during Geomagnetic storms the number and energy of the electron and ions increases. When a satellite travels through this energized environment the charged particles striking the spacecraft differentially charge portions of the spacecraft. Discharges can across space craft components, harming and possibly disabling them. Buck changing also called deep charging occurs when energetic particles, primarily electrons penetrate the outer covering of a satellite and deposit their charge in its internal parts. If sufficient charge accumulates in any one component it may attempt to neutralize by discharging to other component. This discharge is potentially hazardous to the satellite and satellite's electronic system [2, 28].

Mains Electrical grid, when magnetic fields move about in the vicinity of a conductor such as a wire, a Geomagnetically induced current is produced in the conductor. This happens on a grand scale during geomagnetic storms (the same mechanism also influenced telephone and telegraph lines before fiber optic) on all long transmission lines. Long transmission lines (many kilometers in length) are thus subject to damage by the effect of Geomagnetic storm. The currents induced in their lines from geomagnetic storms are harmful to electrical transmission equipment, especially transformers, inducing core saturation, constraining their performance and causing coils and corsets heat up [25, 28].

Geologic Exploration, Earth's magnetic field is used by a geologist to determine subterranean rock structures. For the most part, there geodetic surveyors are searching for oil, gas or mineral deposits. They can accomplish this only when Earth's field is quite, so that true magnetic signatures can be detected. Other geophysicist prefer to work during geomagnetic storms. When strong variations in the Earth's normal surface electric currents allow them to senor sub surface oil or mineral structures. This technique is called magnetellurics. For these reasons, many surveyors use geomagnetic alerts and predications to schedule their mapping activities.

pipe lines, rapidly fluctuating Geomagnetic fields can produce Geomagnetically induced currents (GIC) in pipelines. This can cause multiple problems for pipelines engineers. Pipelines flow meters can transmit erroneous flow information and the corrosion rate of the pipeline is dramatically increased. If engineers incorrectly attempt to balance the current during a Geomagnetic storm, corrosion rates may increases even pipelines managers thus receive space wheatear alerts and wrappings to allow them to implement defensive measures [26]. Fig.(4.1) show the effect of Geomagnetic

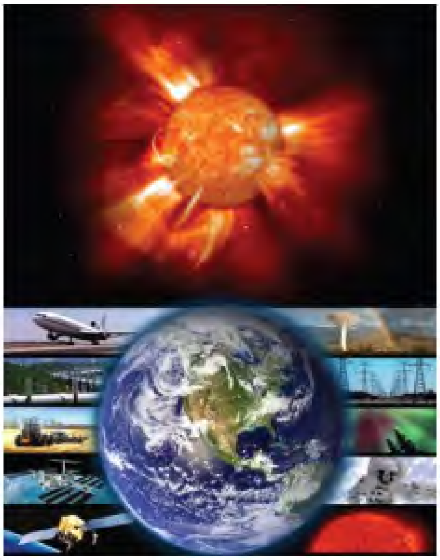

Figure 4.1: Effect of Geomagnetic storm

storm are not limited to one country which affect's all over the world with out discrimination. But the amount of the effect vary from place to place depending on the awareness and development of the country. And also as graph indicates all activity are influenced. From Fig.(4.2) observed that the charged particle comes in to the Earth and affect the humans village.

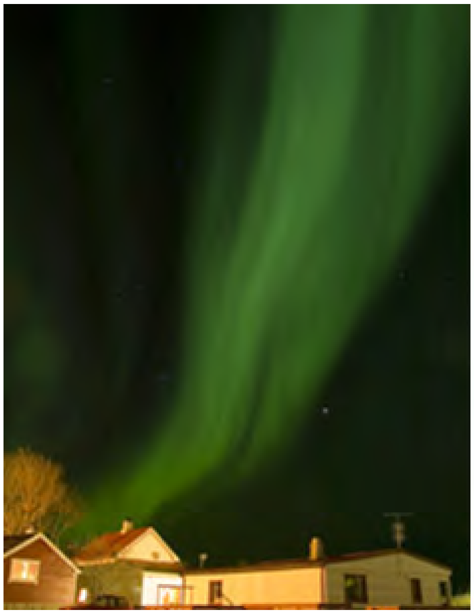

Figure 4.2: Effect of Geomagnetic storm

4.6 Risk assessment for the effect of Geomagnetic storm

There are many way of risk assessment for the effect of geomagnetic storm, these are using Emergency supplies, preparing for power surges and un plug electronic devices. Emergency supplies is used to protect the effect of geomagnetic storm by creating an emergency for all such as flash light, batteries, cooking and heating fuel food as well as clean water. Also consider aback up stash with paper copies of finance and personal records, cash, road maps address book, radio, first aid kit and any thing else you need if your handy digital gizmos along with you car, credit cards, bank and shopping center are out of commission for awhile [23].

Preparing for power surges can be either whole house surge protector or individual surge protector. Whole house surge protector is connected to your breaker panel and provides protection from lighting and other power surges, where as individual surge protector is used in the absence of whole house surge protector install surge protector on computer, Tvs, stereos and other electronics [23].

Chapter 5

DATA AND METHODOLOGIES

The data used in this thesis to study Variation of Geomagnetic storm during solar cycle 24 is obtained from OMNI data explorer. These data contain the interplanetary magnetic field (IMF (Bz)), Dst-index, the solar wind (plasma) speed and interplanetary electric field (IEF (Ey)) which is also accessible using the link http://omniweb.gsfc.gov/form/dx1.html. To be used the OMNI data explorer first assign the Geomagnetic storm by using Dst-index value. The Geomagnetic storm are classified in to three, based on the Dst-index value these are weak Dst-index value -30 nT > Dst > -50 nT,moderate storm Dst-index value -50 nT > Dst > -100 nT and an intense storm Dst-index value < -100 nT, in addition to this if it's Dst-index value < -200 nT is called an extreme storm and Dst-index value < -500 nT is called super-storm [8]. The data for Dst-index value could be down load from , Geomagnetic Equatorial Dst-index home page(htt://wdc.kugi.kyoto-u.ac.jp/dstdir). The Dst-index value quite day is between -20 nT and 20 nT. The interplanetary magnetic field(IMF)value can be determine by Bt-value and the Bt-value of IMF indicates the total strength of IMF i.e, the higher the value is the better condition for enhanced Geomagnetic storm. The IMF is a vector and has three axis component Bx, By and Bz. But the two component (Bx and By) are parallel to the elliptic due to this it has no an auroral activity effects, where as the third (Bz) is perpendicular to the elliptic and is created by the wave and disturbance on solar wind cause for Geomagnetic storm. Because the IMF(Bz) has Geomagnetic storm when it turns either north ward or south ward direction. When the IMF(Bz) towards south ward direction and interact to the north ward direction of the Earth's magnetic field i.e it attracts to each other and causes for the disturbance Geomagnetic storm, this disturbance occurred when the charged particle get easier time to enter the magnetosphere. Fig.(5.1) shows how

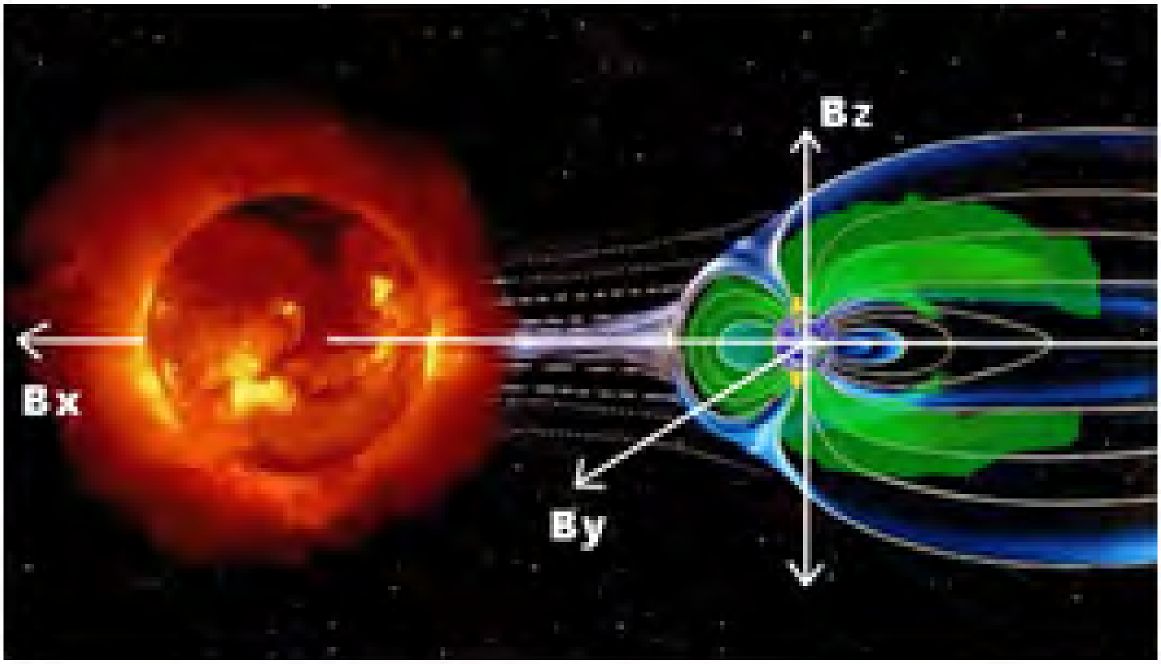

Figure 5.1: Interaction with Earth's magnetosphere

the interplanetary magnetic field pointed in to x, y and z axis, which means that the

Bz are perpendicular to the elliptic and the other (Bx, By) are parallel to the elliptic.

Chapter 6

RESULT AND DISCUSSION

6.1 INTRODUCTION

Geomagnetic storms of solar cycle 24 are analyzed in this study. Among all the storm events occurred during the solar cycle only those storms whose Dst value are less than($<$ -100nT) are considered which represented an intense Geomagnetic storms.

6.1.1 The Geomagnetic Storm of November 6-10 2004

Figs. (6.1) shows plots of interplanetary magnetic field (IMF (Bz)) top panel, solar wind speed (SWS) (upper middle panel), interplanetary electric field(IEF) (lower middle panel) and disturbance storm time (Dst) index (bottom panel) for five Consecutive days from day 6^{th} to 10^{th} November, 2004.

As shown in Fig. (6.1), days 6 and 7 are quiet days. However, on day 8^{th} 2004 at around 1:00 UT the Dst shows a small sudden increase in the Dst value followed a fast decrease up to -342 nT at 5 UT and the storm type was an intense storm. Then started recovering and took about 30 hours to reach its normal Dst value. The IEF of the ring current at time of sudden commencement decreases but during the main storm it starts increasing nearly to 45 V/m at 5:00 UT. This increment is responsible

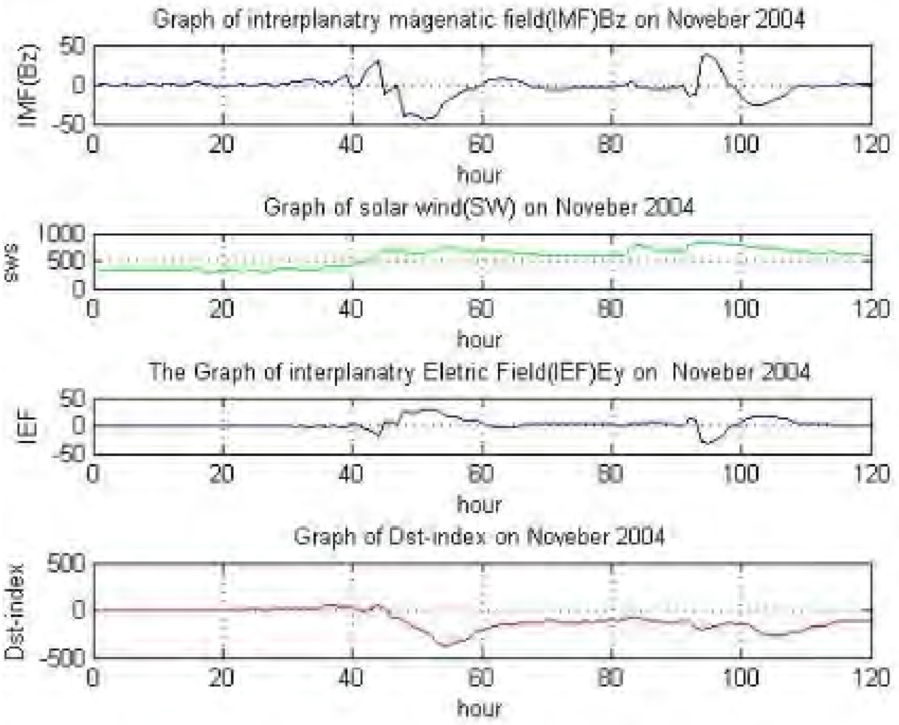

Figure 6.1: The Geomagnetic storm of November 6-10 2004

for the intensifying the ring current in the magnetosphere which in turn weakens the strength of the Earth magnetic field. As we know there are two sources of geomagnetic storm sources, the characteristics of Geomagnetic Storm of 2004 is similar to a storm caused by CME driven storm because the storm is characterized by sudden commencement followed by a shard decrease of main storm and a gentle recovery phase.

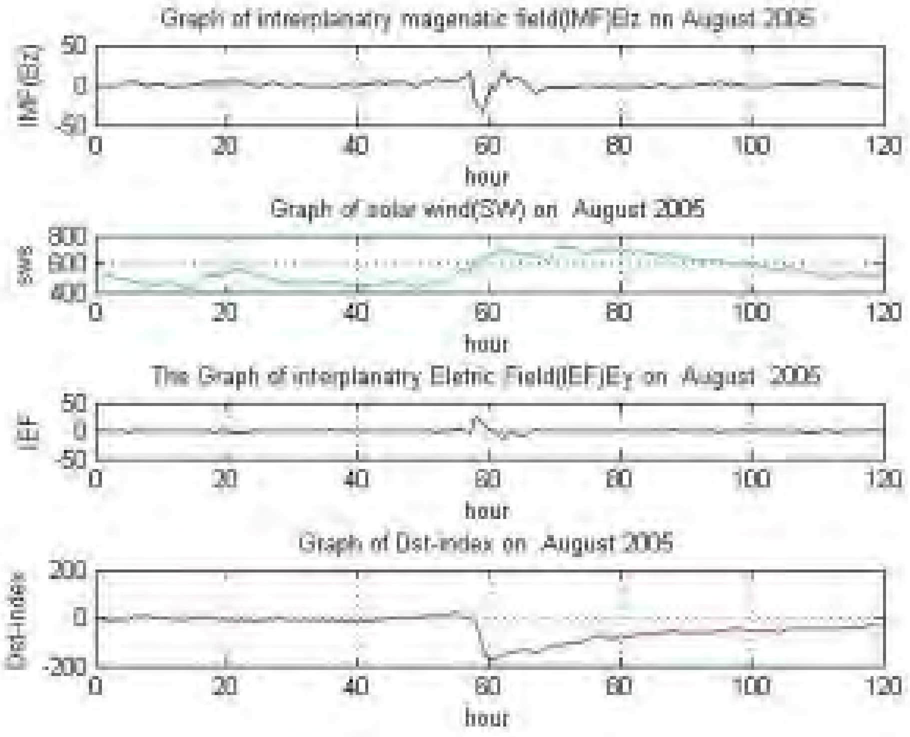

Figure 6.2: The Geomagnetic storm of August 22-26, 2005

6.1.2 The Geomagnetic Storm of August 22-26 2005

The effect of Geomagnetic storm on August 24^{th} 2005 is shown in Fig. (6.2) by plotting, the interplanetary magnetic field (IMF (Bz)) top panel, solar wind speed (SWS) upper middle panel, IEF lower middle panel and disturbance storm time (Dst) index bottom panel plotted from August 22-26 for five consecutive day. The initial phase of the storm day started from August 22 and 23 and as the graph indicates it is quite day. The storm during this period is formed as an intense storm.

The main phase of the storm day started on August 24^{th} with Dst value of -184 nT and which is also an intense storm and the recovery stared on August 25^{th} and 26^{th}

with Dst value -163 nT at 13:00 UT and -160 nT at 14:00 UT respectively. The source of the storm is CME driven geomagnetic storm since all the indicators such as the interplanetary magnetic field (IMF (Bz)) is directed southward implies reconnection with the magnetic field of the magnetic field is occurred as a result of magnetic field is reduced at the main phase, so that voltage is induced the change in magnetic field in the magnetosphere induces current to oppose the change in flux in the magnetosphere. This induced current as observed in Fig. (6.2) intensified the ring current. The IEF is positive means it reduces the magnetic field of the earth.

Also as the graph indicates, more negative value of Dst-index means with an intense geomagnetic storm events. The cause of this Geomagnetic storm event was the CME due to high solar activity. The graph of Dst-index has the same direction to IMF (Bz) but the solar wind speed positively increased. The graph told no turn of fluctuated, meaning the Geomagnetic storm event was observed in large amount and the storm event was measured. The solar wind speed was greater than($>$ 600km/hr) and the Dst-index value less than($<$ -100nT) which indicate the presence of favorable condition for good opportunity for high geomagnetic storm.

6.1.3 The Geomagnetic Storm of December 13-17 2006

Fig.(6.3) represents plots of interplanetary magnetic field IMF (Bz) top panel, solar wind speed (SWS) upper middle panel, interplanetary electric field (IEF) lower middle panel and disturbance storm time (Dst) index bottom panel for five Consecutive days from day 13^{th} to 17^{th} 2006. On day 14 around 16:00 UT minor(weak) storm about -40 nT was observed and followed by another intense storm reaching -162 nT on day 15 at 8:00 UT. This storm took about 70 hrs time to reach its normal Dst value. At the main phase time the IMF (Bz) is south ward lading intensifying the ring current

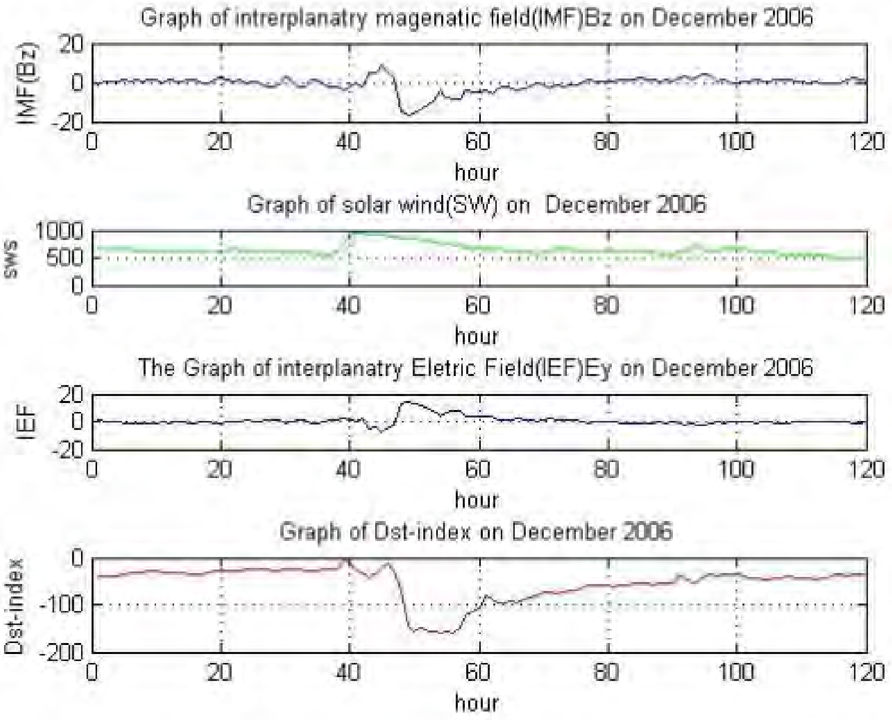

Figure 6.3: The Geomagnetic storm of December 13-17 2006

and IEF is in the north ward. The solar wind shows positive value reviling solar wind is heading towards the Earth. But on day 16 and 17 the recovery storm observed and show a quite day storm, has no negative effect. As observed from the graph, no turn fluctuated on the graph and it could be measured and the source of the storm was the CME due to high solar activity.

6.1.4 The Geomagnetic Storm of March 22-26 2007

The effect of Geomagnetic storm on March 24^{th} 2007 expressed when, the interplanetary magnetic field (IMF) top panel, solar wind speed (SWS) upper middle panel, interplanetary electric field (IEF) lower middle Panel and disturbance storm time (Dst)

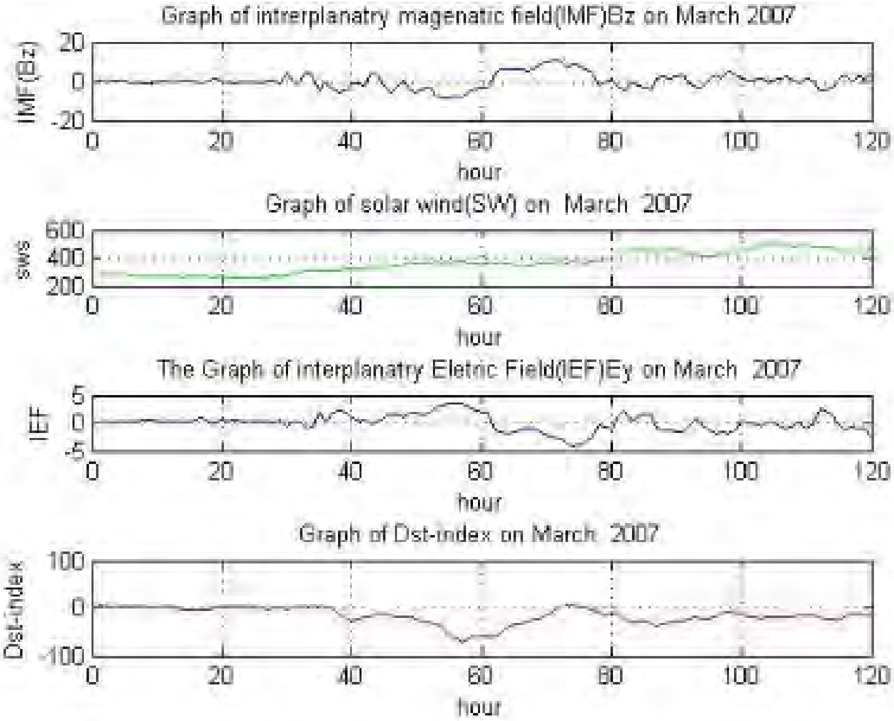

Figure 6.4: The Geomagnetic storm of March 22-26 2007

index bottom panel plotted for five Consecutive days started from March 22/2007 to March 26/2007. The initial phase of the storm day started from March 22 and 23 and their Dst-index value -57 nT at 07:00 UT and -66 nT at 08:00 UT respectively. Another storm was followed on March 24/2007 with maximum Dst -72 nT and the storm was a moderate storm whose source is CIR driven storm. As it is shown in Fig. (6.4), the IMF (Bz) is directed northward and the IEF of the ring current is negative revealing decreasing the magnitude of ring current. From our observation when the IMF (Bz) is southward and the IEF of the ring current is Positive which means the ring current in the magnetosphere is intensified. on the contrary when the

IMF (Bz) is North ward the ring current is negative which shows the induced current is reversed. And also as graph indicated it fluctuated due to this it is not measured.

6.1.5 The Geomagnetic Storm of March 7-11 2008

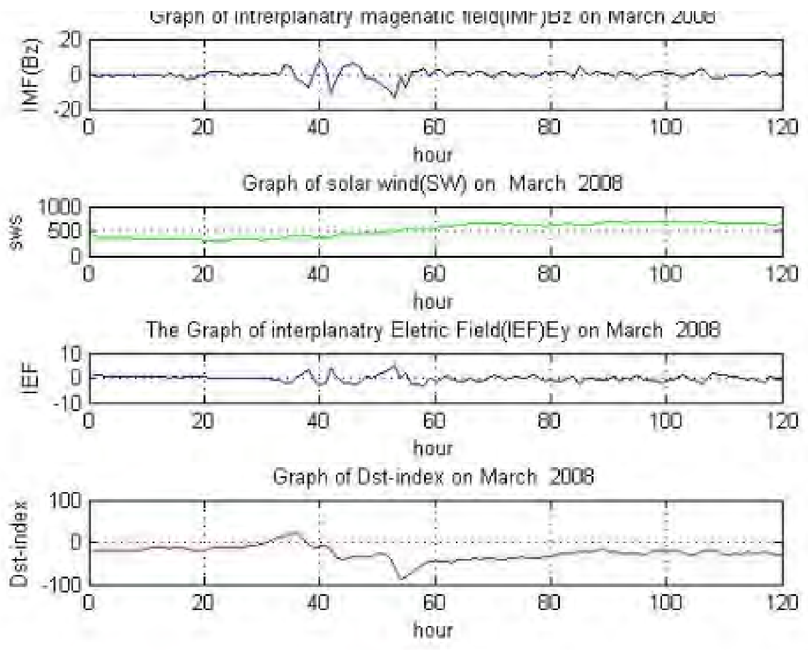

Figure 6.5: The Geomagnetic storm of March 7-11 2008

To describe the effect of Geomagnetic storm event on March 9^{th} 2008, the interplanetary magnetic field (IMF) top panel , solar wind speed (SWS) upper middle panel, interplanetary electric field (IEF) lower middle panel and disturbance storm time (Dst) index bottom panel for five Consecutive days is plotted from March 7/2008 to March 11/2008. The initial phase of the storm day started from March 7 and 8, their Dst index value -36 nT (weak storm) at 04:00 UT followed by moderate storm

(-57 nT) at 05:00 UT. But the main phase of the storm occurred on March 9/2008 which was another type of moderate storm (-86 nT) at 06:00 UT. The Dst-index value increased and the recovery storm started on March 10 and 11, their corresponding Dst-index value -83 nT at 07:00 UT and -70 nT at 08:00 UT and the storm type was moderate storm for both. And from Fig. (6.5) the interplanetary magnetic field (IMF) negative (southward) and the interplanetary electric field (IEF) north ward which means it decreasing the ring current. As indicated in Fig. (6.5), on top panel shows the IMF (Bz) during storm time is continuously changing its polarity from north to south and vis-versa at the same time the Dst index value on bottom panel revels it is a moderate geomagnetic storm. Similarly the Interplanetary electric field, lower middle, also indicating a fluctuating signature. At the same time the solar wind on upper middle Panels small compared to these storms driven by CMEs. These all signature revels the source of the geomagnetic storm is a CIR. And also from Fig.(6.5) the solar wind speed increasing positively and cause for the compression of magnetosphere because of the magnetopause pushed inward.

6.1.6 The Geomagnetic Storm of July 20-24 2009

Fig. (6.6) represents the interplanetary magnetic field (IMF) top panel, solar wind speed (SWS) upper middle panel, interplanetary electric field (IEF) lower middle panel and disturbance storm time (Dst) index bottom panel for five Consecutive days plotted from July 20/2009 to July 24/2009. The IMF (Bz) was initially southward and then reversed to northward direction and oscillates again from north to south directions which means that the graph is fluctuated.

The initial phase of the storm day started from July 20 and 21, their Dst-index value -53 nT (moderate storm) at 05:00 UT and -80 nT (moderate storm) at 06:00 UT

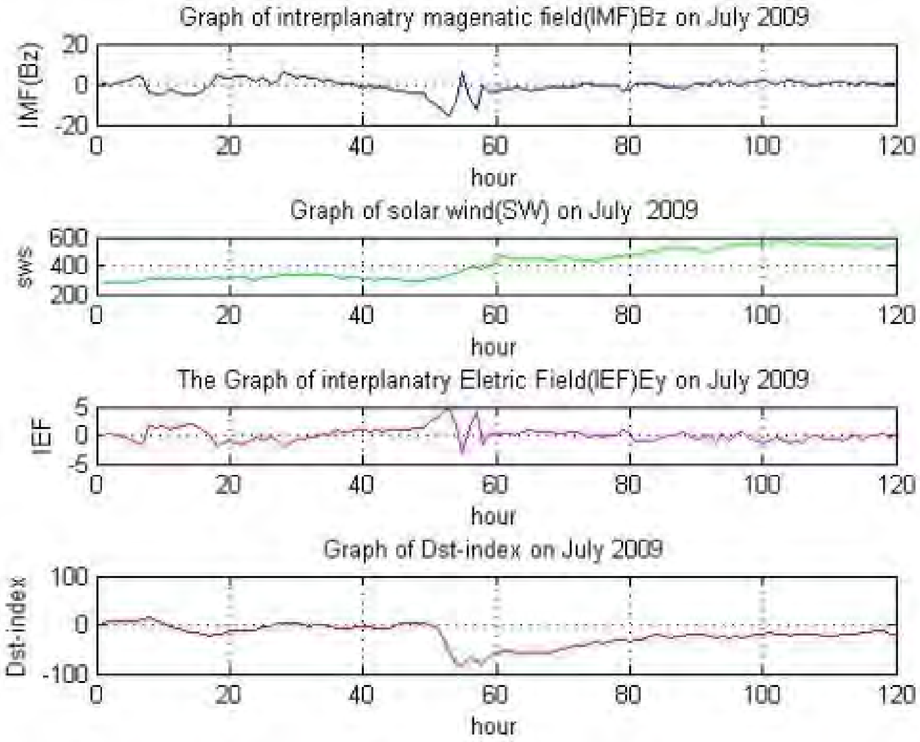

Figure 6.6: The Geomagnetic storm of July 20-24 2009

respectively. But the main phase of the storm occurred on July 22/2009 their value was -83 nT at 07:00 UT which is the maximum Dst index value and the storm was moderate storm to be observed. The Dst index value increase and the recovery phase storm started on July 23 and 24 their corresponding Dst-index value -69 nT at 08:00 UT and -75 nT at 09:00 UT respectively. From Fig. (6.6) their is a good interaction between interplanetary magnetic field (IMF (Bz)) and Interplanetary electric field (IEF) because when the IMF northward (positive) the IEF was south ward (negative), So the solar wind particles have a much easier time entering to our magnetosphere and affect the Earth magnetic field. This mean that the IMF (Bz) often herald widespread auroras by solar wind. In adation to these as the graph show there was turn fluctuated, this means there was low geomagnetic storm events and difficult to measured and the source of the geomagnetic storm event was the CIR due to low solar activity. As observed from Fig. (6.6) the solar wind speed increased positively, so the compression of magnetosphere occurred.

6.1.7 The Geomagnetic Storm of August 2-6 2010

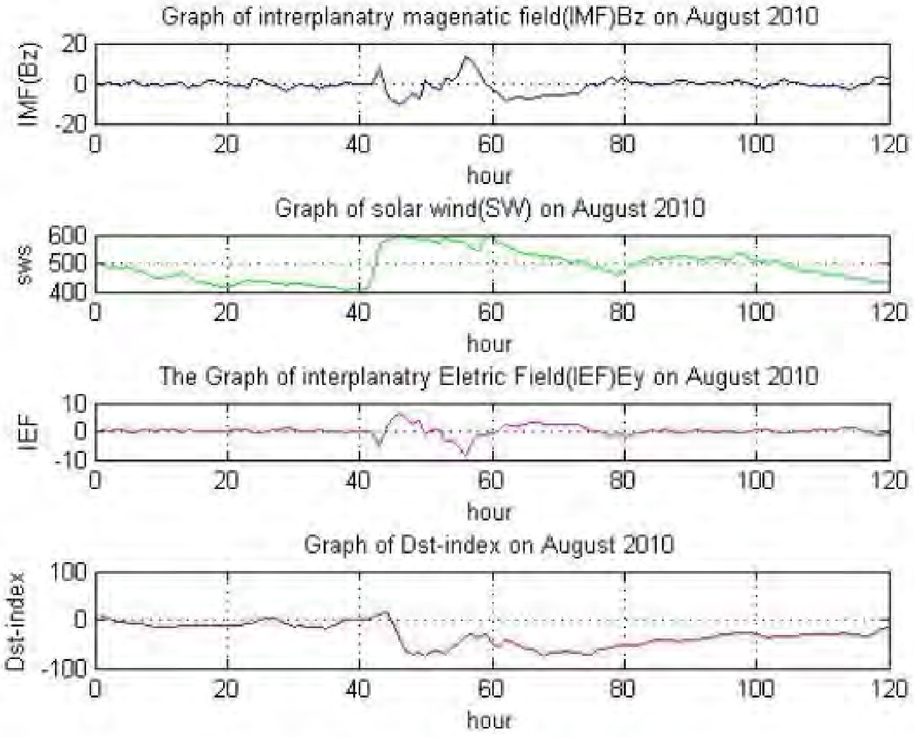

Figure 6.7: The Geomagnetic storm of August 2-6 2010

The effect of Geomagnetic storm on August 4^{th} 2010 expressed, when the interplanetary magnetic field (IMF) top panel, solar wind speed (SWS) upper middle panel, interplanetary electric field (IEF) lower middle panel and disturbance storm time (Dst) index bottom panel for five Consecutive days plotted from August 2/2010 to August 6/2010. The initial phase of the storm day started from August 2 and 3, their Dst-index value -72 nT at 24:00 UT and -69 nT at 01:00 UT, the type of storm for initial phase categorized as moderate storm. The storm was initiated in August 4/2010 and its minimum Dst value is recorded about -74 nT which reveals the storm is moderate storm. The Dst-index value increased and the recovery storm started on August 5 and 6 their corresponding Dst-index value -65 nT at 03:00 UT and -64 nT at 04:00 UT respectively and a moderate storm type was observed. The IMF (Bz) on to panel of Fig.(6.7) shows oscillation from north to south and vis-versa which is one indicator of CIR driven storm. The SWS and IEF on upper middle and lower middle panels respectively are also Showing similar behavior. That is the IEF changing its polarity. The Dst value on the lower panel shows a longer recovery period which is a signature of the CIR driven geomagnetic storm. As observed from Fig. (6.7) the IMF (Bz) negative (south ward) and IEF north ward (positive), so it decreasing the ring current. But the solar wind speed positively increase, so the compression of magnetosphere occurred.

6.1.8 The Geomagnetic Storm of October 23-27 2011

The effect of Geomagnetic storm event on October 25th 2011 expressed as, the interplanetary magnetic field (IMF) top panel, solar wind speed (SWS) upper middle panel, interplanetary electric field (IEF) lower middle panel, and disturbance storm time (Dst) index bottom panel for five Consecutive days plotted from October 23/2011 to October 27/2011. An intense magnetic storm event of October 25th, 2011 is illustrated in Fig. (6.8).This storm had a minimum Dst excursion of -147 nT. The IMF

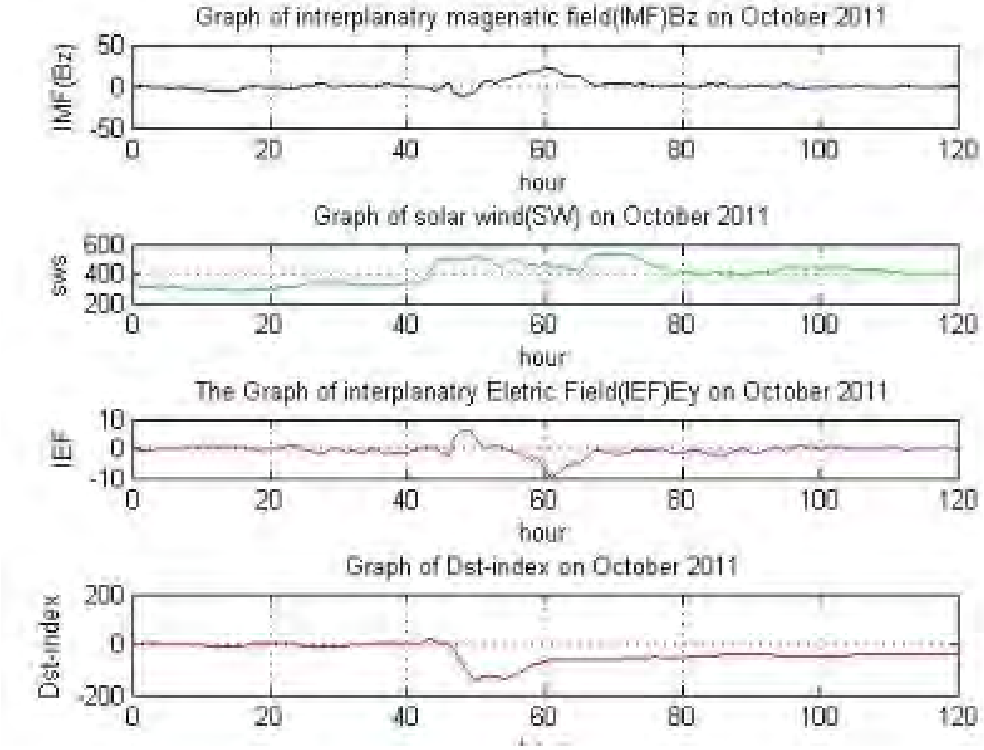

Figure 6.8: The Geomagnetic storm of October 23-27 2011

(Bz) and Dst index for the duration of October, 2011. The sudden storm commencement occurred at 24:00 UT.

The Dst amplitude started decreasing (main phase onset) from 01:00 UT and reached its minimum amplitude of -147 nT at 02:00 UT. It was accompanied with a steep drop and polarity reversal in z component of IMF, Bz. It turns to southward and attain a maximum negative value of -64 nT at 08:00 UT afterwards there was a steep rise noticed and it turns to northwards. In the main phase of storm the IEF has reached its maximum value obtained at the same hour when the IMF (Bz) is turned south and the Dst has obtained its least value. After the IMF (Bz) is turned North the

Dst index gently increases to its normal time in 24 hours time. It is clear from the observations of geomagnetic storm events that the occurrence of geomagnetic storms is highly correlated with the southward turning of Bz, the z component of IMF. The magnitude of turning of Bz into southward direction from northward highly depends upon the severity of the storm.

6.1.9 The Geomagnetic Storm of March 7-11 2012

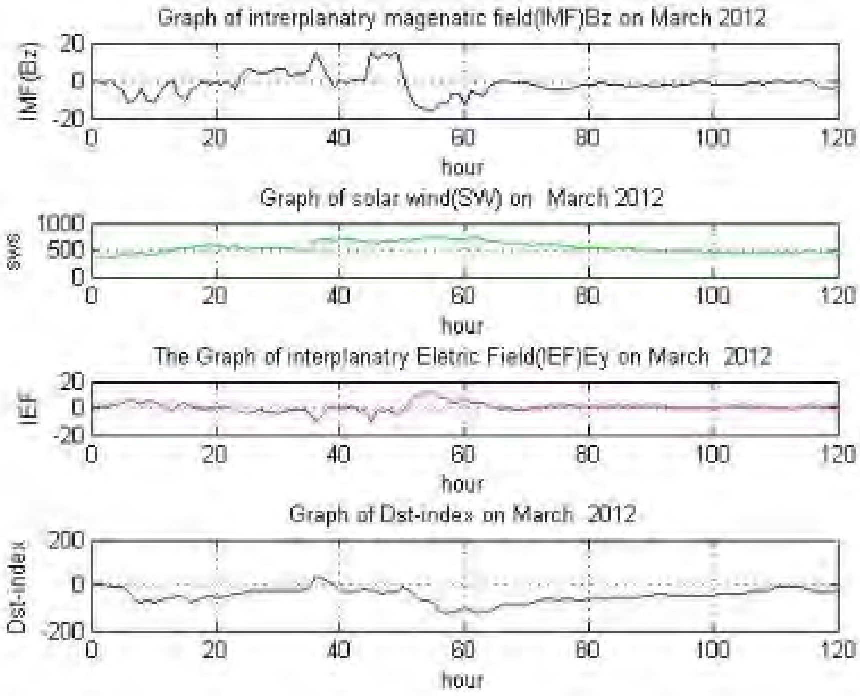

Figure 6.9: The Geomagnetic storm of March 7-11, 2012

The effect of Geomagnetic storm on March 9^{th} 2012 also explained with the value of interplanetary magnetic field (IMF) top panel, solar wind speed (SWS) upper middle panel, interplanetary electric field (IEF) lower middle panel and disturbance storm time (Dst) index bottom panel for five Consecutive days plotted from March 7/2012 to March 11/2012.

The initial phase of the storm day started from March 7 and 8 with a Dst-index value of -78 nT at 08:00 UT and -114 nT at 07:00 UT respectively. But the main phase of the storm occurred on March 9 their value was -131 nT at 09:00 UT which means the minimum Dst-index value and the maximum Geomagnetic storm shown and the storm categorized as an intense storm. The Dst-index value increase the recovery storm started on November 10 and 11 their corresponding Dst-index value -110 nT at 10:00 UT and -111 nT at 11:00 UT the storm type was an intense storm for both. And also the IMF (Bz), top panel of Fig. (6.9) shows southward on day 7 and continuously started to oscillate between south and north directions. This stays up to three days. This type of storm is classified as CIR driven storm. The interplanetary electric field also shows fluctuations in an oscillatory manner. From Fig.(6.9), their is a good interaction between interplanetary magnetic field (IMF (Bz)) and Interplanetary electric field (IEF) because when the IMF south ward (negative) the IEF was positive (northward) which means that they moves in opposite direction, due to this the charged particle easily enter to the magnetosphere and is good opportunity to reduce the Earth magnetic field.

6.1.10 The Geomagnetic Storm of March 15-19 2013

The effect of Geomagnetic storm on March 17^{th} 2013 described with the graph of IMF top panel, SWS upper middle panel, IEF lower middle panel and Dst index bottom panel plotted for five Consecutive days from March 15/2013 to March 19/2013.

The initial phase of the storm day started from March 15 and 16 and their Dst-index value -99 nT at 19:00 UT and -116 nT at 20:00 UT respectively. But the main

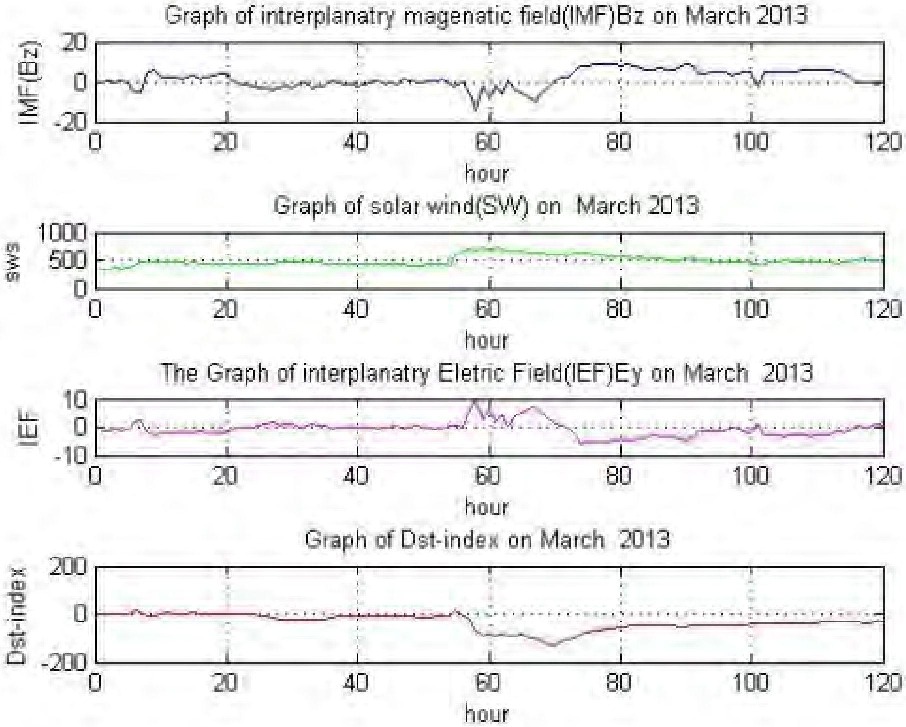

Figure 6.10: The Geomagnetic storm of March 15-19 2013

phase of the storm occurred on March 17 their value was -132 nT at 21:00 UT which means the minimum Dst-index value and the maximum Geomagnetic storm shown and the storm type was an intense storm event. The Dst-index value decrease and the recovery phase storm started on March 18 and 19 their corresponding Dst-index value -131 nT at 22:00 UT and -116 nT at 23:00 UT respectively. The Source of Geomagnetic storm on march 17th 2013 was the occurrence of CME on march 15^{th} 2013 as reported by NASA's Advanced Composition Explorer. As the graph indicates their is a good interaction between IMF (Bz) and IEF because when the IMF south ward and the IEF was north ward, the magnetic reconnection occurred and solar wind particle easier to much on the magnetosphere and reduced the earth magnetic field. In adation to these as the graph show there was no turn fluctuated, this means there was large geomagnetic storm events and to be measured. The source of the geomagnetic storm event was the CME due to high solar activity because as Fig. (6.10), shown the Dst-index value less than (< -100nT), indicates it is good enough to produce shock at the upper boundary of the magnetosphere.

6.1.11 The Geomagnetic Storm of February 17-21 2014

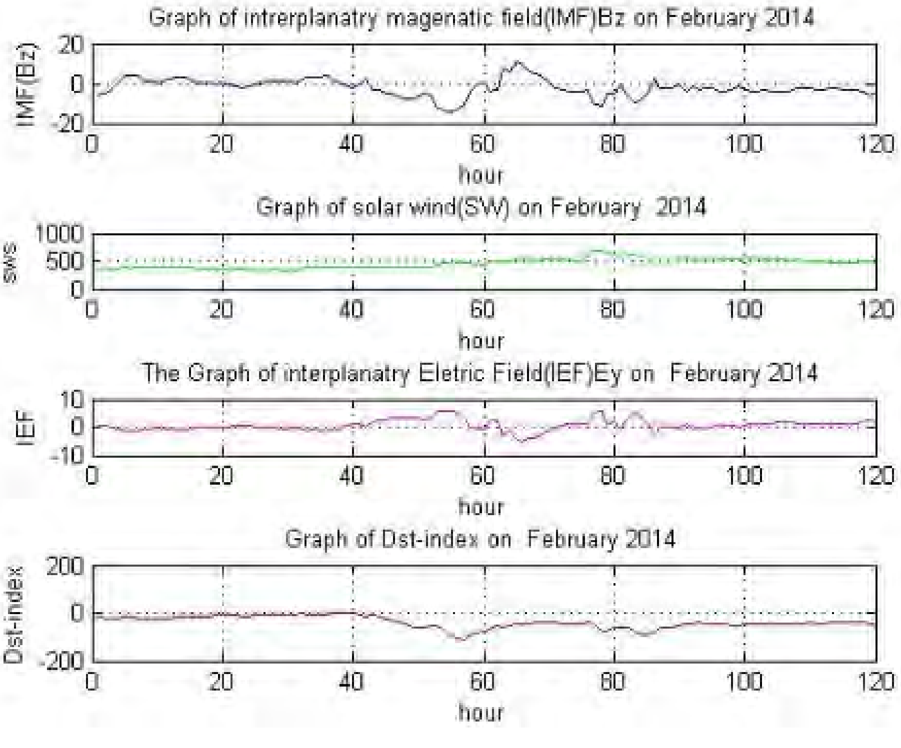

Figure 6.11: The Geomagnetic storm of February 17-21 2014

To describe the storm of February 19th 2014, the interplanetary magnetic field IMF (Bz) top panel, solar wind speed (SWS) upper middle panel, interplanetary electric field (IEF) lower middle panel and the disturbance storm time (Dst) index value bottom panel have been plotted for five Consecutive days during February 17/2014 to February 21/2014 and it's main phase was 19^{th} which was shown in Fig. (6.11). From the variation of the Dst index value the three storm, the initial occurred on 07:00 UT it's value -95 nT (moderate) storm and the main phase occurred later two hours (09:00 UT) the value was -116 nT which was the maximum value Record and high geomagnetic storm occurred and which is called an intense storm event.After one hour later it's value decreased and the recovery phase happened from 10:00 UT to 11:00 UT their value was -94 nT and -83 nT, the storm type was moderate. The significant enhancement of Dst index from February 17-21 on 2014 were the indication of CME interacts to the solar wind and caused for the Geomagnetic storm to be happened. The IMF (Bz) in repeatedly reverses from south to north and viceversa several times implies that several storms were occurred during the storm event time. This is also reflected in the Dst index value. As the graph indicates their was a good interaction between IMF (Bz) and Interplanetary electric field (IEF) because when the IMF south ward the IEF north ward, and the magnetic reconnection occurred and solar wind particle easier to much on the magnetosphere and reduced the earth magnetic field. This mean that the IMF (Bz) southward turn highly depends on the severity of geomagnetic storm. In adation to these as the graph show there was no turn fluctuated, this means there was large geomagnetic storm events and to be measured. Due to this the cause of the geomagnetic storm event was the CME due to high solar activity.

Table (6.1) shows the effect of Geomagnetic storm that observed in my result discussed

year	Dst value(nT)	storm type
2004	-374	exetrem
2005	-184	intense
2006	-162	intense
2007	-72	moderate
2008	-86	moderate
2009	-83	moderate
2010	-74	moderate
2011	-147	intense
2012	-131	intense
2013	-132	intense
2014	-116	intense

Table 6.1: The Effect of Geomagnetic Storm with their type of storm

before, mainly the main phase of the storm event started from 2004 to 2014 with their Dst index value and type of storm that was observed in the result.

Chapter 7

CONCLUSION

7.1 CONCLUSION

The study of this thesis shows the Variation of Geomagnetic storm from November 2004 until February 2014 for solar cycle 24. The present analysis also show starting from the year 2004 to 2006, there was large Geomagnetic storm and the source of the storm was CME but from 2007 to 2010 the Geomagnetic storm was low and the corresponding cause of the storm event was CIR, where as from 2011 until 2014 the Geomagnetic storm event was large and the source of storm was the CME due to high solar activity. But as graph indicate for 2012 it is fluctuated so it is source is CIR rather than CME. In short 9.09 percent of the analysis show Extreme event, 36.36 percent of the analysis show moderate event and the other 54.54 percent was an intense storm event.

Extended periods of southward IMF (Bz) leads to the main phase of the magnetic storm and is responsible for magnetic reconnection. On the other hand northward IMF (Bz) has only minimal day side reconnection. The increase day side reconnection increases the penetration of the solar wind into the magnetosphere, increases convection and ring current injection. The storms caused by CIR storms are usually associated with high speed streams are smaller and their Dst values are greater than (> -100nT), where as the storm caused by CME associated with high speed and Dst value less than (< -100nT), the magnetic field show high storm event and disturb the Earth magnetic field which means that more negative value of Dst index value cause reducing the Earth magnetic field and affect their purpose.

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