GOVERNMENT COLLEGE

CHITTUR

PALAKKAD

Project Report

On

AN ELEMENTARY STUDY OF DYNAMICS OF A GEOMAGNETIC STORM

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CERTIFICATE

Certified that this is the bonafide record of project on **AN ELEMENTARY STUDY OF THE EFFECTS OF DYNAMICS OF A GEOMAGNETIC STORM** that has been presented by …………………………… with register number …………………, B.Sc. Physics, Government College, Chittur in partial fulfillment of the requirements for the award of the degree programme in B.Sc. Physics under the University of Calicut during the year 2021-2024.

Date:

Place:

Head of Department

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External Examiner

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ABSTRACT

The interaction between the solar wind from the sun and the earth's atmosphere forms an integral part of the study of Space Physics. It has enormous implications in various areas like communication systems like the GPS satellites and also leads to an understanding of solar activity. The main impetus in such studies is the geomagnetic storms. The mechanism of coupling between the solar wind and the earth's ionosphere is deep and involves the interplay of some of the most important branches of Physics like electrodynamics, statistical mechanics and plasma physics. In the present work, an analysis of data obtained for one of the most enigmatic super storms of the past few decades is studied. The main solar wind parameter considered is the z-component of the interplanetary magnetic field. The main terrestrial parameter included in the study is the geomagnetic field horizontal component. The solar wind data are obtained from ACE satellite whereas the terrestrial data are taken from the geomagnetic observatory at Huancayo in Peru. It is seen that the prolonged negative turning of the IMF and simultaneous high value of ion densities result in strong fluctuations in the normal patterns of the geomagnetic horizontal intensity. The results obtained corroborates the theory of magnetic field reconnection and the resulting influx of solar wind particles into the earth's atmosphere.

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CONTENTS

1. *Introduction*

Solar-Terrestrial Physics is the branch of physics which studies the interaction between the sun and the earth. Such interaction between the sun and the earth is primarily due to electromagnetic radiation from the sun, particularly in the form of visible radiation, as we all are aware of. But the actual depth of the interaction is more than this and involves the interplay between the electromagnetic radiation, energetic charged particles and electric as well as magnetic fields emitted by the Sun on the one hand and the atmosphere of the Earth, particularly its magnetic field, on the other. This coupling between the solar parameters and the terrestrial environment is not only an interesting area of study but potentially important for the existence of mankind itself since it's the Earth's atmosphere that prevents most of the harmful effects from this coupling from reaching the surface of the Earth.

Since the dawn of civilization, the Sun has elicited worship, inspiration, and study, and the mysteries about its dynamics still occupy the attention of solar astronomers and space physicists. The Sun is one of an estimated 100 billion stars in the Milky Way galaxy. From studying the properties of nearby stars and the age of meteorites, we have learned that the Sun is a typical star about 4.5 billion years old. By observing star formation regions within our galaxy, we know that the Sun was formed out of a giant cloud of gas and dust called the solar nebula. The Sun's energy comes from thermonuclear reactions in the core that fuse protons together to form helium nuclei. In the process, energy is liberated; some of this energy eventually makes its way to the surface and propagates out into space as electromagnetic radiation. Because of the high temperatures on and within the Sun, the gas is ionized in the form of plasma. Due to the motion of ionized gas in the Sun, a strong solar magnetic field is generated. Changes in this highly variable solar magnetic field cause changes in the amount of energy released from the Sun’s surface. A plasma is a gas of charged particles, which consists of equal numbers of free positive and negative charge carriers. Having roughly the same number of charges with opposite signs in the same volume guarantees that the plasma behaves *quasi neutrally*. On an average, a plasma looks electrically neutral to the outside, since the randomly distributed particle electric charge fields mutually cancel.

The solar wind is a stream of charged particles (plasma) released from the upper atmosphere of the Sun. It mostly consists of electrons and protons with energies usually between 1.5 and 10 keV. The stream of particles varies in density, temperature, and speed over time. These particles can escape the Sun's gravity because of their high kinetic energy and the high temperature of the corona. The solar wind flows outward supersonically to great distances, filling a region known as the Heliosphere, an enormous bubble-like volume surrounded by the interstellar medium. It is the solar wind that gives rise to the spectacular tails of comets. The Earth is thus embedded in a stream of solar wind and it is the presence of the terrestrial magnetic field that protects us from the severe radiation associated with the solar wind.

Earth is the third planet from the Sun. It is the densest and fifth-largest of the eight planets in the Solar System. It is also the largest of the Solar System's four inner planets. The physical properties of the Earth, as well as its geological history and orbit, have allowed life to develop and survive. The Earth has a magnetic field that acts as a protective cover which deflects off the solar wind particles and radiation, thereby protecting life. The mechanism of interaction of the terrestrial magnetic field with the solar wind is thus highly important for us to understand.

The terrestrial magnetic field varies in magnitude and direction diurnally. This is controlled in part by the various current systems in the upper atmosphere and in part by its interaction with the solar wind. Near the surface of the Earth, the magnetic field lines resemble those of a magnetic dipole. Farther away from the surface, the field lines are significantly distorted by electric currents flowing in the plasma (e.g. in ionosphere or solar wind). Over Earth's equator, the magnetic field lines become almost horizontal, then return to connect back again at high latitudes. However, at high altitudes, the magnetic field is significantly distorted by the solar wind and its solar magnetic field. The magnetic field couples with the solar wind electromagnetically. This result in magnetic reconnection, and as the magnetic field lines break and reconnect, solar wind particles are able to enter the magnetosphere and thereby to the lower atmosphere, creating brilliant and colourful displays like the Aurora and also violent phenomena like geomagnetic storms. The present study attempts to deal with some important aspects of this coupling between the solar wind and terrestrial magnetic field.

2. Choice of the topic

Present day communication systems are more and more dependent on satellites. The use of GPS network as well as the growing popular interest in technical applications like google maps testifies this fact. The working environment of satellites is the interstellar space and this is where the study of Solar Terrestrial Physics becomes important. The research in space physics is being funded more than in the past in many countries due to its importance in communications. This growing importance of space physics research motivated us to choose this topic.

Another aspect that motivated the choice of the present topic is the availability of space physics data. The data on solar wind and earth’s magnetic fields are mainly available through satellites. The increasing importance of this branch has prompted international space agencies like NASA to offer the satellite data freely through the internet. This has enabled easy availability of data for any parameter pertaining to space physics. This is very encouraging for young researchers and amateurs in this field. This provided ample motivation for choosing this area for study.

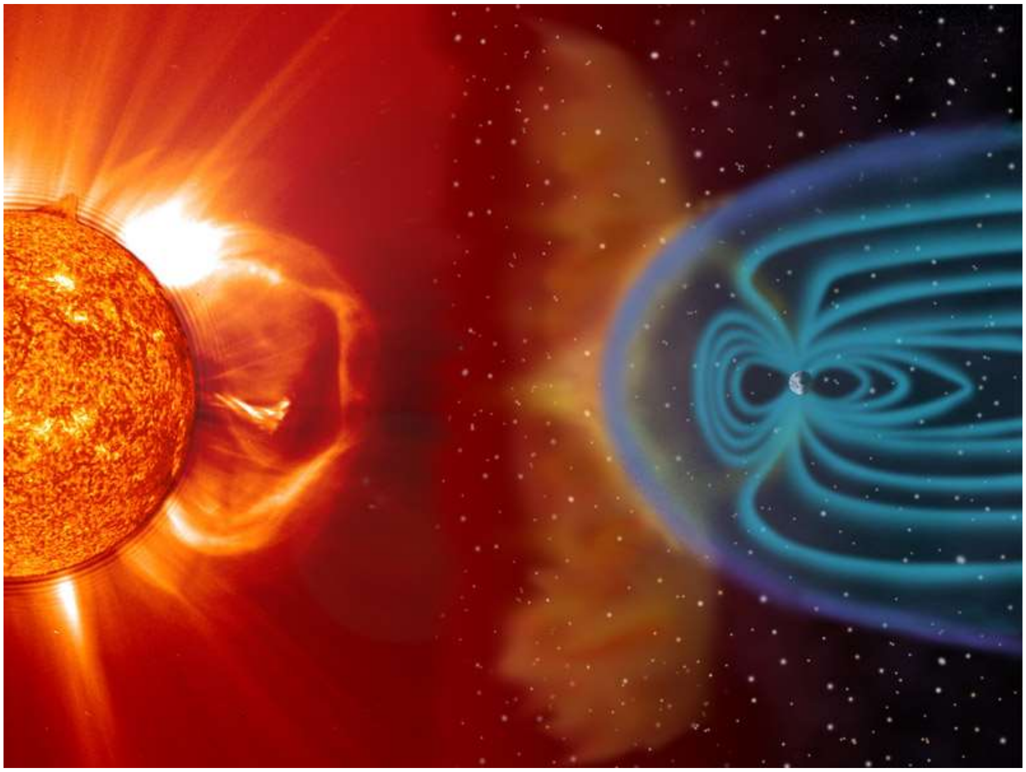
3. Methodology of study

The main aspects of solar terrestrial physics were assimilated through discussions, books and internet resources. Once the basic information required was obtained, the next step was the collection of relevant data. From the literature survey, we obtained information about several websites providing satellite data on Space physics as well as terrestrial atmospheric data. The parameters suitable for study were also selected. The next task was to select the important dates for which an analysis of the data has to be done. This was done based on information about magnetic storm days.

Once the relevant data was downloaded, it had to be converted to a format suitable for analysis. For this the data files downloaded were converted into origin files using both Microsoft Excel and origin software. Using Origin, the required graphs were plotted. By visual comparison of the graphs pertaining to interplanetary conditions and to geomagnetic data, relationships between the data were found and this corroborates with what has been studied from the theory.

4. The solar wind

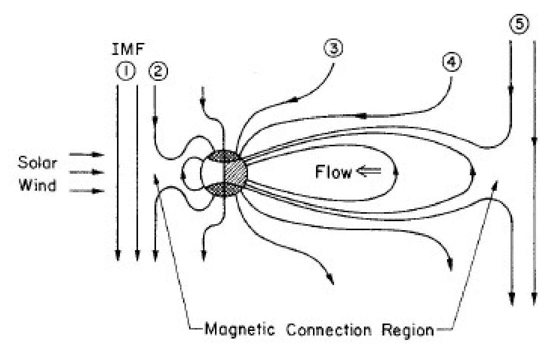
The outermost layer of the sun is called the corona. The outer parts of the corona are always expanding outwards into the interstellar space due to pressure difference. As a result, the earth and all other planets are immersed in a flow of the solar fluid. This flow consists of mainly charged particles like electrons, helium nuclei, protons and also neutral particles. This flow is called the solar wind. The matter in the solar wind is the form of tenuous plasma and has high electrical conductivity. As a result, it drags along with it, a part of the solar magnetic field due to the phenomenon of magnetic flux dragging. This part of the solar magnetic field present in interplanetary space is called the interplanetary magnetic field or IMF. The IMF contains magnetic field lines whose roots are on the solar surface. Due to several factors including the rotation of the sun, the IMF changes polarity with time. In the most generally accepted co-ordinate system, the component of IMF perpendicularly up from the direction of flow is taken to be the z- component and is the most active element in the IMF. It is usually denoted as IMF B_z. An important feature of the solar wind is that it is a supersonic flow.

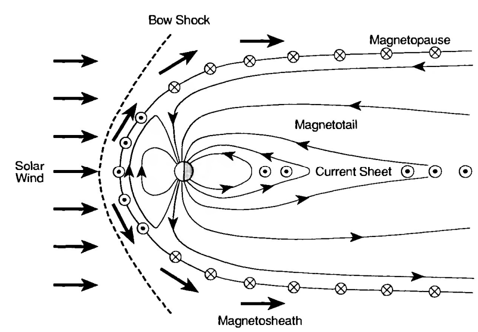


When the solar wind encounters the earth, the terrestrial magnetic field will hold off the IMF and as a result, the solar wind will flow past the earth without any of its constituent particles entering the earth's surface. However, in some special situations, the interplanetary and terrestrial magnetic fields will couple together in a yet not completely understood process called magnetic reconnection, resulting in a large inflow of solar wind particles into the earth's atmosphere. This wonderful phenomenon is called a geomagnetic storm. Small amount of interplanetary material always finds its way into the earth's lower atmosphere giving rise to the wonderful display of colours in the polar sky, which is popularly known as the aurora.

5. Coupling between the terrestrial atmosphere and the solar wind

When the interplanetary magnetic field or IMF is northward, its z-component or IMF B_z is positive and in the same direction as the geomagnetic field. But when the IMF is southward, the IMF B_z is negative. Under such a condition, the IMF can couple with the geomagnetic field such that a field line of solar origin connects itself with a field line of terrestrial origin. This type of coupling between two magnetic field lines is called magnetic reconnection. Then the charged particles linked with the solar field line can enter the terrestrial atmosphere and, in this way, matter and energy can be transferred from the solar wind to the earth's atmosphere. The process is as depicted below. The numbers give successive progress of the process.





The particles of solar wind origin thus entering the earth's atmosphere become part of the ring current system. Since the strength of the ring current affects the value of the geomagnetic field, the entry of solar wind particles through the reconnection process whenever the IMF B_z is negative results in fluctuations of the geomagnetic field as measured on the earth's surface.

6. Geomagnetic storms

The solar surface is constantly changing with violent activities. Sometimes a large mass of charged matter is discharged from the solar surface along with a large amount of magnetic energy. Such an eruption is called a coronal mass ejection or CME. This moves through interplanetary space dragging the solar magnetic field along with it. If such a CME encounters the earth's magnetic field, it will compress the dayside field so that a large and sharp increase in the value of the geomagnetic field will be measured at the earth's surface. During this compression, reconnection may take place at the dayside region, resulting in the transfer of large amount of matter and energy into the earth's atmosphere. This soon joins the ring current and thus the ring current strength increases to very high magnitudes. This causes a sudden large decrease in the geomagnetic field. Also, the highly energetic particles of solar origin can reach the lower regions of the atmosphere through the poles and cause severe electromagnetic effects including power failures. The extra particles in the ring current gradually escape through various mechanisms and the decreased geomagnetic field regains its normal value in a few days. This whole process is known as a geomagnetic storm.

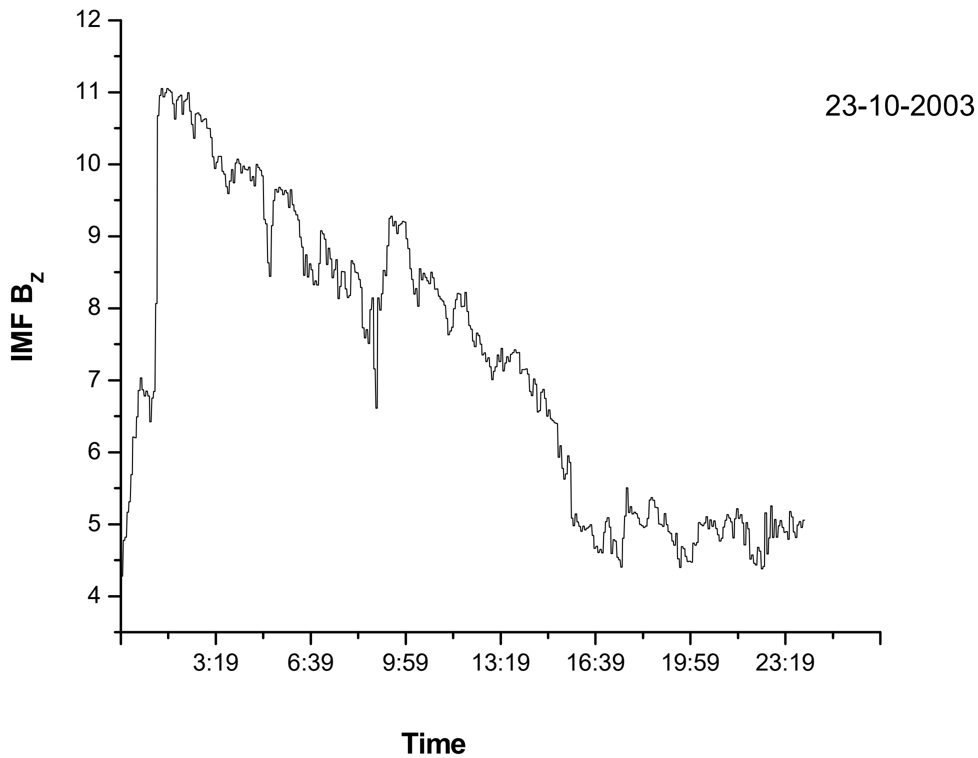
7. Data from satellites and earth stations

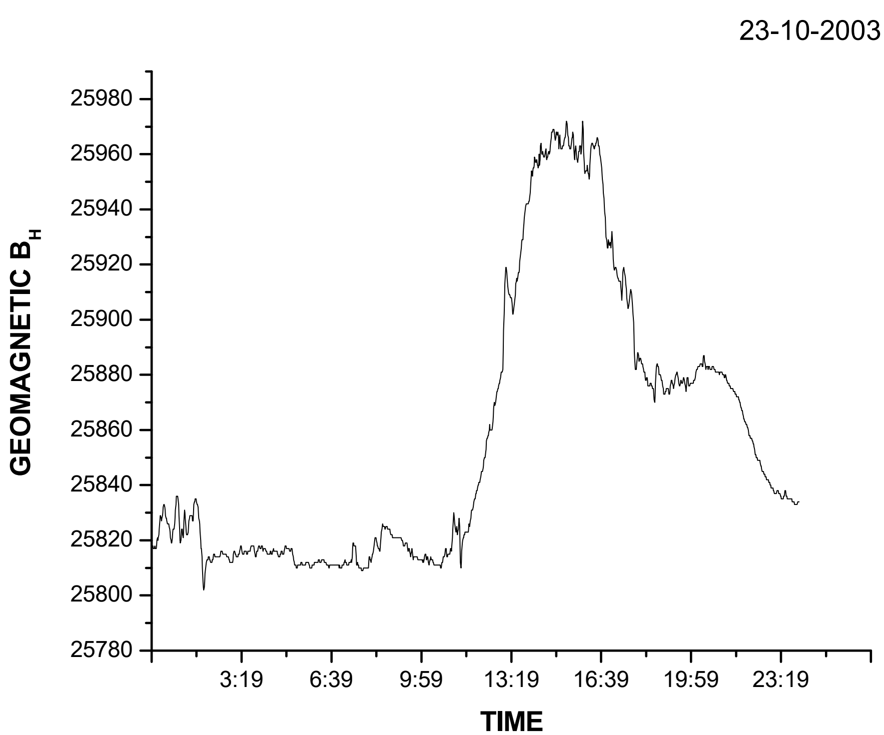
In the present study, the effects of a geomagnetic storm on the horizontal intensity of earth's magnetic field are studied. The storm day period chosen is ten consecutive days from October 23, 2003 to November 4, 2003. This was a period of very violent activity in the interplanetary space and the sun. The interplanetary data for the period is obtained from the Coordinated Data Analysis or CDAWeb facility, which is a part of Space Physics Data Facility (SPDF) provided by NASA through the url **spdf**.gsfc.**nasa**.gov/ . The SPDF is a project of the Heliospheric Science Division or HSD at NASA's Goddard Space Flight Center. SPDF consists of web-based services for survey and high resolution data and trajectories. The CDAWeb supports simultaneous multi-mission, multi-instrument selection and comparison of science data among a wide range of current space missions. The interplanetary space parameter chosen for the present study is the z- component of the interplanetary magnetic field, denoted as IMF B_Z. The data is taken from the ACE satellite. The data is taken from 00 hrs to 23:59 hrs for each day in the above mentioned period. The terrestrial parameter chosen is the horizontal intensity of the earth's magnetic field. These data are obtained from the Space Physics Interactive Data Resource or SPIDR with url http://spidr.ngdc.noaa.gov. The Space Physics Interactive Data Resource (SPIDR) is designed to allow a solar terrestrial physics customer to intelligently access and manage historical space physics data for integration with environment models and space weather forecasts. It is developed and maintained by the National Geophysical Data Centre (NGDC) of the United States of America. To access these data, one has to first register to the site using a username and password. Then one can choose among a variety of data sets having different resolutions in terms of time intervals. The present study uses one minute resolution data since this provides reliable information on the variation of the geomagnetic field with minimum error. The earth station chosen is Huancayo Magnetic Observatory in Peru, South America. This is an equatorial station, with coordinates 12° S 75° W. The choice is because the effects of interplanetary space phenomena in the equatorial atmosphere are very mysterious and poorly understood. It is still actively researched. Also among the equatorial stations, Huancayo has a very large and accurate database. The Huancayo Geomagnetic Observatory is the unique in the magnetic equatorial region and rare anywhere in the world. Huancayo have the longest equatorial magnetic series in the world. The privileged location and the high quality of the scientific information it produces has turned Huancayo into a world-renowned center of Geophysics. In June, 2003, Huancayo Geomagnetic Observatory was accepted as a full INTERMAGNET Observatory (IMO).

The datasets downloaded are in compressed format. This is unzipped and the required data is contained in comma separated text format, with .txt extension. This is opened in Microsoft Excel and the required data alone is selected. This is then converted into an Origin file, with .OBJ extension, which can be opened using Origin software. Both interplanetary data and geomagnetic data are converted into Origin files in this way. The data thus converted is then plotted as a graph using Origin. A graph is plotted for each day of the period and for each parameter. Thus, for each day, one obtains a graph showing the variation with time of the IMF B_z and the horizontal intensity of the geomagnetic field. These are then visually compared to obtain correlations between the data sets.

8. Analysis of data

The data sets are taken for ten consecutive days in the period October 23, 2003 to November 4, 2003. The following are the graphs of the data sets for the days during the abovementioned period.


23-10-2003
IMF B_Z
Time
12
11
10
9
8
7
6
5
4
3:19
6:39
9:59
13:19
16:39
19:59
23:19


23-10-2003
GEOMAGNETIC B_H
TIME
25980
25960
25940
25920
25900
25880
25860
25840
25820
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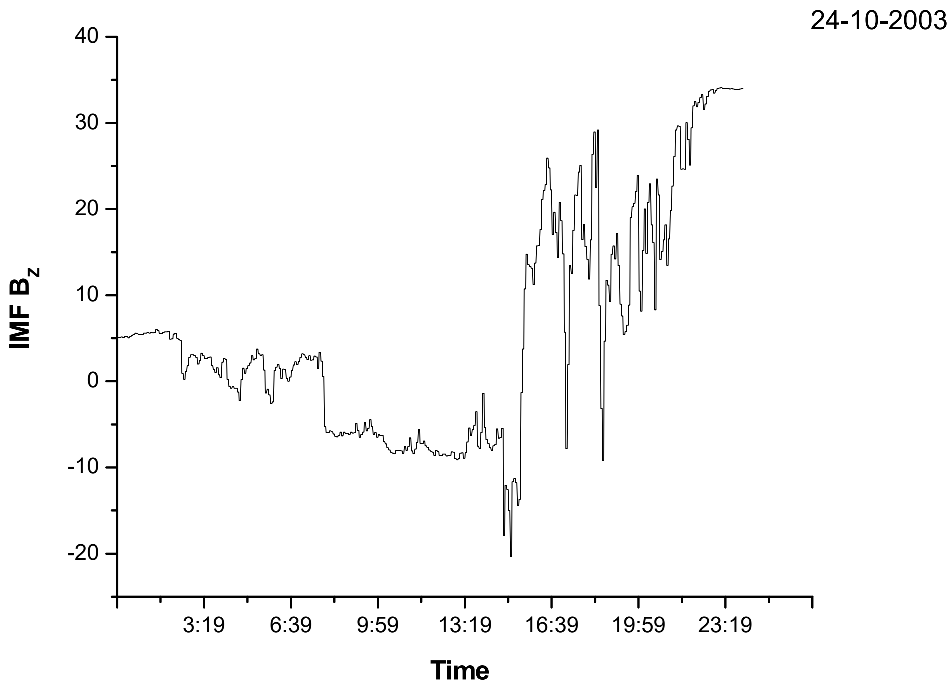
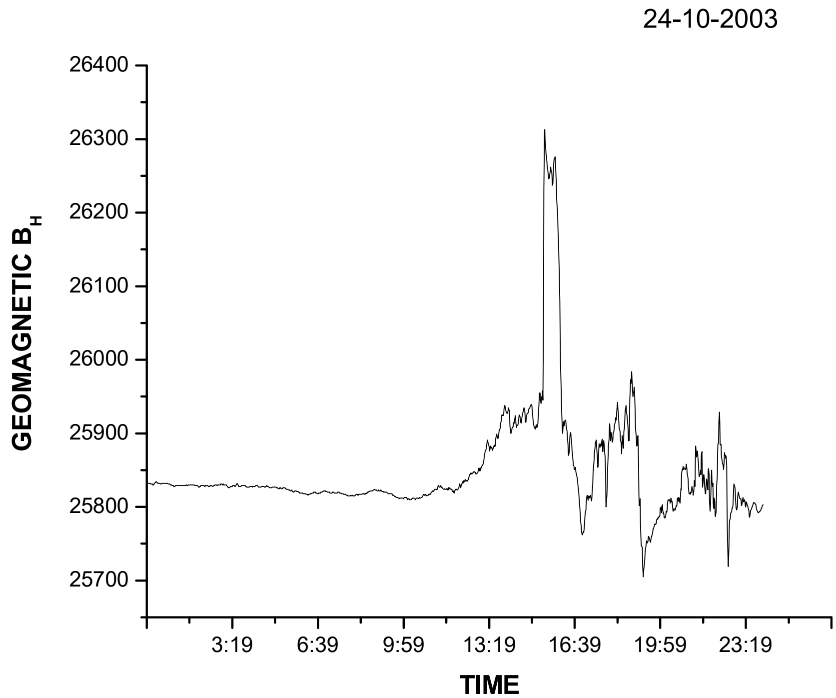
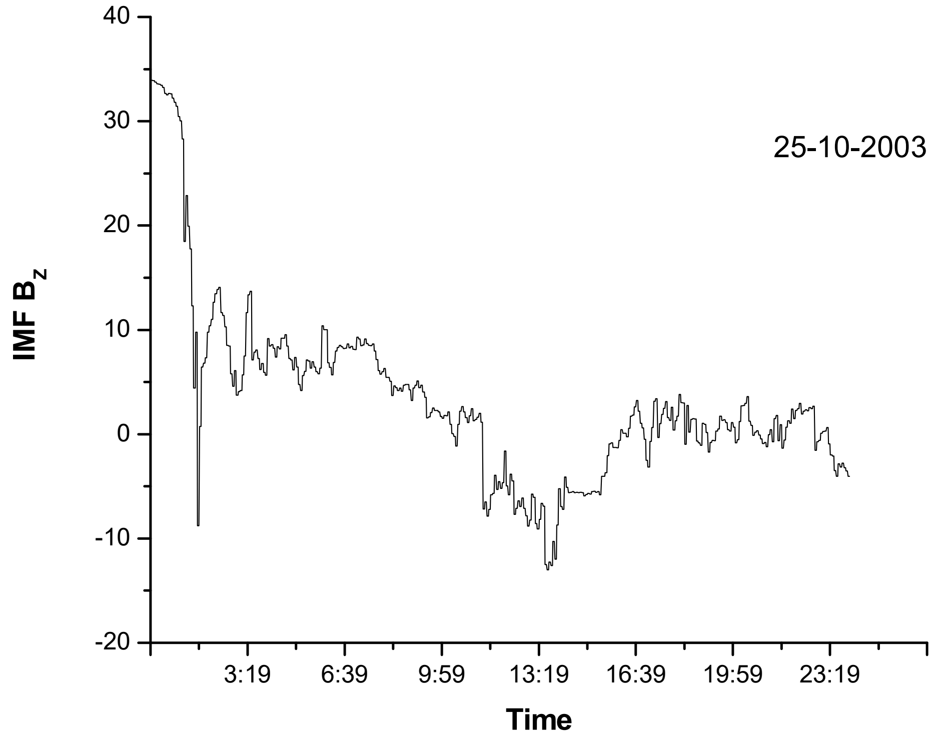
3:19
6:39
9:59
13:19
16:39
19:59
23:19


24-10-2003
40
30
20
10
0
-10
-20
IMF B_z
3:19
6:39
9:59
13:19
16:39
19:59
23:19
Time


24-10-2003
26400
26300
26200
26100
26000
25900
25800
25700
GEOMAGNETIC B_H
3:19
6:39
9:59
13:19
16:39
19:59
23:19
TIME



25-10-2003
IMF B_Z
40
30
20
10
0
-10
-20
3:19
6:39
9:59
13:19
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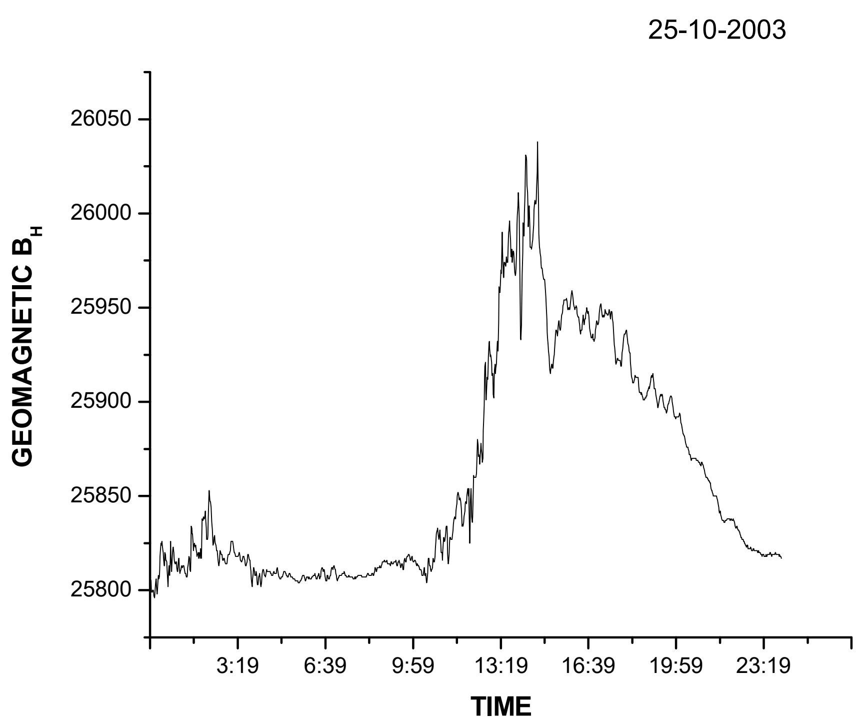
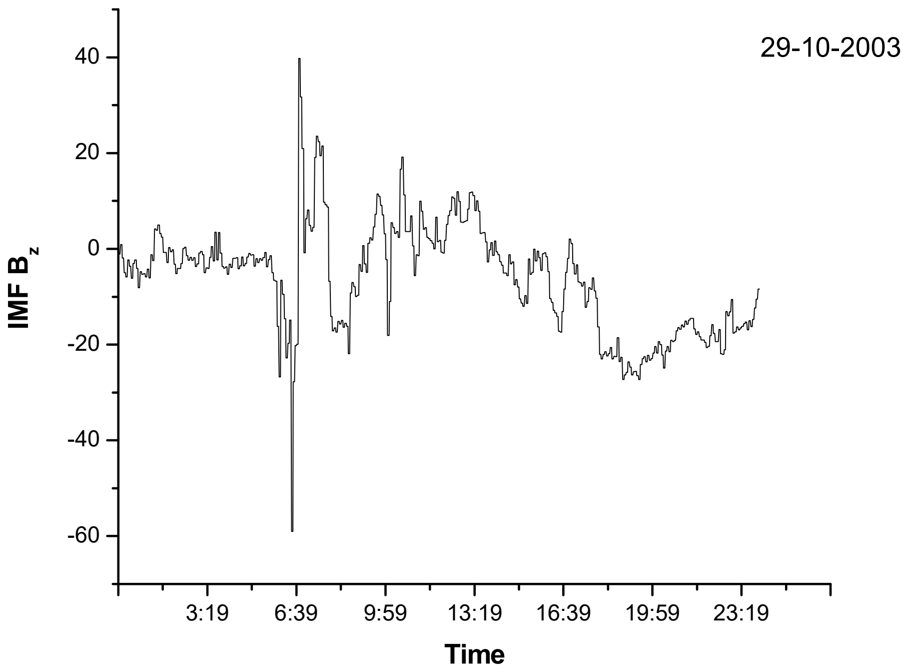
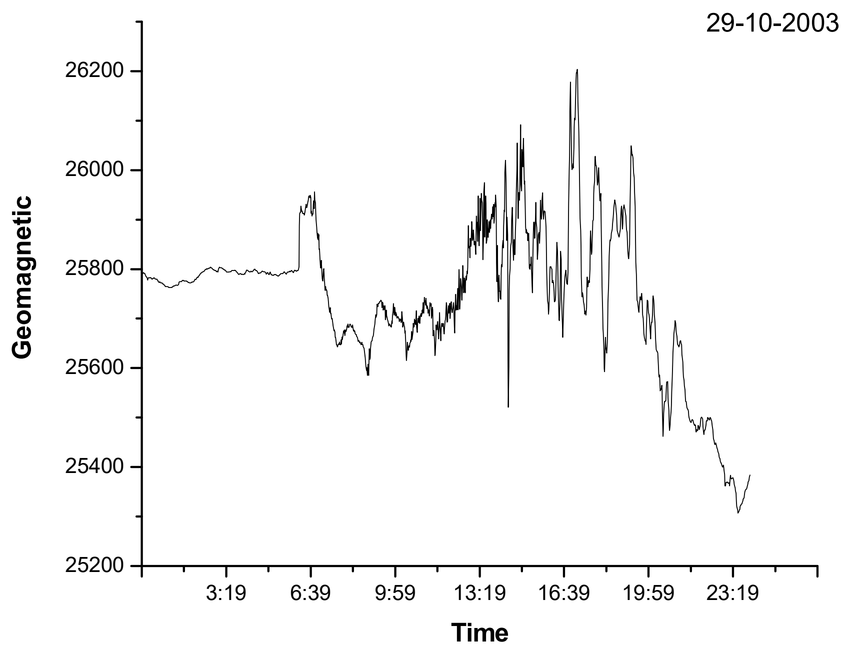
19:59
23:19
Time



25-10-2003
GEOMAGNETIC B_H
26050
26000
25950
25900
25850
25800
3:19
6:39
9:59
13:19
16:39
19:59
23:19
TIME


29-10-2003
IMF B_z
40
20
0
-20
-40
-60
3:19
6:39
9:59
13:19
16:39
19:59
23:19
Time


29-10-2003
Geomagnetic
26200
26000
25800
25600
25400
25200
3:19
6:39
9:59
13:19
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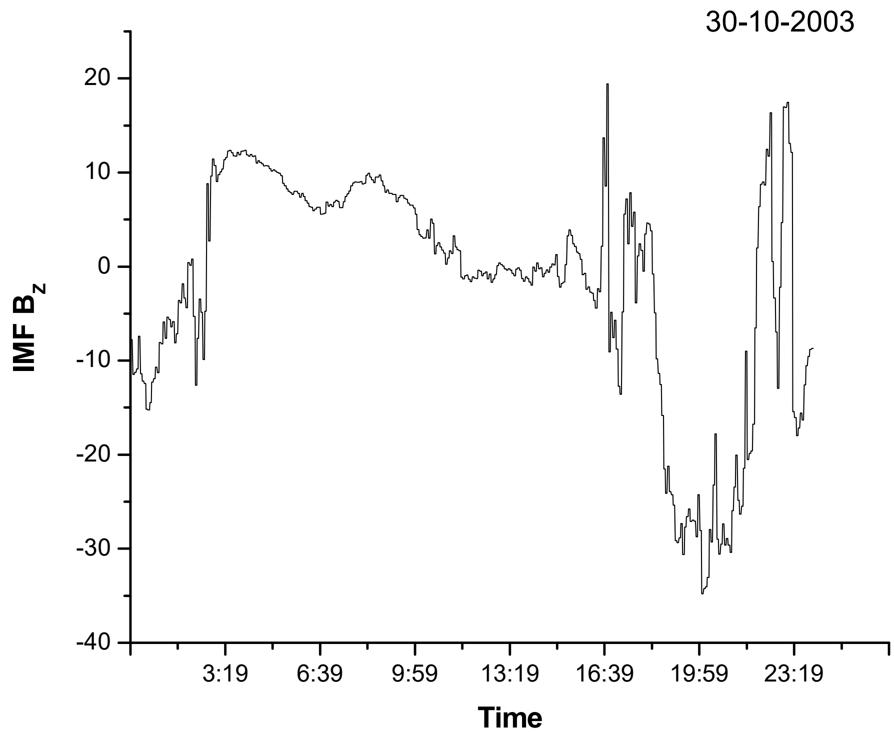
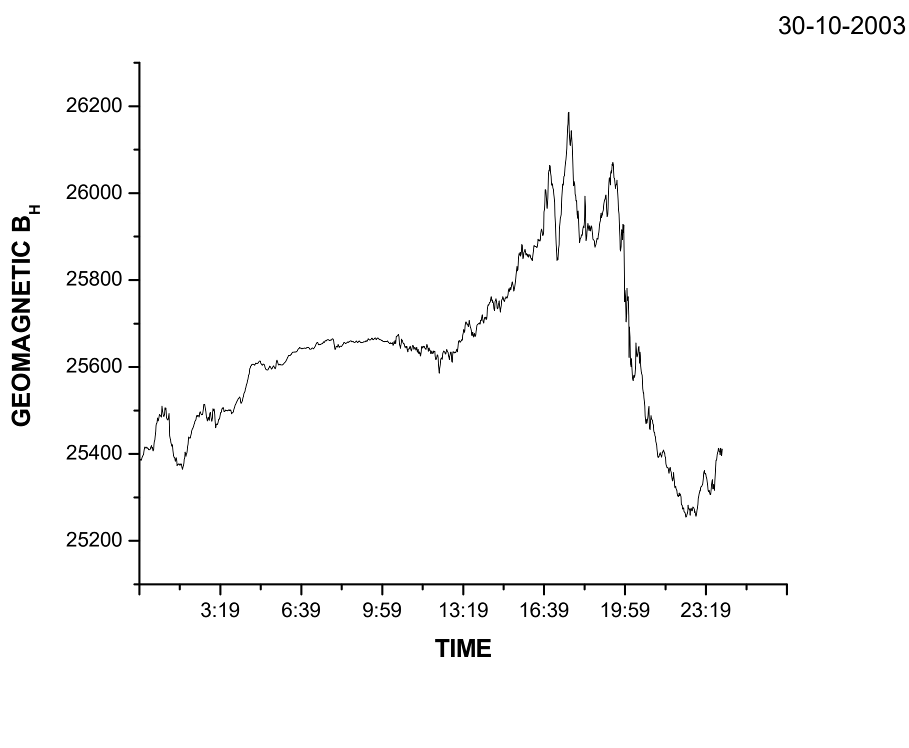
19:59
23:19
Time


30-10-2003
20
10
0
-10
-20
-30
-40
IMF B_Z
3:19
6:39
9:59
13:19
16:39
19:59
23:19
Time


30-10-2003
26200
26000
25800
25600
25400
25200
GEOMAGNETIC B_H
3:19
6:39
9:59
13:19
16:39
19:59
23:19
TIME

The diurnal variation of the horizontal intensity of the geomagnetic field for an equatorial station is typically of the same form as depicted in the plot for geomagnetic field on 23-10-2003. Each magnetic station has a base level of value for the geomagnetic field and for Huancayo, this is 25800 nT. On the same day, the IMF shows only typical variations and does not show any abnormality in its behavior. This is as given in the plot for IMF B_z for the same day. The IMF B_z fluctuates between positive and negative and does not grow very strong on either direction. However, the plot for IMF B_z for the next day shows that the interplanetary field shows abrupt variations and during a particular phase goes negative and continues to be so for a prolonged period, with a minimum of about -20 nT. The corresponding plot for geomagnetic intensity shows that the geomagnetic field is greatly affected and the normal diurnal pattern is lost on 24-10-2003. This is signature of magnetic reconnection that occurred at the dayside magnetosphere. On 25-10-2003 also the IMF B_z shows erratic behavior and again remains strongly negative for a period, reaching a minimum of near -20 nT. For the day, the plot for geomagnetic field shows that the field shows rapid variations although some sort of diurnal pattern is visible.

The data for 29-10-2003 shows very drastic variations in IMF B_z with large and prolonged negative values, even reaching an astonishingly low value of -60 nT. The plot for the geomagnetic field shows that the diurnal pattern is almost completely lost. These are the very signs of a severe geomagnetic storm. The phenomena continue on 30-10-2003, with the IMF B_z reaching a minimum of about -30 nT and completely erratic variations in the geomagnetic field. The geomagnetic field also deviates from the base value and reaches very low levels of about 25400 nT.

9. Results and discussion

The results obtained corroborate the theory of magnetic reconnection. According to the theory of reconnection, the solar field lines and geomagnetic field lines can reconnect when the IMF is southward. Under such conditions, the solar wind particles linked with the solar field lines can link with the geomagnetic field lines and thus enter the earth's atmosphere. In this way, if the IMF stays southward for a prolonged period, sufficient number of solar wind particles can enter the earth's atmosphere. All these newly joined particles add to the ring current and this increases the magnetic field due to the ring current. Since the ring current field opposes the geomagnetic field, this result in a decrease in the earth's magnetic field as measured in an earth station. These facts are reflected in the graphs obtained in the present study.

The plots for 23-10-2003 show that the IMF is positive almost throughout the day. The geomagnetic variation shows the normal diurnal pattern. However, on 24-10-2003, 29-10-2003 and 30-10-2003 the IMF shows strong negative variations and also stays negative for prolonged periods of time. On all these days, the normal diurnal pattern of the geomagnetic field is completely lost. This is explained easily as due to increase in ring current due to reconnection at the dayside magnetosphere. On 25-10-2003, the IMF goes negative for an extended length of time, and this is reflected in the variations of the geomagnetic field. The major results from the theory of magnetic reconnection, viz. the requirement that IMF be southward for effective coupling, the predicted entry of solar wind particles into the earth's atmosphere, the influence of solar wind on the ring current are all amply verified by the analysis of data.

A most important result is that the effect of solar wind is felt in the low latitude regions. This is evident from the fact that the geomagnetic data is taken from Huancayo, which is an equatorial station. The theory gives a clear picture of particles of solar wind origin entering the earth's atmosphere but this is mainly through the polar regions. Still, it has an impact on the dynamics of the equatorial atmosphere. One possible solution to this problem is that the magnetic field lines originating from the polar regions act as equipotentials and transfer particles along them to the equatorial regions, forming a sort of field aligned currents.

10. REFERENCES

1. Introduction to Electrodynamics by D.J.Griffiths, Prentice Hall India
2. Wikipedia articles on Solar wind, Terrestrial Atmosphere, The Earth's Magnetosphere, The Ionosphere, Solar – Terrestrial Physics and Magnetic Reconnection