International Journal of New Technology and Research (IJNTR)
ISSN:2454-4116, Volume-2, Issue-10, October 2016 Pages 28-32

IMF BZ and its Variations with the Geomagnetic Parameters –a Comparative Study at a Low Latitude Station, Visakhapatnam

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***Abstract*— Though the works on geomagnetic storms have many research articles but still the mechanism through which magnetosphere is coupled with low latitude ionosphere during the density pulse events is not comprehensively understood. So the topic is still challenging the present study is of a sudden commencement storm on July 2006 and November 2007 , both the years considered to be in low solar active period was taken into consideration. A detailed comparison of the solar wind parameters with reversal enhancements of IMF Bz and Dst is discussed.**

***Index Terms*— Geomagnetic storm, IMF Bz, low solar active period, solar wind parameters and ionospheric parameters.**

I. INTRODUCTION

The Earth's atmosphere is a layer of gases surrounding the planet Earth that is retained by the Earth's gravity. Dry air contains roughly (by molar content – equivalent to volume, for gases) 78.08% nitrogen, 20.95% oxygen, 0.93% argon, 0.038% carbon dioxide, and trace amounts of other gases; but air also contains a variable amount of water vapor, on average around 1%. This mixture of gases is commonly known as air. The atmosphere protects life on Earth by absorbing ultraviolet solar radiation, warming the surface through heat retention (greenhouse effect), and reducing temperature extremes between day and night. Fig.(a) shows the overview of the atmosphere.

The gaseous medium in which the earth is embedded plays a vital role in understanding the overall sun-earth relationship which is so essential to monitor and control several environmental and biophysical aspects of the terrestrial atmosphere. Near the ground, the atmosphere is dense and its density decreases exponentially with increasing altitude. The density and pressure at 50 km are 10-3 (0.1%) of their values at the ground level. The absorption of UV, EUV and X-ray radiations from the sun by various atmospheric constituents leads to heating, photo-dissociation and photo ionization.

The solar wind carries with it the magnetic field of the Sun. This magnetic field or the IMF (interplanetary magnetic field) has a particular orientation - southward or northward. If the IMF of the solar wind is southward and the solar wind crosses the Earth for long periods of time, geomagnetic storms can be expected. The southward IMF causes magnetic and particle energy to be injected into the Earth's magnetosphere creating storms.

Geomagnetic storms are caused by clouds of solar plasma ejected from the sun flowing a solar flare, coronal mass ejections or coronal hole afflux etc. These storms observed in recordings of magnetograms of the earth's magnetic filed, exhibits great variability and complexity, reflecting the complexity of solar phenomena. However, a classic storm has three main features. The first part consists of a sudden commencement and an initial phase. These result from a change in compression of the magnetosphere following the passage of a discontinuity such as a shock front propagating in the solar wind and correlates well with the pressure exerted by the bulk flow. The second part is the main phase. It results from an inflation of the magnetosphere by a ring current and is best correlated with previous southward turning of the interplanetary filed, which permits energy to be extracted from the solar wind by a merging of the interplanetary and geomagnetic fields at the magnetopause. The final part is the recovery phase where the magnetic filed starts increasing and tends to reach the pre-storm level with a characteristic time.

Figure 1 Overview of atmosphere from space

Ionospheric responses to geomagnetic storms are called ionospheric storms. Magnetic storm-induced behavior of ionosphere is highly variable and complex. It is known to be dependent on severity and phase of the storm, occurrence time, latitude, longitude and season etc. There have been several Studies on these aspects and the results are well documented (Somayajulu, Reddy, & Viswanathan, 1987); (Chandra, Sharma, & Aung, 2010). The most outstanding features are the dramatic decrease of F-region peak electron densities (Ne) at mid- and high latitudes and some modest increase in Ne at equatorial and low latitudes during the main phase of the storm. The F-region peal heights are found to increase at all the latitudes.

A geomagnetic storm is characterized by a main phase during which the magnetic field of the Earth's surface is significantly depressed (Chapman & Warren, 1968) introduced the familiar terms 'sudden commencement', 'initial phase', 'main phase' and 'recovery phase' to describe

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different typical storm features. The storm evolution has been made into three well-known phases: Main phase, early recovery phase where the Dst magnitude decreases rapidly, and late recovery phase where the Dst magnitude decreases at a much slower rate.

i) **Storm Sudden Commencements (SSC's)**

One of the most striking features of the geomagnetic storm is its sudden onset. The starting of the sudden commencement storms is characterized by a sudden increase in the horizontal component of the earth's magnetic field (H), as seen in the low and middle latitude magnetograms, due to a sudden increase in the usual quiet day compression of the geomagnetic field. The increase in the compression propagates into the surface of the earth as an elastic or hydromagnetic wave and is known as the storm sudden commencement (SSC). The increase in H is typically 20-30 gammas although it may occasionally be as high as 50 – 200 gammas. The sudden increase has a rise time of about 1– 6 minutes. (Burlaga & Ogilvie, 1970) showed that the SSC is due to the compression of the front side of the magnetosphere by the impact of a plasma cloud from the sun. After this sudden commencement the storm shows typical time variations as initial, main and recovery phases before the end of the storm.

Initial Phase

The continuation of the solar wind at a high level after the sudden commencement maintains the increased compression of the field, which is known as the initial phase of the storm. The initial phase lasts for about 2 to 6 hours. During the initial phase of the storm, the solar wind pressure increases and is well correlated to the increase in Dst value.

Main Phase

The initial phase is then followed by a main phase, which is characterized by a decrease of the mean value of H attained during the initial phase of the storm. A typical value of the main phase decrease may be in the order of 50-200 gammas, although larger decreases occur in extreme cases and may last for 12 to 24 hours.

This main phase decrease is caused by the flow of a westward current encircling round the earth at an altitude of about 3-4 earth's radii during disturbance times and is known as the ring current. The available ground measurements of the disturbance field (DR) are recorded as DST values (Sugiura, 1964). The DST value is a sum of the disturbance field produced by the ring current, the tail current, and the magnetopause boundary current (DCF). The occurrence of electric currents DR, DCF and tail currents is a consequence of the interaction of solar wind with the geomagnetic field. The boundary current enhances the earth's main field and the enhanced field depends on the size of the magnetosphere. On the other hand, the ring current and the tail current reduce the earth's magnetic field.

Recovery Phase

After attaining a minimum value of H during the main phase, there is a slow recovery towards the initial undisturbed value with a characteristic time of about 24-36 hours. During the recovery phase, the ring current decays due to several loss processes, e.g., charge exchange [(Richardson et al., 2006) and flow-out process [(Fu, Zong, Wilken, & Pu, n.d.) leading to the recovery of Dst index. The solar wind and the Earth's ionosphere are the two sources for the ring current ions (Gloeckler et al., 1985); (Datta-Barua, 2008).

A) Dst Index: The Dst and corrected Dst* indices are generally used on studying magnetic storms (Mayaud, 1980, Greenspan and Hamilton, 2000). Dst is the hourly measure of the globally averaged horizontal component (H) of the geomagnetic field obtained from four magnetometer stations near the equator,.

Based on the Dst index, Gonzales et al. (1994) classified the magnetic storms into three categories, with Dst ☐ -100 nT as great or intense magnetic storm, -50 nT ☐Dst ☐ -100 nT as moderate storm and -30 nT ☐ Dst ☐ -50 nT as weak storm. This classification has been extensively adopted.

B) Kp index: The Kp index is obtained from a number of magnetometer stations at mid-latitudes. The mid-latitude stations are rarely directly under an intense horizontal current system and thus, magnetic perturbations can be dominant in either the H or D component. The Kp index utilizes both these perturbations by taking the logarithm of the largest excursion in H or D over a 3-hour period and placing it on a scale from 0 to 9.

During geomagnetic disturbed times (Kp > 4), the production rate and heating of molecular ions in the topside thermosphere are enhanced and that the location of ion outflow or the acceleration process shifted to lower altitudes.

C) Ap index: The Ap index is a measure of the general level of geomagnetic activity over the globe for a given (UT) day.

D) AE index: AE index is an auroral electrojet index obtained from a number of stations distributed in local time in the latitude (the latitude where the maximum current density of the auroral electrojet flows) region that is typical of northern hemisphere auroral zone..

E) Integral proton flux (IPF): The IPF gives us the measure of number of protons in a unit sq cm area in one sec per unit solid angle (sterdian).the energy range of IPF is(>10Mev,>30Mev).

F) Solar wind Bulk speed: The solar wind consists of a vast number of charged and energetic particles moving with very high speeds. The average of these speeds is taken as Bulk speed measured in Km\sec.The more the bulk speed of the particles the more they possess the Kinetic energy.

G) Ion temperature: The temperature of the ions in the solar wind provides the nature of distribution of ions. It is measured in Kelvin.

H) Proton Density: The proton density gives us the measure of no. of protons in a unit volume .This proton density may be strong contributing to westward proton current

Availability of satellite measurements of various interplanetary plasma and magnetic field parameters associated with the development of geomagnetic storms has provided a unique platform for investigating the interplanetary causes of geomagnetic storms [(Tsurutani, Gonzalez, Kamide, & Arballo, 1997); (Huttunen, 2002); (Vichare, 2005),Besides these observational studies, the problem has been tackled through modeling studies (Alexeev & Feldstein, 2001)], a variety of storm mechanisms have been reported [(Gonzalez, Clúa de Gonzalez, Sobral, Dal Lago, & Vieira, 2001) due to the complexity involved in each storm event. This complexity could be due to varying nature of the storm sources such as simple coronal mass ejections (CMEs), magnetic cloud structures, multiple occurrences of CMEs, high-speed solar wind streams, etc. The magnetosphere responds differently to different interplanetary causes, thus leading to the alteration of the each storm. (Rout et al., 2016) concluded that is important to note that the prompt electric disturbances presented in there investigation occurs essentially through the increase in the ram pressure. However, based on a case study, it is rather difficult to comment on the differences in the ionospheric effects corresponding to change in solar wind density or velocity. More investigations are needed to address this issue.

II. DATA AND METHOD OF ANALYSIS

During the Solar Minimum period of 2006-2007 a two cases of sudden commencement having H (γ) strength greater than 100nT has been considered for the present study. It is known that the Interplanetary Magnetic Field (IMF Bz) Component plays an important role in the generation of geomagnetic activity.

IMF vector near the earth are on average lying near the ecliptic plane, there is often a significant Bz component which is important for the generation of Geomagnetic activity. Two main causes are thought to be responsible for the generation of IMF Bz an inherent magnetic field existing inside plasma clouds in the solar wind and 3-D disturbances of ambient magnetic field by moving plasma inhomogeneties.The purpose of this section is to study the interplanetary causes of magnetic storms and the storm time ionospheric effects observed at a low latitude station, Waltair (17.70N, 83.30E, 200N dip) and the variations of the Solar wind parameters during the period 2006 – 2007.

III. RESULTS AND DISCUSSION

Ionospheric response to geomagnetic activity was discussed by(Araujo-Pradere, Fuller-Rowell, & Spencer, 2006), and (Echer, Gonzalez, & Tsurutani, 2008).It is interesting to note that one of the most important effects of space weather is that on trans-ionospheric radio wave propagation, the effect of ionospheric scintillations is severe. Ionospheric scintillation is defined as the fluctuation in the intensity of the signal as it passes through the irregularities present in the ionosphere. Radio wave signals transmitted from geostationary satellites and recorded by ground based receivers yield information about the ionospheric irregularities producing the scintillations. Several workers have reported geomagnetic control over the occurrence of scintillations at equatorial and low latitudes (Aarons & DasGupta, 1984); (Basu, Groves, Basu, & Sultan, 2002). Nevertheless, it is not yet possible to forecast the response of scintillations to geomagnetic storms, due to the complexity and unique character of each particular geomagnetic storm. The development of a global specification and forecast system for scintillations is needed in view of our increased reliance on space-based navigation and communication systems. This requires obtaining more experimental data on various parameters for every geomagnetic storm to come to a reliable understanding of geomagnetic storm effects on the ionosphere and ionospheric irregularities producing scintillations

Storm of 9th - 12th July 2006

The Sudden commencement magnetic storm with a maximum negative Dst excursion of nearly -23nT occurred around 2145hrs UT and had its recovery phase on 12th July around 2100HrsUT with H(γ) equal to 104.Following the southward turning of IMF Bz the AE-index has started increasing from 250nT around 1400Hrs UT and reached a maximum value of about 600nT around 1600Hrs UT.The Sym H has shown a sudden decrease from 10nT to a negative excursion of about -40nT around 1600Hrs UT and at recovery phase it has decreased to -20nT.The dsymH/dt has exhibited a small negative excursion of about -6nT/10min around 1400Hrs UT. Scintillation patch of 93min duration is observed on 9th July (Fig.2) .The occurrence of maximum Dst excursion of the storm during the post sunset hours has favored for the enhanced occurrence of irregularities during night (Rama Rao et al., 2009)

The h’F value has shown a peak increase of 300Km around 0400Hrs UT during 9th and 10th July 2006.An intense Spread-F is observed on the subsequent days of the storm sudden commencement i.e. on 10th,11thand 12thJuly.The foF2 value has been increased 9MHz on 9th July around 24Hrs UT the above results are well compared with those reported by (Kumar & Gwal, 2000).These results have been interpreted in terms of the coupling of high latitude and magnteospheric current systems with equatorial electric fields.

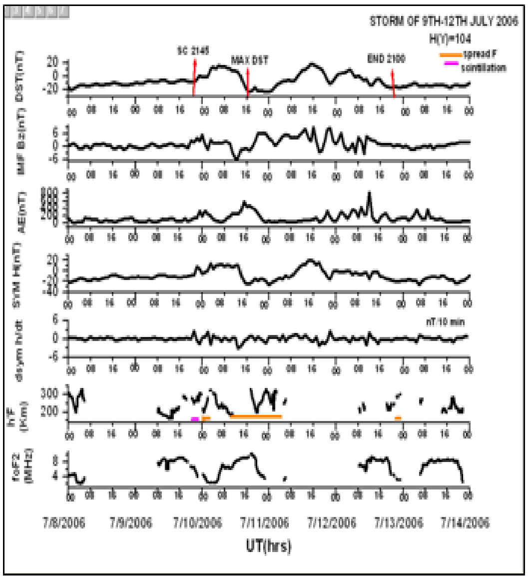
The solar wind parameters Bulk speed and Ion temperature have been increased following the southward turning of IMF Bz (Figure.b) The bulk speed has been increased and reached a maximum value of about 550Km/s around 0800Hrs UT on 12th July. The Ion temperature has shown Maximum value of about 2.50 K around 2000Hrs UT, where as the Proton density has suddenly decreased to 10(p/ster/cm) around 2000hrs UT on 20th July 2006.

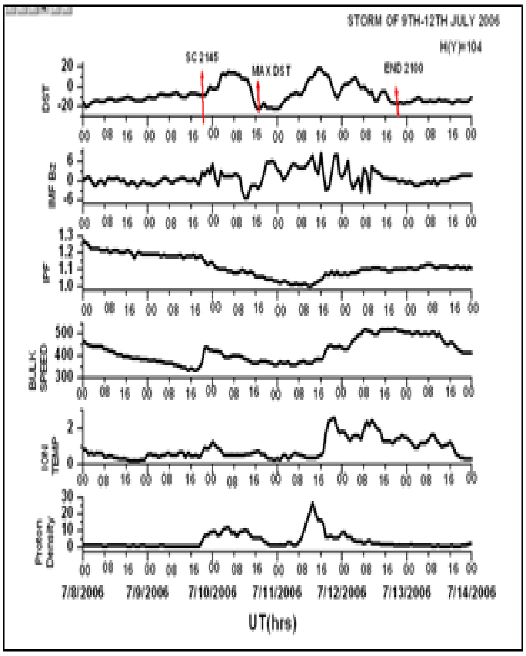
Storm of 19th -21st November 2007

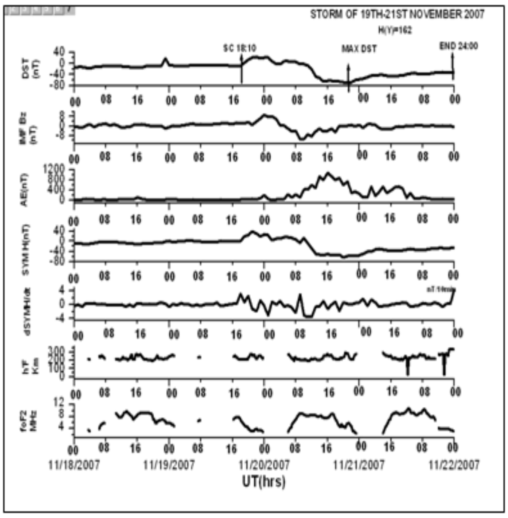
Figure(c) shows the sudden commencement storm that has occurred on 19th November 1810Hrs UT with H(γ) value equal to 162 and reached its recovery phase around 2400Hrs UT on 21st November . The Maximum negative excursion of Dst occurred on 22nd November with a value of -73nT.

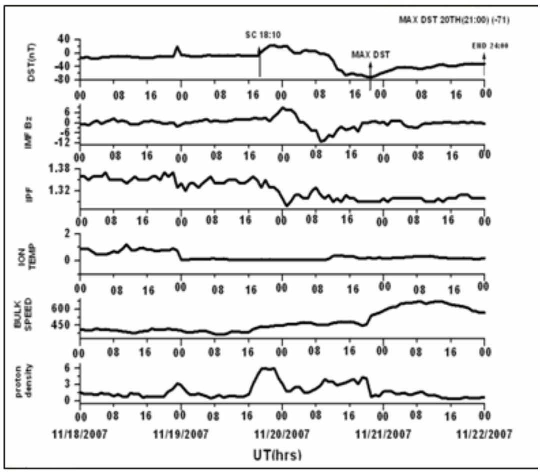
Following the southward turning of the interplanetary magnetic field, IMF Bz showed a strong negative component of -8nT around 1000Hrs UT.During the same time, the AE-index exhibits a sudden increase starting from 400nT around 1000Hrs UT reaching a value of 1200nT around 1600Hrs UT.The Sym-H index has shown a value of -30nT around 1000Hrs UT .It has gained a constant value soon after the recovery phase. Following the southward turning of IMF Bz dsymH/dt exhibited a positive excursions of around 4nT which is very different from the normal observations around 1000Hrs UT on 20th November. On the same day around 1000hrs it has shown a decrease of about -4nT/min around 1200hrs UT .The h’F confined to less than 300Km but at recovery phase it has shown a dip (100Km) in altitude .The foF2 value shown a maximum of 10MHz.

The solar wind parameter the IPF has not shown any definite trend in variations before and after the commencement of the storm (Figure.c). The Bulk speed has shown an increase in its values around the maximum Dst excursion while the Proton Density has been decreased to a value of 3(p/cm/ster) around 1000 Hrs UT on 20th November 2007.









IV. SUMMARY OF RESULTS

Studies on the ionosphere during the storm time are important because they are the regions where many adverse effects occur, and also because they are strongly coupled to the other regions in the space.In the present study the results presented on the behavior of the ionospheric parameters (foF2 and h’F), interplanetary parameters (IPF, AE) and solar wind parameters (proton density, ion temperature, bulk speed, integral proton flux) during some of the moderate geomagnetic storms. In general all the above parameters showed some considerable changes during the storm time. In most of the cases positive storm effect is observed. The time marked decrease in Sym-H index along with the simultaneous occurrence of spread-F during the local post sunset hours is observed which is explained on the basis of the prompt penetration of eastward electric field into low latitudes. The dsymH/dt values for both gradual commencement and sudden commencement storms have shown a marked decrease of about 2 to 10nT/10min during the storm time. A sudden increase in AE-index and / or at the same time with a simultaneous marked decrease in Sym H and southward turning of IMF Bz has been observed. July 2006 and November 2007 storms, VHF scintillations for about 30min to 2hrs duration have been observed over Waltair soon after the commencement of the storm and at the maximum negative excursion of Dst.

Scope of the study As the storms offer an excellent opportunity to study plasma dynamics as well as ionosphere-thermosphere coupling, it is planned to make a comprehensive study on the severe magnetic storms and retrieve the most salient ionospheric effects of the geomagnetic storms.

Acknowledgments

The author is thankful for the data provided by Prof D.S.V.V.D.Prasad and Prof K.Niranjan and also UGC for assisting me with fellowship.

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