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Solar interplanetary transient causes of large geomagnetic storms

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***Abstract-* Geomagnetic storms are intervals of time when a sufficiently intense and long-lasting interplanetary convection electric field leads, through a substantial injection of energy into the magnetosphere-ionosphere system, to an intensified ring current, strong enough to exceed some key threshold of the quantifying storm time D_{st} index. Recently, it is believed that coronal mass ejections (CMEs) are to be responsible for major interplanetary disturbances and large geomagnetic storm. In the present work, we have discussed solar and interplanetary causes of large geomagnetic storms on basis of three case studies. All three geomagnetic storms (observed during 7th April 2000, 16th July 2000 and 22nd October 1999 respectively) were caused by coronal mass ejections. The sources of interplanetary southward magnetic field, B_Z, responsible for the occurrence of the storms were related to the intensified shock/sheath field, interplanetary magnetic cloud's field, or the combination of sheath-cloud or sheath-ejecta field.**

***Keywords:* Coronal mass ejection (CME), Storm time index (D_{st}), Geomagnetic storms, Interplanetary magnetic field.**

I INTRODUCTION

The variation of geomagnetic field can be classified in to short term variation caused by e.g. by flares, geomagnetic storms, and long term variations (some quasi-periodicity of 250,000 years). geomagnetic storm is global disturbances earth's magnetic field usually occurred due to abnormal condition in the inter planetary magnetic field(IMF) and solar wind plasma emission caused by various solar phenomenon. furthermore the magnitude of these geomagnetic effects largely depend upon the configuration and strength of potentially geo-effective solar/interplanetary features.we observed that IMF B is highly geo-effective during main phase of magnetic storms., while it more siginificant at storm peak, which contributed by southward component of IMF Bz substading earlier findings. the correlation between Dst and wind velocity is higher, as compared IMF Bz and ion density. it has been verified geomagnetic storm intensity is correlated well the total magnetic field strong of IMF better than with its southward components .geomagnetic storms – generally occurred due to abnormal condition in interplanetary magnetic field(IMF) and solar wind plasma emission caused by various solar Phenomenon.(Akasofu,1983;Joselyn et al ,1981). geomagnetic activity is related to variety of interplanetary plasma, field parameters, e.g. solar wind velocity, Interplanetary magnetic field IMF(B)and Bz(Akasofu,1983;Joselyn et al ,1981;Gonzalez et al.,1994)., furthermore ,the strong geomagnetic disturbances is associated with passage of magnetic cloud(Gonzalez et al.,1994).,which cause intense and severe Geomagnetic storms(Kaushik et al., 2000). solar wind is commonly emanating from Sun's outer corona and engulf the entire heliosphere.it mainly consist of hot electrons and protons flowing supersonically and caused due to extremely high coronal temperature helping ionized plasma to over come the gravitation attraction of the sun. the density and speed of this flow is highly variable and depends solely upon the conditions which has caused it to ejected ; the solar wind carries with it the magnetic field of Sun,which when enters to the interplanetary medium is termed as Interplanetary Magnetic Filed(IMF). the strength and orientation of this magnetic field associated with solar wind depend up on it's interactionbetween Coronal Holes and leads to create Co-rotating interaction region (CIR). (Akasofu,1983; Kaushik et al., 2000). Geomagnetic disturbances are generally represent by geomagnetic storms and sudden disturbances (SIDs). These caused by the disturbances originated at Solar atmosphere, Interplanetary (IP) shocks and /or stream interface associated with high speed Solar wind stream(HSSWS)(Shrivastava et al.,1990). these are associated with coronal holes. Which occur in Polar Regions or higher latitude? Fast CME produce Transients IP shocks, which cause storm sudden commencement at earth. geomagnetic storms are associated with isolated disappearing filaments(Lakhina,1994).The occurrence of prominences and Flares are also associated with varying phases of sunspot cycle leading to the geomagnetic storms, the strength of IMF and it's fluctuations have also shown to be most important parameters affecting the geomagnetic field condition. South direction of IMF,allow sufficient energy transfer from the solar wind in to earth magnetosphere through magnetic reconnection(Kaushik et al.,1999). As a geomagnetic storms lasts usually a few to several days in duration.However,some times the recovery phase of geomagnetic storms last, one to two weeks .or even for longer durations.

The geomagnetic activity is generally represented by electromagnetic coupling, V×B, where V is the velocity of solar wind streams and B is the IMF magnitude. Two types of solar wind streams: co rotating flows and transient disturbances are responsible to originate two kinds of geomagnetic storms, termed as sudden commencement and gradual commencement storms. The north-south component of IMF B_Z plays a dominant role in determining the amount of solar wind energy to be transferred to the geomagnetosphere (Arnoldy, 1971; Akasofu, 1981). When the IMF has large magnitude (≥10nT) and a large southward component, the amount of transferred energy become very large. On the other hand, the transferred energy becomes very small when the IMF is directed preliminary northward. The energy transfer efficiency is of the order of 10% during intense magnetic storms (Gonzalez et al., 1989). Viscous interaction, the other prime energy transfer mechanism proposed, has been shown to be only <1% efficient during intense northward directed IMFs. Interplanetary Coronal Mass ejections (ICMEs), i.e. , the interplanetary manifestations of Coronal mass ejections (CMEs),are responsible for the severest of geomagnetic storms when they impinge upon Earth's magnetosphere. In fact, Earth spends in the flows related to ICMEs anywhere from 10% of the time during Solar minimum to 35% of the time during Solar maximum (Richardson et al.2002; Clivers et al. 2003). Thus, Studies on ICMEs are important because of their direct to space environment. Webb et al (2000) showed that halo CMEs associated with surface activity within 0.5 R_{Φ} of Sun center appear to be excellent indicator of increased GeoActvity several day latter. Then, it is found that the solar sources of those CMEs that intercepted several day latter. Then, it is found that that solar sources of those CMEs that intercepted Earth mainly located within latitudes ±30˚ (Gopalswamy 2002; Wang et al 2002;Reinard 2005). Recently, Riley et al (2006) showed the evolution of source latitudes of halo CMEs for which corresponding ICMEs could identify in 1AU

The CMEs play a key role in the solar-terrestrial relationship (Gosling 1993, Webb 1995). When an ICME impacts the Earth's magnetosphere, it may disrupt the Earth's magnetosphere, compressing it on the day-side and extending the night-side tail. When the magnetosphere reconnects on the night side, it creates trillions of watts of power which is directed back towards the Earth's upper atmosphere. This process can cause particularly strong aurora also known as the Northern Lights, or aurora borealis (in the Northern Hemisphere), and the Southern Lights, or aurora australis (in the Southern Hemisphere). Geomagnetic storms are often preceded by abrupt increases in the northward component of the Earth's magnetic field, called sudden commencements, which are well correlated with interplanetary shocks.

The strength of interplanetary magnetic field and its fluctuations have been shown to be most important parameters affecting the geomagnetic field variations. The most of important shock waves originate at or near the Sun, as an active region and consequently, the entire shock disturbances engulf the earth, the various phases of geomagnetic storms are produced (Akasofu & Chao, 1980). The exact measurements of geomagnetic field variation are capable to remote sensing the nature of solar wind, IMF and *vice versa*. The north-south component of IMF B_z plays a crucial role in determining the amount of solar wind energy to be transferred to the earth's magnetospheres (Arnoldy, 1971; Tsurutani and Meng, 1972; Russell and McPherron, 1981; Akasofu, 1981). The mechanism of transferred solar wind energy into the earth's magnetosphere depends upon magnetic reconnection between IMF and earth's magnetic field. When the IMF B has large magnitude and a large southward component IMF B_z, the amount of transferred solar wind energy becomes very large, which causes intense geomagnetic disturbances. Conversely, when IMF B_z is directed primarily northward, the transferred energy becomes very small and produces small geomagnetic disturbances. During the solar maximum, the presence of active regions provides an opportunity to increase IMF B magnitude and large southward component, resulting in a large number of intense geomagnetic disturbances. Conversely, small and fewer numbers of geomagnetic disturbances are observed during solar minimum due to solar rotation and presence of coronal holes.

II DATA ANALYSIS

The aim of the statistical study presented in this paper is to analyse solar and interplanetary causes of large geomagnetic storms on basis of three storm events observed during 7th April 2000, 16th July 2000 and 22nd October 1999 respectively. CMEs observations are found by the Large Angle and Spectroscopic Coronagraph (LASCO), and by the Extreme Ultraviolet Imaging Telescope (EIT), both on board of the Solar and Heliospheric Observatory (SOHO). Interplanetary magnetic field and plasma data are taken by the Advanced Composition Explorer (ACE) satellite, sitting in the L1 point, close to the Earth.

III RESULTS AND DISCUSSIONS

Event 1 # Geomagnetic storm observed during 7th April 2000

A large geomagnetic storm event of maximum phase of solar cycle 23 was observed on 7th April 2000 with D_{st}, K_p and A_p magnitude of -288, 8.7 and 300 respectively. This geomagnetic storm is gradual commencement type having main phase duration -8 hours and recovery phase duration -58 hours. The solar origin of this geomagnetic storm is the full halo CME occurred during (16:54 UT and 17:18 UT) at 04/4/2000 measured by LASCO instruments. A solar flare on 4th April 2000 (16:37 UT) measured at heliographic position (N16°W66°) thus far from the central meridian. Associated with this flare was a fast CME, with expansion speed of around 1927 km/s, spreading all around the solar disk, creating a full halo. The CME expansion speed is the CME growth rate in the direction approximately perpendicular to the fastest plane-of sky radial CME speed. Variations of different interplanetary and geomagnetic parameters are presented in **Figure 1**. From the plot soon after the shock "S", the Z-component of the magnetic field turns southward and is intensified because of a compression of the sheath region, remaining like that for approximately 18 hours, making the D_{st} index to fall to -288 nT. The total magnetic field jumps across the shock from 7 to 25 nT. No ejecta structure is observed after the shock.

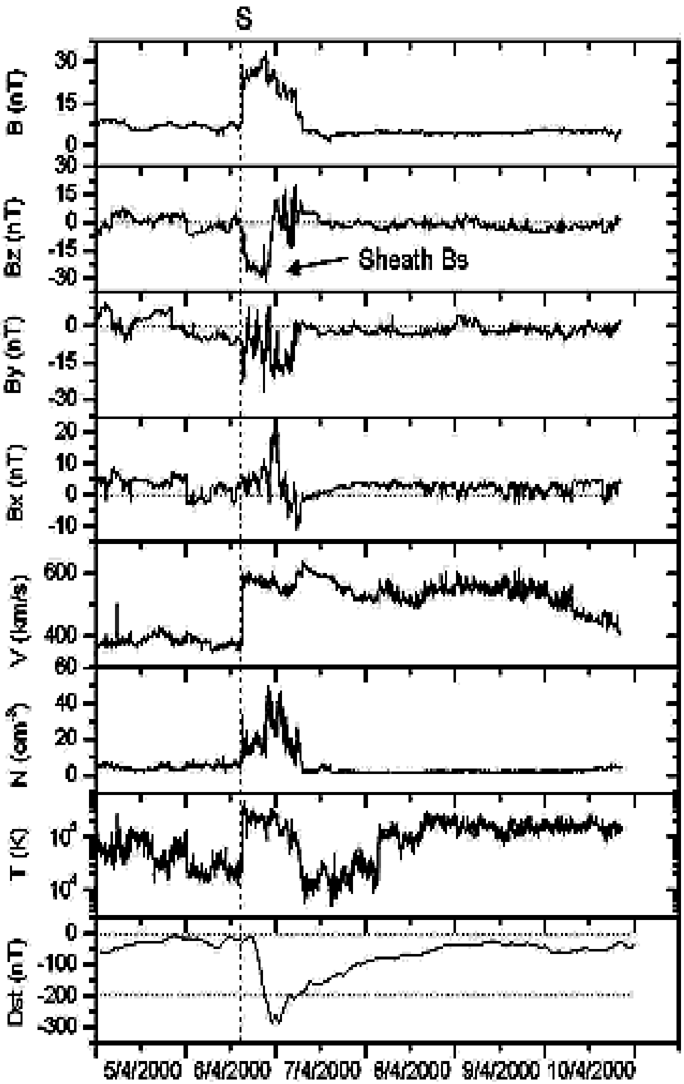

Figure 1 Shows the association of interplanetary magnetic field and its components, B_z, B_y and B_x, solar wind (proton) speed, number density and temperature, and the D_{st} index for the period of 5-11 April 2000.

Event 2 # Geomagnetic storm observed during 16th July 2000

Another large geomagnetic storm event of maximum phase of solar cycle 23 was observed on 16th July 2000 with D_{st}, K_p and A_p magnitude of -301, 9 and 407 respectively. This geomagnetic storm is sudden commencement type having initial phase duration -1 hour, main phase duration -9 hours and recovery phase duration -89 hours. The solar origin of this storm is the full halo CME occurred during (10:54 UT and 11:42 UT) at 14/7/2000 measured by LASCO instrument. A flare measured on 14th July 2000(10:24 UT) at heliographic position (N17E01) from AR9077 thus far from the central meridian. Associated with this flare was a fast CME, with expansion speed of around 2177 km/s, spreading all around the solar disk, creating a full halo. The CME expansion speed is the CME growth rate in the direction approximately perpendicular to the fastest plane-of sky radial CME speed. Variations of different interplanetary and geomagnetic parameters are presented in **Figure 2**. From the plot an interplanetary shock driven by a magnetic cloud, whose intense magnetic field (50 nT) rotates from south to north smoothly. While pointing southward, it causes a very intense fall in the D_{st} index, reaching its minimum of -301 nT. The interplanetary shock at 1 AU indicated by the "S" line in Figure 4.27 could only be identified in the magnetic field data, because the plasma detector aboard ACE suffered a temporary black-out as a consequence of the flare accelerated particles.

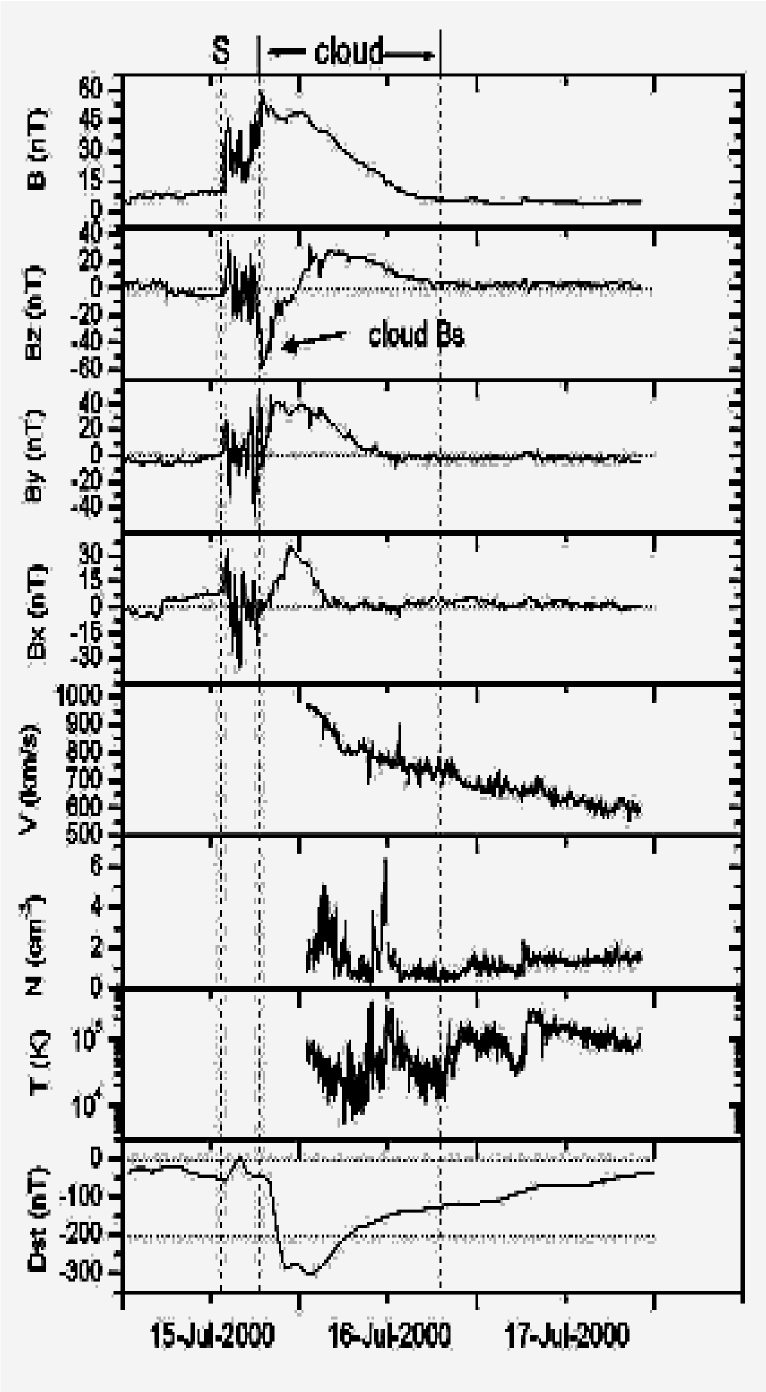

Figure 2 Shows the association of interplanetary magnetic field and its components, B_z, B_y and B_x, solar wind (proton) speed, number density and temperature, and the D_{st} index for the period of 15-17 July 2000.

Event 3 # Geomagnetic storm observed during 22nd October 1999.

Third large geomagnetic storm event of arising phase of solar cycle 23 was observed on 22nd October 1999. This geomagnetic storm is sudden commencement type having peak magnitude -235 nT, initial phase duration -1 hour, main phase duration -7 hours and recovery phase duration -95 hours. The solar origin of this geomagnetic storm is the partial halo CME occurred during (02:06 UT and 10:18 UT) at 18/10/1999 measured by LASCO instrument. A solar flare measured on 17th October 1999 (23:12 UT). Variations of different interplanetary and geomagnetic parameters are presented in **Figure 3**. In the plot dotted line "S" indicates the arrival of a shock, followed by an ejecta, which was not of a magnetic cloud type. The average magnetic field of the structure is of the order of 20 nT, except at the rear part, where it jumps to around 36 nT. At this rear portion of the ejecta, the magnetic field was pointing substantially southward, thus causing the D_{st} to fall to -237 nT. Following this ejecta, one can observe a high speed stream, which is overtaking it. At the interface, a jump in speed, density and temperature is present. Probably this interaction was the cause of the magnetic field of the ejecta to jump, as a result of compression. This event is very interesting, because the related CME had an expansion speed of 546 km/s, which is considered a slow speed, very close to the normal solar wind speed. Also, this CME was not very much traveling towards Earth because it was a partial halo CME, i.e. its main propagation direction was considerably out of the Sun-Earth direction. Nevertheless, it caused a very intense geomagnetic storm. This event is unique in the group, and our conclusion is that the cause of the storm was mostly interplanetary interactions, rather than solar.

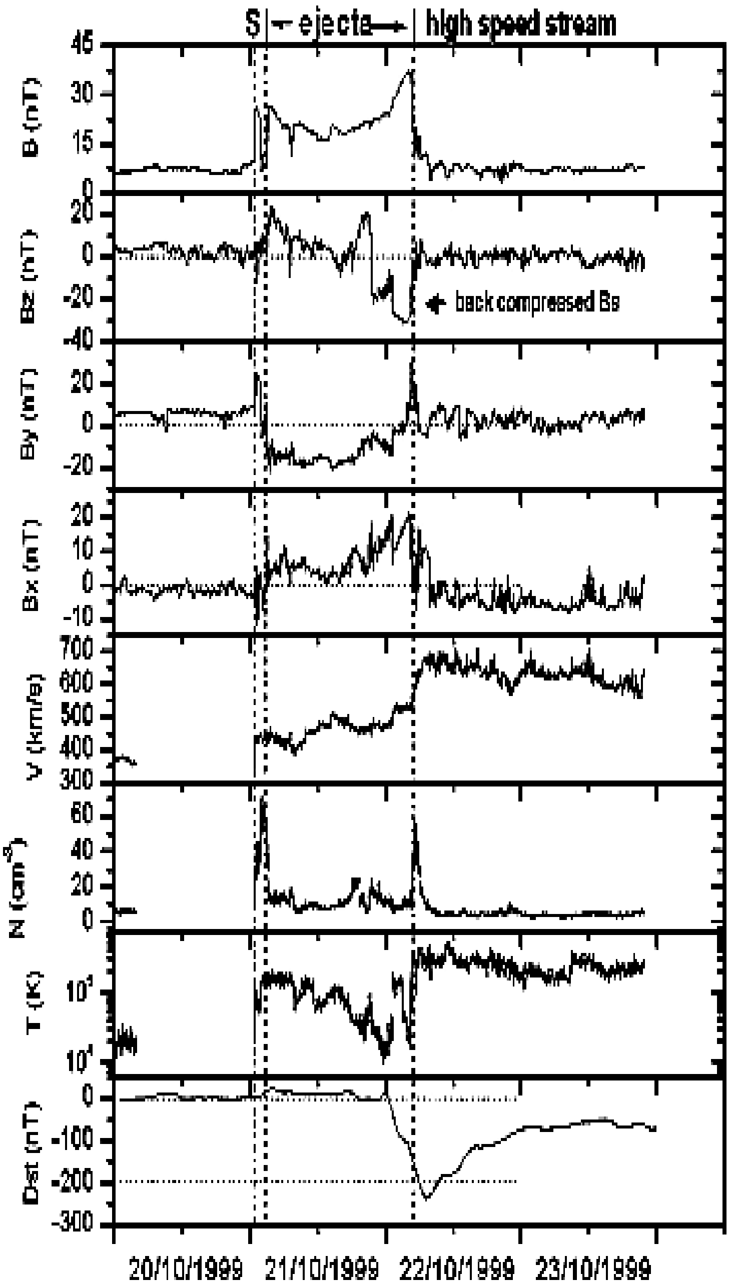

Figure 3 Shows the association of interplanetary magnetic field and its components, B_z, B_y and B_x, solar wind (proton) speed, number density and temperature, and the D_{st} index for the period of 20-23 October 1999.

IV SPACE WEATHER

Solar and interplanetary origin of space weather disturbances, as well as related magnetosphere dynamics,. Geomagnetic storms are usually defined by geomagnetic field Horizontal Component variations, but actually are disturbance in Plasma populations present in the entire magnetosphere.

V SOLAR ACTIVITY

The corona driving the geospace processes has it's Fundamental origin in the Sun's Core. Nuclear Fusion inside the Sun's Core generates radioactive energy that propagate outward, subsequently is transformed in convective motion Energy in Sub-surface Layer's .The dynamo action produces intense magnetic fields in the solar atmosphere, which transported outward to the Interplanetary space with plasma in the Solar Corona.(Parker 1958;Neugebauer and Synder 1996).The magnetized solar wind flows continuously by Interplanetary medium and interact with Planetary magnetic field's delimiting their magnetosphere. Beside the presence of this background and continous solar wind,in the Interplanetary space is permeated the solar activity Flares and CMEs. Solar-terrestrial phenomena such as Solar Interplanetary and magnetospheric.

Large disturbances in Space weather, such as intense geomagnetic storms, shock waves and energetic particles events are mostly associated with two solar activity transients: Solar Flares and CMEs.these events seem to be single phenomenon, a solar magnetic eruption(Gosling 1993).

Solar wind's flows at variaties in the range of 250-1000km/s.such as density,composition,and magnetic field strength,among others,vary with changing condition on the Sun. solar wind basically a Proton-electron gas that flows from the Sun(and outward to entire Solar system) with velocity arround400-500km/s density5cm^{-3} and interplanetary magnetic field of 5nT.

Rapidly fluctuating geomagnetic field can Induced currents into Pipe lines it related to solar origin,the type of disturbances generated near Earth(electromagnetic and particles) and impact on Technological systems(Lanzeroti,1979;Garret,1981;Jansen and Pirjola,2004).

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