ENERGY COUPLING OF SOLAR WIND AND EARTH'S MAGNETOSPHERE DURING SUPER INTENSE STORMS

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Abstract: The present study confirms the crucial role of southward Interplanetary Magnetic Field (IMF) in triggering the geomagnetic storm main phase as well as controlling the magnitude of the storm. The main phase interval shows clear dependence on the duration of southward IMF. The present paper computes the solar wind energies and magnetospheric coupling energies for every intense geomagnetic storm Disturbed Storm Time (Dst ≤-100 nT) of January 2003-March 2005. Computation of the solar wind- magnetosphere coupling function considers the variation of the size of the magnetosphere by using the measured solar wind ram pressure. During the main phase of the storm, the solar wind kinetic energy ranges from 10E+17 to 91E+17 J the total energy dissipated in the auroral ionosphere varies between 135E +15 to 336E+15 J. To see the effect on geomagnetic field components at "Maitri" the Indian Antarctic Station (geog. Latitude and Longitude 70.46^{o} S, 11.44^{o} E) have been taken in the present analysis. It is observed that the geomagnetic field components at "Maitri" vary with respect to these parameters.

Keywords: Solar Wind Energy, Magnetospheric Coupling Function and Geomagnetic Field.

Introduction: Geomagnetic disturbances are driven by solar wind-magnetosphere coupling. Solar wind energy is injected into the magnetosphere through field line merging of the IMF and geomagnetic field. This energy injection is most efficient during southward IMF (Bz component). Observations have shown that a state of Bz ≤ - 10 nT lasting for over 3 hours will always generate a geomagnetic storms and Solar wind velocity (V) is another important factor. Geomagnetic storm development is a strong positive correlation with the product of these two physical quantities, VBz. When the southward component is dominant in the strengthened magnetic field, its interactions with the geomagnetic field are strengthened, driving a geomagnetic storm.

According to some researchers, a fluctuating IMF, even with smaller southward amplitude, could result in enhanced AE but not in larger deviation of Dst index. During magnetic storms, auroralelectrojet shifts equatorward. Hence the AE indices based on subauroral observatories are more relevant for the magnetic storm studies. However, the AE indices of 1-min time resolution used in the present study are downloaded from World Data Center, Kyoto, which is based on maximum of 12 auroral observatories (geomagnetic latitude > 60^{o}).The study confirms the crucial role of southward IMF in triggering the storm main phase as well as controlling the magnitude of the storm. An attempt is made to identify the multipeak signature in the ring current energy injection rate during main phase of the storm. The present analysis computes the solar wind energies and magnetospheric coupling energies of each storm under examination. Computation of the solar wind-magnetosphere coupling function considers the variation of the size of the magnetosphere by solar wind ram pressure. During the main phase of the storm, the solar wind kinetic energy ranges from 9E+17to 72E+17 J with an average of 30E+17 J; the total energy dissipated in auroral ionosphere varies between 2E+15 and 9E+15 J, whereas ring current energies range from 8E+15to 19 E+15 J [1].

In recent years, a number of investigations have been carried out to understand the solar-terrestrial relationship and to ascertain factors that are responsible for severe geomagnetic storms [2]-[5]. The kinetic energy of the interplanetary solar wind impinging on the magnetosphere per unit time can be given as

$$USW = (1/2).\rho.V_{SW}^{3} .A$$

Where Vsw is solar wind velocity and ρ is mass density of solar wind. A is the cross section of the dayside magnetosphere and is taken as (30 R_E)^2 [6] and R_E is the Earth's radius. The solar wind-magnetosphere coupling parameters have been studied for several years [7]. The most widely used coupling parameter is given by [8] as Energy coupling function (ε) ;

$$\varepsilon = VswB^{2} L_{0}^{2} (Sin^{4} \vartheta / 2)$$

Where B is the magnitude of the IMF and ϑ is the angle between the geomagnetic field vector and the IMF vector at the front of the magnetosphere in the equatorial plane, L_o is the radius of the dayside magnetopause. Normally, L_o is considered to be fixed at 7 R_E, under the assumption of stationary dayside magnetopause [8],[9].

1.2. Data selection and methodology: To monitor the effect of orientation of IMF on geomagnetic field components we have taken the data January 2003 -

March 2005 of "Maitri" the Indian Antarctic Station during XXIV Indian Antarctic Expedition. For this study we have taken those events in which the magnitude of IMF_Bz was either 20 nT or grater than 20 nT, Dst ≤-100 nT and AE grater than 1200 nT. The Data of Dst and AE are taken from World Data Center, Kyoto, which are based on maximum of 12 observatories. As the Dst index is a measure of geomagnetic activity and used to assess the strength of geomagnetic storms. The southward orientation of IMF is important for the formation of magnetic storm.

The solar wind parameters such as wind velocity, density, temperature, and IMF components obtained from Advance composition Explorer (ACE) satellite. The data are based on Solar Wind Electron Proton Alpha Monitor (SWEPAM) measurements. We have taken all the components in GSM co-ordinate system. With the help of these parameters we have calculated the kinetic energy of the interplanetary solar wind impinging on the magnetosphere per unit time and total energy input to the magnetosphere. To study the effect of intense storm on the geomagnetic field, we have used the geomagnetic field components of Maitri as north- south component (X), east-west component (Y), vertical component (Z) and horizontal component (H) components. The geomagnetic Latitude and Longitude of Maitri is (70.46° S, 11.44° E). We have selected the X, Y, Z and H component to study because the presence of field align currents causes very rapid fluctuation in D components at high latitude. The data of geomagnetic field components were taken from Indian Institute of Geomagnetism (IIG), Mumbai.

1.3. Observations and results: On behalf of the effect of orientation of IMF on energy of the magnetosphere and the geomagnetic field components we have analyzed the data period of January 2003- March 2005. We have taken all severe events for this study and we found 13 cases in which the IMF has magnitude greater than -20 nT. Out of these cases we took only those cases in which the storm time disturbance was less than -100 nT and AE index was grater than 1500 nT. For these five cases: 29/05/2003, 29/10/2003, 26/7/2004, 7/11/2004 and 21/01/2005 we have calculated the kinetic energy of the interplanetary solar wind impinging on the magnetosphere per unit time (Usw) and total energy input to the magnetosphere (Epsilon). In this study we are presenting the one event only.

1.3. Case 1:29 May 2003: During this event the sudden storm commencement time was 1224 UT on 29 May as shown by **Table 1**. **Figure 1** has seven panels, the first panel shows the proton density in cm $^{-3}$, second panel shows the proton velocity in km/s third panel shows the proton temperature in degree Kelvin, forth, fifth, sixth panels show the X,Y,Z component of IMF in nT and seventh panel shows the magnitude of IMF. The proton density and proton velocity start increasing at 1100 UT on 29 May and gain its maximum peak value ~51 particles per cm ^{3} and 814 km/s at 2200 UT and 1900 UT on the same day. At 1800 UT the velocity of proton was maximum ~ 848 km/s at 1600 UT temperature got its peak 1.12E+6 degree Kelvin. At 1400 UT on 29 May the X component of IMF start fluctuation and it have maximum value of -28 nT at 2000 UT on the same day. Similarly Y and Z component stats vary at 1100 UT on 29 May and at 1800 and 1900 UT they got maximum value ~ - 27 nT and – 33 nT on the same day. The Bmag has one peak on 29 May at 2100 UT ~ 37 nT and on 30 May it got its second peak of ~40 nT 0600 UT.

In **Figure 2** there are five panels. First panel shows the Dst index, second panel shows the AE index third Panel is vertical component of IMF and forth panel is the interplanetary solar Wind kinetic energy (Usw) and last panel is total input energy to the magnetosphere (Epsilon). The Dst and AE indices are the hourly data from world data center. The maximum negative excursion of storm time disturbance was -131 nT at 0300 UT on 30 May and AE index has maximum value of 1758 nT at 2000 UT on 29 May. The vertical component of IMF has southward value ~33 nT at 1800 UT. The kinetic energy of the interplanetary solar wind impinging on the magnetosphere per unit time (Usw) and total energy input to the magnetosphere (Epsilon) were 44E+17 J and 174E+15 J respectively. **Figure 2** shows that when the IMF was southward then the solar wind impinging the magnetosphere and the coupling function was also highest at the same time.

To study the effect of this event on geomagnetic field components we have analyzed the data of high latitude Maitri of the same duration as shown in **Figure 3**. As the SSC time was 1224 UT so the little bit fluctuation starts in X component Earth's magnetic field at 1400 UT on 29 May, on 1800 UT X increases ~ 760 nT and then decreases at 1900 UT and 2200 UT ~ -845 and ~ -944 nT respectively. Y component increases at 1800 UT and 2200 UT with value ~ 614 and 789 nT respectively, at 1900 UT it decreases with value ~ -693 nT. On the same day the Z component decreases with value ~ -1003 nT at 1800 UT. The horizontal component of geomagnetic field shows the first increment at 1500 UT of ~379 nT, second, third and forth at 1800, 1900 and 2200 UT of ~ 860, 846 and 1098 nT respectively. Thus the effect of the event observed at Earth 1400 UT in X component with delay of 0216 UT. As there is the strong IMF value that event is very severe. Hence we have seen that there are the large variation in the geomagnetic field components as the interplanetary magnetic field varies.

1.4. Conclusion and discussion:

We have computed some components of magnetosphere involved during the occurrence of storm. The energies in the units of Joules are obtained through time integration of the energy rates. In order to estimate the total energy input to the magnetosphere, we have used epsilon parameter. Table 1 indicates the energy during main phase of the storm. Usw denotes total kinetic energy of solar wind. During the main phase of the storm, the energy available in the solar wind ranges from 10E+17 to 91E+17 J. Earlier study by [12] have reported an average value of 65E+17 J for the solar wind energies for the four storms taking place between 1980 and 1982, whereas study by [10] estimates the solar wind kinetic energy equal to 20–50E+17 J. Thus the present estimates are in good agreement with the earlier investigations. It should be noted that for the computation of solar wind kinetic energy, the magnetosphere scale length for the effective cross section to be equal to a constant value of 30 RE [6], which could lead to considerable residual uncertainties in the estimates of Usw, whereas computation of magnetosphere coupling energy takes into account the movement of the dayside magnetopause, and hence the uncertainties involved are not significant. The duration of the first phase is determined by the inspection of various energy rates, especially epsilon parameter. It should be noted that in the present study, we consider the recovery phase ends at the time when the derivative of Dst is significantly small, rather than when Dst reaches exactly to its prestorm value. It would be interesting to study the energetics involved in the storm main phase and recovery phase separately. During the main phase of the storm the geomagnetic field components varies at Maitri according to the intensity of the storms and in the recovery phase all the components get smooth.

All five cases confirm the crucial role of southward component of IMF (BZ) in the development of the geomagnetic storm. The present investigation reveals that the strength of ring current (Dst deviation) depends on the magnitude of southward IMF. Thus the present investigation confirms the ring current development is mainly controlled by the southward turning of the IMF. Besides this we also observe measurements of the geomagnetic field components at Maitri appear to have some signatures of southward turning of the IMF of short duration and of the enhancement in solar wind density . This suggests that at high latitude, how much variations are observed? The geometry of the IMF and the Earth's magnetic field favored lobe reconnection on the front surface of the magnetotail in the Southern magnetosphere. The precipitating electrons were probably accelerated by parallel electric fields resulting from converging horizontal electric fields associated with convection enhancements due to lobe reconnection. The location of the subsolar point is found to be sensitive to the solar wind density changes. Hence the epsilon parameter has been computed by taking into account the variation in the size of the magnetosphere.

Thus in the present investigation only the kinetic energy of the solar wind impinging on the magnetosphere and the magnetosphere coupling parameter were calculated ,but in future we would also calculate the Joule heating effect, auroral precipitation and contribution of ring current. We found that the kinetic energy impinging the magnetosphere depends upon the orientation of southward IMF and Magnitude of the IMF_BZ. Our results giving good agreement to the results of [1] except the case of 21 January 2005, during this event 91E+17 J kinetic energy has been observed and it may due to the severe SEP event occurred on that day.

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Figure Captions

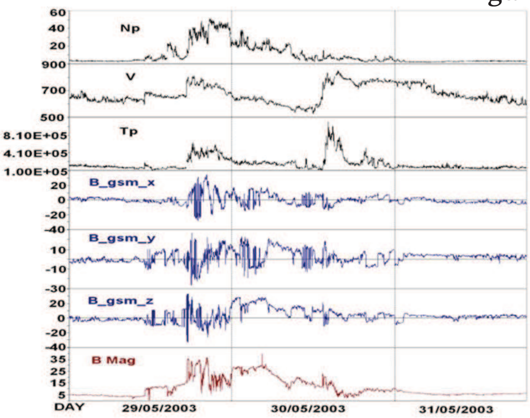

Figure 1: The descending panels show the proton density in cm $^{-3}$, the proton velocity in km/s, the proton temperature in degree Kelvin and X, Y, Z components of IMF in nT and the magnitude of IMF.

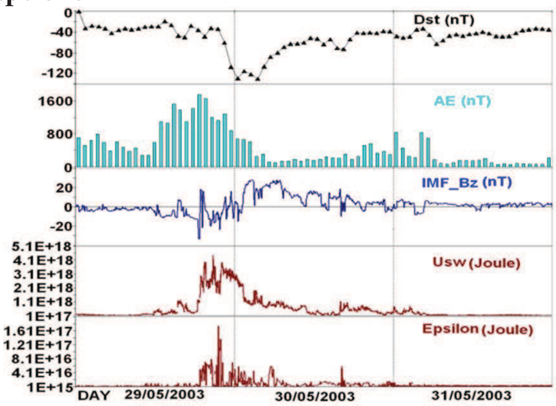

Figure 2: Descending panels show the Dst in nT, AE in nT, IMF_Bz in nTUsw in Joule and epsilon in Joule.

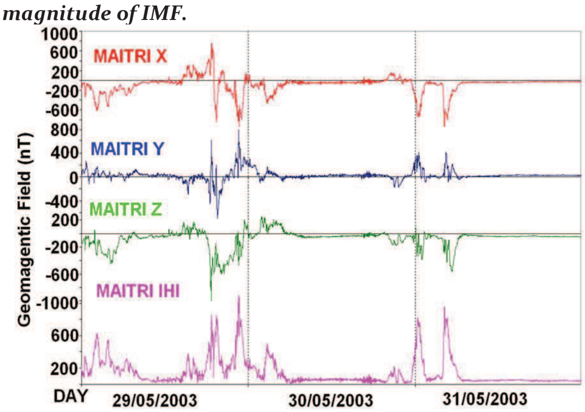

Figure 3: Geomagnetic Field components variation in nT at "MAITRI".

S.N.	Event	IMF_BxnT	IMF_BynT	IMF_BznT	BmagnT	SSC Dst Time (UTC)	Dst (nT)	AE (nT)	Vp (km/s)	Np (1/cm^3)	Tp(1E+6)^0 K	Usw (1E+17)J	Epsilon (1E+15)J
1.	29/05/2003	-28	-26	-33	40	1224	-131	1758	848	51	1.12	44	174
2.	29/10/2003	-42	-45	-54	63	0611	-401	2221	1259	N.D	1.6	23	285
3.	26/07/2004	-18	-25	-23	27	0615	-197	1822	727	27	1.4	10	135
4.	7/11/2004	-28	-46	-50	60	1828	-373	1875	853	78	0.9	37	336
5.	21/01/2005	-27	-27	-27	39	1742	-105	3472	1021	60	1.1	91	192

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