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A study of coupling parameters for solar wind magnetosphere interaction.

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ABSTRACT: Geomagnetic Storms occuring during solar cycle 23 corresponding to which the key solar wind parameters showed a extremum prior to storm commencement were identified . and correlation of these extremum values with Dst index was found out. It was found that the coupling functions B_ZT ,VB_ZT and VB_Z (T is the duration of southward B_Z) had a good correlation with Dst index.

I. Introduction

The sun is a very dynamic object in terms of energetic particles as well as the magnetic field outflow and these changes are transmitted via the solar wind to the earth's magnetosphere sometimes vigorously disturbing the geomagnetic field.These disturbances are transported to the ionosphere via the field aligned current systems and more often than not disrupts radio wave propagation. At times the disturbances are big enough to cause a geomagnetic storm -worldwide disturbance in the geomagnetic field causing radiation hazards to humans, disrupt Communication systems, Navigation systems, Satellite hardware damage, Geologic exploration, effect electric grid and pipelines by geomagnetically induced currents and so on. Thus Space weather prediction - prediction of occurrence of a geomagnetic storm is a major concern for space physicists .

Space weather prediction would be complete only if one could predict, at least approximately, the strength of an ensuing storm in addition to the time of occurrence. Though geomagnetic activity is definitely solar driven, the geo-effectiveness of a solar driver of geomagnetic storm is found to vary with a number solar wind parameters. Extensive study has been done on this front to find out which parameters are most correlated with the storm strength. In addition, several combinations of these solar wind and magnetospheric parameters have come up. The correlation of these combinations, generally known as coupling parameters or coupling functions for Solar wind- Magnetosphere interaction, with storm strength have been found .

[The earliest solar wind parameters considered, even before the solar wind was discovered to be continual and not merely episodic, was the density(ρ) and velocity(v), and hence dynamic pressure($\rho v^2/2$) [Chapman and Ferraro, 1931]. Some early work on the solar wind velocity suggested it might be a key parameter [Crooker et al., 1977] but later works showed to be disappointing [Crooker and Gringauz, 1993; Papitashvili et al., 2000]. The importance of Bz and merging was first contemplated by Dungey(1961) .Since then various combinations of the basic parameters have been tried, with variations on the solar wind electric field most common by Burton et al. [1975], Temerin and Li [2006], Wygant et al. [1983] , Badruddin(2002) to name just a few. Ji et al (2010) made a statistical analysis of the conditions favourable for geo-effectiveness by using contingency table.]

The strength of a geomagnetic storm is found to have a relation to some these parameters. Attempts have been made to quantify the relation of these solar wind parameters with storm strength and in the process correlation of these parameters with geomagnetic indices indicating geomagnetic activity levels have been found. The earliest solar wind parameters considered, even before the solar wind was discovered to be continual and not merely episodic, was the density ρ and velocity V, and hence dynamic pressure [Chapman and Ferraro, 1931]. The latter variable does approximately predict the location of the magnetopause. Some early work on the solar wind velocity suggested it might be a key parameter [Crooker et al., 1977] but later worked showed V to be disappointing [Crooker and Gringauz, 1993; Papitashvili et al., 2000].

Of the various parameters the southward component of interplanetary magnetic field (IMF Bz) is the most important candidate. Badruddin (2002) found that southward component of the magnetic field plays a crucial role both in creating and in determining the magnitude of geomagnetic storms. Solar wind speed, from independent evaluation of the effectiveness of individual parameters, appears to be only a minor factor for the creation of storms. Yermolaev et al (2010) too found that Bz is the most important criteria. Belov et al (2005) showed that, under quiet or weakly disturbed conditions, the variations in the geomagnetic activity index Ap can be forecasted for 3–5 days ahead on the basis of solar magnetic observations.In this study an attempt has been made to compare the correlation co-efficient of various solar wind parameters and their combinations with the Dst index, so as to find out the best coupling parameter to predict the intensity of an ensuing storm.

II. Data and methodology:

Geomagnetic Storms occuring during solar cycle 23 (1997-2008) were identified by observing the Dst index provided by the Geomagnetic Equatorial index Home Page.The solar wind Key parameter profiles provided by ACE (Advancd Composition Explorer) satellite, placed at L1 point were studied for each of these storms. Those storms corresponding to which the solar wind conditions showed a distinct enhancement [Fig(1)] or a decrease prior to storm commencement, were chosen for the correlation study.
The storms selected from category 1 and 2 have also been categorised into intensity groups:

- moderate storms : -100nT<dst<-50 nT
- intense storms : -200 nT <dst<-100 nT
- very intense storms : dst< -200 nT

The Solar Wind parameters selected for the correlation study are: The Southward Component of Interplanetary Magnetic Field (Bz) , Solar wind velocity (v) , Solar wind density (ρ), clock angle (Θ). Enhanced or decreased values of these parameters prior to storm commencment were identified and their extremum value noted. The ACE (Advanced Composition Explorer) data for these parameter values that are available at the SPDF (Space Physics Data Facility) has been used for the study. Many combinations taking two or more of the solar wind parameters Southward IMF Bz, solar wind velocity V, Tangential magnetic field B_T , solar wind density ρ, Clock angle $\theta(\theta = \arctan(B_y / B_z))$, have been used as coupling functions for solar wind – magnetosphere interaction.

III. Discussion and conclusion:

Table(1) shows the correlation of the various coupling functions with Dst index.Some of these coupling functions has references as mentioned in the last column .

Table 1 : Different coupling functions and their correlation co-efficient with Dst index

Functional form of Coupling function	Value of correlation co-efficient with Dst for storm category				Reference
	Moderate	Intense	Very intense	overall	
Bz	0.52	0.1	0.42	0.71	Dungey(1961) (1961)
V	-0.36	0.06	-0.12	-0.48	Crooker et al(1977
ρ	-0.12	0.26	0.07	0.04	--------------------
BzT	0.55	-0.2	0.37	0.53	--------------------
VBz	0.56	0.12	0.56	0.78	Burton et al (1975) al[1975]
VBzT	0.65	-0.11	0.48	0.66	--------------------
ρV	-0.25	0.17	-0.01	-0.17	--------------------
Θ	0.12	0.34	-0.10	0.09	--------------------
B_T	-0.61	-0.08	-0.33	-0.74	--------------------
$B_T (\sin^4(\Theta/2))$	0.001	0.01	0.07	-0.17	--------------------
$VBt(\sin^4(\Theta/2))$	-0.12	-0.22	0.02	-0.21	Wygant et al(1983)
$\rho V^2/2$	-0.33	0.07	-0.05	-0.31	Chapman and Ferraro
$vB_T^2\sin^4(\Theta_c/2)$	-0.14	-0.19	-0.4	-0.34	Perrault and Akasofu(1978)
$vB_T\sin^2(\Theta_c/2)$	-0.17	0.22	-0.43	-0.42	Kan and Lee(1979)
$V^{4/3}B_T^{2/3}$	0.55	0.39	0.56	0.75	--------------------

Though the correlation co-efficients have been found to take the values indicated in the variations removal of one or two extreme event considerably improves the correlation between Dst and a particular parameter.For example Though for very intense storms the correlation co-efficient increases between dst and ρ from 0.06 to 0.2 on removing just two of the storms (8,-383) and (48,-201) from the data.

On removing two data points [$\rho V^2/2$= 80000 , Dst = -383 nT and $\rho V^2/2$= - 88633.25919 , Dst = -422 nT] from the observation improves the correlation between Dst and the coupling function $\rho V^2/2$ considerably (magnitude of correlation co-efficient increases from 0.31 to 0.36). On removing one data point [$V^{4/3}B_T{}^{2/3}$ = 17952.14, Dst = -292nT] from the observation improves the correlation considerably ,(magnitude of correlation co-efficient increases from -0.75 to -0.77).

From this it is obvious predictability of these extreme events or very intense storms somehow even less.

Geomagnetic activity is known to enhance dramatically whenever the solar wind is directed southward. This is obviously because magnetic reconnection which is the principle mode of energy transfer from the solar wind to the magnetosphere causing geomagnetic disturbance happens when the IMF Bz is southward. Thus it was not a surprise that the correlation between DSt index and Bz was found to be good for all category of storms i.e. the correlation is good over the whole range of dst from -50 nT upto 200 nT .

In addition to B_Z the tangential magnetic field $B_T\left[B_T=(B_z{}^2+By^2)^{1/2}\right]$ is found have good correlation (even better than B_Z) with the Dst index . But the relation of between Dst and clock angle $\theta(\theta=\arctan(B_y/B_z))$ was found to be practically nil with a correlation co-efficient of 0.09.

The low value of correlation co-efficient for Dst-V indicates that the relationship Dst-V is moderate. The minimum value of V for all category of storms was 350 km/s which agreed with the findings of Kane (2005) that moderate or intense geomagnetic storm occurs only when V is above 350 km and above this limit any value of V could be associated with any value of Dst. This agrees with the findings of Ballatore (2002) that there is a saturation effect of fast solar wind on geomagnetic storms i.e. Dst do not keep up with larger solar wind speeds.
Though the Dst-ρ correlation was found to be very weak ,the range of ρ values responsible for the whole range of Dst was found to lie practically between 20n/cc to 55n/cc.The correlation between BzT and Dst indicates that magnitude and duration have a important role to play in the generation of geomagnetic storms.
Of the twelve coupling functions composed from the solar wind parameters , the coupling functions B_ZT ,VB_ZT and VB_Z (T is the duration of southward B_Z) were found to have a good correlation with Dst index the correlation co-efficients being 0.53 ,0.65 and 0.79 and respectively. We have tried the variation of Dst with a new parameter $V^{4/3}B_T{}^{2/3}$ and the correlation co-efficient was found to be rather good (≈ 0.76). The scatter is more for each parameter at Dst range <-250nT indicating that for larger values of Dst i.e. for superstorms or extreme events , the behaviour of the solar wind is much more unpredictable than for geomagnetic disturbances of lesser magnitude.

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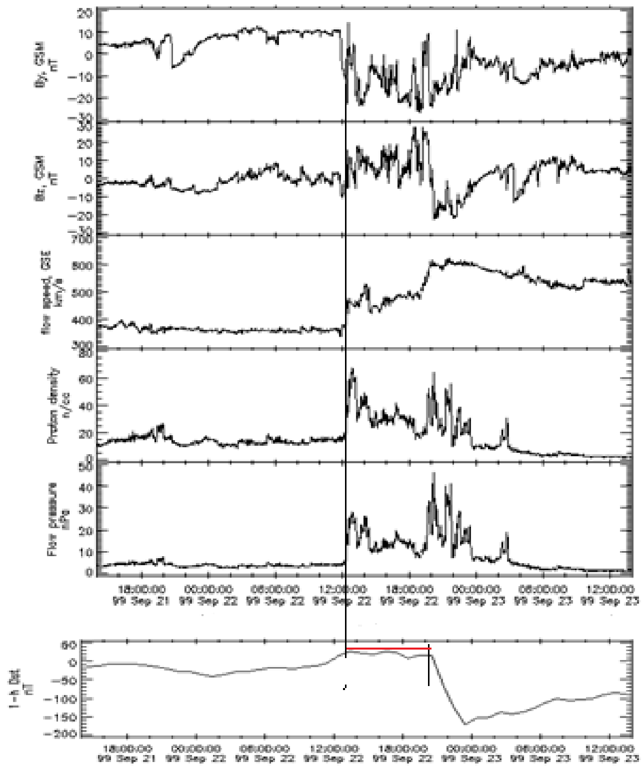
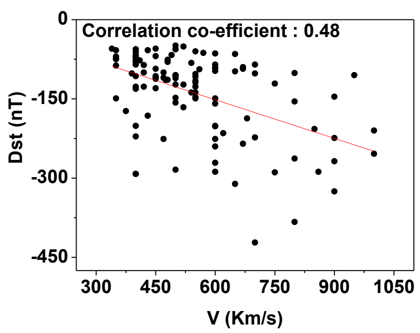
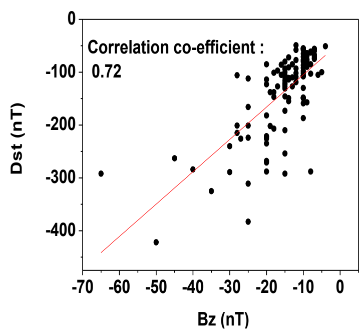
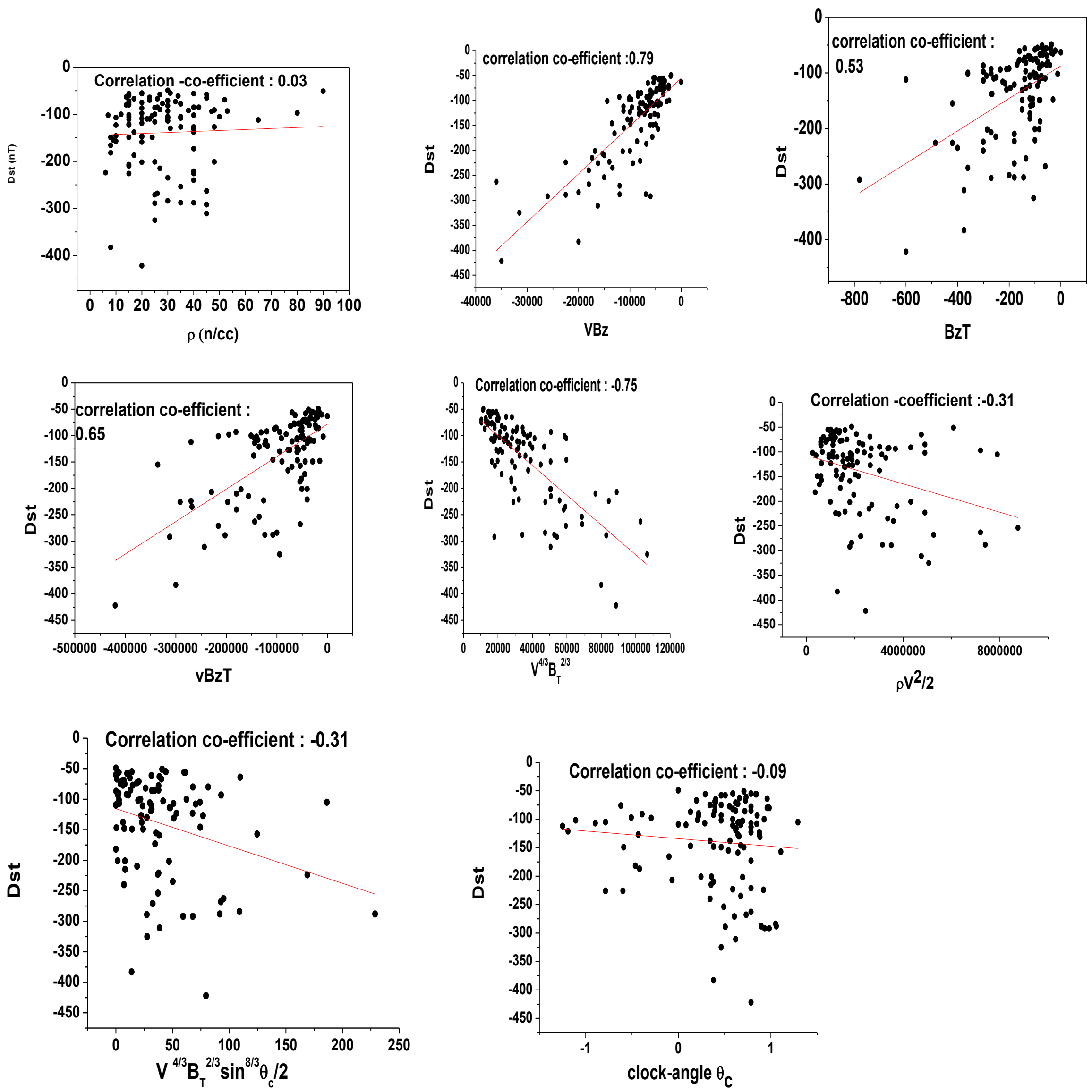
Appendix:



Fig(1):Storm on 23-09-99 corresponding to which the solar wind parameters exhibited a sudden increase/decrease several hours before storm commencement.







Fig(2): Correlation of various solar wind parameters and coupling functions with storm strength indicated by Minimum value of Dst index.