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Dependence of Intense Geomagnetic Storms on the Interplanetary Field / Plasma Parameters during Solar Cycle 23 & 24

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Abstract: We present a statistical analysis of the peak values of geomagnetic activity indices (Kp, ap, AE and Dst) with the interplanetary plasma and field parameters (T,D,V,P, and Bt , Bz , E, and B) along with their product functions (BV,BzV and B^2V) during major geomagnetic storms. We find that peak values of Dst, Kp,ap, and AE are in good correlation with E, V, BV,BzV,B^2V,Bt,Bz. We have obtained specifically high values of correlation between Dst and product functions of plasma parameters (R=-0.75 for BV, R=0.78 for BzV and R=-0.77 for B^2V).This study provides statistical prove that occurrence of intense GMSs depends mainly upon magnetic field, velocity and their product functions(BV, BzV and B^2V).Therefore these parameters may act as reliable indicators for predicting GMSs and their strength. We have also analysed the GMSs data during different phases of the solar cycles 23& 24 and concluded that CMEs are more important drivers of GMSs during the maximum phase of solar cycle while CIR are more significant drivers of GMSs during the decay phase.

Keywords: Geomagnetic Storms, interplanetary field parameters, interplanetary plasma parameters, Geomagnetic Indices.

1 INTRODUCTION

The Sun displays manifestations of periodic magnetic phenomena in solar atmosphere called solar activity features. The 11 year time period in which solar activity varies is called solar cycle. The variation in solar activity is attributed to the variation in magnetosphere-ionosphere system. Solar wind and coronal mass ejection (CME), which originate from the Sun, are directly connected to magnetic field of the Earth's magnetosphere, This process is known as magnetic reconnection. This magnetic reconnection produces a disturbance in the magnetosphere-ionosphere system called geomagnetic storm. [1, 2] stated that this disturbance gives rise to several changes in interplanetary and terrestrial environment. The solar wind at Earth orbit has mean density of about $4cm^{-3}$, mean velocity of about $400kms^{-1}$ and mean interplanetary magnetic field (IMF) magnitude of 5nT. The average direction of IMF along the parker spiral in the ecliptic plane is at an angle of 45^0 from the redial direction [3].GMSs are driven by magnetic reconnection between IMF and terrestrial magnetic field. As the dipole is close to perpendicular to the ecliptic plane which depends on southward component of the IMF, the reconnection rate is proportional to the Y- component of the motional electric field (**E = Vsw × BIMF**) of the solar wind[4].Coronal mass ejection (CMEs) expel vast clouds of solar magnetic flux and plasma into interplanetary space. The interplanetary space formed by the CME propagates from the Sun, often at high velocity[5].The coherent magnetic field structure, the strong varying field and plasma density in the sheath region preceding the ICME proper, the fast solar wind speed as well as the interplanetary shock itself are all effective drivers of geomagnetic activities [6].
Solar wind & CMEs are the main drivers of geomagnetic storms. High speed solar wind streams originate from low latitudes coronal holes, encounter the Earth & give rise to large fluctuations in IMF Bz & solar wind velocity. These are effective drivers of medium level activity in the high latitude magnetosphere [7].The storms associated with them are called CME driven geomagnetic storms(GMSs).When the high speed solar wind that originates from coronal holes decelerates and interacts with magnetosphere, its leads to a compression of the plasma and magnetic fields forming corotating interaction region (CIR) [8, 9].The storms which are associated with such interaction are called CIR driven GMSs. The CIRs driven GMSs exhibit fast shock and continuous strongly southward IMF Bz and thus depict only moderate geomagnetic activity [10, 11]. CIR being associated with the coronal hole structure, also exhibits 27 day periodicity [12].

Indices used to describe the variation in geomagnetic field are called geomagnetic indices. Dst,kp,ap,A.E are the most commonly used geomagnetic activity indices [13] .GMSs are classified on the bases of Dst
Index as: Intense storms (Dst ≤ -100nT) moderate storms (-100nT < Dst < -50nT) & weak storms (Dst > -50nT)[2].

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There are a number of statistical studies which define relationship between geomagnetic indices and interplanetary field parameters. These studies are very important to predict space weather. A statistical study of Kp and ap index with interplanetary field parameters represented the planetary intensity of magnetic activity at subauroral latitude [14, 15, 16]. [17, 18, 19, 20] studied the relationship of intense GMSs with intense IMF and its southern components for a long time (> 3hour).[21] studied the relationship between Dst index solar wind speed and product of southern components Bz of IMF and wind speed V for several events during 1973-2003.This study found that product of southern components and speed investigates the occurrence of moderate and strong GMSs.[18] studied the relationship between 64 GMSs event of Dst index (Dst ≤ -85nT) with southern components Bz of IMF during period of 1997-2002 and found that 75% of peak value of Bz is entire event at peak value of Dst. Coordinated data analysis workshop (CDAW) held at Georgemason university Fairfax Viginia in march 2005 and second workshop held at Florida institute of technology Melbource Folirda in March 2007 focused on the role of CMEs or CIR as the source of geomagnetic storms. These workshops decided the 88 major geomagnetic storms events during the period of 1996 to 2005 and explained how to will decide the solar and interplanetary sources of GMSs.[22] represented a statistical study of interplanetary field parameters with intense geomagnetic storm (Dst ≤ -100nT) of cycle 23 (1996-2006).However, there is a strong need to study the dependence of interplanetary field parameters and plasma field parameters with intense geomagnetic indices (GI) for a large data set.

2 DATA ANALYSIS AND STATISTICAL

Study:

In the present work we have attempted a detailed study of intense geomagnetic storms (Dst ≤ -100nT) and analysed the dependence of intense geomagnetic storms on interplanetary field parameters(Bt,Bz,E,B) and plasma parameters(T,V,D,P,) for a period of 20 years during 1996 to 2016 (solar cycle 23 & 24). During this period 109 intense geomagnetic storms appeared .Out of them 92 events occurred in cycle 23 and 16 events occurred in cycle 24. Solar cycle 24 contains less number of GMSs since there is a significant drop in density, magnetic field, total pressure and Alfven wave speed in the inner Helosphere [23]. The total number of events during this period is classified in two groups- 95 CME driven events and 14 CIR driven events. The data sets for Geomagnetic indices and interplanetary field and plasma parameters data were taken from OMNI website at: http://swdc.kugi.kyoto.u.ac.jp/dstdir

For all the 109 events the peak values of Geomagnetic indices (GIs),inter-planetary field parameters and plasma parameters are presented in table 1.We have used a linear regression analysis Y = A + BX for these parameters where Y is peak value of GIs and X is interplanetary field /plasma parameters. We have studied the relationship between these parameter in different phases of solar cycle 23& 24 namely rising phase (1996 -1999; 2008-2011) maximum phase (2000 - 2002; 2012 -2014) and decay phase (2003-2008; 2015-2016). We have also calculated correlation coefficient, average, median and standard deviation of peak values of various GIs and interplanetary /plasma field parameters in different phases of solar cycle 23 & 24 as well as for total period 1996 - 2016.

3 ANALYSIS AND RESULTS

3.1 Relationship between peak values of geomagnetic activity indices and interplanetary field/Plasma parameters:

To understand the dependence of intense geomagnetic storms on the interplanetary field and plasma parameters during 1996-2016 (cycle 23 & 24), we have represented a statistical correlative study between GIs and interplanetary field/plasma parameters and their functions (BV,BzV,B^2V). Figure 1-figure 4 represent the scatter plots of GIs, interplanetary field and plasma parameters as well as their product functions (BV,BzV,B^2V). The linear regression equation and their correlation coefficient are given in all plots. The correlation coefficients of GIs with interplanetary field/plasma parameters and their product functions (BV,BzV,B^2V) in different phases of solar cycle 23 & 24 and during whole period 1996-2016(cycle 23-24) are represented in table 2. It can be seen from fig.1.that Dst shows good correlation with Bt (R = -0.79),Bz (R = 0.75), E(R = 0.72),BV (R = -0.75),BzV (R = 0.73),B^2V (R =0.77) and moderate correlation with σB(R = -0.54) and V (R = -0.53) whereas it shows weak correlation with T(R = -0.34),D(R = 0.13),P(0.43) and β(beta) (R = -.026).Fig.2. indicates that Kp index shows good correlation with Bt(R = 0.72),V(R = 0:65),BV(R = 0.74)BzV (R =-0.66),B^2V (R = -0.66), moderately correlated with Bz(R = -0.60),σB (R = -0.51),E(R = 0.55),T(R = 0.51),P(R = 0.57) and this index is weakly correlated with D(R = 0.24), β (beta) (R = 0.08).From figure 3, We can see that ap shows good correlation with Bt(R = 0.78),Bz(R = -0.66),E(R = 0.73),V(R = 0.72),BV(R = 0.83), BzV(R = 0.77), B^2V (R = 0.77), moderate correlation with σB (sigma (B)) (R = 0.54), T(R =0.54), P(R = 0.56) while weak correlation with D(R = 0.17),& β(beta) (R = 0.04).It is clear from fig 4. that A.E shows good correlation with Bt (R = 0.63),V(R = 0.63),BV(R = 0.68) and moderate correlation with Bz(R = -0.50),σ (B) (R = 0.52),E(R = 0.54),T(R = 0.54), P(R = 0.55), BzV(R =0.58), B2V (R = 0:60) whereas it is weakly correlated with D(R = 0.23),β (beta) (R = 0.12).This indicates that GIs are in good correlation with

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interplanetary field and plasma parameters except density (D) and plasma β parameter. To understand the mechanism in a better way we have examined the correlation of peak values of different indices with various product functions (BV, BzV,B2V).When we analyse this data in different phases of cycle 23 & 24, we see that GIs show good correlation with interplanetary field/ plasma parameters and specifically high correlation with their product function. However we get weak correlation with density (D), pressure (P) and Plasma β(beta) parameters. GIs are highly correlated with these product functions which indicate that variation in the values of these product functions may serve as reliable indicator of geomagnetic activities thereby allowing us to predict the strength of GMSs.

3.2 Average, Median, Standard deviation analysis of various geomagnetic indices, interplanetary field and plasma parameters:

Average, Median, Standard deviation analysis of various geomagnetic indices, interplanetary field and plasma parameters during cycle23 & 24(1996-2016) have been represented in table 3. We have presented a comparison of average and median of GIs, interplanetary field and plasma parameters and their product functions during the rising, maximum and decay phase of solar cycles 23-24. From table 3, it is clear that averages of GIs, interplanetary field and plasma parameters increase during the decay phase as compared to the rising and maximum phase. Though the number of events in decay phase is less (29 events) but there intensity is relatively high (Dst index reaching up to -442nT in solar cycle 23 & up to -223nT in solar cycle 24) as compared to the events of rising and maximum phase. This accounts for the higher average values in decay phase.

4. CONCLUSION

The present study intends to examine the dependence of GIs on interplanetary field and plasma parameters. The whole study has been focused upon analyzing the relationship among peak values of GIs, interplanetary field and plasma parameters. We have found that GIs exhibit good correlations with interplanetary field and plasma parameters, which indicates that these parameters play an important role to determine the strength of storms and sub storms.

These may also prove vital in making prediction about geomagnetic storms and sub-storms and their strength. We have also presented a correlated study of various GIs with interplanetary field and plasma parameters. Average, median and standard deviation analysis is also done for different phases of cycle 23 & 24 throughout the 20-year period. These analyses indicate that geomagnetic storms immensely affect the magnetospheric environment and occurrence of intense geomagnetic storms depends on the variation in the values of interplanetary field and plasma parameters. Since most of the events 95(87:2% of total event) appear in CME driven and 14 events (12:8% of total event) appear in CIR driven hence CME are more geoeffective driver than CIR. The phase analysis (rising phase, maximum phase and decay phase) for the two solar cycles 23 & 24 indicates that most of the events (45:9% of total events) occurred in maximum phase which implies that maximum phase is more geoeffective than the other phases. However when we made the phase analysis separately, we found that maximum number of events occurred in the maximum phase(47:4%) for CME driven events while maximum number of events occurred in the decay phase (50%) for CIR driven events. This indicates that CMEs are more important drivers of GMSs during the maximum phase of solar cycle while CIR become more significant drivers of GMSs during the decay phase of solar cycle.

Solar wind contains southward components of magnetic field and velocity by which GMSs originated in the magnetosphere[5, 6].Our statistical study indicate that GIs shows good correlation (positive as well as negative) with magnetic field, velocity and their product functions (BV,BzV,B2V). We also found that GIs always show correlation coefficient ≥ 0.70 with their product functions either in the whole period or different phases of solar cycle 23 & 24.A possible reason behind this may be that magnetic field and velocity are factors which produce the geomagnetic storms in magnetosphere-ionosphere system. Combined effect of magnetic field and velocity must be much better than individual magnetic field and velocity. Hence our study gives a statistical prove that the occurrence of intense geomagnetic storms depends on the interplanetary field and plasma parameters.

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Table 1:Peak values of interplanetary field / plasma parameters, geomagnetic activity indices and Various functions of plasma/field parameters (BV, BzV,B^2V) during 1996-2016 (Solar cycle 23 & 24).

S.N	Date (dd/mm/yy)	Time (UT)	Bt (nT)	Bz (nT)	σB (nT)	E (m Vm-1)	T(K)	D (cm^{-3})	V (Kms-1)	P (nPa)	Beta	Kp (nT)	Dst (nT)	AE (nT)	Ap (nT)	BV (nTkm /s)	BzV× 10^3 n Tkm /s	B^2V× 104 $(nT)^2$ km/s
1	21/04/1997	23:00	13.9	-7.7	8	4.01	113138	30.5	441	7.97	13.12	5.3	-107	917	56	6.13	-3.4	8.52
2	15/05/1997	13:00	25.2	-24	13.2	10.23	341122	29.8	524	10.2	18.4	6.7	-115	865	111	13.2	-12.73	33.28
3	10/11/1997	4:00	13.4	-10	7.1	4.51	104825	30.2	449	11.8	2.67	6.3	-130	1043	94	6.02	-4.58	8.06
4	07/11/1997	5:00	17.9	-13	11.9	5.62	374718	23.4	468	9.98	4.17	7	-110	981	132	8.38	-5.85	15
5	23/11/1997	7:00	26.3	-13	18.9	6.46	415513	32.4	591	15.8	5.01	7.3	-108	985	154	15.54	-7.56	40.88
6	18/02/1998	1:00	21.1	-13	11.4	6.18	298693	24.4	478	8.24	5.9	6.7	-100	1210	111	10.09	-6.17	21.28
7	04/05/1998	6:00	38	-20	18.8	23.82	1.00E+06	26	833	36.9	3.43	8.7	-205	1443	300	31.65	-16.24	120.29
8	26/06/1998	5:00	17.4	-13	11	6.04	106347	20.7	496	8.92	6.78	6.3	-101	1234	94	8.63	-6.55	15.02
9	06/08/1998	12:00	20.3	-18	9.4	8.26	128854	39.5	428	11.3	4.94	7.3	-138	971	154	8.69	-7.49	17.64
10	07/08/1998	6:00	11.9	-8.3	8.5	4.2	284853	9.9	530	3.68	3.33	6	-108	862	80	6.31	-4.4	7.51
11	27/08/1998	10:00	16	-11	10.4	9.76	2.00E+06	9.7	847	10.4	3.33	8	-155	1268	207	13.55	-9.23	21.68
12	25/09/1998	10:00	25.4	-18	16.6	13.66	907650	14.6	839	12.6	3.04	8.3	-207	1432	236	21.31	-15.44	54.13
13	19/10/1998	16:00	26.1	-22	13.2	6.71	504349	65.3	698	21.9	6.47	6.7	-112	1020	111	18.22	-15.5	47.55
14	08/11/1998	7:00	34.7	-12	8.9	12.15	331265	24.4	639	14.4	5.31	7.7	-149	***	179	22.17	-7.41	76.94
15	09/11/1998	18:00	21.7	-13	7.2	7.35	136799	23	522	12.5	10.43	6.7	-142	***	111	11.33	-6.89	24.58
16	13/11/1998	22:00	20.9	-18	12.6	7.13	534806	39.6	547	13.3	6.33	6	-131	***	80	11.43	-9.63	23.89
17	14/04/1999	0:00	18.6	-16	11.6	6.04	290371	30.9	593	10.92	3.51	7	-112	994	132	11.03	-9.31	20.52
18	18/02/1999	10:00	28.1	-24	20	13.84	518339	13.7	673	10.7	2.99	6.7	-123	1555	111	18.91	-16.29	53.14
19	23/09/1999	0:00	26.2	-19	17.7	9.39	320171	46	602	18.6	2.73	8	-173	928	207	15.77	-11.14	41.32
20	22/10/1999	7:00	35.6	-28	15.8	16.21	525759	49.8	678	27.5	3.06	8	-237	1139	207	24.14	-19.12	85.93
21	13/11/1999	23:00	11.7	-11	8.7	5.39	155396	12.9	482	2.45	4.77	6.3	-106	756	94	5.64	-5.35	65.98
22	12/02/2000	12:00	19.4	-15	14.2	9.56	413479	24.3	681	15.7	7.94	6.7	-133	1124	111	13.21	-10.21	25.63
23	07/04/2000	1:00	30.3	-22	15	15.78	345986	33.4	625	20.3	4.19	8.7	-288	1550	300	18.94	-13.82	57.38
24	16/07/2000	1:00	50.6	-49	33	51.38	2.00E+06	20.6	1107	41.2	5.6	9	-301	2023	400	56.01	-54.56	28.34
25	11/08/2000	7:00	13.5	-13	4.1	5.77	260592	11.7	441	4.23	0.79	5.7	-106	1107	67	59.54	-5.73	80.37
26	12/08/2000	10:00	33.3	-26	22.7	17.33	463682	18.2	671	12.4	3.22	7.7	-235	1724	179	22.37	-17.72	74.4
27	18/09/2000	0:00	36.6	-23	25.9	14.91	920518	32.8	839	25.5	2.51	8.3	-201	1013	236	30.71	-19.3	11.24
28	05/10/2000	14:00	25.8	-25	16	9.55	261737	32.1	531	15.7	12.24	7.7	-182	1456	179	13.69	-13.06	35.35
29	14/10/2000	15:00	19.5	-13	10.4	6.49	379120	29.2	584	11.1	3.52	6.7	-107	1133	111	11.39	-7.71	22.21
30	29/10/2000	4:00	18.5	-17	14.2	6.87	215502	39.3	460	11.7	4.24	6	-127	839	80	8.51	-7.87	15.75
31	06/11/2000	22:00	24.4	-12	9.2	7.61	457587	32.1	906	14.3	37.36	7	-159	1154	132	22.11	-10.6	53.94
32	29/11/2000	14:00	13.7	-12	7.2	5.57	250108	17.1	587	14	3.15	6.7	-119	1076	11	8.04	-7.04	11.01
33	20/03/2001	14:00	21.4	-20	13	7.33	138018	23.5	490	9.87	4.43	7.3	-149	1372	154	10.49	-9.7	22.44
34	31/03/2001	9:00	46.3	-46	41.8	30.62	704151	37.8	821	38.8	1.61	8.7	-387	1524	300	38.01	-38	175.99
35	12/04/2001	0:00	33.1	-18	20.3	14.86	849339	24.7	832	24.5	4.31	8.3	-271	1699	236	27.54	-14.73	91.15
36	18/04/2001	7:00	22.7	-13	12.3	9.72	393365	29.6	518	14.4	5.37	7.3	-102	1753	154	11.76	-6.83	26.69
37	22/04/2001	16:00	15.1	-12	6.3	4.63	188.33	29.7	445	7.18	6.06	6.3	-102	982	94	6.72	-5.34	10.15
38	17/08/2001	22:00	31.7	-12	18.2	9.07	316659	46.5	599	21.8	15.08	7	-105	1536	132	18.99	-7.13	60.19
39	26/09/2001	2:00	22.1	-10	22	4.33	1.00E+06	40.4	677	37.8	5.24	7.3	-102	1753	154	14.96	-6.97	33.06
40	01/10/2001	9:00	17.2	-10	8.5	6.22	323152	18.9	622	9.81	1.04	6	-148	949	80	10.69	-6.4	18.4
41	03/10/2001	15:00	22.9	-22	18.7	10.95	21321	13.7	573	6.7	16.13	7	-166	1176	132	13.12	-12.49	30.04
42	21/10/2001	22:00	26.1	-17	6.6	10.64	529177	24.8	676	26.9	2.22	7.7	-187	1307	179	17.64	-11.42	46.04
43	28/10/2001	12:00	18.4	-9.9	7.7	7.28	191696	11	502	5.29	16.43	6.7	-157	950	111	9.23	-4.97	16.99
44	01/11/2001	11:00	13.9	-12	23.2	5.03	103199	23.4	387	8.42	10.26	5	-106	676	48	5.38	-4.76	7.48
45	06/11/2001	7:00	64.8	-61	30.7	6.05	216397	42.6	729	14.4	22.28	8.7	-292	1991	300	47.24	-4.45	306.11

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46	24/11/2001	17:00	49.3	-33	8.5	23.44	2.00E+06	43.9	1040	7	4.25	8.3	-221	2006	236	51.27	-3.43	252.77
47	24/03/2002	10:00	19.9	-8.7	18	4.51	324757	15.3	568	5.36	2.64	6	-100	1025	80	11.3	-4.94	22.49
48	18/04/2002	8:00	27.2	-16	12.3	9.36	396426	33.6	611	14.8	1.27	7.3	-127	1356	154	16.62	-9.65	45.2
49	20/04/2002	9:00	20.7	-14	14.4	8.35	531934	12.1	669	8.73	1.95	7.3	-149	1639	154	13.85	-9.29	28.67
50	11/05/2002	20:00	17.6	-15	35.4	7.23	262009	57.2	523	21.3	5.26	6.7	-110	1287	111	9.2	-7.95	16.2
51	23/05/2002	18:00	31.2	-14	9.5	10.83	1.00E+06	17.1	871	20.1	1.21	8.3	-109	1480	236	27.18	-12.28	84.79
52	02/08/2002	6:00	14.8	-13	6.7	6	311710	13.8	524	7.53	1.81	6	-102	1125	80	7.76	-6.86	11.48
53	21/08/2002	7:00	12.6	-8.9	14.6	4.2	143166	12.9	495	5.08	2.96	6.3	-106	1146	94	6.24	-4.4	7.86
54	08/09/2002	1:00	22.4	-22	16.1	11.7	327861	17.5	550	7.76	1.61	7.3	-181	1413	154	12.32	-12.26	27.59
55	01/10/2002	17:00	24.1	-14	8.8	9	246987	42.6	505	10.7	3.01	7.3	-176	1088	154	12.17	-69.18	29.33
56	04/10/2002	9:00	14	-11	22.9	4.71	151059	11.7	516	5.66	2.5	7.3	-146	1159	154	7.22	-5.68	10.11
57	30/05/2003	0:00	27.8	-12	8.8	9.61	1.00E+06	36	806	39.1	4.72	8.3	-144	1957	236	22.41	-9.35	62.29
58	18/06/2003	10:00	19.7	-17	22.9	8.53	361248	10.8	626	6.18	1.62	6.7	-141	1297	111	12.33	-10.77	24.29
59	18/08/2003	16:00	21.9	-17	9.7	7.88	236723	17.6	530	9.18	4.65	7.3	-148	1354	154	11.61	-9.22	25.42
60	30/10/2003	1:00	46.7	-25	10.1	26.22	843705	4.1	1084	9.56	0.23	9	-353	2241	400	50.62	-26.67	236.4
61	30/10/2003	23:00	36.7	-28	23.5	2.52	144508	6	1189	13.8	2.45	9	-389	2147	400	43.64	-33.52	160.14
62	20/11/2003	21:00	55.7	-46	28.9	31.25	534783	20.5	703	16.3	2.14	8.7	-442	1698	300	39.16	-32.27	218.1
63	22/01/2004	14:00	24.4	-15	18.3	9.49	585976	17.7	666	15.2	6.2	7	-149	1152	132	16.25	-9.99	39.65
64	04/04/2004	1:00	18.2	-9.3	8.6	3.96	121421	22.8	515	9.95	3.25	6.3	-112	1130	94	9.37	-4.79	17.06
65	23/07/2004	3:00	17.6	-16	8.7	10.25	581133	15.5	672	6.33	2.2	7	-101	1455	132	11.83	-10.42	20.82
66	25/07/2004	12:00	23	-4.9	16.3	10.58	548972	16.5	692	12.3	1.54	8	-148	1635	207	15.92	-15.15	36.61
67	27/07/2004	14:00	25.8	-18	9.1	17.76	2.00E+06	9	1027	19	2.16	8.7	-197	1940	300	26.5	-18.18	68.36
68	30/08/2004	23:00	14.9	-14	4.9	5.72	307443	19.8	518	5.91	4.79	7	-126	991	132	7.72	-7.4	11.5
69	08/11/2004	7:00	45.8	-45	29.1	29.45	808505	64.5	730	32.8	5.45	8.7	-373	1753	300	33.43	-32.56	153.13
70	10/11/2004	10:00	39	-28	20.4	17.98	935977	21	809	25.2	10.28	8.7	-289	1912	300	31.55	-22.49	123.05
71	12/11/2004	11:00	12.4	-5.4	9.7	2.58	424844	19.1	672	14.4	7.18	4.7	-109	818	39	8.33	-3.63	10.33
72	20/01/2005	7:00	26.6	-6.9	23.8	5.71	664599	33.6	950	60.7	3.88	8	-105	2111	207	25.27	-6.55	67.21
73	15/05/2005	9:00	54.1	-41	16.5	34.01	891191	19.1	959	25.5	6.23	8.3	-263	1184	236	51.88	-39.51	280.68
74	20/05/2005	9:00	14.9	-9.7	7.2	4.3	165803	22.1	478	9.58	4.76	5	-103	1050	48	7.12	-4.64	10.61
75	30/05/2005	14:00	18.7	-16	8.7	7.41	268294	17	541	8.76	36.48	7.7	-138	1357	179	10.12	-8.66	18.91
76	13/06/2005	1:00	23.4	-17	15	8.4	283518	48.7	553	12.2	7.94	7.3	-106	1561	154	12.94	-9.35	30.28
77	24/08/2005	12:00	43.2	-41	35.3	23.6	483718	29.6	720	22.8	3.29	8.7	-216	2227	300	31.1	-29.45	134.37
78	11/09/2005	11:00	18.1	-6.4	9.8	5.47	1.00E+06	7.6	1059	9.2	2.01	7.7	-147	1383	179	19.17	-6.78	34.69
79	14/04/2006	10:00	19.5	-12	7	7.3	322684	16.5	676	8.1	3.93	7	-111	1437	132	13.18	-8.25	25.7
80	15/12/2006	8:00	17.8	-16	11.1	12.39	915012	10.5	896	13.5	7.35	8.3	-146	1616	236	15.95	-13.98	28.39
81	06/08/2011	3:00	12.1	-0.5	2.4	0.28	485385	8.6	567	5.29	1.48	5	-115	740	48	6.86	-0.29	8.3
82	26/09/2011	23:00	12.1	-3.8	2.4	2.5	143172	2.7	657	2.13	0.21	5.3	-118	393	56	7.95	-2.49	9.62
83	24/10/2011	1:00	21.3	-8	1.8	4.13	67094	12	516	6.25	0.22	7.3	-147	483	154	10.99	-4.13	23.41
84	09/03/2012	8:00	16	-11	5.3	7.56	22550	3.2	683	3.71	0.08	8	-131	1138	207	10.93	-7.24	17.48
85	24/04/2012	4:00	10.6	-7.3	1.6	3.05	177017	6.3	713	2.18	0.71	5.7	-108	606	67	7.56	-5.2	8.01
86	15/07/2012	18:00	21.9	-16	4.2	8.85	31626	3.6	418	2.37	0.05	7	-127	951	132	9.15	-6.77	20.05
87	16/07/2012	7:00	14.3	-13	3.2	5.86	73047	0.4	546	0.22	0.02	4.7	-102	745	39	7.81	-6.82	11.17
88	01/10/2012	4:00	20.7	-7.8	2.3	3.07	515558	7.4	469	2.1	0.13	5.7	-119	851	67	9.71	-3.66	20.09
89	09/10/2012	8:00	15.7	-6.6	3.1	2.91	43996	1.6	394	0.58	0.22	5.7	-105	625	67	6.18	-2.6	9.71
90	14/11/2012	7:00	17	-15	3.5	5.96	158370	6	441	1.65	0.22	5.7	-108	627	67	7.49	-6.62	12.74
91	17/03/2013	20:00	12.4	-5.6	5.2	3.42	92491	3.6	610	2.65	0.22	6.7	-132	836	111	7.56	-3.42	9.38
92	01/06/2013	8:00	19.6	-4.5	1.6	2.25	361834	10.4	501	5.34	0.55	6.3	-119	807	94	9.82	-2.25	19.25
93	19/02/2014	8:00	18.4	-6.7	4.4	3.05	64187	9.7	455	3.64	0.23	6.3	-116	520	94	8.37	-3.05	15.4
94	17/03/2015	22:00	30.2	-4.1	5.8	10.57	912227	38.5	609	20.52	2.44	7.7	-223	1570	179	18.3	-2.49	55.54
95	01/01/2016	0:00	15	-14	7.1	6.48	37966	1.8	463	0.58	0.06	6	-110	0	80	6.95	-6.48	10.42
CIR Driven																		
1	23/10/1996	5:00	12.8	-10	7.7	6.48	347442	13	671	6.38	4.08	7.3	-105	0	154	8.59	-6.84	10.99
2	10/03/1996	21:00	21.6	-13	19.4	7.47	362284	51.9	553	12.7	3.73	7.3	-116	881	154	11.99	-7.13	25.8
3	24/05/2000	9:00	30.8	-24	26.6	12	468151	30.8	684	28	15.04	8	-147	1336	207	21.07	-16.48	64.89
4	04/09/2002	6:00	18.6	-18	10.9	6.81	257857	18.4	461	5.09	2.08	6.3	-109	884	94	8.57	-8.29	15.95
5	07/10/2002	8:00	12.8	-6	8.1	3.6	165988	11.5	511	3.36	2.34	6	-115	1067	80	6.54	-3.07	8.37
6	14/10/2002	14:00	17.3	-16	11.5	4.62	502949	34.9	611	7.19	2.48	4.7	-100	1044	39	10.57	-9.78	18.29
7	21/11/2002	11:00	29.9	-12	12.6	5.46	503038	52.6	727	24.1	3.64	6.7	-128	1013	111	21.74	-8.87	64.99
8	12/07/2003	6:00	15.1	-14	8.8	7.77	529872	19.5	674	6.04	2.25	6.7	-105	1248	111	10.18	-9.09	15.37
9	11/02/2004	18:00	21.1	-12	14.1	5.31	856405	21.5	735	6.71	1.96	6.3	-109	994	94	15.51	-9.11	32.72
10	18/01/2005	9:00	32.4	-17	14.3	14.83	1.00E+06	11.3	997	13.6	3.18	7.7	-121	2136	179	32.3	-16.75	104.66
11	08/05/2005	19:00	15.3	-12	13.2	10.45	845807	47	821	14.7	3.88	8.3	-127	1505	236	12.56	-10.18	19.22
12	31/08/2005	20:00	17.3	-17	11.2	6.11	648336	34.7	743	11.7	8.49	7	-131	1162	132	12.85	-12.56	22.24
13	17/03/2015	19:00	16	-13	11.2	7.32	86307	10.6	576	***	0.37	7.3	-165	978	154	9.21	-7.31	14.75
14	23/06/2015	12:00	5.9	-0.9	12.1	4.57	729009	3.7	578	***	3.79	5.7	-138	1386	67	3.41	-0.52	20.12

Table 2. Correlation coefficient between various interplanetary parameters (IP) and geomagnetic Indices (GI) during the rising phase, maximum phase,

Decay Phase of cycle 23 & 24 and total period

IP/GI	Rising phase (Cycle 23 & 24)				Maximum Phase (Cycle 23 &24)				Decay Phase (Cycle 23 &24)				Total Period (1996-2016)			
	Dst	Kp	Ap	AE	Dst	Kp	Ap	AE	Dst	Kp	ap	AE	Dst	Kp	ap	A.E
Bt	-0.65	0.69	0.69	0.21	-0.78	0.75	0.83	0.72	-0.84	0.74	0.78	0.54	-0.79	0.72	0.78	0.83
Bz	0.47	-0.54	-0.47	-0.37	0.8	0.57	-0.79	-0.65	0.77	-0.6	-0.65	-0.34	0.75	-0.6	-0.66	-0.5
σB	-0.32	0.48	0.48	0.39	-0.58	0.52	0.57	0.58	-0.55	0.53	0.55	0.57	-0.54	0.51	0.54	0.52

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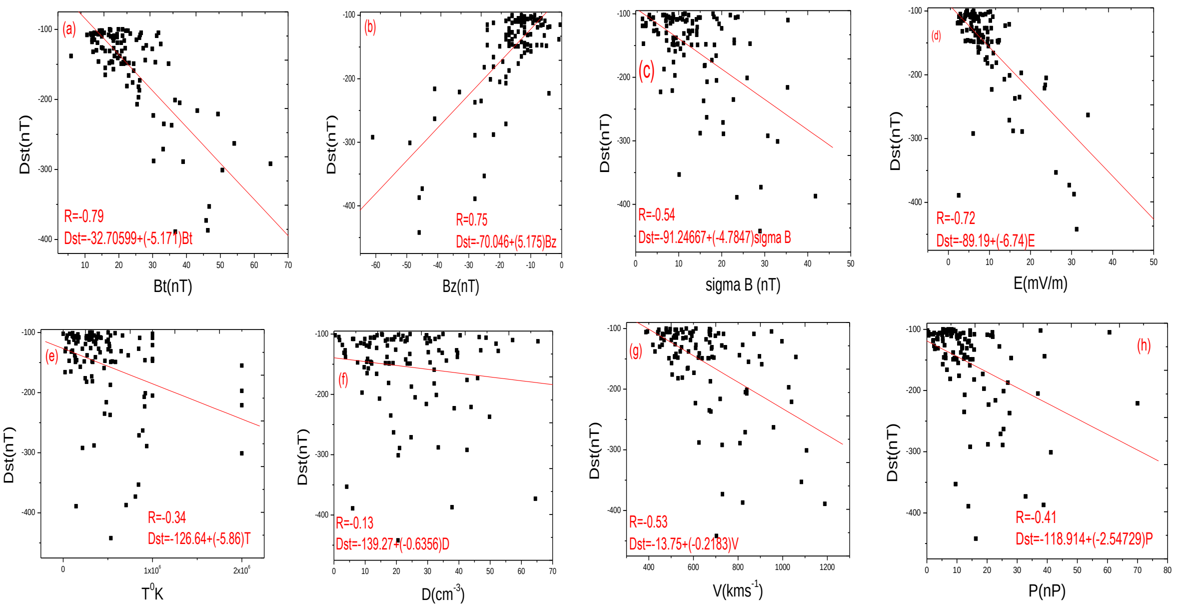
E	-0.74	0.76	0.81	0.37	-0.74	0.64	0.77	0.6	-0.7	0.64	0.63	0.37	-0.73	0.55	0.73	0.54
T	-0.42	0.48	0.54	0.36	-0.45	0.52	0.6	0.62	-0.22	0.47	0.43	0.47	-0.34	0.51	0.54	0.54
D	-0.16	0.24	0.18	0.09	-0.28	0.36	0.33	0.48	-0.11	0.17	0.08	0.26	0.13	0.24	0.17	0.23
V	-0.58	0.57	0.65	0.24	-0.58	0.65	0.7	0.61	-0.49	0.66	0.74	0.63	-0.53	0.65	0.72	0.63
P	0.09	0.04	0.01	0.07	-0.53	0.63	0.63	0.68	-0.19	0.44	0.38	0.54	-0.41	0.57	0.56	0.55
β	0.24	-0.18	-0.23	-0.1	-0.17	0.2	0.17	0.25	0.11	0.01	-0.04	-0.01	0.02	0.08	0.04	0.12
BV	-0.74	0.73	0.78	0.29	-0.62	0.56	0.66	0.62	-0.82	0.77	0.86	0.61	-0.75	0.74	0.83	0.68
BzV	0.63	-0.64	-0.62	-0.44	0.53	-0.44	-0.52	-0.3	0.83	-0.72	-0.8	-0.48	0.73	-0.66	0.77	0.58
B²V	-0.66	0.62	0.68	0.24	-0.61	0.53	0.55	0.61	-0.84	0.66	0.76	0.49	0.77	0.66	0.77	0.68

Table.3. Average (AV),Median(Med) and standard deviations (SD) of various geomagnetic indices(GIs), interplanetry field parameters , plasma parameters and their prouduct functions during the rising, maximum and decay phases of cycle 23 & 24 as well as the total period 1996-2016.

	Rising Phase (cycle 23 &24)			Maximum Phase (cycle 23 &24)			Decay Phase (cycle 23 &24)			Total Phase (1996-2016)		
	AV	Med	SD	AV	Med	SD	AV	Med	SD	AV	Med	SD
Dst(nT)	-133.47	-117	35.98	-150.5	-127	63.43	-185.42	-146.5	97.79	-154	-128	70.29
Kp(nT)	6.89	6.85	0.94	6.9	6.85	1.05	7.49	7.7	1.17	7.06	7	1.07
ap(nT)	135.65	121.5	60.25	139.26	121.5	78.55	192.42	179	97.9	152.6	132	81.99
A.E(nT)	850	949.5	452.81	1192.8	1129	376.2	1476	1446	490.46	1228	1153	441.8
Bt(nT)	21.16	21	7.52	23.42	20.3	10.94	26.17	22.45	13.02	23.44	20.7	10.74
Bz(nT)	-14.12	-13	6.41	-16.58	-13.5	10.87	-17.8	-15.5	12.45	-16.2	-13.5	10.2
σB(nT)	10.16	10.7	7.28	12.87	11.9	9.98	13.3	9.75	8.99	13.4	11	14.52
E(mV/m)	7.99	6.59	4.85	9.1	7.05	8.05	11.68	8.46	9.17	9.49	7.32	7.64
T(°K)	415321	336190	396380	397790	314180	409760	578410	541880	412900	5.00E+05	347442	4.00E+05
D(cm⁻³)	26.34	24.4	15.36	22.71	19.75	14.15	20.01	17.65	14.06	23.06	20.5	14.42
V(km/s)	589.31	560	120.84	607.98	578.5	158.64	724.89	674	201.23	642.1	609	171.9
P(nPa)	53.61	11	211.92	13.62	9.84	12.97	15.23	12.25	12.85	23.87	11.05	104.9
β(beta)	4.97	3.91	3.88	5.03	2.8	6.84	5.04	3.83	6.63	4.97	3.33	6.003
BV ×10³(nTkm/s)	33.89	23.65	28.09	16.48	11.34	13.09	20.18	15.93	13.55	16.56	12.08	12.02
BzV×10³(nTkm/S)	-8.51	-7.27	4.79	-10.81	-7.18	12.09	-13.94	-9.35	10.91	-11.2	-8.1	10.29
B²V×10⁴ ((nT)²km/s)	12.86	11.18	6.51	42.25	22.32	57.73	69.24	32.48	76.09	46.95	24.435	58.37



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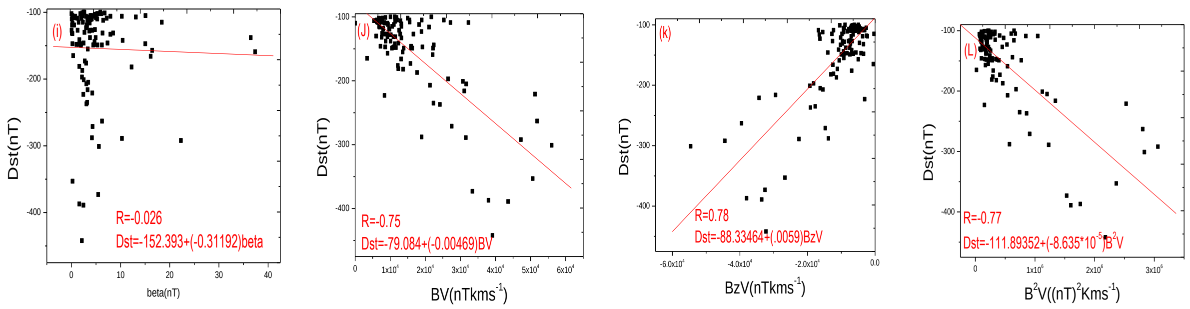

Fig:1. Relations of Dst with interplanetary fields(Bt,Bz,Sigma B, E) , plasma parameters(T, P,V, D, Beta(β)) and there product (BtV,BzV,B^2V).

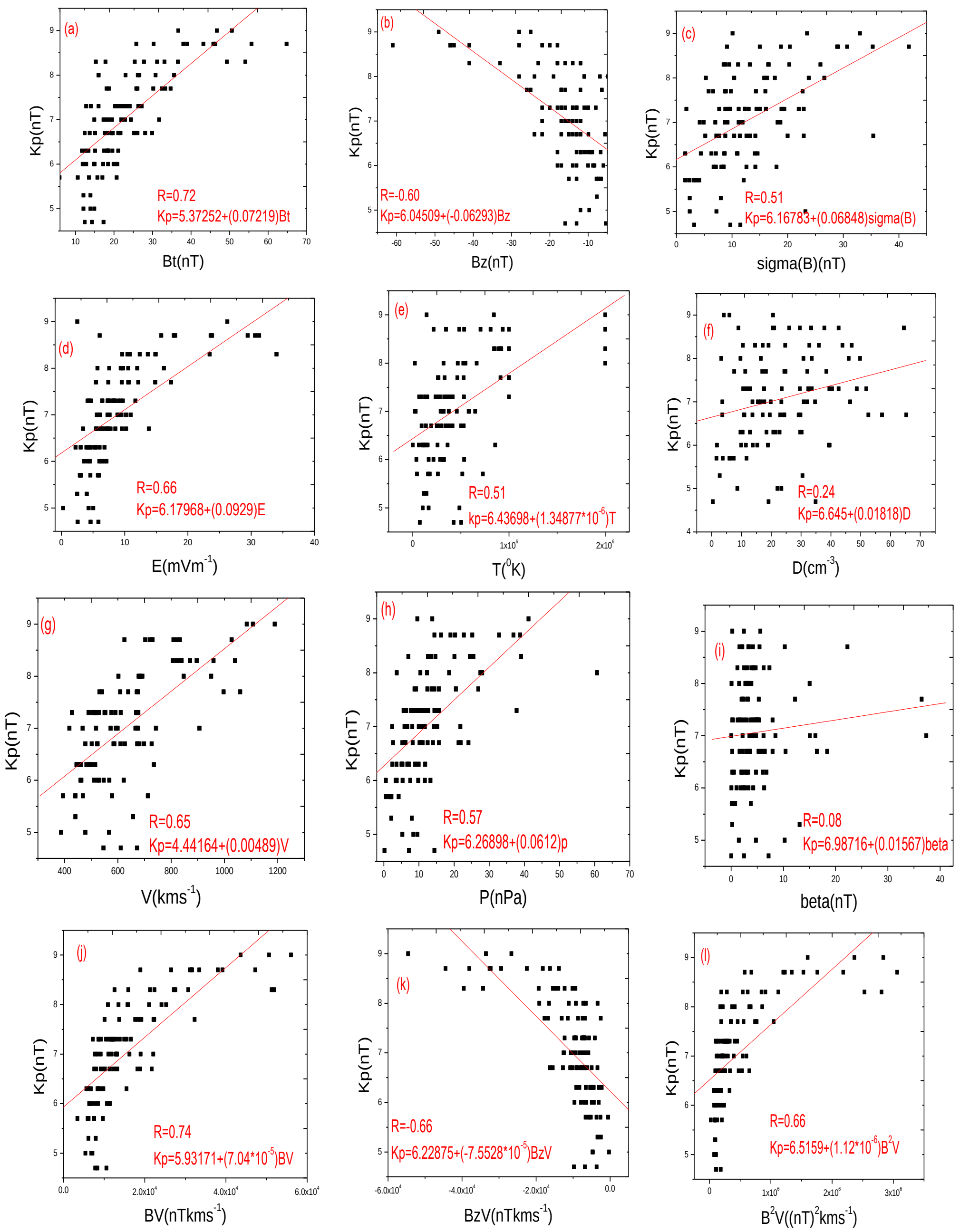

Fig:2. Relations of Kp with interplanetary fields(Bt,Bz,Sigma B, E) , plasma parameters(T, P,V, D, Beta(β)) and there product (BtV,BzV,B2V).

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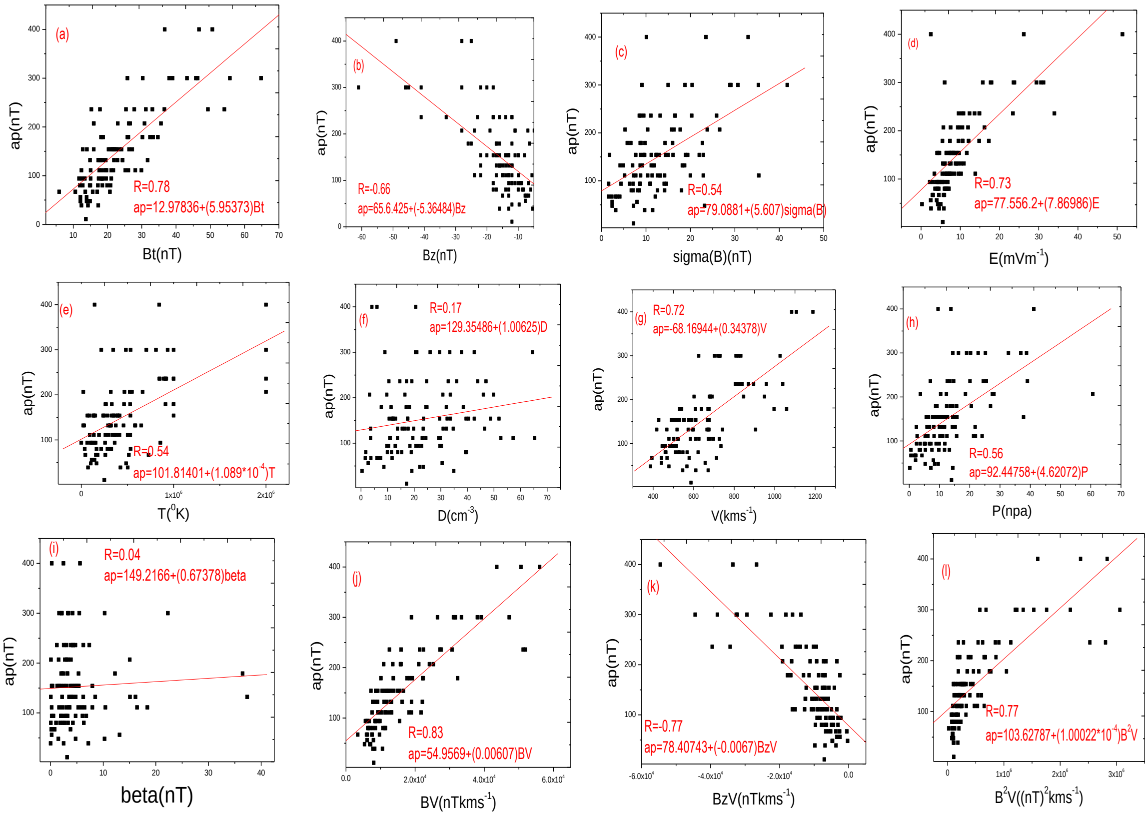

Fig:3. Relations of ap with interplanetary fields(Bt,Bz,Sigma B, E) , plasma parameters(T, P,V, D, Beta(β)) and there product (BtV,BzV,B^2V).

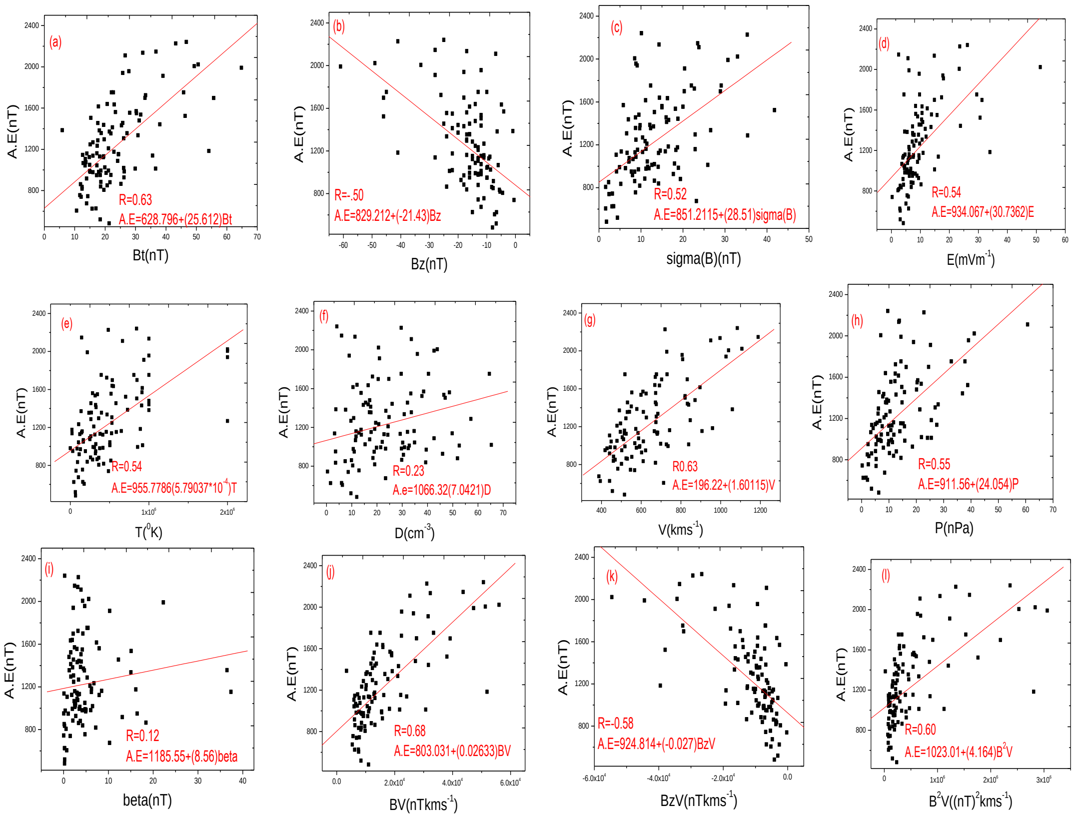

Fig:4. Relations of A.E with interplanetary fields (Bt, Bz, Sigma B, E) , plasma parameters(T, P,V, D, Beta(β)) and there product (BtV,BzV,B^2V).