INTERNATIONAL JOURNAL OF GEOMAGNETISM AND AERONOMY
VOL. 4, NO. 1, PAGES 1–9, APRIL 2003

# Relation of the *Dst* index to solar wind parameters

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**Abstract.** We used more than 100,000 hourly $Dst$ and solar wind data from 1963 to 1990 for statistical study of the coupling function $Q$ and characteristic time $\tau$ in the equation $d\,Dst_0/dt = Q - Dst_0/\tau$ where $Dst_0$ is the $Dst$ index corrected for the dynamic pressure. The dependence of $d\,Dst_0/dt$ on a certain chosen parameter was analyzed under the other parameters being fixed, or more exactly, varying in a narrow range. The coupling function $Q$ was found to depend mainly on the $B_z$ interplanetary magnetic field (IMF) component and solar wind velocity $V$, with negligible dependence on the $B_x$ and $B_y$ IMF components as well as on the solar wind proton density $n$. The dependence on the Akasofu parameter epsilon is also week if it is considered under nearly constant duskward interplanetary electric field $E_{yr}$ and $Dst_0$. The characteristic time depends mainly on $E_{yr}$. We obtained the following expressions for the coupling function $Q = 1.05 - 4.00E_{yr} - V/243$ and for the characteristic time $\tau = 15.4/(1 + 0.326E_{yr})$. The $Dst$ index itself is statistically related to the majority of solar wind parameters. The statistical relations between some solar wind parameters are also revealed.

## 1. Introduction

The major manifestation of a magnetic storm is the global decrease (depression) of the geomagnetic field. The quantitative measure of this perturbation is the $Dst$ index, which is determined as the $H$ component disturbance at low-latitude observatories averaged over longitudes. The temporal behavior of the $Dst$ index corrected for the solar wind dynamic pressure is commonly described by the following equation [*Feldstein*, 1992; *Gonzalez et al.*, 1994]

$$\frac{dDst_0}{dt} = Q - \frac{Dst_0}{\tau} \qquad (1)$$

where $Q$ is the so-called coupling function, $\tau$ is the decay time of the electric currents responsible for the storm-time geomagnetic field depression. The problem of contribution of different solar wind parameters to the function $Q$ has not been finally solved yet. The majority of the investigators relate it mainly to the interplanetary electric field $E_y = -VB_z$ [*Burton et al.*, 1975; *Feldstein et al.*, 1984; *Grafe*, 1988; *Murayama*, 1982; *O'Brien and McPherron*, 2000; *Pisarsky et al.*, 1989; *Pudovkin et al.*, 1985, 1988; *Valdivia et al.*, 1996] where $V$ is the solar wind velocity, $B_z$ is the IMF vertical component in the GSM coordinate system. In particular, *O'Brien and McPherron* [2000] obtained the following empirical expression

$$\begin{aligned} &Q = -4.4(E_y - E_c) \qquad &&\text{for } E_{yr} > E_c \\ &Q = 0 &&\text{for } E_{yr} < E_c \end{aligned} \qquad (2)$$

Here $E_c = 0.49$ mV m$^{-1}$, $E_{yr} = -VB_s$ is the "refined" electric field component directed duskward, $B_s$ is the IMF southward component. Some investigators report that the coupling function $Q$ depends not only on $E_y$ but also on the proton density [*Murayama*, 1982] and velocity [*Pisarsky et al.*, 1989]. Another expression for $Q$ was suggested by *Perreault and Akasofu* [1978]

$$Q = -\varepsilon \qquad \varepsilon = aVB^2 \sin^4 \frac{\theta}{2} \qquad (3)$$

Here $a$ is a constant, $B = (B_x^2 + B_y^2 + B_z^2)^{1/2}$ is the IMF modulus, $\theta = \arctan(B_y/B_z)$, $B_y$ is the dawn-to-dusk IMF

Paper number GAI03406.
CCC: 1524–4423/2003/0401–0406$18.00

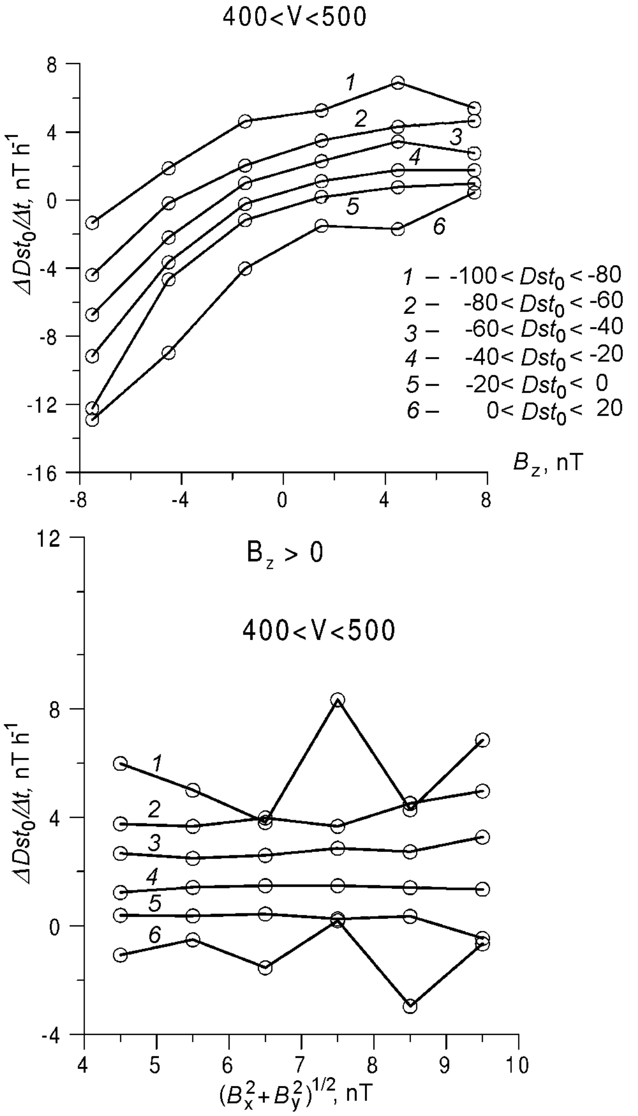


**Figure 1.** Dependence of $\Delta Dst_0$ on the vertical (top panel) and horizontal (bottom panel) IMF component in several ranges of $Dst_0$ and velocity in the range $400 < V < 500$ km s$^{-1}$.

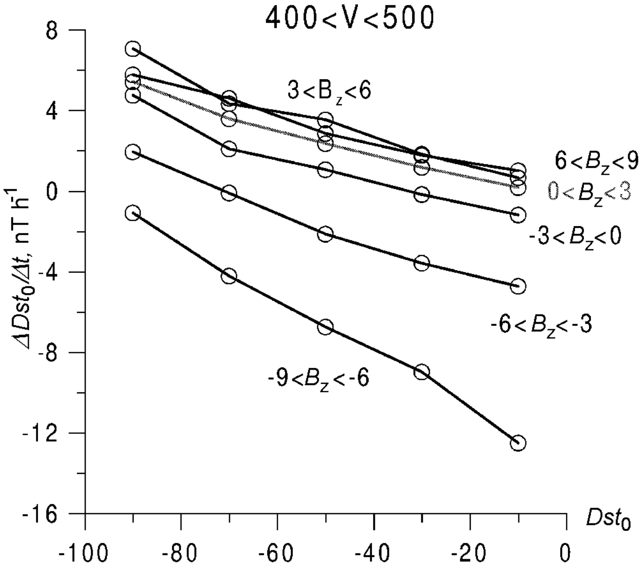


**Figure 2.** $\Delta Dst_0$ versus $Dst_0$ in several ranges of $B_z$ IMF and the solar wind velocity in the range $400 < V < 500$ km s$^{-1}$.

component. The parameter $\varepsilon$ is commonly called the Akasofu parameter.

Expressions (2) and (3) have some similarity — they both show that the magnetosphere behaves as a half-wave rectifier: the IMF southward component affects it considerably stronger than the northward component does. The main difference is that (3) presumes dependence on two other IMF components (on $B_x$ and $B_y$, with a smaller weight, though), whereas these components are absent in (2).

For decades an opinion existed that substorms contribute to the coupling function $Q$. However, *Iyemori and Rao* [1996] have shown convincingly that substorms rather weaken slightly the storm time depression than enhance it.

The characteristic relaxation time $\tau$ of the magnetospheric currents responsible for the geomagnetic depression is of the order of 10 hr and varies in the course of a storm [*Feldstein*, 1992; *Gonzalez et al.*, 1994]. It is not quite clear what factors affect this quantity. For instance, *Valdivia et al.* [1996] assume $\tau = 12.5/(1 - 0.0012\,Dst_0)$ hr whereas *O'Brien and McPherron* [2000] found $\tau = 2.40 \times \exp[9.74/(4.69 + E_{yr})]$ hr.

In this paper we examine the influence of various parameters on the coupling function $Q$ and characteristic time $\tau$. Studying storm activity's relation to the solar wind parameters is complicated by the intercorrelation of the parameters themselves. One purpose of this paper is the analysis of the relation between different solar wind parameters. In order to exclude the effect of the intercorrelation of the parameters we shall try to examine the response of the $Dst_0$ to each parameter separately, that is, under the other parameters being kept constant.

## 2. Experimental Data

We used the OMNI database, which includes hourly values of all IMF components, velocity, and concentration of the solar wind protons as well as hourly *Dst* indices for 28 years, from 1963 to 1990. A total of 112,000 hourly data were used. The *Dst* index was corrected according to the following equation [*Maltsev and Rezhenov*, 2002]

$$Dst_0 = Dst - 8\sqrt{p} \tag{4}$$

where $p = mnV^2$ is the solar wind proton dynamic pressure expressed in nPa, $m$ is the proton mass, $V$ is the solar wind velocity, and $n$ is the proton concentration. The derivative $d\,Dst_0/dt$ was replaced by the ratio $\Delta Dst_0/\Delta t$ where $\Delta t =$

1 hr and $\Delta Dst_0$ is the difference between the values of $Dst_0$ for two successive hours.

$$\Delta Dst_0 = Dst_0(t+1) - Dst_0(t)$$

## 3. Results

### 3.1. Dependence of $\Delta Dst_0/\Delta t$ on $Dst_0$ and on Solar Wind Parameters

Figure 1 shows the $\Delta Dst_0$ versus the vertical $B_z$ and horizontal $(B_x^2 + B_y^2)^{1/2}$ IMF components for the solar wind velocity in the range of $400 < V < 500$ km s$^{-1}$. The dependence is given for several ranges of $Dst_0$. The effect of the horizontal IMF component was analyzed under the northward $B_z$ IMF. One can see that the southward IMF component ($B_z < 0$) affects $\Delta Dst_0/\Delta t$ more than the northward component IMF ($B_z > 0$). There is no dependence of $Dst_0$ on the horizontal IMF component.

Figure 2 shows the $\Delta Dst_0$ versus $Dst_0$ at $400 < V < 500$ km s$^{-1}$ for several ranges of the $B_z$ IMF. The dependence has a form of almost straight lines, their slope depending on $B_z$ IMF. Thus, according to formula (1), the characteristic time $\tau$ depends on $B_z$ IMF and does not depend on $Dst_0$.

Figure 3 shows the $\Delta Dst_0$ versus the solar wind velocity under the northward (left panel) and southward (right panel) orientation of the IMF. In both cases the dependence is almost linear. The slope of the curves is greater under the southward IMF. The right-hand side of Figure 3 together with the left-hand side of Figure 1 suggest that $\Delta Dst_0$ depends nearly linearly on the product $-VB_s$, that is, on the duskward electric field. The left-hand side of Figure 3 reveals a weak dependence of $\Delta Dst_0$ on the velocity under the northward IMF.

Figures 1–3 were drawn for all values of the solar wind density. The dependence of $\Delta Dst_0$ on the density is shown in Figure 4 for $400 < V < 500$ km s$^{-1}$ under the northward (left panel) and southward (right panel) orientation of the IMF in several ranges of $Dst_0$. One can see that there is no pronounced dependence of the $Dst_0$ on the proton density.

It is interesting to compare the relative effect of the electric field and Akasofu parameter on $\Delta Dst_0$. We have looked for the dependence of $\Delta Dst_0$ on each of these parameters under the condition that the other parameter was kept fixed. The result is shown in Figures 5 and 6. While calculating the Akasofu parameter according to formula (3), we assumed $a = 1$. The comparison of Figures 5 and 6 shows that the Akasofu parameter is considerably less geoefficient (its influence on $\Delta Dst_0$ is weaker) than the duskward electric field.

The curves shown in Figures 1 and 2 allow us to find approximation formulas for $Q$ and $\tau$. First we averaged $\Delta Dst_0$ in bins with a size of 20 nT in $Dst_0$, 3 nT in $B_z$ IMF, and 100 km s$^{-1}$ in $V$. Then we found by the least square method the following formulae:

$$Q = 1.05 - 4.00E_{yr} - \frac{V}{243} \qquad (5)$$

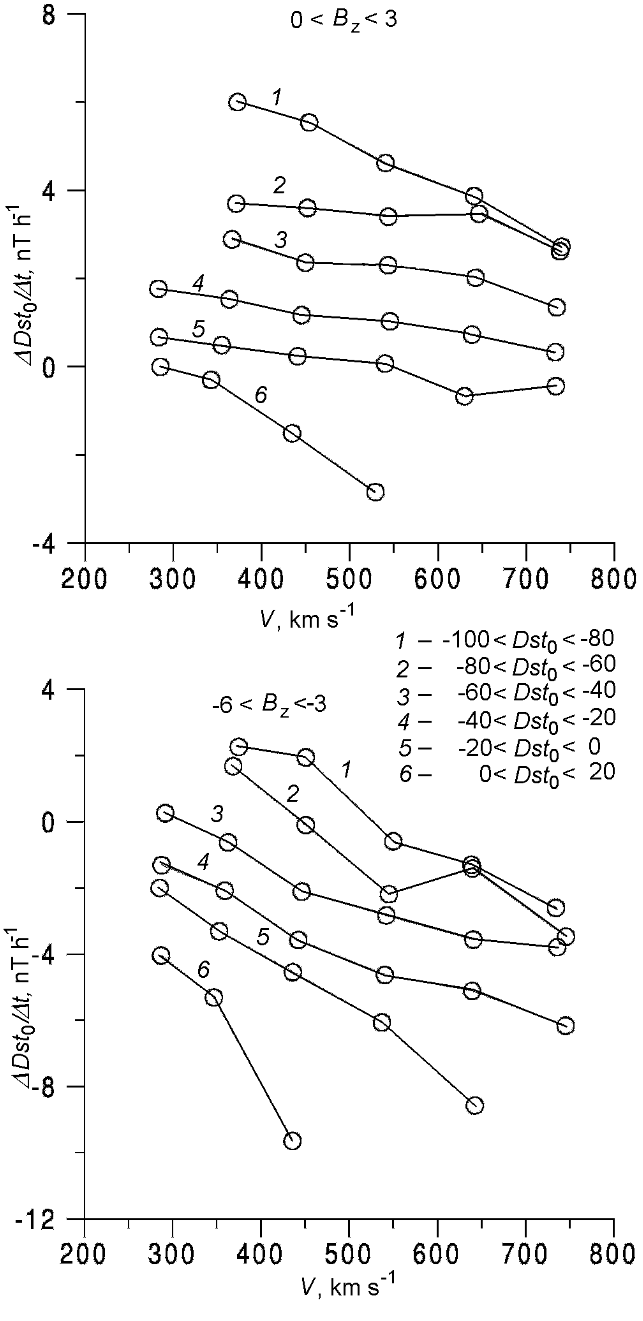


**Figure 3.** $\Delta Dst_0$ versus the solar wind velocity for several ranges of $Dst_0$ under the northward (top panel) and southward (bottom panel) $B_z$ IMF.

$$\tau = \frac{15.4}{1 + 0.326E_{yr}} \qquad (6)$$

### 3.2. Interrelation of the Solar Wind Parameters

Figure 7 demonstrates some statistical relations between the following solar wind parameters: $n$, $V$, $B_z$, $B_{\rm horiz}$, $|B|$, $E_{yr}$, and $\varepsilon$. One can see that the relations $\varepsilon(E_{yr})$, $\varepsilon(B_z)$, $B_{\rm horiz}(B_z)$, $n(B_z)$, $n(V)$ are strong; relations $\varepsilon(E_{yr})$, $\varepsilon(B_z)$,

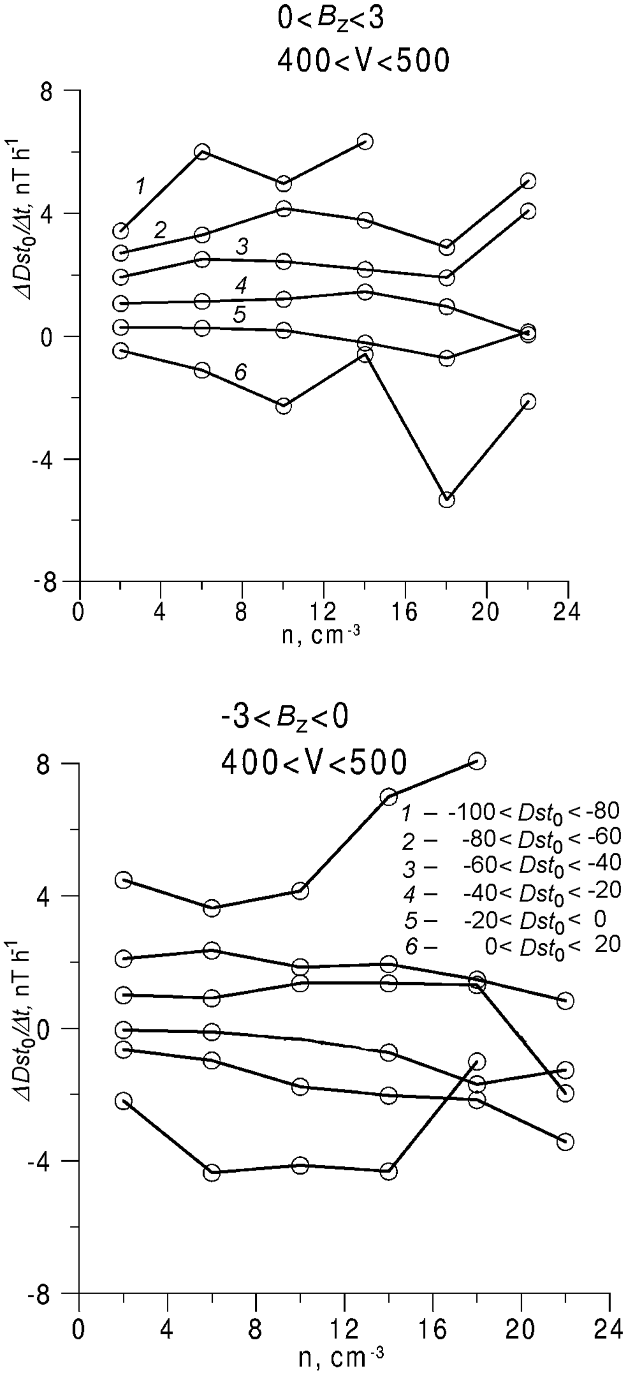


**Figure 4.** $\Delta Dst_0$ versus the solar proton density for several ranges of $Dst_0$ under the northward (top panel) and southward (bottom panel) $B_z$ IMF.

$B_{\text{horiz}}(B_z)$, $n(B_z)$, $n(V)$ are moderate; and relations $V(B_z)$, $V(|B|)$, $|B|(V)$ are weak.

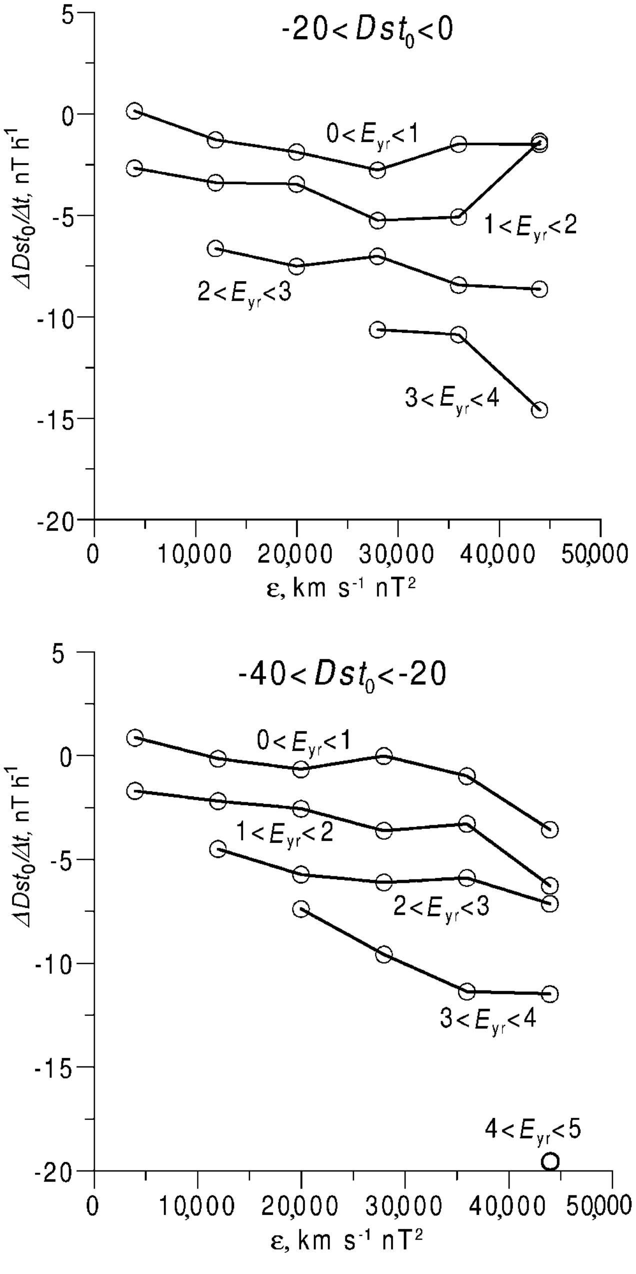


**Figure 5.** Dependence of $\Delta Dst_0$ on the Akasofu parameter for several ranges of the duskward electric field $E_{yr} = -VBs$ and two ranges of $Dst_0$.

### 3.3. Correlation Between *Dst* and Solar Wind Parameters

Figure 8 shows the dependence of *Dst* and $Dst_0$ on three IMF components, on the solar wind velocity and density, and on the $\varepsilon$ parameter. The strongest dependence is on the IMF southward component, velocity, and $\varepsilon$ parameter. The strengthening of the storm activity with the growth of the northward IMF as well as with the increase of $B_x$ and $B_y$ components seems unexpected. But taking into account

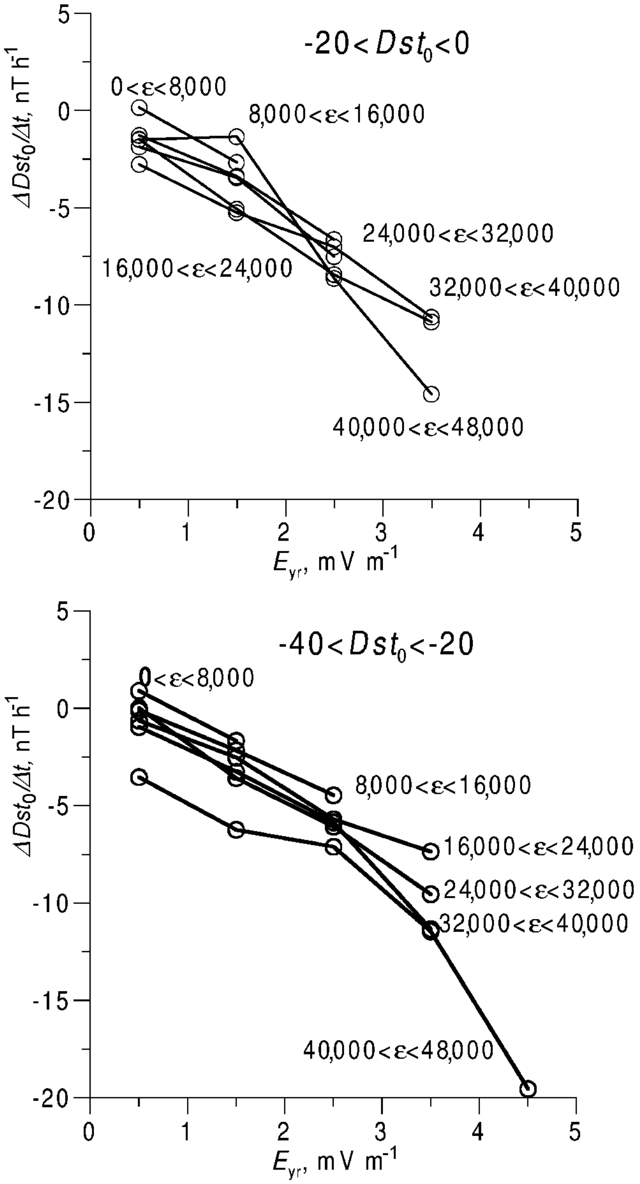


**Figure 6.** Dependence of $\Delta Dst_0$ on the duskward electric field $E_{yr} = -VB_s$ for several ranges of the Akasofu parameter and two ranges of $Dst_0$.

the mutual correlation of the solar wind parameters, we can infer that it is just manifestation of the growing velocity and southward IMF. Both latter facts are a result of the solar wind velocity increase. Indeed, the dependence of $Dst$ on $B_x$ and $B_y$ almost disappears once we introduce the restrictions $400 < V < 500$ km s$^{-1}$ and $B_z > 0$.

## 4. Discussion

Our formulae (5) and (6) do not differ strongly from expression (2) and the formula for $\tau$ by *O'Brien and McPherron* [2000], who suggested that the coupling function $Q$ depends on the duskward interplanetary electric field only. We added the linear term for the solar wind velocity into the expression for $Q$. The dependence on $V$ was found by *Pisarsky et al.* [1989] but with the coefficients strongly different from ours in expression (5). Our Figure 4 does not confirm the dependence of $Q$ on the solar wind proton density obtained by *Murayama* [1982]. While calculating the characteristic time $\tau$ we looked over many kinds of dependencies including $\tau(Dst_0)$, suggested by *Valdivia et al.* [1996]. The dependence $\tau(E_{yr})$ provides the best fit. One can see this fact directly in Figure 2.

As one can see from Figures 5 and 6, the Akasofu parameter $\varepsilon$ is less related to $\Delta Dst_0$ than the electric field $E_{yr}$. Analyzing a number of storm events, *Feldstein* [1992] and *Murayama* [1982] have found earlier that the behavior of $\Delta Dst_0/\Delta t$ is better described by the coupling function $Q$ dependent on $E_{yr}$ rather than on $\varepsilon$. A similar result was obtained by *Wu and Lundstedt* [1997] with the help of the neural network technique. The good relation between $Q$ and $\varepsilon$ found by *Perreault and Akasofu* [1978], *Akasofu* [1981, 1996], and *Gonzalez et al.* [1989] can be explained by the strong statistical correlation between $\varepsilon$ and $E_{yr}$.

Formulas (1) and (5) are important not only for a prediction of $Dst_0$ but also for distinguishing between the two existing theories of magnetic storms. The traditional theory regards the geomagnetic storm time depression as the ring-current effect. The ground magnetic disturbance produced by the ring current is proportional to the total energy content of magnetically trapped particles [*Dessler and Parker,* 1959; *Sckopke*, 1966]. The parameter $\varepsilon$ satisfies this concept perfectly because it is proportional to the solar wind magnetic energy flow. However, till now there have been no theoretical studies explaining quantitatively the observed dependence of $Q$ on $\varepsilon$ (or on $E_{yr}$) under the ring current concept. Moreover, by 2000 the Dessler-Parker-Sckopke relationship had been experimentally tested only in a few case studies. The first statistical study was performed by *Greenspan and Hamilton* [2000], who analyzed 40 storms and did not find any correlation between the total particle energy content in the dayside and $Dst$ index.

A new theory of magnetic storms suggested by *Maltsev* [1991] relates the storm-time depression to an increase of the magnetic flux in the magnetotail lobes. The magnetotail flux grows during storms due to the magnetic flux transport from the dayside to the tail as a result of the terrestrial magnetic field reconnection with the IMF southward component. The rate of this process does not depend on the solar wind energy flux. It depends on the duskward interplanetary electric field [*Maltsev et al.,* 1996]. On the basis of this theory, *Arykov and Maltsev* [1996] calculated the coupling function $Q(E_{yr})$, which is in quantitative agreement with the empirical expression obtained by *Burton et al.* [1975]. The latter does not differ much from (2) and (5). *Maltsev and Ostapenko* [2002] processed a large database containing 20-year measurements of 11 satellites and found that the observed variation of the magnetotail magnetic flux is capable of contributing as much as 80% to $Dst$. *Alexeev et al.* [1996, 2001] also report on a large contribution of the magnetotail current to the storm-time depression.

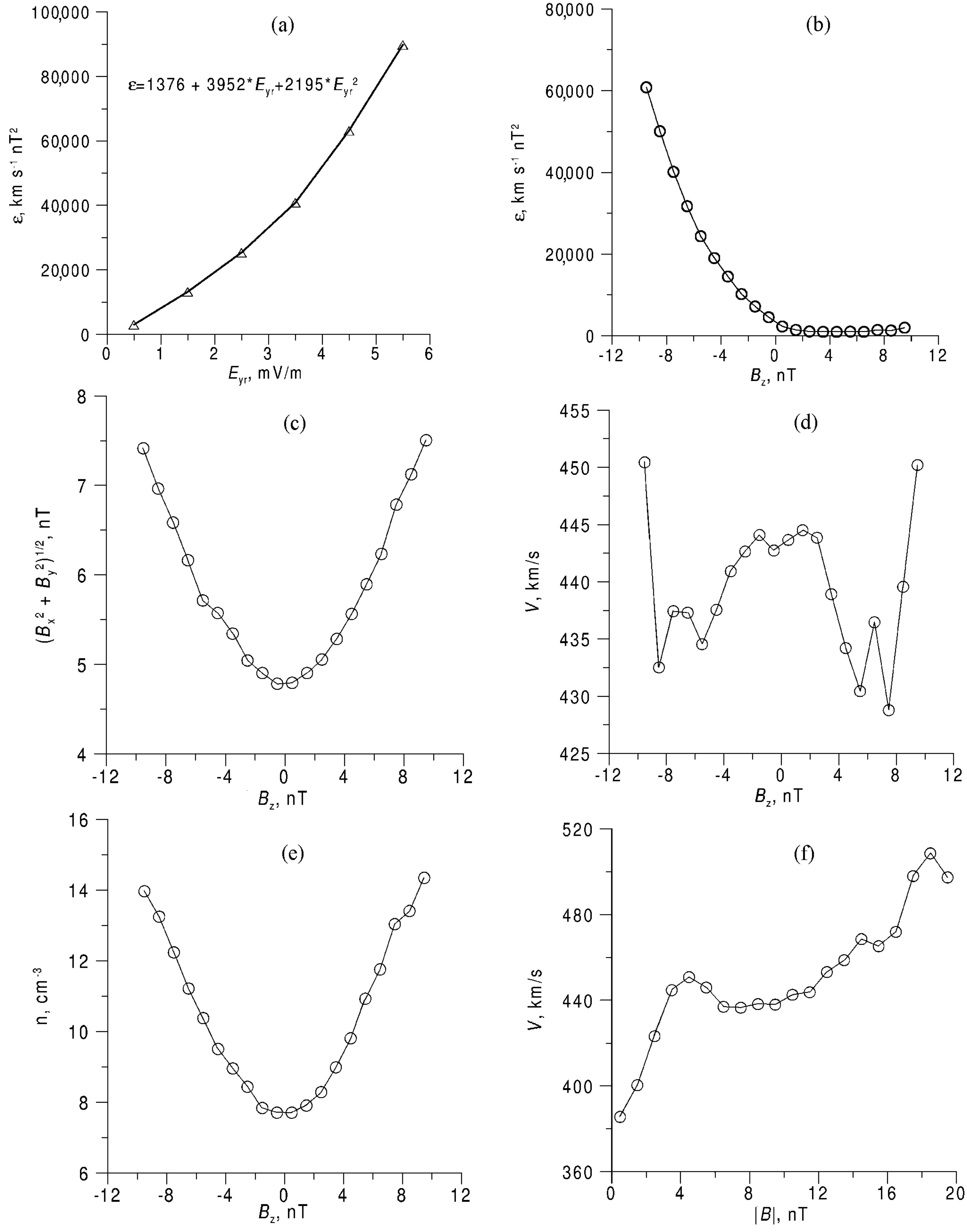
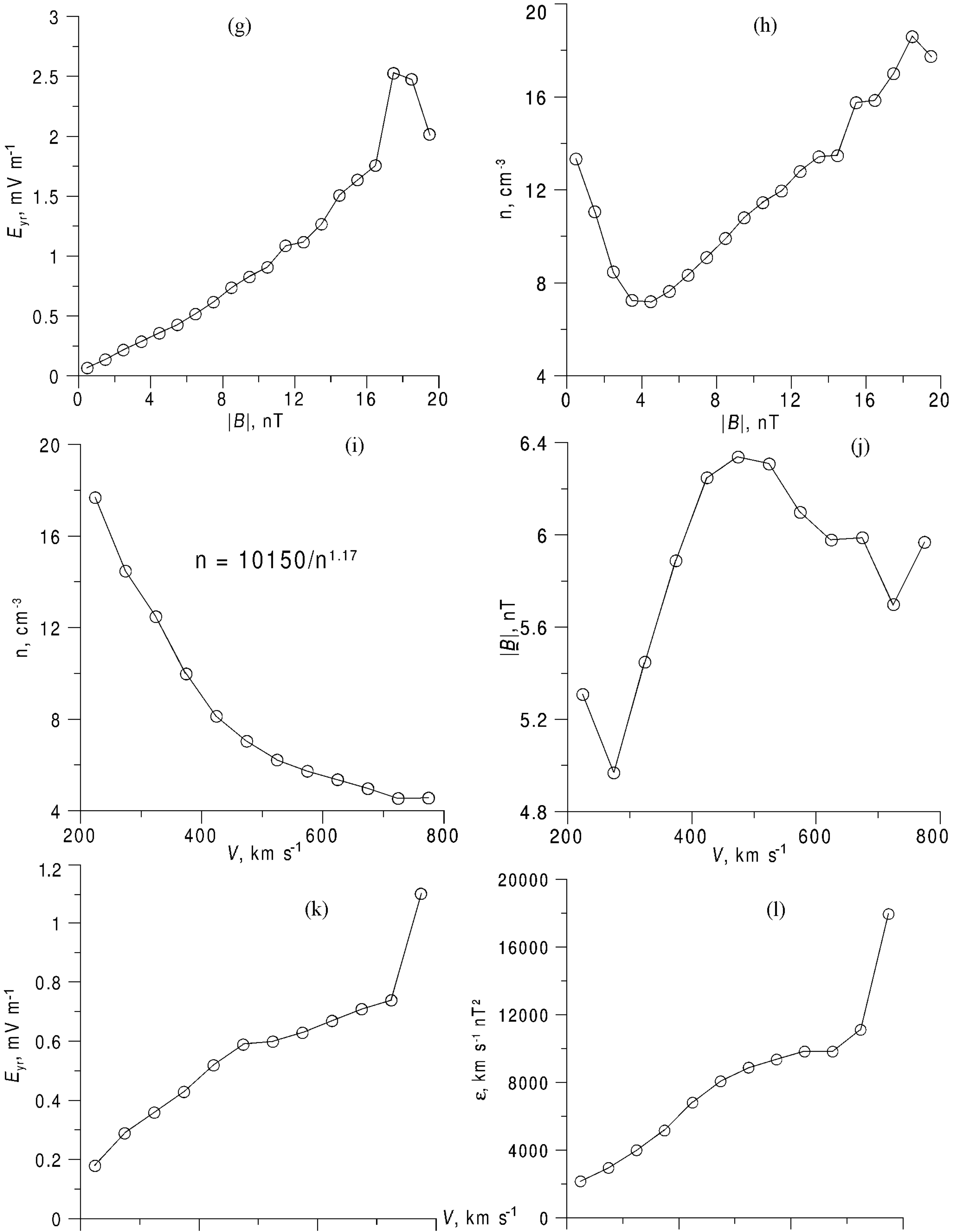


**Figure 7.** Mutual relation between various solar wind parameters.


(g)
E_yr, mV m^-1
0
0.5
1
1.5
2
2.5
3
|B|, nT
0
4
8
12
16
20
(h)
n, cm^-3
4
8
12
16
20
|B|, nT
0
4
8
12
16
20
(i)
n = 10150/n^1.17
n, cm^-3
4
8
12
16
20
V, km s^-1
200
400
600
800
(j)
|B|, nT
4.8
5.2
5.6
6
6.4
V, km s^-1
200
400
600
800
(k)
E_yr, mV m^-1
0
0.2
0.4
0.6
0.8
1
1.2
V, km s^-1
200
400
600
800
(l)
ε, km s^-1 nT^2
0
4000
8000
12000
16000
20000
200
400
600
800

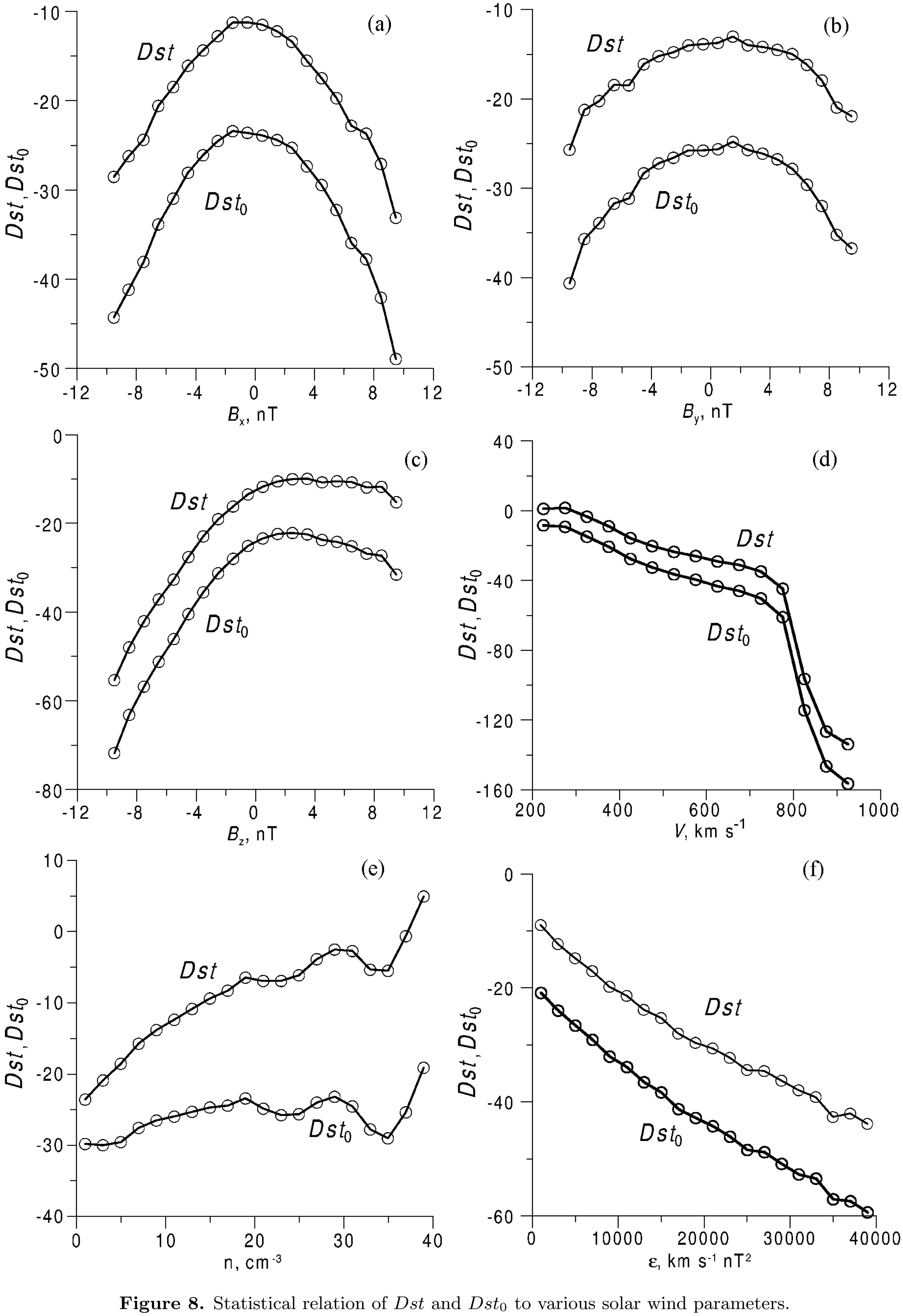


**Figure 8.** Statistical relation of $Dst$ and $Dst_0$ to various solar wind parameters.

## 5. Conclusions

We analyzed the hourly $Dst$ and solar wind parameters for the 28-year period (112,000 data) and found that the solar wind coupling function $Q$ in equation (1) can be presented as a linear combination of the duskward electric field $E_{yr}$ (this term dominates) and velocity. The dependence on $B_x$ and $B_y$ IMF as well as on the solar wind density is negligible. The dependence on the Akasofu parameter $\varepsilon$ appeared to be weak if one examines it under nearly constant $E_{yr}$, whereas the dependence on $E_{yr}$ remains strong and almost invariable when $\varepsilon$ is restricted by a narrow range. Thus, one can conclude that the storm activity is controlled by the magnetic flux transport from the dayside to the magnetotail rather than by the solar wind magnetic energy flow.

The value of $Dst$ itself reveals a significant statistical correlation with the solar wind velocity and all IMF components. The relation of $Dst$ to $B_x$, $B_y$, and $\varepsilon$ seems to be caused by intercorrelation of the majority of the solar wind parameters.

**Acknowledgments.** The solar wind and IMF data have been taken from NSSDC CD-ROM. We are obliged to J. King and N. Papitashvili for providing us with the data. This work was supported by the Russian Basic Research Foundation (grant 03-05-65379) and INTAS (grant 94-1695).

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(Received 26 December 2002; accepted 21 March 2003)