"Physics of Auroral Phenomena", Proc. XXI Annual Seminar, Apatity, pp.99-102, 1998
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COMPARISON OF EFFECTS OF DIFFERENT SOLAR WIND PARAMETERS ON THE Dst VARIATION

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Abstract. The response of the hourly *Dst* index to the IMF B_x, B_y, and B_z components as well as to the solar wind velocity V and number density N has been studied for period from 1963 to 1990. It is shown that the response does not practically depend on B_x, B_y, V, and N in all the ranges of B_z. At the same time the dependence of the *Dst* response on B_z is clearly seen. The injection function of the storm time magnetospheric currents $Q = dDst/dt + Dst/\tau$ appears to be a function of the IMF southward component B_s rather than of the epsilon parameter and of the dawn-to-dusk interplanetary electric field. The time behavior of the ram pressure corrected *Dst* index can be described by the following empirical formula: $dDst_o/dt = 1.2\ B_s - (Dst_o + 20)/12.5$ where Dst_o and B_s are expressed in nT, t is in hours.

Introduction

The main signature of geomagnetic storm is a global depression of the geomagnetic field. The quantitative measure of storm time geomagnetic disturbance is the *Dst* variation, which is determined as a longitude-averaged disturbance of the *H* component observed at low-latitude observatories. Temporal behavior of the ram pressure corrected *Dst* variation is commonly described by the following equation (e.g. [*Feldstein*, 1992; *Gonzalez*, 1994])

$$\frac{d\,Dst_o}{dt} = Q - \frac{Dst_o}{\tau}\ , \qquad (1)$$

where Q is the so-called injection function dependent on the solar wind parameters, τ is the time of decay of the electric currents responsible for the storm time depression. The main factor affecting the injection function Q is the southward component of the interplanetary magnetic field. *Burton et al.* [1975] obtained for Q an empirical formula that can be presented as follows

$$Q = -5.4\,(E_y - 0.5) \quad \text{for } E_y > 0.5 \text{ mV/m}, \qquad (2)$$
$$Q = 0 \quad \text{for } E_y < 0.5 \text{ mV/m}$$

where $E_y = -VB_z$ is the dawn-to-dusk electric field in the solar wind expressed in mV/m, V is the solar wind velocity, and B_z is the IMF vertical component; Q is expressed in nT/hr.

Akasofu [1981, 1996] suggested a different expression:

$$Q = -\varepsilon\ ,\ \text{where}\ \ \varepsilon = a\,V B^2 \sin^4 \theta/2\ , \qquad (3)$$

a is a constant coefficient, $B = (B_x{}^2 + B_y{}^2 + B_z{}^2)^{1/2}$ is the IMF modulus, $\theta = \tan^{-1}(B_y / B_z)$, and B_y is the dawn-to-dusk IMF component. There is some similarity in expressions (2) and (3): they both suggest that the magnetosphere is a kind of a half-wave rectifier – it is affected much stronger by southward IMF than by northward one. The main distinction between formulas (2) and (3) is different dependence of Q on two other IMF components, i.e. B_x and B_y. Formula (2) neglects these components whereas formula (3) includes them although with a smaller weight than the southward B_z.

In order to distinguish which expression is more preferable, we have examined the relation of $dDst/dt$ to B_x and B_y IMF components as well as to the solar wind velocity and density in several ranges of B_z.

Data

We used the OMNI database of the National Space Science Data Center which included hourly values of the IMF (B_x, B_y, and B_z IMF components in the GSM coordinates), solar wind velocity, proton number density, and *Dst* for 28-year period, from 1963 to 1990. There appeared 110,000 hours for which all the values were available. For calculating the ram pressure corrected *Dst* index we used the following expression [*Burton et al.* 1975]

$$Dst_o\,(\text{nT}) = Dst - 0.02\sqrt{nV^2} + 20 \qquad (4)$$

where the solar wind velocity V is expressed in km/s, the proton number density n in cm^{-3}.

The derivative $dDst_o/dt$ may be replaced by the ratio $\Delta Dst_o/\Delta t$ where $\Delta t = 1$ hour, ΔDst_o is the difference between Dst_o values at two successive hours:

$$\Delta Dst_o = Dst_o(t+1) - Dst_o(t)\ . \qquad (5)$$

There is a noticeable mutual correlation between various solar wind parameters (Figure 1). In order to establish their correct physical relation to the *Dst* index, one should study the Dst response to several pairs of the parameters.

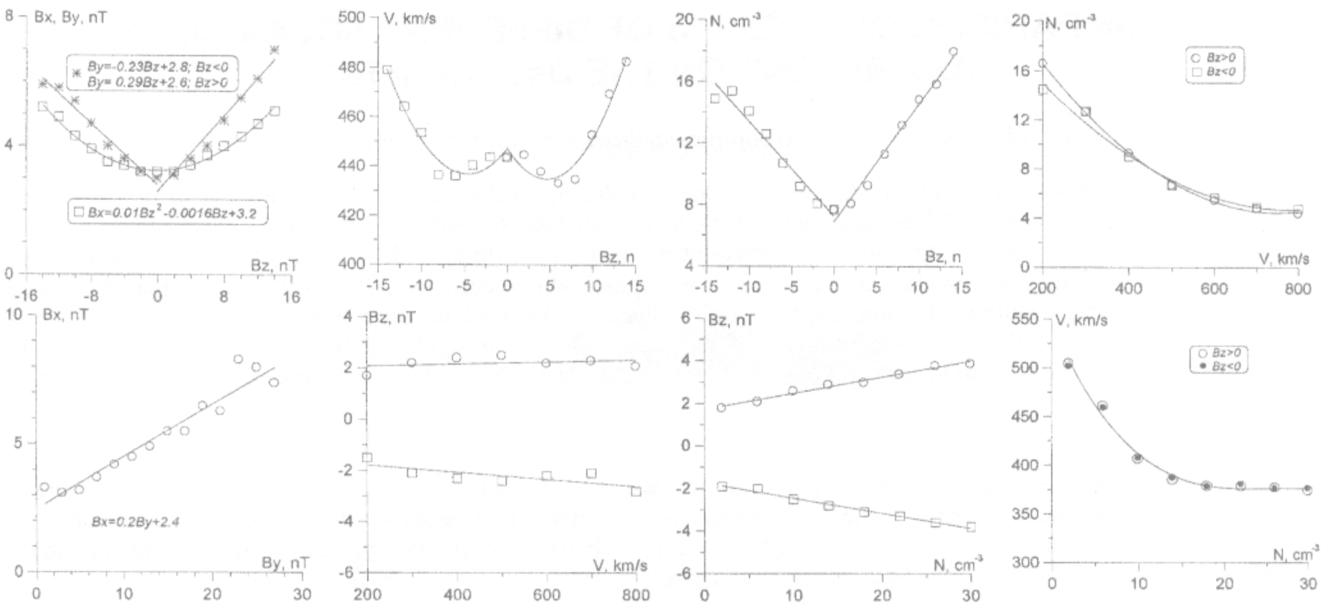

Figure 1. Pair correlation of various solar wind parameters.

Results

Figure 2 (the left top panel) shows contours of equal $\Delta Dst_o = dDst_o/dt$ in the Dst_o, B_z plane. The Dst_o values are averaged in bins with the sizes of 40 nT for Dst and 4 nT for B_z. The rectifying effect is clearly seen in considerably stronger response of Dst index to the southward ($B_z < 0$) IMF than to the northward ($B_z > 0$) one.

Figure 2 (the right top panel) shows contours ΔDst_o = const in the plane of Dst_o and modulus of the IMF for $B_z > 0$. The sizes of bins are 40 nT for Dst and 4 nT for $|B|$. One can see no distinct dependence of ΔDst_o on $|B|$. There is a weak tendency for increasing ΔDst_o with the growth of $|B|$, the tendency being opposite to that predicted by expression (3).

The middle and bottom panels in Figure 2 show contours ΔDst_o = const in the plane of Dst_o and V and N, respectively. One can see a noticeable dependence of ΔDst_o on V and N especially strong under $B_z < 0$ but the dependence seems to be the result of the mutual correlation between B_z and these parameters.

To compare the effect of various solar wind parameters on Dst index we have built contours of equal ΔDst_o in four planes (Figure 3): (B_x, B_z), (B_y, B_z), (V, B_z) and (N, B_z). The linear size of the bins is 2 nT for B, 100 km/s for V, and 4 cm^{-3} for N. The influence of B_z on ΔDst is considerable on all the panels. The dependence of ΔDst_o on B_x, B_y, and N appeared to be negligible as compared to that on B_z.
But rather unexpected result is that there is no pronounced relation of ΔDst_o to V. So the dawn-to-dusk electric field $E_y = -VB_z$ seems to have no advantages before B_z for studying the Dst response.

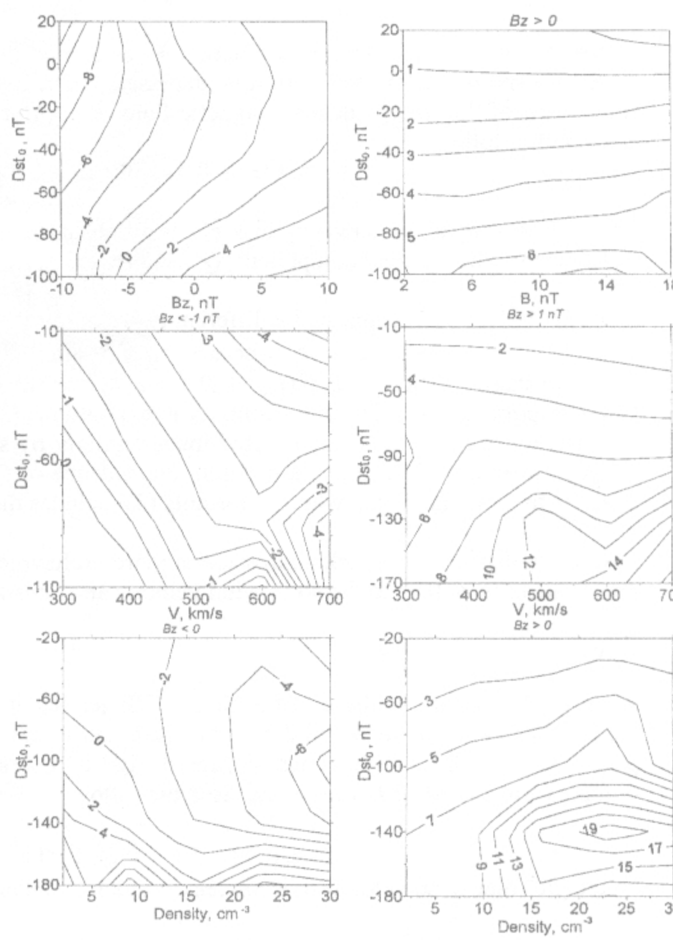

Figure 2. Contours of $dDst_o/dt$ = const (in nT/hr) as a function of the ram pressure corrected Dst index and several solar wind parameters.

Figure 2 (the top left panel) allows us to predict *Dst* one hour ahead if we know *Dst* and B_z for the previous hour. It also permits to estimate the values of Q and τ in expression (1). In order to find τ we have built the dependence of ΔDst_o on Dst_o under three values of B_z (Figure 4, the left panel). The dependencies have been approximated by straight lines, which appeared to have the same slope with the coefficient 0.08. According to expression (1), this coefficient is equal to the reverse time of decay. Hence we have τ = 12.5 hour. *Burton et al.* [1975] obtained τ = 7.7 hours by processing a smaller data set. The right panel in Figure 4 shows the dependence of ΔDst_o on B_z under three values of Dst_o. The dependencies in Figure 4 can be approximated as follows

$$\frac{d\,Dst_o}{dt} = 1.2\ B_s - \frac{Dst_o + 20}{12.5} \qquad (6)$$

where B_s is the IMF southward component ($B_s = B_z$ for $B_z < 0$, $B_s = 0$ for $B_z > 0$). Comparison of (6) with (1) yields

$$Q\ (\text{nT/hr}) = 1.2\ B_s\ (\text{nT}) - 1.6\ . \qquad (7)$$

For typical V = 400 km/s expression (7) yields Q which is about two times smaller than that predicted by (2).

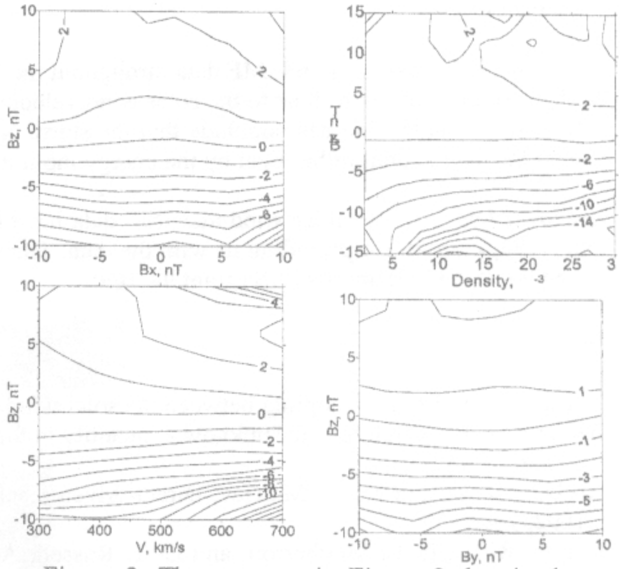

Figure 3. The same as in Figure 2, but in the planes of (B_x, B_z), (B_y, B_z), (V, B_z) and (N, B_z).

Discussion

Equations (1) and (6) are useful not only for the *Dst* prediction but also for better understanding of storms physics. As seen from Figures 2 and 3, epsilon parameter (3) has no advantages for the prediction compared to function (7) dependent on the southward IMF component B_s. Earlier *Wu and Lundstedt* [1997] showed that *Dst* correlated better with B_s than with ε. They did not use equation (1); hence their approach being plausible for forecasting does not fit quite well theoretical speculations.

Akasofu [1981] introduced epsilon parameter (3) by physical reasons. He believed the storm time depression to be the ring current effect. The ground disturbance produced by the ring current is proportional to the total energy content of the particles trapped in the magnetosphere [*Dessler and Parker*, 1959; *Sckopke*, 1966]. The epsilon parameter agrees well with this concept because it is proportional to the flux of magnetic energy in the solar wind.

A new theory of storms suggested by *Maltsev et al.* [1996], *Arykov and Maltsev* [1996] relates the storm time depression mainly to the magnetic flux in the magnetotail. The magnetotail flux during storms grows owing to magnetic flux transport from the day side to the night side in result of reconnection with the southward IMF component [*Dungey*, 1961], the rate of the process being independent on the solar wind energy flux. Thus, expression (7) agrees well with the new theory of magnetic storms.

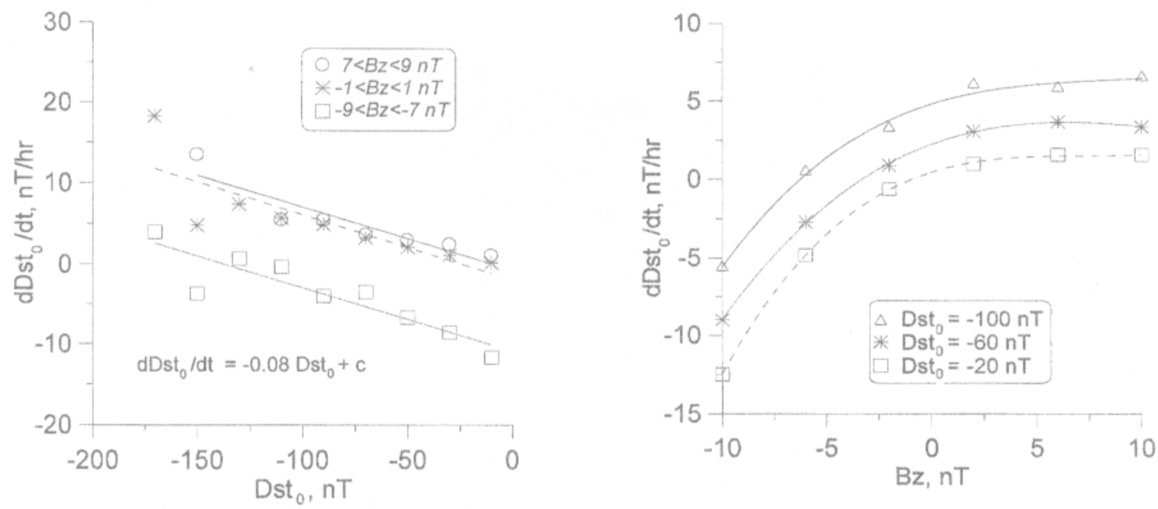

Figure 4. Dependence of $dDst_o/dt$ on Dst_o (the left panel) and IMF B_z (the right panel)

Conclusion

Processing the hourly *Dst* and IMF data throughout the 28-year period showed very different *Dst* response to B_x, B_y, and B_z IMF components as well as to the solar wind velocity *V*. The response to B_z is strong whereas the response to B_x, B_y, and *V* is negligible. One can conclude that the storm activity is controlled by the magnetic flux transport from the day side to the magnetotail rather than by the energy input into the magnetosphere.

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 96-05-64305) and INTAS (grant 94-1695).

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