Prediction of Geomagnetic Disturbance Profile from Interplanetary Shock Wave Energy Transfer Index, $F_s$, in Interplanetary Space

F. S. Wei and S. Q. Liu

Lab. of Numerical Study for Heliospheric Physics, Center for Space Science and Applied Research, Academia Sinica, P.O. Box 8701, Beijing 100080, China

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Based on 297 interplanetary shock waves and corresponding geomagnetic disturbances, the relation between their structures has been studied. For the case in which the interplanetary magnetic field lies basically in the ecliptic plane, we found that (1) the temporal profile of geomagnetic disturbance is mainly determined by the plasma state of the shock waves, especially, the closed relation exists between the plasma temperature profile and the recovery phase of geomagnetic disturbances; (2) shock wave energy transfer index, $F_s$, as defined in the paper, can give a good prediction of the temporal profiles of geomagnetic disturbances. Thus, it may be deduced that there is a basic energy transfer mechanism associated with plasma processes, which would control geomagnetic disturbance profiles, when a southward-component of interplanetary magnetic field is not significant.

1. Introduction

In order to predict geomagnetic activity caused by interplanetary disturbances, various solar wind-magnetosphere coupling functions were proposed by many authors (e.g., Perreault and Akasofu, 1978; Vasyliunas et al., 1983; Murayama, 1986; Bargatze et al., 1986; Gonzalez et al., 1989). Recently, Gonzalez (1990) has given a expression to unite those coupling functions suggested by the authors mentioned above. They mainly discussed the role of the direction of interplanetary magnetic field in geomagnetic storm generation.

In the recent years, solar and interplanetary sources of the geomagnetic storms have been widely investigated by Klein and Burlaga (1982), Schwenn (1986), Gosling et al. (1990), Tsurutani et al. (1992), and so on. They found that CMEs is solar source of intense geomagnetic disturbances and that orientation and behaviors of the interplanetary magnetic field (IMF) are very important to large geomagnetic storms, especially during high solar activity.

Because of some geomagnetic storms which are not associated with larger southward-component of IMF, we think that there is a possible energy transfer mechanism associated with a shocked plasma processes, by which geomagnetic storms would be caused. Here, we mainly analyse the temporal profile relation between interplanetary shock wave parameters and corresponding geomagnetic disturbance index, $K_p$, especially for the case in which a southward component of the interplanetary magnetic field is not significant.

2. Data and Analyses

297 interplanetary shock wave (SW) and corresponding geomagnetic disturbance (GD) events, respectively, were chosen from Interplanetary Medium Data Book (King, 1977, 1979, 1983, 1986) and Solar Geophysical Data (1966–1981). We have used the following combined criteria to identify interplanetary shock waves. These criteria include: (1) a sudden velocity increase, exceeding 50 km/s; (2) sudden increases of magnetic field, density, and temperature are basically at the same time as increase of...
the velocity; (3) consideration of isolated shock events that are separated from other events by a minimum
time difference > 4 days; and (4) sufficient data, for at least 7 days, for each event. All of these criteria were
simultaneously satisfied by the 297 samples in 1966–1981.

In order to investigate the temporal profile relation between SW and GD, different parameters, such
as density, velocity, magnetic field etc., will be used for the division of groups of SW events. It should
be noted that only data with no significant \( B_z \)-value of IMF (in GSM coordinate system) were analyzed
by using a superposed epoch method.

![Fig. 1. Average temperature profiles in \( F_s \) and the correspondent GD structures for the case of no significant \( B_z \).](image)

(a) slow density jump (for about 12 hours); (b) quick density jump (for about 6 hours); (c) short duration of maximum density (< 12 hours); (d) long duration of maximum density (> 12 hours). NE—Number of Events.
3. Results and Discussions

3.1 Energy transfer index, $F_s$, based on the thermo-pressure

By the comparison of geomagnetic disturbance index, $K_p$, with many shocked parameters, such as speed ($V$), density ($D$), temperature ($T$), magnetic field strength ($B$), $\beta$, $1/2\rho V^2$, $2\rho V^2$, and the Mach number $M_A$, we found that the correlation between $K_p$ and $T$ is the best in all shocked parameters. Figure 1 shows temporal profiles of the temperature, $T$, for the various types of shock waves and the $K_p$ index during the corresponding geomagnetic disturbance events. According to the time interval of density jump and the

![Fig. 2. Comparisons of the average $F_s$ and $K_p$ index. (a) small velocity jump and short duration; (b) small velocity jump and long duration; (c) large velocity jump and short duration; (d) large velocity jump and long duration. NE—Number of Events.](image-url)
duration of the maximum density in the front of the shock waves, they were divided into the four types (a) slow density jump (for about 12 hours); (b) quick density jump (for about 6 hours); (c) short duration of maximum density (<12 hours); and (d) long duration of the maximum density (>12 hours). Here, t(d) = 0.00 hour indicates the arrival time of a shock wave at the earth. There is a good correlation between the profiles of logT and the Kp index, during the background, disturbance and recovery phases. Especially in their recovery phases consistence between the parameters is very good for the four kinds of shock waves mentioned above.

According to the good correlation between logT and Kp, we suggest a shock wave energy transfer index,

\[ F_s = a\sqrt{\log\left(\frac{P}{M_A}\right)} + b \]

where the constants a and b, are the constants determined by the transform factor between \( F_s \) and \( K_p \) of different kinds of the shock wave: 
\[ P = 2nKT/P_0 \]
\[ P_0 = 4.00 \times 10^{-17} \text{ J/m}^2 \]
\[ M_A = V/V_A \]
Alfven speed \( V_A \). \( F_s \) index could be used for predicting the \( K_p \) index for GD that is caused by interplanetary shock waves. Usually, higher \( M_A \) occurs after larger \( P \) by 1–2 days for the time profile of a shock wave event. The formula, \( F_s \), therefore, means that a larger thermo-pressure, \( P \), would cause a larger geomagnetic distur-

![Graphs showing comparisons of Kp index and predictions F_s from four random samples: Feb. 7, 1967 (No. 23), March 9, 1967 (No. 26), Feb. 7, 1968 (No. 53) and Sept. 12, 1977 (No. 124).]
bance and that $P$ could be main control factor of correspondent GD for the case of a little southward component of IMF. For this point we will obtain further understanding from an example as shows in Fig. 4 below.

3.2 Prediction of $K_p$ index from $F_s$

The energy transfer index, $F_s$, were used for the predictions of the geomagnetic disturbances, $K_p$, index.

![Graphs showing comparisons of various parameters and geomagnetic disturbances](image)

Fig. 4. Comparisons of the various shocked parameters and the geomagnetic disturbance index and the shock wave energy transfer index, $F_s$, during the period of the solar-terrestrial disturbance event, March 9, 1967.
All of the predictions for various divisions of the groups of shock waves is good as little southward component, $B_s$. Here, the results of the groups divided on the basis of speed jump are discussed below.

Figure 2(a) shows the comparisons between the observations and the predictions for GD, in which $a = 7.50$, $b = -12.00$. The shock events here are divided into the four groups based on the speed jump in the front of the shock waves. Figure 2(b) shows the southward component, $B_s$, of the magnetic field for the corresponding events in Fig. 2(a), in order to investigate the role of $B_s$ in predicting temporal profile of the geomagnetic disturbance by $F_s$ index. Better coincidence between the temporal profiles of $K_p$ and $F_s$ indices is evident in the recovery phases. We also see that for the case of a large southward component, the coincidence can not be obtained around the maxima.

3.3 Prediction test for individual event

We took 4 samples out of 297 interplanetary shock wave events at random and used them to make the prediction test of the correspondent geomagnetic disturbances.

Figure 3 shows comparison between the observed $K_p$ and the predicted $F_s$ values for the four random samples. The constants $a$ and $b$ for those $F_s$ functions are respectively, 8.67, $-14.23$ (Feb. 7, 1967), 7.01, $-12.11$ (March 9, 1967); 7.05, $-10.21$ (Feb. 7, 1968) and 7.58, $-12.08$ (Sept. 12, 1977). The results indicate that the predictions of $K_p$ from $F_s$ are also successful for individual event. Not too good coincidences only occur in the period before sweeping of the shock wave over the earth.

Figure 4 gives various shocked parameters: $V, D, T, B, B_s, E_k$ and geomagnetic disturbance index, $K_p$ and $D_{st}$ and energy transfer index $F_s$ for one event in March 9, 1967 ($a = 7.10$, $b = -12.11$). It is clear that the $F_s$ index proposed in this paper is a good prediction measure for the $K_p$ index. It should be noted that the dynamic pressure, $E_k = 1/2 \rho V^2$ and the others do not correlate with $K_p$ and $F_s$.

4. Conclusion

When $B_s$ in the shocked region downstream has no significant southward component, the shock wave energy transfer index, $F_s$, can give good predictions to the temporal variations of geomagnetic disturbances ($K_p$ or $D_{st}$).

We may deduce that there is a basic energy transfer mechanism associated with the shocked plasma processes for small southward component of IMF, additionally to that of magnetically-reconnection which is important for larger $B_s$. The controlling factor of the geomagnetic disturbances is mainly determined by interplanetary disturbances. We think that a synthesis of the plasma thermo-states with magnetic states owned by the interplanetary shock wave is necessary to improve the predication of geomagnetic activities further.

REFERENCES


