Time Delay Between Dst Index and Magnetic Storm Related Structure in the Solar Wind

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Abstract

Benson et al. (2015, this volume) selected 10 large magnetic storms, with associated Dst minimum values ≤ -100 nT, for which high-latitude topside ionospheric electron density profiles are available from topside-sounder satellites. For these 10 storms, we performed a superposition of Dst and interplanetary parameters B, v, N_p and T_p. We have found that two interplanetary parameters, namely B and v, are sufficient to reproduce Dst with correlation coefficient cc ~ 0.96 provided that the interplanetary parameter times are taken 0.15 days earlier than the associated Dst times. Thus we have found which part of the solar wind is responsible for each phase of the magnetic storm. This result is also verified for individual storms as well. The total duration of SRS (storm related structure in the solar wind) is 4 – 5 days which is the same as the associated Dst interval of the magnetic storm.

1. Introduction: Concept of Storm Related Structure.

Strong magnetic storms (Dst ≤ -100 nT) are often associated with the arrival of interplanetary magnetic clouds. The durations of magnetic clouds observed near the Earth are usually about one day. Magnetic storms, however, may last up to 4 - 5 days, i.e., significantly longer than the associated magnetic clouds. By studying individual magnetic storms, as well as a superposition of many storms, we identify the boundaries of the storm related structure in the solar wind (SRS) and relate different phases of a magnetic storm to interplanetary parameters of the SRS.

Empirical relations between Dst and solar wind parameters such as total magnetic field strength B, components of vector $\vec{B}$, solar wind speed v, solar wind density ρ (or proton number density N_p), have been offered previously. For example, Perreault and Akasofu (1978) have suggested the epsilon parameter which is proportional to the vector product of $\vec{B}$ and $\vec{E}$ vectors and also depends on the IMF solar clock angle. Burton, McPherron and Russell (1975) have offered an empirical linear differential equation for Dst with a driver dependent on solar wind parameters. More elaborate empirical models for Dst can be found in the literature (such as Temerin and Li 2006, Tsyganenko and Sitnov 2007 and references in both papers).

Osherovich, Fainberg and Stone (1999) suggested a new index of solar activity based on solar wind parameters. They defined a solar wind quasi-invariant

$$QI \equiv (B^2/8\pi)/(\rho v^2/2) \quad (1)$$

as a ratio between magnetic energy density in the solar wind and energy density of solar wind flow. QI increases by 10 – 100 times for magnetic clouds in comparison to values in undisturbed solar wind. For the magnetic cloud which caused the great magnetic storm of March 31, 2001, Wind spacecraft data were used to calculate QI (Osherovich et al. 2007). IMAGE magnetospheric sounder (RPI) data for this storm permitted a determination of electron density N_e (and therefore plasma frequency f_{pe}) and electron gyrofrequency f_{ce}. The ratio f_{pe}/f_{ce} has been found to correlate closely (87%) with QI using a time delay of about 3h. This work provided the motivation for similar research in the ionosphere (Benson et al. 2015). In our paper we have focused on the time delay between the SRS and the Dst index.

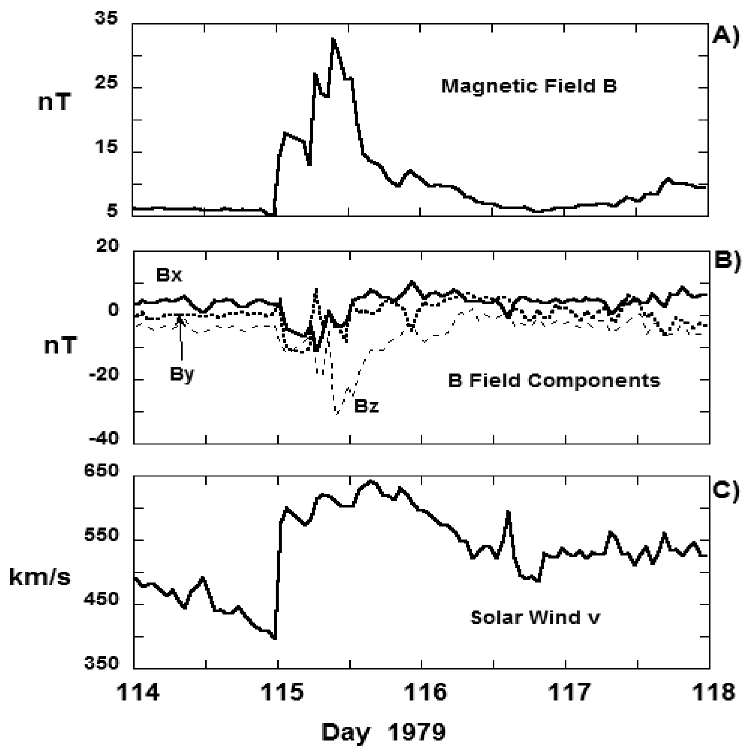

Figure 1. Magnetic Cloud and Storm Related Structure

For one of the 10 selected magnetic storms for which N_e ionospheric profiles were measured, we show in Figures 1 and 2 data (OMNI 2, King and Papitashvili 2004) for the interplanetary magnetic cloud (MC) of 1979 day 115. Three properties define a MC (Burlaga et al. 1981, Osherovich and Burlaga 1997), namely, **1)** Significant increase of B, as shown in Figure 1A, **2)** rotation of vector $\vec{B}$ (bipolar signature of at least one of the $\vec{B}$ components) as shown in Figure

1B and **3)** drop in proton temperature T_p shown in Figure 2B near day 115.5. The arrival of the MC sheath is marked by the shock with the abrupt increase of v on day 115 (see Figure 1C) accompanied by the increase of proton number density N_p (see Figure 2A) and related increase in T_p (Figure 2B). The solid line in Figure 2C represents the Dst index for the MC. In both Figures 1 and 2, hourly data are used.

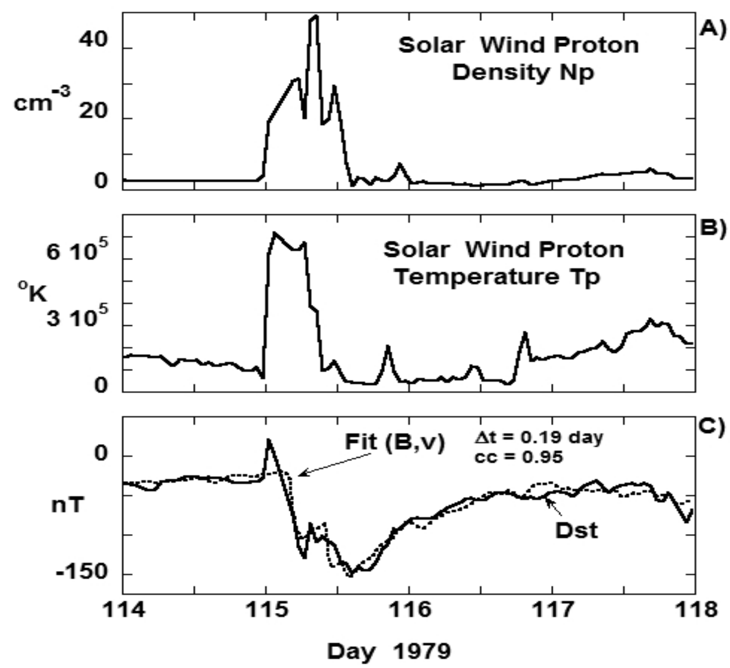

Figure 2. Dst for Magnetic Storm and Storm Related Structure

In Figure 2C, the dotted line shows our solar wind proxy for Dst for this event. We found that the total magnetic field B and solar wind speed v are sufficient to represent Dst for large magnetic storms (Dst ≤ -100 nT). Our coupling function is

$$Dst(t) = -m1 \bullet B_{(t-\Delta t)}^{m2} \bullet v_{(t-\Delta t)}^{m3} \qquad (2)$$

where m1, m2, m3 and Δt are constants determined for each storm, and Δι ιs the time lag between the solar wind parameters and the later measurements of Dst. For the magnetic storm shown in Figure 2C, we find $m1 = 1.5 \bullet 10^{-5}$, m2 = 0.61, m3 = 2.19 and Δt = 0.19 days. Formula (2) reproduces Dst with correlation coefficient cc = 0.95. For fixed values of Δt and m1, the errors for m2 is 0.03 and for m3 is 0.01. Equation (2) represents our solar wind proxy for Dst, which depicts the SRS for both the main phase and the relaxation tail of the storm. The sudden commencement of Dst (Dst positive), however, is not represented by our proxy.

2. Superposition of Dst for 10 Magnetic Storms and Corresponding Storm Related Structure.

Figure 3A is similar to Figure 2C. The solid line in Figure 3A shows the superposition of Dst for the 10 large magnetic storms. The magnetic storm in Figure 2C is one of these 10 storms. The time for the superposition (time at 0 days) is chosen to be the time (interpolated) when each storm first reaches -50 nT. The period selected for analysis is -1 day to +5 days. Averaging is done for each 0.1 day interval, and the averages and their standard errors are shown in Figure 3A-C. Using the B and v superpositions presented by the solid lines in Figures 3B and 3C, and Formula (2), we have determined the Dst proxy which is shown by the dotted line in Figure 3A; the significant deviation of the fit near the arrow in this figure is due to the selection criteria used, i.e., the availability of topside ionospheric data rather than clean single-storm events.

This proxy fit has a correlation coefficient = 0.96 with Dst and a time delay $\Delta t = 0.15$ days. For this 10 event proxy, $m1 = 1.17 \cdot 10^{-10}$, $m2 = 1$ and $m3 = 4$. Thus the dependence on v dominates in the proxy (Equation 2) in comparison with B. In contrast, the energy coupling function epsilon of Perreault and Akasofu (1978) utilizes B to the second power and v to the first power, i.e., the magnetic field dominates.

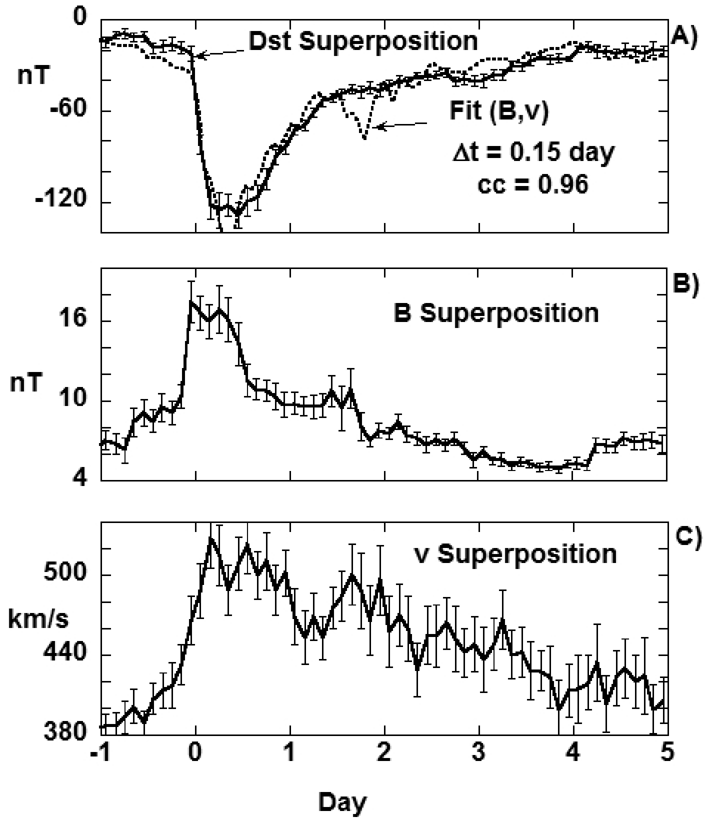

Figure 3. Superposition of 10 Magnetic Storms with Solar Wind Proxy

3. Discussion and Summary

For large magnetic storms (Dst ≤ -100 nT) we have found a solar wind proxy (Equation 2) for Dst which depends only on B and v in the solar wind. The dependence on v is stronger than on B. This proxy reproduces the Dst for the magnetic storm of 1979 day 115 with a correlation coefficient cc = 0.95 and with a time delay of $\Delta t = 0.19$ days. When applied to a superposition of 10 magnetic storms, cc = 0.96 and $\Delta t = 0.15$ days. This time delay between the magnetic storm and storm related structure is comparable but slightly larger than the time delay $\Delta t = 3$ hours between the solar wind quasi-invariant and f_{pe}/f_{ce} in the polar magnetosphere (Osherovich et al. 2007). Our proxy provides a one to one correspondence between different phases of the magnetic storm with parts of the solar wind that are responsible for related changes of the Dst index.

Acknowledgements

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