THE MAGNETOSPHERIC RESPONSE TO A TWO-STREAM SOLAR WIND INTERVAL DURING SOLAR MAXIMUM: A SELF-CONSISTENT MAGNETOSPHERIC MODEL

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ABSTRACT

A two-stream solar wind interval (two interplanetary CME events) during 1-7 May 1998 is examined and the magnetospheric response to these events is modeled and compared to satellite data. The solar ejecta (CMEs) and resultant fast interplanetary streams cause magnetic storms with minimum Dst values of –85 nT and –205 nT, respectively. For the second, more intense magnetic storm, it is found that at the Earth's surface the maximum values of the disturbance fields are -208 nT for the ring current contribution (DR), 112 nT for the Chapman-Ferraro (DCF) magnetopause current system, and -161 nT for the tail current system (DT). Although DT is large, it is counterbalanced by DCF. These currents significantly modify the magnetospheric geometry and size and must be included for any accurate magnetic field representation during storm periods.

1. INTRODUCTION

Solar activity varies as a function of the phase of the solar cycle. At and near solar maximum, coronal mass ejections (CMEs) are the most important phenomena that generate magnetic storms at Earth. During solar minimum, high-speed streams emanating from coronal holes are the most frequently occurring and most important solar features. The stream interactions with the slow speed solar wind create compressive regions called corotating interaction regions (CIRs) that can cause 27-day recurrent geomagnetic storms.

For CMEs that are "fast" relative to the background slow solar wind, a forward shock and sheath form upstream of the ejecta. The shocks compress both the upstream plasma and magnetic fields. The higher density plasmas constitute higher ram pressures which compress the Earth's magnetosphere when they impinge upon it. Since the major solar wind energy transfer to the magnetosphere is through magnetic field reconnection [1] between the interplanetary magnetic field (IMF) and the Earth's magnetic field (when the IMF is southward), both the compressed sheath fields and the intrinsically strong ejecta magnetic fields are important. For CIRs, although the compressed magnetic fields are intense, they are highly varying in Bz sign and amplitude and magnetic reconnection is therefore sporadic and not continuous. Therefore, magnetic storms caused by CIRs are only "moderate" in intensity [2].

For space weather studies, the energy and momentum flow from the Sun through interplanetary space to the magnetosphere and ionosphere is of utmost importance. The principal interplanetary parameters controlling the magnetospheric response are the solar wind ram pressure and the IMF magnitude and direction. Our magnetospheric model [3] not only includes the interplanetary parameters but also spacecraft magnetospheric and ionospheric data that are used to calculate resultant self-consistent, time-dependent large-scale currents. The model includes a ring current, a tail current, field-aligned currents flowing between the magnetosphere and the ionosphere, and also currents along the outer regions of the magnetosphere (magnetopause currents). It is important to consider these magnetospheric currents to fully and accurately understand the solar wind-magnetosphere interaction.

2. THE 1-7 MAY 1998 INTERPLANETARY DRIVERS AND RESULTANT MAGNETIC STORMS

Because of limited space, we will discuss only one interval in the ascending phase of the solar cycle

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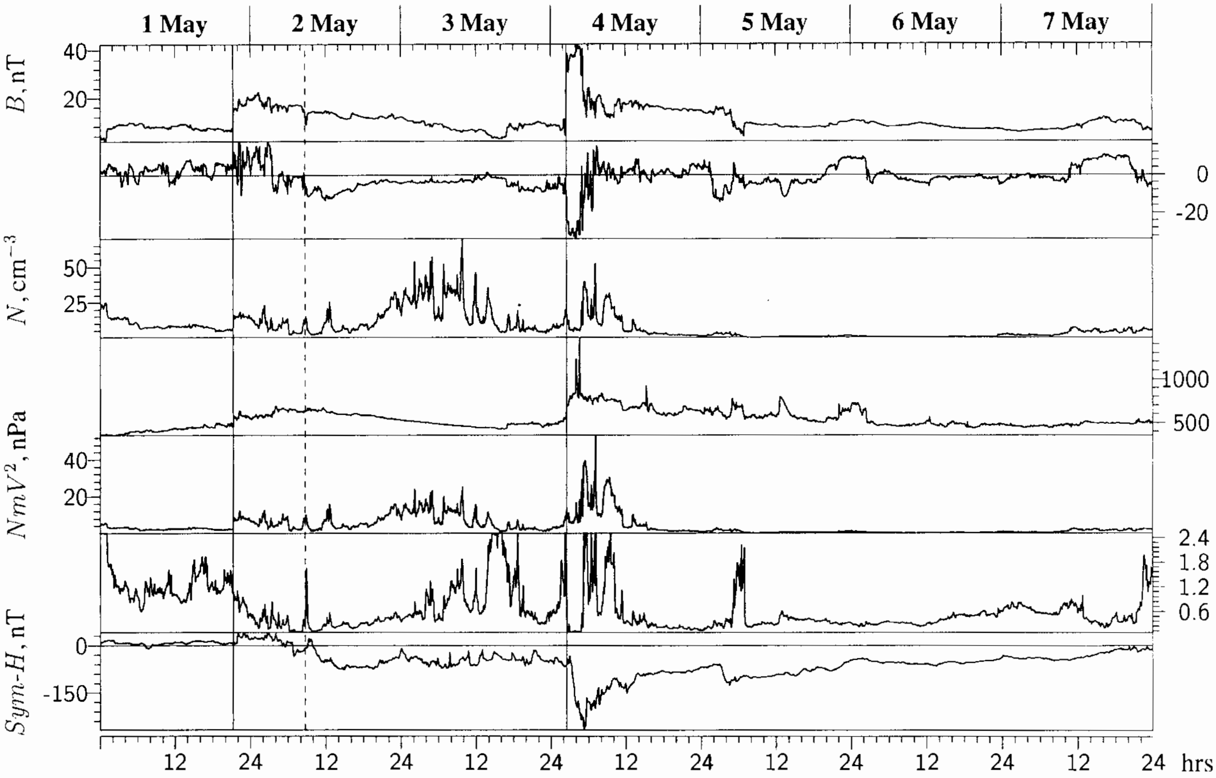

Fig. 1. The development of selected solar wind and IMF parameters and Sym-H index during the 1-7 May 1998 interval. The 5-min means are used.

23 (solar activity culminated in 2000-2001). During 1-7 May 1998, two fast interplanetary streams caused one small and one large magnetic storm. The peak Dst values (this is a geomagnetic index that gives a global average depression of the Earth's magnetic field) for the two storms were –85 nT and –205 nT.

The high time resolution data from CDAWeb WIND database were used to identify solar wind stream events. In Fig. 1, the IMF B magnitude, Bz component, solar wind plasma parameters density (N), velocity (V), ram pressure (NmV^2) and plasma β (ratio of plasma pressure to magnetic pressure) are shown. The development of the storm variation (Sym-H is a high time resolution version of the Dst index) is given in the bottom panel.

From Fig. 1, two separate interplanetary high-speed streams can be noted. They are indicated by vertical lines. The first begins with a shock at ~2115 UT 1 May and ends at ~1600 UT 3 May. The second stream starts at ~0230 UT 4 May again with a shock and ends on 6 May. In the first event, the solar wind velocity increases from ~450 km/s to ~570 km/s across the shock. The ram pressure across the shock increases from ~2.2 nPa to ~ 8.8 nPa and this causes a positive increase in the Sym-H index (called a storm sudden commencement or SSC) due to the resultant compression of the magnetosphere.

At ~0845 UT 2 May, the IMF Bz turns southward (negative). This is shown by a dashed vertical line. *Burlaga et al.* [4] have identified this as the onset of a magnetic cloud. This field configuration leads to more effective magnetic reconnection and the onset of the main phase of the first, smaller magnetic storm (see the associated Sym-H decrease).

At the start of the second high-speed stream, the velocity across the shock increases from ~520 km/s to ~700 km/s and the magnetic field magnitude from ~5 nT to ~38 nT. This was accompanied by an abrupt increase of the ram pressure reported earlier in [5]. The Bz value was –5 nT prior to the shock. Shock-compression increased this value to ~-30 nT and this intensity had a duration of ~2.5 hours. In this case, shock compression was the mechanism that produced the strong negative Bz that caused the magnetic storm (shown for other events by *Tsurutani et al.* [6]) with the intense depression Sym-H=-268 nT at 0520 UT 4 May.

In this same high-speed stream, two clouds followed the geoeffective shock/sheath. The first magnetic cloud arrived at ~1000 UT 4 May and is

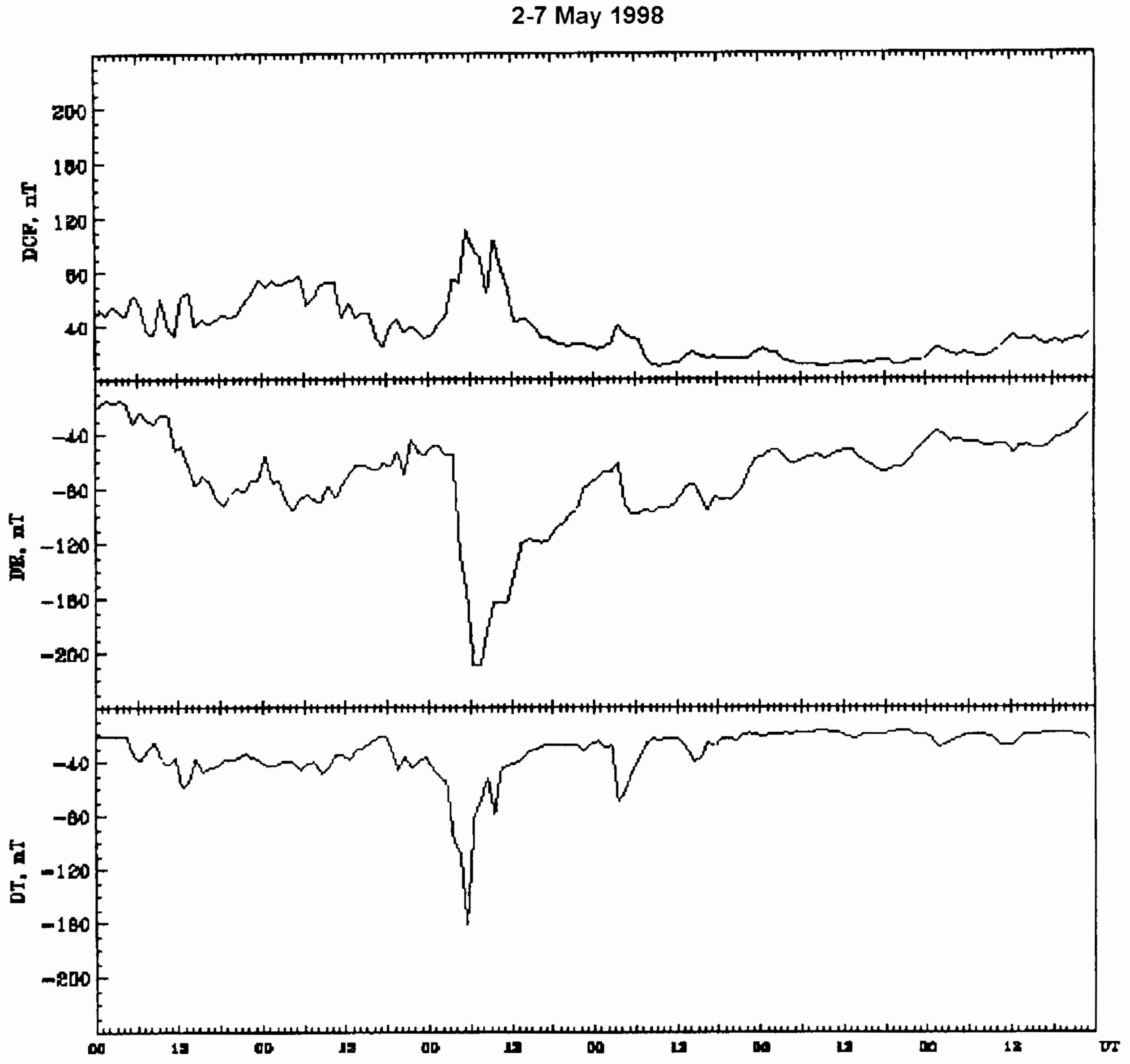

Fig. 2. The variation of DCF, DR, and DT for hourly time resolution during 2-7 May 1998.

identified by the smooth magnetic fields and β that decreases from ~2 to < 1.0. β reaches ~0.2 at 1800 UT. A second cloud follows at ~0700 UT 5 May. β decreases from ~1.5 to 0.3 at the onset of the magnetic cloud. The first cloud event was not geoeffective and the second event caused only a small storm (minimum Sym-H = -125 nT).

3. A STORM MAGNETOSPHERIC MAGNETIC FIELD MODEL

A new self-consistent version of a time-dependent magnetic field model [3] based on the Paraboloid Model [7] is used in the following analysis. The solar wind ram pressure and IMF Bz are inputs to the model. The model also uses DMSP satellite measurements of the magnetotail current sheet boundary and the tail lobe magnetic flux, and their changes with time. The subsolar point of the magnetopause (R1) and the plasma sheet inner boundary at midnight (R2) are iteratively calculated. The model outputs are: the disturbance magnetic fields due to the ring current (DR), the magnetopause current (DCF), and the magnetotail current (DT).

Fig. 2 shows the results of the model analysis for the 2-7 May 1998 magnetic storms. The top panel

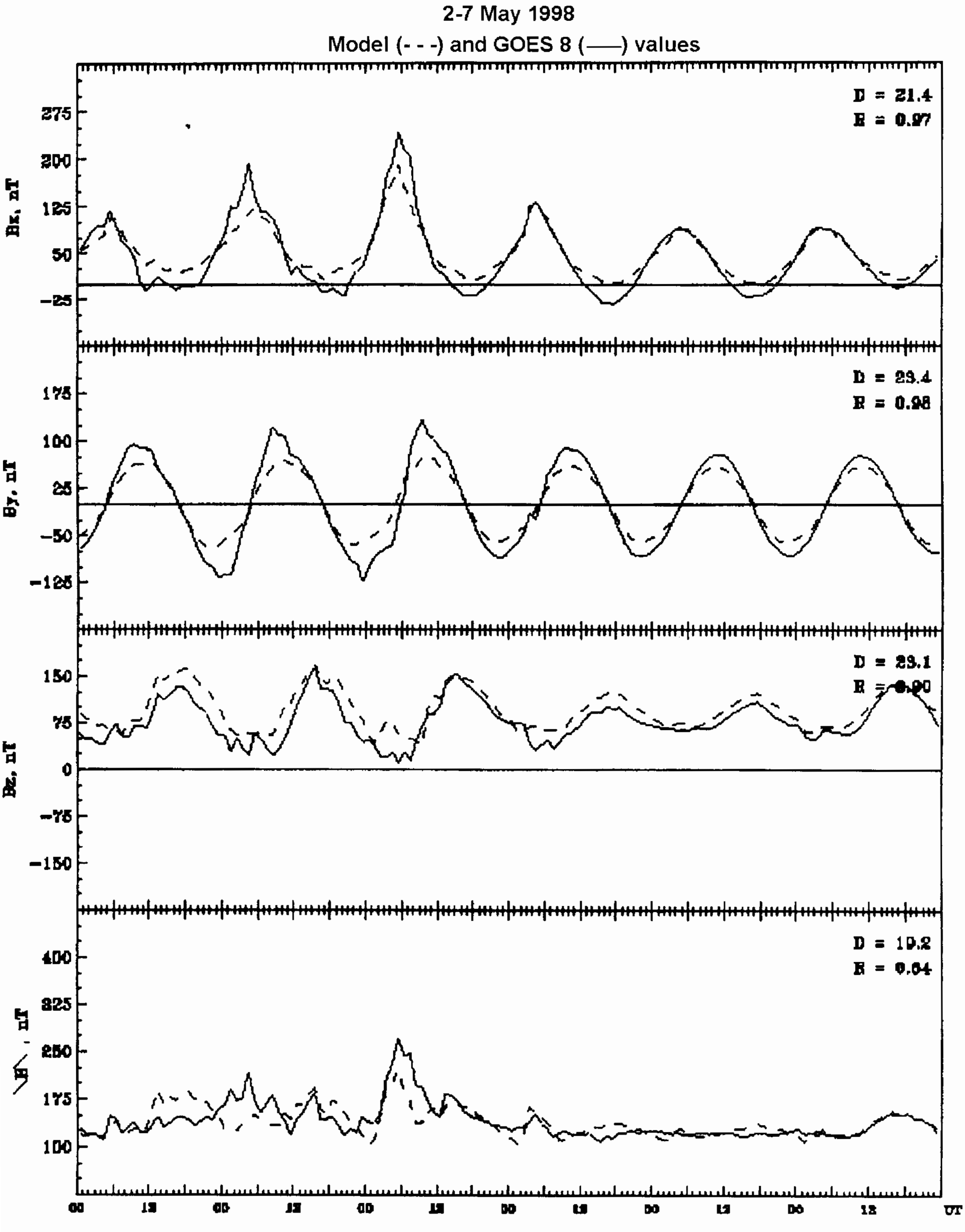

Fig. 3. Three model magnetospheric magnetic field components and magnitude superposed on geosynchronous GOES 8 measurements for hourly time resolution during 2-7 May 1998.

shows the variation of DCF throughout the interval. The second panel gives the contribution (DR) from the ring current (consisting of 30-300 keV protons and oxygen ions). The bottom panel gives DT, the contribution from the magnetotail current sheet. The maximum values of DCF, DR, and DT are: ~112 nT, ~-208 nT and ~-161 nT, respectively. We note that DCF and DT are approximately the same magnitude, so their contributions to Sym-H approximately cancel. Fig. 3 shows the model magnetic field for 6 days at the geosynchronous GOES 8 spacecraft (~ 6.6 R_E). The three components and total intensity of the magnetic field from the model (dashed lines) are superposed on the GOES 8 measurements (solid lines). As seen the model reproduces the measured field quite well.

4. DISCUSSION AND CONCLUSION

We have briefly outlined solar and interplanetary effects on the Earth's magnetosphere. We have illustrated this by giving a specific example of two fast solar ejecta (interplanetary CMEs) causing weaker and intense magnetic storms. We show how the interplanetary parameters are used in magnetospheric modeling. One important point is that the internally generated current systems are an integral part of the interaction and the magnetospheric response cannot be accurately represented without their inclusion.

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6. REFERENCES

1. Dungey J.W., Interplanetary magnetic field and auroral zones. *Phys. Rev. Lett.*, Vol. 6, 47-48, 1961
2. Tsurutani B. et al., Interplanetary origin of geomagnetic activity in the declining phase of the solar cycle, *J. Geophys. Res.*, 100, 21717-21733, 1995.
3. Feldstein Y.I. et al., Self-consistent modeling of the large-scale distortions in the geomagnetic field during the 24-27 September 1998 major magnetic storm, in press, 2003.
4. Burlaga L.F. et al., Fast ejecta during the ascending phase of solar cycle 23: ACE observations, 1998-1999, *J. Geophys. Res.*, Vol. 106, 20957-20977, 2001.
5. Song P. et al., Polar observations and model predictions during May 4, 1998, magnetopause, magnetosheath, and bow shock crossing, *J. Geophys. Res.*, Vol. 106, 18927-18942, 2001.
6. Tsurutani B. et al., Solar wind southward Bz features responsible for major magnetic storms of 1978-1979, *J. Geophys. Res.*, 93, 8519-8531, 1988.
7. Alexeev I.I. et al., Magnetic storms and magnetotail currents, *J. Geophys. Res.*, Vol. 101, 7737-7747, 1996.