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Citation: [AIP Conference Proceedings](#) **345**, 391 (1995); doi: 10.1063/1.48999

View online: <http://dx.doi.org/10.1063/1.48999>

View Table of Contents: <http://aip.scitation.org/toc/apc/345/1>

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REVIEW ON INTERPLANETARY-MAGNETOSPHERE INTERACTIONS

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ABSTRACT

This review deals with the interplanetary-magnetosphere coupling during intense geomagnetic activity, especially near solar maximum. For this purpose we use the plasma and magnetic field measurements obtained mainly by the ISEE-3 satellite during the interval of time when it was at the L_1 libration point of the sun-earth system.

During this interval 90% of the intense geomagnetic storms (Peak Dst < -100nT) were preceded by the arrival of interplanetary fast forward shocks at 1AU. For these events we show the interplanetary structures that are associated with the large-amplitude and long-duration negative B_z fields that were found in the sheath and/or driver gas regions of the shock and that are thought to be the main cause of the intense storms.

On the other hand, during this same interval, "High-Intensity, Long-Duration and Continuous Auroral Activity" events (HILDCAAs for short) were found to be caused by the southward magnetic fields of large-amplitude interplanetary Alfvén waves, presumably through magnetic reconnection with the geomagnetic field.

With respect to geomagnetic storm predictability we emphasize the need to have a satellite at the L_1 point, such as ISEE-3, continuously monitoring the solar wind, as perhaps the only reliable tool at the moment.

INTRODUCTION

Recent studies (1 - 4) indicate that the category of storms that have the largest association with interplanetary shocks, or coronal mass ejections (CMEs), are the most intense ones. This level of storm intensity can be expressed by the storm index threshold, peak Dst < -100 nT. It was shown (1-3, 5) that the main interplanetary feature associated with intense storms, accompanying the CMEs, is the presence of a large-amplitude (<-10 nT), long-duration (> 3 hours), negative B_z component of the IMF.

Figure 1 shows schematically the solar-interplanetary-magnetosphere coupling of interest. At the Sun the main ingredient is assumed to be a CME, which can also involve a low-latitude, short-lived, coronal hole (e.g. Gonzalez and Tsurutani, 6), whereas at the interplanetary medium the main responsible feature for the development of the storm is the presence of a

southward IMF carried by the solar wind. At the magnetosphere this southward field reconnects with the geomagnetic field leading to an effective momentum and energy transfer via a magnetospheric dynamo. In this figure two of the most important dissipation regions within the magnetosphere are indicated, the auroral and the ring current. The former refers to the substorm process, for which the level of intensity is monitored by the auroral electrojet index AE, and the latter refers to the storm process itself with its intensity monitored by the storm index Dst.

Fig. 1 - Schematic of solar-interplanetary-magnetosphere coupling during solar maximum years.

THE ISEE-3 MEASUREMENTS

The ISEE-3 satellite was situated in a halo orbit (about the L_1 libration point), at approximately 240 Earth radii in front of the Earth, and measured 56 unambiguous fast forward shocks during the interval of August 16, 1978 to December 28, 1979. The satellite provided a full set of magnetic field (7) and plasma (8) data. From these 56 shocks Gonzalez and Tsurutani (11) reported that only nine preceded (within typical time lags) the occurrence of an intense geomagnetic storm (peak Dst < -100 nT). Thus, from the predictive point of view one can say that only about 14% of the interplanetary shocks during solar maximum are expected to lead to the development of intense storms.

On the other hand, since nine of intense storms that occurred within this interval were associated to shocks one can also say that during solar maximum 90% of the intense storms are expected to be associated with fast forward shocks within 1 AU. A similar conclusion was reached by Gosling et al. (4) for CMEs.

Figure 2 is an example of some of the solar wind parameters measured by the ISEE-3 satellite (during the interval of August 26 to September 4, 1978). From top to bottom we have: the solar wind speed, density, IMF amplitude and the B_y and B_z components of the IMF (in Geocentric Solar Ecliptic coordinates). The last two panels at the bottom of this figure give the auroral electrojet (AE) and the ring current (Dst) indices of geomagnetic activity.

Fig. 2 - Example of the ISEE-3 measurements.

INTERPLANETARY-MAGNETOSPHERE COUPLING

From the vantage location of the ISEE-3 satellite one could study both, the "solar-interplanetary" as well as the "interplanetary-magnetosphere" couplings. In this review we concentrate in the latter type.

Gonzalez and Tsurutani (1) reported that all ten intense storms (peak Dst < -100 nT) that occurred during the ISEE-3 studied interval were associated with large-amplitude (< -10 nT), long duration (> 3 hours) negative B_z fields in the interplanetary medium. Figure 2 shows one example of such an association for the August 28, 1978 storm. This figure illustrates the fast forward shock event that was observed at 02:00 UT of day 27, the compressed (and heated) sheath field region lasting approximately till 18:25 hours UT of day 27 and also a driver gas region approximately till 12:00 hours UT of day 28. The large negative B_z event is associated in this case with a driver gas-magnetic cloud structure (with a rotation in the B_y component).

Figure 2 also shows the occurrence of a high-intensity, long-duration and continuous auroral activity (HILDCAA) event as shown by the horizontal bar in the AE panel. For the ISEE-3 studied interval Tsurutani and Gonzalez (9) reported the occurrence of 8 HILDCAA events, five of which followed intense storm events as in the case of this figure. In (9) and (10) these HILDCAA events were associated with the simultaneous occurrence of large-amplitude interplanetary Alfvénic fluctuations and it was argued that magnetic reconnection between the southward field of these fluctuations and the geomagnetic field is responsible for the magnetospheric energization.

Tsurutani et al. (2) studied the interplanetary structures that were associated with the negative B_z events responsible for the 10 intense storms of the Gonzalez and Tsurutani (1) study. Figure 3 is an updated version of those structures. They are divided in two groups: those that belong to the sheath region of the shock and those that are encountered within the driver gas region. About half of the 10 events belong to each of these two groups and can be associated with any of the suggested possibilities. Although the suggested structures are self explanatory the reader is referred to Tsurutani et al. (2) for further details.

Fig. 3 - The various interplanetary features that involve large-amplitude, long-duration B_s fields during solar maximum.

For the ISEE-3 studied interval, Gonzalez and Tsurutani (1) also reported the occurrence of northward B_z events similar to the southward events but opposite in polarity ($B_z > +10$ nT, $T > 3$ hours). These northward IMF events were similar to the southward field events in several ways: the number is about the same (11 northward events vs. 10 southward events); for both the northward and southward events, nine followed shocks within similar time lags. It is possible that these northward fields are also associated with structures similar to those shown in Figure 3 and, therefore, that the responsible physical process for generating them do so with random orientations. However, during these northward B_z events the magnetosphere is in a quiet state, namely, the level of intensity of storms or substorms, if any, is very low.

Using the ISEE-3 measurements, several authors (5, 9-11) have also studied the solar wind-magnetosphere coupling problem through coupling functions associated with the reconnection process at the magnetopause. The reader is referred to Gonzalez (12) for a review on this type of study.

In (13) and (4) the ISEE-3 measurements were also studied in association of CMEs with solar wind electron heat flux events and it was shown that this association serves as an important tool for CME identification.

For the interval of 1973-1975 (near solar minimum), it was shown (14) using IMP-7 and IMP-8 satellite measurements that intense storms were still associated to CMEs, whereas most of the moderate storms ($-100 \text{ nT} \leq \text{peak Dst} < -50 \text{ nT}$) were found to be associated to corotating streams, thus leading to a recurrent storm behavior. The negative IMF-Bz structures accompanying these recurring events were of a different nature than those shown on Figure 3. Such Bz features were caused mainly by the interaction of high speed streams with the heliospheric current sheet. Another interesting feature found (14) for solar minimum, associated to corotating streams, was the frequent occurrence of HILDCAA events (8). This led for 1974 to an average value of the AE index higher than that for 1979, the latter being close to solar maximum.

Fig. 4 - Schematic of "geomagnetic activity alert" as learned from ISEE-3.

CONCLUDING REMARKS

The ISEE-3 measurements during the interval of August 1978 - December 1979 helped to understand several interesting features of the interplanetary-magnetosphere coupling as well as of the solar-interplanetary coupling problems. Since for the former a more quantitative knowledge was advanced, there is a particular interest in extending it to a purpose of a short-term geomagnetic storm predictability or "geomagnetic activity alert". Thus, for such a purpose, Figure 4 shows a schematic with features obtained from the ISEE-3 study as applied to a coming similar space mission, such as WIND (during the ISTP program).

ACKNOWLEDGMENTS

This work was partially supported by the "Fundo Nacional de Desenvolvimento Científico e Tecnológico" of Brazil and by the Jet Propulsion Laboratory, California Institute of Technology under contract with NASA.

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