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Geomagnetic storms and Forbush decreases during the passage of the Earth through the flanks of large-scale solar wind disturbances

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Abstract. The cases when the Earth passes the flanks of large-scale solar wind disturbances have been selected using in situ multisatellite observations. The criterion of such a selection was the fact when the solar wind parameter changes were not observed by one of two spacecraft. The results of *Shadrina et al.* [1996] were confirmed where it was assumed that the separate observation of Forbush decreases and geomagnetic storms was due to the passage of the Earth through different flanks of the disturbed solar wind region. When the Earth passes the west flank of the disturbance the Forbush decreases without geomagnetic storms occur, and vice verse, when the Earth passes the east flank, the geomagnetic storms are observed in the absence of the Forbush decreases.

1. Introduction

As it is known, Forbush decreases of cosmic ray intensity and geomagnetic storms are produced by large-scale solar wind disturbances. The observations at the Earth show that quite often, these events occur separately, and in this case, the amplitudes of events are far less than during their simultaneous occurrence. We used these facts [*Shadrina et al.*, 1996] for so-called "Forbush-storm classification of the events." This classification is used to identify the magnetic and plasma structures of interplanetary disturbances. Further investigations have shown that the joint or separate course of the effects in cosmic rays and the geomagnetic field strongly depends on the location where the Earth intersects the disturbed region, i.e., on the orientation of the disturbance boundary with respect to its comparatively small angular size [*Cane et al.*, 1994; *St. Cyr et al.*, 1999]. To define the role of the heliolongitudinal factor arising in this case, it is necessary to use in situ multisatellite observations.

In the majority of similar papers [e.g., *Cane et al.*, 1994; *Gonzalez et al.*, 1999; *Tsurutani et al.*, 1988; *Zhang and Burlaga*, 1988], most of the attention was given to intense ground events that usually occur during central passages of the Earth through the disturbed region by using data from the spacecrafts located not far from each other. Contrary to those studies, we use spacecraft data when they are separated by distances compared with the size of the disturbed region. The aim of our paper is to study the role of the heliolongitudinal factor in producing the ground events (cosmic ray intensity decreases and geomagnetic storms) when the Earth passes through the flanks of solar wind disturbances.

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2. Analysis and Results

We examined the solar wind plasma and magnetic field data from the well-known OMNI and COHO databases together with the ground-based observations of the cosmic ray intensity and the geomagnetic index *Dst*. For the analysis we have chosen the events when the disturbance was detected at the Earth and at one of the Helios (1 or 2) spacecrafts, but it was notregistered at the other one.

An example of such an event, on 23–25 February 1980, is shown in Figure 1. Both Helios spacecrafts were located at a distance of about 0.97 AU from the Sun, and in this case, Helios 2 was closer to the Earth (heliolongitude $\sim$30) than Helios 1 (heliolongitude $\sim$80). It is evident that both at the Earth and at Helios 2 there were solar wind speed enhancements and density burst in its leading front, but such

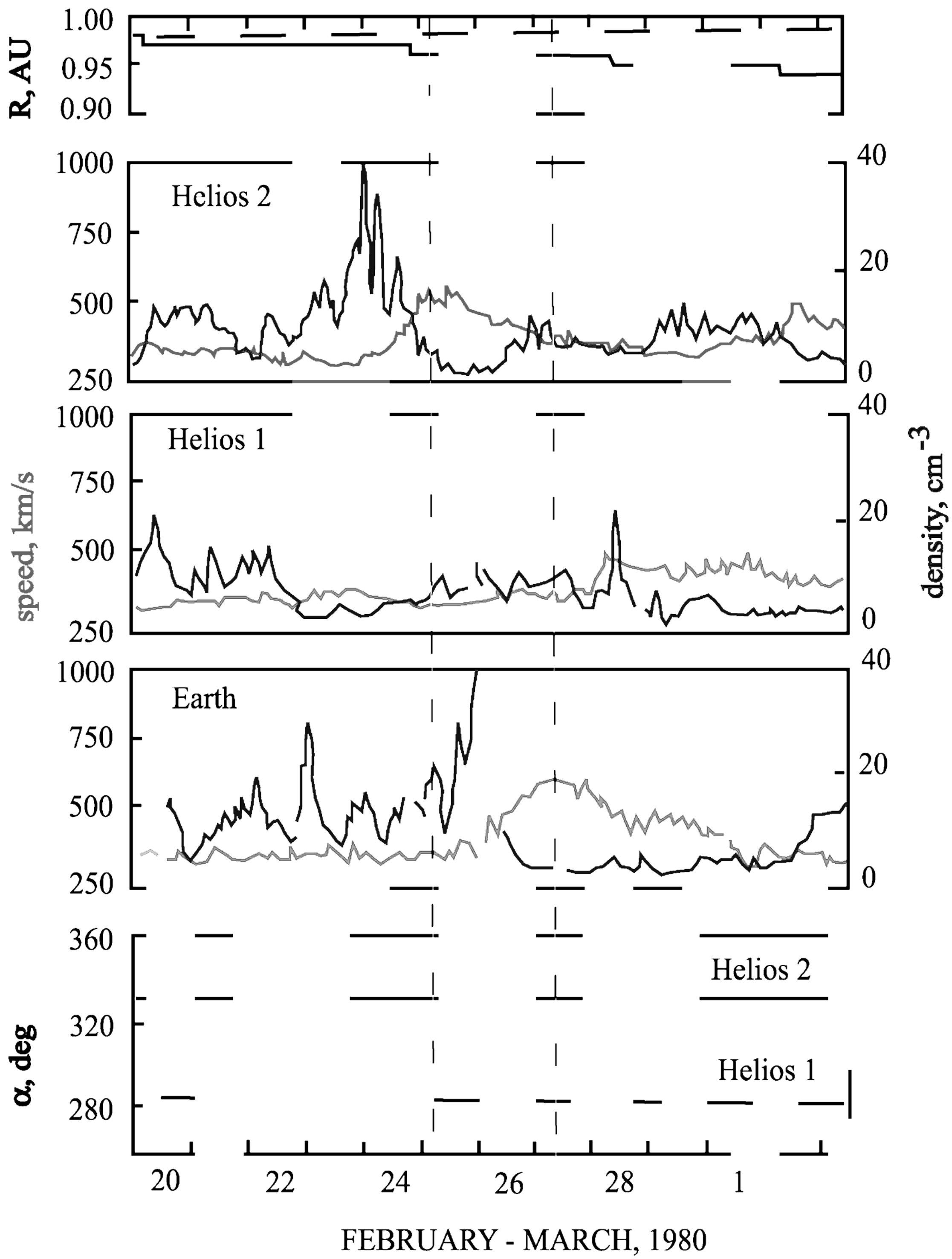

Figure 1. The event registered by Helios 1 and 2 and near the Earth on 23–25 February 1980. Solar wind parameters – velocity (speed, thick curves) and density (slim curves) – together with the radial distance (top) and heliocentric angle (bottom) of Helios 1 and 2 are shown.

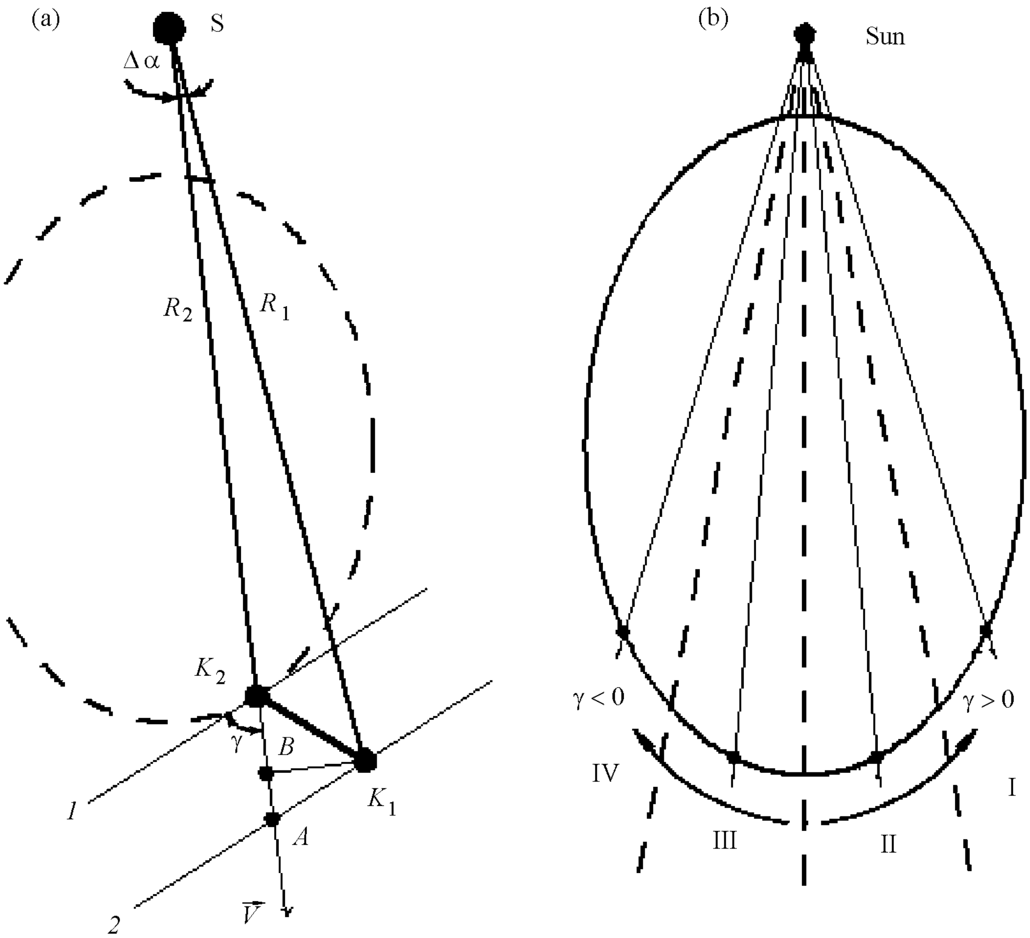

Figure 2. The sketch illustrating (a) the calculation of the inclination angle γ of the disturbed region boundary (ellipse) relative to the Sun–spacecraft line and (b) the relation of the angle γ with ground disturbance classes. The sectors corresponding to the different classes are divided by dashed lines. Solid lines show their intersections.

changes were not detected by Helios 1. It is necessary to notice that at the Earth the disturbance was observed almost two days later (after 47 hours) than by Helios 2, whereas the disturbance ought to have passed the distance of 0.03 AU with the speed of 400 km s^{-1} during about 3 hours. Such a delay can be explained, as we think, by the heliolongitudinal factor [*Shadrina et al.*, 1999].

Eighteen similar events for 1977–1980 (see Table 1) have been selected. The year, day, and delay time (Δt) of the events observed at the Earth and by Helios 1 and Helios 2 are listed in the columns 2, 3, and 4. Columns 5, 6, 7, and 8 present the radial distances of Helios 1 and Helios 2 from the Sun (R_1 and R_2), the heliocentric angle between the Earth and the Helios, which detected the disturbance ($\Delta\alpha$), and the heliocentric angle between Helios 1 and Helios 2 ($\Delta\alpha_{12}$). Angle γ is listed next. This is the angle of inclination of the disturbed region boundary to the Sun–spacecraft line. The last two columns show the class of the event defined by two independent method: "Class d" and "Class g."

The first method (Class d) is based on the determination of angle γ using direct observations by spacecraft. Figure 2a explains it. Geometrical consideration of the two right triangles SBK_1 and ABK_1 allows us to find the distance $K_2A = V\,\Delta t$ (this is a displacement of the disturbance front location 1 to location 2), which is equal to the sum of legs SB and BA minus the distance $SK_2 = R_2$.

Substituting $SB = SK_1 \cos(\Delta\alpha) = R_1 \cos(\Delta\alpha)$ and $BA = SK_1 \sin(\Delta\alpha)/\tan(\gamma)$, and bearing in mind that $\Delta R \ll R\Delta\alpha$, we obtain

$$\tan(\gamma) = \frac{R_1 \sin(\Delta\alpha)}{V\Delta t + R_2 - R_1 \cos(\Delta\alpha)}$$

Figure 2 illustrates the relationship of the heliolongitudinal factor, which can explain four classes of the events in cosmic rays and the geomagnetic field introduced by *Shadrina et al.* [1996] to angle γ. One can see from the sketch that γ is about 0° for the central intersections has large positive values for the west intersections and large negative values for the east intersections.

In Table 2 the ranges of γ are proposed for different points

Table 1. Characteristics of the Events and Corresponding Classes

N	Year	Day	Δt, hour	R_1	R_2	$\Delta\alpha$	$\Delta\alpha_{12}$	γ	Class d	Class g
1	1977	10	2	0.98	0.98	−3	−28	−4	III	III
2		28	0	0.95	0.98	−9	−28	53	II	III
3		43	44	0.92	0.98	−29	−29	68	I	I
4	1978	54	−35	0.92	0.93	−20	−34	41	II	II
5		54	58	0.90	0.92	−21	−34	48	II	II
6		66	17	0.83	0.85	−23	−33	−10	III	II
7		106	23	0.40	0.41	8	−28	81	I	II
8		346	20	0.71	0.75	−9	−44	−21	III	II
9		350	27	0.75	0.78	−9	−43	24	II	II
10		362	39	0.85	0.88	−9	−42	75	I	II
11	1979	34	7	0.91	0.98	−20	−40	5	III	III
12		51	13	0.97	0.96	−25	−40	5	III	II
13		66	55	0.92	0.89	−29	−40	41	II	II
14		70	81	0.91	0.86	−29	−41	52	II	I
15		92	54	0.74	0.68	−27	−43	37	II	II
16		108	71	0.58	0.48	−11	−50	−11	III	II
17		364	18	0.73	0.83	−16	−51	−4	III	III
18	1980	56	47	0.98	0.97	−30	−46	20	II	II

of intersections of the disturbed region boundary according to four classes of the ground-based events. It is accepted here that γ varies in the following ranges: from 80° to 65° in the first class, from 65° to 10°, in the second class, from 10° to −70° in the third class, and from −70° to −80° in the fourth class. Using Table 2 and the calculated γ, we defined the class for each of the 18 events, and these results are in Table 1, column 10 (Class d).

To verify whether the class definition is correct, we use the second method ("Class g") based on the "Forbush-storm classification of ground events." According to *Shadrina et al.* [1996] the observations of three ground disturbance classes (Forbush-decreases without geomagnetic storms (I), Forbush decreases accompanied by storms (II), and geomagnetic storms without cosmic ray decreases (III)) can be explained by the flank or central intersections of the disturbed region by the Earth (see Figure 3a).

In Figure 3a the main disturbed solar wind structures (the shock, stream body (ejects), and region with the reduced cosmic ray intensity, i.e., the Forbush-decrease (FD) region), are shown. The Forbush-decrease region is located asymmetrically relative to the disturbance region axis (dashed line) which is connected to the magnetic field line configuration in the solar wind stream with open magnetic lines at the east flank. It is in agreement with the known west-east asymmetry of Forbush-decrease amplitudes [*Barnden,* 1973; *Belmalkhedkar et al.,* 1975; *Krymsky and Transky*, 1977].

Table 2. Ranges of an Inclination Angle γ Corresponding to Four Ground Disturbance Classes

N	Class	γ_1	γ_2	$\Delta\gamma$
1	FD, no storm	80°	65°	15°
2	FD and storm	65°	10°	55°
3	Storm, no FD	10°	−70°	80°
4	No FD, no storm	−70°	−80°	10°

The location of magnetic and plasma structures in the disturbed solar wind region also coincides with the results of *Pudovkin et al.*, [1985] where it was shown that the geoefficiency of the stream body in producing geomagnetic storms depends on the magnetic field orientation within the compressed solar wind region. We consider this orientation to be quasi-perpendicular at the west flank and quasi-parallel at the east flank. It is also very important for the geoefficiency of the stream in cosmic rays.

According to Figure 3a the events of the second class (intense Forbush decreases and geomagnetic storms) occur when the Earth intersects the disturbed region near the central line. The first class of events (only cosmic ray decreases) occur at the west intersection of the disturbed region. The third class of events (only geomagnetic storms) occur at the east intersection. The extreme east and west intersections produce the fourth class of ground disturbances: there is an increase of the interplanetary magnetic field, and the dynamic pressure produces the increase of the geomagnetic field only. Results of the second method, with the use of the ground observation analysis, are listed in the last column of Table 1 (Class g).

Thus the definitions of ground manifestations of solar wind disturbances by the two method, using (1) the direct measurements on the spacecraft and (2) the "Forbush-storm classification" are in good agreement. In 10 out of 18 cases the classes of events coincide, and in 8 cases the next adjacent classes are observed. It could be caused by the rather arbitrary definition of γ ranges for four classes of the events or by the definition of class signs by the data of objects located far from each other: in the interplanetary medium and on the Earth's surface. In Figure 3 the locations of Helios 1 and Helios 2 and the Earth for the two events of April 17–19,

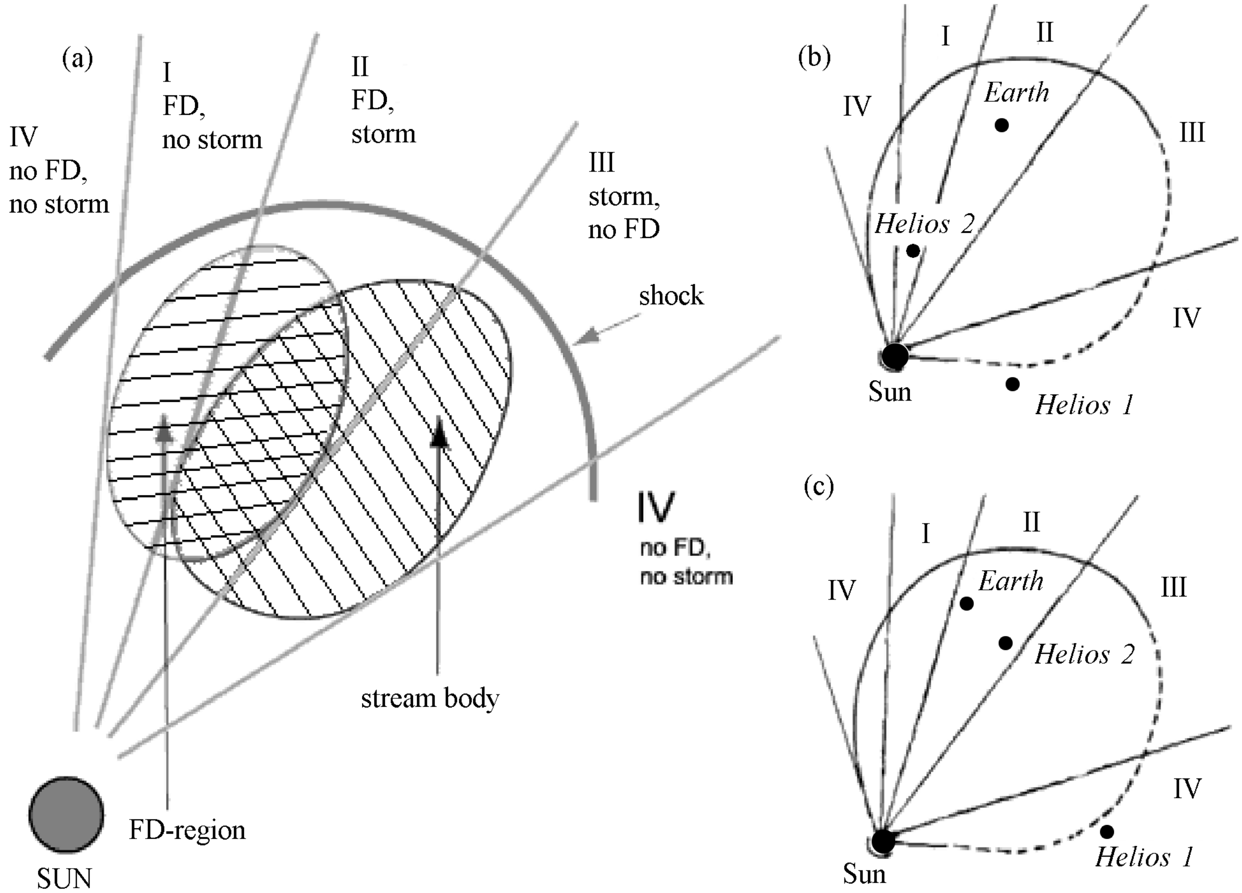

Figure 3. The sketch of (a) sporadic solar wind disturbance with the main structural boundaries corresponding to four classes of the ground disturbances, and (b and c) two examples of the Earth and Helios 1, 2 locations relative to the disturbed region.

1978 (1978, 106, case 7, Figure 3b) and 23–25 February 1980 (1980, 56, case 18, Figure 3c) are shown as an example. One can see that if the Earth and Helios are in the same sector (Figure 3c), then the class is determined more precisely than if they are in different sectors (Figure 3b).

3. Conclusions

Thus the analysis of flank intersections of solar wind disturbances according to the in situ multispacecraft data gives a rather good agreement with the sketch (Figure 3a) proposed by *Shadrina et al.* [1996] Therefore the conclusion of *Shadrina et al.* [1999] is confirmed that (1) the disturbed solar wind region has a limited transverse size and (2) the region is characterized by its nonsphericity; that is, its transverse size is considerably less than the longitudinal size. From our point of view the considerable time delay of the disturbance registration by separate spacecrafts depends on the boundary orientation for the flank intersections of the disturbed solar wind region.

References

Barnden, L. R., The large-scale magnetic field configuration associated with Forbush-decrease, *Proc. XIII ICRC, 2*, 1277, 1973.

Belmalkhedkar, M. M., Y. H. Hazdan, and C. L. Kaul, Cosmic ray modulation by corotating solar streams in presence of flare plasma clouds, *Proc. XIV ICRC, 3*, 1058, 1975.

Cane, H. V., I. G. Richardson, and I. J. Rosenwinge, Cosmic ray decrease and shock structure: A mutispacecraft study, *J. Geophys. Res., 99*, 21,429, 1994.

Gonzalez, W. D., B. T. Tsurutani, and A. L. de Gonzalez, Interplanetary origin of geomagnetic storms, *Planet. Space. Sci., 88*, 529, 1999.

Krymsky, G. F., and I. A. Transky, The Forbush-decreases profile and convective shock waves in the interplanetary medium, *Proc. XV ICRC, 3*, 181, 1977.

Pudovkin, M. I., S. A. Zaitseva, and S. P. Puchenkina, Dependence of the flare stream velocity on magnetic field orientation, *Solar Phys., 95*, 371, 1985.

Shadrina, L. P., V. P. Mamrukova, and I. Ya. Plotnikov, A combined analysis of solar wind disturbances, cosmic ray intensity decreases and geomagnetic storms, *Geomagn. Aeron.* (in Russian), *36*, 399, 1996.

Shadrina, L. P., S. A. Starodubtsev, and I. Ya. Plotnikov, Propagation velocity and configuration of large-scale solar wind disturbances, in *Proceedings of the International Conference on "Large Scale Solar Activity Structure: Achievements and Per-*

spectives," pp. 231–236, Pulkovo, Russia, 1999.

St. Cyr, O. C., J. T. Burkepile, A. J. Hundhausen, and A. R. Lecinski, A comparison of ground-based an spacecraft observations of coronal mass ejections from 1980 to 1989, *J. Geophys. Res., 104*, 12,493 1999.

Tsurutani, B. T., W. D. Gonzalez, F. Jang, S.-I. Akasofu, and E. J. Smith, Origin of interplanetary magnetic fields responsible for major magnetic storms near solar maximum, *J. Geophys. Res., 93*, 8519, 1988.

Zhang, G., and L. F. Burlaga, Magnetic clouds, geomagnetic disturbances, and cosmic ray decreases, *J. Geophys. Res., 93*, 2511, 1988.

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