# GEOMAGNETIC DISTURBANCES ASSOCIATED WITH DISAPPEARING SOLAR FILAMENTS

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**Abstract.** To gain an insight into the origin of enhanced geomagnetic activity that is recently reported to follow the 'disparition brusque' (DB) of quiescent solar filaments, a study is made of the interplanetary plasma and magnetic field data at 1 AU, in relation to DBs over the period January 1967 through March 1978. The investigation revealed that the 'minor' ($Ap \geq 30$) and 'major' ($Ap \geq 50$) geomagnetic disturbances that manifested within 8 days of DBs, almost invariably occurred (in 28 out of the 30 events studied) in association with the passage at Earth of high-speed streams in the solar wind. A majority of the streams (19 out of the 28 streams) exhibited a 27-day recurrence pattern and, thus, the associated enhancement in geomagnetic activity (and apparently followed DBs). The date of transit of the high-speed stream at Earth seems to control the delay time of the geomagnetic disturbance, rather than the size of the filament. A systematic spatial relationship between DB's and the potential solar sources of the high-speed streams (coronal holes and flares) does not appear to be present. The results point out the relevance and a prominent role of recurrent and transient high-speed structures in the solar wind in the enhancement of geomagnetic activity that accompagnies DBs.

## 1. Introduction

Recently, Joselyn and McIntosh (1981) showed that a significant number of geomagnetic storms (including some large ones) can only be associated, among the possible solar sources, with the sudden disappearance ('disparition brusque', DB) of quiescent solar filaments. This work not only revived the interest in the historic topic of the relationship between DBs and geomagnetic activity (see Joselyn and McIntosh, 1981, and references cited therein for details of previous inconclusive studies), but also indicated the applicability of information on DBs in schemes of forecasting geomagnetic storms. The subsequent statistical studies of McNamara and Wright (1982) and Wright and McNamara (1983) provided further convincing evidence in support of a close link between DBs and geomagnetic activity. These authors found that the level of geomagnetic activity, on average, undergoes a significant increase typically within 3–6 days of the DBs, and that the time delay of the onset and magnitude of the geomagnetic disturbances depend on the characteristics of filaments such as their size, darkness and position on the solar disc. The fundamental question as to why and how the DBs lead to geomagnetic disturbances remained by and large unresolved. Wright and McNamara (1983) suggested that the enhancement in geomagnetic activity that follows DBs may be due to the interception at Earth of disturbances in the solar wind with enhanced particle densities and magnetic fields (and consequent changes in the interaction of the solar wind with the Earth's magnetosphere), directly associated with either the coronal mass ejection phenomenon itself or the modulations in the particle

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and magnetic flux density brought about by the changes in the coronal magnetic structure in the vicinity of the filament. Joseleyn and McIntosh (1981), however, reported that their efforts to identify a source 'signature' in the solar wind that can be held responsible for the geomagnetic storms associated with DBs were inconclusive.

In this paper, we undertake a study of the interplanetary plasma and magnetic data obtained at 1 AU, with a view to exploring the origin of the geomagnetic disturbances that are now established to follow some, if not all, DBs.

## 2. Data and Method

The present study covers the period between January 1967 and March 1978 inclusive. Daily H$\alpha$ filtergrams recorded at the Kodaikanal solar observatory coupled with those published in Prompt Reports of *Solar-Geophysical Data* (SGD) by ESSA/NOAA, Boulder, U.S.A., are used to detect DBs over the period January 1967 through December 1973. For the period January 1974 through March 1978, we used the list of DBs compiled by C. S. Wright, Ionospheric Prediction Service, NSW, Australia, from daily H$\alpha$ filtergrams of the Culgoora solar observatory (supplemented by those published in SGD where required), and kindly supplied to us. A data sample of 104 events of DBs which occurred essentially outside of active regions is selected for the present study. In arriving at this data sample, only those filaments with estimated sizes greater than 15 square degrees are taken into consideration. This selection criterion is adopted in view of the finding by Wright and McNamara (1983) that filaments with sizes less than 25 square degrees do not, on average, result in enhanced geomagnetic activity. Two instances, wherein the DB was followed by a clearcut and significant enhancement in geomagnetic activity, although the size of the relevant filament was less than 15 square degrees, are retained as our aim here is to reach an understanding of the cause of the enhancement in geomagnetic activity rather than infer its dependence on the filament characteristics. For the period January 1967 through December 1973, the positions (heliographic coordinates of the midpoint of the filament) and sizes (projected area of the filament on the solar disc, corrected for foreshortening) of the filaments are estimated from Kodaikanal H$\alpha$ filtergrams, while their times of disappearance derived from a comparative study of consecutive daily Kodaikanal H$\alpha$ filtergrams in conjunction with those published in SGD. The list compiled by C. S. Wright is exclusively referred to for information on the characteristics of DBs over the period January 1974 through March 1978.

The response of geomagnetic activity to each DB in our data sample is assessed by examining the monthly tables of the daily *Ap* index, published in Prompt Reports of SGD. Geomagnetic disturbances ('minor' with $Ap \geq 30$ and 'major' with $Ap \geq 50$) occurred within 8 days of the filament disappearance on 30 occasions and these positive response or YES events are accepted for further study. The delay time of 8 days that we have adopted here is felt to be quite adequate to assess any DB related enhancement in geomagnetic activity, as Wright and McNamara (1983) showed that the enhancement in geomagnetic activity occurs, on average, with a delay of 3–6 days. Besides, the

Sun–Earth delay time of 8 days corresponds to a transit speed of $\sim 215$ km s$^{-1}$, and the low speed limit of the solar wind near Earth is $\sim 250$ km s$^{-1}$ (King, 1977). A substantial number of events exist in our data sample wherein DBs were followed by an increase in geomagnetic activity, but the *Ap* remained less than 30. In several other instances, the increase in geomagnetic activity was noticed with a delay in the range of 9–11 days (Wright *et al.* 1984). Detailed investigations of these events are in progress and are not dealt with here. The strategy by which to infer the cause of the geomagnetic disturbances that occurred in the wake of DBs is to search for the consistent presence of any typical 'signature' in the solar wind in the case of 'YES' events. The listings and plots of the hourly averages of the solar wind plasma parameters and magnetic fields compiled by King (1977, 1979) from multispacecraft observations near Earth are used for the purpose.

## 3. Results and Discussion

A visual inspection of the temporal profiles of the solar wind plasma parameters indicated the presence of high-speed stream structures around the times of occurrence of 'minor' and 'major' geomagnetic disturbances that followed the DBs in our data sample. It is well known that the transit near Earth of high-speed streams in the solar wind, in general, leads to geomagnetic disturbances, and interplanetary streams are a key link in the complex chain of events that link geomagnetic activity to solar activity (e.g. Arnoldy, 1971; Burlaga, 1975; Burlaga and Lepping, 1977; Akasofu, 1981). To ascertain the genuineness of the first impression of a relation between the geomagnetic disturbances that followed DBs and high-speed regions in the solar wind, we referred to the catalogues of high-speed streams compiled by Lindblad and Lundstedt (1981, 1983) for the period January 1964 through May 1978. These catalogues were prepared from the interplanetary plasma and magnetic field data sets of King (1977, 1979), using a definition of high-speed stream that emphasizes the leading edge, rather than the maximum speed attained by the stream. A high-speed stream was listed if the velocity difference ($\Delta V_0$) between any consecutive days was $\geq 100$ km s$^{-1}$ and was preceded by a discernible increase in the ion number density and/or a rapidly varying magnetic field. The comparison of our list of DBs with the catalogues of Lindblad and Lundstedt (1981, 1983) revealed the passage past Earth of high-speed streams in the solar wind within 7 days of DBs in 28 out of the 30 YES events. Of these 28 streams, 19 were members of a 27-day recurrent series, 7 were possibly solar flare-associated and 2 were non-recurrent in nature (see, Lindblad and Lunstedt, 1981, 1983, for the procedure of classifying streams into flare-associated or corotating categories). In view of the established association between low-latitude coronal holes, recurrent high-speed streams in the solar wind and geomagnetic disturbances (Krieger *et al.*, 1973; Neupert and Pizzo, 1974; Bell and Noci, 1976; Broussard *et al.*, 1977; Sheeley *et al.*, 1976; Sheeley and Harvey, 1981), we referred to the literature available on coronal hole occurrence (Bell and Noci, 1976; Sheeley *et al.*, 1976; Sheeley and Harvey, 1981) to ascertain whether the recurrent high-speed streams that occurred in the wake of DBs were of coronal hole origin. Although coronal holes are the sources of most high-speed streams in the interplanetary medium, our action was felt necessary because some long-lived high-speed streams are not correlated with coronal holes (D'Uston and Bosqued, 1980). In view of the well-known association between flares and geomagnetic storms (see Joselyn and McIntosh, 1981, and references cited therein), we also referred to the X-ray (1–8 Å) and/or optical flare data published in SGD, particularly for the geomagnetic disturbances that were associated with possible 'flare-related' streams in our data sample.

Table I summarizes the outcome of the data compilations. The A portion of Table I is for DBs that were followed by geomagnetic disturbances due to recurrent and non-recurrent streams, while the B portion refers to those associated with possible flare-related streams. The expected association with low-latitude coronal holes is evident in all but two of the recurrent high-speed streams in our sample (Table IA). The doubtful association is seen with the streams on January 28, 1978 and February 14, 1978 where there was a mismatch of polarity of the magnetic field in the hole and in the stream. It is to be noted, however, that the polarity of the interplanetary magnetic field in these streams was inferred from geomagnetic data (Sheeley and Harvey, 1981) and is not 100% accurate. The anticipated connection with X-ray flares is also apparent for 5 of the 7 transient possible 'flare-related' streams in our sample, as may be seen from the data of Table IB. With a view to providing complete information on YES events, the geomagnetic disturbances that occurred without an apparent association with streams are also included in Table IB. It is pertinent to mention here that we consider the geomagnetic disturbance on December 2, 1977 as being associated with a high-speed streams on the same day (the stream was not listed by Lindblad and Lunstedt, 1983 because of gaps in data; see, King, 1979). Perusal of the A and B portions of Table I (see also Figure 1) shows that the delay in the onset of geomagnetic disturbances with reference to the date of DBs (counted as day zero) varies in the range 1 to 6 days, and was controlled by the time of occurrence of high-speed streams at Earth rather than by the size of the filaments. Also, the intensity and persistence of geomagnetic disturbances do not seem to depend on the size of the filaments (compare events 4, 9, 14, and 18 with 3 and 21 of Table IA; events 1 and 2 with 6 of Table IB).

With a view to ascertaining whether the geomagnetic disturbances that followed DBs in close association with the recurrent streams in the solar wind were repetitive in character (as can be expected), we performed an analysis of daily $Ap$ indices using the method of superposed epochs. An epoch length of 76 days is used, commencing 30 days before day zero and terminating 45 days after day zero (day zero is the date of DB which is fixed following the procedure of Wright and McNamara, 1983). The significance of the changes in the average values, $\overline{Ap}$ of the daily $Ap$ indices on days preceding and following day zero is assessed by calculating the values of the mean background $Ap$, $\langle \overline{Ap} \rangle$ (from that portion of the superposed epoch between days 9 and 29 inclusive which is considered to be free from any influence of disapperaring filaments), and the rms deviation ($\sigma$) of $\overline{Ap}$ about the mean background. The result presented in Figure 1

TABLE IA

List of disappearing solar filaments and geomagnetic disturbances ($Ap \geq 30$) that followed in association with the passage of high-speed streams in the solar wind at 1 AU

| Sl. no. | Last appearance of filament | | Position | | Area (sq. deg) | Geomagnetic disturbances[b] | High-speed streams in solar wind[c] | | | | Coronal holes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date (D M Y) | Time (UT) | Lat. | Long. | | | Date (D M Y) | Duration (days) | $V_{max}$ (km s$^{-1}$) | IMF polarity | Dates of CMP | Magnetic polarity |
| (A) *with recurrent streams* | | | | | | | | | | | | |
| 1. | 23 Sep 67 | 01:51[a] | N 50 | E 10[a] | 27.3[a] | *Ap* = 36 on 28 Sep 67 | 28 Sep 67 | 5 | 661 | + | no data | |
| | | | | | | = 45 on 29 Sep 67 | | | | | | |
| | | | | | | = 35 on 30 Sep 67 | | | | | | |
| 2. | 25 Dec 69 | 18:42[b] | S 37 | E 45[a] | 51.3[a] | *Ap* = 30 on 2 Jan 70 | 1 Jan 70 | 10 | 631 | + | no data | |
| 3. | 11 Nov 72 | 13:11[b] | S 26 | E 25[a] | 73.6[a] | *Ap* = 31 on 16 Nov 72 | 15 Nov 72 | 5* | 518 | + | 13 Nov 72[d] | |
| 4. | 10 Dec 72 | 18:34[b] | S 7.5 | E 25[a] | 12.2[a] | *Ap* = 30 on 13 Dec 72 | 12 Dec 72 | 3* | 512 | + | 10–11 Dec 72[d] | |
| | | | | | | = 33 on 16 Dec 72 | | | | | | |
| 5. | 19 Dec 72 | 03:44[a] | S 19 | 0°[a] | 32.3[a] | *Ap* = 30 on 23 Dec 72 | 22 Dec 72 | 5* | 505 | – | no data | |
| 6. | 11 Jul 73 | 20:40[b] | N 56 | E 17[a] | 14.6[a] | *Ap* = 32 on 15 Jul 73 | 15 Jul 73 | 3* | 690 | – | 11–13 Jul 73[e] | –[e] |
| 7. | 20 Jan 74 | 22:06[f] | N 32 | W 28 | 44.0[f] | *Ap* = 50 on 25 Jan 74 | 25 Jan 74 | 15 | 770 | – | 21–25 Jan 74[e] | –[e] |
| | | | | | | = 38 on 26 Jan 74 | | | | | | |
| | | | | | | = 34 on 27 Jan 74 | | | | | | |
| 8. | 15 Apr 74 | 03:50[f] | S 33 | W 18[f] | 45.0[f] | *Ap* = 48 on 18 Apr 74 | 18 Apr 74 | 13 | 702 | – | no data | |
| | | | | | | = 39 on 19 Apr 74 | | | | | | |
| | | | | | | = 46 on 20 Apr 74 | | | | | | |
| | | | | | | = 35 on 21 Apr 74 | | | | | | |
| | | | | | | = 31 on 22 Apr 74 | | | | | | |
| 9. | 28 Apr 74 | 23:45[f] | N 46 | E 10[f] | 17.0[f] | *Ap* = 34 on 4 May 74 | 3 May 74 | 6 | 763 | + | no data | |
| | | | | | | = 35 on 5 May 74 | | | | | | |
| 10. | 27 May 74 | 22:35[f] | N 42 | E 21[f] | 27.0[f] | *Ap* = 30 on 31 May 74 | 30 May 74 | 9 | 806 | + | 28 May–2 June 74[e] | +[e] |
| 11. | 25 Jan 75 | 21:10[f] | N 30 | E 28[f] | 16.0[f] | *Ap* = 37 on 1 Feb 75 | 31 Jan 75 | 4 | 737 | + | 30 Jan–2 Feb 75[e] | +[e] |
| 12. | 2 Apr 75 | 23:10[f] | N 10 | E 38[f] | 39.0[f] | *Ap* = 32 on 8 Apr 75 | 6 Apr 75 | 10 | 692 | – | 3–8 Apr 75[e] | –[e] |
| | | | | | | = 52 on 9 Apr 75 | | | | | | |
| | | | | | | = 35 on 10 Apr 75 | | | | | | |
| | | | | | | = 34 on 11 Apr 75 | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13. | 20 May 76 | 22:45[f] | S 45 | E 30[f] | 46.0[f] | Ap = 138 on 26 Mar 76<br>= 35 on 27 Mar 76 | 25 Mar 76 | 7 | 593 | – | no data | |
| 14. | 14 Sep 76 | 23:05[f] | N 53 | E 8[f] | 16.0[f] | Ap = 33 on 18 Sep 76<br>= 51 on 20 Sep 76 | 17 Sep 76 | 8 | 653 | + | 14–17 Sep 76[g] | +[g] |
| 15. | 22 Jul 77 | 00:50[f] | N 50 | E 45[f] | 18.0[f] | Ap = 61 on 29 Jul 77 | 28 Jul 77 | 6 | 477 | + | 25–26 Jul 77[g] | +[g] |
| 16. | 31 Jul 77 | 23:30[f] | N 40 | W 40[f] | 20.0[f] | Ap = 40 on 5 Aug 77 | 4 Aug 77 | 7 | 735 | – | 1– 6 Aug 77[g] | –[g] |
| 17. | 22 Oct 77 | 16:22[f] | S 45 | E 23[f] | 30.0[f] | Ap = 62 on 27 Oct 77<br>= 47 on 28 Oct 77 | 28 Oct 77 | 7* | 535 | – | 25–29 Oct 77[g] | –[g] |
| 18. | 25 Jan 78 | 21:20[f] | N 50 | E 16[f] | 52.0[f] | Ap = 36 on 29 Jan 78 | 28 Jan 78 | 11 | 632 | – | 23–25 Jan 78[g] | +[g] |
| 19. | 8 Feb 78 | 21:30[f] | N 45 | E 45[f] | 18.0[f] | Ap = 48 on 15 Feb 68 | 14 Feb 78 | 5 | 680 | – | 4– 9 Feb 78[g] | +[g] |
| (B) *with non-recurrent streams* | | | | | | | | | | | | |
| 20. | 28 Apr 67 | 14:44[b] | S 33 | W 23[a] | 51.7[a] | Ap = 87 on 3 May 67 | 3* | | 523 | – | | |
| 21. | 25 Jan 77 | 22:11[f] | S 40 | E 50[f] | 75.0[f] | Ap = 30 on 30 Jan 77 | 3 | | 505 | – | | |

*Notes*:
[a] from Kodaikanal Hα filtergrams.
[b] SGD (Prompt Reports), ESSA/NOAA, Boulder, U.S.A.
[c] Lindblad and Lundstedt (1981, 1983).
[d] Bell and Noci (1976).
[e] Sheelev *et al.* (1976).
[f] C. S. Wright (private communication).
[g] Sheeley and Harvey (1981).
* beginning and/or end date is uncertain.

demonstrates that the significant enhancement in *Ap* about 5 days after DBs exhibits the 27-day recurrence pattern as anticipated. This feature can also be seen from the top panel of Figure 1, wherein the occurrence patterns of the recurrent high-speed streams and associated geomagnetic disturbances are shown with reference to the date of DBs. The present study thus shows that a significant number of geomagnetic disturbances (19 out of the 30 YES-events studied here) that occurred in the wake of DBs were not sporadic, but repetitive in nature as they were closely associated with the passage of 27-day recurrent high-speed streams at Earth. The reason for this feature not being evident in the very recent study of Wright *et al.* (1984), wherein an epoch lasting 81 days (spanning the interval − 30 through + 50 days of the date of DBs) was used, is that they have not studied the solar wind data in relation to DBs. As such, when the geomagnetic activity patterns associated with recurrent, non-recurrent and sporadic flare-related streams (and, perhaps, also some NO events where the DBs were not followed by geomagnetic storms) were lumped together, the 27-day repetitive pattern was lost in the results of the superposed epoch analysis. Support for this point of view is also provided by the fact that the mere occurrence of a high-speed stream does not always result in a 'minor' or 'major' geomagnetic disturbance (see the top panel of Figure 1 and also Figure 21(a) of Akasofu, 1981). As a result, the amplitudes of the repetitive peaks in *Ap* in a superposed epoch analysis, even when restricted to recurrent streams (as in the present study), will not be equal, as may be seen from the bottom panel of Figure 1 (the number of streams is not exactly the same for the 3 solar rotations shown in Figure 1).

To substantiate further the evidence of a relationship between the geomagnetic disturbances that followed DBs and high-speed regions in the solar wind presented above, we have examined the data on solar wind parameters (King, 1979, 1983) and coronal hole occurrence (Sheeley and Harvey, 1981) relevant to the geomagnetic storms inferred by Joselyn and McIntosh (1981) as associated with only DBs. As may be seen from Table II, wherein the outcome of the data compilations is summarised, 9 out of the 12 storms listed by Joselyn and McIntosh (Table 2 of their paper) were closely related to the transit past Earth of high-speed streams in the solar wind (3 of the 12 storms also figure in our data sample, events 16 and 21 of Table IA and event 9 of Table IB). Among the remaining 3 storms, we believe that those on 2 December 1977 and 3 April, 1978 were associated with the streams on 2 December 1977 and 2 April, 1978 respectively (see velocity-time plots in King, 1979), although these were not listed by Lindblad and Lundstedt (1983) partly because of gaps in the data, particularly for the former stream as already mentioned. Besides, potential association with low-latitude coronal holes is evident for 5 of the 9 high-speed streams, as may be seen from the data of Table II.

It is widely recognised and documented in the literature that the magnitude $|B|$ and sign of the north–south component, $B_z$, of the interplanetary magnetic field, IMF, play an important role in regulating geomagnetic activity (e.g. Burlaga and Lepping, 1977; Svalgaard, 1977; Akasofu, 1981). We have examined the IMF characteristics of the high-speed streams that caused geomagnetic disturbances (in the wake of DBs) in our data sample, in view of the suggestion of Wright and McNamara (1983) that the

TABLE IB

List of DBs and geomagnetic disturbances ($Ap \geq 30$) that followed in association with the passage of high-speed streams (possibly flare-associated) in the solar wind at 1 AU

| Sl. no. | Last appearance of filament: Date (D M Yr) | Last appearance of filament: Time (UT) | Position: Lat. | Position: Long. | Area (sq. deg) | Geomagnetic disturbances[b] | High-speed stream in solar wind[c]: Date | Duration | $V_{max}$ (km $s^{-1}$) | IMF polarity |
|---|---|---|---|---|---|---|---|---|---|---|
| (A) *with possible flare-related streams* | | | | | | | | | | |
| 1. | 14 Sep 67 | 14:17[a] | S 37 | E 05[a] | 18.8[a] | *Ap* = 44 on 20 Sep<br>= 85 on 21 Sep | 19 Sep | 5 | 821 | – |
| 2. | 31 Jan 69 | 02:42[a] | N43 | W02[a] | 30.9[a] | *Ap* = 47 on 2 Feb<br>= 54 on 3 Feb | 2 Feb | 5* | 647 | – |
| 3. | 7 Feb 69 | 20:08[b] | S 30 | W 17[a] | 21.3[a] | *Ap* = 62 on 11 Feb | 10 Feb | 2 | 557 | – |
| 4. | 23 May 70 | 02:55[a] | S 30 | W 25[a] | 41.5[a] | *Ap* = 45 on 28 May | 28 May | 2* | 478 | + |
| 5. | 6 Jul 70 | 04:58[a] | N37 | W 20[a] | 46.2[a] | *Ap* = 87 on 9 Jul<br>= 34 on 10 Jul | 8 Jul | 2 | 492 | + |
| 6. | 11 Apr 71 | 05:03[a] | N42 | E 01[a] | 111.5[a] | *Ap* = 39 on 14 Apr<br>= 36 on 15 Apr | 15 Apr | 3 | 560 | – |
| 7. | 13 May 72 | 11:38[a] | S 35 | E 15[a] | 15.2[a] | *Ap* = 38 on 15 May | 15 May | 4 | 589 | + |
| (B) *without streams* | | | | | | | | | | |
| 8. | 3 Sep 68 | 14:23[b] | N27 | E 40[a] | 51.4[a] | *Ap* = 48 on 8 Sep | | possible CME | | |
| 9. | 27 Nov 77 | 22:00[d] | S 35 | E 45[d] | 16.0[d] | *Ap* = 69 on 2 Dec | | ** | | |
| | | 22:00[d] | N55 | E 48[d] | 32.0[d] | | | | | |

*Notes*:
[a] from Kodaikanal Hα filtergrams.
[b] *Solar-Geophysical Data*, ESSA/NOAA, Boulder, U.S.A.
[c] Lindblad and Lundstedt (1981, 1983).
[d] C. S. Wright (private communication).
[e] Dodson and Hedeman (1971, 1975).
CME – cold magnetic enhancement.
* beginning and/or end date is uncertain.
** possible high-speed stream.

| X-ray flare[b] | | | | Optical flare[e] | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Start (UT) | End (UT) | Peak flux 1–8 Å (erg cm$^{-2}$ s$^{-1}$) | Date | Start (UT) | End (UT) | Lat. | Long. | Imp. |
| | | | | 17 Sep | 10:50 | 12:00 | N18 | W38 | 1n |
| | | | | 18 Sep | 23:16 | 25:45 | N16 | W60 | 2b |
| 1 Feb | 21:31 | 22:03 | 0.38 | 1 Feb | 21:25 | 22:05 | N11 | E77 | 1b |
| 8 Feb | 12:05 | 12:19 | 0.039 | | | | | | |
| 8 Feb | 17:51 | 18:02 | 0.043 | 8 Feb | 17:50 | 18:07 | N18 | E13 | Sb |
| 9 Feb | 06:59 | 07:09 | 0.013 | | | | | | |
| 9 Feb | 14:32 | 14:38 | 0.013 | 9 Feb | 14:31 | 14:49 | N18 | E02 | Sb |
| 9 Feb | 16:02 | 16:13 | 0.013 | | | | | | |
| 9 Feb | 17:24 | 17:36 | 0.190 | 9 Feb | 17:23 | 17:37 | N18 | E00 | Sb |
| 25 May | 05:26 | 07:24 | 0.013 | | | | | | |
| 25 May | 09:11 | 09:43 | 0.013 | | | | | | |
| 26 May | 01:04 | 01:25 | 0.017 | | | | | | |
| 26 May | 02:43 | 02:56 | 0.013 | | | | | | |
| 26 May | 04:46 | 05:03 | 0.043 | | | | | | |
| 26 May | 08:17 | 08:40 | 0.030 | | | | | | |
| 26 May | 11:21 | 11:33 | 0.230 | | | | | | |
| 26 May | 17:47 | 17:49 | 0.021 | | | | | | |
| 6 Jul | 21:37 | 22:04 | 0.086 | 6 Jul | 21:37 | 22:30 | N22 | W90 | 1b |
| | | | | 11 Apr | 15:04 | 15:32 | N20 | W25 | Sf |
| | | | | 11 Apr | 16:37 | 16:46 | N03 | E65 | Sn |
| 12 May | 13:01 | 13:12 | 0.013 | | | | | | |

geomagnetic disturbances might be due to solar wind disturbances characterised by enhanced particle density and magnetic fields. It is found that almost all the streams possessed strong magnetic fields ($|B| > 10$ nT) lasting for several hours (the duration

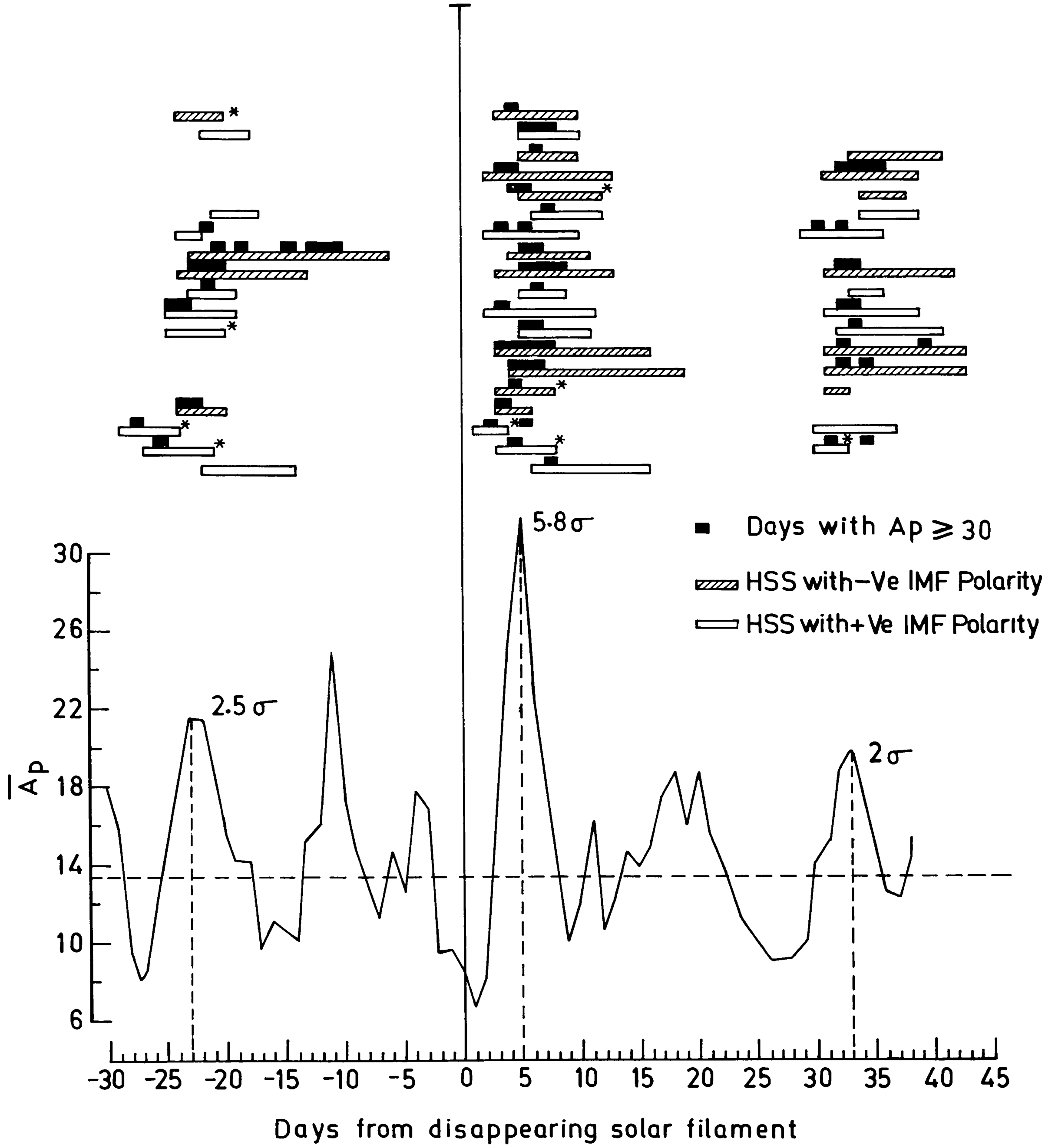


Fig. 1. Result of superposed epoch analysis showing the changes in $\overline{Ap}$ before and after the sudden disappearance ('disparition brusque', DB) of solar filaments, that were followed by geomagnetic disturbances in association with recurrent high-speed streams (HSS) in the solar wind. The horizontal dashed line represents the mean background level of $\overline{Ap}$. The heights of the relevant peaks in $Ap$ above the background are indicated in units of rms deviation ($\sigma$). The 27-day recurrence pattern of the enhancement in $\overline{Ap}$ about 5 days after the filament disappearence may be noted. The top panel shows the occurrence pattern, with reference to the date of filament disappearance, of recurrent high-speed streams and associated geomagnetic disturbances. Note that the days with $Ap \geq 30$ are shown only for periods in the vicinity of the streams. The asterisk indicates that the beginning and/or end date of the stream is uncertain.

TABLE II

List of geomagnetic storms considered by Joselyn and McIntosh (1981) as associated with only DBs

| Sl. no. | Date of last appearance of filament[a] | Approximate location of filament[a] | Date of geomagnetic storm ($Ap \geq 30$)[a] | High-speed stream in solar wind[b, c, e] | | | Coronal holes[d] | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Date | $V_{max}$ (km $s^{-1}$) | IMF polarity | Dates of CMP | Magnetic polarity | |
| | (A) | (B) | (C) | (D) | | | (E) | | (F) |
| 1. | 28 Oct 1976 | S 40 E 40 | 31 Oct | 30 Oct | 525 | | no data | | |
| 2. | 25 Jan 1977 | S 40 E 50 | 30 Jan* | 28 Jan | 505 | – | | + | |
| 3. | 1 Aug 1977<br>1 Aug 1977 | N 40 W 40<br>S 20 E 00 | 5 Aug* | 4 Aug | 735 | – | 1– 6 Aug | – | The storm was associated with a coronal hole. |
| 4. | 27 Nov 1977<br>27 Nov 1977<br>27 Nov 1977 | N 55 E 50<br>S 35 E 60<br>N 30 E 36 | 2 Dec | | ? | | | | Signature of high-speed stream on 2 Dec., but not listed due to gaps in data. |
| 5. | 29 Mar 1978<br>30 Mar 1978 | S 50 E 25<br>S 25 W 25 | 3 Apr | | ? | | | | Signature of high-speed stream on 2 April, but not listed due to gaps in data. |
| 6. | 30 Jun 1978<br>30 Jun 1978 | N 10 E 40<br>N 50 E 35 | 4 Jul | 3 Jul | 499 | + | 25–30 Jun | + | |

*Table II (continued)*

| Sl. no. | Date of last appearance of filament[a] | Approximate location of filament[a] | Date of geomagnetic storm ($Ap \geq 30$)[a] | High-speed stream in solar wind[b, c, e] | | | Coronal holes[d] | | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Date | $V_{max}$ (km $s^{-1}$) | IMF polarity | Dates of CMP | Magnetic polarity | |
| | (A) | (B) | (C) | (D) | | | (E) | | (F) |
| 7. | 22 Aug 1978 | N 15 E 15 | 28 Aug | 27 Aug | 567 | + | 22 Aug | + | Transient coronal hole; the solar wind disturbance also tracked by IPS technique by Tappin *et al.* (1983) |
| 8. | 3 Sep 1978 | S 30 E 00 | 9 Sep | | ? | | | | |
| 9. | 19 Nov 1978 | N 35 W 50 | 25 Nov, 26 Nov | 25 Nov | 627 | + | 19–23 Nov | + | |
| | 19 Nov 1978 | S 40 E 10 | | | | | | | |
| | 19 Nov 1978 | S 20 W 46 | | | | | | | |
| 10. | 3 Jan 1979 | S 40 E 00 | 7 Jan | 5 Jan | 581 | | Weak hole? | | |
| 11. | 19 Apr 1979 | S 20 W 05 | 25 Apr | 24 Apr | 651 | – | 17–22 Apr | – | |
| 12. | 17 May 1979 | N 15 E 40 | 22 May | 22 May | 593 | | Weak hole? | | |

*Notes*:
[a] Joselyn and McIntosh (1981).
[b] Lindblad and Lundstedt (1983).
[c] King (1983).
[d] Sheeley and Harvey (1981).
[e] Richardson and Zwickl (1984).
* This storm also figures in the data sample of the present study.

with $|B| > 10$ nT varied in the range 4 to 36 hr for individual streams), usually on their leading edges. A similar behaviour was also apparent with the streams (4 of the 9 streams) that were related to the geomagnetic storms studied by Joselyn and McIntosh (1981). The origin of the strong and persistent magnetic fields in the streams is, however, not clear at the moment. A high-speed stream from a coronal hole or from solar active regions can cause an impulsive increase of the interplanetary magnetic field ($B$) through stream-stream interaction (e.g. Dryer, 1975). In fact, enhancements of $B$ were observed at 1 AU in association with flare-related shocks, high-speed stream interfaces, and cold magnetic enhancements (CME) by Burlaga and King, 1979 (the strong magnetic fields seen with the streams of January 25, 1974 and May 15, 1972 in our data sample are among the typical examples presented by Burlaga and King). Investigations of the characteristics of recurring streams and causative coronal holes in relation to DBs will help to assess the relative role of the spatial evolution of the streams in their transits to Earth and components of possible coronal mass ejections associated with DBs in the enhanced magnetic fields evidenced at the leading edges of the streams. This is because (a) high-speed streams of coronal hole origin, although recurrent, change in detail (speed profiles and magnetic field intensity patterns) from one rotation to the next due to changes in the area and latitude of the coronal hole and (b) boundaries of coronal holes can be altered by filament eruptions (Weber *et al.*, 1978; Harvey and Sheeley, 1979). Interplanetary 'magnetic clouds' characterised by high magnetic fields ($B \gtrsim 10$ nT) lasting for approximately a day, and in which the magnetic field direction changes from large southern (northern) directions to northern (southern) directions, were detected at Earth and were interpreted as manifestations at 1 AU of coronal mass ejections (Klein and Burlaga, 1982). Support for this hypothesis was recently reported by Wilson and Hildner (1984) who investigated the post-1970 magnetic clouds preceded by shocks. Our data sample contains two magnetic clouds. The first cloud is preceded by a shock and is seen with the stream on February 10, 1969 (event 3 of Table IB; discussed in detail by Klein and Burlaga, see Figure 1 of their paper). The second is possibly a CME-associated cloud that occurred during September 6–9, 1968 (see, plots in King, 1977) in concert with the lone geomagnetic disturbance in our data sample that was not associated with any high-speed stream (event 8 of Table IB). We could neither investigate in detail or ascertain the relationship of these clouds with DBs adopting, for example, the methodology of Wilson and Hildner (1984) for the following reasons. For the first cloud, the DB (S 30, W 17) on February 7, 1969 (Table IB) was followed by a solar flare (N 13, 7 E) on February 8 at 00 : 5 UT and a associated type II radio burst (Dodson and Hedeman, 1971). Since both the DB and the flare are found to occur at an appropriate earlier time (in the so-called 'event window' of Wilson and Hildner), ambiguity exists as to whether the cloud was due to ejecta associated with the flare and/or DB. For the second cloud, extensive gaps in the solar wind data, particularly regarding the proton temperature in the period preceding the cloud, prevented a further study.

The principal and positive finding of the case studies attempted here is the identification of the high-speed stream (either of coronal hole or flare origin) as the candidate 'signature' in the solar wind that was basically responsible for the geomagnetic disturbances ($Ap \geq 30$) noticed after DBs. It is known that (a) as mentioned earlier, filament eruptions can lead to changes in the boundaries of established coronal holes (Weber *et al.*, 1978; Harvey and Sheeley, 1979), (b) filament eruptions distant from existing coronal holes as well as flares can lead to short-lived appearances of small coronal holes (Solodyna *et al.*, 1977; Harvey and Sheeley, 1979; Sheeley and Harvey, 1981), and (c) a significant correlation in time (within ~1 day) exists between DBs of large filaments and the occurrence of 'major' flares (Dodson *et al.*, 1972). These observational results lead us to inquire whether the geomagnetic disturbances that followed DBs were due to a physical link, if any, in the solar atmosphere between DBs and the sources of high-speed streams in the solar wind or due to chance coincidences, i.e. association in time. We addressed this question by evaluating and examining the time delays between the date of CMP of the DB site and the data of onset of a geomagnetic storm for the 30 events, as a function of the latitude of DB. The result presented in Figure 2 indicates the absence of a systematic spatial association between DBs and the sources of the high-speed streams in the solar wind. The relationship between DBs and geomagnetic storms (with delay < 8 days) thus appears to stem from a fortuitous temporal association between DBs and the transits at Earth of high-speed structures

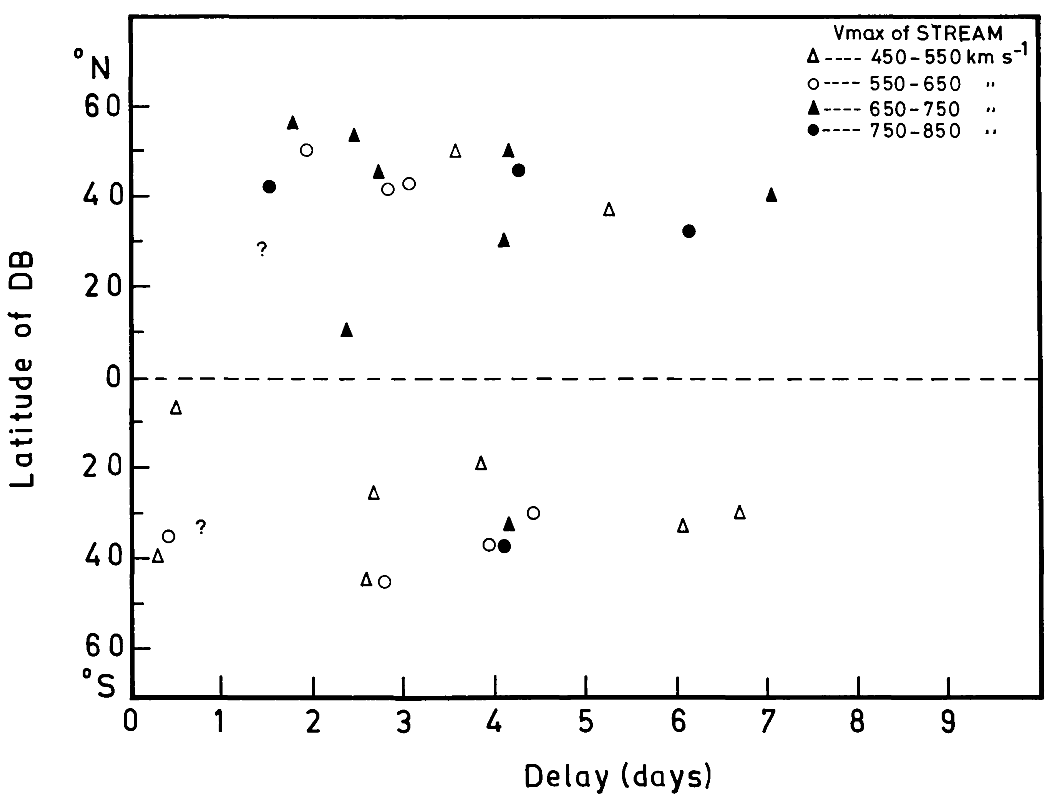


Fig. 2. Plot showing the delays between the CMP of DB sites and the start of the geomagnetic disturbances ($Ap \geq 30$), as a function of the latitude of the DBs. The maximum speed ($V_{max}$) of the high-speed streams in the solar wind that were primarily responsible for the geomagnetic disturbances are also indicated. The symbol (?) corresponds to geomagnetic disturbances that occurred without an apparent association with high-speed streams.

in the solar wind that result in geomagnetic activity. The case studies attempted here do not lend credence to the view developed over the past few years that DBs constitute a *unique* source of geomagnetic storms and, as such, the utility value of DBs in forecasting geomagnetic activity needs to be reexamined. Besides, let us consider the guide lines or rules enumerated by Joselyn and McIntosh (1981) to be applied to the characteristics of DBs to infer whether a particular DB would lead to geomagnetic activity or not. Although the first rule that the filament (which should be of quiescent type) length or size is not a good indicator of ensuing geomagnetic activity (a similar trend is seen in the present study) seems to be well founded, the second rule, that the filament should preferentially lie in the same north–south hemisphere of the Sun as the Earth, does not seem to be reliable. If this were to be the case, we should have noticed a season dependent influence of the north–south location of the DB site in the occurrence of geomagnetic storms, and as may be seen from Table IA and B, such a trend was not apparent. The nature of the present study does not permit an evaluation of the effectiveness of other guide lines; for example, the nature of the magnetic polarities bordering the filament. To sum up, our investigation brings into focus the difficulties involved in the task of predicting geomagnetic activity from solar observations alone, particularly in evolving criteria to be applied to DB reports in the current schemes of forecasting geomagnetic activity.

## 4. Summary

We have investigated the cause of the geomagnetic disturbances that followed the DBs of quiescent solar filaments, through case studies of the relevant interplanetary plasma and magnetic field data obtained at 1 AU. The following are the salient results obtained:

(1) A near one-to-one correspondence is found between the occurrence of geomagnetic disturbances in the wake of DBs and the transit at Earth of high-speed stream structures in the solar wind.

(2) A majority ($\approx 68\%$) of the streams were members of a 27-day recurrent series, and so also were the geomagnetic disturbances caused by them and linked to DBs.

(3) Strong magnetic fields ($|B| > 10$ nT) lasting for several hours manifest generally around the leading edges of the streams.

(4) The date of transit of the high-speed streams at Earth, rather than the size of the filaments, seems to control the delay time of the geomagnetic disturbances that accompany DBs.

(5) DBs and the solar sources (coronal holes and flares) of the high-speed streams do not appear to possess a systematic spatial association. It is thus likely that the relationship between DBs and geomagnetic storms originates from fortuitous coincidences between the times of DBs and the transits at Earth of high-speed streams, which are primarily responsible for the enhanced geomagnetic activity noticed in the wake of DBs.

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