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# Eruptive prominences and long-delay geomagnetic disturbances

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**Abstract.** From a study of the interplanetary plasma and magnetic field data at 1 AU, and of geomagnetic activity in relation to solar eruptive prominences at the limb (EPLs), it is shown that the geomagnetic disturbances (Ap $\geqslant 30$) that follow EPLs with long delays (8–12 days) are essentially caused by the transit of high-speed streams in the solar wind at the earth. A significant number (55%) of the streams and the enhancement in geomagnetic activity associated with them exhibit the $\sim$ 27-day recurrence pattern. The delay time, intensity, and persistence of the geomagnetic disturbances do not show a systemic dependence on the importance of the EPLs. The results strongly suggest that the recently reported relationship between EPLs and long-delay geomagnetic disturbances (Wright 1983) stems from fortuitous temporal association between EPLs and the passage of high-speed solar wind streams at the earth, and that EPLs do not constitute a unique solar source of long-delay geomagnetic disturbanecs.

*Key words* : eruptive prominences—geomagnetic disturbances—solar wind streams

## 1. Introduction

Over the past few years, a relationship has been reported to exist between the sudden disappearances ('disparition brusques', DBs) of quiescent solar filaments and geomagnetic storms (Joselyn & Bryson 1980; Joselyn & McIntosh 1981; McNamara & Wright 1982; Wright & McNamara 1983). These studies have given credence to the points of view that DBs of filaments represent a source of geomagnetic storms besides flares and coronal holes, and that DB reports can be of potential use in predicting geomagnetic activity. In gross behaviour, the delays of the onset of geomagnetic storms with respect to DBs (which typically lie in the range 3–6 d) were found to depend on the size of the filaments and in a complex way on the longitudes of the filaments, and could be as large as $\sim$ 10 d (Wright & McNamara 1983; Wright 1983; Wright *et al* 1984). The long-delay ($\geqslant$ 8 d) storms were reported to occur essentially with DBs of filaments well removed from the disc centre (angular distance from the disc centre $\phi \geqslant 60°$) and with eruptive prominences EPLs (of importance 3) which are filament disappearances as seen on the limb (Wright & McNamara 1983; Wright 1983; Wright *et al.* 1984).

The physics underlying the apparent cause and effect relationship between DBs (and EPLs) and geomagnetic storms however remained ill understood. Joselyn & McIntosh (1981) and Wright & McNamara (1983) suggested that the storms that accompany DBs may be due to the passage over the earth of interplanetary clouds with enhanced particle density and/or magnetic flux density produced by DBs and subsequent coronal mass ejections. This interpretation relied on the observational results that (a) among the various forms of surface solar activity, coronal mass ejections (transients) show a high degree of association ($> 70\%$) with DBs and EPLs, with or without flares (Weber *et al.* 1978; Munro *et al.* 1979); and (b) the delays of 3–6 d between DBs and geomagnetic storms are consistent with the observed speeds (100–800 km $s^{-1}$; average $330 \pm 40$ km $s^{-1}$) of coronal transients associated with DBs and EPLs (Gosling *et al.* 1976). Experimental evidence of a direct nature in support of the interpretation has not been reported so far. Even if one assumes that interplanetary clouds of the type suggested are responsible for the association of geomagnetic storms with DBs, the occurrence of storms with long delay ($\sim$ 10 d) after DBs and EPLs posed a puzzle. This is because the delays of $\sim$ 10 d correspond to an average value of $\sim$ 170 km $s^{-1}$ for the transit speed of the envisaged interplanetary clouds, whereas the low speed limit of the solar wind flow at the earth is $\sim$ 250 km $s^{-1}$ (King 1977). To overcome this unrealistic physical situation, it has been suggested that the low speed interplanetary clouds undergo gradual acceleration due to the dynamic pressure of the ambient solar wind during their transit to the earth (Wright 1983).

We have very recenlty examined the plausible origin of the geomagnetic storms that accompany DBs with delays $< 8$ d, through a study of the interplanetary plasma and magnetic field data obtained at 1 AU (Sastri *et al.* 1985). Our investigation revealed that 27-d recurrent and transient high-speed streams (of coronal holes and flare origin) in the solar wind are primarily responsible for the geomagnetic storms noticed in the wake of DBs. The data of transit of the stream at the earth is found to control the delay time of the geomagnetic storms with reference to DB, rather than the size of the filament; and temporal rather than spatial correlation between DBs and the solar sources of the streams has been noticed to play a dominant role in the relationship between DBs and geomagnetic storms.

These results motivated us to address the question whether the geomagnetic storms that follow EPLs with long delays ($\sim$ 10 d) are also due to high-speed streams in the solar wind at 1 AU, and whether the relationship between EPLs and geomagnetic storms arises from chance time coincidences between EPLs and the transists at the earth of streams. In this paper, we present and discuss the evidence obtained from a study of interplanetary plasma and magnetic field data, compiled from multispacecraft observations near the earth by King (1977 a,b; 1979, 1983), which provides an answer in the affirmative to the question posed.

## 2. Results and discussion

The present study covers the period 1967 January through 1979 December. Information on EPLs over this period has been compiled from the reports of Kodaikanal and Tokyo observatories, supplemented with the list of EPLs prepared by C. S. Wright (personal communication) from $H_\alpha$ data of Culgoora observatory. A data sample of 120 EPLs became available for analysis. In arriving at this data sample attention has not been paid to the importance (generally classified as 1, 2 and 3) of EPLs, as the aim here is to attempt an understanding of the origin of geomagnetic storms that follow EPLs rather than infer the dependence of their characteristics on the importance of EPL, which had already been studied to a certain extent by Wright (1983). Examination of the daily values of the geomagnetic Ap index (Solar-Geophysical Data, ESSA/NOAA, USA) in relation to the dates of EPL showed that 'minor' ($Ap \geqslant 30$) and 'major' ($Ap \geqslant 50$) geomagnetic disturbances with delays in the range of 8–12 d occurred with 24 out of the 102 EPLs in our data sample, and these are taken up for further study. Perusal of the temporal profiles of solar wind plasma parameters (King 1977b, 1979, 1983) indicated that the geomagnetic disturbances that followed EPLs with long delays were closely associated with high-speed flows of solar wind near the earth as anticipated. It is to be recalled here that geomagnetic disturbances are in general caused by the transists of high-speed solar wind streams at the earth, and that the streams constitute a vital link between solar and geomagnetic activity (*e.g.* Arnoldy 1971; Burlaga 1975; Burlaga & Lepping 1977; Akasofu 1981 and references therein). We therefore referred to the catalogues of high-speed streams (Lindblad & Lundstedt 1981; 1983) for the period 1967 January-1978 May to substantiate the first impression of a relationship of the geomagnetic disturbances that followed EPLs with long delays to high-speed streams at 1 AU. For the period 1978 June through 1979 December, information on high-speed streams is taken from Richarson & Zwickl (1984), and by applying the selection criteria of Lindblad & Lundstedt (1981, 1983) to the published solar wind data of King (1983).

Solar wind data temporal coverage was more or less complete around 19 out of the 24 EPLs taken up for study, and for these 19 events a one-to-one correspondence is found between geomagnetic disturbances that followed EPLs with long-delays and the passages of high-speed streams in solar wind at the earth. A substantial number of the streams were members of a 27-d recurrent series while some were of transient nature (see Lindblad & Lundstedt 1981, 1983, and references therein for the criteria of classification of streams into possible flare associated and recurrent ones). In view of the well established association between low latitude coronal holes and recurrent streams on one hand (see Sheeley & Harvey 1981, and references therein) and flares and transient streams on the other (Joselyn & McIntosh 1981, and references therein), we examined the published data on low latitude coronal holes (Sheeley & Harvey 1981) and 'major' flares (Dodson & Hedeman 1971, 1981) to infer the possible solar sources of the high-speed streams responsible for the long-delay geomagnetic disturbances. Various data are summarized in table 1. Presented here coloumnwise are the details of EPL (data, time(s) of occurrence, latitude, longitude, and importance); geomagnetic disturbances (Ap value(s) and date); delays in days between EPL and geomagnetic disturbances; high-speed streams (date, maximum speed, polarity of interplanetary magnetic field in the stream); coronal holes (dates of CMP, and magnetic polarity); optical/x-ray flares (date, times of occurrence, latitude and longitude, and importance) and finally the dates of DBs of quiescent solar filaments that occurred after EPLs under consideration. In figure 1 are illustrated typical examples of the changes in the daily Ap index and the occurrence of solar wind streams near the earth in the vicinity of EPLs (4 days before to 21 days after EPL). The following features may be seen from the data of table 1 and figure 1 :

(a) The incidence of long-delay geomagnetic disturbances after EPLs is invariably associated with the transit of high-speed streams in the solar wind near the earth, rather than with the importance of EPLs. In fact, out of the 19 events only four were associated with EPLs of importance 3 as may be seen from table 1.

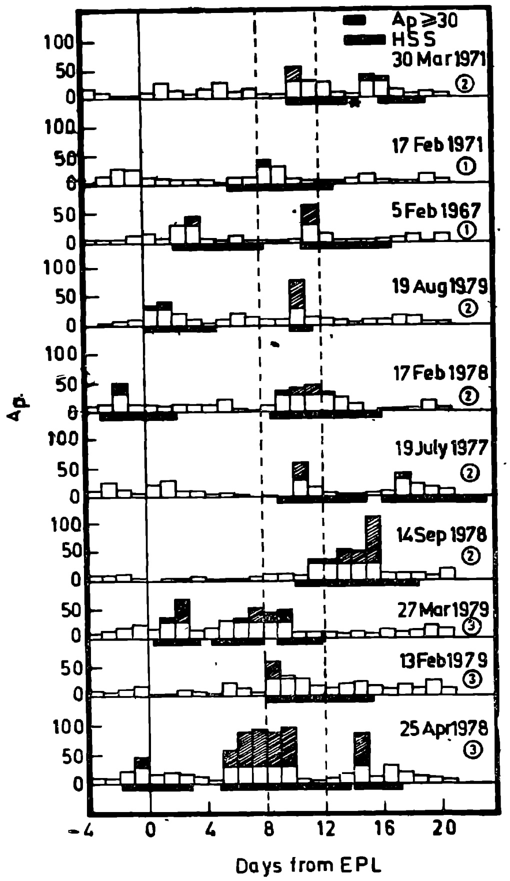

**Figure 1.** Typical examples of the temporal patterns of geomagnetic activity (Ap index) and occurrence of high-speed streams (HSS) in the solar wind at earth in the vicinity of EPLs. The hatched portions of the histograms refer to days with Ap ⩾ 30 and the horizontal solid bars correspond to HSS. The dates of EPLs and their importance (circled numbers) are also shown. The asterisk indicates that the beginning and/or end date of the stream is uncertain. The striking temporal correlation of geomagnetic disturbances that followed EPLs with long-delays (8–12 days) with HSS may be noted.

(b) The delays in the onset of the geomagnetic disturbances *w.r.t.* EPLs is controlled by the dates of transit of the streams, rather than by the importance of EPLs.

(c) The severity and persistence of the disturbances are not uniquely dependent on the importance of EPL (compare, for example, events 2, 11, 16 and 17 with 6, 8, 9, 10, and 12 in table 1).

The geomagnetic disturbances that manifested themselves after EPLs in our data sample were associated with 22 solar wind streams as indicated in table 1 (the number of streams/disturbances is not the same as the number of EPLs, because prolonged geomagnetic activity after some EPLs was due to more than one stream, and a particular disturbance can sometimes be associated with more than one EPL as indicated in table 1). Twelve out of the 22 streams were recurring in nature, 4 were transient or non-recurrent ones and 6 were possible 'flare-associated' ones. As mentioned earlier, we have attempted to ascertain the possible solar source of the streams following the procedures currently in vogue. Five out of the 6 possible 'flare-related' streams can be associated with flares as may be seen from table 1. Out of the 12 recurrent streams, excluding 3 streams for which coronal hole data were not available, it is noticed that 6 out of 9 streams show a potential association with coronal holes (a coronal hole is held responsible for a stream if the latter follows the central meridian passage of the apparent centre of the hole from 3 to 5 days, and there is an agreement of the magnetic polarity under the hole and in the stream). Besides, 1 out of 4 non-recurrent streams may be associated with a transient coronal hole (event 13 of table 1). The rather imperfect association of the recurrent streams in our data sample with coronal holes is not unexpected, and is in line with the prevailing opinion that not all coronal holes are associated with high-speed streams in the solar wind and that some long-lived streams are not correlated with coronal holes (D'uston & Bosqued 1980). Instead, diverging, unipolar coronal magnetic field areas seem to be the sources of some persistent streams (Levine 1978; Burlaga *et al.* 1978).

To assess whether the long-delay geomagnetic activity that followed EPLs in close association with recurrent streams in the solar wind was repetetive in nature as can be expected, we performed a superposed epoch analysis of daily Ap indices for the 12 such events in our data sample. An epoch of 65 d length starting 22 d before EPL to 42 d after EPL is used The significance of the changes in average values, $\bar{A}p$ of daily Ap indices on days preceding and following EPLs is assessed by evaluating the values of the mean background Ap, $\langle \bar{A}p \rangle$ (from that portion of the superposed epoch between days 16 and 32 inclusive, which is considered to be free from any influence of EPLs), and the rms deviation ($\sigma$) of $\bar{A}p$ about the mean background. The temporal pattern of $\bar{A}p$ around EPLs shown in figure 2 demonstrates that the significant and broad enhancement in $\bar{A}p$ about 10 days after EPLs forms part of a $\sim$ 27 d recurrence pattern of geomagnetic activity. This feature can also be seen from the top panel of figure 2 wherein the occurrence of the 12 recurrent streams and associated geomagnetic activity are shown *w.r.t.* the date of EPLs. The reason as to why the amplitude and width of the enhancement in $\bar{A}p$ about 10 d after EPLs was not the same on the previous and following solar

**Table 1.** List of eruptive prominences at limb (EPL) and geomagnetic distrubances (Ap $\geqslant$ 30) that

| Sl No. | Date | Time (UT) | EPL$^a$ Lat. | Long. | Imp | Geomagnetic disturbance$^b$ | | | Delay (d) |
|---|---|---|---|---|---|---|---|---|---|
| 1. | 1967 Feb. 5 | 0120–0238 | S42 | W90 | 1 | Ap = 64 | on 1967 Feb. 16 | Y | 11 |
| 2. | 1968 Feb. 16 | (0155)–0256 | N18 | W90 | 3 | Ap = 35 | 1968 Feb. 20 | | 4 |
| | | | | | | Ap = 30 | 1968 Feb. 28 | | 12 |
| 3. | 1971 Feb. 15 } | 2348–0215 | S41 | E 90 | 2 | Ap = 43 | 1971 Feb. 14 } | Y** | 10,11 |
| 4. | 1971 Feb. 17 } | 0338–0353 | N32 | E 90 | 1 | = 31 | 26 } | | 8, 9 |
| 5. | 1971 Mar. 30 | 0156–(0205) | S17 | W90 | 2 | Ap = 53 | 1971 Apr. 9 } | Y | 10,11 |
| | | | | | | = 30 | 10 } | | |
| 6. | 1975 Jan. 2 | 0553 | N17 | E 90 | 1 | Ap = 32 | 1975 Jan. 13 } | | 11–12 |
| | | | | | | = 33 | 25 } | | |
| 7. | 1977 Jul. 19 | 2148 | N28 | E 90 | 2 | Ap = 61 | 1977 Jul. 29 | Y | 10 |
| 8. | 1977 Sep. 10 | 0130 | N40 | E 90 | 1 | Ap = 42 | 1977 Sep. 19 } | | 9–12 |
| | | | | | | = 44 | 20 } | Y | |
| | | | | | | = 64 | 21 } | | |
| | | | | | | = 63 | 22 } | | |
| 9. | 1978 Feb. 17 | 0423 | N21 | E 90 | 2 | Ap = 37 | 1978 Feb. 26 } | Y | 9–12 |
| | | | | | | = 42 | 27 } | | |
| | | | | | | = 46 | 28 } | | |
| | | | | | | = 33 | Mar. 1 } | | |
| 10. | 1978 Apr. 3 } | 0135 | N23 | E 90 | 1 | Ap = 36 | 1978 Apr. 10 } | Y | 7–8,11 |
| | | | | | | = 64 | 11 } | | |
| | 5 } | 0110 | N23 | E 90 | 1 | = 51 | 14 } | Y | 9 |
| 11. | 1978 Apr. 25 | 0326 | N30 | E 90 | 3 | Ap = 54 | 1978 Apr. 31 } | | 5–9 |
| | | | | | | = 88 | 1978 May 1 } | | |
| | | | | | | = 94 | 2 } | Y | |
| | | | | | | = 83 | 3 } | | |
| | | | | | | = 96 | 4 } | | |
| 12. | 1978 Sep. 14 | 2043 | S45 | E 90 | 2 | Ap = 36 | 1978 Oct. 25 } | Y* | 11–15 |
| | | | | | | = 36 | 26 } | | |
| | | | | | | = 51 | 27 } | | |
| | | | | | | = 50 | 28 } | | |
| | | | | | | = 109 | 29 } | | |
| 13. | 1978 Oct. 8 | 0005 | S26 | E 90 | 1 | Ap = 32 | 1978 Oct. 18 | Y** | 10 |
| 14. | 1978 Nov. 3 | 0015–0123 | N34 | W90 | 2 | Ap = 53 | 1978 Nov. 12 | Y* | 9 |
| | | 2331–2353 | N67 | W90 | 2 | | | | |
| 15. | 1978 Dec. 6 } | 2213 | S20 | W90 | 1 | | | | 12 |
| | 7 } | 0750 | N30 | E 90 | 1 | Ap = 48 | 1978 Dec. 18 | | 11 |
| | 9 } | 0040 | N33 | W90 | 1 | | | | 9 |
| 16. | 1979 Feb. 13 | 2214 | N45 | W90 | 3 | Ap = 59 | 1979 Feb. 21 } | Y** | 8–9 |
| | | | | | | = 33 | 22 } | | |
| 17. | 1979 Mar. 27 | 0557 | N08 | E 90 | 3 | Ap = 33 | 1979 Apr. 1 } | | 5–9 |
| | | | | | | = 36 | 2 } | | |
| | | | | | | = 54 | 3 } | | |
| | | | | | | = 47 | 4 } | | |
| | | | | | | = 52 | 5 } | Y* | |
| 18. | 1979 Aug. 10 | 0459 | N28 | E 90 | 2 | Ap = 35 | 1979 Aug. 19 } | | 9–10 |
| | | | | | | = 42 | 20 } | Y* | |
| 19. | 1979 Aug. 19 | 2257 | N06 | W90 | 2 | Ap = 77 | 1979 Aug. 29 | | 10 |

Notes : (a) Reports from Solar Observatories of Kodaikanal, Tokyo and C. S. Wright (personal communication)
(b) Solar-Geophysical Data, ESSA/NOAA, Boulder, USA
(c) Lindblad & Lundstedt (1981, 1983)
(d) King (1983)
(e) Sheeley & Harvey (1981)
(f) Dodson & Hedeman (1971, 1981)
(g) Richardson & Zwickl (1984)
(h) C. S. Wright (personal communication)
(i) Cane & Stone (1984)

ollowed with long delays (8-12 days) in association with high-speed streams in the solar wind at 1 AU

| High-speed stream[c,d] Date | Vmax (kms$^{-1}$) | IMP polarity | Coronal Hole[e,g] Date of CMP | Coronal Hole Polarity | Optical/x-ray flare[f,i] Date | Time (UT) | Lat. | Long. | Imp | Date of DB[a,b,h] |
|---|---|---|---|---|---|---|---|---|---|---|
| 1967 Feb. 15 F | 652 | + | | | 1967 Feb. 13 | 1747-2130 | N21 | W11 | 3b | |
| 1968 Feb. 18 F | 691 | + | | | 1968 Feb. 16 | 2354–2407 | N05 | E 64 | Sn | |
| | | | | | 1968 Feb. 17 | 0252–0313 | N17 | W47 | 1n | 1968 Feb. 19 |
| 1968 Feb. 28 R | 470 | – | No data | | | | | | | |
| 1971 Feb. 23 R | 670 | + | No data | | | | | | | 1971 Feb. 14 |
| 1971 Apr. 9 R | 606 | – | No data | | | | | | | |
| 1975 Jan. 12 R | 653 | – | | | | | | | | |
| 1977 Jul. 28 R | 477 | + | 1977 Jul. 25–26 | + | | | | | | 1977 Jul. 19, 22, 26 (Harvey & Sheeley 1979) |
| 1977 Sep. 19 | 544 | + | 1977 Sep. 16–19 Weak hole | + | | | | | | |
| 1977 Sep. 20 R | 744 | + | | | | | | | | |
| 1978 Feb. 25F/R | 684 | – | 1978 Feb. 19–22 | + | 1978 Feb. 24 | 0101–0105 | N20 | E 03 | Sn | |
| 1978 Apr. 9 | 646 | + | | | | | | | | |
| 1978 Apr. 12F | 607 | – | | | | | | | | |
| 1978 Apr. 29R | 996 | – | 1978 Apr. 23–26 | – | | | | | | 1978 Apr. 27 |
| 1978 Sep. 25R | 911 | – | | | 1978 Sep. 23 | 0958 | N35 | W50 | X1 | 1978 Sep. 25 |
| 1978 Oct. 18 | 482 | + | 1978 Oct. 14–16 | + | | | | | | |
| 1978 Nov. 12F | 685 | | | | 1978 Nov. 10 | 0048-0232 | N17 | E 01 | 2n (M2) | 1978 Nov. 9 |
| 1978 Dec. 18R | 703 | + | 1978 Dec. 15–17 | + | | | | | | 1978 Dec. 8,14 |
| 1979 Feb. 21R | 629 | + | 1979 Feb. 13–17 | + | | | | | | 1979 Feb. 15, 18 |
| 1979 Mar. 31 | 670 | – | | | | | | | | 1979 Mar. 27 |
| 1979 Apr. 5F | 721 | – | | | 1979 Apr. 3 | 0105–0230 | S25 | W14 | 1b (M4) | |
| 1979 Aug. 19R | 707 | – | 1979 Aug. 13–18 | – | | | | | | |
| | | | | | 1979 Aug. 18 | 1412 | | E 90? | X6 | |
| 1979 Aug. 29F | 555 | + | | | 1979 Aug. 27 | 2137–2315 | N18 | E 62 | 1b | 1979 Aug. 25 |
| | | | | | 1979 Aug. 28 | 0028–0031 | N17 | E 63 | Sn | |

F — possible 'flare-related' stream
R — 27-d recurrent stream
DB — 'disparition brasque' of quiescent solar filament (corrected area $\geqslant$ 15 deg$^2$)
Y — Disturbance associated with a sudden commencent (SC)
* — Unambiguously associated with x-ray flares by Cane & Stone (1984) from data of ISEE radio astronomy experiment.
** — Possible corotating shock/SC.

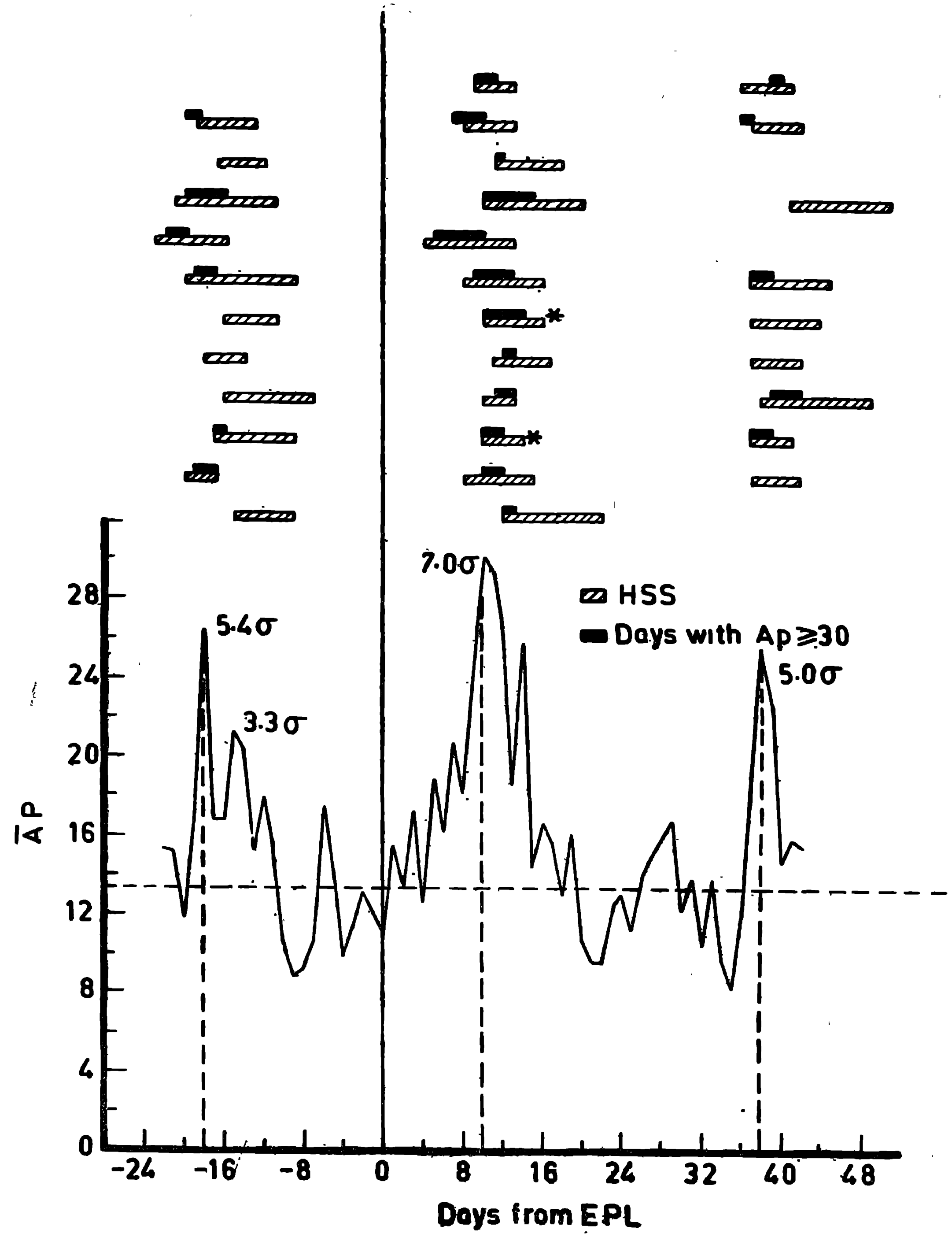

**Figure 2.** Result of superposed epoch analysis showing the changes in $\bar{A}p$ before and after EPLs that were followed by geomagnetic disturbances in association with recurrent solar wind streams. The horizontal dashed line represents the mean background level of $\bar{A}p$. The heights of the relevent peaks in $\bar{A}p$ above the background are indicated in units of rms deviation ($\sigma$). The 27-day recurrence pattern of the enhancement in $\bar{A}p$ around 10 days after EPL may be noted.

The top panel illustrates the occurrence pattern, with reference to the dates of EPL, of recurrent high-speed streams (HSS) and associated geomagnetic disturbances. Note that the days with Ap $\geqslant$ 30 are shown only for periods in the vicinity of streams.

rotations is that the mere passage of a stream near the earth does not invariably lead to geomagnetic activity (see top panel of figure 2) and that a favourable combination of temporal changes in solar wind parameters (bulk speed, magnitude of interplanetary magnetic field, and the direction of the north-south component) are required to lead to geomagnetic disturbances (Burlaga & Lepping 1977; Akasofu 1981, and references therein). The statistical analysis attempted thus indicates that the significant enhancement of geomagnetic activity that followed EPLs with long delays was not sporadic but recurrent in character.

For the sake of completeness, we present in table 2 the outcome of the data compilations for EPLs that were followed by long delay geomagnetic disturbances, but for which the temporal coverage of solar wind data was incomplete. It is noticed that although the solar wind data were riddled with many gaps for these events, the temporal profiles of the plasma parameters (King 1977b, 1979) do suggest that these disturbances were also associated with high-speed streams in the solar wind, as indicated in table 2.

The present study unambiguously demonstrates that the geomagnetic disturbances ($Ap \geqslant 30$) that follow EPLs with long-delays (8-12 d) are primarily caused by the transit of high-speed streams in the solar wind (a majority of which show potential association with either coronal holes or flares) at the earth. Since there is no *a priori* reason to expect a close physical link in the solar atmosphere between the sources of high-speed streams at 1 AU (responsible for long-delay disturbances) and EPLs, we argue that EPL cannot be reckoned as a unique source of geomagnetic activity, and the long-delay geomagnetic disturbances that occur in the wake of some EPLs are due to chance coincidences between EPLs and transits of streams near the earth. This point of view receives support from the following evidences :

(i) As may be seen from table 1, DBs of quiescent solar filaments (corrected area $\geqslant 15$ sq. deg) occurred in the time interval between EPL and the onset of the long-delay geomagnetic disturbances in 11 out of the 19 events studied here. When

**Table 2.** List of eruptive prominences at limb (EPL) and geomagnetic disturbances ($Ap \geqslant 30$) that followed with long-delays (8–12 days) for which solar wind data is incomplete

| Sl No. | Date | EPL[a] | | | | Geomagnetic disturbances[b] | Delay (d) | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Time (UT) | Lat. | Long. | Imp | | | |
| 1. | 1970 Mar. 20 | 015$\overset{*}{2}$–031$\overset{*}{6}$ | N80 | E90 | 3 | Ap = 51 on 1970 Mar. 31[c] | 11 | High-speed stream apparent on 1970 Mar. 31 but gaps in data |
| | | 0030–0154 | N25 | E90 | 3 | | 10 | |
| 2. | 21 | 0053–0350 | N40 | E90 | 2 | | 10 | |
| 3. | 1972 Apr. 19 | 0212–0515 | N21 | W90 | 2 | Ap = 42 | 10 | Small amplitude stream on 1972 Apr. 29, gaps in data of $\|B\|$ and $B_z$ |
| 4. | 20 | 0342–0550 | N17 | W90 | 2 | | 9 | |
| 5. | 1977 Apr. 22 | 0152–(0251) | N24 | E90 | 2 | Ap = 66 on 1977 May 2 | 11 | Stream signature apparent on 1977 May 2. No data of N, $T_p$, $\|B\|$ and $B_z$. |

Notes : (a) Reports from solar observatories of Kodaikanal, Tokyo
(b) Solar-Geophysical Data, ESSA/NOAA, Boulder, USA
(c) Disturbance associated with a sudden commencement (SC)

considered in the context of the results of the statistical studies of McNamara & Wright (1982) and Wright & McNamara (1983), the disturbances can also be associated with DBs.

(ii) Out of the 21 geomagnetic disturbances that followed EPLs in our data sample, 17 occurred with an interplanetary shock (Borrini *et al.* 1982) and/or a confirmed (reported by more than 10 stations) sudden commencement (SC). This feature does not support the interpretation of Wright (1983) that low speed (~ 190 km $s^{-1}$) interplanetary disturbances are the cause of the long-delay geomagnetic storms noticed after EPLs, for the following reasons. Recent comparative studies of coronal mass ejections, type II metric radio bursts (signature of shocks in the lower solar corona) and interplanetary shocks showed that coronal mass ejections with speeds in excess of 400 km $s^{-1}$ are in general required to lead to type II bursts and interplanetary shocks (Gosling *et al.* 1976; Sheeley *et al.* 1984, 1985). Coronal mass ejections associated with EPLs are found to have an average speed of $330 \pm 40$ km $s^{-1}$, while those associated with flares have an average speed of $775 \pm 110$ km $s^{-1}$ (Gosling *et al.* 1976). It is therefore quite unlikely that low speed mass ejections are responsible for the long-delay geomagnetic disturbances noticed after EPLs with interplanetary shocks and/or sudden commencements. In fact, out of the 17 shocks and/or SCs in our data sample, 4 have been unambiguously associated with x-ray flares by Cane & Stone (1984) from the benefit of interplanetary observations of low frequency type II radio bursts (see table 1) and 3 are possible corotating shocks. Corotating shocks are due to the steeping of high-speed streams in the interplanetary medium, and occur usually in the outer heliosphere beyond 2 AU and only rarely at 1AU; see Hundhausen & Gosling (1976) and Smith & Wolfe (1979)

(iii) Finally, let us examine the possibilily of the relationship between EPLs and long-delay geomagnetic storms arising out of a chance coincidences between EPLs and streams passages at the earth. From a study of the long-term variations in the occurrence of high-speed streams at the earth, Intriligator (1977) estimated that approximately 0.14 streams occur per day. Since a temporal association between EPL and geomagnetic disturbance is defined here for a time window of 4 d dura- (8–12 d after EPL), the total number of chance associations that can be expected in the sample of 102 EPLs is 56, which is higher than the observed number of correlated events of 24. We can therefore safely infer that the relationship of long-delay geomagnetic disturbances to EPLs is essentially fortuitous.

Wright (1983) opined that the interplanetary distrubances envisaged by him (as responsible for long-delay geomagnetic disturbances after EPLs) resemble the highly coherent 'magnetic clouds' observed at 1 AU by Klein & Burlaga (1982). Magnetic clouds at 1 AU are regions with a high magnetic field strength in which the field direction changes appreciably by means of rotation of one component of B nearly parallel to a plane; these occur basically in association with shocks, stream interfaces and 'cold magnetic enhancements (CEMs), and are believed to be interplanetary manifestations of coronal transients. We have examined the interplanetary magnetic field characteristics in the vicinity of the geomagnetic disturbances that followed EPLs with long delays. Only 3 clouds are evident in our data sample.

The first one which occurred between 1968 February 27 (1800 UT) and 1968 February 28 (1200 UT) is a confirmed cloud (see table 2 of Klein & Burlaga 1982), whereas the other two which occurred in the interval 1979 April 3 (0900 UT) to 1979 April 5 (0100 UT) are possible candidates. The obvious paucity of the occurrence of 'magnetic clouds' around the time of the long-delay geomagnetic disturbances is quite contrary to the interpretation of Wright (1983).

## 3. Conclusion

We have pointed out that there is no physical basis for directly associating EPLs with geomagnetic disturbances (Ap $\geqslant$ 30) that follow them with delays in the range 8–12 d, and that the apparent relationship between EPLs and long-delay geomagnetic disturbances is primarily due to chance temporal correlations between EPLs and transits near the earth of high-speed solar wind streams.

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