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Dynamic disappearance of prominences and their geoeffectiveness

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Resumen

Estudiamos 14 casos de " disparition brusque" (DBd) dinámicos, la repentina desaparición de filamentos/ prominencias tranquilas, durante dos mínimos solares: 1985-1986 y 1994. El material básico consiste en las observaciones ópticas sistemáticas, especialmente del Observatorio de París - Meudon (PMO). Discutimos la asociación de los DBs con la corona solar, como agujeros coronales (CHs) y Eyecciones de Masa Coronal (CMEs), y las consiguientes perturbaciones de viento solar y de campo geomagnético (tormentas geomagnéticas o GMSs). Identificamos dos GMSs extremos correlacionados con un conjunto de eventos compuesto por los DBs con CHs sin un CME asociado. Adicionalmente, observamos la mayor geoefectividad cuando se tiene un DBd de mayor tamaño (> 30 °) acompañado por un CH ecuatorial y cercano (<15 ° de distancia), que se reduce o desaparece hasta la siguiente Rotación de Carrington (CR).

Palabras clave: Desaparición de prominencias, agujeros coronales, expulsón de masa coronal, tormenta geomagnética.

Abstract

We study 14 cases of dynamic "disparition brusque" (DBd), the sudden disappearance of quiescent filaments/prominences, during two solar minima: 1985-1986 and 1994. The basic material is the systematic optical observations especially from Paris-Meudon Observatory (PMO). We discuss the association of DBs to the solar corona such as coronal holes (CHs) and Coronal Mass Ejections (CMEs) and consequent solar wind and geomagnetic field disturbances (geomagnetic storms or GMSs). We identified two extreme GMSs correlated to joint event cases composed by dynamic DBs with adjacent CHs without associated CME. Furthermore, the highest geoeffectiveness is observed in association to a largest size (>30°) DBd accompanied by a nearby (<15° distance) equatorial CH, which reduces or disappears until the following Carrington Rotation (CR).

Key words: Prominence disappearance, coronal hole, coronal mass ejection, geomagnetic storm.

Introduction

Solar prominence formation, structure and disappearance (DBs) represent one of the basic unsolved problems in Solar and Space Physics research and forecasting of Space Weather. However, it is well known that a high number of magnetic tubes with inside cool plasma compose a prominence. Tandberg-Hanssen (1974) defined two types of filaments according to the position with respect to the unipolar magnetic region of the quiet sun magnetic field. The type A filaments are the ones that are located at the same neutral line of the magnetic field of active regions (AR), whose filaments are known as AR filaments. The type B filaments, located between ARs, present no activity and are called quiescent filaments. Leroy (1989) added "polar crown filaments" to this classification, which was named type C; this are located on the neutral line delimiting the magnetic poles.

Concerning the energetic evolution of prominences, the term DB actually covered two different physical processes: a) Dynamic DB (DBd) is the classic disruption of the prominence, when the plasma is ejected into the corona and heliosphere, due to reconnection of the magnetic field of filaments (Raadu *et al.*, 1988). Observations show that magnetic reconnection follows an emergence of magnetic flux at one of the filament foot-points (Mouradian *et al.*, 1987). b) Mouradian *et al.* (1981, 1986) revealed the existence of thermal DB (DBt), due to the heating of the plasma as a consequence of growing energy in the prominence body. Consequently, the hydrogen atoms become completely ionized and the filament or prominence disappears in Hα line images. Then, due to heating the filament becomes visible in ionized EUV lines. Some time later, when the filament cools down, it becomes again visible in Hα line observations.

Now, concerning the eruption of the quiescent filament, it frequently appear accompanied by soft X-ray enhancement (e.g., Webb *et al.*, 1976). Several authors have attributed this brightness enhancement to an interaction between the expanding prominence and the coronal gas. On the other hand, the occurring magnetic reconnection can be the cause of X-ray enhancements (Rust and Webb, 1977). The small CHs, which are open magnetic field regions, or transient depressions of coronal brightness, forming occasionally adjacent to the sites of DBs (Solodyna *et al*., 1977). Harvey and Sheely (1979) showed that transient changes in the CH geometry, including the formation of new coronal holes, were observed in association with DBs. It was suggested by T.Watanabe *et al*. (1992) that the formation of the new CH may be the cause of DB. Nevertheless, the interaction between DB and CH is yet unclear.

The transients correlated with eruptive prominences were revealed to have the strongest correlation with an eruptive prominence, more than any other event, including flares (Poland *et al*., 1981). Belov *et al*. (1991) have studied 43 non-flares DBs, bigger than 20°, not associated with active regions or with type II bursts. Afterwards, they noticed that magnetic storms and Forbusch decreases (FDs) were always observed 87±7 hours after the DB start time. Additionally, the mean amplitude of the FDs produced by DBs near to the solar equator is almost an order of magnitude greater than those produced from the periphery.

Consequently, DBs are the most likely forms of activity, which can be the origin of CMEs (Webb *et al*., 1976; Munro *et al*., 1979, Webb and Hundhausen, 1987; O. C. St. Cyr and Webb, D. F., 1991; Webb D.F., 1991). It is now well known that those CMEs are the key causal link between solar activity, major interplanetary disturbances and geomagnetic storms (Burlaga *et al*., 1981; Wilson and Hildner, 1984; Kahler, 1992). However, not all CMEs are produced this way. Only those earth-directed CMEs where the magnetic field has a southward component produce large GMSs (Russell *et al*., 1974; Gonzalez *et al*., 1994; Cane *et al*., 2000; Pevtsov and Canfield, 2001).

Not all DBs are correlated with CMEs. In fact, statistical studies of DBs show that about 30% of filament or prominence disappearance is not associated to CMEs (Pojoga and Huang, 2003; Gopalswami *et al*., 2003). Mouradian *et al*. (1995) have discussed the differences between the two classes (DBd and DBt) of filament-prominence disappearance and their relation to CME, and they found that for some few cases a DBd was associated to a CME, whereas DBt are only local disturbances of the lower corona.

There are many statistical studies about the origin and geoeffectiveness of CMEs and DBs, but it is not clear which starting processes or initial physical conditions define the amplitude of their geoeffectiveness, i.e., their abilities to generate the GMSs. In addition, the importance of adjacent CHs with DBs during the starting process of CMEs is not clear either. Therefore, it is important to see the detailed evolution of DBs close to CHs. To do this, we must have continuous observations in order to establish the best correlation between the origin of CMEs and their geoeffectiveness.

The present study will be focused on the problem of dynamic types of DBs and their association with CHs, CMEs, solar wind and geomagnetic response.

Working method

During the maximum solar activity there are many flares, DBs, etc., whose effect may superimpose or/and interact together, making it difficult to study clearly the geoeffectiveness separately for each activity. That is why we decided to search the filaments/prominences disappearing during the minimum solar activity, when the active structures can be well isolated in time and space. We consider that at least 11 days are required for the clear detection of DB effects: 4 days before and 7 days following the DB starting time, when the DB event was the only solar chromospheric activity.

We chose 14 DBd events, listed in Table 1, produced during the last two solar minima. In order to point out the fundamental characteristic parameters of the DB process, we examine the evolution of each prominences/filaments mainly based on Hα patrol filtrograms and/or spectroheliograms of the Paris-Meudon Observatory (PMO) solar archive. We selected nine well-isolated DBs for the first studied minimum of solar cycle 21 (1985-1986) and five DBs for the second solar minimum, that of solar cycle 22 (1994-1995). Each event (or group of events) as a single solar chromospheric activity, has a unique geo-effective consequence. For each event, or group of events, we analyze adjacent CHs evolutions and CMEs detected if any. In order to check the detailed evolution of DBs and CHs turning out at the backside of the Sun, we analyze the CR optic and magnetic synoptic maps with respect to DBs occurrence, as well as the preceding and following one.

For a better understanding of the geoeffectiveness of every DB or group of DBs, we consider the study of 7 day intervals beginning from the DB starting time, using the direct tracing method DB – GMS. We discuss the correlated solar wind velocity (Vsw) and the interplanetary magnetic field (B, Bz). Also, we use GMSs scales according to NOAA standards and classify them as low (Dst>-20nT), medium (-20 nT> Dst >-50 nT), high (-50 nT> Dst >-100 nT) and extreme (Dst < -100 nT) GMSs.

Data sources

Spectroheliograms in spectral lines of hydrogen (Hα) and of Ca II (K3 and K3-prom), as well as filtrograms movies from the 3λ heliograph (line center and blue and red wings) of Meudon and an Hα line center heliograph located at St. Michel Observatory, are available at PMO archive of solar activity on the web page: http://bass2000.obspm.fr/gallery/spectro. Solar activity information for selection of isolated or combined DBs events comes from Solar Geophysical Data (SGD) published by NOAA. The unfold of filaments for 1985-1986 were checked from "Cartes Synoptiques de la Chromosphere Solare", published by PMO and from Pulkovo Observatory synoptique maps for 1994.

The CHs data was extracted from the Catalogue of Coronal Holes that is available at NGDC (http://www.ngdc.noaa.gov/stp/SOLAR/ftpsolarcorona.html). Also, the CHs evolution was studied based on the daily helium images (NSO/KP: http://diglib.nso.edu/DigLib_thumbnail/512/hel/) and synthesized in Coronal Holes Synoptic Charts, corresponding to years 1985 through 1986 in digital format, as well as from the NGDC web page. For the year 1994 they are from NSO/KP.

Concerning the CMEs data and Synoptic Maps during the years, 1985-1986, they were taken from the Solar Maximum Mission (SMM) CME catalogue (web page: http://www.hao.ucar.edu/public/research/svosa/smm/smmcp_cme.html). CMEs data set during the year 1994 was taken from the reports of the Mauna Loa Solar Observatory (http://download.hao.ucar.edu/d5/mlso/log/event/mlso.events.1994).

Solar wind velocity and interplanetary magnetic field (B, Bz) and geomagnetic field (Dst) data are taken from NSSDC OMNIWeb system. In case of a data gap, we used the average value between the preceding and following data of the corresponding parameters.

Discussion and comments of observations

The fundamental characteristic of this type of studies is the impossibility of forecasting the interesting events to start a complete observational program. Consequently, we were obliged to collect the existing material from patrol or systematic daily observations as a checkup of events.

In our analysis, we considered joint group events in case of superposition effect detection. Those effects occur particularly when either various DBs were observed simultaneously or when they took place during an interval of 1-3 days. Moreover, we distinguished different cases of joint events formed by selected dynamic DBs, CHs and consequent CMEs: DBd, DBd+CH, and DBd+CME.

DBd

Out of 14 DBds that were observed, only four simultaneous DBds were unique chromospheric activities, observed far from a CH and without of subsequent CME detection during the solar cycle 21. There was a system of nearby small filaments characterized by a length of 4° - 8° (see, table 1; events (1), (2), (3), (4)), which initiated their activity simultaneously. This joint DBds were associated with a positive daily value of Dst, with a minimum peak of -8 nT. This is a unique result that we have obtained particularly when the DBd was associated with positive daily Dst. However, we propose that this result could be explained by the fact that it was a very small size filament group. The statistical relationship between DBs and geomagnetic activity (Wright and McNamara, 1983) shows that the magnitude of the disturbance increases with the extension of the DB.

Other DBd events were observed as combined events accompanied by CHs or CMEs, and generally were correlated to at least a medium GMS.

DBd+CME

Prominences (5) and (6) were observed as simultaneous dynamic incomplete West-limb DBs. The following CR synoptic map shows a prevailing ~10° unstable section from a ~20° size prominence (5); besides, a ~17° size prominence (6) disappeared completely, which means that the DBd (6) completed in the backside of the Sun. Therefore, no CHs have been observed near these prominences. After 2 h of DBs start time, a CME was detected at PA=270° as a faint and slow moving cloud superposed on streamers without a clear front. Based on these two simultaneous DBds, as a possible origin of this CME, a good correlation was found between the position angles of both, the CME (PA=270°) and the center of those two DBds (event (5), PA~300° and event (6), PA~250°).

The day after the start of the DBs, an enhancement was detected in Vsw and B until the 4th day, when B~10 nT during 5h and Dst was minimum, Dst=-45 nT, corresponding to a daily value of Vsw~420 km/s and negative Bz ~-6 during 5h. Therefore, this case is a good representative of a DBd associated to CME observation and their geoeffectiveness.

DBd+CH

Eight DBds were observed associated to CHs. There were two separate DBds and six DBds observed as two different joint groups composed by three DBds in each of them.

Table 1

No	CR	DB Start	DB End	DB Abs. C.	DB L	DB PA	CH	CME PA	CME Start	CME End	CME W	Vcme Km/s
1	1776	17/06/86 : 07:34	19/06/86 : 16:47	N05°, 130	~8°	85°						
2	1776	17/06/86 : 07:34	18/06/86:<06:01	N18°, 125	~5°	72°						
3	1776	17/06/86 : 07:34	18/06/86:<06:01	N01, 113	~4°	89°						
4	1776	17/06/86 : 07:34	18/06/86:<06:01	N10, 109	~4°	80°						
5	1781	07/11/86 : 15:33	09/11/86:>09:53	N30°, 122	20°	300°		270°	07/11/86:~09:29	09/11/86:17:32	60°	Slow
6	1781	07/11/86 : 15:33	09/11/86:>09:53	S20°, 115	17°	250°		270°	07/11/86:~09:29	09/11/86:17:32	60°	Slow
7	1782	19/11/86:<05:15	21/11/86 : 11:21	S23°, 163	50°	115°						
8	1782	21/11/86:<09:59	23/11/86:<08:26	N15°, 244	13°	280°	N15°, 214 S10°, 216					
9	1782	20/11/86:<10:20	23/11/86:<08:26	N40°, 214	40°	50°	N55°, 215					
10	1880	15/03/94:<16:47	18/03/94 : 16:37	N07°, 215	30°	83°	N07°, 225 N05°, 185					
11	1880	16/03/94:<09:30	17/03/94:<07:04	N25°, 137	19°	65°						
12	1880	16/03/94:<09:30	17/03/94:<07:04	N05°, 317	17°	275°						
13	1880	26/03/94:<15:50	30/03/94:<06:54	N20°, 50	55°	70°	N14°, 86					
14	1880	30/03/94:<09:10	31/03/94:07:21	815°, 146	30°	255°	S20°, 108					

Properties of DB (columns 3-7: start and end (ddmmyy) time (UT), absolute coordinates, length and central position angle) and associated CH (column 8: absolute coordinates), CME (columns 9-13: central position angle, start and end times, angular width and velocity). Columns 1 and 2 are numbers of the event under study and corresponding CR, respectively.

Events (13) and (14) were two separate DBds, considered as a unique chromosphere activity, related to nearby CHs when no CME was detected during and following erupting processes. The East-limb DBd (13) was the longest duration DB (~5 days) of our study; this prominence was unstable, changed intensity and size several times, indicating the presence of high turbulence in the body of the filament. During the five days of observation of this dynamic partial DB of prominence/filament, only the North section of ~28° of the filament disappeared. The remnants of the filament (original size was ~55°), erupted at the backside of the Sun, which was ascertained by the analysis of the following CR synoptic map. A long-lived equatorial CH was observed close to this filament, specifically the northern unstable section of the filament was close to (~10°) the Northern boundary of the CH. Following the DBd of this north section, the north part of the CH also diminished. The following CR map showed this smaller CH.

We observed that the DBd of the West-limb prominence (14) started after the DBd of the filament (13) was finished. It was a ~22h duration DBd of prominence (~30° in size), situated close to a long-lived equatorial CH. This CH decreased its area following the starting time of the DBd of prominence (14), disappearing subsequently at its end time and was not observed anymore in the following CR.

A medium GMS was detected with a minimum of Dst=-43 nT on the 5th day from the DB (13) starting time, correlated to Vsw=411 km/s, and a high GMS, Dst=-96 nT, on the 3rd day from the end of DB (13). The DBd (13) can be the cause of these two GMSs. Also, an extreme GMS, Dst=-111nT (Vsw~590 km/s), was detected on the 5th day from the starting time of a DB (14). There was a data gap in the solar wind key parameters from the 3rd to the 7th day of the start time of the DBd or prominence (14). Also, 17 hours before the data gap, on this 3rd day, Bz shows fluctuations, with a minimum at -4 nT lasting 1h, and high values of B (~9 nT), following the data gap period corresponding to a high solar wind speed Vsw~800 km/s, fluctuating Bz and B~6 nT.

The energy from the solar wind is injected into the magnetosphere only when the interplanetary magnetic field has a significant component parallel to the terrestrial magnetic dipole, i.e., southward or negative Bz component (Russell and McPherron, 1974; Akasofu, 1981; Gonzalez *et al.*, 1999), and an intense storm can be produced if Bz is higher than -l0 nT during more than ~3 hours. A small or highly fluctuating Bz can cause only a small or moderate storm (Gonzalez *et al.*, 1987).

Furthermore, two joint groups of dynamic DBs were observed, accompanied by adjacent CHs, when no CME was detected; the first joint groups were DBds: (7), (8), (9) and the second: (10), (11), (12).

The first joint group DBds (7), (8) and (9) were observed with one day interval between them; DBd (7) was a large ~50°, very low-density, East-limb prominence. No filament corresponding to the prominence was observed in $H\alpha$, which can be explained by the difficulty to detect a low-density filament's structure in the $H\alpha$ image

(Mouradian *et al.*, 1995). This DBd was accompanied by other two dynamic, central and N-W DBs (8) and (9), respectively, situated near to the AR. We observed some perturbations of the AR filament, but there was no eruption during the DBds of these two separate filaments. There were two equatorial CHs close to filaments (8). Both CHs were absent in the following CR. In addition, the one long-lived polar CH was observed close to filament (9) and was growing toward the DB position in the following CR.

From the 4th day of the DB (7) an enhancement in B and Vsw was detected, with maximum values of B=19nT (~15.6 nT, during 24 hours) and Vsw =519 km/s on the 5th day, following, a rapid decay in B and Vsw. Bz was negative from the 5th day on (Bz= -6 -11 nT) during 9 hours with a minimum Bz=-11 nT during 2 hours. Dst decreased rapidly from the 4th day of the start time of the DBd (7) and it reached the first minimum on the 4th day (Dst = -53 nT), second minimum on the 5th day (Dst = -86 nT) and third minimum on the 6th day (Dst = -105 nT). These GMSs, two high and one extreme, can be associated with three dynamic DBs (7), (8) and (9).

The second joint group events started with a central dynamic DB of the filament (10); then, 16 h later, a West-limb DBd (11) and an East-limb DBd (12) started simultaneously. Two equatorial CHs were observed around the filament (10). One of them, a small CH was on the West side and disappeared until the following CR; meanwhile, the other big CH, situated near the East side of the filament (10), changed its form and grew toward the DB position until the following CR. No CHs were observed close to the prominence (11) and (12).

A medium GMS (Dst=-58 nT) was detected on the 4th day from the DBd (10) start time; Bz fluctuated, and B shows small variations (B~4-8 nT) from the starting day and was B~6-7 nT on 4th day; the Vsw decreased slowly from 730 km/s to 546 km/s from the start day to the 4th day. Interplanetary observations have confirmed that solar minimum polar CHs are the source of an extremely stable and uniform high-speed solar wind, within velocities of about 750 km/s (Forsyth *et al.*, 1996; Woch *et al.*, 1997; McComas *et al.*, 2000).

Generally, transient changes in the CH geometry around a filament are related to magnetic reconnection and large-scale magnetic restructuring that have been suggested to be responsible for the eruption of a filament (T. Watanabe *et al.*, 1992). The possibility of magnetic reconnection at CHs boundaries (Wang *et al.* 1996), due to a rigid rotation of CHs (Wagner 1975; Timothy *et al.* 1975), will probably increase, (Mouradian and Soru-Escaut, 1989) because DBd occurs for prominences without pivot point and hence, rotating with a general differential rotation. Also, if a prominence without a pivot point suffers DBd, material and magnetic field are expelled. Thus, the filament/prominence plasma can be ejected into the high corona and also can originate a CME.

Conclusions

Based on this detailed study of the continuous observations on PMO - Hα movies, Hα spectro-heliograms / filtrograms or Ca II K lines, we exposed the evolution of three different cases of separate and combined DBd events: DBd (of 4 simultaneous DBds), DBd+CME (with 2 simultaneous DBds) and DBd+CH (with 8 DBds) and the geoeffectiveness associated with them.

Only one group of four small sizes (4° - 8°) simultaneous DBds corresponds to low GMS. The additional 10 DBds of our study have been related to at least 10° size filament/prominences, and have been associated to no less than medium GMS. This indicates that such a small <10° size filament/prominence DBd can probably be associated to a low GMS only.

Concerning their geoeffectivenes, we revealed that a total of six GMSs correlated with them: one low (4 DBs), one medium (2 DBs), two high (4 DBds) and two extremely high GMSs (4 DBds). The extreme and high GMSs were found to correlate with DBd+CH (even if not associated with corresponding CMEs). Moreover, the medium GMS correlated with a DBd+CME, while a low GMSs with a DBd. Thus, the highest geoeffectiveness was detected when the largest size (>30°) DBd was accompanied by a nearby (<15° distance) equatorial CH, which diminished in size or disappeared until the following CR. Hence, DBd+CH type interacting processes are essential to comprehend DBs geoeffectiveness, but still, they need be further investigated.

The associated solar wind velocity is characterized by a 2-interval range: medium 350-450 km/s and high 500-700 km/s. The 350-450 km/s interval corresponds to low (4 DBd), medium (2 DBd), high (1 DBd) and extreme (3 DBd) GMSs, whereas the 500-700 km/s interval corresponds to high (3 DBd) and extreme (1 DBd) GMSs. In addition, it seems that the Vsw is highly correlated to solar processes. Especially, large-duration DBs associated to medium and quick DBs are related to high solar wind velocity. Also, separate events of DBd and joint events of DBd+CME are correlated with Vsw~350-450 km/s, while interacting processes DBd+CH are correlated with both, medium and high solar wind velocity. We can say that for all studied events, those of long duration and with lowest southward direction Bz, correlate with the highest B and lowest Dst.

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