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Disappearances of High-Latitude Filaments as Sources of High-Latitude CMEs

E. W. Cliver

Air Force Research Laboratory, Hanscom Air Force Base, Massachusetts 01731-3010, USA

D. F. Webb

Institute for Scientific Research, Boston College, Chestnut Hill, Massachusetts 02467, USA

Abstract. From a statistical comparison of high-latitude coronal mass ejections (CMEs) and disappearing solar filaments (DSFs), we find: (1) Beginning with the "rush to the poles", DSFs arise at an increasing rate from the "emerging" or polar crown relative to the "true" polar crown. At maximum, these "opposite polarity" filaments are the dominant source of high-latitude DSFs. Following polarity reversal, the emergent polar crown becomes the true polar crown and the source of virtually all high-latitude DSFs. (2) At the last two solar maxima, we estimate that there were $\sim$ 4 times as many high-latitude ($\geq 60°$) CMEs as high-latitude ($\geq 45°$) DSFs. Possible reasons for this discrepancy include the following: (a) DSFs, particularly small ones, are under-reported, (b) propagation effects, whereby radially propagating CMEs appear at higher latitudes than their underlying source regions, are more important than currently thought, or (c) some combination of these effects.

1. Introduction

The characteristic behavior of high-latitude filaments over the solar cycle, i.e., the "rush to the poles", disappearance near solar maximum, and subsequent residence at $\sim 50°$ during solar minimum, has been known for over a century. McIntosh (1992) has refined this picture by separating high-latitude filaments into two groups, those having "correct" polarity for the cycle and those having opposite polarity. "Correct" polarity implies that the magnetic field lying poleward of east–west oriented filaments will be appropriate for that cycle, e.g., negative or inward-directed in the northern hemisphere for the years 1980–1990. We will refer to the irregular band of high-latitude filaments having correct polarity as the "true" polar crown and high-latitude filaments of opposite polarity as the "emergent" polar crown. For cycles 20–22, McIntosh determined the maximum latitude, north and south of the equator for each rotation, for both types of filaments. His results are shown in Webb (1998, these proceedings) where it can be seen that the emergent polar crown becomes the true polar crown for the next cycle near solar maximum at the time of polarity reversal.

During the past two decades, it has been recognized (e.g., Webb and Hundhausen 1987) that disappearing solar filaments are a common lower atmosphere manifestation of CMEs. In this study, we examine the relative importance of the true and emergent polar crowns as sources of CMEs. In addition, we attempt to determine if each high-latitude CME is associated with a high-latitude DSF.

2. Disappearances of True and Emergent Polar Crown Filaments as Sources of CMEs

We began with Wright's (1991) compilation of DSFs covering the years 1964–1980. For cycle 20 (1965–1976) we used McIntosh's (1979; also Solar-Geophysical Data) synoptic maps to determine whether each listed high-latitude (midpoint $\geq 40°$) DSF originated in the true or emerging polar crown. An example of this determination for Carrington Rotation 1517 is shown in Figure 1 and the results of this analysis are given in Figure 2. In Figure 2, annual rates of $\geq 40°$ latitude DSFs (from Wright 1991) and yearly sunspot numbers are given in panels (a) and (c), respectively. Panel (b) shows that the percentage of DSFs from the true polar crown steadily decreases beginning near the time of the onset of the rush to the poles in 1966 and reaches a minimum of ~25% at solar maximum. Following polarity reversal, the emergent crown becomes the true crown and is the dominant source of high-latitude CMEs throughout solar minimum until the next rush to the poles when the process is repeated.

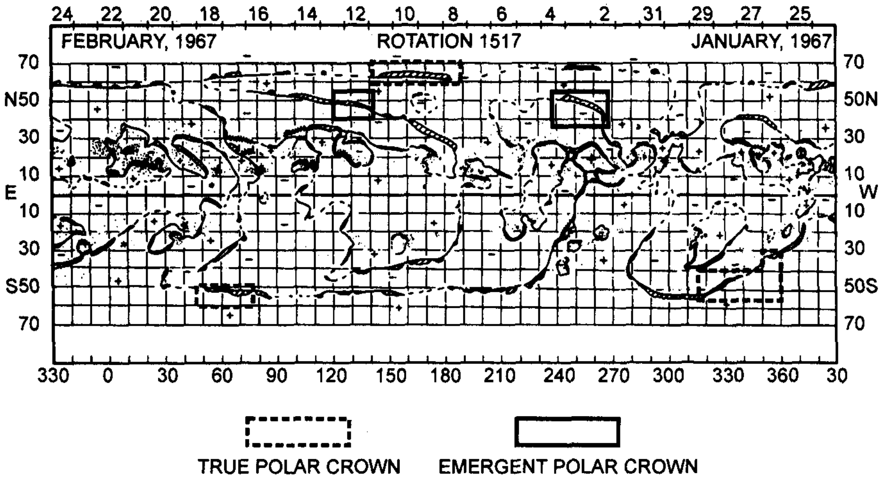

Figure 1. Classification of disappearing solar filaments as belonging to either the true or the emerging polar crown during Carrington Rotation 1517. The disappearing filaments in the northern hemisphere (solid box) originated in the emergent polar crown; those in the south (dashed boxes) originated in the true polar crown for that hemisphere.

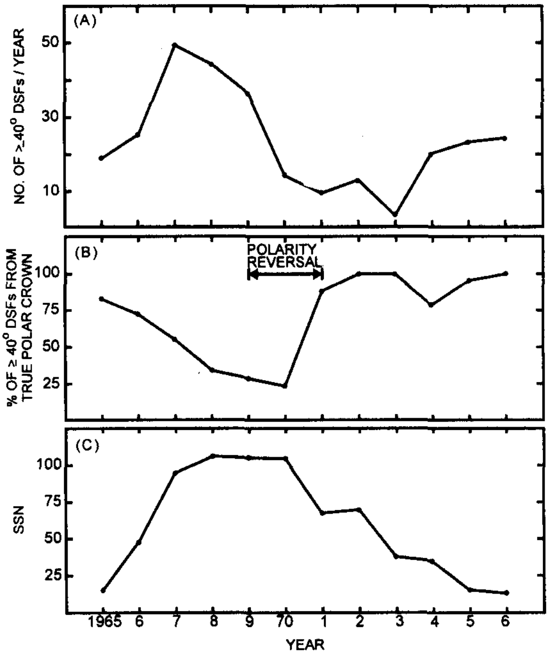

Figure 2. (a) Annual rates (no corrections applied) of high-latitude ($\geq 40°$) DSFs from Wright's (1991) catalog for cycle 20. (b) Percentage of high latitude DSFs that originated in the true polar crown over cycle 20. (c) Annual sunspot numbers for cycle 20.

3. Is There a One-to-One Correspondence Between High-Latitude DSFs and CMEs?

We determined the relative frequency of these phenomena for the early rise of the solar cycle and for solar maximum (Table 1). The CMEs in this table are those having central position angles (measured from the solar equator) with absolute values $\geq 40°$ and the DSFs are those having midpoint latitudes $\geq 40°$. The coronagraph data are from the Solwind (R.A. Howard, 1997, private communication) and Solar Maximum Mission (SMM) (Burkepile and St. Cyr 1993), and the DSF data are from Wright's (1991) catalog through 1980 and from the Meudon Cartes Synoptiques for later years. Previously, we had shown (Cliver et al. 1994) that the CME rate during cycle 22 exhibited a quasi-discontinuity in October 1988, when it jumped from an average daily rate of ~0.9 CME/day to an average rate of ~ 1.8 CME/day where it remained until the end of SMM observations in late 1989. Thus, we used 1988.7 as a breakpoint between epochs for the maximum of cycle 21. The other interval endpoints in Table 1 were determined by the onset of Solwind observations in late March 1979, the end of the Wright compilation in December 1980, and a 4-month data gap in the SMM record ending in late March 1987. The following correction factors were applied to the data: (1) the rate of high-latitude Solwind CMEs was multiplied by a factor of 1.8 to reflect a ~55% duty cycle (Howard et al. 1985); (2) the SMM CME rate was multiplied by 1.2 based on a duty cycle of ~85% for the 1987–1989 period (Cliver et al. 1994) for which these data were used; and (3) the DSF rate was multiplied by a factor of 2.8. This last correction was based on the assumption that CMEs originating at all longitudes at latitudes ≥ 40° are visible from Earth. Thus we multiplied the DSF rate by a factor of 2 to compensate for backside DSFs not visible from Earth. In addition, Wright has shown that the visibility of frontside DSFs decreases near the limbs for an additional correction factor of 1.4, yielding the final upward correction of 2.8.

Table 1. Ratio of high-latitude (≥ 40°) CMEs to DSFs.

Year	CMEs	DSFs	CMEs/DSFs
1979.3 – 1981.0	493	143	3.4
1987.3 – 1988.7	46	104	0.4
1988.7 – 1989.9	289	115	2.5

The evolution of the high-latitude CME/DSF ratio on the rise of cycle 21 during 1987–1989 (Table 1) is remarkable. We suspect that the low ratio (<0.5) prior to October 1988 is a reflection of the non-radiality of coronal streamers that is characteristic of solar minimum.

Here, however, we wish to explore the cause of the high (>2.5) CME/DSF ratio observed at the maxima of both cycles 21 and 22. The apparent excess of high-latitude CMEs could result from a projection effect whereby radially propagating CMEs arising in source regions away from the solar limb appear at higher latitudes than their source regions. Hundhausen (1993) has argued that CMEs having apparent central position angles ≥ 60° arise from solar sources lying poleward of about 45°. For the period 1979.3–1981.0, Wright's catalog contains 25 DSFs at latitudes ≥ 45°, yielding a corrected count of 70. For the same interval, Solwind observed 135 CMEs with central position angles ≥ 60°N or ≥ 60°S for a duty-cycle corrected count of 243. Thus a factor of 3.5 discrepancy remains after taking the projection effect into account. We are forced to conclude either that the projection effect is more important than currently thought or that a significant fraction of high-latitude CMEs originate in solar eruptions that lack reported DSFs. We repeated the above analysis for the maximum of cycle 22. During 1988.7–1989.9, 87 high-latitude CMEs (≥ 60°) and 27 DSFs (≥ 45°) were reported for duty-cycle corrected counts of 104 and 76, respectively. The resultant CME/DSF ratio of 1.4 is significantly lower than the 3.5 ratio for the maximum of cycle 21. On closer examination, however, we were only able to associate 8 of the 87 high-latitude CMEs with high-latitude DSFs (based on timing and position) vs. an expected number of 31 associations (87/2.8). Thus high-latitude CMEs were approximately 4 times as plentiful (31/8 = 3.9) as high-latitude DSFs at the maximum of cycle 22. Stated differently, approximately $\frac{3}{4}$ of high-latitude CMEs at the maximum of cycle 22 lacked reported high-latitude DSFs as sources. (Presumably, this CME/DSF imbalance was even greater for the peak of cycle 21.) Our study also indicates that a significant fraction of high-latitude DSFs are not followed by CMEs, but a detailed investigation, taking into account such factors as DSF longitude, coronagraph patrol windows, thermal Disparition Brusques (Mouradian et al. 1995), and associated CMEs at lower latitudes is needed.

Why do we see so many more high-latitude CMEs than DSFs? One very real possibility is that high-latitude DSFs, and more generally all DSFs, are underreported. Counts of DSFs by different observers vary widely. For example, during the years 1978–1980 the Wright catalog lists $2\frac{1}{2}$ times as many high-latitude DSFs as the Cartes Synoptiques. For this same interval an unpublished list compiled by Joselyn (see Webb and Howard 1994) contains about $3\frac{1}{2}$ times as many DSFs as are listed in the Wright catalog. For the 1988–1989 epoch Joselyn lists approximately three times as many DSFs as the Cartes Synoptiques. Fortunately, Wright (1991) provided annual size distributions of the cataloged DSFs. From the absence of an experimental roll-over in his lowest bin sizes, we conclude that any non-reported high-latitude DSFs were small, with areas less than about 5 square degrees. Thus many high-latitude CMEs may be associated with relatively small DSFs. That such events exist is underscored by the April 1994 magnetic cloud event that was traced to a high-latitude $\sim$ 150° long soft X-ray arcade but only a minor DSF (McAllister et al. 1996). A second possible cause of the excess of high-latitude CMEs in comparison with DSFs is that some polar ($\geq 60°$) CMEs may arise in low-latitude ($< 45°$) DSFs. To make the numbers of high-latitude CMEs and DSFs (at any latitude) match for the 1979–1980 period, it is necessary to assume that all DSFs in the Wright catalog with midpoint latitudes greater than about 30–35° resulted in a CME with central position angle $\geq 60°$. This seems a strong assumption, implying either that even lower latitude DSFs contribute to the high-latitude CME population or that a significant fraction of high-latitude CMEs originate in eruptions of high-latitude magnetic arcades that lack sufficient mass to be observed as a DSF.

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