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The solar origin of the January 1997 coronal mass ejection, magnetic cloud and geomagnetic storm

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Abstract. The magnetic cloud and geomagnetic storm on January 10–11, 1997 were associated with a halo-type Coronal Mass Ejection (CME) observed by the SOHO/LASCO coronagraphs near the sun on January 6. We summarize the solar activity related to this CME and the subsequent storm at Earth. This solar activity was remarkably weak and unimpressive. If the wide CME had not been observed, the storm would not have been forecast. Thus this case represents an extreme example of so-called "problem" magnetic storms that lack obvious surface signatures of eruptive solar activity. It supports the view that CMEs involve the destabilization of large-scale coronal structures which may or may not have associated surface activity, and that CMEs, not the surface activity, are the key causal link between solar eruptions and space weather at Earth.

Introduction

Coronal Mass Ejections (CMEs), vast structures of plasma and magnetic fields that are expelled from the sun, are now known to be a key causal link between solar eruptions and major interplanetary disturbances and geomagnetic storms [*Kahler,* 1992; *Gosling et al.,* 1991]. A partial halo CME was observed by LASCO [Large Angle Spectrometric Coronagraph] on SOHO[1] late on January 6, and used to forecast the arrival at Earth on January 10 of the magnetic cloud (MC) associated with a geomagnetic storm (Dst maximum of –84 nT). This forecast was made because the CME was halo-like and there were reports of activity near sun center as viewed from Earth, suggesting the launch of a disturbance moving towards the Earth [*Howard et al.,* 1982]. A travel time to Earth of about 85 hrs. was predicted based upon a typical CME speed of 450 km s^{-1} [D. Michels, private communication].

The importance of this particular event is that it represents an extreme example of a so-called "problem" geomagnetic storm. Such storms lack traditional signatures of causative solar activity, such as flares and large disappearing filaments [e.g., *Dodson and Hedeman,* 1964; *McAllister et al.,* 1996a and references therein]. The January 6–10 event is the first such problem storm for which the antecedent CME was actually observed. The associated solar surface activity was so weak and unimpressive that, had the CME not been observed, the storm would not have been forecast. In addition, the January solar/interplanetary activity was well observed by nearly the full complement of spacecraft in the International Solar Terrestrial Program [ISTP] program, making it the first geoeffective solar eruption/CME event to be so completely studied from the sun to Earth. In this paper we present and discuss the solar and interplanetary observations to demonstrate the importance that early detection and study of CMEs has in space weather research.

The Solar Source of the January 6–11, 1997 Event

The Halo CME

This event was the first involving SOHO data to become a major ISTP collaborative study [http://www-istp.gsfc.nasa.gov/istp/cloud_jan97/event.html]. This report is part of that study by members of SHINE [Solar, Heliospheric, and INterplanetary Environment; http://www.sec.noaa.gov/~vpizzo/shine], an ad-hoc group whose purpose is to provide solar-interplanetary inputs to research on space weather.

The CME was observed first in the field of view of the C2 coronagraph on January 6 at 1734 UT and later in the C3 coronagraph [see Fig.4 in *Burlaga et al.,* 1998]. Measurements of the expansion speed of the front on a height/time diagram yield a speed of about 100–150 km s^{-1}. This expansion speed is projected in the sky-plane and, thus, represents a lower limit of the true CME speed along the sun-Earth line. Back extrapolations of the CME front from height-time plots, assuming constant speed, to the center of the solar disk using the C2 and C3 data yield estimates of the onset time of the CME of ~1400 and ~1500 UT, respectively.

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[1] NASA/ESA Solar and Heliospheric Observatory [SOHO]. LASCO consists of 3 coronagraphs, C1, C2 and C3, which together view the corona from 1.1–30 R_s [*Brueckner et al.,* 1995; *Howard et al.,* 1997].

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CMEs moving outward from the sun along the sun-Earth line can, in principle, be detected when they have expanded to a size that exceeds the diameter of a coronagraph's occulting disk. Since CMEs are likely to be, to first order, spherically symmetric structures, Earth- (or anti-Earth) directed CMEs should appear as expanding halo-like brightenings surrounding the occulter. Indeed, LASCO, the most sensitive and largest-field coronagraph ever flown, has now observed several such CMEs [see, e.g., *Brueckner et al.,* this volume]. The January 6 CME appeared as a partial arc over the SSW part of the sun moving in a southwesterly direction. Although it did not appear as a complete halo around the sun, the CME's large span of $\geq 140°$ greatly exceeded that of most CMEs, suggesting an eruption aimed primarily toward or away from the spacecraft positioned at L1 in front of Earth. A similarly positioned partial halo CME observed by LASCO on September 27, 1996 was associated with an erupting filament/active region and X-ray arcade just south of sun center [*van Driel-Gesztelyi et al.,* 1998], suggesting a similar source location on the disk for this event.

Associated Solar Surface Activity

We examined the observations and reports of all solar activity on January 6, especially around the estimated time of the CME onset in the middle of the day. The solar surface was relatively quiet on January 6 and lacked any prominent active regions. The GOES whole-sun plot [Figure 1] showed little X-ray activity above the background level [average flux of 1×10^{-8} Wm^{-2}, or A1], and Hα and Yohkoh Soft X-ray Telescope [SXT] X-ray images during the day showed little change. The only notable regions were NOAA 8009, a small but bright emerging flux region west of sun center, and Air Force SN84, a large, weak plage area with no sunspots near central meridian at S30°. Region SN84 was bifurcated by a northwest to southeast-oriented magnetic polarity inversion line over which filament fragments had come and gone during its disk passage. This boundary was along a segment of the persistent southern polar crown neutral line and was located where it bent sharply to the north. This section of the neutral line was evolving over several solar rotations before and after the January period and was also the site of emerging magnetic flux, as evidenced by an increasing area of X-ray emission and increased magnetic flux. This site was also the origin one solar rotation later of the February 7 CME and ensuing magnetic storm.

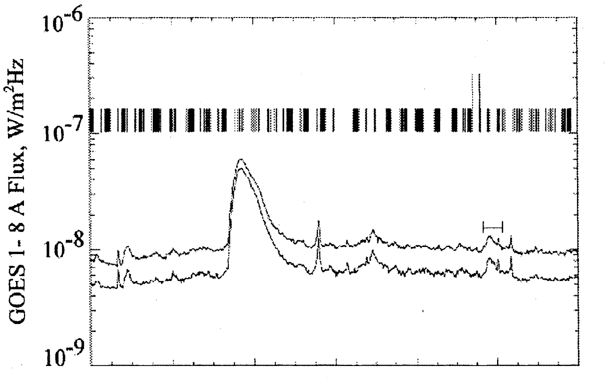

Figure 1. GOES whole-sun plots of soft X-ray [1–8Å] activity on January 5 and 6, 1997. Note the relatively bright A6–level LDE on the 5th, but the general lack of activity above the A1 background on the 6th. The horizontal bar indicates the time of the weak LDE on January 6, 1430–1630 UT (see Figure 3). Band of vertical lines indicate times of Yohkoh SXT images.

The U. S. Air Force observers at the Ramey, Puerto Rico SOON station reported no disappearing filaments (DSFs) on the disk on January 5 during the observing day, 1117–2119 UT [S. Dahl and D. Rose, private communication, 1997]. However, a small filament centered at S18°E06° did disappear in region SN84 between January 5 and 6 [Solar Geophysical Data Bulletins, 1997]. This filament was gone by the start of Ramey observations on January 6 at 1113 UT, so its disappearance was too early to be associated with the CME. However, another filament segment in SN84 centered at S23°W03° disappeared between 1301 and 1453 UT [listed in SGD as 13° long and of major importance]. This filament was not visible on a high-quality Hα image at 0850 from Meudon Observatory in France, so it must have reformed on the 6th between 0850 and 1113 UT. Regardless, it is clear that a long-lived filament in the northern part of region SN84 disappeared during the day on January 6.

We summarize the Ramey report of this second DSF: A normal-density filament lying over the northern fringe of region SN84 "disappeared in a slightly eruptive fashion" (between the times above). The filament had been very stable beforehand but suddenly began dissipating over a curved path. Simultaneously with the DSF, an 8° long, previously stable filament in the southern part of SN84 suddenly displayed strong structural changes. In addition, numerous plage flucations occurred in the region center (between the filaments). Two small sunspots appeared at ≈S35°E05° during this period. The northern filament did not reform before the end of observations at 2043 UT but did begin reforming on January 7. A closer look at observations at radio and X-ray wavelengths on January 6 shows that there was weak coronal activity associated with this DSF. A dark "radio filament" consistent with the location of the Hα filament, disappeared between 0645 and 2345 UT on the 6th in 17 GHz images from Nobeyama Radio Observatory in Japan. We examined Yohkoh SXT images and found that preexisting loops crossing over the filament position north of the bright active region loops had dimmed during the DSF between images at 1338 and 1423 UT [Figure 2]. Other faint large loops to the south appeared during this period, which includes the estimated onset time of the CME. However, there were no apparent motions associated with any of these structures. Plots of the GOES X-ray channels on January 6 [Figure 1] show evidence of a very weak [peak flux level of 1.3×10^{-8} Wm^{-2}, or A1.3] long-duration event (LDE) from 14:30–16:30 UT. Comparisons between SXT images during this period show that this LDE signified the brightening of the interior loops in region SN84. X-ray LDEs have often been associated with filament eruptions and CMEs [e.g., *Webb,* 1992]. Also, this event was consistent with the typical DSF/LDE event in which the peak brightening of the LDE tends to lag the disappearance of the filament. However, we emphasize that such a weak event would never be detected near solar maximum when the GOES background level

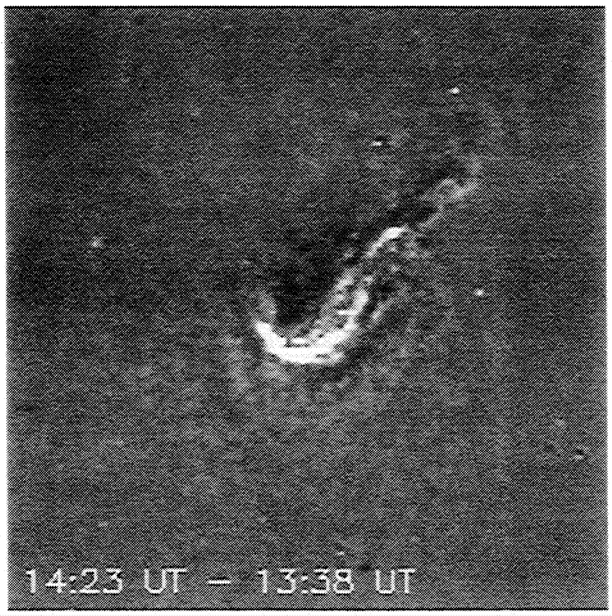

Figure 2. Difference of two Yohkoh SXT images of region SN84 on January 6 at 1423 and 1338 UT (long vertical lines on Fig. 1). Image shows evolution of the coronal loops above plage in Fig. 2 during the DSF: the northern loops over the filament dimmed between the images, whereas loops crossing the main plage brightened. The brightening structures are associated with the faint GOES LDE in Figure 1 during estimated onset time of the CME. Other faint, large loops to the south, not apparent in these images, appeared during this period.

is generally two orders of magnitude higher, and would generally be ignored even at solar minimum. The GOES data in Figure 1 also show a distinct solar LDE [6×10^{-8} Wm^{-2}, or A6–level] that occurred on January 5 from 1331–1610 UT. The Yohkoh images indicate this event came from the same region that gave rise to the aforementioned DSFs. Initially, we thought that this event was the source of the CME on January 6 and/or the MC at Earth on January 10. However we rejected this possibility because: 1) The LDE occurred much too early to match the extrapolated onset time of the CME; 2) It was not consistent with the timing of the interplanetary disturbance (see below); and 3) There was no LASCO CME observed on January 5 that would be consistent with an association with the LDE (there was an earlier CME at 0521 UT). We note that the height vs. time plots of the leading edge of the January 6 CME are consistent with motion through both of the LASCO C2 and C3 fields of view at constant velocity. Extrapolated to zero height, these plots are consistent with CME onset during the weak activity on Jan. 6 but inconsistent with association with the Jan. 5 LDE, which would require an implausibly slow acceleration of the CME.

Interplanetary Propagation of Disturbance

We also checked the CME/MC association using two assumptions involving the transit speed of the disturbance to Earth. On January 10 the WIND spacecraft was located 85 R_e upstream of the earth. The front of the MC was detected at WIND on January 10 at 0445 UT, and was preceded by an interplanetary shock arriving at 0100 UT [see Fig. 1 in *Burlaga et al.,* 1998]. If the MC was embedded in the CME observed on January 6, then the transit speed from the sun to Earth would have been 490 km s^{-1}. This is slightly higher than typical CME speeds [e.g., *Howard et al.,* 1985] and, thus, consistent with the extrapolated onset times of the CME and DSF near sun center after midday on January 6.

As an additional check, if we assume we know the solar source time of the shock, we can calculate its transit time to WIND and compare it with an empirical relation between shock transit speeds to Earth and the peak solar wind speeds observed at 1 AU [*Cliver, Feynman and Garrett,* 1990]. Assuming that the January 5 LDE event was the solar source of the shock implies an average transit speed to WIND of 385 km s^{-1}. Assuming that the CME launched at 1400 UT on January 6, consistent with the C2 onset time, was the source yields the above transit speed of 490 km s^{-1}. On January 10 the peak hourly-averaged wind speed following the shock at WIND was 465 km s^{-1}. Figure 3 is adapted from the Cliver et al. study and shows that, although the data points for both the January 5 and 6 candidate sources for the shock lie above the original best-fit line, the January 6 event is the preferred candidate source.

Conclusions

We conclude that the geomagnetic storm (and magnetic cloud) on January 10–11, 1997 was generated by the halo-type CME observed by LASCO near the sun on January 6. This CME, in turn, was associated with a DSF and remarkably weak coronal activity just south of disk center around midday on January 6. In a global context, this activity occurred along an evolving section of a polar crown neutral line which, over several solar rotations before and after the January period, developed a sharp bend and was the site of possible emerging magnetic flux. For example, during the January 6 activity newly formed sunspots in this region provided evidence of rapidly emerging flux. Such evolving, angled neutral line locations may favor the production of CMEs [*McAllister et al.,* 1996a; *Webb et al.,* 1997; D.F. Webb et al.,

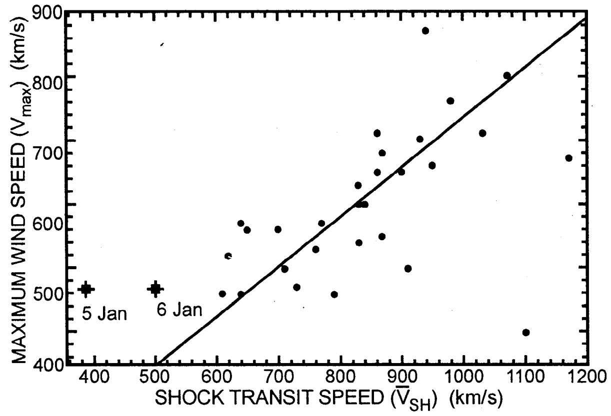

Figure 3. The maximum in-situ solar wind speed at 1 AU of disturbances with confidently identified solar sources plotted against associated shock transit speed adapted from *Cliver, Feynman and Garrett* [1990]. Dashed line is linear best-fit to the data points (filled circles) from the Cliver et al. study.

Halo CMEs and the Characteristics of Related Geoactivity, submitted to *J. Geophys. Res.*, 1998], as may the emergence of appropriately oriented magnetic flux [*Feynman and Martin*, 1995]. The association of X-ray arcades and CMEs with evolving opposite-polarity flux and polar crown neutral lines supports results found by *McAllister et al.* [1996b] for the declining phase of the recent solar cycle.

The January 6–10 event is the first "problem storm" for which a CME was actually observed. As such, it underscores the importance of CMEs, in general, and halo-type CMEs, in particular, to space weather research. In a separate paper [D.F. Webb et al., submitted to *J. Geophys. Res.*, 1998], we demonstrate that a halo or partial halo CME is an excellent indicator of increased geomagnetic activity 3–5 days later [see also *Brueckner et al.,* this volume], especially if associated with long-enduring surface activity within ~30° of sun center. This combination greatly increases the certainty that the CME has been launched towards the Earth. Note that the surface activity need not be intense to confirm that the CME is aimed in the "right" direction. The January event teaches us why forecasting geoeffective disturbances can be so difficult. The observable manifestations on the solar surface were weak and unimpressive. Without the halo CME, the storm would not have been predicted and, thus, would have become one of the many "problem" storms that have been a challenge to solar-terrestrial forecasters and researchers [e.g., *Dodson and Hedeman*, 1964].

A fundamental forecasting difficulty has been the lack of solar observables of the ejected coronal material itself. Soft X-ray arcades on the disk have long been recognized as potential signatures of Earth-directed CMEs. However, the size and brightness parameters of such arcades seem poorly correlated with those of associated CMEs [*Hundhausen*, 1997]. For example, although both the January 1997 event and one in April 1994 were associated with significant "problem" storms, the April 1994 transient X-ray structure [*McAllister et al.,* 1996a] consisted of a large arcade spanning >150° in solar longitude, whereas the X-ray area of the January 6 event was much smaller and its peak flux an order of magnitude lower. Such observations again support the view that CMEs, not solar flares, are the key causal link with significant space weather activity.

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References

Brueckner, G.E. et al., The large angle spectroscopic coronagraph (LASCO), *Solar Phys., 162,* 357, 1995.

Burlaga, L. et al., A magnetic cloud containing prominence material: January 1997, *J. Geophys. Res., 103,* 277, 1998.

Cliver, E.W., J. Feynman, and H.B. Garrett, An estimate of the maximum speed of the solar wind, 1938–1989, *J. Geophys. Res., 95,* 17,103, 1990.

Dodson, H.W., and E.R. Hedeman, Problems of differentiation of flares with respect to geophysical effects, *Planet. Space Sci., 12* (5), 393, 1964.

Gosling, J.T., D.J. McComas, J.L. Phillips, and S.J. Bame, Geomagnetic activity associated with earth passage of interplanetary shock disturbances and coronal mass ejections, *J. Geophys. Res., 96,* 7831, 1991.

Howard, R.A., D.J. Michels, N.R. Sheeley, Jr., and M.J. Koomen, The observation of a coronal transient directed at Earth, *Astrophys. J., 263,* L101, 1982.

Howard, R.A., N.R. Sheeley, Jr., M.J. Koomen and D.J. Michels, Coronal mass ejections: 1979–1981, *J. Geophys. Res., 90,* 8173, 1985.

Howard, R.A. et al., Observations of CMEs from SOHO/-LASCO, in *Coronal Mass Ejections,* GM 99, edited by N. Crooker et al., p. 17, AGU, Washington, D.C., 1997.

Hundhausen, A.J., Coronal mass ejections, in *Cosmic Winds and the Heliosphere,* edited by J. Jokipi et al., Univ. of Arizona Press, Tucson, AZ, 1997.

Kahler, S.W., Solar flares and coronal mass ejections, *Annu. Rev. Astron. Astrophys., 30,* 113, 1992.

McAllister, A. H., M. Dryer, P. McIntosh, H. Singer, and L. Weiss, A large polar crown CME and a "problem" geomagnetic storm: April 14–23, 1994, *J. Geophys. Res., 101,* 13,497, 1996a.

McAllister, A. H., A.J. Hundhausen, J.T. Burkepile, P. McIntosh, and E. Hiei, Declining Phase Coronal Evolution: The Statistics of X-ray Arcades, in *Magnetohydrodynamic Phenomena in the Solar Atmosphere, Prototypes of Stellar Magnetic Activity,* edited by Y. Uchida et al., p. 123, Kluwer, Norwell, MA, 1996b.

van Driel-Gesztelyi, L., B. Schmieder, G. Aulanier, and P. Demoulin, Filament disparition brusque and CME – Sept. 25–26, 1996 event, in *New Perspectives on Solar Prominences,* edited by D. Webb et al., ASP Conf. Series, San Francisco, in press, 1998.

Webb, D.F., The solar sources of coronal mass ejections, in *Eruptive Solar Flares,* edited by Z. Svestka et al., p. 234, Springer-Verlag, Berlin, 1992.

Webb, D.F., S.W. Kahler, P.S. McIntosh, and J.A. Klimchuk, Large-scale structures and multiple neutral lines associated with coronal mass ejections, *J. Geophys. Res., 102,* 24,161, 1997.

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