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Solar and interplanetary origins of the November 2004 superstorms

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Abstract

During the first half of November 2004, many solar flares and coronal mass ejections (CMEs) were associated with solar active region (AR) 10696. This paper attempts to identify the solar and interplanetary origins of two superstorms which occurred on 8 and 10 November with peak intensities of $Dst = -373$ nT and -289 nT, respectively. Southward interplanetary magnetic fields within a magnetic cloud (MC), and a sheath + MC were the causes of these two superstorms, respectively. Two different CME propagation models [Gopalswamy, N., Yashiro, S., Kaiser, M.L. et al. Predicting the 1-AU arrival times of coronal mass ejections. J. Geophys. Res. 106, 29207–29219, 2001; Gopalswamy, N.S., Lara, A., Manoharan, P.K. et al. An empirical model to predict the 1-AU arrival of interplanetary shocks. Adv. Space Res. 36, 2289–2294, 2005] were employed to attempt to identify the solar sources. It is found that the models identify several potential CMEs as possible sources for each of the superstorms. The two Gopalswamy et al. models give the possible sources for the first superstorm as CMEs on 2330 UT 4 November 2004 or on 1454 UT 5 November 2004. For the second superstorm, the possible solar source was a CME that on 0754 UT 5 November 2004 or one that occurred on 1206 UT 5 November 2004. We note that other propagation models sometimes agree and other times disagree with the above results. It is concluded that during high solar/interplanetary activity intervals such as this one, the exact solar source is difficult to identify. More refined propagation models are needed.

Keywords: Geomagnetic storms; Solar flares; CMEs; Shocks; Magnetic clouds

1. Introduction

Coronal mass ejections (CMEs) and solar flares are large solar disturbances which cause significant effects on the space weather of the Earth and other planets (e.g., Echer et al., 2005; Tsurutani et al., in press). The sun was particularly active in the declining phase of solar cycle 23. Flares and related CMEs from large solar active regions (ARs) were the causes of major geomagnetic storms or superstorms in the post-solar maximum years 2003–2005 (Gopalswamy et al., 2006; Echer et al., 2008a). In the first half of November 2004, AR 10696 (or "'696' for brevity") was the origin of multiple CMEs, causing two superintense geomagnetic storms on 8 and 10 November, with peak Dst of -373 nT and of -289 nT, respectively (Yermolaev et al., 2005; Gopalswamy et al., 2006; Culhane et al., 2007; Zhang et al., 2007; Echer et al., 2008a,b; Tsurutani et al., 2008).

It is the purpose of this paper to identify and describe the solar and interplanetary origins of these two superstorms. In this effort, solar coronagraph data, solar wind plasma and magnetic field data (measured by the ACE spacecraft instruments orbiting the L1 libration point) and geomagnetic activity indices will be used. We will use SOHO CME initiation times and initial velocities and apply two different empirical CME propagation models to identify potential solar CME sources. Fourteen different potential CMEs are considered. The results will be compared with previously published works.

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2. Data and methods of analyses

The solar and interplanetary origins of the November 2004 superstorms are studied. Coronagraph data from SOHO LASCO (Domingo et al., 1994) are used for CME identification. High time resolution (64 s) solar wind plasma and magnetic field data measured by instruments onboard the ACE spacecraft (Stone et al., 1998) are used to identify the solar wind structures (shocks, waves and magnetic clouds (MCs)). Geomagnetic 1-h Dst index data from the World Data Center for Geomagnetism (WDC – Kyoto) are used to identify the magnetic storm phases (Gonzalez et al., 1994, 2007; Echer et al., 2008c).

MCs are identified using Burlaga's criteria (Burlaga et al., 1981; Burlaga, 1995): strong magnetic fields and a smooth rotation of the field direction through a large angle. A further criterion, such as low plasma β (Tsurutani and Gonzalez, 1994; Farrugia et al., 1997), has also been applied. In this work, both conditions are required for the identification of magnetic clouds.

Observations show that fast CMEs are first accelerated from 0 km s^{-1} at the surface of the sun to maximum speeds slightly further from the sun. After maximum speeds are reached, CMEs decelerate as they propagate outward to 1 AU. CME propagation models usually do not consider the short duration acceleration portion, but do consider CME deceleration thereafter. The two models used in this study are of the latter category.

We use the SOHO catalog (http://cdaw.gsfc.nasa.gov/CME_list/) to obtain the CME initiation times and speeds. These speeds are then used as input parameters to the propagation models to compute the travel times from the sun to 1 AU (Gopalswamy et al., 2001, 2005).

3. Results

3.1. Solar and interplanetary origins of the November 2004 superstorms

Fig. 1 shows solar images on 7 November 2004 at different wavelengths observed with the SOHO instruments for AR 696. Panel (a) is a SOHO MDI image where AR 696 is indicated. Panel (b) shows the solar active regions (bright regions) at 190014 UT from the SOHO EUV EIT 171 Å data. Panel (c) is the SOHO LASCO C3 coronal image

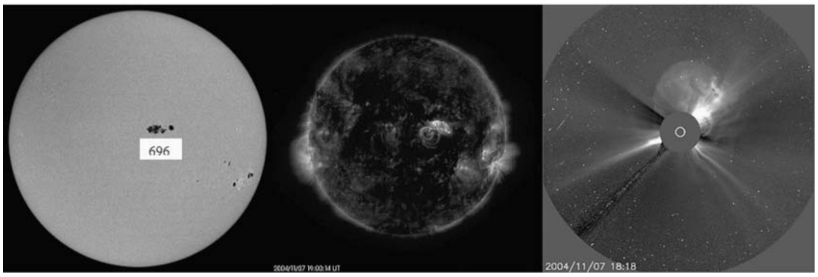

Fig. 1. Solar images of (a) SOHO MDI data of the solar disk on 7 November 2004, with AR 696 indicated; (b) SOHO EUV EIT 171 Å data of solar active regions 1900 UT 7 November 2004; (c) SOHO LASCO C3 data of the CME 7 November 2004, 1818 UT.

Table 1
CME parameters – CMEs from SOHO catalog, excluded "poor" events and slow (<400 km s^{-1}) CMEs – acceleration (a) and propagation time from Gopalswamy et al. (2001, 2005) ECA models (ECA-1 – acceleration constant until 1 AU), ECA-2.

CME	Time event Sun	u (km s^{-1})	a (m s)	ECA-1 model (a cte)		ECA-2 model	
				Time of propagation (days)	Predicted time at ~1 AU	Time of propagation (days)	Predicted time at ~1 AU
1	0354 UT 03 November 2004	918	−2.76	3.36	~13 UT 06 November 2004	2.82	~23 UT 05 November 2004
2	1606 UT (Halo) 03 November 2004	1068	−3.57	2.61	~06 UT 06 November 2004	2.34	~00 UT 06 November 2004
3	0954 UT (Halo) 04 November 2004	653	−1.33	4.26	~16 UT 08 November 2004	3.82	~ 06 UT 08 November 2004
4	2330 UT 04 November 2004	1055	−3.50	2.66	~15 UT 07 November 2004	2.38	~09 UT 07 November 2004
5	0754 UT 05 November 2004	772	−1.98	4.19	~12 UT 09 November 2004	3.38	~17 UT 08 November 2004
6	1206 UT 05 November 2004	745	−1.83	4.22	~17 UT 09 November 2004	3.49	~00 UT 09 November 2004
7	1454 UT 05 November 2004	1188	−4.22	2.21	~20 UT 07 November 2004	2.04	~16 UT 07 November 2004
8	0131 UT (Halo) 06 November 2004	818	−2.22	4.03	~02 UT 10 November 2004	3.19	~06 UT 09 November 2004
9	0806 UT 06 November 2004	1215	−4.37	2.14	~11 UT 08 November 2004	1.98	~08 UT 08 November 2004
10	0954 UT 07 November 2004	467	−0.33	4.27	~14 UT 11 November 2004	4.22	~15 UT 11 November 2004
11	1654 UT (Halo) 07 November 2004	1759	−7.30	1.28	~01 UT 09 November 2004	1.24	~23 UT 08 November 2004
12	0354 UT (Halo) 08 November 2004	462	−0.302	4.27	~10 UT 12 November 2004	4.23	~09 UT 12 November 2004
13	1726 UT (Halo) 09 November 2004	2000	−8.60	1.09	~19 UT 10 November 2004	1.06	~19 UT 10 November 2004
14	0226 UT (Halo) 10 November 2004	3387	−16.1	0.58	~16 UT 10 November 2004	0.58	~16 UT 10 November 2004