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Testing the asymmetric cone model for halo CMEs using STEREO/SECCHI coronagraphic observations

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Abstract

Space weather is significantly controlled by halo coronal mass ejections (HCMEs) originating close to the central meridian and directing toward the Earth. Unfortunately, coronagraphic observations (especially for HCMEs) are subject to a projection effect which makes it impossible to determine the true radial velocity and width of CMEs. However, these parameters can be estimated by correcting for the projection effect using the asymmetric cone model (Michalek, 2006). A set of 20 CMEs, observed as halo events in the LASCO field of view and simultaneously as limb events in the STEREO/SECCHI field of view, are used to check the accuracy of the asymmetric cone model. For this purpose, characteristics of the considered CMEs (angular widths and radial speeds) measured in STEREO/SECCHI images are compared with those obtained by the asymmetric cone model. We demonstrate that the widths and speeds determined by both methods are very similar. Correlation coefficients for speeds and angular widths are 0.99 and 0.96, respectively. We have also shown that the projection effect is unpredictable and could sometimes be very significant (up to 100% of the velocity measured in the LASCO field of view). On average, the SOHO/LASCO projected speeds for the HCMEs are 23% smaller than the radial velocities obtained from the STEREO/SECCHI images.

Keywords: Sun; Coronal mass ejections; Space weather

1. Introduction

Coronal mass ejections (CMEs) were first recorded in the 1970s by the OSO-7 satellite (Tousey, 1973). They are expulsions of magnetized plasma from the Sun and can be sources of geomagnetic activity. Halo coronal mass ejections (HCMEs) that appear in coronagraphic observations around the entire occulting disc are likely to originate from the central meridian of the Sun. It means that frontside HCMEs direct towards the Earth and have a significant impact on the space weather. Due to their source location, HCMEs are subject to a significant projection effect. The SOHO/LASCO observations do not allow to determine the true radial velocity (V_{rad}), width, and source location of HCMEs.

The first attempt made to estimate the projection effect, based on the location of the source, employed an ad hoc assumption on the width of CMEs (Sheeley et al., 1999; Leblanc et al., 2001). Burkepile et al. (2004), who separately investigated 111 limb events observed by Solar Maximum Mission (SMM), demonstrated that their average speed is significantly larger than the average speed of all CMEs recorded by SMM. Similar results were obtained by Vrsnak and Zic (2007), who investigated a statistical relationship between the plane-of-sky speeds of CMEs and the direction of their propagation. They considered only a sample of CMEs observed to radial distances larger than 10 solar radii by the Large Angle and Spectrometric

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COronagraph (LASCO) in the period 1996–2005. They found a correlation between the CME projected speed and the distance of the source region from the disc center. They concluded that the projection effect causes limb CMEs to have a greater apparent speed than disc events. Studying all CMEs listed in the CDAW CME catalogue during 1997–1998, Wang et al., 2011 did not find such a correlation.

It is widely accepted that projection effect of CMEs could be corrected by a cone model (e.g. Howard et al., 1982; Fisher and Munro, 1984; St.Cyr et al., 1996; Webb et al., 2000; Zhao et al., 2002). Assuming that, in the early phase, CMEs propagate with near-constant radial speed and angular width, various cone models were developed (Zhao et al., 2002; Michalek et al., 2003; Xie et al., 2004; Xue et al., 2005) to determine the following parameters: the radial speed, the angular width, and the source location. It is important to note that Michalek et al., 2003 and Xue et al., 2005) determined these parameters by using velocities measured in the LASCO field of view (LFOV), while Xie et al., 2004 considered the shapes of CMEs. Later it was recognized that CMEs have a flux-rope geometry (e.g. Chen et al., 1997; Dere et al., 1999; Chen et al., 2000; Plunket et al., 2000; Forbes, 2000; Chen and Krall, 2003). This encouraged Michalek (2006) to develop the asymmetric cone model (ACM): the shape of CMEs has a cone geometry but the cone cross-section is an ellipse. It was demonstrated that the asymmetric cone model reproduces the measured projected speeds much better than the symmetric cone model. This method was applied to determine these parameters of HCMEs recorded by SOHO/LASCO coronagraph in the period 2001–2002 (Michalek et al., 2007). Then, the true speeds were applied for the space weather prediction. They showed that the de-projected speeds are strongly correlated with both the travel times of CMEs from the Sun to Earth and the intensity of geomagnetic disturbance. Using statistical methods, Michalek (2010) has tested the reliability of the ACM. To this aim, he compared the properties of HCMEs considered by Michalek et al. (2007) with limb CMEs which are wide and could potentially be halo events when directing towards the Earth. They showed that the width and speed distributions for both samples of CMEs are similar and very probably represent the same distributions of events. Recently, Na et al. (2013) have compared three cone models to discuss their strengths and weaknesses in terms of space weather prediction. Using the Graduated Cylindrical Shell (Thernisien et al., 2006; Thernisien et al., 2009; Thernisien, 2011) model Shen et al. (2013), obtained the de-projected values of the radial velocity of 86 halo CMEs listed in the CDAW CME catalogue from March 1 2007 to May 31 2012. They demonstrated that the projection effect exists for halo CMEs, but not all of these events need to be corrected for this effect. They showed that full HCMEs originating far from the vicinity of the solar disc center or moving faster than 900 km s^{-1} manifest a small projection effect. This result is not surprising. Full HCMEs originating far from the disc center must be very wide to appear around the entire disk and therefore their plane-of-sky speeds are close to their real propagation velocities. Similar conclusions were also presented by Michalek et al. (2003).

Launching a pair of STEREO twin spacecraft allowed us to observe the Sun from two additional directions. These observations provide a unique opportunity for direct validation of the ACM and consideration of the projection effect. In the present paper, based on a set of 20 HCME events in the SOHO/LASCO field of view, we study the impact of the projection effect by tracking the HCMEs leading edge features in the plane-of-sky from combined STEREO/SECCHI and SOHO/LASCO coronagraphic observations. The STEREO/SECCHI observations for the HCMEs could be free from the projection effect and provide almost the true values of parameters characterising these events. This is possible when the satellites are separated from the Earth by about 90°. It should be mentioned that even this specific configuration of satellites does not guarantee that halo CMEs in LFOV are limb events in STEREO FOV, because CMEs may experience a deflected propagation due to interaction with magnetic structures when they move away from the Sun (e.g. MacQueen et al., 1986; Gopalswamy et al., 2004; Wang et al., 2011; Shen et al., 2011; Gui et al., 2011).

To test the accuracy of the ACM we compare the parameters obtained from the direct observations using STEREO/SECCHI coronagraphs and the ACM applied to the SOHO/LASCO data. This paper is organized as follows: in Section 2 data used for the study and methods are described. In Section 3 we present the results of our analysis. Finally, conclusions and discussion are presented in Section 4.

2. Data and measurements

2.1. SOHO/LASCO halo CMEs and CDAW catalogue data

To carry out the planned investigations, we consider CMEs observed simultaneously by the SOHO/LASCO and STEREO/SECCHI coronagraphs. Observations from both instruments have overlapped since 2006. For the purposes of the present research we use only observations in the period 2010–2011. At that time the satellites were found in the quadrature respect to the Earth. By searching all CMEs in the CDAW catalogue within the period 2010–2011, we were able to select 20 events observed as halo CMEs in the SOHO/LASCO field of view. In our sample there are both frontside and backside HCMEs. For frontside events, we can determine their source locations by checking associated X-ray flares. In the case of backside halo events, for which we do not have X-ray data, EUV images from STEREO/EUVI telescopes were used (EUVI event catalogue, http://secchi.lmsal.com/EUVI/euvi-autodetection/euvi-events.txt). This is the standard procedure and allows us to designate a part of the Sun from which an eruption originated.