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Determination of projection effects of CMEs using quadrature observations with the two STEREO spacecraft

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Abstract

Since 1995 coronal mass ejections (CMEs) have been routinely observed thanks to the sensitive *Large Angle and Spectrometric Coronagraphs* (LASCO) on board the *Solar and Heliospheric Observatory* (SOHO) mission. Their observed characteristics are stored, among other, in the SOHO/LASCO catalog. These parameters are commonly used in scientific studies. Unfortunately, coronagraphic observations of CMEs are subject to projection effects. This makes it practically impossible to determine the true properties of CMEs and therefore makes it more difficult to forecast their geoeffectiveness. In this study, using quadrature observations with the two *Solar Terrestrial Relations Observatory* (STEREO) spacecrafts, we estimate the projection effect affecting velocity of CMEs included in the SOHO/LASCO catalog. It was demonstrated that this effect depends significantly on width and source location of CMEs. It can be very significant for narrow events and originating from the disk center. The effect diminishes with increasing width and absolute longitude of source location of CMEs. For very wide (width $\geqslant 250°$) or limb events (|longitude $\geqslant 70°$) projection effects completely disappears.

Keywords: Solar activity; Coronal mass ejection (CMEs); Projection effects of CMEs

1. Introduction

Coronal mass ejections (CMEs) are huge expulsions of magnetized plasma from the Sun. They generate the most sever geomagnetic storms therefore they have been intensively studied. Since 1995 CMEs have been routinely observed thanks to the sensitive *Large Angle and Spectrometric Coronagraphs* (LASCO, Brueckner et al., 1995) on board the *Solar and Heliospheric Observatory* (SOHO) mission. The SOHO/LASCO instruments have already recorded about 30,000 CMEs by December 2016. The basic, observed or derived, attributes of CMEs are stored, among other, in the SOHO/LASCO catalog (cdaw.gsfc.nasa.gov/CME_list, Yashiro et al., 2004; Gopalswamy et al., 2009). This catalog has been widely used for scientific studies. Unfortunately, coronagraphic observations of CMEs are subject to projection effects. The basic attributes of CMEs (*e.g.* velocity, acceleration, and width) are obtained from height-time plots. The heights of the leading features of CMEs are determined manually from running difference images. Coronagraphs record 2-dimensional images of the optically-thin CMEs which means that they are observed as projected onto the plane-of-the-sky. This makes it practically impossible to determine the true properties of CMEs and therefore makes it more difficult to forecast their geoeffectiveness. In many scientific studies the impact of projection effect is overlooked. For example, the high accuracy of the CME kinematics are extremely important for considerations of interacting CMEs (*e.g.*, Gopalswamy et al., 2002; Temmer et al., 2012) or their arrival time (*e.g.*, Odstrcil et al., 2005; Vršnak et al., 2013). Some aspects of the projection effect were discussed just before SOHO era by Hundhausen (1993) and

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Hundhausen et al. (1994). Gopalswamy et al. (2000) demonstrated a definite correlation between the longitude of the source location and speed of CMEs confirming the existence of a significant projection effect in the LASCO images. This was also proved by comparison of properties of limb events (having source location at the solar limb) with these obtained from a general population of CMEs (*e.g.* Burkepile et al., 2004). There were a few attempts to estimate the projection effect based on the width of CMEs (Sheeley et al., 1999; Leblanc and Dulk, 2000) or type III radio bursts associated with CMEs (Michalek et al., 2005). Various cone models (*e.g.*, Zhao et al., 2002; Michalek et al., 2003; Xie et al., 2004; Xue et al., 2005; Michalek, 2006; Zhao, 2008) were developed to estimate the real parameters of halo or partial halo CMEs. It was found that the corrected values of CME parameters can significantly differ from the projected measurements, especially for halo events originating from the disk center. Since the successful launch of the *Solar Terrestrial Relations Observatory* (STEREO, Kaiser et al., 2008) in 2006 we have a unique opportunity to observe the solar corona from two additional directions. Based on multiple-point observations and different assumptions various models to correct the basic attributes of CMEs were developed such as graduated cylindrical shell model (Thernisien et al., 2006, 2009; Thernisien, 2011), triangulation methods (*e.g.*, Temmer et al., 2009; Lugaz et al., 2009, 2010; Liu et al., 2010), mask fitting methods (Feng et al., 2013), geometric localisation (de Koning et al., 2009), and local correlation tracking plus triangulation (Mierla et al., 2010). The accuracy and difference of some models have been compared and discussed by Lugaz et al. (2010) and Feng et al. (2013). These studies mostly have been concentrated only on wide and fast CMEs. However, energetic events represent only few percent of all events included in the SOHO/LASCO catalog. In this paper, we attempt to correct the basic attributes of CMEs, included in the SOHO/LASCO catalog, for the projection effect using quadrature STEREO observations. These observations provide a unique opportunity to evaluate the projection effect for all kinds of CMEs. Without any assumptions or models this approach enables us to the direct determination of the true parameters of CMEs, especially those originating from the disk center.

To evaluate the projection effect we compared the basic attributes of CMEs recorded simultaneously by SOHO/LASCO and STEREO/SECCHI coronagraphs. This paper is organized as follows. The data and method used for the study are described in Section 2. In Section 3, we present results of our study. Finally, conclusions and discussions are presented in Section 4.

2. Method and data

The aim of the study is to evaluate the impact of the projection effect on the basic attributes of CMEs included in the SOHO/LASCO catalog. For this purpose, observations from the two separate STEREO coronagraphs are employed. This method must be used carefully due to two important concerns. In the study we use data from different coronagraphs having distinct technical properties. Furthermore, we compare data from the two CME catalogues (CMEs identified by manual (SOHO/LASCO) and automatic computer aided CME tracking (CACTus) methods) which use other analytical approaches. To use this technique it is necessary to demonstrate that the two catalogs nearly perfectly overlap. Yashiro et al. (2008) shown that, in Solar Cycle 23, properties of CMEs identified by manual (SOHO/LASCO) and automatic (CACTus) methods are consistent for wide events (width $> 120°$). Unfortunately, for narrow CMEs (width $< 30°$) this coherence disappears. The differences were very significant during the unusual last minimum of solar activity. However, after this period of time, during the rising phase of Solar Cycle 24, this disagreement between the catalogs vanished. Petrie (2015) analyzed three databases (SOHO/LASCO, CACTus, SEED (solar eruption event detection system)). The study shown (Figs. 1, 2, 3, 4, 8, 9, 11) that during the rising phase of Solar Cycle 24 (2010–2012) SOHO/LASCO and CACTus databases almost perfectly overlap. The same result has been recently obtained by Hess and Colaninno (2017). They demonstrated that all considered automatic CME detection techniques, applied for LASCO and SECCHI observations, give the same detection rate and properties of CMEs only during the rising phase of Solar Cycle 24 (2009–2012, Fig. 1, Hess and Colaninno, 2017). This indicates that the rising phase of Solar Cycle 24 is an exceptional period, over the last two solar activity cycles, when all the detection methods are coherent. This coherence resulted due to the specific structure of magnetic field generated on the Sun and condition of the interplanetary medium after the significant last solar minimum (Petrie, 2015; Gopalswamy et al., 2015). Additionally, small differences between catalogs can be neglected since the basic attributes of CMEs included in the SOHO/LASCO catalog are subject to random errors introduced by subjective nature of manual measurements. Our recent study (Michalek et al., 2017) has demonstrated that the mean value of velocity relative errors, due to manual measurements, are about 5% of the velocity itself. All of these argument allow us to employ the different databases to estimate projection effects of CMEs included in the SOHO/LASCO database. It is important to note that this technique has been successfully applied for determination of visibility function of LASCO coronagraphs (Bronarska et al., 2017).

To achieve expected result, we compiled a list of CMEs observed by both satellites. We concentrated on the period of June 2011–October 2011 since at this time the STEREO spacecrafts were found in quadrature with respect to the Earth. Additionally during this period of time, after the unusual minimum of solar activity, a significant rise in the number of events was reported. This is essential for a statistical study. The configurations of the STEREO spacecrafts enable us to observe, without projection effects,