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Properties and relationship between solar eruptive flares and Coronal Mass Ejections during rising phase of Solar Cycles 23 and 24

M. Syed Ibrahim [a,*], A. Shanmugaraju [a], Y.-J. Moon [b], B. Vrsnak [c], S. Umapathy [d]

[a] Department of Physics, Arul Anandhar College, Karumathur 625514, Madurai, India
[b] School of Space Research, Kyung Hee University, Yongin 446-701, Republic of Korea
[c] Faculty of Geodesy, Hvar Observatory, Zagreb, Croatia
[d] Department of Science & Humanities, Rathinam Institute of Technology, Coimbatore, India

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Abstract

Statistical relationship between major flares and the associated CMEs during rising phases of Solar Cycles 23 and 24 are studied. Totally more than 6000 and 10,000 CMEs were observed by SOHO/LASCO (Solar and Heliospheric Observatory/Large Angle Spectrometric Coronagraph) during 23rd [May 1996–June 2002] and 24th [December 2008–December 2014] solar cycles, respectively. In particular, we studied the relationship between properties of flares and CMEs using the limb events (longitude 70–85°) to avoid projection effects of CMEs and partial occultation of flares that occurred near 90°. After selecting a sample of limb flares, we used certain spatial and temporal constraints to find the flare-CME pairs. Using these constraints, we compiled 129 events in Solar Cycle 23 and 92 events in Solar Cycle 24. We compared the flare-CME relationship in the two solar cycles and no significant differences are found between the two cycles. We only found out that the CME mean width was slightly larger and the CME mean acceleration was slightly higher in cycle 24, and that there was somewhat a better relation between flare flux and CME deceleration in cycle 24 than in cycle 23.

Keywords: Coronal Mass Ejection (CME); Flare

1. Introduction

Coronal mass ejections (CMEs) are powerful solar eruptive events that launch large amounts of plasma and magnetic flux from the solar atmosphere into the heliosphere (e.g., Manoharan et al., 2004; Manoharan, 2006). These sudden "explosions" are frequently associated with sudden enhancements of the emission in the H-alpha, radio, EUV, and X-ray wavelengths, called solar flares (Joshi et al., 2007, 2009, 2011, 2012). On the other hand, a significant fraction of flares is not associated with CMEs; typically the association rate increases with the intensity of flares (Gosling et al., 1976; MacQueen and Fisher, 1983; Harrison, 1995; Sheeley et al., 1999; Andrews and Howard, 2001). The most powerful events usually occur in regions of strong complex magnetic field that becomes unstable and erupts violently into the interplanetary medium, resulting also in rapid heating of chromospheric and coronal plasma (Kahler, 1992). Zhang et al. (2001), Zhang and Dere (2006) and Shanmugaraju et al. (2003), Vrsnak et al. (2004) and Maricic et al. (2007) reported the coincidence between the main acceleration stage of CMEs and flare impulsive phase, whereas Vrsnak et al. (2007) found that, statistically, the magnitude of CME

* Corresponding author.
E-mail addresses: pgphysicsibrahim@gmail.com (M. Syed Ibrahim), ashanmugaraju@gmail.com (A. Shanmugaraju), moonyj@khu.ac.kr (Y.-J. Moon), bvrsnak@gmail.com (B. Vrsnak), umapathymku@gmail.com (S. Umapathy).

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acceleration depends on the impulsiveness of the associated solar flare.

The relationship between CMEs and flares was investigated by many authors in the past (e.g. Munro et al., 1979; Kahler, 1992; Harrison, 1995; Hundhausen, 1997) up to present days (Mahrous et al., 2009; Jain et al., 2010; Youssef, 2012; Salas-Matamoros and Klein, 2015, and references therein). Mahrous et al. (2009) analysed the flare-CME association during the Solar Cycle 23. Initially, they took 224 flare-CME events and found correlation between the CME energy and flare flux, characterized by a correlation coefficient of $R = 0.52$. After that they reduced the sample to 55 flare-CME events that satisfied a temporal constraint, which increased the correlation coefficient to $R = 0.61$. Finally, they took only 41 flare-CME pairs that satisfied the spatial and temporal conditions, and the correlation increased up to 76%. Using a set of 26 events in cycle 23, Jain et al. (2010) studied the relationship between the velocity of CMEs and the plasma temperature of the associated X-ray solar flares and found a positive correlation between the CME velocity and plasma temperature, characterized by a correlation coefficient of $R = 0.82$.

Youssef (2012) examined the relationship between the CMEs and flares during the period of 1996–2010. Initially, a set of 776 flare-CME events was studied and a correlation of $R = 0.38$ between flare flux and CME energy was found. After using the temporal and spatial constraints, the correlation coefficient increased up to $R = 0.65$. Salas-Matamoros and Klein (2015) found the relationship between the CME and flares using a set of 77 flare-CME pairs observed in the period 1996–2008. They excluded events with the central position angle below $\pm 60°$, limited the CME width to the range 60–120° and excluded CMEs with speeds below 100 km/s. They found a correlation between the CME speed and the soft X-ray flux and fluence of the associated flares, characterized by $R = 0.48$ for flare flux and 0.58 for fluence. They also performed the analysis separately for three types of flares, considering the flare time profiles: (i) simple bursts showing a single peak, (ii) events constituted of a superposition of two different soft X-ray bursts and (iii) a bursts characterized by a very complex time profile.

Shanmugaraju et al. (2011) compared the relationship between physical properties of CMEs and flares associated with type II radio bursts with those without type II bursts. They analysed a sample of 290 events during the period January 1997 to December 2000. In this study, a better CME-flare relationship was found for the events associated with type II bursts. Bak-Steslicka et al. (2013) investigated 24 CME-associated long-duration flares and found a positive correlation between the CME speed and the flare flux of $R = 0.77$.

Thus, the flare-CME relationship is not completely, since the results depend very much on the applied the selection criteria and the employed statistical procedure. Furthermore, the difference between Solar Cycles 23 and 24 has been recently noted by Gopalswamy et al. (2015a). They reported that although the sunspot number in cycle 24 has dropped by ~40%; the number of halo CMEs in cycle 24 was nearly the same as in cycle 23. They also found that the distribution of halo-CME source locations is different in the cycle 24. Prasanna Subramanian and Shanmugaraju (2016) examined intense flares (>M5.0 class) in cycle 24 and reported that the number of intense flares reduced by ~34% from that in cycle 23. Hence, a comparison of the flare-CME relationship in cycles 23 and 24 is an important objective to be studied.

In this paper, we compared the basic properties of CMEs and flares, and the characteristics of the flare-CME relationship during the rising phase of these two solar cycles. We focus on limb events that originated in regions 70–85° from the disc centre. We analyse a sample of 129 flare-CME pairs observed in Solar Cycle 23 and 92 flare-CME pairs from Solar Cycle 24, using these two samples, we study characteristics and relationships between CMEs and flares to investigate possible differences between Solar Cycles 23 and 24, considering all events, as well as M + X class flares separately. The number of M + X events was 40 and 31 in Solar Cycles 23 and 24, respectively. Data analysis is presented in Section 2, and results and discussion are presented in Section 3. Conclusions are drawn in Section 4.

2. Data analysis

During the rising phase of Solar Cycles 23 [1996 (May)–2002 (June)] and 24 [2008 (December)–2014 (December)], more than 6000 and 10,000 CMEs was observed by SOHO/LASCO (Solar and Heliospheric Observatory/Large Angle Spectrometric Coronagraph) spacecraft. We selected the events observed during the period of 73 months (as considered by Gopalswamy et al., 2015b) to investigate the limb flares and CMEs. Within 73 months, data for 4 months are excluded because of missing SOHO/LASCO data. The CME data are taken from the SOHO/LASCO online catalogue of CMEs (http://cdaw.gsfc.nasa.gov/CME_list/index.html). The soft X-ray (SXR) flare burst data are gathered from Geostationary Environmental satellite (GOES) (http://www.ngdc.noaa.gov/stp/space-weather/solar-data/solar-features/solar-flares/x-rays/goes/xrs/). From the complete sample of events, we selected limb events, located within 70–85° from the disc centre, since the projection effect on the properties of limb CMEs is significantly reduced compared to the on-disc events. We excluded the events that occurred beyond 85° to avoid the events too close to the limb, carrying the risk that some are partly occulted and their SXR flux being reduced. From the complete list of events, we associate the flares and CMEs using several temporal and spatial constraints. First, the time difference between the flare start and CME onset was constrained to a time window of ± 90 min. Here, CME onset means the initiation time of the CME, i.e., the back-extrapolated onset time based on the LASCO C2