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Solar proton event's production in relation to the associated coronal mass ejections

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Abstract

In this work a study of the main properties of all detected coronal mass ejections (CMEs) from the Solar and Heliospheric Observatory (SOHO) mission from January 2006 until December 2008 as well as their association with the connected solar proton enhancements is performed. The primary findings of this study are that the coronal mass ejections escaping from the Sun vary in the same way as the sunspot number only during the rising phase of the solar cycle 23, while in the maximum and the declining phase of this cycle they present large fluctuations and secondly that these ejections seem to be well connected with SXR flares with importance >M4 (correlation coefficient r=0.7). The probability of detection of a solar proton enhancement with flux >0.1pfu at energy>10MeV at the Earth's orbit before or after the associated coronal mass ejections with respect to different properties such as their linear speed and kinetic energy, is also estimated giving interesting results for Space Weather applications.

Data selection

In this work the analysis concerns the time period from January 1996 until December 2008 and is based on :

a) **13985** coronal mass ejections as registered by the telescopes C1 and C2 of Large Angle and Spectrometric Coronograph on board the Solar and Heliospheric Observatory (SOHO) mission (http://cdaw.gsfc.nasa.gov/CME_list)

b) **23435** soft X-Ray measurements as listed in NOAA website (http://www.ngdc.noaa.gov/stp/SOLAR/ftpsolarflares.htl#Xray) and 8178 sunspot number and

c) **368** solar proton enhancements having energy >10MeV and flux >0.1pfu from the updated database provided by Belov et al. (2005).

Data Processing includes

-Calculation of data gaps in time scale of hours.
-Correction of yearly and monthly CMEs according to data gaps.
-Separation of CMEs according to their linear speed, their width and their kinetic energy during the rising and the declining phase of the solar cycle 23.
-Correlative analysis of all datasets.

Coronal Mass Ejections and Solar Proton Enhancements during solar cycle 23

In spite of existing controversies in the treating of the main SEP sources, it is now accepted that major SEPs seen at Earth are associated with CMEs. The investigation of the behavior of CMEs during the different phases of solar cycle 23 is presented in Fig 1. The monthly corrected number of CMEs seems to be well connected with monthly number of sunspots during the ascending phase of solar cycle 23, while large fluctuations appear in the maximum and descending phase.

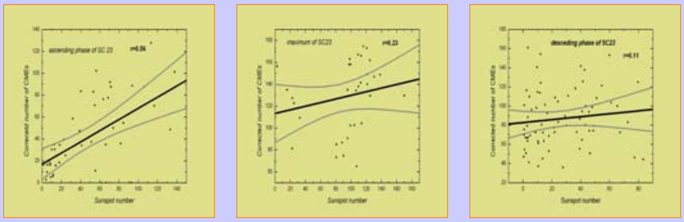


Fig. 1 Scatter plot of monthly corrected number of CMEs versus sunspot number for the ascending (left panel), maximum (center panel) and descending phase of the solar cycle 23.

Correlation coefficient for the great majority of CMEs having linear speed 300 – 600 km/sec		
	R	**SD**
Ascending phase	0.62	14.00
Max phase	0.28	7.80
Descending phase	0.33	12.22

Coronal Mass Ejections and SXR flares

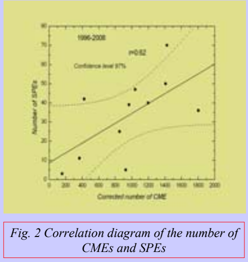


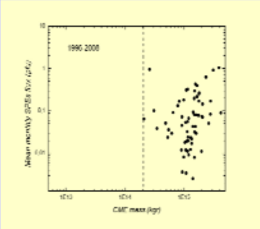
Fig. 2 Correlation diagram of the number of CMEs and SPEs

It is known from previous works that SPEs are well related with SXR flares >M4.

CMEs and SPEs seem to be strongly correlated since the correlation coefficient is high (r=0.62).

As a result CMEs and SXR flares >M4 are well related and the correlation coefficient reaches the value 0.7.

Coronal Mass Ejections and Solar Proton Events



It is obvious from our analysis that CMEs with mass less than $2\cdot10^{14}$ kg can not be considered as sources of SPEs. (Gopalswamy, 2006)

Fig. 3 Scatter plot of SPEs mean flux in relation to CMEs mean mass on monthly basis.

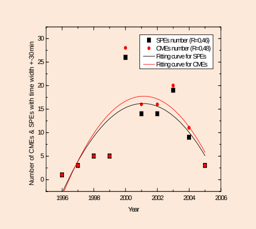


Fig. 4 Yearly distribution of CMEs and associated SPEs in the time width ± 30min.

It is resulted that CMEs with linear speed in the interval 600-899 km/sec have the maximum probability to follow or to be followed by a SPE within ±30min. (Belov et al., 2007)

CMEs with mean kinetic energy almost $1.17\cdot10^{31}$ erg have the maximum probability to follow or to be followed by a SPE within ±30min.

The yearly number of CMEs is greater than the yearly number of SPEs due to the fact that more than one CME seem to be associated with one SPE with time width ±30min.

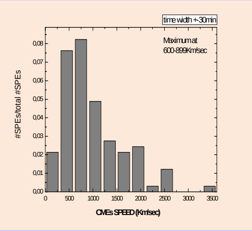


Fig. 5 Distribution of SPEs number according to associated CMEs' linear speed, with which they are connected in time width ± 30min.

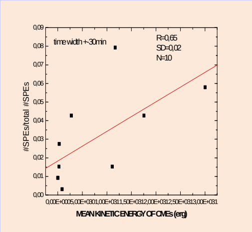


Fig. 6 Scatter plot of the ratio SPEs number associated with CMEs to the total SPEs number versus the mean kinetic energy of time connected CMEs in time width ±30min.

Conclusions

►Coronal mass ejections escaping from the Sun vary in the same way as the sunspot number only during the rising phase of solar cycle 23. On the contrary CMEs have large fluctuations in the maximum and declining phase of solar cycle.

► CMEs seem to be well related to SXR flares with importance >M4 since the correlation coefficient is 0.7. This result is important because as it is known from previous work the solar proton events are well associated with SXR flares >M4 (Belov et al., 2005).

►The yearly number of CMEs is greater than the yearly number of SPEs due to the fact that more than one CMEs seem to be associated with one SPE with time width ±30min.

►CMEs with mean mass less than $2\cdot10^{14}$ kg can not be considered as sources of SPEs .

►CMEs with linear speed in the interval 600-899 km/sec have the maximum probability to follow or to be followed by a SPE within ± 30min.

►CMEs with mean kinetic energy almost $1.17\cdot10^{31}$ erg have the maximum probability to follow or to be followed by a SPE within ± 30min.

► The calculated time delay between the detection of CMEs and the onset time of the proton flares reveals a pronounced maximum of this time delay from 0 to 0.5 hours.

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