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Relation between Solar Flares, Halo and Partial Halo Coronal Mass Ejections and Solar Energetic Particle Events

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ABSTRACT:

Two very important active events from Sun are the solar flares and Coronal Mass Ejections (CMEs), particularly in the context of Solar Energetic Particle (SEP) events. It is widely believed that the flares and CMEs play a vital role in producing the SEPs. The studies on flares, CMEs, SEPs and particularly the relation or association between them is a very active subject for academicians in the field. Arguments in favour of association and otherwise still continue.

The study of any association involves in relating the parameters of the events. Flare intensity/ class and duration are two important parameters of the flares. Linear speed and angular width are two parameters of the CMEs. With the idea to find the relation with SEPs, Halo and Partial Halo CMEs are considered for this study as they are directed towards Earth and are likely to be involved with SEPs reaching Earth. Using the parameters of the flares, the CMEs and the relative timing between them some qualifiers are derived. Using these qualifiers, control events are generated. A control event is a pair of qualified flare and CME. Analysis is done on whether these control events lead to an SEP or not in a given span of time. Depending on the ratio of control events leading to the SEPs to that of total control events impact factors for each contributing parameter are derived. Finally, the relation between the SEP proton flux with respect to the two major parameters with high impact factor is studied.

KEYWORDS: Solar flare, Halo Coronal Mass Ejection (CME), Partial Halo CME, Solar Energetic Particle (SEP) event; Solar Proton Event (SPE).

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INTRODUCTION

Several studies indicate the role of solar flares and interplanetary shock waves due to CMEs in producing SEPs. Sun is an efficient particle accelerator and hence governs the energetic particles in the solar system. SEPs with energies from few 10s of keV to few GeV are accelerated near the Sun. They are classified into two different types of events (i) impulsive events and (ii) gradual events. The acceleration of electrons and charged nuclei to high energies is a phenomenon occurring at many astrophysical sites throughout the universe. In the heliosphere, processes in the solar corona associated with flares and coronal mass ejections (CMEs) are the most energetic natural particle accelerators, sometimes accelerating electrons and ions to relativistic energies (Droge 2003)[1].The gradual SEP events cause high risk to the health of humans in space and in future colonies of humans on other planets within the solar system since they accompany very high energies (> 10s of MeV). They are also hazardous to spacecraft. The understanding of this gradual SEP events can be found in (Desai and Geacalone)[2].

The correlation between SEP peak intensities and speed of CMEs was carried out earlier by Kahler (2001)[3]. He observed that the peak intensity of an SEP event observed at 1 AU depends on several factors, one of which is the speed of the CME driving the interplanetary shock. After studying the properties of solar x-ray flares and proton events Belov (2009)[4]stated that inside of complexes of the solar sporadic phenomena there is a steady enough proportionality between energies released in the soft X-ray radiation and in the high energy protons. A statistical analysis and a mapping of the logarithm of the proton peak flux at E > 10 MeV, on different pairs of the parent solar source characteristics was performed by Athanasios Papaioannou et al[5]. This analysis revealed correlations in 3-D space and demonstrated that the gradual SEP events that stem from the central part of the visible solar disk constitute a significant radiation risk. The velocity of the associated CMEs, as well as the SXR peak flux and fluence, are all fairly significantly correlated to both the proton peak flux and the fluence of the SEP events. The strongest correlation to SEP characteristics is manifested by the CME velocity. A statistical analysis of the relationship between SEPs, and properties of solar flares and CMEs, during Solar Cycle 23, is presented by Dierckxsens et al[6]. SEP events are selected which are associated with solar flares originating on the visible hemisphere of the Sun and at least of magnitude M1. They observed a strong rise in both the probability of SEP occurrence and mean proton peak fluxes with increasing flare intensities. The analysis showed that the probability for SEP occurrence grows significantly when the flare occurs more towards the western side of the Sun, while the proton peak fluxes show almost no correlation with. Several studies have already investigated the dependence of SEP probabilities and peak fluxes on multiple solar parameters, but were limited to a few combinations of two parameters or derived the dependence on one variable in the specific range of another parameter.

The study of the relation involving the parameters of all events is important to understand the physics behind them. Flare intensity/ class and duration are two important parameters of the flares. Linear speed and angular width are two parameters of the CMEs. X-ray flares are considered in this study and the flare classes are as per the notation followed for x-ray flares. Halo and Partial Halo CMEs are considered for this study as they are directed towards Earth and are likely to be involved with SEPs reaching Earth. Using the parameters of the flares, the CMEs, and the relative timing between them, some qualifiers are derived by stipulating the limits on these parameters. The qualifier limits are arrived by means of a preliminary study. Control events, in terms of pairs of a flare and a CME that satisfy the qualifier criteria, are generated. Analysis is carried out to find whether these control events lead to an SEP or not in a given span of time. Depending on the ratio of control events leading to the SEPs to that of total control events 'Impact factor' for each contributing parameter is derived. Finally, the relation between the SEP proton flux with respect to the two major parameters with high impact factor is studied. The analysis presented in this paper is statistical in nature. Data from various sources for the period from 1st January 2002 to 2nd January 2016 is used. This represents a fair amount of data base for meaningful statistical results.

SOURCES OF DATA

Solar flare data

Solar flare data is as measured in the soft x-ray region, taken from the yearly catalogs generated using X-ray Sensor (XRS)[7] on GOES satellites. The catalogs are compiled and archived by National Centers for Environmental Information (NCEI, formerly NGDC) of National Oceanic and Atmospheric Administration (NOAA), Department of Commerce[8]. This catalog gives information on date and time corresponding to the start, peak and end times of the flare as well as the class of the flare.

CME data

The CME data is obtained from the catalog containing all CMEs manually identified since 1996 from the Large Angle and Spectrometric Coronagraph (LASCO) on board the Solar and Heliospheric Observatory (SOHO) mission[9]. The CME Catalog derived from LASCO coronagraph on SOHO is used from CDAW Data Center by NASA and the Catholic University of America in cooperation with the Naval Research Laboratory. SOHO is a project of international cooperation between ESA and NASA. Data from this catalog is extracted from the year 1996 to March 2017. The catalog gives information on date and time of occurrence of CME in the Field of View of LASCO, the Central Position Angle (CPA), sky plane width of the CME, Linear Speed (LS), acceleration, mass, kinetic energy etc. CMEs of an apparent width of 360^o are marked as 'Halo' in the CPA. Partial Halo CMEs have a minimum angular width of 120^o.

SEP data

The SEP event data is obtained from SWPC of NOAA[10]. This data contains, apart from other details, a list of SEP events with the starting time of the event, time at which the maximum proton flux occurred and the maximum proton flux. The Proton fluxes are integral 5-minute averages for energies > 10 MeV, given in Particle Flux Units (pfu), measured by GOES spacecraft at Geosynchronous orbit (near 1 AU): 1 pfu = 1 p/sq. cm-s-sr.

Data summary

The summary of the data from all the sources is shown in table 1. It showsthe available entries from the three catalogs.

Table 1 Entries available from the Flare, CME and SEP catalogs

Period	01-01-2002 to 02-01-2016
Total number of flares	23,660
Total number of CMEs	21,445
Number of Halo CMEs	502
Number of Partial Halo CMEs	1351
Number of SEPs	78

The distribution of the flares in terms of numbers w.r.t. the flare class is shown in figure 1. The class of the flare is as defined by their intensity in the soft x-ray. This is useful for understanding how each class of the flare, in terms of quantity, is related to SEP events.

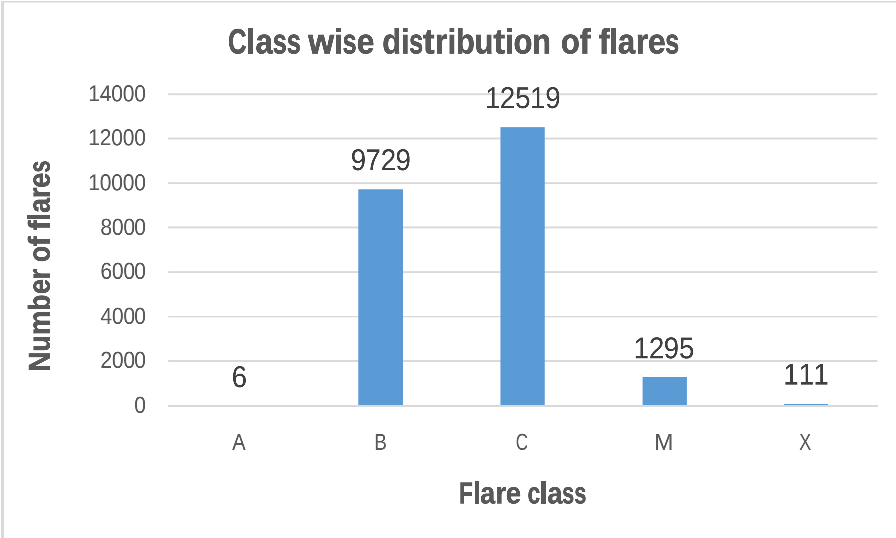


Figure 1 Distribution of flares w.r.t. the class of the flare

ANALYSIS

To establish the relation between flares and CMEs that eventually are expected to result in the occurrence of an SEP, time nearness between the two events is applied. Time nearness criteria for this study is set as

|Time of occurrence of Halo CME - Time of flare peak| < 2 hours.

Time of occurrence of CME is the observed time in the field of view of the LASCO instrument. All the Halo and Partial Halo CMEs are categorized into three groups depending on their occurrence w.r.t. the flare.

Group 1: CME occurred during (between start and end of) the flare and CME occurrence time is prior to flare peak time.

Group 2: CME occurred during (between start and end of) the flare and CME occurrence time is later to flare peak time.

Group 3: CME occurred after the end of the flare.

With the application of this time criteria the number of Halo CMES got reduced to 308 from 502 and the number of Partial Halo CMEs got reduced to 658 from 1351.

Setting qualifiers

As it is observed that the CMEs with Linear speeds less than 650 km/s are not associated with any SEPs another qualifier is defined, in terms of the CME Linear Speed, as

Linear Speed of the CME > 650 km/sec

With this qualifying criteria the number of Halo CMEs got reduced to 258 and the Partial Halo CMEs got reduced to 299. Applying another qualifier in terms of the flare duration defined as the flare duration > 10 minutes reduced the Halo CMEs to 245 and Partial Halo CMEs to 273.

With the idea of narrowing down the association between flares, CMEs and SEPs some “Qualifiers” are set. The qualifiers are carefully selected so that they do not have much impact on leaving out some of the SEPs from this relational study. The qualifier details are given in table 2.

Table 2 The qualifiers and their limits

Qualifier	Limit
CME Linear Speed (km/s)	> 650
CME Angular width (deg.)	> 120
Flare duration (minutes)	> 10
Class of flare	≥ C1
Time delay between CME and Flare	± 2 hours
Time delay between SEP and CME	< 4 days

Control events

Satisfying the qualifying criteria mentioned above, the “Control Events” are identified. A control event is a valid pair of a flare and a CME. This valid pair may or may not be associated in resulting in an SEP occurrence. If the control event results in an SEP it is tagged as “True” and otherwise it is tagged as “False”. In preparing the pairs some of the flares have two or more CMEs paired with them as they have occurred within set limit of ± 2 hours. The result is that the number of CMEs is equal to the control events, whereas the number of flares is slightly less than the number of control events. Table 3 gives the number of control events in each category.

Table 3 Control events

	True	False	Total
Number of control events	130	306	436
Number of Halo CMES	90	129	219
Number of Partial Halo CMES	40	177	217
Percentage (Total control events)	30	70	
Number of flares	128	302	430

Association of SEPs with control events

Out of the total 78 SEPs during the period under consideration 72 are found to be associated with the control events. 130 control events are found to lead to the occurrence of 72 SEP events. The number of control events are more than the SEP events. The reason is that, within the set four day limit between the occurrence of the CME of the control event and the occurrence of SEP, more than one control event occurred in some cases. Number of SEPs associated and that are not associated are given in table 4.

Table 4 SEP association with control events

	Number	Percentage
Total number of SEPs	78	
Number of SEPs associated with control events	72	92.31
Number of SEPs not associated with control events	6	7.69

Distribution of control events

It is evident from table 3 that 70% of the control events are false indicating no association with SEPs. One would like to explore what are the parameters contributing to this observed non-association. The parameters selected for this study are the ‘linear speed’ and the ‘angular width’ of the CMEs, ‘flare class’ and ‘duration’ of the flares, and the time delay between the flare and the CME.

With CME linear speed

The linear speed of the CMEs that are part of all the control events, vary from 650 km/s to more than 2150 km/s. This total range of speeds is divided into five segments.

Table 5: Distribution of control events w.r.t. Linear speed

Linear Speed (km/s)	TRUE	FALSE	True %
650-900	22	165	12
900-1150	27	63	30
1150-1650	36	55	40
1650-2150	30	21	59
> 2150	15	2	88
Total	130	306	30

The number of true and false control events are marked under each segment as shown in table 5 and graphically represented in figure 2.Percentage of true control events is defined as the ratio of true events to the total events expressed as percentage.

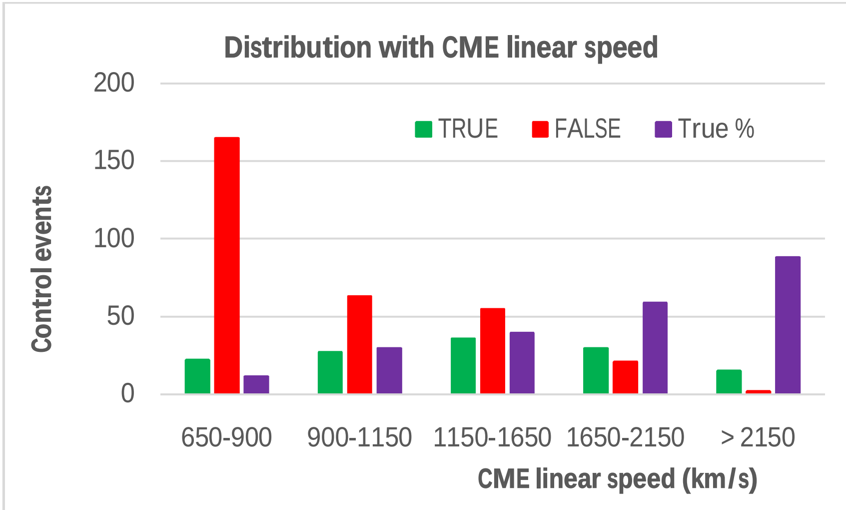


Figure 2 Distribution of control events with CME linear speed

The true percentage drastically increases with the linear speed. At speeds in the range of 650-900 km/sec the percentage is abnormally small (only 12%). At speeds higher than 2150 km/s the true percentage shoots up to 88%. This indicates that the linear speed of the CME plays an important role in the association SEPs with the control events.

With angular width

Angular width of the CME is another parameter as measured by the LASCO instrument. Distribution of control events w.r.t. the angular width is given in table 6.

Table 6 Distribution of control events w.r.t. Angular width

Angular Width (degrees)	True	False	True %
<120	0	0	
120-170	16	83	16
170-220	13	56	19
220-270	6	29	17
270-320	5	9	36
>320	90	129	41
Total	130	306	30

As defined in the CME catalog Halo CMEs are of angular width of 360^{o} and Partial Halo CMEs are of angular width $\geq 120^{o}$. As the CMEs selected for this study are either Halo or Partial Halo CMEs there are no control events with angular width less than 120^{0}, as seen in table 6. The impact of angular width is not as strong as in the case of linear speed, but moderate. True % variation is from 16% to 41%. For angular widths more than 320^{o} the main contribution in true % is from Halo

CMEs. This can be seen as 90 out of 130 true events are from CMEs with angular width > 320°. This also indicates Halo CMEs contribute much more compared to Partial Halo CMEs for True control events. The graphical representation of the distribution of the control events with CME angular width is given in figure 3.

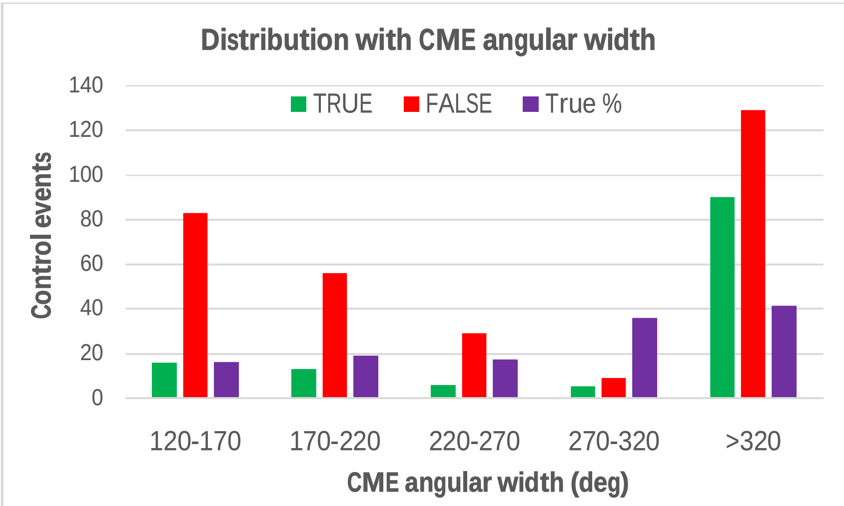


Figure 3 Distribution of control events with CME angular width

With flare class

Above two paragraphs indicate the impact of the two CME parameters called linear speed and angular width. It is necessary to study the impact of the flare parameters also. Flare class is a major parameter of the solar flare. The flare classes are C, M and X each at 10 levels on a logarithmic scale. For graphical convenience flare class is divided in to six segments and the distribution of the control events w.r.t. these six segments is shown in table 7.The flare class has a large impact on the true % of control events. The impact is almost as significant as in the case of CME linear speed. The true % varies from 11% to 80% for flare classes C1-C5 and X5-X10 respectively. Contribution of C1-C5 class of flares is 114 events out of a total of 302 false events. This is a large fraction and is a vital input for those who are interested in SEP prediction. The distribution of the control events with flare class, in a graphical form, is sown in figure 4.

Table 7 Distribution of control events w.r.t. flare class

Flare class	True	False	True %
C1-C5	14	114	11
C5-C10	12	55	18
M1-M5	43	85	34
M5-M10	23	26	47
X1-X5	28	20	58
X5-X10	8	2	80
Total	128	302	30

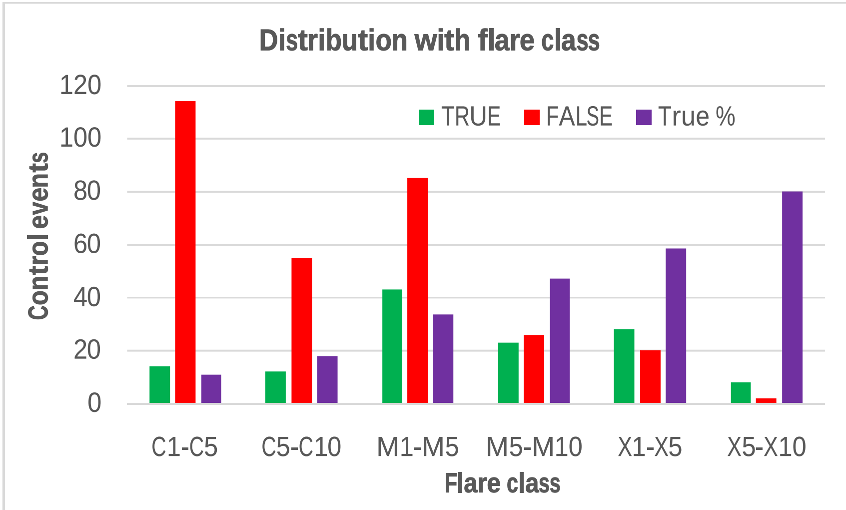


Figure 4 Distribution of control events with flare class

With flare duration

The effect of the flare duration on the distribution of control events is given in table 8. The same in graphical format is shown in figure 5. Flares of duration less than 10 minutes do not contribute to any true control events leading to SEPs. They are already eliminated while defining the qualifiers. Accordingly, the first set in the table is from 10-30 minutes duration. Flare duration has not much impact on the distribution. The true % variation is only from a minimum 25% to a maximum of 39%.

Table 8 Distribution of control events w.r.t. flare duration

Flare duration (minutes)	TRUE	FALSE	True %
>10-30	35	107	25
30-60	37	91	29
60-90	25	40	38
90-120	15	23	39
>120	16	41	28
Total	128	302	30

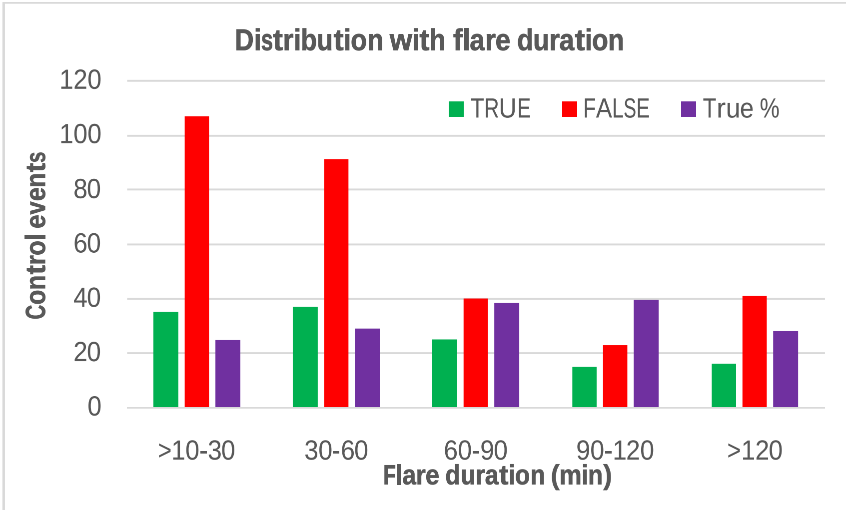


Figure 5 Distribution of control events with flare duration

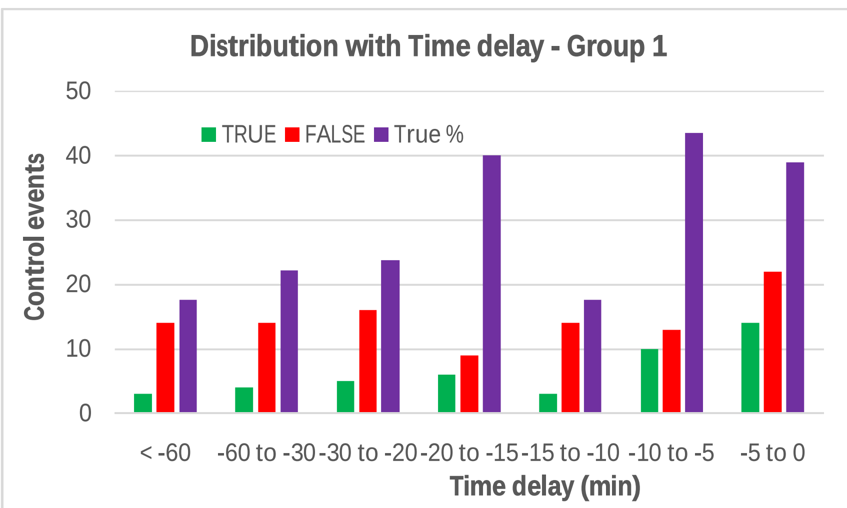
With the time difference between the flare peak and CME

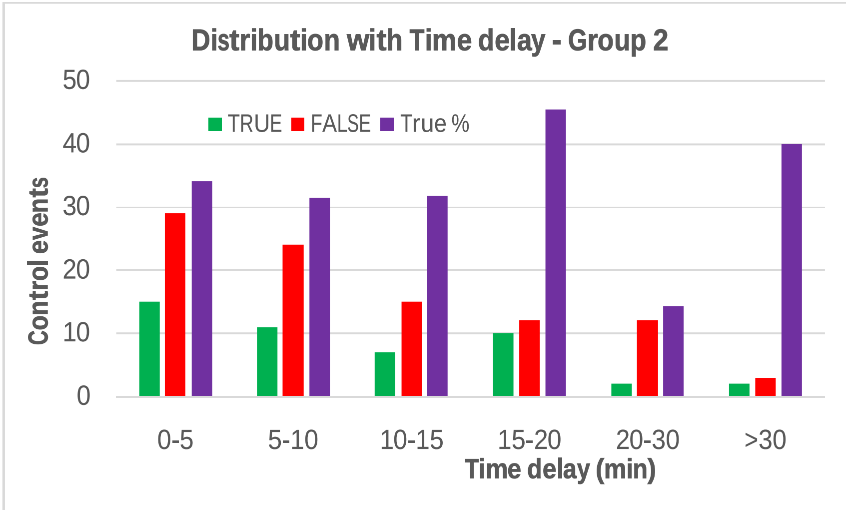
Analysis of the distribution of the control events, so far, is with respect to the individual parameters of flares and CMEs. There is a common parameter between flare and CME, that is the Time difference between the flare peak and CME occurrences. For this analysis the three groups of CMEs, as described earlier, have been considered separately. The distribution of the control events, for the three groups, is given in table 9. Time delay between the flare and the CME is positive if the CME occurred after the flare peak and is negative if the CME occurred before the flare peak. Accordingly, as per the definition of the group, the time delay values are negative for group 1 and positive for group 2 and group 3.

It is interesting to see that though the ‘qualifier’ limit for the time delay is fixed as ± 2 hours for this analysis, only 3 true events in group 1 are beyond the limit of -1 hour and 7 events in group 3 are beyond +1 hour limit. In group 3 except 2 true events all others are within a limit of 30 minutes. Total number of true and false events is almost equally distributed among the three groups. The total true% is slightly less for group 3 compared to group 1and group 2. The distribution of the control events, group wise are depicted graphically in figure 6.

Table 9 Distribution of control events w.r.t. the time difference between the flare and the CME

Time difference (minutes)	Group 1			Group 2			Group 3		
	True	False	True %	True	False	True %	True	False	True %
< -60	3	14	18						
-60 to -30	4	14	22						
-30 to -20	5	16	24						
-20 to -15	6	9	40						
-15 to -10	3	14	18						
-10 to -5	10	13	43						
-5 to 0	14	22	39						
0-5				15	29	34	0	0	0
5-10				11	24	31	4	6	40
10-15				7	15	32	2	13	13
15-20				10	12	45	7	16	30
20-30				2	12	14	12	27	31
>30				2	3	40			
30-60							6	27	18
>60							7	20	26
Total	45	102	31	47	95	33	38	109	26





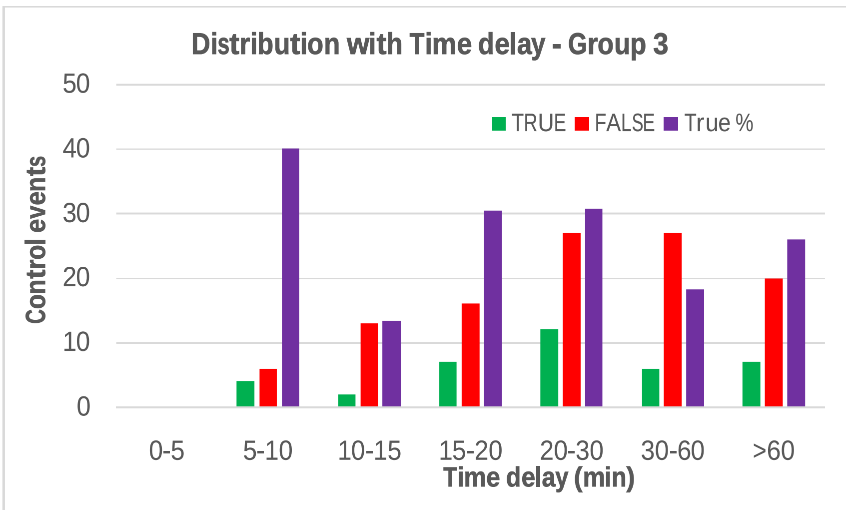


Figure 6 Distribution of control events with time difference between flare and CME

The Impact factor

It can be seen from the analysis done so far that some of the parameters of the flares and CMEs effect or 'Impact' the distribution of true and false control events to a lesser extent compared to some other parameters. In order to quantify the effect an "Impact factor" concept is brought in here. The impact factor, for each of the factors influencing the distribution, is defined as the ratio of the peak true% to the total true%. The impact factors thus calculated for each parameter are given in table 10. The list is as per the descending order of the impact factor.

Table 10 Impact factor for the parameters effecting control events distribution

Parameter	Impact factor	Normalized Impact factor
CME linear speed	2.96	1
Flare class	2.69	0.908161315
Time delay - Group3	1.55	0.522887494
Time delay – Group1	1.42	0.479945043
Angular width	1.38	0.465753425
Time delay – Group2	1.37	0.464068757
Flare duration	1.33	0.448105912

The last column in table 10 gives the 'Normalized Impact factor'. Normalization is done w.r.t. the highest impact factor of 2.96 corresponding to the parameter CME linear speed. Figure 7 is the graphical presentation of the normalized impact factor.

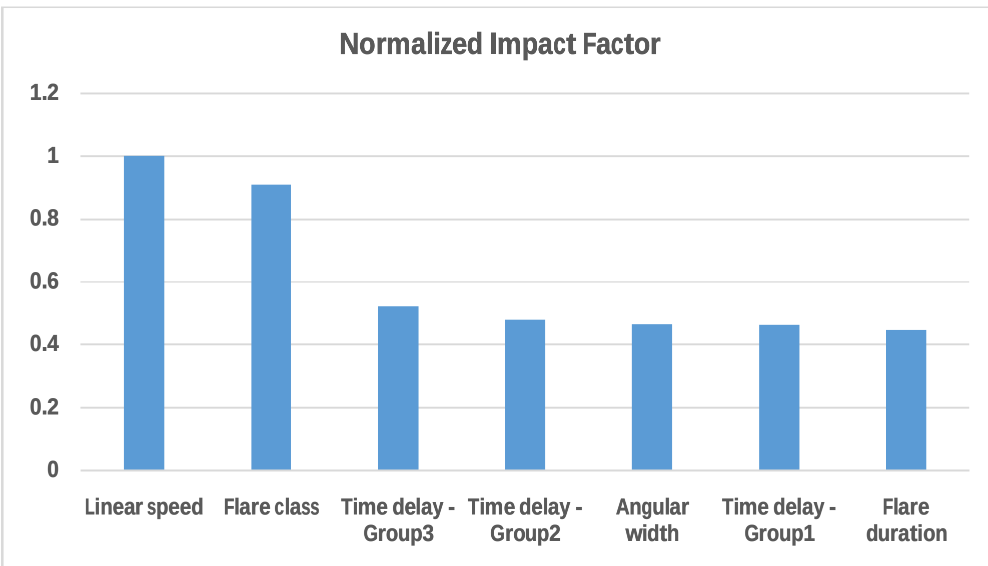


Figure 7 Normalized impact factor w.r.t. the effecting parameters

Relation between dominant parameters of SEPs, CMEs and flares

The top two parameters influencing the distribution of control events are the CME linear speed and flare class. These two parameters are selected for studying their relation with the proton flux of the associated SEP event. In some cases, more than one flare-CME pair appear to be associated with an SEP. Wherever more than one pair is associated, the one with higher value is taken for the association and the relation is studied. This is for computational convenience and believed not to effect the results. Figure 8 gives the relation between the SEP proton flux and the CME linear speed. Proton flux is on logarithmic Y scale.

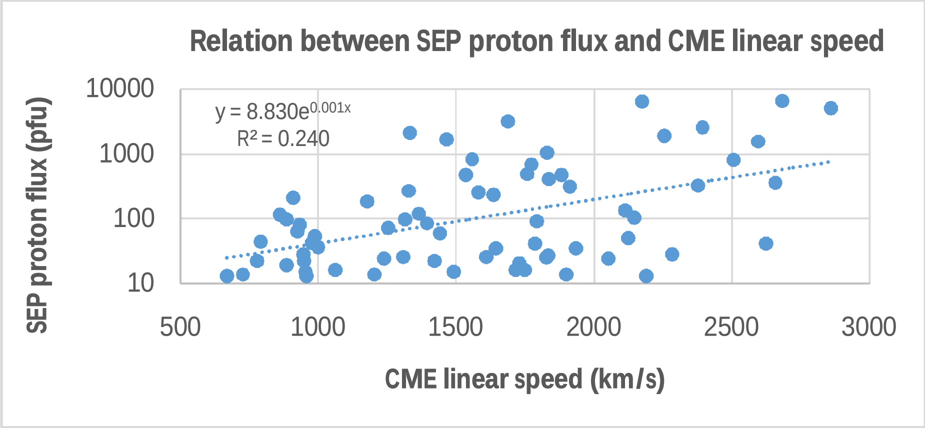


Figure 8 Relation between proton flux of SEP and linear speed of CME

The relation between the SEP proton flux and flare intensity is shown in figure 9. SEP proton flux is on logarithmic Y scale. Class of the flare is converted to intensity and the log of intensity is on the X scale. The plot represents the log-log relation between the two parameters.

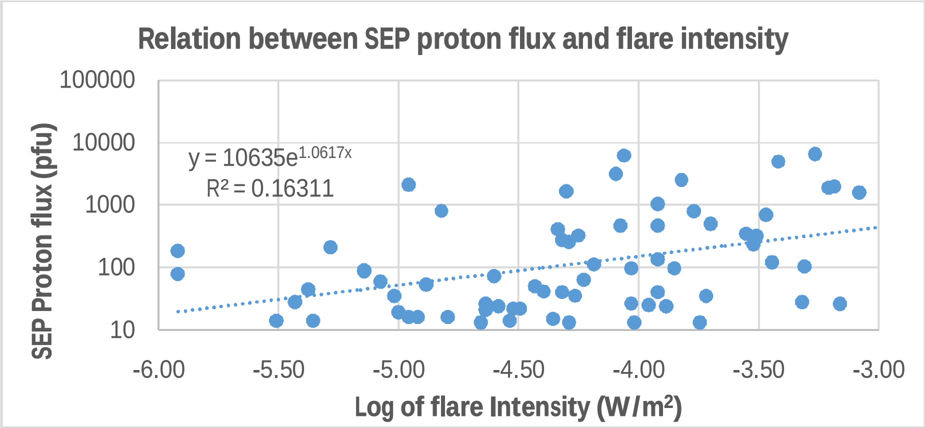


Figure 9 Relation between proton flux of SEP and flare intensity

SEP Prediction time

The SEP prediction time is defined as the difference between the time of peak SEP flux and the time of observation of the CME of the associated true control event. For analyzing the prediction times for statistical distribution all 130 control events leading to 72 SEPs are considered. The statistical distribution of the SEP prediction times is given in figure 10. The prediction times varied from a minimum of 48 minutes to a maximum of 3 days 15 hours. The mean prediction time is 32 hours 10 minutes.

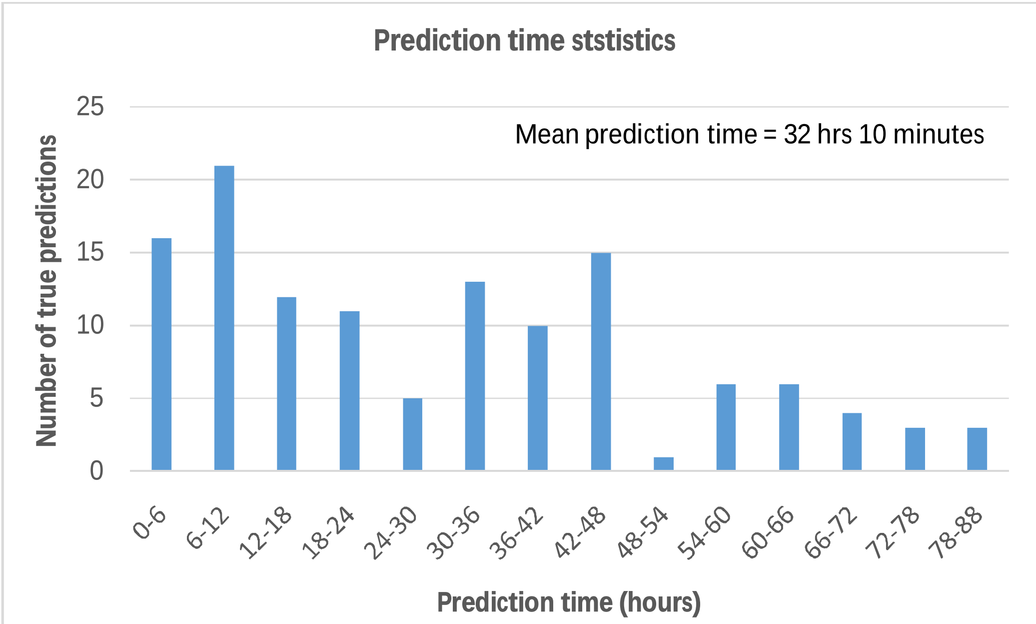


Figure 10 Distribution of SEP prediction times

RESULTS AND DISCUSSION

The study is focused on finding the relation between SEPs and, their widely believed sources of cause, solar flares and CMEs. Only Halo and Partial Halo CMEs are considered for this study as they are directed towards Earth and hence are likely to cause SEPs measured at 1 AU. The control events generation is by some sort of trials to balance between associating them with almost all SEPs on one hand, and not to have many control events labeled under 'false' on the other hand. Satisfying this criteria, a set of qualifiers are defined and the control events are generated. Out of the 78 SEP events reported during the period from 1st January 2002 to 2nd January 2016, as many as 72 events are successfully associated. This is more than 92%, probably higher than many of the current predictions in practice. Based on the control events leading to SEPs or not the control events are labeled as 'true' or 'false'. The distributions of the true and false control events with respect to flare and CME parameters are studied. These results are expected to be very useful for the community in the field of generating operational systems for predicting SEPs as much in advance as possible. For example, looking at the distribution with linear speeds, CMEs with 650-900 km/sec speed produced 22 true and 165 false events, whereas CMEs with speeds more than 2150 km/s produced 15 true and 2 false events. This fact emphasizes the CMEs association with SEPs and the impact of the CME speed in producing an SEP. In the same way flares of C1-C5 class produced 14 true events and 114 false events, whereas flares of class X5-X10 produced 8 true events and 2 false events. This fact emphasizes the association of flares with SEP and the impact of flare class on producing an SEP. The study gives the impact of other main parameters of CMEs and flares on producing SEPs. The relation between SEP proton flux, CME linear speed and flare class reveal that (i) log of the SEP proton flux is proportional to the speed of CME and (ii) that a log-log relation exists between the SEP proton flux and the Intensity of the flare. A moderate correlation exists for these two relations. Using the control events for prediction of SEPs the prediction times are computed and found to be varying between 48 minutes to 3 days 15 hours, which appear to be quite good for any ground based or space based alerts.

CONCLUSIONS

This study indicates a possibility of deriving a simple algorithm, using only X-ray flare data and CME data, for predicting SEP events. These two data are more than adequate to predict >90 % of the SEPs. Only Halo or Partial Halo CMEs are required to be considered for generating the necessary control events for SEP prediction. Flares with duration less than 10 minutes and flare class <C1 do not lead to SEP events. CMEs with linear speeds less than 650 km/s also do not lead to SEP events. A log-linear relation between the SEP proton flux and CME speed, and a log-log relation between the SEP proton flux and flare intensity exists with a moderate correlation. Probably the correlations may improve in future with more certain and accurate measurements. Another important factor, the kinetic energy of the CME, is not included in the study. This is because lack of complete data in the CME catalog for all the CME events during the period under consideration. The qualifiers are a balance between predicting as many SEPs as possible and at the same time not to have a large number of false events. For a given application these qualifiers can be changed based on compromises. This analysis is expected to provide useful inputs for the developers of simple algorithms for predicting SEP events. Future scope of this study is to develop a robust algorithm for SEP event prediction, its time duration, time of peak flux, fluence of proton flux and probably the complete time signature of the SEP.

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REFERENCES:

1 Droge. W; Acceleration and propagation of Solar Energetic Particles, In: Klein K L. (eds) energy Conversion and Particle Acceleration in the Solar Corona; Lecture notes in physics, Vol 612, Springer, Berlin, Heidelberg, DOI: 10-1007/3-540-36242-8_12

2 Desai, M., and Giacalone, J. Large Gradual Solar Energetic Particle Events, Living Rev. Sol. Phys. 13 (3), 1 – 132, 2016, DOI: 10.1007/s41116-016-0002-5

3 Kahler. S. W; The correlation between solar energetic particle peak intensities and speeds of coronal mass ejections: Effects of ambient particle intensities and energy spectra; Journal of Geophysical Research; 106(A10): 20,947-20,955

4 Belov. A; Properties of solar X-ray flares and proton event forecasting; Science Direct; Advances in Space Research 2009; 43: 467–473

5 Athanasios Papaioannou et al; Solar flares, coronal mass ejections and solar energetic particle event characteristics; J. Space Weather Space Climate; 6, A42 (2016); DOI: 10.1051/swsc/2016035

6 Dierckxsens. M; Tziotziou. K; Dalla. S; Patsou. I; Marsh. M.S; Crosby. N.B; Malandraki. O; Tsiropoula. G; Relationship between Solar Energetic Particles and Properties of Flares and CMEs: Statistical Analysis of Solar Cycle 23 Events; Solar Physics; DOI: 10.1007

7 Patricia L. Bornmann ; David Speich ; Joseph Hirman ; Lorne Matheson ; Richard Grubb; Howard A. Garcia and R. Viereck; "GOES x-ray sensor and its use in predicting solar-terrestrial disturbances", Proc. SPIE 2812, GOES-8 and Beyond, [cited 1996October 18];Available fromhttp://dx.doi.org/10.1117/12.254076; doi:10.1117/12.254076

8 https://www.ngdc.noaa.gov/stp/space-weather/solardata/solar-features/solar-flares/x-rays/goes/xrs

9 https://cdaw.gsfc.nasa.gov/CME_list

10 ftp://ftp.swpc.noaa.gov/pub/indices/ SPE.txt