Observation of coronal mass ejections in association with sun spot number and solar flares

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Abstract. The sun’s atmosphere is frequently disrupted by coronal mass ejections (CMEs) coupled with different solar happening like sun spot number (SSN), geomagnetic storms (GMS), solar energetic particle and solar flare. CMEs play the important role in the root cause of weather in earth’s space environment among all solar events. CMEs are considered as the major natural hazardous happening at the surface of sun because this event can cause several other phenomena like solar flare and many more. In this work, we report a statistical observation for the relationship of CMEs having linear speed >500 km/s with SSN and solar flares that were registered during the period 1997-2015. Test results of the annual correlation between SSN and CMEs is 0.77 and can be represented by a linear regression equation. We concluded that SSN and solar flares are well correlated with CMEs in most of the yearly compiled data for this time span.

1. Introduction

Coronal mass ejections (CMEs) consist of large structures containing plasma and magnetic fields that are expelled from the Sun into the atmosphere. They are of importance for both scientific and technological reasons. Scientifically they are of significance because they remove built-up magnetic energy and plasma from the solar corona [1] and technologically they are of significance because they are liable for the most extreme space weather effects at Earth [2] as well as at other planets and spacecraft throughout the atmosphere. Maximum ejected material comes from the low corona, although cooler and denser material probably from chromosphere or photosphere is also involved sometimes. The CMEs plasma is entrained on an expanding magnetic field, which has commonly the form of helical field lines with changing pitch angles. Up to the early years of this century, the images of CMEs had been made near the Sun firstly by coronagraphs on board spacecraft. Coronagraphs sight the outward flow of density structures flowing from the Sun by observing Thomson-scattered sunlight from the free electrons in coronal and heliospheric plasma. This outflow has an angular dependence which must be noted in the measured brightness [3-5]. CME related phenomena such as solar flares and prominences have been observed since the late 19th century, and energetic particles [6] type II and IV radio bursts [7] and interplanetary shocks [8] have been known since the 1940s, 50s and 60s.

On the positive side, there is a concord on the origination of CMEs by a loss of equilibrium of a magnetic configuration in the solar corona [9] and the conversion of magnetic energy to radiative energy and kinetic energy that accelerates the plasma cloud into the heliosphere. The magnetic reconnection process play a fundamental role ends up in a reconfiguration of the disrupted magnetic fields. Several
models have been proposed to explain the initial phase of eruption, particularly the “mass-loading model” [1] the “catastrophe model” [10] the “breakout model” [11] and the “shearing arcade model” [12], see [13] for a review. The identification and measurement of CMEs remain difficult due to their complexity and the variety of shapes [14] further complicated by their temporal evolution and the effects of viewing geometry.

Solar cycle is a key parameter in the heliospheric phenomena which takes approximately 11 years on the average. With this time, the sunspot number (SSN) starts from a minimum value and increases which marks the start of the solar cycle. Then, the SSN tends to reach a maximum value, then decreases to a minimum value again which marks the end of a solar cycle. The reason for this phenomenon is due to the continuous fluctuation of the solar magnetic field, and this credence is strongly supported by the observed fact that a sunspot maintains a strong magnetic field compared to that of the sun’s surface [15]. Sunspots are the most apparent feature on the disturbed surface of the photosphere above the solar atmosphere and appear to play a key role in major solar and terrestrial disturbances [16]. Many researchers study the occurrence of CMEs in relation to sunspot number and found that sometimes the correlation is quite weak between them during the maximum phase of solar cycle [17-18].

2. Data Sources
During the rising phase of solar cycles 23 and 24 more than thousands CMEs were observed by SOHO/LASCO (Solar and Heliospheric observatory/large angle spectrometric coronagraph) spacecraft LASCO has three telescope C1, C2, C3. Linear speed of CMEs should be equal or greater than 500km/sec. The CME data was collected from the CDAW data centre of SOHO/LASCO online catalogue of CMEs [19]. X-ray solar flare data was collected from online catalogue of GOES (geostationary environmental satellite) [20]. The SSN was extracted from NOAA National Geophysical Data Center [21] shown in table-1.

| Year | SSN  | No. of CMEs |
|------|------|-------------|
| 1997 | 249.6| 2375        |
| 1998 | 739  | 9486        |
| 1999 | 1151.8| 7488       |
| 2000 | 1479.3| 11679      |
| 2001 | 1478.9| 11921      |
| 2002 | 1313.6| 14840      |
| 2003 | 789.1 | 9226        |
| 2004 | 519.9 | 9968        |
| 2005 | 372.4 | 11512       |
| 2006 | 184  | 5582        |
| 2007 | 101.4 | 1527        |
| 2008 | 29   | 0           |
| 2009 | 33.8 | 0           |
| 2010 | 186  | 3153        |
| 2011 | 601.6| 9157        |
| 2012 | 633  | 8714        |
| 2013 | 729  | 11783       |
| 2014 | 896.4| 8963        |
| 2015 | 553.4| 10637       |
| Total| 12041.2 | 148011    |
3. Analysis Result and Discussion
In this study we find out the linear relationship of coronal mass ejections with X-ray solar flares and sunspot number. For this study we extracted CMEs data from CDAW data center [19] at angular width $360^\circ$ and having acceleration $2000 \, \text{m/s}^2$ which are associated with solar flare in the period 1997 to 2015. The relation between coronal mass ejection and intensity of solar flares which is calculated here is during 23 & 24 solar magnetic cycle (1997 to 2015).

The correlation coefficient is a degree of association, denoted by $r$. It is sometimes called Pearson’s correlation coefficient after its originator and is a measure of linear association. The correlation coefficient is measured on a scale that varies from $+1$ through $0$ to $-1$. Complete correlation between two variables is expressed by either $+1$ or $-1$. When one variable increases as the other increases the correlation is positive; when one decreases as the other increases it is negative. Complete absence of correlation is represented by $0$.

The calculation of the correlation coefficient with $x$ representing the values of the independent variable (CMEs) and $y$ representing the values of the dependent variable (Solar flares). The formula to be used is:

$$ r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 (y - \bar{y})^2}} \quad (1) $$

3.1 Coronal mass ejection and solar flares
We have selected those CMEs events whose velocity will be equal or greater than 500km/sec. we have no observed CMEs events for 2007, 2008 & 2009. During 1997-2015 we have found 412 CMEs events which were associated with different categories of X-ray solar flares (A, B, C, M, & X). No CMEs events observed for A-class solar flares, out of 412 CMEs events 55, 160, 126 and 71 events are associated with B, C, M and X-class X-ray solar flares respectively. The relation between flares and CMEs are positive as well as negative. There are total five types of solar flares A, B, C, M, & X. when speed of CMEs are correlated by intensity of solar flares via correlation coefficient whose value vary from -1 to +1.

To understand the correlation between CMEs and B-class solar flares draw a scatter plot from the trend line of the plot there is weak negative correlation between these two events with correlation coefficient -0.3(figure 1).

![Figure 1. Scatter plot between CMEs speed and B class flares with correlation coefficient -0.35.](image-url)
From the trend line of the scatter plot shown in figure 2 we have no correlation between CMEs and C class solar flares with correlation coefficient – 0.0 between these two events.

Figure 2. Scatter plot between CMEs speed and C class flares with correlation coefficient -0.00.

Further to understand the statistical behavior between CMEs and M class X-ray solar flares draw a scatter plot and from the trend line of the scatter plot we have found that there is a weak positive correlation between these two events with correlation coefficient 0.3 (figure 3).

Figure 3. Scatter plot between CMEs speed and M class flares with correlation coefficient 0.31.

To understand the statistical behavior between CMEs and X class X-ray solar flares draw a scatter plot and from the trend line of the scatter plot we have found that there is no correlation between these two events with correlation coefficient 0.09 (figure 4).
3.2 Coronal mass ejection and sunspot number

The statistical analysis was conducted to derive the correlation between SSN and CMEs for the annual time during the period from 1997-2015 through solar cycles 23 and 24 to investigate the behaviors of these parameters. A total of 12041 sun spot number and 148011 CMEs of velocity over 500 km/s were observed during the period from 1997-2015 through solar cycles 23 & 24. Table-2 shows the values of the observed SSNs and CMEs for the selected period. The number of occurrence of CMEs slightly increases towards solar maxima and slightly decreases towards solar minima. We have found that in the years 2008 and 2009 didn’t record even single CMEs over the speed of 500 km/sec. On the other side sunspots have shown regularity even in the declining phase of the solar cycle. It can be seen that in 2008 and 2009 doesn’t show any relation between CMEs and sunspots. Since 2008 and 2009 went through the declining phase of solar cycle; the record of CMEs has kept low.

In this article, we find that the linear regression equation is $y = 0.0825x - 9.1293$ and the correlation coefficient is 0.77, which measures the degree of a linear relation. A very good relationship rate with the positive slope is observed between the occurrence rate of CMEs and SSN, as shown in the correlation chart of figure 5.

Figure 5. Correlation between CMEs and SSN for 1997-2015 with correlation coefficient 0.77.
4. Conclusion
In this study, the statistical analysis was conducted to investigate the behaviors of CMEs with solar flares and SSN and derive the mutual correlation between these parameters for the annual time during the period from 1997 to 2015 through solar cycle 23 & 24. Although the solar cycle number 24 started in December 2008, data were taken before that to increase the sample number which gives better statistics in the curve fitting. The solar cycle 24 initially have activity less than cycle 23. Emissions of CMEs can occur at any time during a solar activity but increase with solar activity and solar energy. The present results foreshowed a high affiliation relation between CMEs and SSNs as expected since both generate from active regions of the sun. A good relationship with a positive slope exists between SSN and the occurrence rate of CMEs. The correlation coefficient between CMEs and SSN is 0.77. The present results for CMEs and solar flares is not as per expectation, only M class X-ray solar flare is weakly related to CMEs other type of solar flares are having no correlation with CMEs.

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