# RELATION BETWEEN CORONAL MASS EJECTIONS AND SUNSPOT NUMBER DURING SOLAR CYCLE 24

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**ABSTRACT:** In this paper, we report on the statistical relationships between coronal mass ejections (CMEs) and sunspot *number (SSN) that were suggested during 2008–2017 for solar cycle 24. We used SSN from Sunspot Index and Long-term Solar Observations and CMEs observed by the Large Angle and Spectrometric Coronagraph on board the Solar and Heliospheric Observatory mission. The annual time of the years (2008–2017) of solar cycle 24 was adopted to conduct the investigation and obtain the mutual correlation between SSN and CMEs. The relationship between CME rates, halo speed, and partial halo CMEs for solar cycle 24 was studied. The analysis of results indicated that the average speed of halo CMEs is almost faster than the average speed of partial halo CMEs. The maximum average speed of halo CMEs was found to be as high as 1487.9 km/sec in 2017, while the minimum speed of halo CMEs in 2008 was 47 km/sec. CMEs are principally from sunspot regions. Test results of the annual correlation between SSN and CMEs are simple and can be represented by a linear regression equation.*

**Keywords**: Coronal mass ejection, Sunspot number, solar cycle, solar activity.

## INTRODUCTION

Solar atmosphere is one of the richest and most dynamic environments studied in modern astrophysics. Similar to Earth, the sun has seasons. A cycle in the sun takes approximately 11 years, and during this time, the number of sunspots increases, decreases and then increases again. The reason for this phenomenon is the fluctuation of the solar magnetic field. The dynamics of the outer layer of the sun are affected by the fluctuation of the magnetic field and are recorded by many solar parameters, such as a number of sunspots, frequency of coronal mass ejections (CMEs), solar plasma temperature, and solar wind speed [1]. Based on its calculated number of sunspots, which was considered to be the smallest number since the beginning of the space age, solar cycle 24 was very weak. This weak activity is believed to be due to the low polar field strength in cycle 23. Many scholars noted that the low activity of cycle 24 may lead to a global minimum [2]. The main reason for the existence of the sun is space weather because of its ability to fade and its clarity. Electromagnetic emission consists of semi-stable and horizontal radiation. The long-term variation in photon emission may be related to climate impact, but short-term variation (solar energy) affects the ionosphere on Earth, leading to communication problems. The mass emission of the sun consists of three components: the solar wind everywhere, active solar energetic particles (SEPs), and CMEs. CMEs and solar wind carry the coronal magnetic field in the solar system. CMEs share solar wind and shock movement, and shocks, in turn, accelerate SEPs. Burners also accelerate particles but generally in the shortest and lowest levels. CMEs interact with the Earth’s magnetic envelope upon reaching it and are responsible for the occurrence of geomagnetic storms; their effects are numerous from the magnetosphere to Earth [3].

A halo CME surrounds the occulting disk of the observation paragraph in the plane's projection. Halo CMEs were first registered by Howard et al. (1982). Only a handful of CMEs were recorded by the Solwind coronagraph on board the P78-1 mission. Halo CMEs represent only ~3% of all CMEs. They also represent an energetic population because most CMEs that generate large SEPs and major geomagnetic storms are halos. A halo CME is usually created from close to the center of the disk, while ~10%) are created close to the limb. In the halos of the limbs, the disorder that appears on the opposite side is likely to be unexpected [4].

## MATERIALS AND METHODS

### Data Selection

In this research, the data on sunspot numbers (SSNs) were obtained from the Sunspot Index and Long-term Solar Observations, which is supported by the International Council for Science World Data System [5]. Meanwhile, the data on CMEs and halo CMEs were downloaded from Large Angle and Spectrometric Coronagraph detectors on board the Solar and Heliospheric Observatory. Other data were taken from the CDAW catalog [6, 7] during the period from January 2008 to December 2017 through solar cycle 24.

## RESULTS AND DISCUSSION

In this study, we conducted statistical analysis to investigate the behaviors of SSN and CMEs and derive the mutual correlation between these parameters for the annual time during the period from January 2008 to December 2017 through solar cycle 24. Solar cycle 24 started in December 2008. We analyzed the speed of full halo CMEs and partial halo CMEs for solar cycle 24. The angular width of 360 was considered for full halo CMEs, while 121–359 was considered for partial halo CMEs.

The size and speed of CMEs are important parameters to determine when attempting to predict if and when the CMEs will impact the Earth. These properties of CMEs can be estimated using observations from an instrument known as a coronagraph, which blocks the bright light of the solar disk, thus allowing the outer solar atmosphere (chromosphere and corona) to be observed. CMEs manifest as huge bright clouds of plasma moving outward space weather toward the Earth. The average halo speed of CMEs is twice that of the total CMEs.

A total 6452.3 SSN and 15,843 CMEs were observed during the period from January 2008 to December 2017 through solar cycle 24. Out of 15,843 CMEs, 324 were full halo and 1040 were partial halo. Table 1 shows the values of the observed SSNs and CMEs for the years 2008–2017 of solar cycle 24.

**Table 1 Occurrence rates of SSNs and CMEs for 2008–2017 of solar cycle 24.**

| year | SSN | # no. of all CME | no. of CME speed>=1000 | Types of CMEs | No. of events | Average speed (Km/S) | (halo/all CME) % |
|---|---|---|---|---|---|---|---|
| 2008 | 49.8 | 863 | 1 | Halo | 1 | 125 | 0.1 |
| | | | | Partial Halo | 12 | 389.3 | |
| 2009 | 57 | 746 | 0 | Halo | 1 | 47 | 0.1 |
| | | | | Partial Halo | 2 | 260.5 | |
| 2010 | 298.8 | 1117 | 11 | Halo | 11 | 696.3 | 1.0 |
| | | | | Partial Halo | 41 | 395.3 | |
| 2011 | 969.1 | 1990 | 33 | Halo | 41 | 930.9 | 2.0 |
| | | | | Partial Halo | 143 | 572.8 | |
| 2012 | 1012.7 | 2177 | 43 | Halo | 84 | 949.0 | 3.9 |
| | | | | Partial Halo | 189 | 549.1 | |
| 2013 | 1124.5 | 2338 | 36 | Halo | 55 | 888.7 | 2.4 |
| | | | | Partial Halo | 190 | 537.8 | |
| 2014 | 1363.3 | 2478 | 42 | Halo | 69 | 908.5 | 2.8 |
| | | | | Partial Halo | 265 | 502.4 | |
| 2015 | 837.4 | 2058 | 24 | Halo | 41 | 873.5 | 2.0 |
| | | | | Partial Halo | 128 | 528.5 | |
| 2016 | 477.9 | 1393 | 4 | Halo | 12 | 554.8 | 0.9 |
| | | | | Partial Halo | 58 | 377.1 | |
| 2017 | 261.8 | 683 | 5 | Halo | 9 | 1487.9 | 1.3 |
| | | | | Partial Halo | 12 | 291.7 | |
| total | 6452.3 | 15843 | | | | | 2.0 |

From Table 1, the following results were derived:

1. At the beginning of the period in 2008, the total SSNs were (49.8) and the total number of CMEs was 863. The number of CMEs that had a speed greater than or equal to 1000 was 1. The number of halo CMEs was 1 with an average speed of 125, while the number of partial halos was 12 with an average speed of 389.3. The ratio of the number of halo CMEs to all CMEs was 0.1.
2. In 2009, the total SSNs were 57 and the total number of CMEs was 746. The number of CMEs that had a speed greater than or equal to 1000 was 0. The number of halo CME was 1 with an average speed of 47, while the number of partial halos was 2 with an average speed of 260.5. The ratio of the number of halo CMEs to all CMEs was 0.1.
3. In 2010 the total SSNs were 298.8 and the total number of CMEs was 1117. The number of CMEs that had a speed greater than or equal to 1000 was 11. The number of halo CMEs was 11 with an average speed of 696.3, while the number of partial halos was 41 with an average speed of 395.3. The ratio of the number of halo CMEs to all CMEs was 1.
4. In 2011 the total SSNs were 969.1 and the total number of CMEs was 1990. The number of CMEs that had a speed greater than or equal to 1000 was (33). The number of halo CMEs was 41 with an average speed of 930.9, while the number of partial halos was 143 with an average speed of 572.8. The ratio of the number of halo CMEs to all CMEs was 2.
5. In 2012, a total of 1012.7 SSNs were obtained along with a total number of CMEs equal to 2177. The number of CMEs that had a speed greater than or equal to 1000 was 43. The number of halo CMEs was 84 with an average speed of 949, while the number of partial halos was 189 with an average speed of 549.1. The ratio of the number of halo CMEs to all CMEs was 3.9.
6. In 2013, 1124.5 SSNs were found along with 2338 CMEs. The number of CMEs that had a speed greater than or equal to 1000 was 36. The number of halo CMEs was 55 with an average speed of 888.7, while the number of partial halos was 190 with an average speed of 537.8. The ratio of the number of halo CMEs to all CMEs was 2.4.
7. In 2014, there were 1363.3 SSNs and 2478 CMEs. The number of CMEs that had a speed greater than or equal to 1000 was 42. The number of halo CMEs was 69 with an average speed of 908.5, while the number of partial halos was 265 with an average speed of 502.4. The ratio of the number of halo CMEs to all CMEs was 2.8.
8. In 2015, there were 837.4 SSNs and 2058 CMEs. The number of CMEs that had a speed greater than or equal to 1000 was 24. The number of halo CMEs was 41 with an average speed of 873.5, while the number of partial halos was 128 with an average speed of 528.5. The ratio of the number of halo CMEs to all CMEs was 2.
9. In 2016, the total SSNs and number of CMEs were 477.9 and 1393, respectively. The number of CMEs that had a speed greater than or equal to 1000 was 4. The number of halo CMEs was 12 with an average speed of 554.8, while the number of partial halos was 58 with an average speed of 377.1. The ratio of the number of halo CMEs to all CMEs was 0.9.
10. Finally, in 2017, the total SSNs and number of CMEs were 261 and 683, respectively. The number of

CMEs that had a speed greater than or equal to 1000 was 5. The number of halo CMEs was 9 with an average speed of 1487.9, while the number of partial halos was 12 with an average speed of 291.7. The ratio of the number of halo CMEs to all CMEs was 1.3.

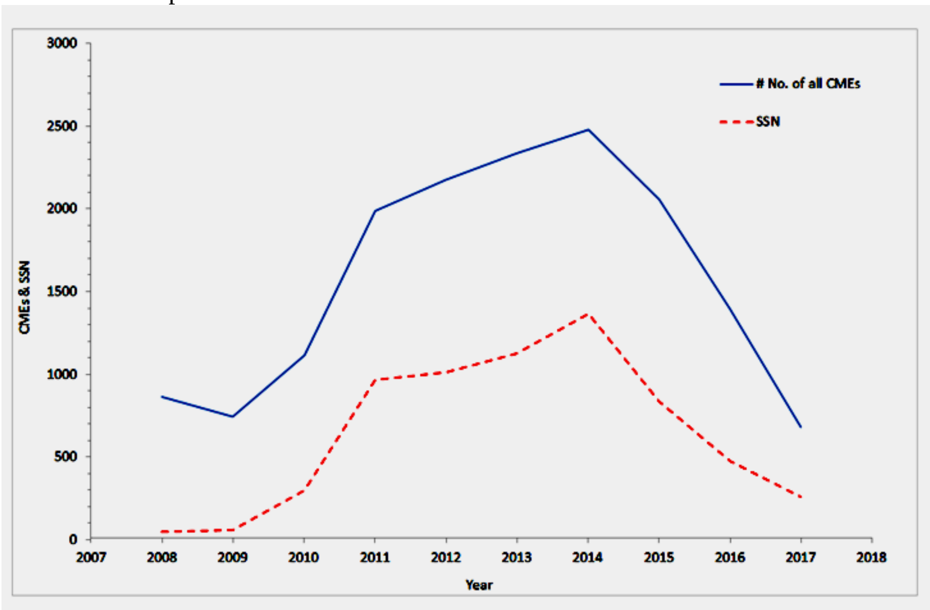


**Fig. 1. The linear plot for the annual occurrence rate of CMEs and SSN for 2008–2017 of solar cycle 24.**

Fig. 1 shows the linear plot for the annual occurrence rate of CMEs and SSN for 2008–2017) of solar cycle 24. The occurrence rate of CMEs increases with the active region measured by the SSN.

In this study, we find that the linear regression equation is y = 0.6607, x – 401.49 and the correlation coefficient is R=0.975, 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 Fig.2.

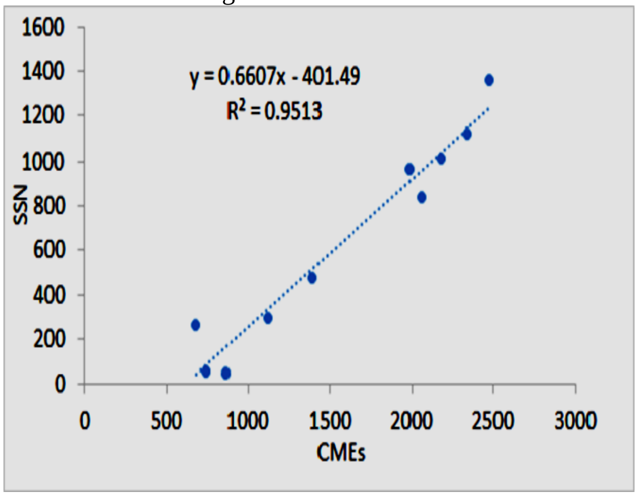


**Fig. 2. Correlation relationship between CMEs and SSN for 2008–2017 of solar cycle 24.**

Moreover, Fig. 3 illustrates that during solar cycle 24, the maximum SSNs and number of CMEs occurred in 2014, and the highest number of CME occurrences (43) with a speed $\geq$ 1000 was in 2012 (Fig. 3). The maximum number of halo CMEs (84) with an average speed of 949 also occurred in 2012 (Fig. 3), while the maximum number of partial halos were 265 with an average speed of 502.4 occurred in 2014 (Fig. 4.)

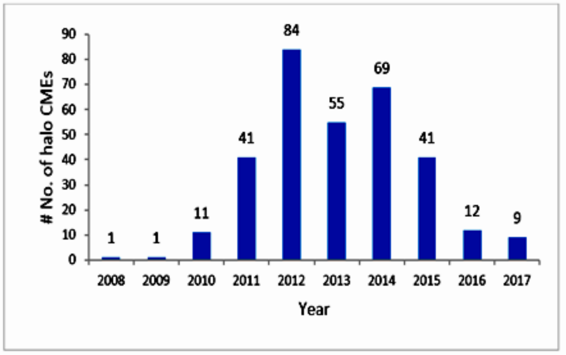


**Fig. 3. Number of halo CMEs per year for 2008–2017 of solar cycle 24.**

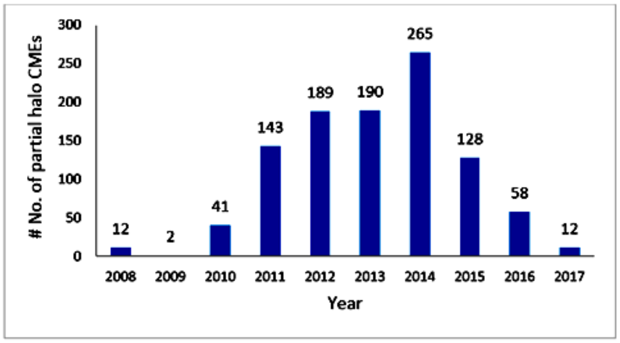


**Fig. 4. Number of partial halo CMEs per year for 2008–2017 of solar cycle 24.**

## CONCLUSION

1. The solar cycle 24 initially had little activity.
2. Emissions of CMEs can occur at any time during a solar activity but increase with solar activity and solar energy.
3. Emissions of CMEs emerge not only from sunspot reigns but also from other forms of solar activity.
4. When SSN increases, the number of CMEs slightly increases, and vice versa.
5. The peak of halo CMEs occurred in 2012.
6. The approximate average speed of halo CMEs is twice the speed of partial halo CMEs.
7. A comparison of SSNs with all CMEs does not show the delay of about two years in the peak of the latter but is very apparent with the former.
8. The number of CME occurrences slightly increases toward the sunspot maxima and slightly decreases toward the sunspot minima.
9. A very good relationship rate with positive slope exists between SSN and the occurrence rate of CMEs. The correlation coefficient between CMEs and SSN is 0.975.

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