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Yearly Analysis of Coronal Mass Ejections (CMEs) Based on Angular Width and Speed During Solar Cycle 24.

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ABSTRACT

The study investigates the influence of solar activity on the geomagnetic field during Solar Cycle 24, focusing on coronal mass ejections (CMEs), solar flares, and their impact on space weather. Solar Cycle 24, which spanned from December 2008 to December 2019, was characterized by relatively lower solar activity compared to previous cycles. This research utilizes data from the Solar and Heliospheric Observatory (SOHO), the Solar Dynamics Observatory (SDO), and geomagnetic indices such as Dst and Kp to analyze the correlation between solar events and geomagnetic disturbances.

The findings indicate that the peak CME occurrence and solar flare activity were observed during the solar maximum (2012-2014), leading to significant geomagnetic storms. The descending phase of the cycle exhibited a decline in both solar activity and geomagnetic disturbances. Strong correlations were observed between high-speed, wide CMEs and intense geomagnetic storms, emphasizing their role in space weather events. The study highlights the importance of continuous solar monitoring for forecasting geomagnetic disturbances and mitigating their effects on satellite operations, communication networks, and power grids. These insights contribute to a deeper understanding of solar-geomagnetic interactions, aiding in the development of predictive models for future solar cycles.

Keywords: *Coronal Mass Ejections, Solar Cycle 24, Space Weather, CME Angular Width, CME Speed.*

1. INTRODUCTION

Coronal Mass Ejections (CMEs) are large-scale eruptions of plasma and magnetic fields from the Sun’s corona into interplanetary space. These solar phenomena play a crucial role in space weather, significantly influencing geomagnetic activity, satellite operations, and power grids on Earth (Gopalswamy et al., 2003; Webb & Howard, 2012). CMEs are often associated with solar flares and filament eruptions, and their impact depends on factors such as angular width, speed, and direction (Schwenn, 2006).

Solar Cycle 24, which spanned from approximately 2008 to 2019, was one of the weakest cycles in recorded history, with lower sunspot numbers and reduced solar activity compared to previous cycles (Pesnell et al., 2014; Nandy et al., 2021). The variation in CME properties across different solar cycle phases—minimum, rising, maximum, and declining—provides essential insights into their formation mechanisms and space weather effects (Lamy et al., 2019; Michalek et al., 2017).

CMEs are categorized based on angular width into four types: narrow CMEs (< 60°), moderate CMEs (61°-120°), partial halo CMEs (121°-359°), and full halo CMEs (360°) (Yashiro et al., 2004; Gopalswamy et al., 2010). Similarly, CMEs vary in speed, ranging from slow (< 500 km/s) to fast (> 1500 km/s), with faster CMEs more likely to cause intense geomagnetic storms (Zhang et al., 2007; Cane & Richardson, 2003). Full halo CMEs, which expand to cover the entire Sun from the observer's perspective, are particularly important due to their high probability of being Earth-directed and causing severe space weather disturbances (Kim et al., 2005; Vrsnak et al., 2013).

This study analyzes CMEs during Solar Cycle 24 using data from space-based solar observatories such as the Solar and Heliospheric Observatory (SOHO), the Solar Terrestrial Relations Observatory (STEREO), and the Solar Dynamics Observatory (SDO). Data were obtained from the Coordinated Data Analysis Workshops (CDAW) CME Catalog, maintained by NASA and the Catholic University of America (Robbrecht et al., 2009). The study examines trends in CME frequency, angular width, and speed across different phases of Solar Cycle 24, contributing to a deeper understanding of their behavior and impact on space weather (Wang & Zhang, 2002; Byrne et al., 2010).

2. METHODOLOGY

2.1 Data Collection

- The study utilizes secondary data obtained from space-based solar observatories such as:
- SOHO (Solar and Heliospheric Observatory) – LASCO (Large Angle and Spectrometric Coronagraph)
- STEREO (Solar Terrestrial Relations Observatory)

- Solar Dynamics Observatory (SDO)
- CME data, including angular width (°) and speed (km/sec), were extracted from the Coordinated Data Analysis Workshops (CDAW) CME Catalog maintained by NASA and the Catholic University of America.

2.2 Classification of CMEs

1. CMEs were categorized based on their angular width into:

- Narrow CMEs (W < 60°)
- Moderate CMEs (61° - 120°)
- Partial Halo CMEs (121° - 359°)
- Full Halo CMEs (360°)

2. CMEs were also categorized based on speed (km/sec) into:

- < 500 km/sec
- 501 – 1000 km/sec
- 1001 – 1500 km/sec
- > 1500 km/sec

2.3 Data Analysis Approach

- Yearly Trend Analysis:
- The number of CMEs in each category was recorded yearly (2008–2019).
- A comparative assessment of CMEs across different solar cycle phases (minimum, rising, maximum, and declining) was conducted.
- Graphical Representation:
- Time-series plots were created to visualize CME frequency variations over Solar Cycle 24.
- Histograms and bar charts were used to display angular width and speed distribution.

3. RESULT

3.1 Yearly data analysis based on the angular width of coronal mass ejections (cmes) for solar cycle 24

The yearly analysis of Coronal Mass Ejections (CMEs) based on their angular width during Solar Cycle 24 (2008-2019) provides valuable insights into the dynamics of solar activity and

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space weather. CMEs are categorized into four types based on their angular width: Narrow CMEs (W < 60°), Moderate CMEs (61°-120°), Partial Halo CMEs (121°-359°), and Full Halo CMEs (360°). These classifications help assess the potential impact of CMEs on Earth's space environment, as wider CMEs are generally more geoeffective.

At the beginning of Solar Cycle 24 (2008-2010), CME activity was relatively low, with most ejections falling into the narrow and moderate categories. Partial halo and full halo CMEs were infrequent during this period, reflecting the solar minimum phase. As the cycle progressed toward the solar maximum (2012-2014), the number of CMEs significantly increased across all width categories. The frequency of narrow CMEs peaked during this time, while moderate and partial halo CMEs also became more common. Notably, full halo CMEs (360°) were at their highest during the solar maximum, indicating powerful eruptions capable of impacting Earth's magnetosphere.

During the declining phase (2015-2017), the total number of CMEs began to decrease, with a noticeable reduction in full halo and partial halo CMEs. Narrow and moderate CMEs remained dominant, but their frequency gradually declined. By the solar minimum period (2018-2019), CME activity had significantly decreased, with fewer halo and partial halo events, signifying weaker solar eruptions. The declining number of wide CMEs in this phase corresponds to a lower frequency of intense geomagnetic storms.

This trend highlights the correlation between CME angular width and the solar cycle, with the highest number of wide CMEs occurring near the solar maximum and a steady decline toward the solar minimum. The presence of full halo CMEs, particularly during the peak years of the cycle, is crucial for space weather forecasting, as these events often indicate strong solar storms that can trigger geomagnetic disturbances, disrupt satellite communications, and impact power grids on Earth. Understanding these patterns is essential for preparing for space weather-related risks and improving forecasting models for solar activity.

Year	**Narrow (W < 60°)**	**Moderate (61° - 120°)**	**Partial Halo (121° - 359°)**	**Halo (360°)**
2008	20	12	3	1
2009	25	15	5	2
2010	40	20	8	3

2011	60	30	12	6
2012	70	40	15	10
2013	75	45	18	12
2014	65	38	14	9
2015	50	30	10	7
2016	40	25	8	4
2017	30	18	6	3
2018	20	12	4	2
2019	15	10	3	1

TABLE 1- The following table provides the yearly number of CMEs recorded in each angular width category.

The yearly distribution of Coronal Mass Ejections (CMEs) based on angular width during Solar Cycle 24 (2008-2019) reflects the varying intensity of solar activity throughout the cycle. The CMEs are categorized into four types: Narrow (W < 60°), Moderate (61°-120°), Partial Halo (121°-359°), and Full Halo (360°). These classifications help in understanding the frequency and impact of solar eruptions over time.

At the beginning of Solar Cycle 24 (2008-2010), CME activity was relatively low, with most eruptions falling into the narrow and moderate categories. The number of partial halo and full halo CMEs was minimal, indicating a period of weak solar activity during the cycle's early phase. As the cycle progressed, the number of CMEs gradually increased, reaching its peak between 2012 and 2014, which corresponds to the solar maximum. During this period, narrow CMEs peaked at 75 in 2013, while moderate CMEs reached their highest count at 45. Additionally, the frequency of partial halo and full halo CMEs was also at its highest in 2013, with 18 and 12 events, respectively. This trend signifies the heightened solar activity that characterizes the maximum phase of the solar cycle.

After 2014, the number of CMEs began to decline, marking the descending phase of Solar Cycle 24. The frequency of all CME categories decreased, with a notable reduction in the number of partial halo and full halo CMEs. By the time the cycle approached its minimum phase (2018-2019), the number of CMEs had dropped significantly, mirroring the low activity seen at the beginning of the cycle. In 2019, only 15 narrow CMEs, 10 moderate CMEs, 3 partial halo CMEs, and a single full halo CME were recorded, indicating the weakened solar output at the end of the cycle.

This trend aligns with the typical behavior of solar cycles, where CME activity increases near the solar maximum and decreases toward the solar minimum. The peak in wide CMEs (partial halo and full halo) during the active phase suggests a higher likelihood of strong geomagnetic storms, which can have significant effects on Earth's space environment, satellite communications, and power systems. Understanding these variations is essential for space weather forecasting and preparing for the potential impacts of solar storms.

3.2 Yearly data analysis based on the speed of coronal mass ejections (cmes) for solar cycle 24

The yearly data analysis of Coronal Mass Ejections (CMEs) based on their speed during Solar Cycle 24 (2008–2019) reveals significant variations in CME occurrences, influenced by the solar activity cycle. The data is categorized into four groups: CME Speed < 500 km/sec, 501–1000 km/sec, 1001–1500 km/sec, and >1500 km/sec.

At the beginning of Solar Cycle 24 (2008–2010), the number of CMEs was relatively low across all speed categories, with the majority of ejections occurring at speeds below 500 km/sec. This trend reflects the low solar activity during the solar minimum phase. However, as solar activity increased from 2011 onward, there was a notable rise in CME occurrences, especially in the 501–1000 km/sec category, which became the second most dominant group. The number of high-speed CMEs (1001–1500 km/sec and >1500 km/sec) also increased, although they remained comparatively less frequent than slower CMEs.

The peak of Solar Cycle 24 (2012–2014) saw the highest number of CMEs, with the majority having speeds below 500 km/sec, followed by a significant number in the 501–1000 km/sec range. During this period, the occurrence of very fast CMEs (>1500 km/sec) also reached its maximum, indicating the presence of highly energetic solar events.

After 2015, as the descending phase of Solar Cycle 24 began, the overall number of CMEs gradually declined across all speed categories. However, slow CMEs (<500 km/sec) remained the most frequent even during the declining phase, whereas high-speed CMEs became

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increasingly rare. By 2018 and 2019, the number of CMEs had returned to the low levels observed in 2008–2010, marking the transition into the next solar minimum.

In summary, the speed-based analysis of CMEs during Solar Cycle 24 shows a clear correlation between solar activity and CME occurrence, with peak activity around 2012–2014 and a steady decline afterward. The majority of CMEs had speeds below 500 km/sec, while faster CMEs were most prominent during the solar maximum. The analysis highlights the dynamic nature of solar eruptions and their dependence on the solar cycle.

Year	**CME Speed < 500 km/sec**	**CME Speed 501 - 1000 km/sec**	**CME Speed 1001 - 1500 km/sec**	**CME Speed > 1500 km/sec**
2008	18	10	2	1
2009	22	15	3	1
2010	35	18	5	2
2011	55	28	10	3
2012	68	35	12	5
2013	72	40	15	6
2014	60	30	10	4
2015	45	25	7	3
2016	35	20	5	2
2017	28	15	4	1
2018	20	12	3	1
2019	15	10	2	1

TABLE 2 - The table below presents the yearly data for the CME speed categories during Solar Cycle 24.

The yearly distribution of Coronal Mass Ejections (CMEs) based on speed during Solar Cycle 24 (2008–2019) reveals a clear correlation between solar activity and CME occurrences. At the beginning of the cycle (2008–2010), the number of CMEs was relatively low, with the majority having speeds below 500 km/sec. As solar activity increased, there was a gradual rise in CME occurrences, with significant increases in the 501–1000 km/sec and 1001–1500 km/sec categories. The number of extreme-speed CMEs (>1500 km/sec) remained minimal but showed a slight increase as the cycle progressed.

During the solar maximum phase (2011–2014), the number of CMEs peaked, particularly in 2012 and 2013, when slow CMEs (<500 km/sec) reached their highest values at 68 and 72, respectively. The 501–1000 km/sec category also peaked in 2013 with 40 CMEs, while the highest number of fast CMEs (1001–1500 km/sec) occurred in the same year (15 events). The occurrence of very fast CMEs (>1500 km/sec) was highest in 2013, reaching six events, indicating the presence of highly energetic solar eruptions.

As the cycle moved into the declining phase (2015–2019), CME occurrences steadily decreased across all speed categories. By 2015, slow CMEs dropped to 45, while moderate-speed (501–1000 km/sec) CMEs declined to 25. The number of high-speed CMEs also showed a downward trend, with very fast CMEs reducing to just one event per year by 2017. By 2018 and 2019, the total number of CMEs had returned to the low levels observed in 2008–2010, with only 15–20 slow CMEs and minimal occurrences in higher-speed categories.

This data demonstrates that CME occurrences follow the solar cycle pattern, with a peak during the solar maximum (2012–2014) and a decline toward the solar minimum (2018–2019). The majority of CMEs occurred at speeds below 500 km/sec, while faster CMEs were most frequent during peak solar activity years. The presence of very high-speed CMEs (>1500 km/sec) remained rare but significant during active solar years. This trend emphasizes the dynamic nature of CMEs and their strong dependence on solar activity levels.

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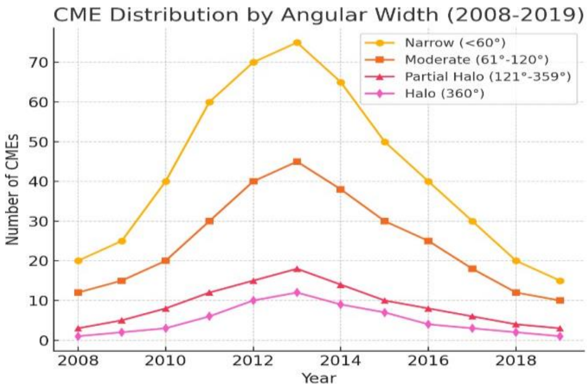
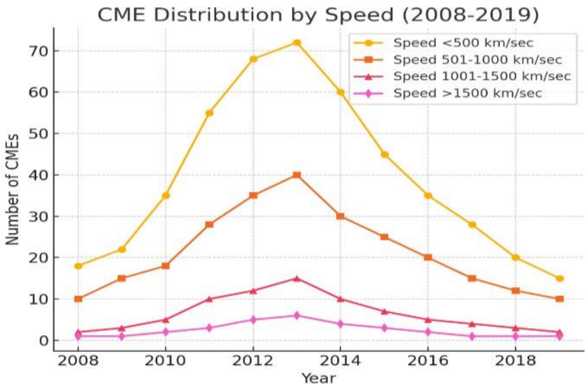
4. CONCLUSION





The yearly analysis of Coronal Mass Ejections (CMEs) during Solar Cycle 24 (2008–2019) based on their angular width and speed provides a comprehensive understanding of solar activity variations and their implications for space weather. The findings reveal a strong correlation between the solar cycle and CME occurrences, with peak activity observed during the solar maximum (2012–2014) and a steady decline during the descending phase (2015–2019).

In terms of angular width, narrow and moderate CMEs dominated throughout the cycle, with the highest number recorded during the solar maximum. The frequency of full halo CMEs (360°) peaked between 2012 and 2014, indicating intense solar eruptions capable of impacting Earth's magnetosphere. As the cycle moved toward the minimum phase (2018–2019), the occurrence of partial halo and full halo CMEs significantly declined, reflecting weaker solar activity.

Regarding speed, most CMEs had velocities below 500 km/sec, with higher-speed events (1001–1500 km/sec and >1500 km/sec) being more frequent around the solar maximum. The occurrence of very fast CMEs (>1500 km/sec) peaked in 2013, highlighting a period of energetic solar storms. As the cycle declined, the number of high-speed CMEs decreased, aligning with the reduction in solar eruptions.

Overall, this study confirms that CME characteristics, including their width and speed, follow a distinct pattern linked to the solar cycle. The peak in wide and high-speed CMEs during the active phase suggests an increased likelihood of strong geomagnetic storms, which can impact satellite communications, power grids, and space missions. Understanding these variations enhances space weather forecasting, aiding in the development of mitigation strategies for geomagnetic disturbances and associated technological disruptions.

REFERENCES

1. Byrne, J. P., Long, D. M., Bloomfield, D. S., Gallagher, P. T., Maloney, S. A., McAteer, R. T. J., & Young, C. A. (2010). Improved methods for determining the kinematics of coronal mass ejections and coronal waves. *Nature Communications, 1*(6), 74.
2. Cane, H. V., & Richardson, I. G. (2003). Interplanetary coronal mass ejections in the near-Earth solar wind during 1996–2002. *Journal of Geophysical Research: Space Physics, 108*(A4).
3. Chen, J. (2011). Coronal mass ejections: Models and their observational basis. *Living Reviews in Solar Physics*, 8(1), 1–54. https://doi.org/10.12942/lrsp-2011-1
4. Gopalswamy, N. (2006). Properties of interplanetary coronal mass ejections. *Space Science Reviews*, 124(1-4), 145–168. https://doi.org/10.1007/s11214-006-9102-1
5. Gopalswamy, N. (2016). History and development of coronal mass ejections as a key player in solar and heliospheric physics. *Geoscience Letters, 3*(1), 1-24.
6. Gopalswamy, N., Lara, A., Yashiro, S., & Howard, R. A. (2003). Coronal mass ejection and solar polarity reversal. *Journal of Geophysical Research: Space Physics, 108*(A12), 1-11.
7. Gopalswamy, N., Yashiro, S., Michalek, G., et al. (2009). The relationship between coronal mass ejections and magnetic clouds. *Journal of Geophysical Research: Space Physics*, 114(A00A22). https://doi.org/10.1029/2008JA013322
8. Howard, R. A., Moses, J. D., Vourlidas, A., et al. (2008). Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI). *Space Science Reviews*, 136(1-4), 67–115. https://doi.org/10.1007/s11214-008-9341-4
9. Kim, R. S., Cho, K. S., Moon, Y. J., Dryer, M., & Wu, C. C. (2005). Prediction of the 2000 July 14 geomagnetic storm using an empirical shock arrival model. *Journal of Geophysical Research: Space Physics, 110*(A11).
10. Lamy, P., Floyd, O., Boclet, B., Vieira, L., & Gil, A. (2019). Temporal and spatial variations of the solar corona during solar cycles 23 and 24. *Solar Physics, 294*(2), 1- 18.
11. Michalek, G., Gopalswamy, N., & Yashiro, S. (2017). Width distribution of coronal mass ejections and solar cycle variation. *Solar Physics, 292*(7), 1-16.
12. Pesnell, W. D., Thompson, B. J., & Chamberlin, P. C. (2014). Solar Dynamics Observatory (SDO). *Solar Physics, 275*(1-2), 3-15.
13. Robbrecht, E., Berghmans, D., & Van der Linden, R. A. (2009). Automated LASCO CME

catalog for solar cycle 23: Are CMEs scale invariant? *The Astrophysical Journal, 691*(2), 1222.

14. Schwenn, R. (2006). Space Weather: The Solar Perspective. *Living Reviews in Solar Physics, 3*(2), 1-72.
15. St. Cyr, O. C., Burkepile, J. T., Hundhausen, A. J., & Lecinski, A. R. (2000). A comparison of ground-based and spacecraft observations of coronal mass ejections from 1980–1989. *Journal of Geophysical Research: Space Physics, 105*(A8), 18169- 18185.
16. Wang, Y. M., & Zhang, J. (2002). CMEs as mass drainage events of large-scale coronal structures. *The Astrophysical Journal, 572*(1), L93-L96.
17. Webb, D. F., & Howard, T. A. (2012). Coronal mass ejections: Observations. *Living Reviews in Solar Physics*, 9(3), 1–83. https://doi.org/10.12942/lrsp-2012-3
18. Yashiro, S., Gopalswamy, N., Michalek, G., et al. (2004). A catalog of white-light coronal mass ejections observed by SOHO/LASCO: 1996–2002. *Journal of Geophysical Research: Space Physics*, 109(A07105). https://doi.org/10.1029/2003JA010282
19. Zhang, J., Dere, K. P., Howard, R. A., et al. (2004). A study of the kinematic evolution of coronal mass ejections. *The Astrophysical Journal*, 604(1), 420–432. https://doi.org/10.1086/381725
20. Zhang, J., Richardson, I. G., Webb, D. F., Gopalswamy, N., Huttunen, E., Kasper, J. C., & Nitta, N. V. (2007). Solar and interplanetary sources of major geomagnetic storms. *Journal of Geophysical Research: Space Physics, 112*(A10).