Relation Of Solar Flares, Cmes And Sunspot Number From Solar Minimum (Dec.2019) To Predicted Solar Maximum (April 2025).

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Abstract

The ongoing Solar Cycle 25 presents a crucial opportunity to study coronal mass ejections (CMEs) solar flares and Sunspot numbers, key drivers of space weather that significantly impact Earth's magnetosphere and technological systems. From the solar minimum phase to the predicted solar maximum, this study examines the properties, occurrence, and severity of CMEs and solar flares. Utilizing information from space-based observatories like the Parker Solar Probe, the Solar Dynamics Observatory, and the Solar and Heliospheric Observatory (SOHO), we examine patterns in magnetic field fluctuations, plasma dynamics, and solar activity. In this work, we seek to establish relationships between flare activity, CME occurrence rates, and solar magnetic field changes in order to enhance prediction models for space weather forecasting. By improving our knowledge of solar energetic events and their possible effects on Earth's space environment, the findings will help create mitigation plans for communication and satellite operations.

Keywords:

Solar Cycle 25, coronal mass ejections (CMEs), solar flares, space weather, solar minimum, solar maximum, solar magnetic field, plasma dynamics, heliophysics, space environment, solar activity forecasting.

Introduction

Variations in the Sun's magnetic field, sunspot numbers, and the occurrence of solar events like solar flares and coronal mass ejections (CMEs) are all part of the solar cycle, which is a roughly 11-year cycle of solar activity. These explosions have a significant impact on satellite operations, international communication networks, Earth's electrical grids, and space weather. Because of improvements in observational technologies that enable more accurate monitoring and forecast of solar activity, Solar Cycle 25, which started in December 2019, is particularly noteworthy.Solar flares, which are violent outbursts of electromagnetic radiation brought on by the reconnection of solar magnetic fields, are frequently linked to CMEs, which are enormous eruptions of magnetized plasma from the Sun's corona. The frequency and intensity of these occurrences tend to peak around the solar maximum, even though they happen throughout the solar cycle. Improving space weather forecasting and reducing the possible negative effects of CMEs and solar flares on technology infrastructure require an understanding of how these phenomena change from the solar minimum to the solar maximum.

The purpose of this study is to investigate the features of solar flares and CMEs during Solar Cycle 25, from its initial minimum phase to its anticipated maximum. We examine patterns in solar activity, plasma dynamics, and magnetic field irregularities using data from space-based projects like the Parker Solar Probe, the Solar Dynamics Observatory, and the Solar and Heliospheric Observatory (SOHO). Our research will advance our knowledge of solar energetic events and how they affect space weather forecasting, which will ultimately improve readiness for technology systems based on Earth and space.

Data and Methodology

This study investigates the characteristics of coronal mass ejections (CMEs) and solar flares throughout Solar Cycle 25, from the solar minimum in December 2019 to the solar maximum, which was reached earlier than anticipated in 2024. The analysis encompasses data up to March 2025, providing a comprehensive overview of solar activity during this period.

Data Sources

Solar and Heliospheric Observatory (SOHO)Solar Dynamics Observatory (SDO), Geostationary Operational Environmental Satellites (GOES),Parker Solar Probe (PSP) which offered in-situ measurements of the solar wind and magnetic field variations in proximity to the Sun, enhancing understanding of CME initiation mechanisms.Solar Terrestrial Relations Observatory (STEREO-A)also enabled three-dimensional tracking of CMEs, improving velocity and propagation modeling.Ground-Based Solar Observatories also included data from the Global Oscillation Network Group (GONG) for synoptic magnetograms and H-alpha imaging pertinent to flare observations.

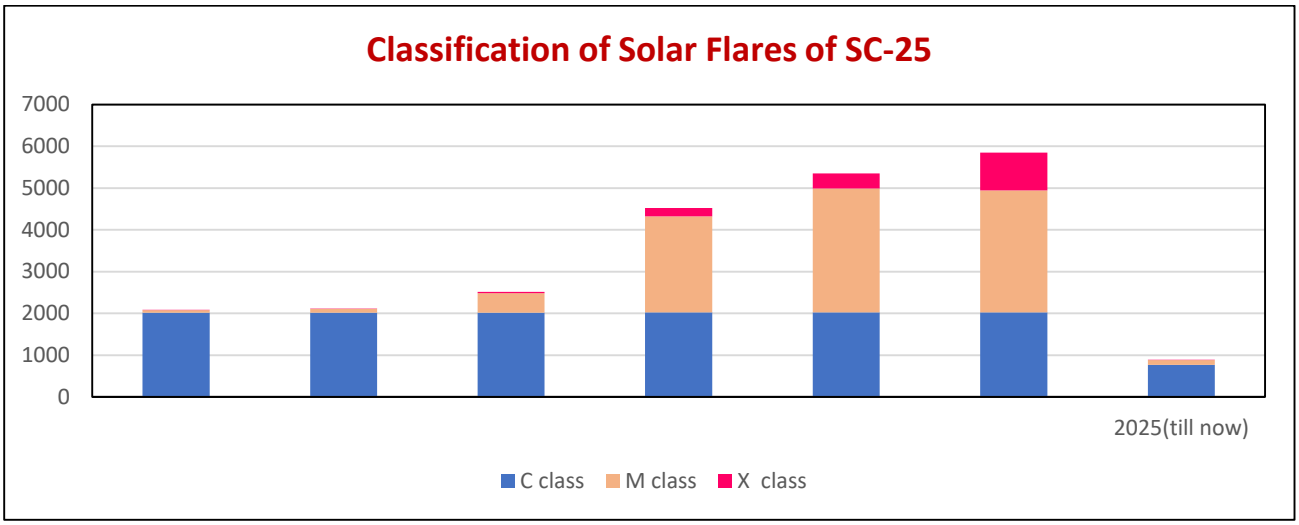
Methodology

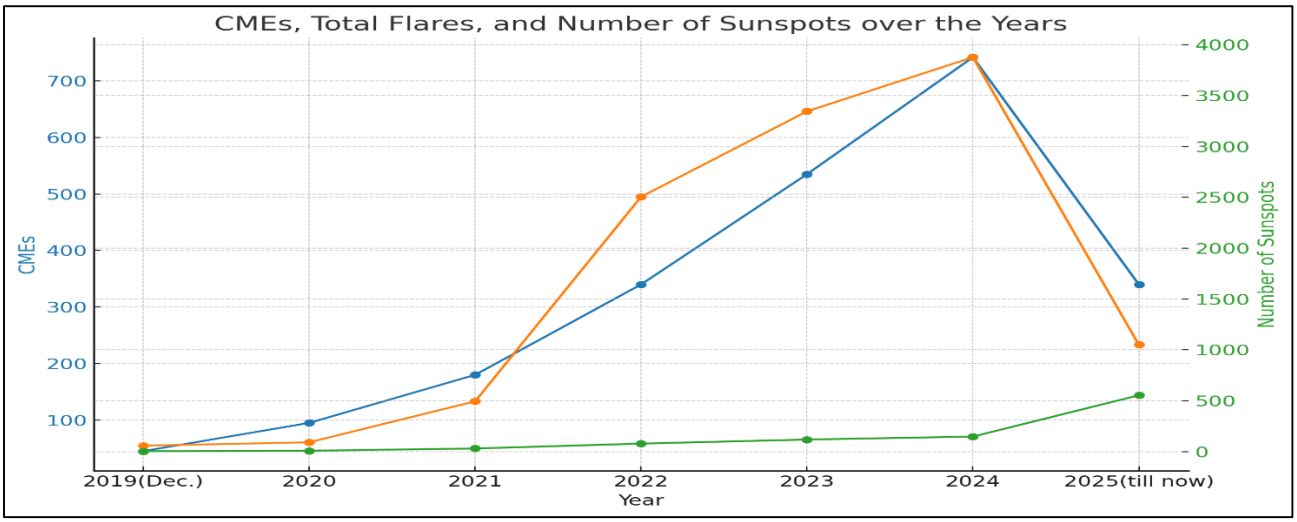
CMEs are identified using coronagraph images from SOHO/LASCO and STEREO-A, with measurements of speed and angular width aiding in categorization e.g., fast vs. slow CMEs and Solar Flares Classifications are based on GOES X-ray flux data into A, B, C, M, and X categories, with further structural analysis conducted using SDO/AIA imagery. Impact Assessment of Space Weather is that by monitoring the CMEs' movement with STEREO-A and contrasting their arrival times with geomagnetic indices like the Disturbance Storm Time (Dst) index and Kp index, the geoeffectiveness of the CMEs was evaluated
which also examined the effects of solar energetic particle (SEP) events linked to flares and CMEs on the Earth's magnetosphere.By integrating observations from multiple missions and employing advanced data analysis techniques, this study provides a comprehensive evaluation of CMEs and solar flares during Solar Cycle 25, enhancing our understanding of solar energetic events and their implications for space weather forecasting.

Table:

Year	Solar Cycle Phase	CMEs	C class	M class	X class	Number of Sunspots
2019	Solar minimum	45	56	2	0	4
2020	Solar minimum	95	89	2	0	8
2021	Ascending Phase	180	463	29	2	30
2022	Ascending Phase	340	2302	196	7	78
2023	Strong Ascending	535	2965	367	13	118
2024	Near Maximum	742	2919	904	54	147
2025(till now)	Solar Maximum	340	768	112	6	170

Graph





The graph displaying the trends of CMEs (blue line), Total Flares (orange line), and the Number of Sunspots (green line) over the years from 2019 to 2025 (till now). The y-axes on the left, right, and top represent CMEs, Total Flares, and Number of Sunspots, respectively**.**

Result and Discussion

Solar Activity Trends (2019(Dec.)–2025(April)

The information in the table describes solar activity from 2019 to 2025 with particular attention on Coronal Mass Ejections (CMEs), solar flare classifications (C, M, X), and the quantity of sunspots. The time frame covers the changes from Solar Minimum to Solar Maximum, which correspond to the different stages of the solar cycle.1. Solar Cycle Phases and Their Impact:

2019 and 2020 (Solar Minimum): During the solar minimum, solar activity is typically at its lowest. The CMEs during this period were moderate (45 in 2019 and 95 in 2020).Solar flare activity was mostly low, with a significant dominance of C-class flares. The M-class flares were limited, and no X-class flares were observed.The number of sunspots was low, consistent with the expected quiet solar activity during the minimum phase.

2021 and 2022 (Ascending Phase): As the solar cycle progressed into the ascending phase, solar activity began to increase. CMEs significantly rose, with 180 in 2021 and 340 in 2022. The flare activity also increased dramatically. In 2021, the number of C-class flares was the highest at 463, and by 2022, there were 2302 C-class flares, marking a substantial increase in flare activity. M-class flares were observed

more frequently, and the number of sunspots rose accordingly, from 30 in 2021 to 78 in 2022, indicating the Sun's gradual approach toward its maximum activity**.**

2023 (Strong Ascending Phase): Solar activity peaked further in 2023, as the Sun entered a strong ascending phase. CMEs reached 535, and flare activity reached new heights with 2965 C-class and 367 M-class flares.X-class flares began to appear with 13 recorded in 2023, signaling that the Sun was moving closer to its solar maximum. The number of sunspots continued to rise, peaking at 118, reflecting the intensified solar activity.

2024 (Near Maximum): By 2024, solar activity reached its maximum levels. CMEs surged to 742, and flare activity was at its highest, with 2919 C-class, 904 M-class, and 54 X-class flares. The number of sunspots also peaked at 147, signifying that the solar maximum was fully underway.

2025 (Solar Maximum, till now): As of 2025, the solar cycle is at its maximum phase, though activity began to dip slightly compared to 2024 but we are at the starting of the year. CMEs dropped to 340, but flare activity remained high. There were still significant numbers of C-class and M-class flares, and a few X-class flares were recorded. Sunspot activity continued its upward trend, reaching 170, but may start declining towards the end of 2025 as the cycle begins to wane.

Discussion:

The data highlights the fact that solar activity is cyclical and controlled by the phases of the solar cycle. The amount of sunspots, flare activity, and CME frequency are all influenced by the solar minimum and maximum phases. The solar maximum, which corresponds with past patterns of solar behavior, is the peak in CMEs, solar flares, and sunspot numbers in 2024.
Space weather events may be affected by the dramatic increase in flare activity, especially M-class and X-class flares. Since powerful solar flares release high-energy radiation that might interfere with Earth's magnetosphere, these could potentially interfere with satellite communications, GPS systems, and power grids on Earth. A prolonged period of increased solar activity is evident in the data from 2024 and 2025, which is crucial for researchers tracking space weather because of its possible influence on contemporary technologies. With a notable rise in CMEs, solar flares, and sunspot activity, the solar cycle from 2019 to 2025 amply demonstrates the shift from solar minimum to solar maximum. Even though the data shows the typical patterns of solar behavior, it is crucial to keep an eye on solar activity in order to forecast future space weather events and lessen their effects on communication and technological systems. Given that the Sun's activity is cyclical, the anticipated drop in solar activity after 2025 will signal the return to the next solar minimum**.**

Future Scope:

1. Continuous Observation Following Maximum (2025–2029): A more comprehensive understanding of Solar Cycle 25's behavior and the ability to compare it to previous cycles will be made possible by ongoing observation during its falling phase.
   2. CME/Flare Forecasting Using Machine Learning :The accuracy of CME and flare predictions based on real-time solar data could be improved by integrating AI and machine learning models.
   3. Studies of Solar-Terrestrial Impact : To better understand the effects of space weather, it will be necessary to correlate CME and flare activity with Earth-based phenomena including satellite anomalies, geomagnetic storms, and auroras.

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Conflicts of Interest

Regarding the publication of this study, the author states that there are no conflicts of interest. The investigation was carried out independently, without financial or personal bias, and with data that was readily available to the public.

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