THE RELATIONSHIP BETWEEN SUNSPOT NUMBERS AND CORONAL MASS EJECTIONS WITHIN AN 11-YEAR SOLAR CYCLE

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СВЯЗЬ МЕЖДУ ЧИСЛОМ СОЛНЕЧНЫХ ПЯТЕН И КОРОНАЛЬНЫМИ ВЫБРОСАМИ МАСС В ТЕЧЕНИЕ 11-ЛЕТНЕГО СОЛНЕЧНОГО ЦИКЛА

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На Солнце наблюдается множество эруптивных явлений, включая солнечные пятна и корональные выбросы массы (CME), которые являются неотъемлемой частью понимания его магнитной активности. Солнечные пятна – это темные, более холодные области на поверхности Солнца, которые тесно связаны с магнитными полями. С другой стороны, КВМ – это массивные выбросы намагниченной плазмы из солнечной короны в межпланетное пространство. Целью этого исследования является изучение взаимосвязи между количеством солнечных пятен и появлением КВМ в течение 11-летнего солнечного цикла.

Introduction

When we speak about changes in solar activity, it is typically understood as a variation in the number of sunspots. It has been found that there is an 11 year cycle in the number of sunspots. The beginning of the cycle is defined as the time when we observe a minimum in the number of sunspots, which may be different for different cycles both in terms of duration and number of spots, , followed by an increase leading to a maximum and then a decrease again until the next minimum. Later, the existence of a quasi-centennial cycle, the Gleissberg cycle, has been identified. During about 80–100 years, amplitude of the 11-year cycles gradually increases and decreases. For a long time, only the number of sunspots was a measure of solar activity. Sunspots are known to be areas with a lower temperature than the surrounding area. We now know that sunpots are areas where strong magnetic fields emerge in the photosphere, and in this sense they are a manifestation of the Sun's toroidal magnetic field. Many eruptive phenomena are observed on the Sun, including coronal mass ejections (CMEs), which are integral to understanding magnetic activity. CMEs are massive ejections of magnetized plasma from the solar corona into interplanetary space. In the present work, we compare the number of sunspots in the different phases of the last two 11-year solar cycles and compare them to the analogous period of the previous century minimum. We try to establish a correlation between the number of sunspots and the occurrence of CMEs during the 11-year solar cycle cycle.

Data

We study the amplitudes of cycles 12, 13, 14, 23, 24, and 25 using the following indices:

1. The sunspot number (SSN). The most commonly used index of solar activity is the relative sunspot number or Wolf number. Since 1849, Wolf numbers have been regularly determined at the Zurich Observatory. Since 1981, Wolf number determinations have been carried out at the World Data Center (WDC-SILSO) in Brussels (https://www.sidc.be/silso/datafiles). As of July 1, 2015, the original sunspot relative number data provided by WDC-SILSO was replaced by a new, completely revised data series. This version is numbered 2.0. Due to the great ambiguity in version 2, we use version 1 until 01.07.2015, and for the following years we have restored version 1 based on version 2. Figure 1 shows the Wolff numbers of the original version 1 and version 1 calculated from version 2.

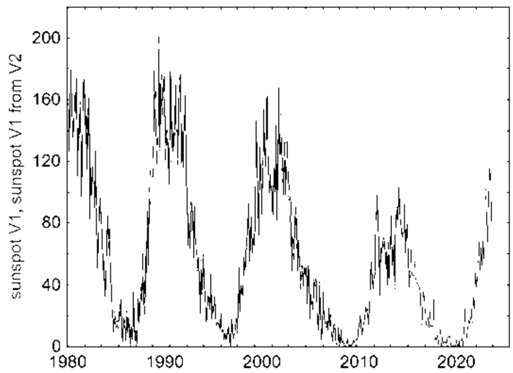

Fig. 1.

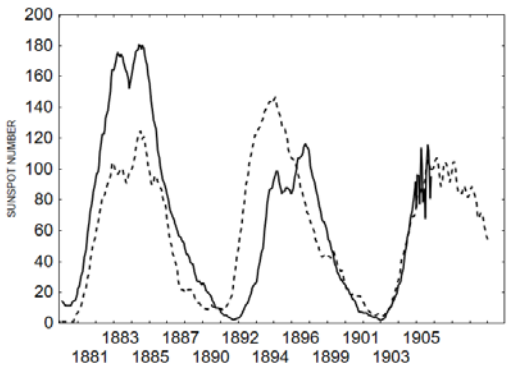

Fig. 2.

2. Data for Coronal Mass Ejections (CMEs). We used to SOHO LASCO CME CATALOG https://cdaw.gsfc.nasa.gov/CME_list/ . This catalog contains all CMEs manually identified since 1996 by the Large-Angle and Spectrometric Coronagraph (LASCO) on board the Solar and Heliospheric Observatory (SOHO) mission.

Comparison of cycles 12, 13 and 14 with cycles 23, 24 and 25

While discussing solar cycles, it's worth noting that cycles 12-14 (dotted line) exhibit single maxima, whereas cycles 23-25 (solid line), Fig. 2, have double peaks. This phenomenon can be explained by the solar dynamo operating in different regimes, as elucidated by researchers like Georgieva [1] and studies by Paul Bushby and Joanne Mason [2] in 2004. These regimes are determined by the balance between diffusion and advection in the upper and lower regions of the solar convection zone.

When we consider the speed of surface poleward meridional circulation and diffusion in the upper part of the convection zone, it becomes clear that the dynamo operates in a moderately diffusion-dominated regime. In this regime, some of the magnetic flux shortcuts the meridional circulation and diffuses directly to the bottom of the convection zone at mid-latitudes. Another part of the flux follows a path to the poles, down to the base of the convection zone, and then moves equatorward to latitudes where sunspots tend to form.

These two components of the magnetic flux, influenced by the differential rotation at the convection zone's base, give rise to the occurrence of two distinct peaks in sunspot activity. These peaks are closely related but not perfectly synchronized, explaining the phenomenon of double-peaked sunspot cycles and the Gnevyshev gap.

In conclusion, the flux transport dynamo theory provides a natural explanation for the double-peaked sunspot cycle and the Gnevyshev gap, indicating that during cycles 23 and 24, the solar dynamo functions in a moderately diffusion-dominated regime, while cycles 12 and 13 are in an advection-dominated regime.

Number of sunspots and number of coronal mass ejections cycle

The analysis revealed a clear relationship between the number of sunspots and the occurrence of CMEs within an 11-year solar cycle. Correlation analysis demonstrated a statistically significant positive correlation between sunspot numbers and the frequency of CMEs. Furthermore, time series analysis revealed that periods of high sunspot activity were accompanied by increased CME occurrence, while periods of low sunspot activity exhibited a reduced number of CMEs. Subramanian and Dere [3] found that 84% were associated with ARs. Yashiro et al. [4] suggested that almost all CMEs associated with sizable flares (stronger than class C3.0) occur in ARs. Figure 3 shows the relationship

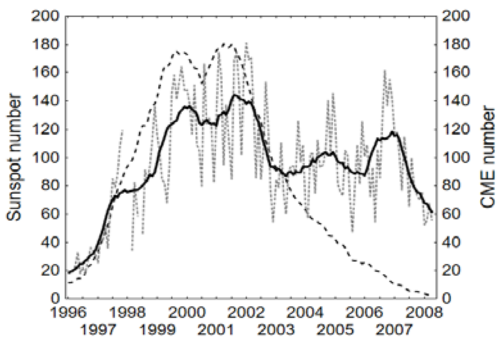

Fig. 3

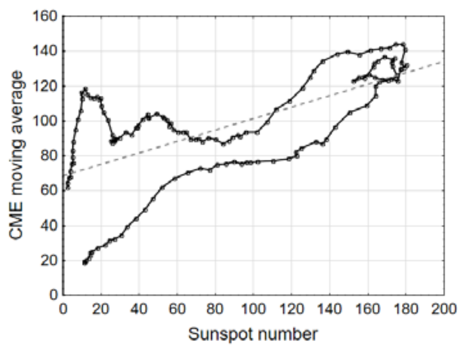

Fig. 4.

between the number of sunspots (dashed dottedline, black) and CMEs (dotted line, grey) during cycle 23. It can be seen that after 2003 this relationship practically does not exist. While the number of sunspots decreases, the number of CMEs remains quasi-constant. Figure 4 shows a scatterplot of the relationship between the number of sunspots and CMEs for the same cycle. The presence of hysteresis between the ascending and descending part of the cycle can be seen.

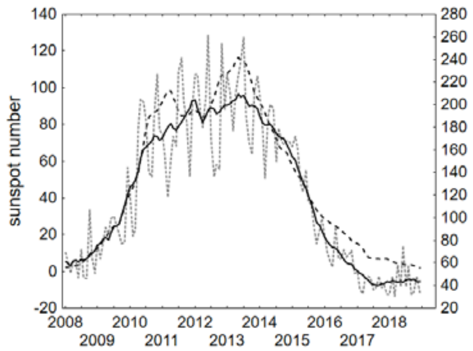

Fig. 5.

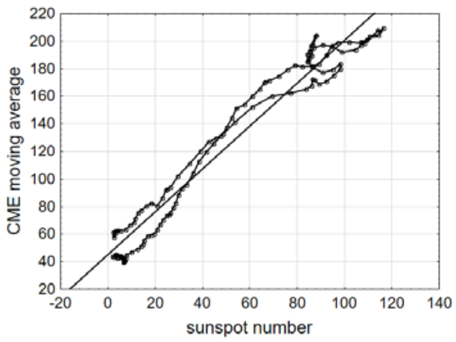

Fig. 6.

In contrast to cycle 23, during cycle 24 the number of CMEs follows throughout the cycle the number of sunspots Fig 5. sunspots (dashed dottedline, black) and CMEs (dotted line, grey). A from the scatterplota shows a very small hysteresis between the ascending and descending part of the cycle Fig. 6. The study of the indicators of the solar wind during the 23rd cycle shows that precisely in the year 2003 we have a maximum of temperature, a maximum of flow pressure and a maximum of the speed of the solar wind.

Summary

While sunspots serve as a primary indicator of solar activity, other indicators, such as magnetic loops, flares, and prominences, can contribute to the generation of CMEs. These phenomena are not solely dependent on the presence of sunspots and can maintain or even increase CME activity independently of sunspot numbers.

Understanding these complex relationships is crucial for accurately predicting solar activity and its potential impacts on Earth and space weather. Further research into the interplay of various solar phenomena during different phases of the solar cycle is necessary to gain a comprehensive understanding of the underlying mechanisms governing the Sun's behavior.

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