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Statistical Study of Solar Activity Parameters of Solar Cycle 24

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Abstract: **The solar atmosphere is one of the most dynamic environments studied in modern astrophysics. The term solar activity refers to physical phenomena occurring within the magnetically heated outer atmosphere of the Sun at various time scales. Sunspots, high-speed solar wind, solar flares and coronal mass ejections are the basic parameters that govern solar activity. All solar activity is driven by the solar magnetic field. The present paper studies the relation between various solar features during solar cycle 24. The study reveals that there exists a good correlation between various parameters. This indicates that they all belong to same origin i.e., the variability of Sun's magnetic field.**

Index Terms: **Coronal Mass Ejections - Solar Activity- Sunspot Number- Solar Radio Emission Flux- Solar wind**

I. INTRODUCTION

Sun's ambience is wide and has ever active surroundings that are under education in today's current astrophysics because of its continuous changes in the Sun's magnetic field. The Sun's surface changes with time during its 11 years cycle and its magnetic flux affects robustly the entire environment. The 11 year tenure was earlier defined by the sunspot number change (Schwabe, 1844). As we are running in the solar cycle 24, which has its beginning in December 2008, is the weakest solar cycle (Jiang et al. 2015; Singh & Bhargawa, 2017, 2019) and it is leading into minimal stage of the solar cycle 25. Of all astrophysical activity features, the sunspots are the most easily observed and have been tracked since around early 1600s by Galileo. The sunspots can come into view as solitary, remote dark central region covered by a regular less dark region around umbra (Spiegel, 1994). Since last four hundred years, the periodic changes in the Sun's activity were featured with smoothed sunspot numbers that was brought into existence with its classification (Kunzel, 1961). The number predicts short term periodic high and low activity of the Sun. The part of the cycle with low sunspot activity is referred to as "solar minimum" while region with maximum solar activity is called as "solar maximum". Hathaway et al. (2002) examined the 'group' sunspot number which shows it use in featuring the Sun's performance during the solar year (Hoyt & Schatten, 1998a).

Coronal mass ejections (CMEs) are the explosions in the solar corona during its high magnetic conditions. CMEs from the solar corona are the most spectacular phenomena of solar activity and perhaps the primary driver and source of space weather (Gosling, 1997; Singh et al. 2010). Traditionally, the coronal mass ejection ejects away around 1014–1017g of the core which gives out the energy of the order (~10^{19} – 10^{25} J) (Chen, 2011; Howard et al. 1985; Vourlidas et al. 2002). Solar flares are the other class of the most spectacular disturbances seen on the Sun, typically lasting several minutes. It can be defined as the sudden brightening and explosive release of energy of order same as CME (~10^{19} – 10^{25} J) from a localized active region of the Sun, mainly with the appearance like electric and magnetic field radiations containing X-rays, UV rays, visible light, and radio waves. Flares takes place in lively area just about sunspots, here the strong field containing magnetic character go through the photosphere to interact with the corona. The association of solar flares and CMEs have been widely (Gopalswamy, 2006). Solar flux is also fundamental pointer of the Sun's performance that helps to find out the level of radiation obtained from the Sun. The solar flux (10.7 cm) unit is solar flux units (SFUs), where 1 SFU = 10^{-22} Watts per metre^2 per Hz. Astrophysical storm is a river of plasma consists mainly of negative charged particle, positive charged particle and α-particles, ejected from the higher environment of the Sun. The attractive region of the

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Sun, and various structures, energy and unstable changes are entrenched inside the astrophysical storm on a very large extent. Based on the 110 Skylab CMEs, (Hildner, 1976) the relation between coronal mass ejection occurrence (CMEO) and the numeral spot on the surface of the Sun is given as:

$$CMEO = 0.96 + 0.084\ N \qquad (1)$$

The above relation is autonomous of the astrophysical performance cycle which showed a velocity of 3.2 for each daytime for maximum stage of the solar cycle. In 2012, learning was made by Webb and Howard for the tenure from 1973 to 1989, with the result showing the coronal mass ejection rate of recurrence follows the astrophysical performance activity series for amplitude and phase together. Gopalswamy et al. (2009) made a revision for the relation between coronal mass ejection and numeral spot number on the surface of the Sun and they found that the relation between them was weak during the maximal stage of the astrophysical cycle whereas in the uprising and the downfall time of the astrophysical cycle the trend is not the same. Sharma & Verma (2013) also revised the link among the various solar characteristics. They were with the good agreement as an inference. Visakh et al. (2017) studied solar activity for 24th solar cycle with the inference that coronal mass ejection and sunspot cycle are not in good correlation. Christian (2018) have analyzed coronal mass ejection (CME) observed parameters, sunspot number (SSN) and sunspot area (SSA) for solar cycle 23, comparing them to check for possible similarities in their variation pattern within the solar cycle. For the present work the analysis has been done among the various astrophysical parameters for the tenure of 2009 to 2017.

II. DATA USED

The sunspot and solar flux information has been taken from the link: http://omniweb.gsfc.nasa.gov/form/dx1.html. The astrophysical flares information has been taken from: spaceweatherlive.com. The CME data used in this study is collected from LASCO and SOHO available in CME catalogue that can be found at http://cdaw.gsfc.NASA.gov/CME.

III. RESULTS AND DISCUSSION

Fig. 1 depicts the changes in various solar parameters during the period from 2009 to 2017, which shows that in the starting of solar cycle 24, the Sun is quiet with low sunspot number and solar activity. Fig. 1(a) depicts the annually averaged numeral number of the sunspot on the surface of the Sun, for the time of 2009 - 2017. In 2009, the numeral is 4.75 which ascend to the value of 113.63 in 2014 showing the maximal stage of the solar cycle. After that numeral value of the spot on the surface of the Sun descends for the minimal stage of the astrophysical period. In 2017, the sunspot number was 13.8. Fig. 1(b) depicts the annual happening rate of regularity of the coronal mass ejections (CME) shown in SOHO LASCO directory. Minimal rate of occurrence was 746 in 2009. Rate of regularity maximizes continuously as sunspot number and reaches to maximum 2477 in the year 2014. Thereafter CME occurrence frequency continuously decreases reaches to 784 in 2017. Fig. 1(c) and 1(d) are graph plotted for intense solar flares and 2800 MHz astrophysical radio release (F-10) correspondingly during the same period. These plots are awfully to a great extent alike to the numeral spot on the surface of the Sun. For detailed analysis scatter plots have also been plotted.

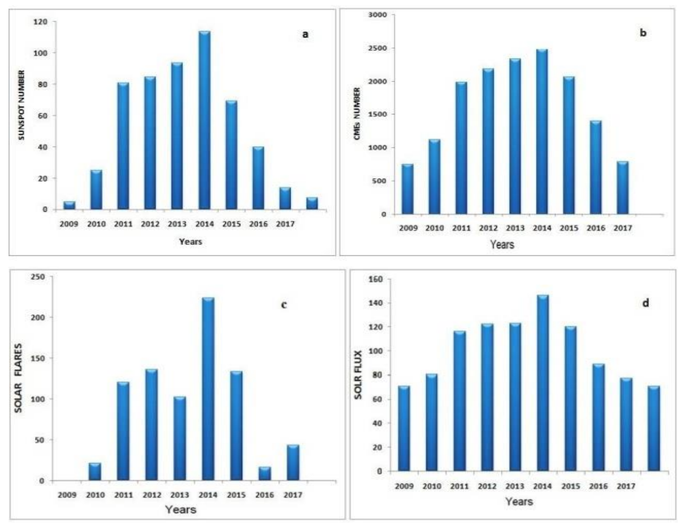

Fig. 1. Variations of (a) Sunspot Number, (b) CMEs Number, (c) Solar Flares and (d) Solar Flux during the period from 2009 to 2017.

Fig. 2 (a, b and c) shows the correlation between different solar activity parameters. It is clear that sunspot has good correlation with solar parameters like CMEs, solar flares and solar flux. The correlation coefficients were found to be 0.98, 0.91 and 0.98 for these parameters respectively. Fig. 3 shows the yearly analysis of the solar flux with its classification and its comparison with the smoothed sunspot number (SSN). From this figure we observed that the maximum peak is obtained in the year 2014 for the C- class flare, M-class Flare and the X-class flare with their respective values as 1776, 207 and 16 respectively for the year 2014.

Correspondingly, the smoothed sunspot number observed was 113.3 for the year 2014. Hence, it was found that the year 2014 was the maximum solar flare year of the cycle 24. Solar year 2009 and 2017 shows the minimum values for the C, M and X class of the solar flare as they are the minimal year of the solar cycle with the SSN values as 4.8 and 21.7 respectively. It is also observed that from 2009-2014 the SSN increases and then decreases. Same trend has been followed by the C, M, X class flare for the maximum years.

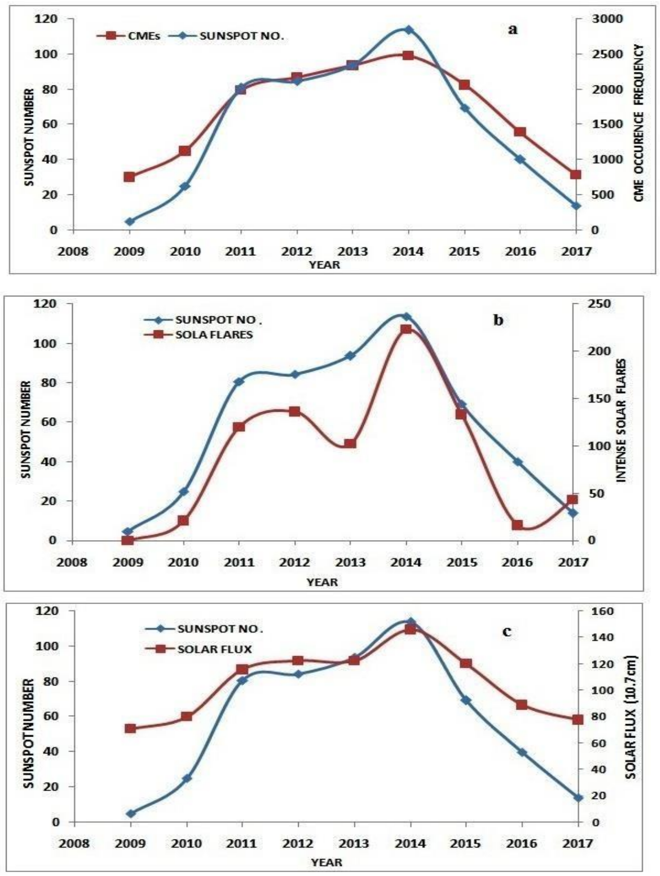

Fig. 2. Correlation between various solar parameters during the period from 2009 to 2017.

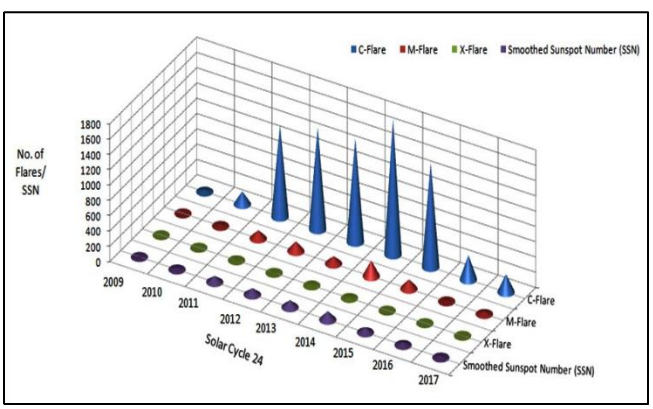

Fig. 3. Annual variation of Solar Flares with Smoothed Sunspot Number (SSN).

Fig. 4 shows the variation of the yearly solar indices and its comparison with sunspot number, it is observed that mean value of the solar indices is minimal for 2009 with the respective values of 0.02 with the maximum indices value as 6.34 for the year 2014. On the other hand same increasing trend has been followed by SSN with the maximum value of 113 for the year 2014 and minimum as 4.8 in 2009.

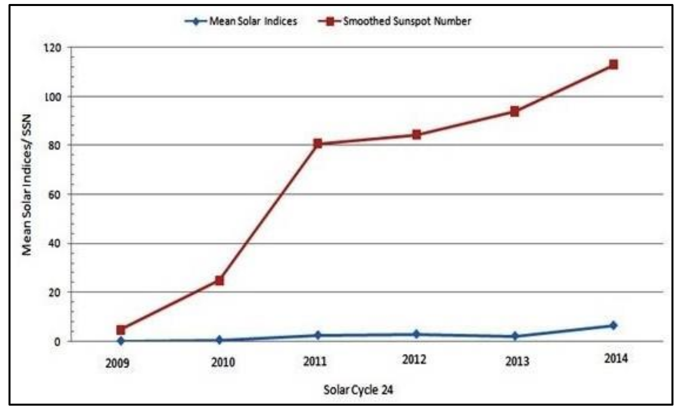

Fig. 4. Variation of solar indices till 2014 with its Smoothed Sunspot Number (SSN).

In fig. 5, we have shown the variation of Dst storms with the smoothed sunspot number. The figure predicts that the minimum occurrence of disturbed storm time index (Dst) for the year 2009 with SSN as 4.8. Smoothed sunspot number increases till 2014 and then declining phase. Same behavior is observed by the disturbed storm time index with little contradiction for the year2013 and 2014 which is due to the variation of Dst occurrence for moderate, intense, severe storms for the same year which on total shows some contradiction.

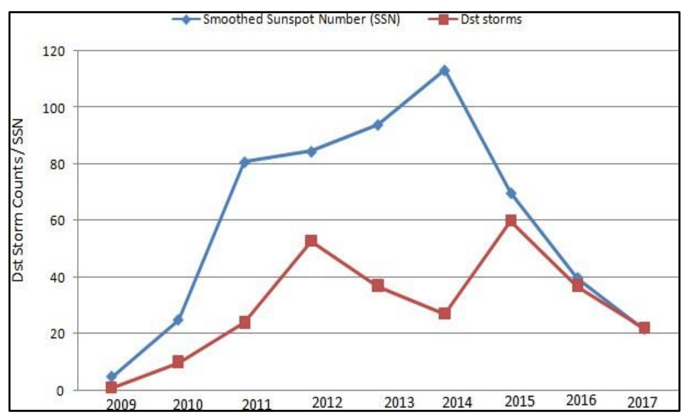

Fig. 5. Yearly variation of disturbed storm time counts with its Smoothed Sunspot Number (SSN).

From the above results, it is found that the strong correlation is observed for the declining phase of the solar cycle than the uprising phase. This factor is in very well agreement with the results available. Also it is observed as an inference that Coronal mass ejections and as a result disturbed storm time index is more for the year when the solar flare energy are more with the high smoothed sunspot number for the particular year which is in good agreement with other published works.

SUMMARY & CONCLUSION

Solar Cycle 24 started with minimal activity in the beginning. The number of occurrence of CME (per year) increases/ decreases with increase/decrease in sunspot numbers, but the variations are different. Coronal mass ejection occurrence rate when compared with the sunspot numbers on the surface of the Sun depicts a strong link between them. Kane (2011) in his findings observed the same inference for the previous period. Ramesh & Rohini (2008) and Ramesh (2010) reported that the CME ejection occurrence rate was in good agreement with the sunspot area on the surface of the Sun than that with the sunspot numbers on the surface of the Sun. Conversely, Kane (2008) stated that spot area on the surface of the Sun is strongly linked with the sunspot numbers on the surface of the Sun. The sunspot numbers on the surface of the Sun and astrophysical change are in good link with coefficient value as 0.98. Year 2014, was the maximum solar flare year whereas solar year 2009 and 2017 are the minimal solar flare year. Comparison of the yearly solar indices with sunspot number shows that mean value of the solar indices is minimal for 2009 with the respective values of 0.02 with the maximum indices value as 6.34 for the year 2014. Same behaviour of occurrence is there smooth sunspot number and Dst storms with some contradiction due to the variation of Dst occurrence for moderate, intense, severe storms for the same year.

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