Relation Between Solar Wind Parameters, Coronal Mass Ejections And Sunspot Numbers

Visakh kumar U.L, Bilin Susan Varghese, P.J Kurian

Abstract— **The solar atmosphere is one of the most dynamic environments studied in modern Astrophysics. The sun has a complex system of magnetic field. Solar activity refers to any natural phenomenon occurring on the sun such as sunspots, solar flare and coronal mass ejection etc. Such phenomenon has their roots deep inside the sun, mainly driven by the variability of the sun's, 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 belongs to same origin i.e.; the variability of Sun's magnetic field.**

Index Terms—**About four key words or phrases in alphabetical order, separated by commas.**

I. INTRODUCTION

The solar atmosphere continues to be one of the richest and most dynamic environments studied in modern astrophysics. Like earth, the sun has seasons. More precisely, it has a cycle that lasts about 11 years. The number of sunspots rises and falls and rises again in about 11 years. This is due to the variability of solar magnetic field. The variability of the magnetic field has a strong influence on the dynamics of the outer layer of the sun and is registered by several solar parameters such as the sunspot number, CME occurrence frequency, solar wind plasma temperature and solar wind speed.

The current solar cycle 24, is the weakest solar cycle in more than a century and it is now heading towards the next solar minimum phase which would be the beginning of solar cycle 25. The last solar minimum phase lasted from 2007 to 2009 and it was historically weak. In fact, it produced three of the most spotless days on the sun since the middle 1800's . The current solar cycle is the 24^{th} solar cycle since 1755 when extensive recording of solar sunspot activity began. Solar cycle 24 is currently on pace to be the weakest sunspot cycle with the fewest sunspots since cycle 14. Solar cycle 24 continues a recent trend of weakening solar cycles which began with solar cycle 22 .

Coronal mass ejections are the most spectacular phenomenon of solar activity. CMEs occur in regions of closed magnetic fields that overlie magnetic inversion lines [1]. A study on CME is an important topic that is related directly to space environment [2]. The sunspot cycle is an important form of solar variability that indicates the extent of closed magnetic field structure on the sun, and hence is important to the study of the origin of coronal mass ejections. The solar wind is a stream of charged particles released from the upper atmosphere of the Sun. This plasma consists of mostly electrons, protons and alpha particles. The magnetic field of the Sun, as well as different structures, waves and turbulent fluctuations on a wide range of scales are embedded within the solar wind.

Webb & Howard [3] studied CMEs from 1973 to 1989 concluding that CME occurrence frequency tends to follow the solar activity cycle in both amplitude and phase. Gopalswamy et al. (2009) [4] have also studied CME occurrence in relation to sunspot number and found that the correlation between them is quite weak during the maximum phase period of solar cycle as compared to that in both ascending as well as descending phase. Researchers have studied the solar cycle that ended in December 2008 which is known as solar cycle 23. This cycle was longer than normal. The present solar cycle 24 started in December 2008 and is expected to have a shorter time period. In this paper we have studied the relation between various solar features during January 2009 to December 2015 for this cycle.

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II. SOURCES OF DATA

Data were obtained from the omniweb data explorer, http://omniweb.gsfc.nasa.gov/form/dx1.html.

The solar wind parameters, namely, proton temperature in Kelvin together with the solar wind speed in km/ s from 2009 – 2015, were downloaded from NOAA centres collected by the ACE satellite.

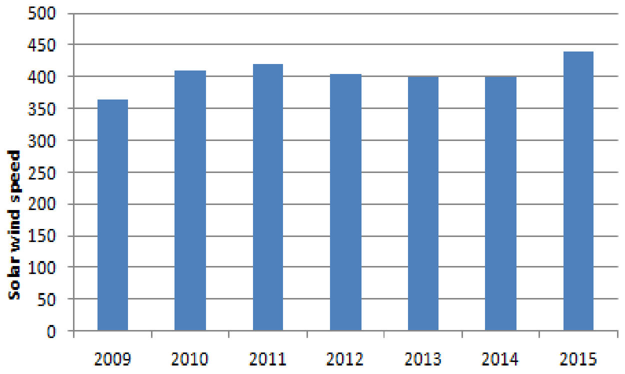
III. DATA ANALYSIS

Figure 1 shows the variation of different solar parameters during January 2009 to December 2015. The figure shows that the sun is very quiet with less sunspots and solar activity in the beginning of solar cycle 24.

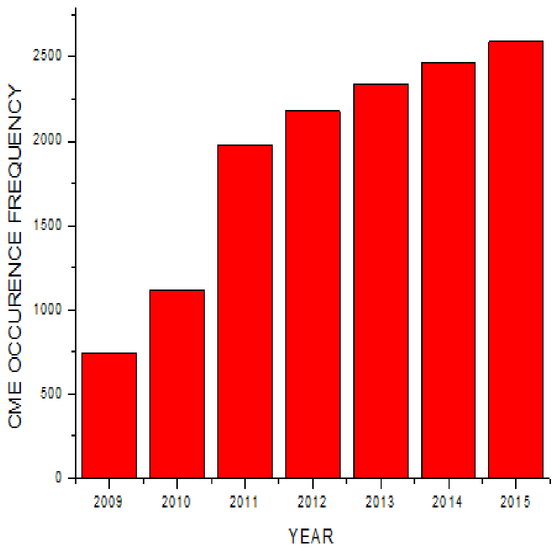
Figure 1(a) shows the yearly averaged solar wind speed in km/s during the period 2009-2015. In 2009, the solar wind speed was 363 km/s. It continuously increases and reaches up to 419 in 2011.Then it decreases up to 398 km/s in 2014.This is because during "solar maximum," CME's and SEP's originating from the solar surface play a more prominent role than the normal solar wind in the solar wind magnetospheric interactions. The solar wind speed is highest during the year 2015. On comparing yearly average wind speed with yearly average CME number , when the speed of the wind is high the total number of CMEs is also high.

Figure 1(b) shows the yearly occurrence frequency of the coronal mass ejections (CME) given in SOHO LASCO catalogue. The lowest frequency has been 746 in 2009. The frequency increases in the year 2010 to 117. In 2011 CME frequency increases further, reaching at 1979 .Thereafter CME occurrence frequency continuously increases up to 2588 in 2015.

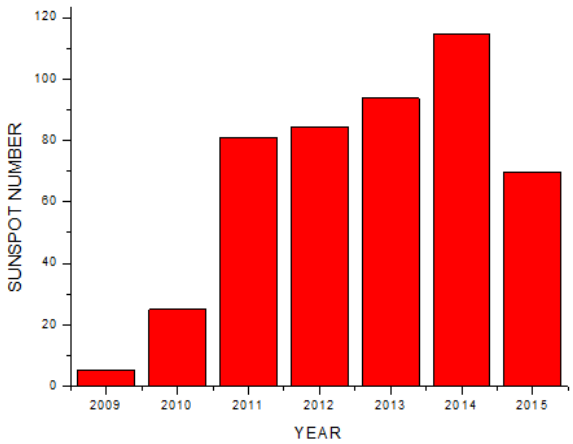
Figure 1(c) shows a similar plot for sunspot numbers during the same period. In 2009, the sunspot number was 5.18. It continuously increases and reaches up to 114.44 in 2014 which indicates solar maximum. In 2015,the sunspot number was 69.8.



(a)



(b)



(c)

Figure 1

Variation of different solar parameters during January 2009 to December 2015.

For detailed analysis linear plots have also been plotted.

Figure 2 shows the linear plot for yearly occurrence frequency of CME and sunspot number. The mismatch in peak occurrence is obvious. The correlation coefficient was found to be 0.91.

Figure 3 shows the linear plot for yearly occurrence frequency of CME and solar wind speed in km/s. The correlation coefficient was found to be 0.66.The correlation is least during solar maximum and highest during solar minimum.

Figure 4 shows the linear plot for solar wind plasma temperature in Kelvin and solar wind speed in km/s. The correlation coefficient was found to be 0.96. As solar wind temperature increases solar wind speed also increases.

Figure 5 shows the linear plot for sunspot number and solar wind speed in km/s. The correlation coefficient was found to be 0.42. Here also very good correlation was obtained in solar minimum conditions.

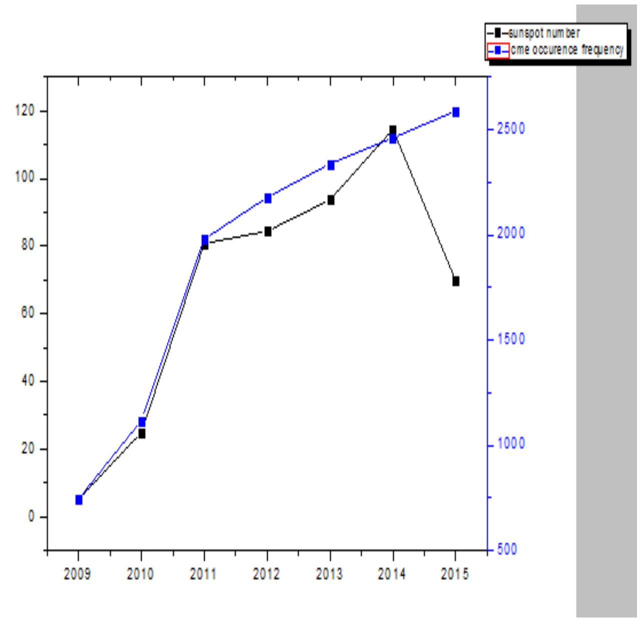


Fig 2

Linear plot for yearly occurrence frequency of CME and sunspot number.

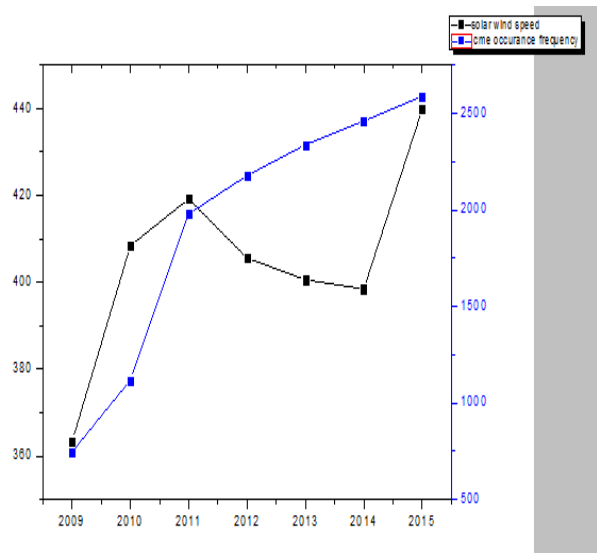


Figure 3

Linear plot for yearly occurrence frequency of CME and solar wind speed

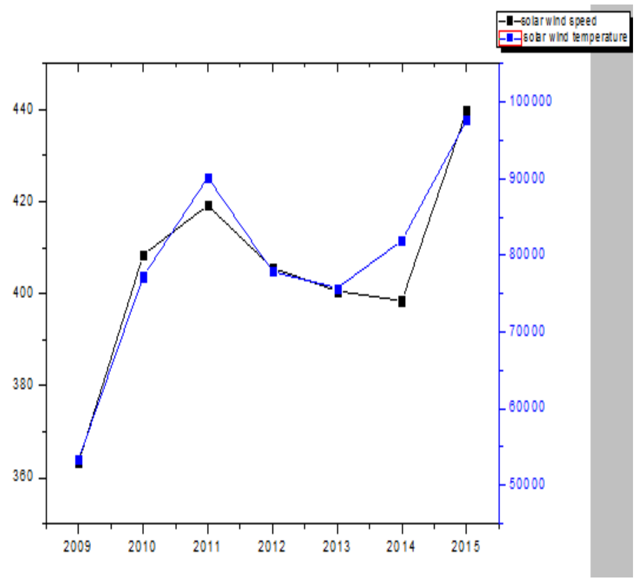


Figure 4
Linear plot for solar wind plasma temperature and solar wind speed

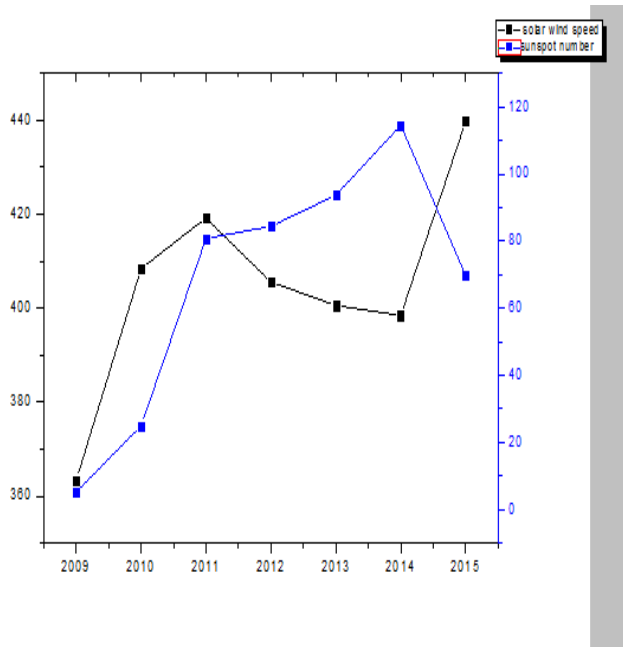


Figure 5
Linear plot for sunspot number and solar wind speed.

IV. Results and Discussion

1) Solar cycle 24 has initially displayed much less activity.
2) CME occurrence frequency shows almost similar variational pattern with other forms of solar activity. This indicates similar origins, probably due to similar magnetic configuration affecting all parameter simultaneously.
3) CME occurrence frequency and sunspot number show very high & positive correlation.

Kane 2011 [5] has found similar result for earlier cycle. But on comparing the plots of 1(b) & 1(c) we see that CME activity and sunspot cycle do not match exactly. It may be due to the fact that CME's originate not only from sunspot regions but also from non-sunspot regions. Ramesh & Rohini [6] and Ramesh [7] have shown that CME frequency is better related with sunspot area than with sunspot numbers. However, Kane [8] has mentioned that sunspot areas and sunspot numbers are very highly correlated. Therefore, sunspot number, sunspot group number and sunspot area could be used as good proxies for each other.
4) Solar wind speed and solar plasma temperature show positive and high correlation with a correlation coefficient of 0.96.
5) Solar wind speed and sunspot number shows low correlation of 0.42. Here very good correlation was obtained under solar minimum conditions.
6) The correlation coefficient between CME occurrence frequency and solar wind speed found to be 0.66.The correlation is least during solar maximum and highest during solar minimum.

Acknowledgements

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