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CME speed as a measure of Solar and Geomagnetic activities

Niyaz Ahmad[1*], Sarver Ahmad[2], C. M, Tiwari[3], G. N. Singh[4]
[1, 2, 3]Department of Physics A.P.S University Rewa (M. P.) , India.
[4] Department of Physics, Sudarshan College, Lalgaon Rewa (M.P.)
[1]* Corresponding author mail: naazneen786.94@gmail.com,

Abstract: *The key intent of this paper is to investigate the association between the monthly mean speeds of coronal mass ejections (CMEs), sunspot number (SSN), geomagnetic Dst and Ap indices during the period 1996 – 2008 (solar cycle 23). We have observed a notable relationship between the monthly mean maximum speeds and sunspot numbers, Ap and Dst indices. The anomalies in the monthly Dst index depict stronger correlation with the CME speed as compared to ISSN data. Contrasted to sunspot numbers, CME speed index lacks a double peak maximum. However CME speed profile peaks during the declining phase of the given cycle. The three parameters- Ap, Dst and CME speed lag behind the sunspot number in a similar fashion by some months. A double peak is shown by CME number similar to that observed in sunspot number. The occurrence rate remained very high even near the solar minimum of cycle 23, whereas both sunspot number and CME mean maximum speed were approaching their minimum values. Also the Ap index shows a distinct peak between the period May 2002 and August 2004 for SC 23. It is thus obvious from the above results that the CME speed index can be a good measure of both solar and geomagnetic activities.*

Key Words: *Solar activity, Solar-terrestrial relations, coronal mass ejections (CMEs).*

1. INTRODUCTION:

Whenever the coronal mass ejections blow up from the sun, the fast moving particles and powerful magnetic fields may heave towards earth producing geomagnetic storms and cause adverse impacts on satellites, communications, electric power, pipelines etc. In the maximum phase of SC, several severe storms have been examined having their association with coronal mass ejections (Gopalswamy et al. 2007, Zhang et al. 2007). The near-earth perturbations are indicated/measured through several parameters, for example aa (Mayaud 1972), Ap (Bartels et al. 1939) and Dst (Sugiuara 1964). Sunspot number is a good measure for solar activity (Hoty and Schatten 1998), SFI (Klick et al. 2010), & TSI (Lean et al. 1995). Gopalswamy (2006) also brought in the daily CME rate to be a novel measure/indicator of solar activity strongly associated with geomagnetic activity. A correlative association is depicted by all these indices among each other. A satisfactory description (Etcher et al. 2004) is nevertheless evaded, even though the association between solar and interplanetary parameters has been elaborately investigated (Etcher et al. 1999).

In the current paper, the linear CME speeds have been utilized to discover their geomagnetic activity. Because CMEs have frequently been correlated with strong GMSs (Srivastava and Venkatakrishnan 2004, Yurchyshyn et al. 2004, 2005) and they display the most significant correlation whenever the CME directed towards the earth (Gopalswamy 2010) is associated with a magnetic cloud. Since Solar activity is also characterized by the SSNs, but they cannot all the time be the precise reflectors of the net intensity of solar outbreaks because the sunspots are not uniformly able to generate high energetic events (Shi & Wang 1994, Abramenko 2005). In the decreasing phase of solar cycle more flares are prone to occur and during the decreasing phase of cycle 23, it was found even stronger (Bai, 2006). The maximal CME speeds normally do not pursue the sunspot cycle (Gopalswamy et al 2006). So the CME speed index is a measure of geoeffective solar activity and thus has advantages over the SSNS n the way that it is more purposeful & significantly reflects the intensity of earth directed solar eruptions.

The changes correlated with the sunspot activity cycle had been accounted prior to CME occurrence rate and speeds (Hildner et al. 1976, Webb & Howard 1994, Gopalswamy et al. 20003), angular widths (Kahler et al. 1989, St. Cry & Webb 1991). Also several research papers have revealed the substantial association among various coronal ejection mass parameters (speed, rate, angular extent etc.) & GMSs (Richardson et al. 2002, Yurchyshyn et al. 2004), Kp index (Zhang et al. 2003, Miyoshi & Kataoka 2005), ap index (Leamon et al. 2003, Forbes et al. 2005), & aa index (Luhmann 1997, Richardson et al.2002). Gopalswamy et al. (2003) analyzed the that there is a time delay of 2 years between the CME occurrence rate against the sunspot maximum. This time lag/delay is further reduced as the solar cycle is explained by the sunspot region. The high speed CMEs are found to follow the sunspot cycle streets ahead than the whole CME population.

We will discuss the CME speed index along with its maximal speeds, compare CME speed index with SSNs and the geomagnetic Ap and Dst indices.

2. Data Sources and Methods :

The monthly mean CME speed including maximal speeds are obtained from the Solar and Heliospheric Observatory (SOHO) mission's Large Angle and Spectroscopic Coronagraph (LASCO, Brueckner et al., 1995) assembled in CME catalog, http://cdaw.gsfc.nasa.gov/CME_list/index.html (Yashiro et al. 2004, Gopalswamy et al. 2009). The entire period from 1996 till present is covered by this catalog. We have selected the monthly mean along with the maximal speeds as shown in figure 1. After selecting the speeds, two huge gaps in the CME data during July-September 1998 and January 1999 have been observed. CME rate has been calculated from CME number by calculating all events over a given Carrington rotation number (CR) & using LASCO operational time over that CR (Gopalswamy et al. 2003). In this analysis (paper), the CME number has been determined covering all events in the CME catalog.

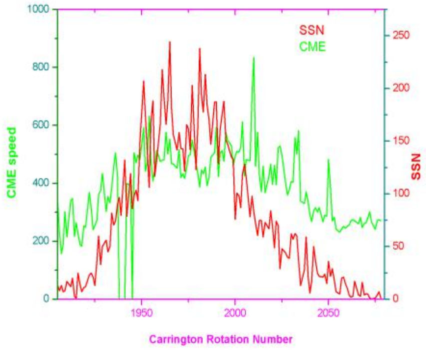

Figure 1. In this plot, the data sets (SSN and CME speed) for solar cycle 23 have been compared, taken monthly. The ISSN has been represented by red line while the green curve shows CME speed.

We have obtained the ISSN & Ap (geomagnetic index) from the national Geophysical data Center (http://www.ngdc.noaa.gov/) to studying SC 23 and the World data Center for Geomagnetism in Kyoto university (http://wdc.kugi.kyoto-u.ac.jp/dstdir/) provided the Dst for the same time interval.

The solar particle effect on the magnetic field of earth is determined by the Ap geomagnetic index & the normal rank of geomagnetic activity at the earth on a particular day is also distinguished by this index. The Ap index is obtained from a & Kp indices (Batels et al. 1939). Calculated at various mid-latitude stations globally, differentiating the changes in the geomagnetic field by virtue of currents produced within the ionosphere of the earth as well geomagnetosphere.

The Dst on the hourly basis (Sugiura1964) has been collected from various magnetometer stations around the equator. The Dst index directly determines the disturbance in the H-component of the geomagnetic field whose source being the ring current. The intensity in the geomagnetic storm is indicated by the large negative Dst values. Ap & Dst have been shown to be strongly correlated when the GMSs are active as the ring current contributes to it much significantly (Fares Saba et al. 2005). The below figure 2 depicts the 30 days mean values of both Ap & Dst indices. They displays strong correlation (-0.81), though there is a variation in their exact value, also their coincident crests & troughs are obvious.

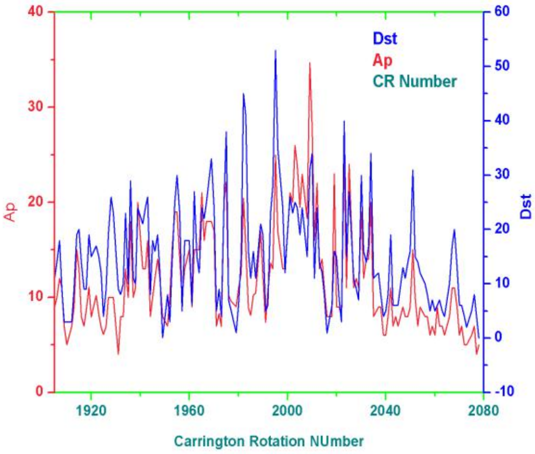

Figure 2 It represents the geomagnetic monthly Ap (red) and Dst (blue) indices. Here for convenience the Dst sign was taken as positive.

3. Results:

In figure 1, we have plotted CME and ISSN for SC 23. Clearly the occurrence of the11-year sunspot activity is depicted by the CME speed index. In the maximum phase, the speeds of monthly average of daily CMEs surpass 7000 km/s and attain a value of nearly 370 km/s for the ascending and descending phases of the sunspot cycle. The monthly mean maximum CME speeds have been accentuated not to follow precisely the ISSN during the sunspot cycle 23. However in the increasing phase of the SC, both the indices display same nature and the descending & the maximum phase show some dissimilarities among them. The CME speed index lacks the well-known double peak as observed in the ISSN. Instead, there is a steady increase in the CME peak till it shows a peak for CR 1995 (October 2000). Whereas there is a rapid fall in the SSN during the decreasing phase of solar cycle, the monthly mean CME speed comparatively retains its high value even though in the presence of merely few spots. It is clear from the figure, that the peak value of CME speed index lags relative to the maximum (October 2000) of sunspot cycle 23rd by almost two years.

The peaks visible from fig. 1 have also been revealed in (Gopalswamy et al. 2010) in the plot drawn for average speed. From the results of (Gopalswamy et al. 2003, 2009), it is obvious that the average CME shows a difference when compared to the present work. The average speeds cover speeds of entire CMEs when their mean is taken at the CR periods. It has been observed that ISSN and average speed follow each other depicting a double spike with a dip in the solar maximum when its average was plotted annually (2001, Gopalswamy et al. 2008b). Here we have drawn the monthly mean speed index. The super active regions have a higher weightage by producing high speed CMEs in large numbers (Gopalswamy et al. 2007, Klick et al. 2010). The CME maximal speed index is same as the number of fast & broad CMEs verified from Gopalswamy et al. 2008b. Because the geo-effective population of CMEs being broad 7 speedy, we can infer that CME speed index can be treated as a significant measure of the geo-effectiveness.

When we perform correlation analysis, it is found that a stronger correlation is observed between CME speed index & Ap than with SSN. So we can conclude that CME index is responsible for both geomagnetic as well as solar activity. Also Dst and CME speed index are least correlated, the reason being the uneven time profile of the Dst in contrast to Ap. There can be 2 reasons for not being with a good correlation:- 1) The direction of some powerful bursts/eruptions were not earth-directed so produced no response in the Dst index, during their contribution to the CMEs, 2) It is thought that there could have been critical direction/ orientation of their magnetic fields and so did not give rise to strong GMSs. The reason for this is also clear from a higher correlation shown by Dst & CME speeds, linked with magnetic cloud structures (Burlaga et al. 1981; Yurchyshyn et al. 2004, 2005: Gopalswamy et al. 2008a). But Gopalswamy (2010) showed that such correlation is physically feeble when only non-magnetic clouds are taken into account.

From the given below plots we will point out several inferences. The mean maximum spike of CME speed (CR 1995, Oct. 2002) & the maximum in the CME number (CR 1933, August 2002) lag relative to 2nd solar maximum (CR 1985, January 2002). Results of Gopalswamy et al., 2009 and Ramesh (2010) depict that a similar trend is shown by CME rate & solar maximum.

The parameters CME speeds, CME numbers and sunspot numbers show a quite different nature during the decreasing phase of SC 23. The mean maximum speed index, the Dst index and the SSN, beyond Oct. 2002 (CR 1995) display a decreasing trend. But during year 2004, both the CME speed index & Dst index again showed a rise in their nature and a peak was observed in the middle of 2005 (CR 2035), and on the other hand the sunspot number steadily kept on vanishing.

Also from the give figures, one more interesting characteristic is that the CME number increases in the solar minimum period (CR 2055-2075). Faded tapering CMEs have been detected at ease in the decreasing phase in contrast durig rising phase (Yashiro et al. 2008). This dissimilar nature may also have been described by the fact that a considerable fraction of CMEs at this time could be low speed events related to quiescent and high latitude polar crown filaments not associated with sunspots (Gopalswamy et al. 2010, Ramesh 2010).

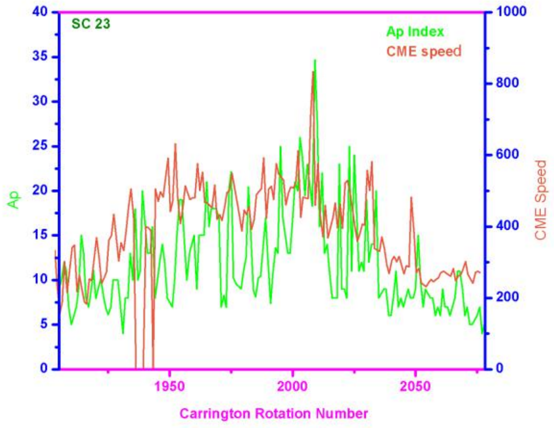

Fig. 4. Ap index plotted against CME speed and both show the peak for almost the same Carrington rotation number.

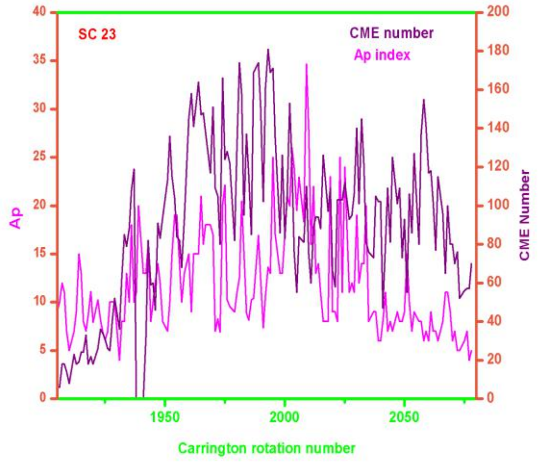

Fig.5. It compares the Coronal Mass Ejection number (CME Number) with Geomagnetic Ap index.

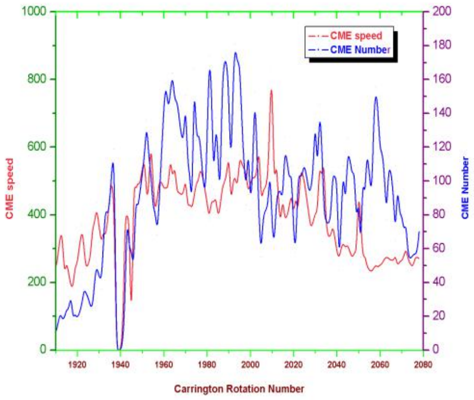

Fig. 6. It represents the cross plots of CME speed and CME number for SC 23.

One more noticeable point is the reason for the explosion of geo-magnetic activity occurred in 2003. Also the figures clearly show that Dst & Ap are explained by distinct drivers as per one sunspot cycle data investigation inferences, though CME activity occasionally imprints onto Ap configuration (when the periods between CR 1955 & CR1975 are considered for CME number & Ap profiles). The maxima/peaks of Dst & CME speed indices occur almost simultaneously, whereas Ap index peaks at (CR2010) when there is a drop in CME number and CHs on the solar disk also showed a peak (Abramenko) et al. 2010). Thus it can be said that CME activity leaked into each of the geomagnetic parameters, describing the time delay amid Dst & Ap parameters.

4. Discussion and Conclusions

The whole investigation discusses on the comparison of CME speed index, SSNs, Ap & Dst indices and verifies that CME speed index is a significant measure of solar & geomagnetic activity. More investigations are required to discover the aspects of the association between CME speed index & geomagnetic effects.

5. **The principal findings are summarized as follows:**

- A significant correlation is found between the monthly mean CME speeds, SSNs, Ap & Dst indices
- CME speed index has been found to be strongly correlated with geomagnetic indices in contrast to sunspot numbers, which implies that CME speed index can be used as a measure of both solar and geomagnetic activity.
- CME speed index lacks a double peak maximum as is found in the sunspot number. However a peak is observed in the CME speed index in the declining phase of the SC 23.
- A double peak is exhibited by the CME number in the same way as sunspot number shows. Near the solar minimum the CME rate displayed a higher value where as the CME mean maximum and SSN were attaining their lowest values.
- Also a prominent spike during the period May 2002 & August 2004 for Ap index was coexisting with the surplus of the mid-latitude CHs for SC 23.

The descending phase of solar cycle 23 showed a surplus of low-latitude CHs (Abramenko et al. 2010). However our investigation holds up the Etcher et al. (2004) statement, while the novel CME speed index elaborates the reason/cause for the second peak displayed by geomagnetic activity. It is suggested that the peak between CME speed & Ap indices is coincident. The high speed CMEs are believed to be the cause of the rupture of geomagnetic activity for a 2-year duration beginning in May 2002. It was Klick et al. (2010) who examined the time dissemination of both trivial & considerable (big) sunspot groups, hence deduced that for the SC 23 the number of huge sets shows a peak almost 2 years later the utmost time of the ISSN & little groups. It is thus obvious that the enhanced CME maximum speed during the descending phase of the sunspot cycle may help to interpret the surplus of huge and complicated active regions of the given time period.

One more feature on which we would like to accentuate is that there is a considerable association between the monthly mean CME speeds & the Ap and Dst indices. This high correlation is due to the variable CME speed & geomagnetic indices. This investigation agrees with the earlier findings (Shrivastava and Venkatakrishnan 2004 & Yurchyshyn et al. 2004, 2005), which had been founded on the investigation of separate events. CME speed index and the intensity of Bz component of the linked magnetic clouds (Qiu & Yurchyshyn 2005), have been observed to be directly related with each other, thus affecting the geomagnetic Dst index. The association between the CME speed & Dst indices was investigated by Gopalswamy (2010) considering several ejecta disjointedly. The CMEs showing a high correlation with the Dst as the CMEs burst out of the disk & headed directly towards our planet.

Since the sunspot numbers do not provide sufficient information about the magnitude of magnetic strength of sunspot regions, they are not considered as the significant gauges of sunspot activity. The sunspots usually disappear in the solar minimum period and thus the SSNs completely stop providing data regarding the future events at earth. However the maximum CME speed index furnishes information regarding the energy of solar incidents. Hence we utilize a substantial relationship between the coronal mass ejections & geomagnetism and introduce a different & more eventful parameter to delineate solar Geoeffectiveness.

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