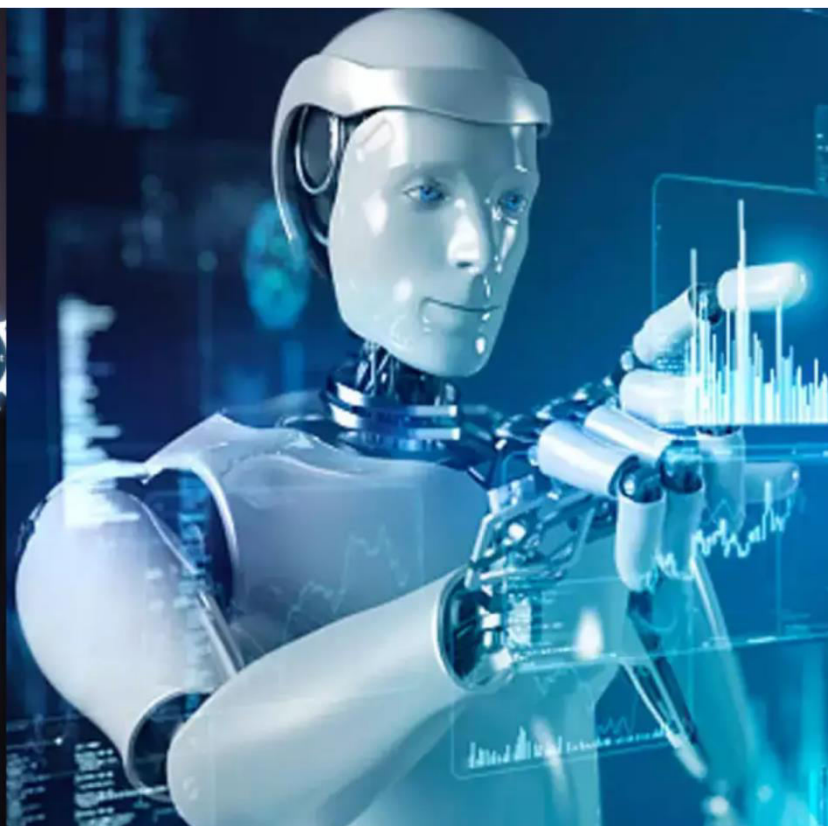




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Effect of Solar Interplanetary Features on Earth Magnetic Field during Ascending and Descending Phase of Solar Cycle 24

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ABSTRACT: Our study provides a comprehensive analysis of the behaviour of Coronal Mass Ejections (CMEs) and geomagnetic (GM) events over the course of solar cycle 24, examining both the ascending (2008–2014) and descending (2015–2019) phases. We observed a total of 16,934 CMEs during solar cycle 24, with the majority (11,707) occurring in the ascending phase (2008–2014) and the remaining 5,227 in the descending phase (2015–2019) of solar cycle 24. We recorded a total of 69 GMs events during solar cycle 24, with 36 events during the ascending phase and 33 events during the descending phase of cycle 24. Additionally, we observed that a higher intensity of large-scale CMEs (i.e., halo CMEs & partial Halo CMEs) during the ascending phase, consistent with the peak of solar activity. The peak activity for most events (GMs, Halo CMEs, and Partial Halo CMEs) is marked in 2012 during the ascending phase, while 2015 was the year with the highest number of events during the descending phase, likely reflecting the tail end of solar maximum activity transitioning into the declining phase of the cycle 24. The correlation between CME rates and solar/geomagnetic indices (Dst, Ap, Kp, IMF B, Vsp, B*V) was stronger during the descending phase of solar cycle 24. Our findings align with the general understanding that solar maximum (ascending phase) typically produces more CMEs and geomagnetic disturbances. But the stronger relationship between CMEs and geomagnetic indices during the descending phase might indicate that solar activity is still having an more impact on Earth's magnetosphere.

KEYWORDS: CMEs, Geomagnetic indices, GMs and solar cycle.

I. INTRODUCTION

Solar activity and geomagnetic activity, respectively, are disturbances brought on by variations in the earth's and sun's magnetic fields. The interplanetary medium, which lies between the sun and the interstellar medium, connects the two processes. The solar wind is severely disturbed by CMEs. Geomagnetic storms and Forbush reductions are mostly caused by these disturbances. Major disruptions in the interplanetary medium, which in turn result in abrupt changes in the Earth's magnetic field and GMs, are caused by CMEs (Lalan et al., 2013). The significance of coronal mass ejection (CME) in increasing interplanetary and geomagnetic activity is now widely recognized (Tsurutani et al., 1988; Gosling, 1993; Jadeja et al., 2008). The connection between CMEs and geomagnetic storms has been demonstrated by numerous researchers (Shrivastava & Venkatakrishnan, 2002; Gopalswami, 2006; Moon et al., 2010; Richardson, 2013). Since 1996, the large angle and spectrometric coronagraph (LASCO) of the solar and heliosphere observatory (SOHO) missions has been used to identify coronal mass ejections in images of the solar corona.

This study examines how CMEs with GMs and other solar interplanetary parameters relate to one another throughout the ascending and descending phases of the cycle 24. Additionally, we have examined the relationship between these characteristics across the chosen time frame.

II. DATA DETECTION AND METHOD ANALYSIS

We picked up CMEs, Dst, IMF B, Kp, Ap, Vsp, and V*B during solar cycle 24's ascending and descending phases. The first seven years of solar cycle 24 (2008–2014) have been chosen for the rising phase, and the final five years (2015–2019) for the declining phase. Based on angular width, we have chosen CME event data for this

investigation from SOHO/LASCO (cdaw.gsfc.nasa.gov/CME_list/). Based on the daily data, the annual average of the storm time index DST, Ap, Kp, Vsp, and IMF B for geomagnetic disturbances was obtained from the Omni web (<http://omniweb.gsfc.nasa.gov/form/dx1.html>). We have calculated the correlation coefficient between the ascending and descending phases of solar cycle 24 by plotting the cross-correlation graph between CMEs with solar and geomagnetic indices.

III. RESULT AND DISCUSSION

Based on the CME database, we have selected the solar cycle 24 ascending and descending phases. We have taken into account the years 2008–2014 for the solar cycle 24 ascending phase and 2015–2019 for the falling phase. Figure 1 shows the annual occurrence of CMEs event for ascending and descending phase of solar cycle 24. It is noted that 16,934 CMEs occurred during solar cycle 24, with the majority (11,707) occurring in the ascending phase (2008–2014) and the remaining 5,227 in the descending phase (2015–2019). This indicate that the highest number of CMEs event occurred during the ascending phase of cycle 24.

Figure 2 shows the pie diagram of the halo and partial halo CMEs event during the ascending and descending phase of solar cycle 24. There were 272 Halo CMEs and 833 Partial Halo CMEs in the ascending phase, and 64 Halo CMEs and 221 Partial Halo CMEs in the descending phase. This suggests a higher intensity of large-scale CMEs (i.e., halo and partial halo CMEs) during the ascending phase, consistent with the peak of solar activity.

Figure 3 shows the annual occurrence of number of event (halo, partial halo CMEs and GMs) during ascending and descending phase of solar cycle 24. We recorded a total of 69 GM events during solar cycle 24, with 36 events during the ascending phase and 33 events during the descending phase. During the ascending stage, the majority of occurrences (GMs, Halo CMEs, and Partial Halo CMEs) peaked in 2012. The tail end of solar maximum activity moving into the cycle's descending phase are probably the reasons as 2015 witnessed the most incidents during the descending phase.

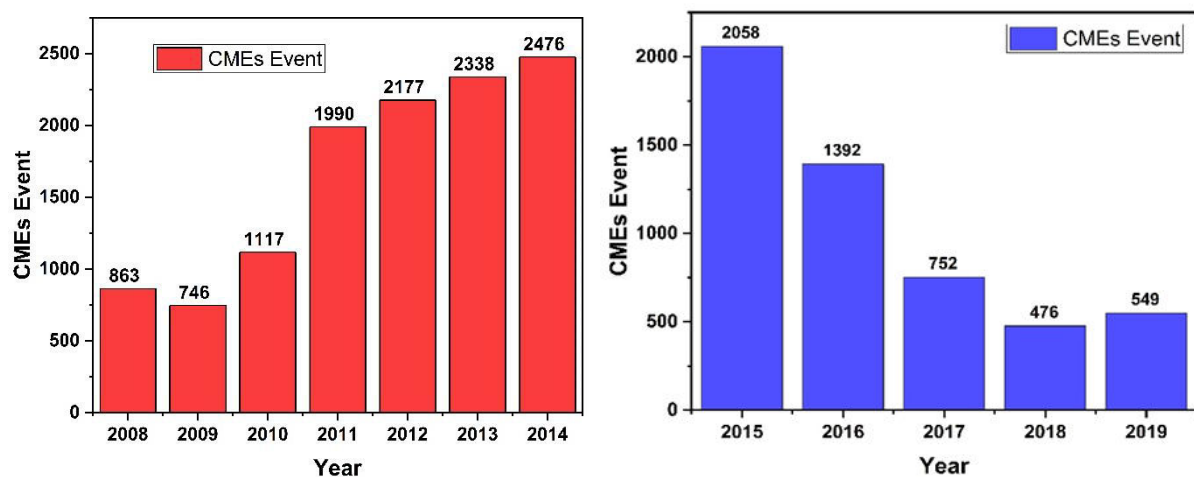


Fig 1. Show the graph of annual occurrence of CME events for the ascending (left panel) and descending phase (right panel) of solar cycle 24.

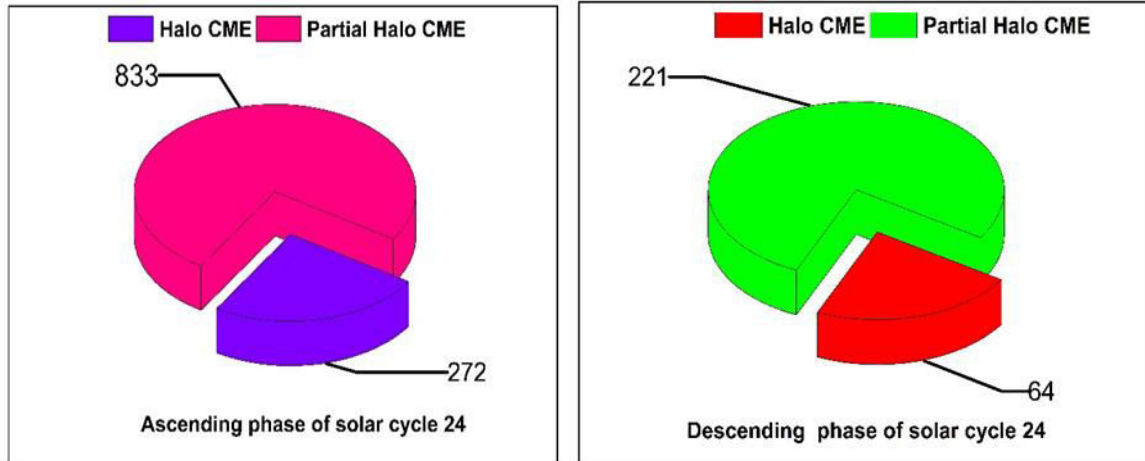


Fig 2. Shows the distribution of halo and partial halo CME event during ascending (left panel) and descending (right panel) phase of solar cycle 24.

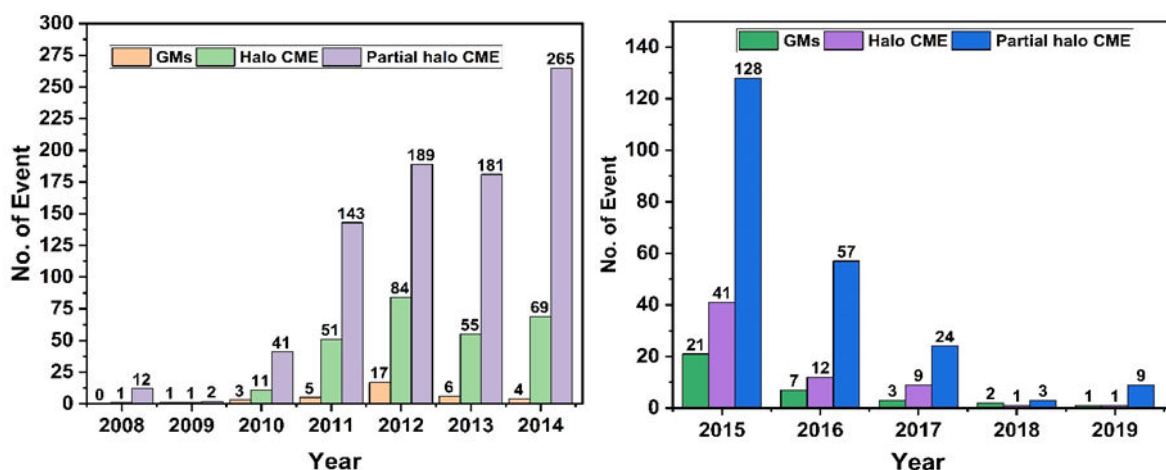


Fig 3. Shows the annual occurrence of number of events (GMs, halo and partial halo CMEs) during ascending (left panel) and descending (right panel) phase of solar cycle 24.

Figure 4 shows the relationship between the coronal mass ejection (CME) rate and three geomagnetic indices (Dst, Ap, and Kp) during the ascending and descending phases of solar cycle 24. We've specifically noted the anticorrelation between the CME rate and the Dst index, with the correlation coefficients for the ascending and descending phases being -0.79 and -0.98, respectively. The CME rate and the Dst index show an inverse relationship, meaning that as the number of CMEs increases, the Dst value tends to become more negative, indicating stronger geomagnetic storms. This is typical because CMEs are often responsible for triggering geomagnetic storms. During the ascending phase of Solar Cycle 24, there is a moderately strong negative correlation between CME rate and Dst index. This suggests that as the Sun moves towards the solar maximum (increasing activity), higher CME rates are associated with more significant geomagnetic disturbances. During the descending phase, the correlation becomes much stronger, indicating that the CME rate has an even more pronounced inverse relationship with Dst. This could suggest that as solar activity decreases after the solar maximum, CMEs still have a significant impact on Earth's geomagnetic environment, but perhaps less frequently, leading to stronger storms when they do occur. The stronger anticorrelation in the descending phase (correlation of -0.98) suggests that during this period, even fewer CMEs may lead to more intense geomagnetic disturbances, possibly due to the remaining high-speed solar wind streams or other solar phenomena. It may also imply

that while the overall CME rate decreases, the impact of each CME could be more dramatic when it interacts with Earth's magnetic field.

Additionally, we discovered a favourable association between the CME rate and the Ap and Kp index. The descending phase of solar cycle 24 has a correlation value of 0.87 and 0.86, whereas the ascending phase has a correlation coefficient of 0.78 and Ap and Kp index, respectively. Additionally, we observed that Ap and Kp exhibit the same fluctuation with CME rate during cycle 24 throughout the ascending and descending phases.

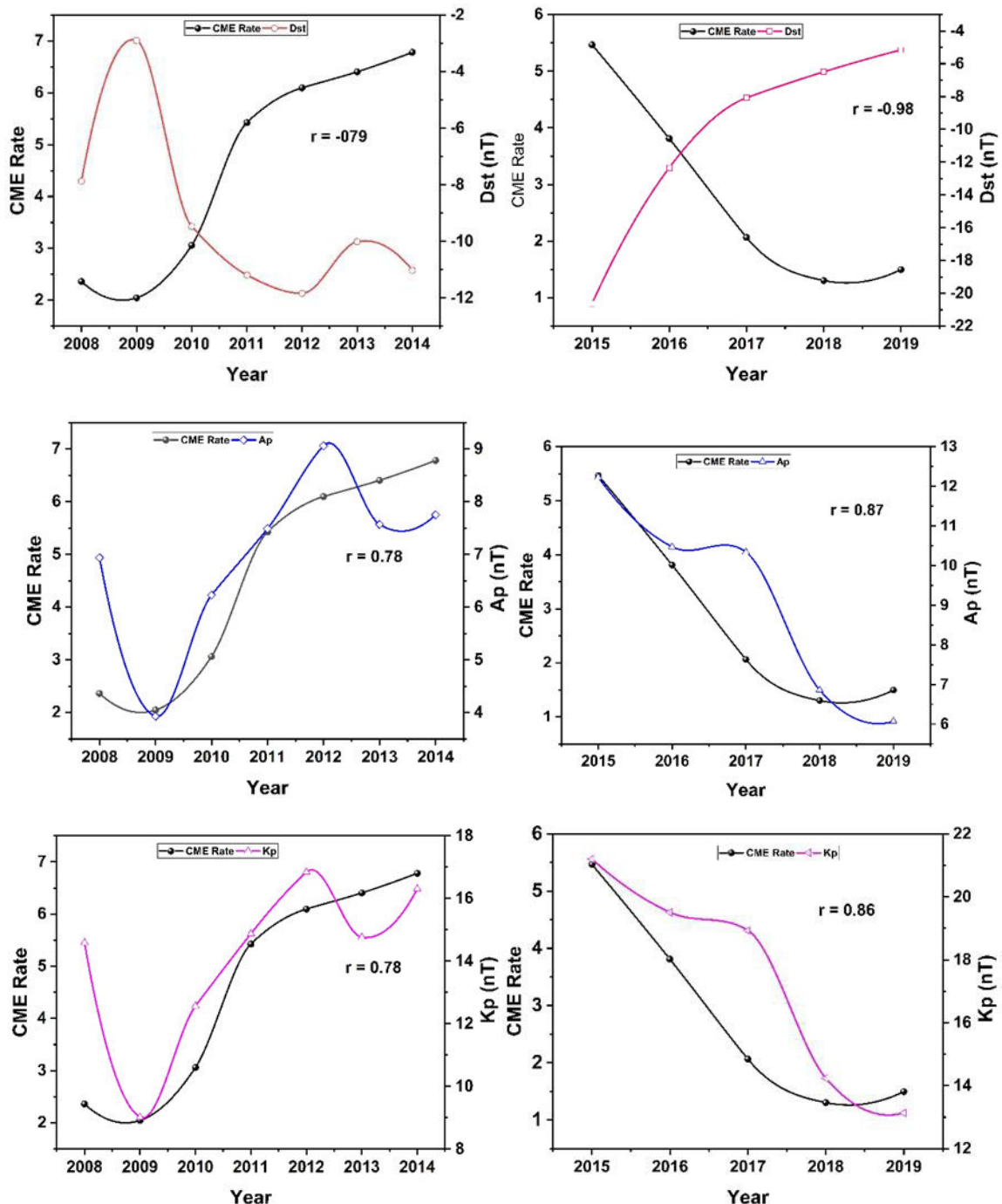
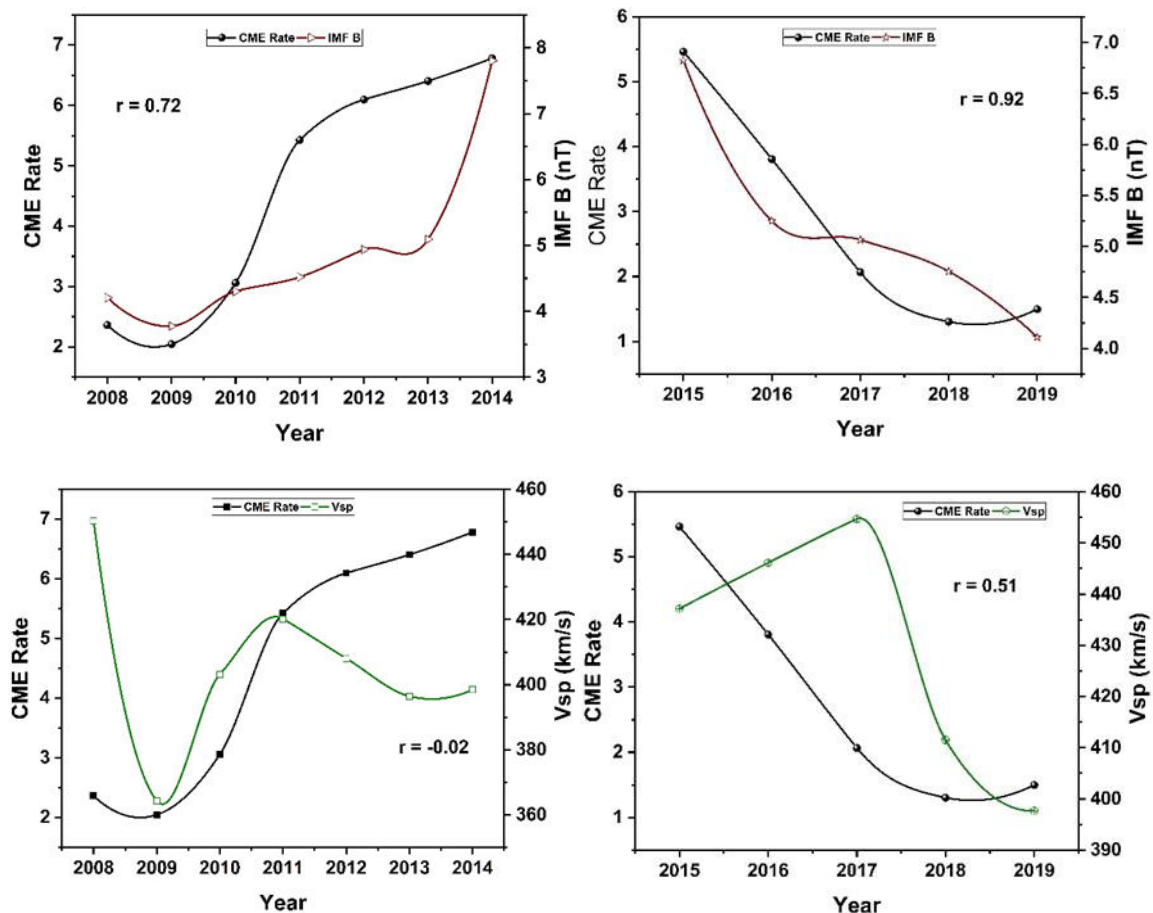


Figure 4. Shows the cross-correlation plot between CME rate and geomagnetic indices (Dst, Ap, and Kp) during ascending (left panel) and descending (right panel) phase of cycle 24.

Figure 5 shows the relationship between the coronal mass ejection (CME) rate and various solar parameters (interplanetary magnetic field (IMF B), solar plasma speed (Vsp), and the product of solar plasma speed and IMF B ($V \cdot B$)) during the ascending and descending phases of Solar Cycle 24. The correlation of 0.72 between CME rate and IMF B indicates a fairly strong relationship. This strong positive correlation suggests that during the ascending phase of the solar cycle, as the interplanetary magnetic field strength increases, the CME rate also tends to increase. The correlation between CME rate and solar plasma speed (Vsp) is almost zero, which suggests that during the ascending phase, there is no significant relationship between the CME rate and the speed of the solar wind. The negative value (-0.02) is so small that it can be considered negligible in this context. The product of solar plasma speed and IMF B ($V \cdot B$) shows a very strong positive correlation with CME rate (0.86). This implies that during the ascending phase, a combination of both solar wind speed and magnetic field strength plays a dominant role in driving the CME rate, and an increase in the product of these parameters is strongly associated with an increase in CME occurrence.

The correlation between CME rate and IMF B is even stronger during the descending phase (0.92). This suggests that IMF B has a very strong influence on the CME rate during this phase of the solar cycle. As the IMF B increases, the CME rate also increases substantially. The positive correlation (0.51) between CME rate and solar plasma speed during the descending phase indicates a moderate relationship. This suggests that, unlike during the ascending phase, the solar wind speed starts to play a more significant role in the occurrence of CMEs as the solar cycle progresses toward its maximum. The product of solar plasma speed and IMF B ($V \cdot B$) shows an even stronger positive correlation with CME rate (0.93) in the descending phase than in the ascending phase. This reinforces the idea that a combination of high solar wind speed and strong magnetic field strength drives CMEs, especially in the declining phase of the solar cycle.



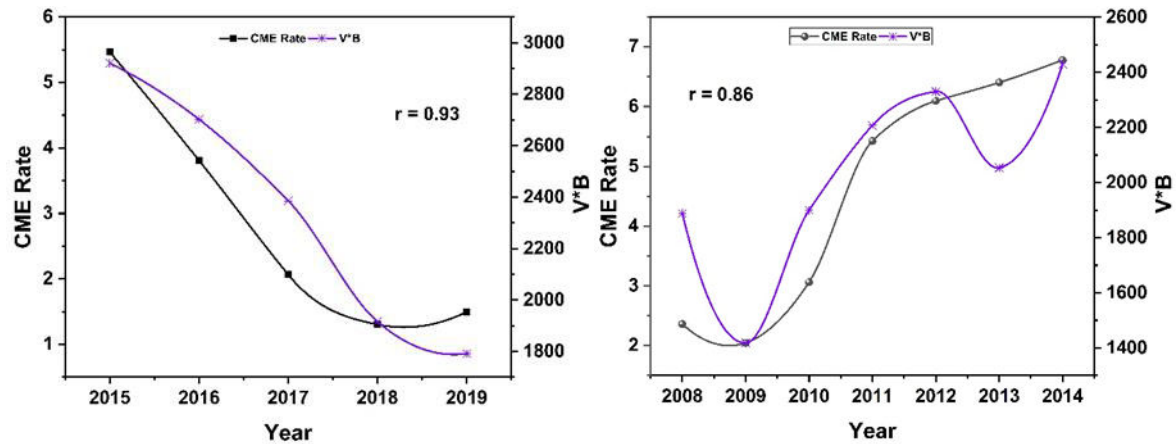


Figure 5. Shows the cross-correlation plot between CME rate IMF B, Vsp and V*B during ascending (left panel) and descending (right panel) phase of cycle 24.

IV. CONCLUSION

The present study intends to examine the effect of solar interplanetary features on earth magnetic field during ascending and descending phase of solar cycle 24. Our conclusion are as follows-

- The highest number of CMEs event occurred during the ascending phase of cycle 24.
- Higher intensity of large-scale CMEs (i.e., halo and partial halo CMEs) observed during the ascending phase, consistent with the peak of solar activity.
- During the ascending phase, the majority of occurrences (GMs, Halo CMEs, and Partial Halo CMEs) peaked in 2012, while in the descending phase the majority of occurrences in 2015.
- We observed the higher correlation between CMEs and solar interplanetary and geomagnetic indices in the descending phase rather than ascending phase of solar cycle 24.
- The V*B (velocity times magnetic field) index was found to be more effective in correlating with CME rates compared to Vsp (solar wind speed) or IMF B (interplanetary magnetic field strength). This indicates that the combined effects of solar wind speed and magnetic field strength may be more crucial in driving geomagnetic disturbances than either parameter alone.
- During the descending phase, both IMF B and V * B show a very strong positive correlation with CME rate.
- IMF B and V*B are key drivers of CME activity throughout both phases, but their influence becomes stronger in the descending phase, with solar wind speed playing a more prominent role as the cycle moves towards its maximum.

This observation could be important for understanding space weather patterns, as geomagnetic storms can have various effects on satellite operations, communication systems, and even power grids on Earth. The analysis of CMEs during both phases of the solar cycle helps researchers predict and prepare for such space weather events.

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