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Research Article

A Study of The Effects of Solar Activity on The Magnetosphere During the Ascending Phase of Solar Cycle 25

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Abstract

In the present research, the ascending phase (2019-2024) of solar cycle 25 has been investigated. The largest yearly mean sunspot number was recorded in the year 2024. The occurrence of 244 halo CMEs (coronal mass ejections) and 146 GMNSs (geomagnetic storms) based on Dst index was recorded during 2019-2024. No severe geomagnetic storm occurred during 2019 - 2022. Out of three severe geomagnetic storms, one was recorded in 2023 and two were recorded in 2024. The present research also focuses on the correlation between geomagnetic activity and solar wind parameters (interplanetary magnetic field, electric field, speed and proton density). The phase relationship of solar cycle 25 between halo CMEs and geomagnetic storms has also been investigated.

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KEYWORDS: GMNSs (geomagnetic storms), Dst index, CMEs (coronal mass ejections), Solar cycle.

1. INTRODUCTION

A sunspot is a dark patch on the surface of sun and made of two parts. The central part is called umbra and the outer part is called penumbra as shown in Figure 1. Hale was the first person to prove that the sunspots are magnetic in nature. He analyzed the spectral lines of the light coming from the sunspots and found the splitting of the spectral lines was the result of Zeeman effect. Since Hale did not get any stark shift so he concluded the electric field of these sunspots is weak. In Babcock Leighton picture, the poloidal magnetic field of sun is transformed in to the toroidal magnetic field by the differential motion of the sun Babcock [1], Leighton [2]. The magnetic field lines of the toroidal magnetic field are concentrated in the convection zone and create magnetic flux tubes. These magnetic flux tubes rise due to magnetic buoyancy and Coriolis force. On the surface these flux tubes create a pair of sunspots having opposite polarity. These sunspots lives vary from a few days to several weeks depending on their sizes Solanki [3]. These sunspots vary from minimum to maximum and again maximum to minimum on surface of sun. This cycle of sunspots is called solar cycle.

A CME is an abrupt ejection of vast amount of plasma (10^{12}-10^{13}kg) from the sun. CMEs weaken Earth's magnetic field and generate geomagnetic storms. Large fluctuations in the magnetic field of Earth are called geomagnetic storms Svalgaard [4]. The sheath region of ICME is main source of disturbance in Earth's magnetosphere Siscoe and Schwenn [5]. Patel et al. [6] investigated the declining phase of solar cycle 2019 and found that the solar events like corotating interaction regions and coronal mass ejections are responsible for geomagnetic storms. Strong GMNSs are observed near the peak of a solar cycle [7]. GMNSs effect orbits of satellites, human health, radio wave communication, GPS systems Singh et al. [8], Yang and Mortan [9], Miteva [10]. The geomagnetic indices like aa, Ap, K, Kp, Dst etc. are the indicators of geomagnetic storms.

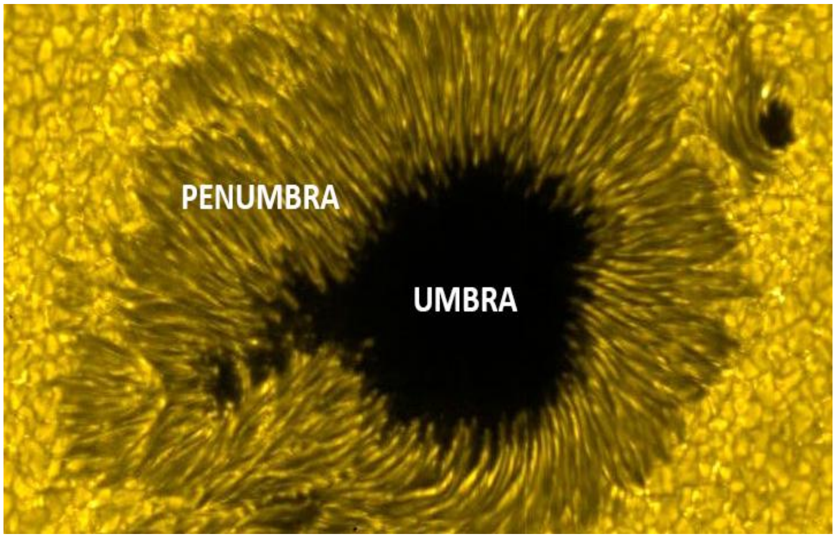

Figure 1: Parts of a sunspot (Penumbra and Umbra)

DATA AND METHOD

In the present research Dst index has been applied for the study of geomagnetic storms. Dst index is an indicator of weakness of Earth's magnetic field that measures hourly fluctuations of the Earth's magnetic field Le [11]. If Dst index is zero or positive it means the Earth's magnetic field has not been disturbed In the ascending phase of solar cycle 25, it occurred 146 geomagnetic storms (Dst< 50nT). Based on the Dst index, GMNSs are classified as moderate (-50nT >DST≥-100nT), Intense (-100nT> DST≥-200nT) and severe (Dst<-200nT) geomagnetic storms, Loewe and Prolss [12].

In this research, DST index data have been collected from the website http://swdc.kungi.kyoto.u.ac.jp/dstdir. Data for solar wind parameters like electric field, proton density, speed and Interplanetary magnetic field has been collected from OMNIWEB available at https://omniweb.gsfc.nasa.gov/form/dx1.html. The sunspot number data has been collected from SILSO website available at https://www.sidc.be/SILSO/datafiles. The catalogue of halo CMEs has been obtained from the CDAW data centre available at https://cdaw.gsfc.nasa.gov

3. RESULTS AND DISCUSSION

Data of yearly mean sunspot number, number of halo CMEs and GMNSs during 2019-2024 is shown in Table1. It is clear from the Table1 that the minimum number of sunspot number and CMEs were observed in year 2019. The number of geomagnetic storms was also minimum in 2019. It means both solar activity and geomagnetic activity were minimum in year 2019.

Table 1: List of SSNs, GMNSs, halo CMEs and Severe GMNSs per year during years 2019-2024

Year	Sunspot Number	Geomagnetic Storms	Halo CMEs	Severe Geomagnetic Storms
2019	3.6	6	1	0
2020	8.8	7	4	0
2021	29.6	12	16	0
2022	83.2	23	44	0
2023	125.5	52	80	1
2024	154.7	46	99	2

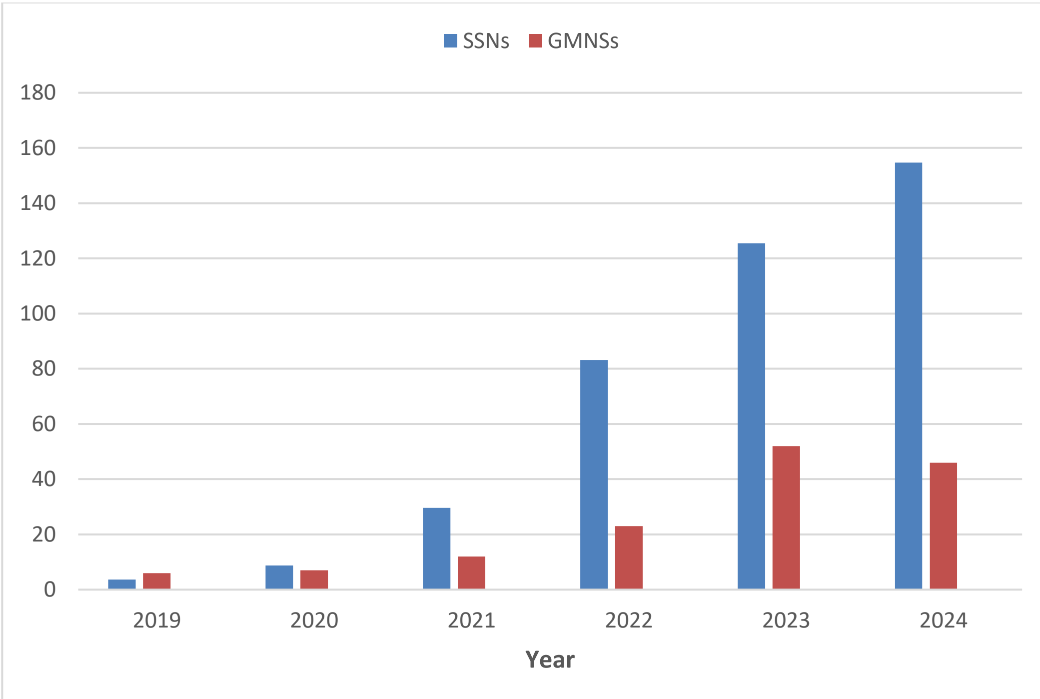

Figure 2: Mean SSNs and GMNSs per year

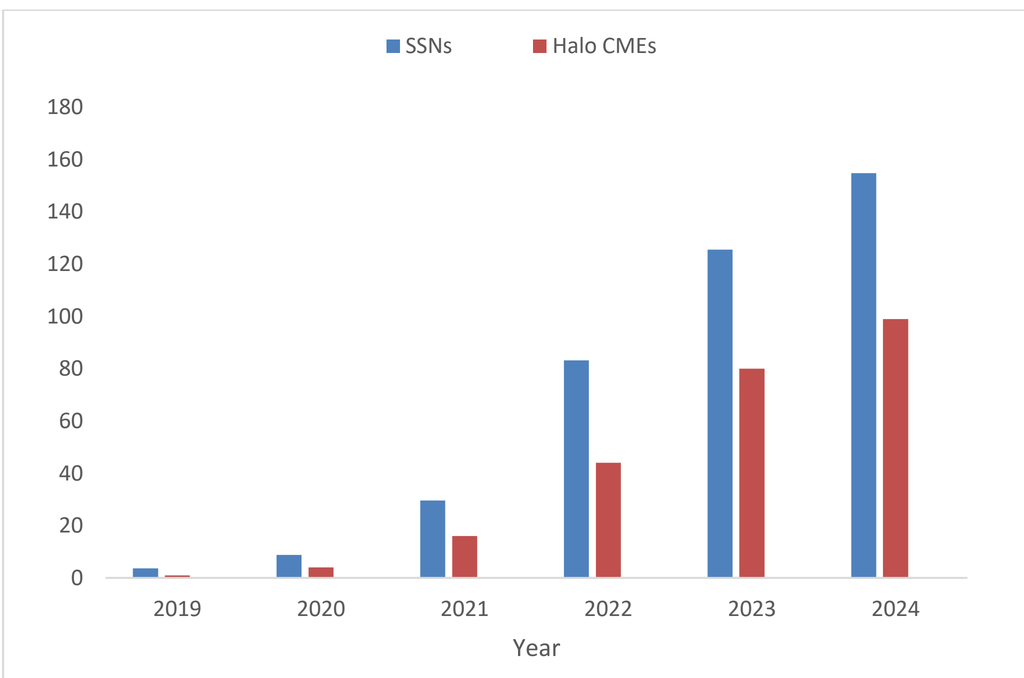

Figure 3: Mean SSNs and halo CMEs per year

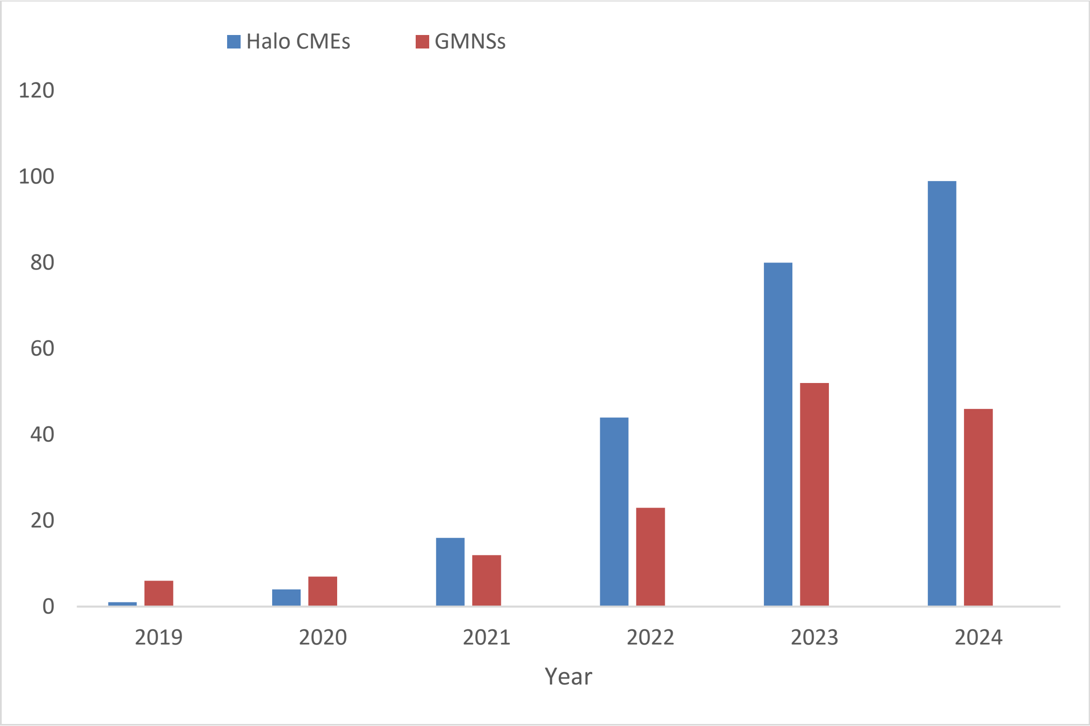

Figure 4: Halo CMEs and GMNSs per year

The maximum yearly mean sunspot number and halo CMEs were observed in year 2024 but the number of geomagnetic storms were maximum in year 2018. This is due to fact that only one severe geomagnetic storm occurred in year 2018 but two severe geomagnetic storms occurred in year 2024.In Figure 2, the geomagnetic storms follow the phase of solar cycle during 2019-2023 but the number of geomagnetic storms decrease in year 2024. Therefore, occurrence of strong geomagnetic storms disturbs the phase relationship between geomagnetic storms and solar cycle. In Figure 3, It is clear that the number of halo CMEs increase with increase in yearly mean sunspot number. Halo CMEs seem to follow the phase of solar cycle 25. In Figure 4, It is clear that the number of halo CMEs was smaller than the number of GMNSs in starting of solar cycle 25. As the Solar cycle 25 moves forward in time the number of halo CMEs continuously increase but the number of GMNSs decrease in year 2024. The number of GMNSs do not follow the phase of number of CMEs.

3.1 Geomagnetic Activity Observed in April, 2024

In April 2024, the minimum Dst index (-117nT) was recorded at 15 UT (19 April) as shown in Figure 5. It indicates the occurrence of an intense geomagnetic storm. On 19 April, the electric field E_y was positive from 3UT to 22UT.The solar wind speed was normal during this geomagnetic storm. The maximum electric field (6.36mV/m) for April, 2024 was also recorded on 19 April at 15 UT. On 19 April, the proton density increases from 9.9 N/cm^3 (3UT) to 24.9 N/cm^3 (9UT) then decreases and becomes normal. On 19 April, the value of interplanetary magnetic field increases from 6.2 nT (at 0 UT) to 16.6nT (at 15UT) with small fluctuations.

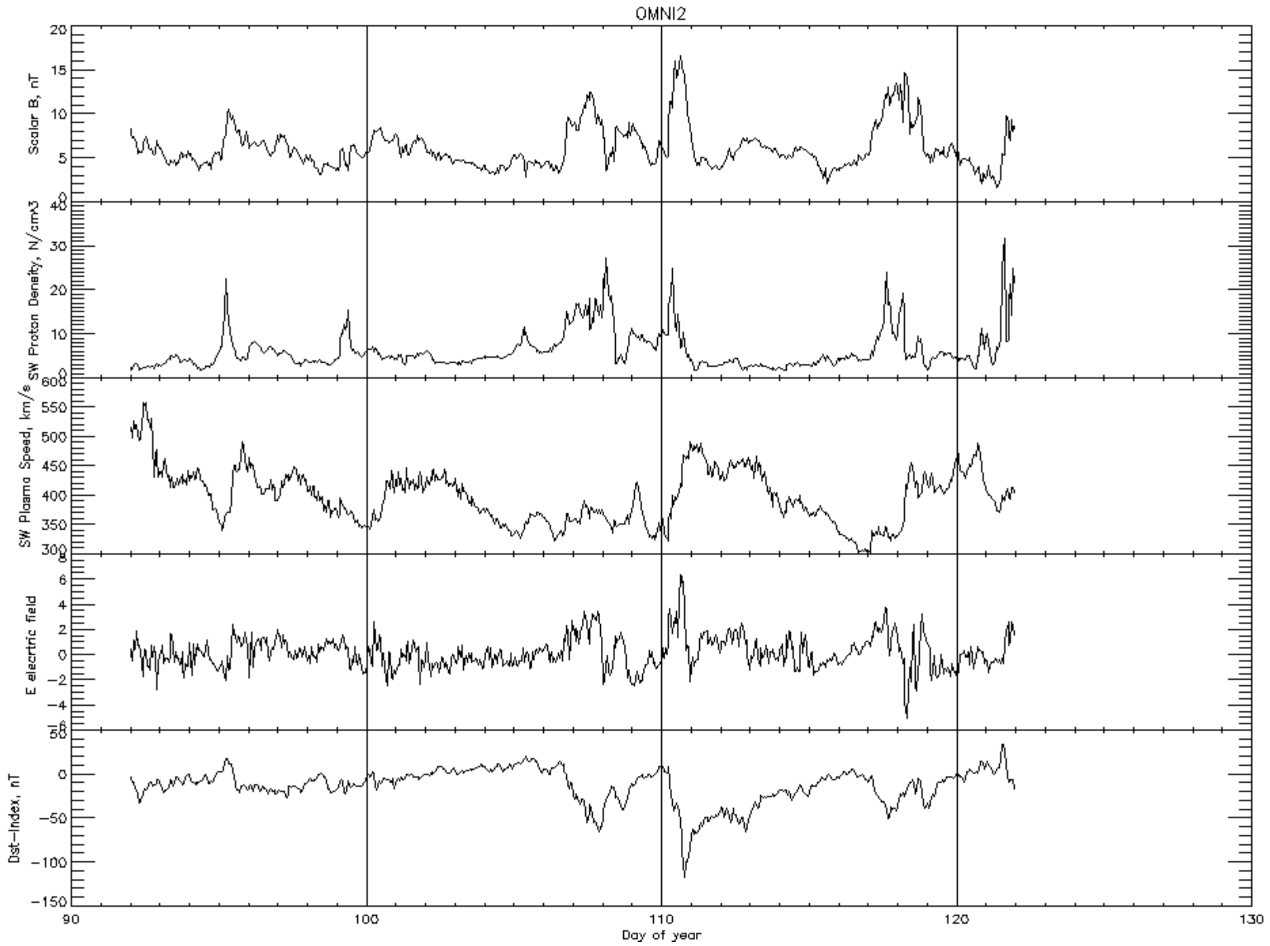

Figure 5: Solar wind parameters along with Dst index recorded in April 2024)

3.2 Geomagnetic Activity Observed in May, 2024

The Dst index decreases from -31nT (10 May at 18:00 UT) to -406nT (11May at 02:00 UT) and then increases up to -51nT (14 May at 07:00UT) as shown in Figure 6. On 11 May, 2024 a severe geomagnetic storm occurred with minimum Dst index -406nT. Both positive and negative values of electric field are observed during 10- 14 May. The maximum positive value of electric field recorded for May was 26.19mV/m observed on 11 May at 0 UT. During 10-14 May, the solar wind is high and maximum(1006Km/sec) on 12 May at 01:00 UT. From 10 May (at 15:00 UT) to 11 May (at 12:00UT) the proton density is high, after that it becomes normal. During 10-14 May the maximum proton density was observed at 20:00 UT. During 10-14 May, the maximum interplanetary magnetic field (68.9nT) was recorded on 10 May at 23:00 UT.

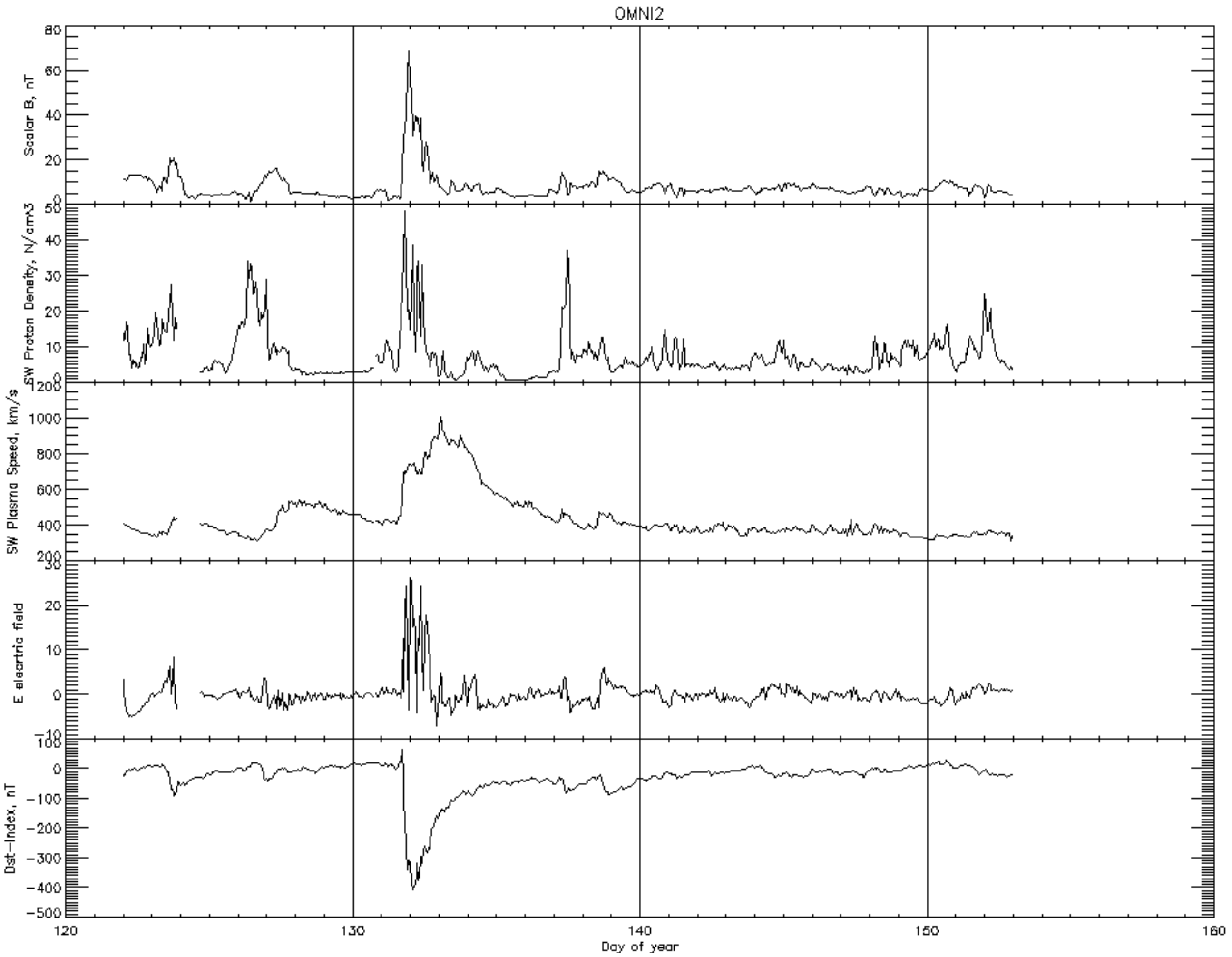

Figure 6: (solar wind parameters along with Dst index recorded in May, 2024)

3.3 Geomagnetic Activity Observed in October 2024

Dst index begins to decrease from -58nT (7 October at 17:00 UT) to -148nT (8 October at 07:00UT) and then increases to -52nT (9 October 15:00UT) with small fluctuations as shown in Figure 7. After that the conditions become normal. It means that an intense geomagnetic storm had occurred on 8 October with minimum Dst -148nT.During 8-9 October, the maximum value of electric field (6.59mV/m) was recorded on 8 October at 03:00 UT. During 7-9 October, the solar wind speed is normal, maximum proton density was recorded on 7 October at 22:00 UT and maximum interplanetary magnetic field (15.4nT) was also recorded on 7 October at 16:00UT.

Dst index abruptly decreases from -50nT (10 October at 17:00nT) to -333nT (11 October at 01:00UT) and then increase to -52nT (12 October at 18:00UT). It means that a severe geomagnetic storm had occurred with minimum Dst index -333nT. During 10-12 October, the maximum value of electric field E_y (28.95mV/m) was recorded on 10 October at 23:00 UT, the maximum value of solar wind speed (753Km/sec) was recorded on 11 October at 11:00 UT, the maximum value of proton density (31.6N/cm^3) was recorded on10 October at 21:00UT and maximum value of interplanetary magnetic field (43.7nT) was recorded on 10 October at 21:00UT.

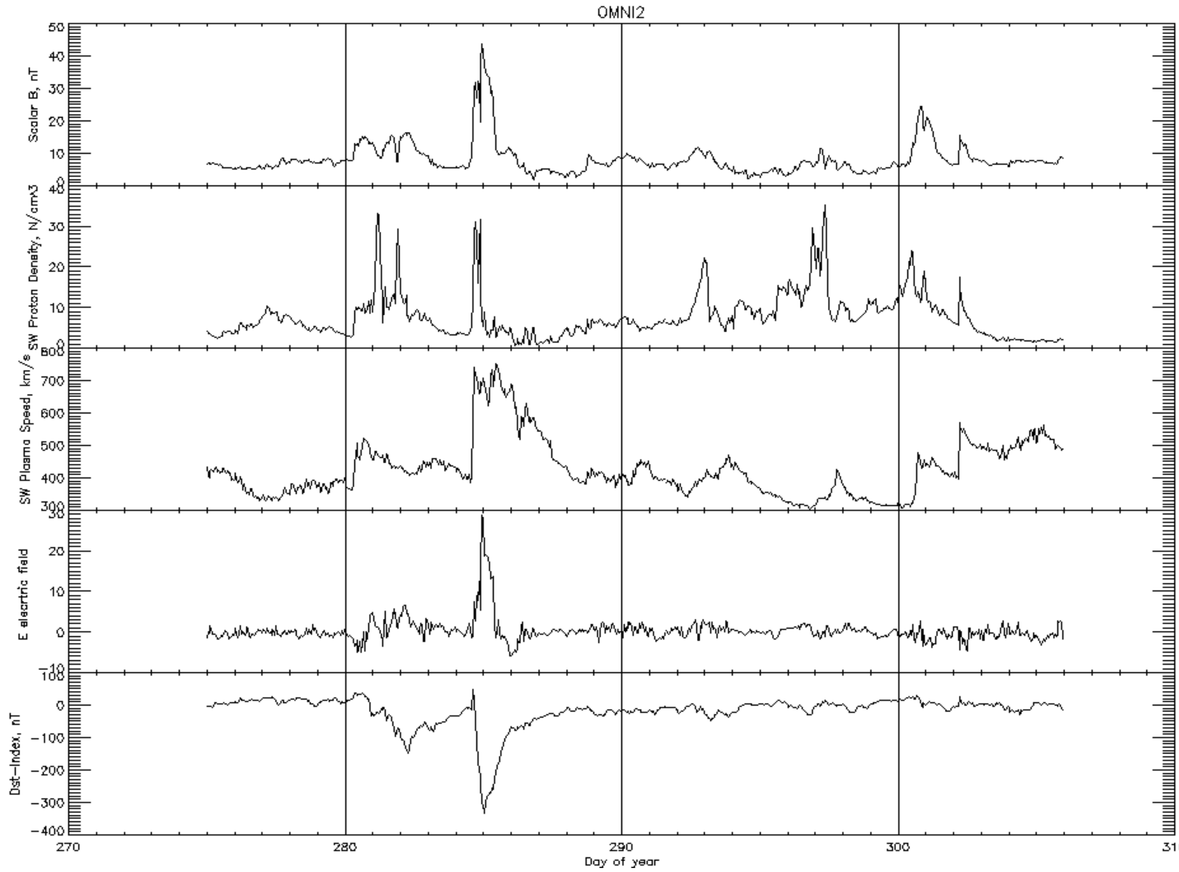

Figure 7: (solar wind parameters along with Dst index recorded in October, 2024)

CONCLUSION

During the investigation of the ascending phase of solar cycle (2019-2024), It has been found that the number of halo CMEs per year followed the phase of solar cycle 25. The number of geomagnetic storms was greater near the peak than the initial phase of solar cycle 25 but the number of GMNSs per year do not exactly follow the phase of solar cycle 25 due to occurrence of strong GMNSs near the peak. During investigation of geomagnetic activity, it has been found that solar wind speed is normal (less than 550Km/sec) during intense geomagnetic storms but the solar wind speed is high (greater than 700Km/sec) before the severe GMNSs. The large positive values of electric field are observed during intense and severe geomagnetic storms. If only proton density is high, it cannot cause a strong geomagnetic storm. The large values of interplanetary magnetic field are also observed before few hours of GMNSs

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