

ANALYSIS OF GEOMAGNETIC ACTIVITY AND SUNSPOT NUMBER FLUCTUATIONS DURING THE MAXIMA AND MINIMA OF SOLAR CYCLE 24

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ABSTRACT

In this paper, a variability of sun spot numbers with geomagnetic indices Dst has been studied during maxima and minima of solar cycle 24. In this analysis we used statistical methods to filter data. Solar activity of this cycle is deep minimum one since solar cycle 14(1902-1913). We observed no strong correlation of sunspot numbers with geomagnetic indices Dst. For this study, the Dst index data, with hourly resolution, was obtained from the WDC for Geomagnetism's at the University of Kyoto and dataset of sunspots number (SSN) was obtained from NASA/OMNI (<http://omniweb.gsfc.nasa.gov>). The storm days were identified as days for which the $Dst \leq -50$ nT.

KEYWORDS:

Sun Spot Number (SSN); Geomagnetic indices, Dst, Solar minima and maxima.

INTRODUCTION:

The Sun's activity, characterized by solar cycles, plays a crucial role in influencing the Earth's space environment. Solar Cycle 24, which existed from 2008 to 2019, witnessed significant variations in solar activity, marked by periodic increases and decreases in solar-phenomena such as sunspots and geomagnetic indices. Understanding the variabilities of these indices during the minima and maxima of the solar cycle is vital for comprehending the Sun-Earth connection, as it affects space weather events like satellite operations, and global communication systems. The approx 11 years Solar cycles typically with solar maxima and minima representing periods of heightened and concealed solar activity, respectively. In the duration of solar maximum, sunspot numbers reach their peak, and solar storms become more frequent. In the opposition, at the solar minimum, the Sun's activity diminishes, leading to a turn down in sunspots and geo-magnetic disturbances. The relationship between geomagnetic indices, like as the Ap index and the Dst index, and sunspot numbers during these phases provides insight into the Sun's magnetic behavior and its interface with Earth's magnetosphere.

This study delves into the variability of geo-magnetic indices and sunspot numbers throughout the distinct phases of Solar Cycle 24, focus on the contrasting behaviors throughout the solar minima and maxima. By examining this variability, we aim to deepen our perceptive of solar activity's direct impact on the Earth's space weather, with implications for together scientific research and practical applications in space weather prediction and mitigation strategies. The Sun's activity, characterized by solar cycles, plays a crucial role in influencing the Earth's space environment.

The period of solar minimum between cycles 23 and 24 represented the most prolonged and lowest phase since the minimum between cycles 14 and 15, often referred to as the 'deep minimum' (Russell et al. 2010). The solar activity throughout the current solar cycle 24, following this exceptionally low minimum, remains subdued (Kamide and Kusano 2013). The peak of cycle 24 was recorded in April 2014, determined through the 13-month sharp monthly sunspot number (SSN), with a maximum SSN of 116.4, as per information to the World Data Center for Sunspot Index and Long-term Solar Observation based in Brussels, Belgium. This figure marks the lowest maximum recorded since cycle 14, which had an sun spot number(SSN) of 107.1 in February 1906. The SSNs for cycle 24 exhibited two notable peaks are 98.3 in March 2012 and 116.4 in April 2014 (Svalgaard & Kamide 2013; G. swamy 2015).

To observe the subdued activity characteristics in cycle 24, we conducted an analysis of long term trends in geomagnetic activities, as represent by the Dst catalog, and compared these trends with sunspot numbers (SSNs) data. Furthermore, we investigate the solar origins of geo-magnetic storms during both the mounting and peak phases of solar cycle 24 by employing solar sunspot data. Numerous studies have addressed geo-magnetic storms and their solar origins in earlier cycles. Previous research indicates that the main solar sources of severe geo-magnetic storms (min Dst < -100nT) were identified as Coronal mass ejections (CMEs), with approximately 11to14% of the storms associated to high-speed stream from coronal. We aim to compare these findings from earlier cycles by means of our analysis of cycle 24.

Geomagnetic storms are global disturbances caused by the inter action between the magnetized plasma ejected from Sun and Earth's magnetic field creates, when transfer of enormous amounts of energy to the magnetosphere take place. Such global and big response and the rapid transfer of massive amounts of energy to the Earth's magnetic field also impact in a broad range of technological instruments such as damages and disruptions to satellites and its communication systems (Chapman et al., 2020; Wrenn, 2009; Wrenn et al., 2002), global positioning system scintillation, jamming of radio signals, and disruptions, but can also create a threat to human exploration at high latitudes that enhanced radiation doses. These actions can result in technological disruptions, economic losses, and dangerous to our life in the earlier period and most likely in the future (Baker et al., 2004; Eastwood et al., 2017), thus, the study of such storm occurrence and their intensity over time is fundamental to develop our forecasting models, and to avert or mitigate the risk associated or added with them.

The Dst index is determine of low-latitude ground distortion measured at four magnetic observatories which is available in Hermanus, South Africa; Kakioka, Japan; Honolulu, Hawaii; and San Juan, Puerto Rico. This is a name for the strength and evolution of the magnetospheric circulation and has been use to analyze the intensity of geo-magnetic storms (Gonzalez et al., 1994; Kamide and Chian, 2007). Generally speaking, the more negative the Dst index, the stronger the geomagnetic storm. In understanding the physical processes that determine storms, we must look to Sun to determine its driving force.

Events occurring within astrophysical cycles are inconsistent. The solar activity throughout the 24th solar cycle and completed that coronal mass ejections do not show a strong correlation with sunspot cycles (Weissach et al. (2017). After analyzed data from the coronal mass ejection (CME) index, sunspot number (SSN), and sunspot area (SSA) during the 23rd solar cycle, comparing these observations to identify any shifts in their patterns (Christian ,2018). Consistency is predictable to be observed during daytime hours. The current study focuses on analyzing various astrophysical parameters from 2009 to 2017.

DATASETS AND METHODOLOGY:

For this study, the Dst index data, with hourly resolution, was obtained from the WDC for Geomagnetism's at the University of Kyoto and is derived by averaging the deviation of the horizontal component of the ground magnetic field. The dataset is composed by hourly Dst values. Similarly the dataset of sunspots number (SSN) was obtained from NASA/OMNI (<http://omniweb.gsfc.nasa.gov>), with hourly time resolution. In both data we have taken Solar minima 2009, solar maxima 2014 and solar minima 2019 data to find correlation between them. The storm days were identified as days for which the $Dst \leq -50$ nT. The storm statistics for each year and were obtained for all the years within the phase of study. The storm statistics for each year were obtained for all the years within the period of study. The results of the annual geomagnetic storm number and the annual sunspot number were observed and compared. Anomalous variation of data is taken to be different from the observed day-to-day variability. We know that perturbation in solar plasma parameter value is also related to geomagnetic condition.

RESULTS AND DISCUSSION:

In this research Variation of geo-magnetic activity in solar cycle 24 which is starting from 2009 to 2019 examined in the form of parameters Geo Strom and Sunspot numbers and graph plotted for solar Maxima and solar minima and variations are examined with the help of Dst and SSN data for the solar minima, solar Maxima and again solar minima.

Sun spot number also examine during solar minimum solar maximum and again in solar minimum and trying to observe the deviation of these parameters during this solar cycle. The average daily datasets have been used for research and the results of the annual geomagnetic storm number & the annual sunspot number were observed and compared with time duration of solar minima and maxima. Figure 1.1 demonstrate the Dst index profile for the entire time span or duration of solar cycle 24.

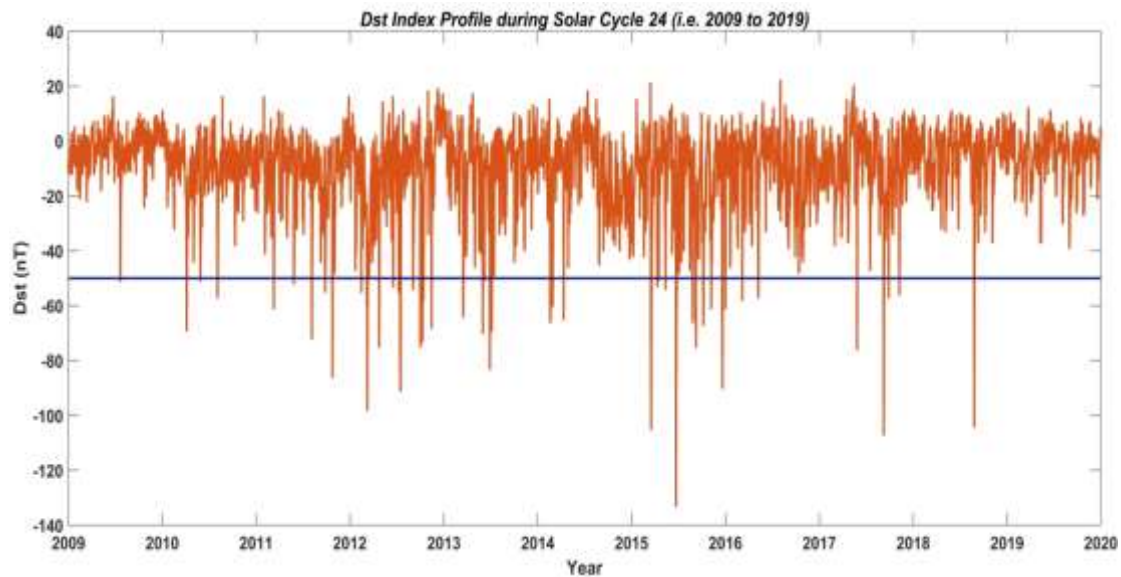


Fig. 1.1 – Distribution Storm Time (Dst) Index Profile during Solar Cycle 24 (i.e. 2009 to 2019).

In Figures 1.1, the orange line indicating the Dst daily average values while the blue line marked at -50 nT is indicating the boundary conditions for significant geo storms. The following Figure 1.2 shows that Dst index profile for the year 2009. This year is known as solar minimum of solar cycle 24 and Graph indicates that in whole year only in the month of August one significant geo Strom noticed while all the year no significant geo storm registered that's why this time period of solar cycle 24 is known as solar minima for solar cycle.

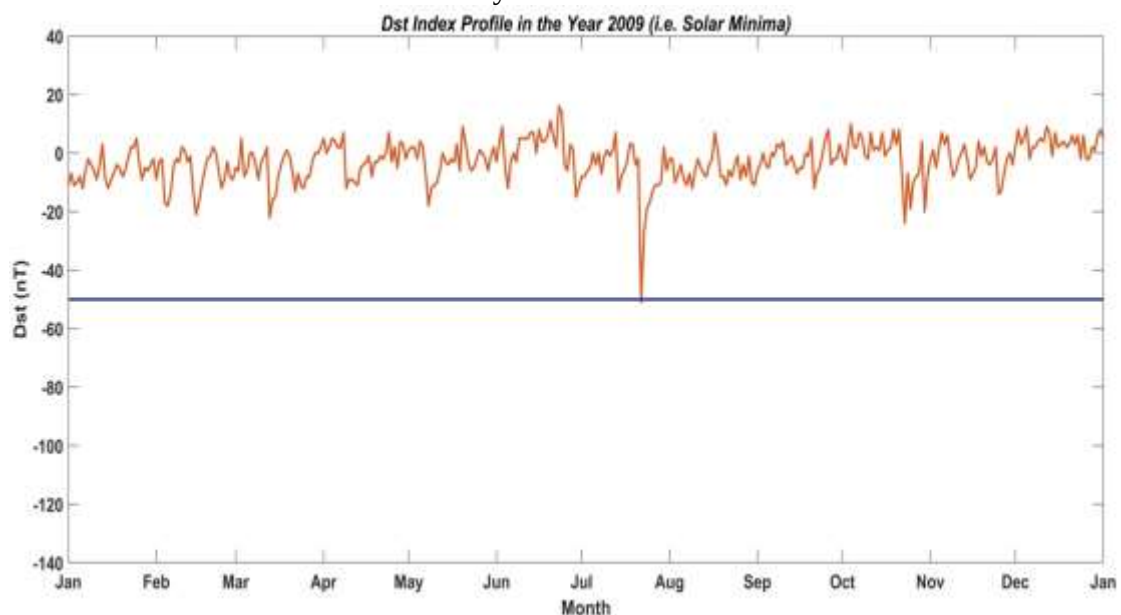


Fig. 1.2 – Distribution Storm Time (Dst) Index Profile during Solar Minima (i.e. 2009) of Solar Cycle 24.

In Figures 1.2, the orange line indicating the Dst daily average values while the blue line marked at -50 nT is indicating the boundary conditions for significant geo storms. In following figure 1.3 more geomagnetic storms were noticed in month of February, March and in April. Also noticed variations in Dst data throughout the cycle. Due to this variability in this time zone or time duration of solar cycle 24 is known as solar maxima.

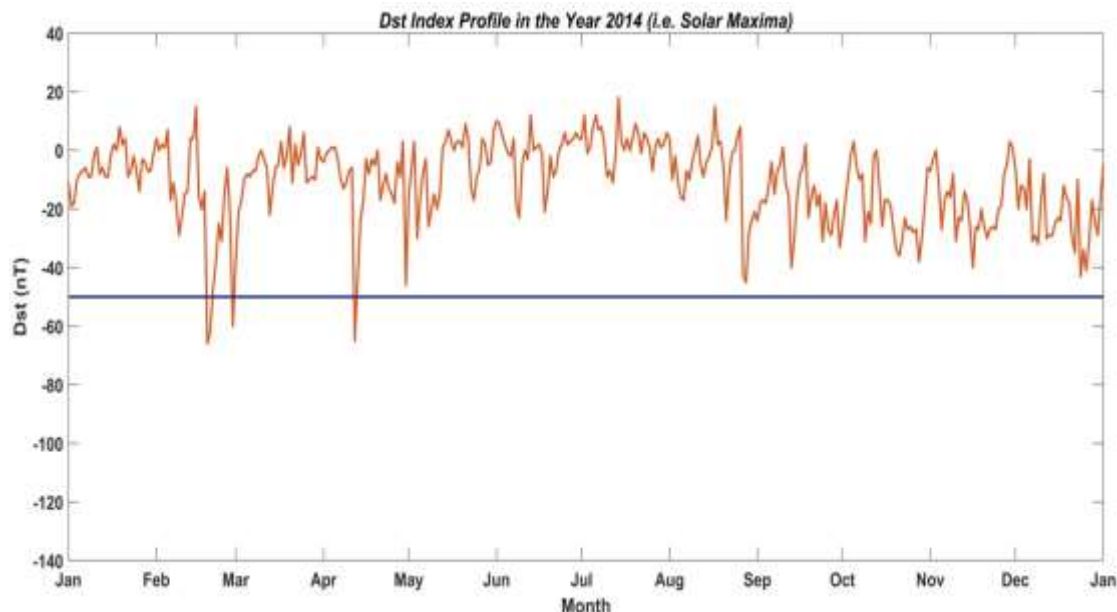


Fig. 1.3 – Distribution Storm Time (Dst) Index Profile during Solar Maxima (i.e. 2014) of Solar Cycle 24.

In Figure 1.3, the orange line indicating the Dst daily average values while the blue line marked at -50 nT is indicating the boundary conditions for significant geo storms. Following Figure 1.4 indicates the Dst data of last year of this cycle 24 and indicating that no measurable variations occurred in this time period known as solar minima.

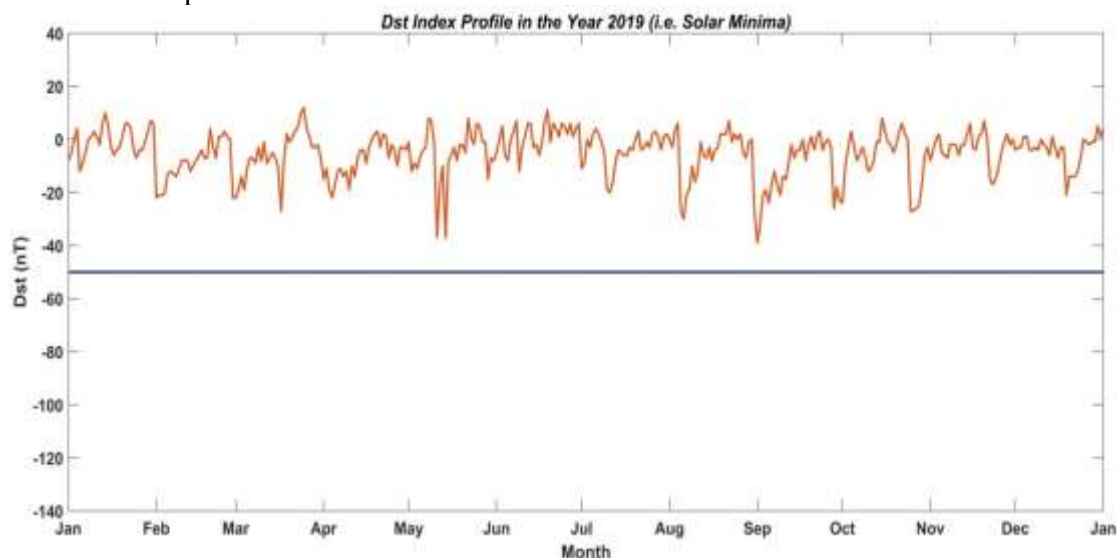


Fig. 1.4 – Distribution Storm Time (Dst) Index Profile during Solar Minima (i.e. 2019) of Solar Cycle 24.

In Figure 1.4 orange line indicating the Dst day average value while blue line marked at -50 nT indicating the boundary conditions for significant geo storm. The Figure 1.5 is indicating the combined data for both minima and Maxima of this cycle.

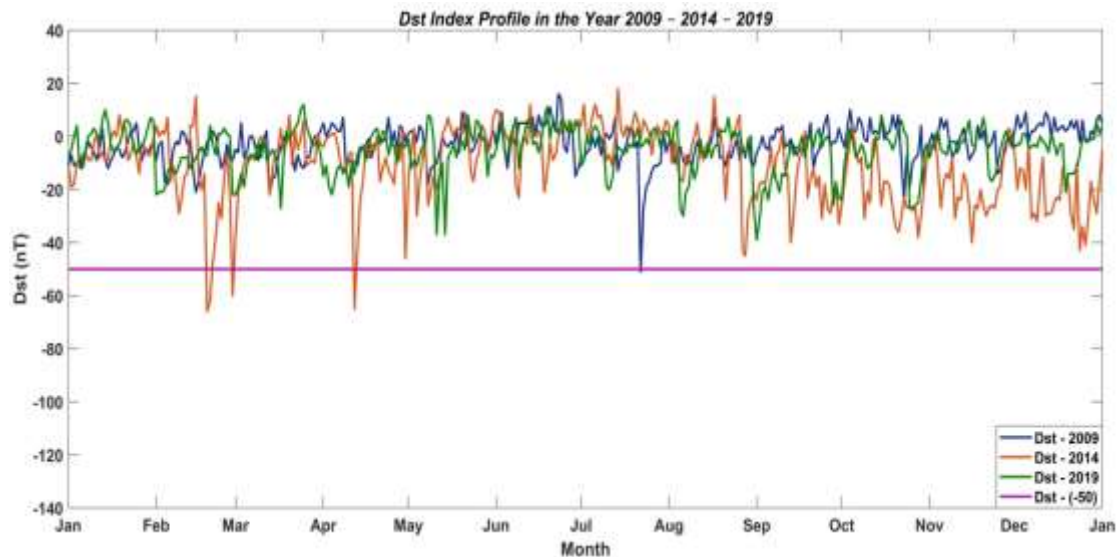


Fig. 1.5 – Combined Graph of Distribution Storm Time (Dst) Index Profile during the Year 2009 (i.e. Solar Minima), 2014 (i.e. Solar Maxima) and 2019 (i.e. Solar Minima) of Solar Cycle 24.

In Figure 1.5 blue line indicating Dst data for first solar minima (2009), orange line indicating the Dst data for solar Maxima (2014) and green line indicating the Dst data for another solar minima (2019) while pink line indicating the boundary conditions for significant geo storm in solar cycle 24. Figure 1.6 is indicating the graph of sunspot number (SSN) throughout the 11 year for solar cycles 24 (2009-2019). Figure indicate that the number of sunspots is minimum in year 2009 and in 2019 by which these years is known as solar minima while sunspot numbers get its highest value approx 225 in the year of 2014 and represent this year as solar maxima.

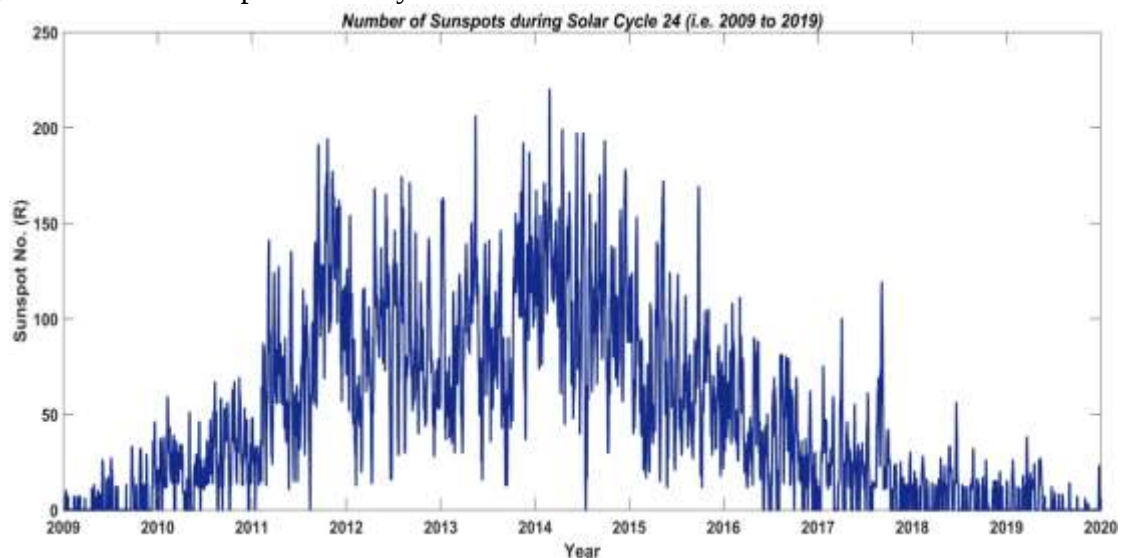


Fig. 1.6 – Number of Sunspots during Solar Cycle 24 (i.e. 2009 to 2019).

Following Figure 1.7 represents the sunspot numbers for solar minima for the year 2009 and indicating that all month of this year get SSN value is less than 50.

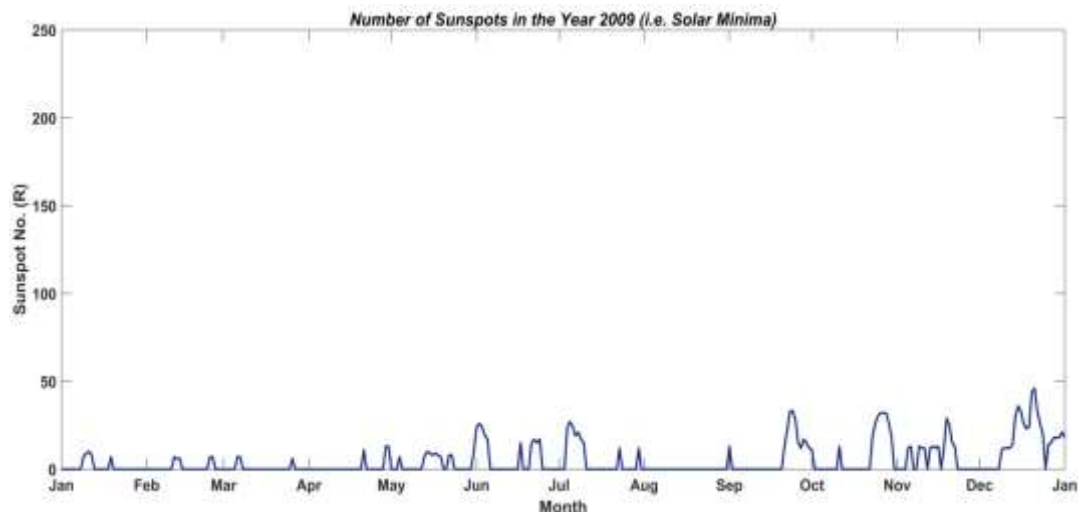


Fig. 1.7 – Number of Sunspots during Solar Minima (i.e. 2009) of Solar Cycle 24.

The sudden variations in SSN were observed in year 2014 where values increase up to 225 and shown in Figure 1.8.

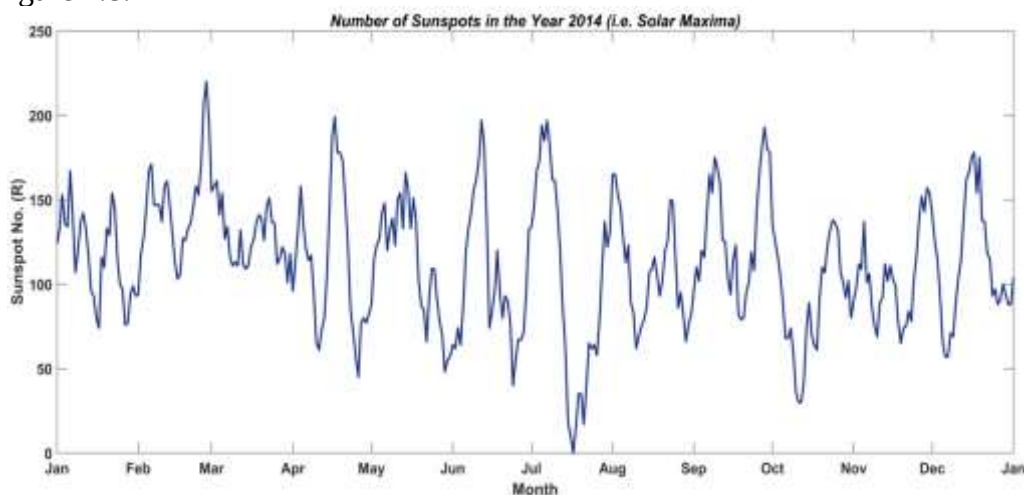


Fig. 1.8 – No. of Sunspots during Solar Maxima (i.e. 2014) of Solar Cycle 24.

Similar values just like the first solar minima of solar cycle 24 were also registered in the year of 2019 and represents in Figure 1.9.

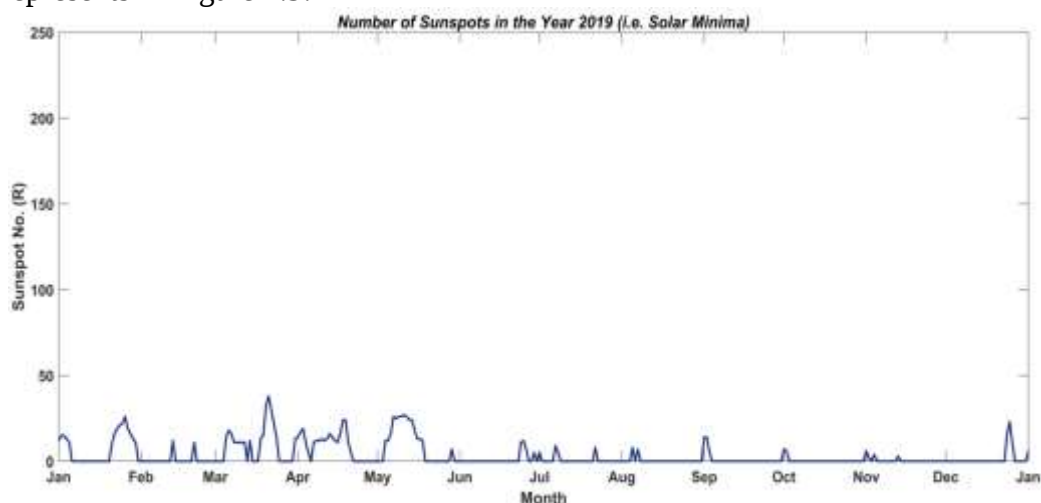


Fig. 1.9 – Number of Sunspots during Solar Minima (i.e. 2019) of Solar Cycle 24.

Figure 1.10 represents the SSN combined graph for solar minima and maxima and showing huge variation between them. It is clearly observed that the sun spot numbers are lowest in the year of

2009 and 2019 (both solar minima) while the maximum number of sunspots are recorded in the year 2014.

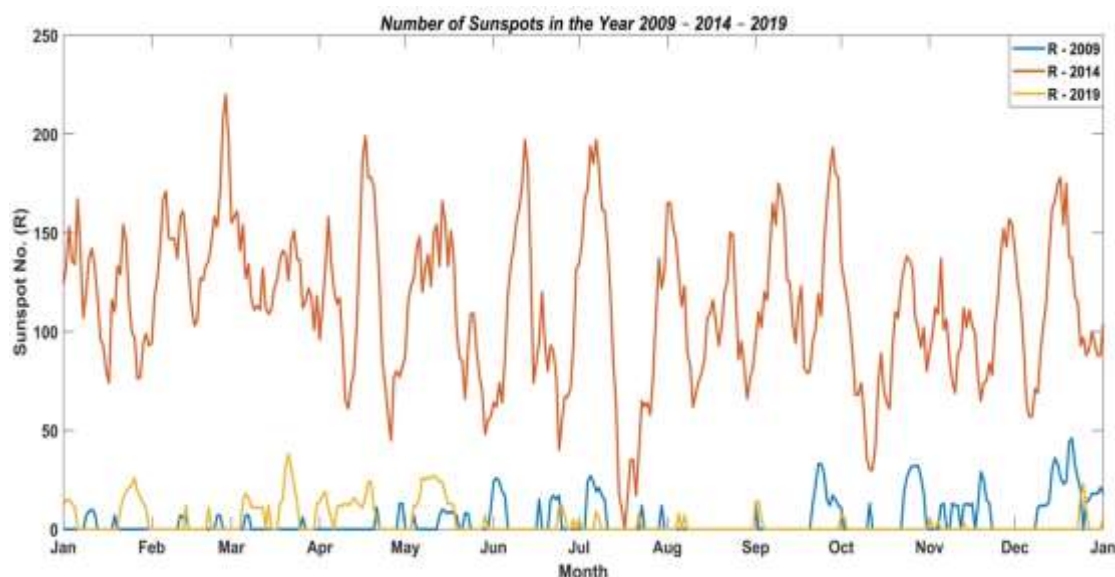


Fig. 1.10 – Combined Graph of Number of Sunspots during the Year 2009 (i.e. Solar Minima), 2014 (i.e. Solar Maxima) and 2019 (i.e. Solar Minima) of Solar Cycle 24.

CONCLUSIONS:

In Solar Cycle-24 begins with very little activity. The number of CME (annual) increases/decreases with solar radiation, but is not the same. The nature of CME on the Sun's surface compare to the sun's surface suggests their connection. Kane (2011) observed the same result in his results for the previous period. It is also reported that CME ejection incidence rates match the solar field better than the solar system. It is also pointed out that the solar field of the solar system is closely related to the solar system. The number of sunspots on solar surface correlates well with astrophysical changes, with a coefficient value of 0.98. While 2014 was the year with the highest solar radiation, 2009 and 2017 were the years with the least solar radiation. When annual sunlight and number of sunlight are compared, it is seen that average sunlight was smallest in 2009 with 0.02, while the maximum sunlight was 6.34 in 2014. The same result is found for corrected sunspot number and Dst. There are some differences in the formation of storms due to changes in Dst between moderate, strong and severe storms in the same year.

Historically, the variation with peaks in geomagnetic activities noted in solar cycles has been analyzed by Gonzalez et al. (1994) and Echer et al. (2011). They pointed out that the initial peak, which occurs during the maximum phase, is influenced by coronal mass ejections (CMEs), while the subsequent peak, observed in the declining phase, is linked to high-speed streams that originate from coronal holes. Gopalswamy (2008) highlighted the strong connection between the latitudinal distribution of CMEs and the dual-peak nature of geomagnetic activities.

The solar cycle has the maximum amount of sunlight. The peak of Solar Cycle 24 was observed between 2011, 2013 and 2014, meaning the peak of Solar Cycle 24 was achieved. There are no major storms in solar cycle 24. For the remainder of Solar Cycle 24, we average more than 101.3 days of sunshine per month. It is unlikely that any major storms will occur during the remainder of Solar Cycle 24. This is a very unusual situation seen in the past. 50 years. This is clearly seen in the figures. The occurrence of geomagnetic storms is closely related to the solar cycle and is directly proportional to the amount of sunlight. We can also conclude that Solar Cycle 24 is the least active cycle of the last 50 years.

The research shows the Sunspot and Geomagnetic storm causal relationship during 24 solar cycle periods. The sunspot increases and decreases through an average cycle of 11 years. The geomagnetic storm occurrence rate strongly follow the occurrence of the yearly occurrence rate of sunspot number but not simultaneous across the years and do not follow specific pattern. The relation

of sunspot number to the geomagnetic storm with different intensity revealed a quietly strong relation with intense storm and a very weak relationship with great storm.

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