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Relationship Between Sunspot and Solar Wind Parameters During the Ascending Phase

[1*]Abisha S Santham , [2]A. Iren Sobia, [3]Mariya Shaniya , [4]S.S. Bidhu

[1*] Research scholar Reg.No: 21113092132005, Department of Physics and Research Centre, Muslim Arts College, Thiruvithancode,Tamilnadu, India..
[2]Assistant Professor, Department of Physics and Research Centre, Muslim Arts College, Thiruvithancode, Tamilnadu, India.
[3]Research scholar Reg.No: 21213092132006, Department of Physics and Research Centre, Muslim Arts College, Thiruvithancode,Tamilnadu, India
[4]Assistant Professor, Department of Physics, Nanjil Catholic College of Arts and Science, Kaliyakkavilai.
Affiliated to Manonmaniam Sundaranar University, Abishekapatti-627012,Tirunelveli,Tamilnadu,India.
*Corresponding Author E-mail: abishassantham01@gmail.com.

Abstract: The characteristics of the solar wind, such as the magnetic field and plasma velocity, are dependent on the sunspot activity cycle overall. One of the most significant indicators for determining the sun's overall activity levels is the sunspot cycle. In the plot, we examine solar wind measurements made during solar cycle 25's rising phase and contrast them with comparable information from cycles 24 before. To determine the association between solar wind plasma properties and sunspots, information collected by the ACE and STEREO A spacecraft and NOAA (National Oceanic and Atmospheric Administration) was utilised. Analysis was done on the solar wind details during the 24 and 25 solar increasing activity phases, including sunspot, magnetic field, temperature, density, and wind speed. Many correlations between different features of the sunspot cycle have been discovered. A softer form of the solar wind emerges from the corona during solar minimum due to the Sun's low activity.
Keywords: sunspot, magnetic field, proton density, speed, temperature

1. Introduction

One of the primary objectives of space study is to understand the solar wind (SW), which is created when the heated solar corona expands into the interplanetary medium. On the one hand, research on the solar wind helps us comprehend the characteristics of the solar atmosphere and the mechanisms behind its plasma outflow [1-2]. It is essential to consider the solar magnetic field and how it interacts with plasma properties when elucidating specific reactions in the solar atmosphere. The magnetic field within the sun is produced by the solar dynamo process [3]. In the solar atmosphere, this expression is seen as a range of events [4-5]. An important component that sheds light on solar corona dynamics is the shift in profile of density and temperature during the solar cycle. The changes in temperature, emission, and density are caused by the solar magnetic field's structure evolving. Density changes with both solar and interplanetary sources are seen in solar wind data at 1 AU across a wide variety of time periods. The largest scale fluctuations show the wind's solar origin: high densities are found in the sluggish flow from the area of the streamer belt, while low densities are found in the rapid flow from coronal holes [6]. The quantity and area of sunspots produced during a sunspot cycle serve as indicators of its intensity. Trends in the average features of individual sunspots during a sunspot cycle or between succeeding sunspot cycles have been hard to find, despite the fact that the quantity of sunspots varies significantly from one cycle to the next, suggesting an intrinsic variability in the mechanism that creates sunspots. Additionally, we may anticipate that at a cycle's maximum rather than its rising or descending phase, stronger, larger sunspots would emerge more frequently [7]. The border between rising chromospheric temperature and falling density is marked by the transition area. Similarly, rising temperature and falling density are observed through the solar corona. Solar wind velocity (V) multiplied by magnetic field (B), or V * B, is the most significant indicator of the degree of solar wind connection with the terrestrial atmosphere and magnetosphere [8]. The solar cycle is one of the most important indicators of the sun's overall activity. Radars, high-frequency signals, radio transmissions, ground power lines, spaceflights, the geospace environment, and life on Earth are all significantly impacted by solar activity [9]. For this reason, predicting solar activity is essential to both comprehending the solar activity process and safeguarding contemporary systems.

Due to the interdependence between solar wind characteristics, this work has evaluated many solar wind and sunspot parameters, including temperature, density, magnetic field, and wind velocity. Several parameters change in this case: magnetic field, proton density, temperature, and speed of the solar wind.

2. Data Analysis

For the current investigation, these two rising eras were taken into consideration. The spacecraft's ACE and STEREO A provided the daily averaged parameters of the solar wind values, while NOAA provided the sunspot data. In the study, measurements of the sunspot and solar wind parameters during the ascending phase of 24 and 25 solar cycles were obtained. In mid-2008, the solar cycle 24 started, and it concluded in 2019, and the ascending phase relates to the end of 2011–2013. Solar cycle 25 began in December 2019 and is still going on, with the ascending phase spanning from 2020 to 2022. For the current investigation, these two rising eras were taken into consideration. The spacecraft's ACE and STEREO A provided the daily averaged values of the solar wind parameters, while NOAA provided the sunspot data. The Solar Wind Electron, Proton, and Alpha Monitor (SWEPAM) instrument for ACE and the Solar Wind Experiment (SWE) instrument for STEREO A studied the speed, temperature, and density of the solar wind. The Sun-Earth Connection Coronal and Heliospheric Investigation (SECCHI) sensors, the magnetometer (MAG), and the STEREO/WAVES (SWAVES) instruments provided the magnetic field data for ACE. IMPACT will offer the regional magnetic field and plasma parameters of solar energetic particles. PLASTIC will offer plasma characteristics for protons, alpha particles, and large ions in the solar wind.

3. The Relation Between Solar Wind Parameters

Changes in temperature and density profiles over the solar cycle are substantial and provide an understanding of the dynamics of the solar corona. A velocity vs. temperature graph for the 24 and 25 solar ascending phases is shown in Figure 1. The solar wind temperature and velocity as noticed by the ACE (red) and STEREO A (green) spacecrafts are shown in the graphic. Solar wind speeds vary throughout the rising phase of the solar cycle due to the sun's increasingly distorted magnetic field. These figures also show that the solar wind velocity stays between 400 and 600 km/s for most of the data set. During solar cycle 24, the highest recorded speed was 1200 km/s at a temperature of 300,000 K. At a temperature of 400000K, the solar cycle 25 achieved its maximum velocity of 750 km/s. Since the particle speed and temperature of the solar wind are related, temperature changes should be observed in parallel with variations in solar wind speed. It is often noticed that a stream moving at a very rapid speed has relatively high temperatures; slower streams are typically cooler. [10] concluded that the solar wind's acceleration near the sun is related to temperature fluctuations caused by the stream's growth in the interplanetary medium. The component event on the sun's surface caused the huge amplitude of the solar wind's temperature and speed in Figure 1. It is believed that this stream of particles is extremely tenuous due to its rapid and high temperature.

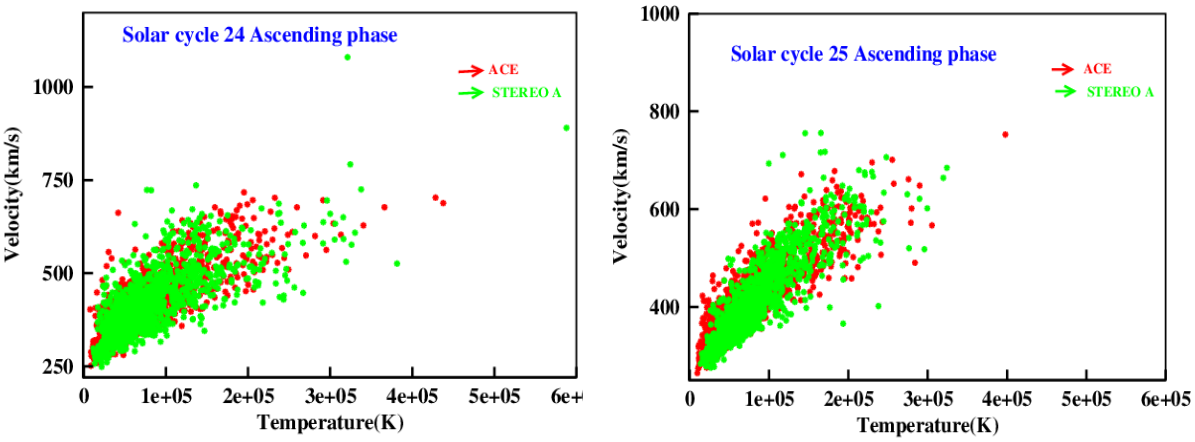

Fig 1: solar wind velocity Vs .temperature for 24 and 25 solar cycle ascending phase

For the rising phase of solar cycles 24 and 25, the density versus velocity charts is displayed in Figure 2. While most of the highest densities were seen at lower velocities, the combined plot of the density vs. velocity values for the observation time showed an increase in the extreme values of density over the velocity range. The increased density was caused by the lower velocity streams' faster journey, which packed the particles within. The square root of the medium's density and velocity are negatively correlated. This implies a reduction in velocity with an increase in density. The greatest densities, which range from 300 km/s to 500 km/s, are observed for most data series during the ascending portion of solar cycles 24 and 25. Since the results of tomographical density measurements reveal a very narrow belt of high-density (low-speed) streamers during the solar minimum and because the belt's small latitudinal meanderings permit regions of extremely low density to stretch from the poles to the equator, there is a periodic presence of very high-speed solar wind streams that originate from polar coronal holes close to the equator [11-12]. Due to the increasing quantity of high-velocity streams leaving the solar surface during the solar rising phase, the density values are abnormally low. The particles spread out at very fast speeds, making the stream extremely flimsy.

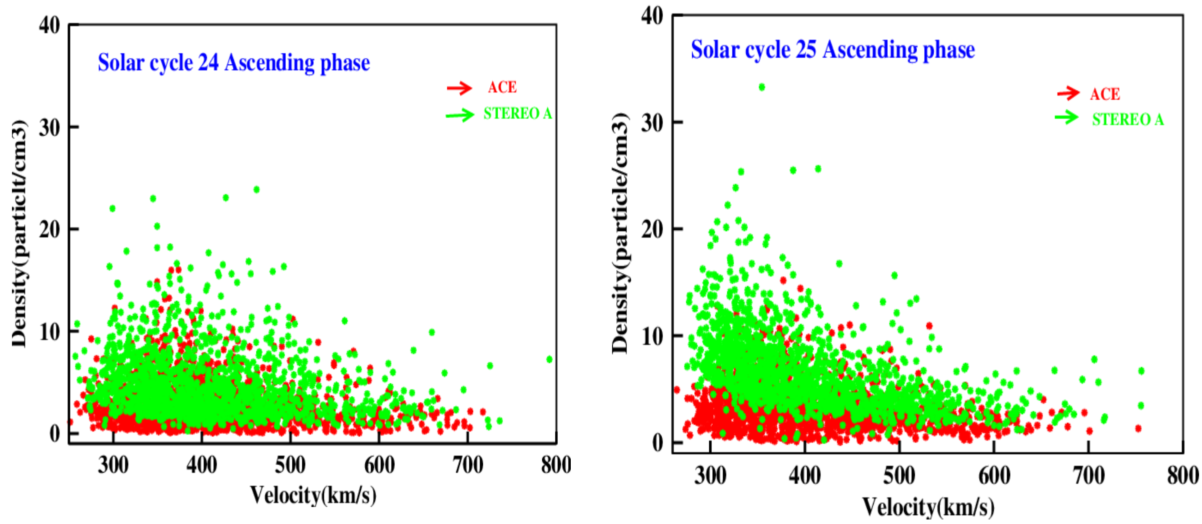

Fig 2: solar wind density Vs. velocity for 24 and 25 solar cycle ascending phase

Thus, it is widely recognised that higher solar wind velocities originate from lower-density areas of the corona and vice versa [13-14]. A spacecraft experiences a decrease in density as its velocity increase. [15-16] the quick solar wind is characterised by less density, smaller charge state ratios, and greater proton temperatures when compared to the slow solar wind.

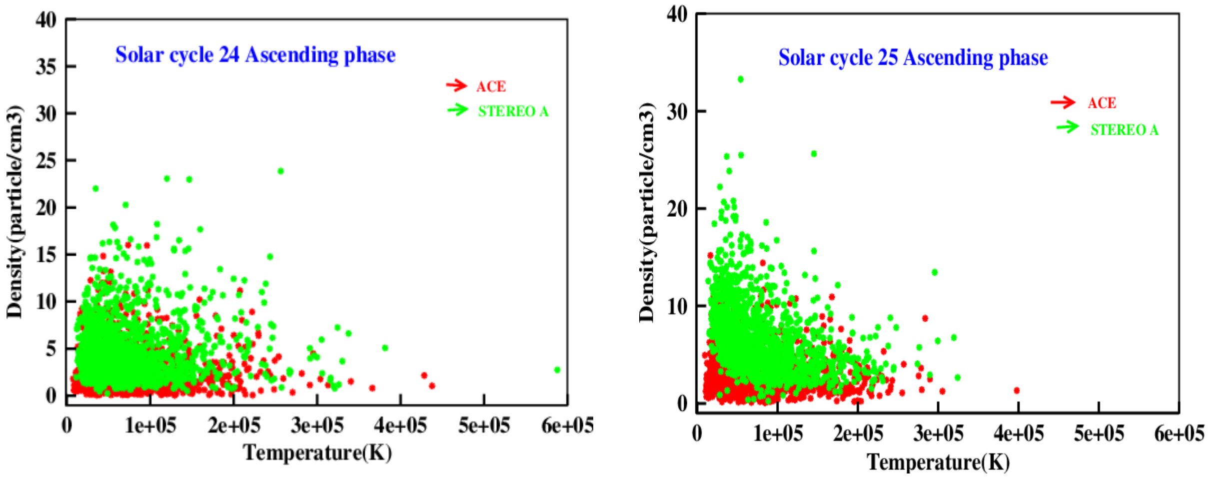

Fig 3: solar wind density Vs. temperature for 24 and 25 solar cycle ascending phase

The solar wind's temperature and velocity both affect its particle density. The magnetic field is linked to the temperature and density profiles. The density vs. temperature graph for stages 24 and 25 of the solar ascending process is displayed in Figure 3. The values on the density axis in this instance increase to 24 p/cm ^{3} for solar cycle ascending phase 24 and to 35 p/cm ^{3} for solar cycle ascending phase 25. In solar cycle 25, the temperature axis moved to 600,000 K, while in cycle 24, it reached up to 400,000 K. Because of a greater rate of density, higher temperatures result in a decrease in pressure across the solar cycle. As solar activity increases, temperatures rise somewhat and density decreases. The link between temperature and density is obviously inverse, with rising temperatures resulting in declining densities. Because of the higher solar wind density in both solar ascending phases, a lower temperature profile was observed. Where the lines of magnetic field are open as well as the solar wind is free to circulate, these are known as coronal holes in the sun. The temperatures are lower and the concentrations are lower in these locations. The temperature and density patterns are significantly dependent on the intensity of the magnetic field since the density distribution is directly proportional to the magnetic field while the temperature profiles are inversely proportional [17]. During solar cycle 25, as opposed to cycle 24, greater values in the density profiles are more common.

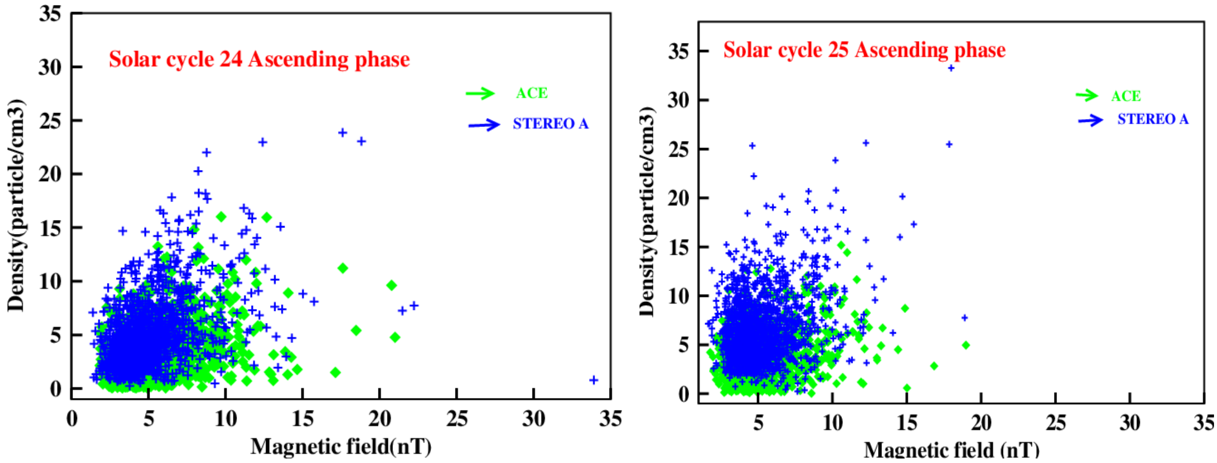

Fig 4: solar wind density Vs. magneticfield for 24 and 25 solar cycle ascending phase

Density was lowest at higher magnetic field strengths, and vice versa. Peak magnetic field values were recorded during both solar cycles, with density falling between 15 n T and 20 n T. While density varies sharply, no event lasts long enough to generate several hours in a row with extremely high or low density values. The regions with higher density values in the areas with lower magnetic fields are shown in the figure 4. A passing CME can be identified by its typical reduction in density. There is an active region connected to these places. Structures like coronal mass ejections (CMEs) and solar flares, which originate on the solar surface, produce large-scale changes in the density of the solar wind [18]. The density variations' distribution, which coronal holes are likely to influence, is thus linked to the activity of the sun's magnetic field.

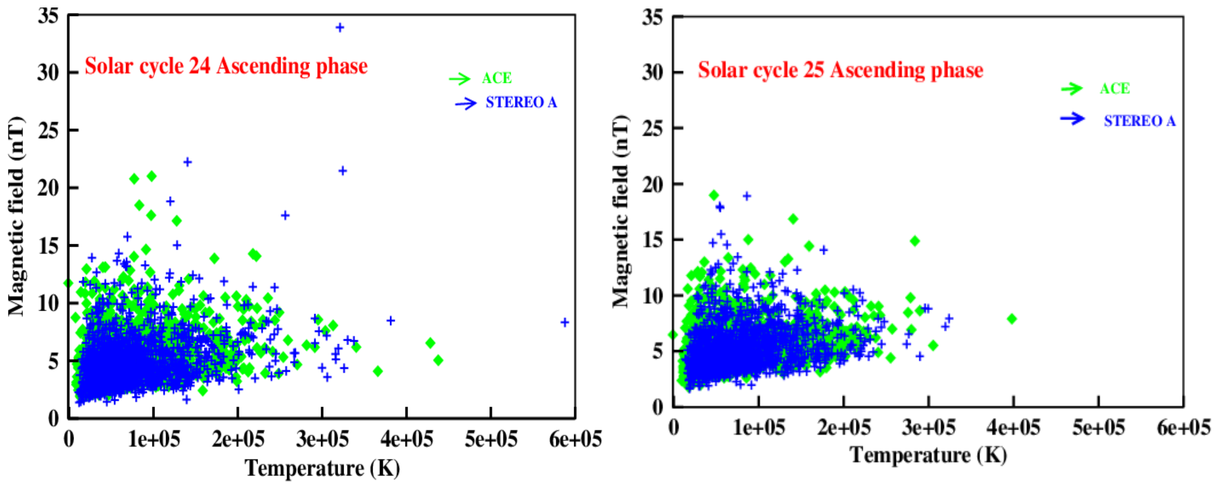

Fig 5: sun wind magneticfield Vs. temperature for 24 and 25 solar cycle ascending phase

Plots of the magnetic field vs. temperature for the 24 and 25 ascending phases are displayed in Figure 5. In both cycles, the solar wind was dispersed disorderly for greater levels of magnetic field and temperature and tightly distributed for lower values. The magnetic fields were stronger in the 24 solar cycles when the maximum was seen for the same temperature range in two solar cycles. In both solar ascending phases, its magnetic field weakened as the temperature of the sun wind rose. MCs have plasma values much lower because of the powerful magnetic field and low proton temperatures.

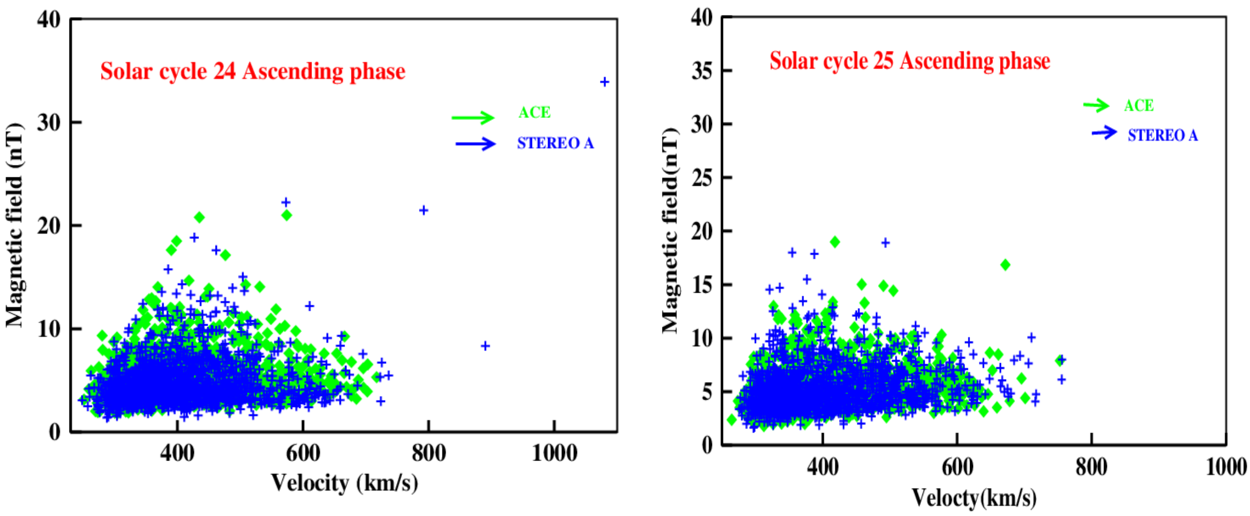

Fig 6: solar wind magneticfield Vs. velocity for 24 and 25 solar cycle ascending phase

The magnetism of the sun becomes more and more distorted throughout the rising part of the solar cycle, which causes variations in solar wind speed. A depiction of the solar wind magnetic field against velocity for the ascending periods of solar cycles 24 and 25 is presented in Figure 6. The greatest magnetic field of 35 nT was reported during solar cycle 24, and just one magnetic field was observed after 1000 km/s. The greatest magnetic field of 20 n T was reported during solar cycle 25. The maximum magnetic field that may be produced is 400–600 km/h. Lower-speed streams in the solar cycle flow at the rate at which the particles inside them compress and cause a drop in solar activity. Interplanetary disturbances were most likely unconnected to changes in velocity and magnetic fields. Consequently, [19] found that at times of low solar activity, there is a strong connection between the radial and vertical components of the magnetic field that exists between planets and that indicates the relationship coefficient relies on both mean magnetic field directions.

4. The Relationship Between Sunspot And Solar Wind Characteristics In The Solar Wind Rising Phase

On the surface of the sun, activity varies in tandem with changes in magnetic fields. Sunspot counts are one method of monitoring the solar cycle. A solar lowest number of sunspots on the solar, marks the start of a solar cycle. Both solar activity and the number of sunspots increase with time. We examine charts showing sunspot numbers in relation to several solar wind characteristics that the spacecraft measured.

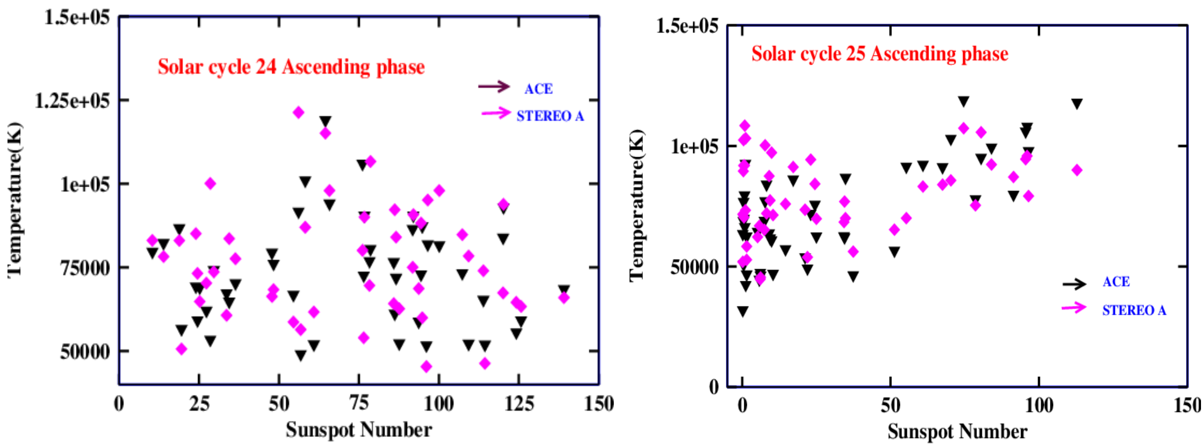

Fig 7: Solar wind temperature Vs .sunspot number in 24 and 25 solar ascending

A plot of the sunspot number against speed for the minimum-year solar cycle 24 and another plot for the solar cycle 25 are shown in Figure 7. The graph depicts the spread rates of the solar cycle 24 and the more condensed values of the solar cycle 25. On both the vertical and horizontal axes, the values are more dispersed. The sunspot numbers during solar cycles 24 and 25 ranged from 10 to 140 and 1 to 120, respectively. 125000K was the hottest temperature recorded throughout both cycles. The temperatures increased because more sunspots produced more energy. According to Brooks and Warren (2012)[20], the figure illustrates that active area outflows have high coronal temperatures. Additionally, [21] have shown that these outflows have open field lines that let plasma slip into the heliosphere.

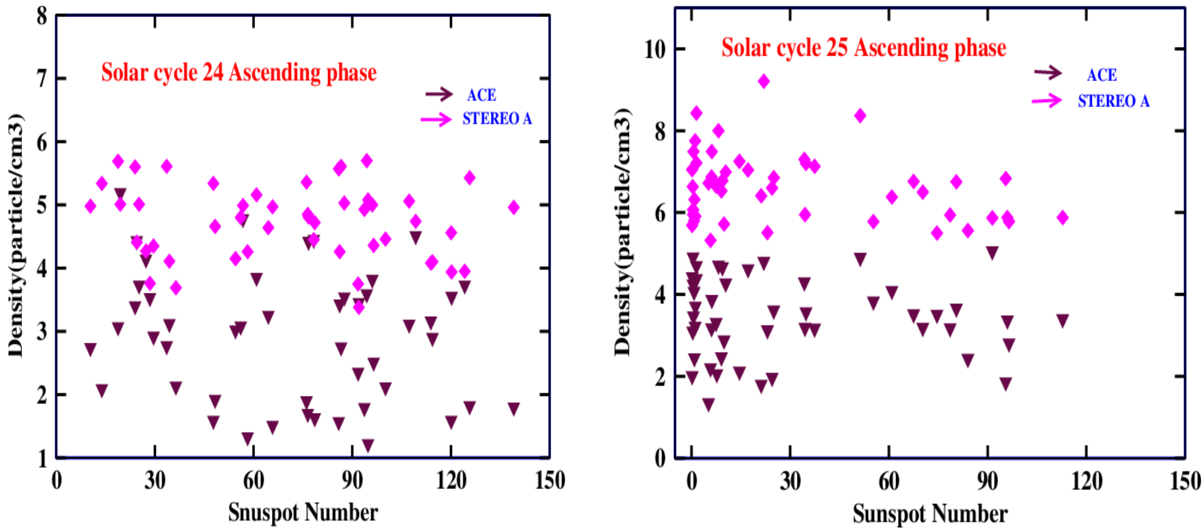

Fig 8: Solar wind density Vs .sunspot number in 24 and 25 solar ascending

A composite plot of particle density vs. sunspot number for the ascending phase is shown in Figure 8. Values on the vertical and horizontal axes are spread more equally during the solar minimum. For solar cycles 24 and 25, respectively, the range is 1 to 6 and 1 to 9 p/cm3. The greatest density occurrences recorded by the STEREO A satellite were both solar cycles 24 and 25. Given that the magnetic field and the density profile are proportionate. [17] noted that the density profiles correspond to the sunspot movement over the solar cycle, along with fluctuations in the magnetic field. The density of particles rises in colder, slower-moving streams, whereas it decreases in hotter, faster-moving streams. According to [22] the solar wind's maximum temperatures and speeds really happen during the cycle's dropping phase, whereas its maximum densities happen during its rising phase. Between 1 and 75 au, there is a strong agreement between the theoretical and measured solar wind densities, which decline with increasing heliocentric distance [23].

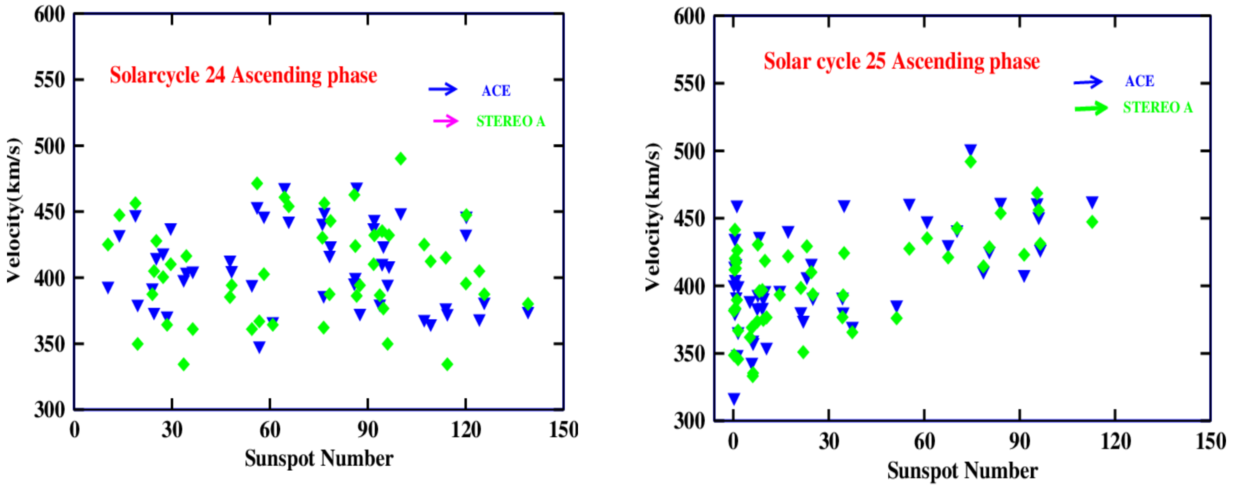

Fig 9: Solar wind velocity Vs .sunspot number in 24 and 25 solar ascending

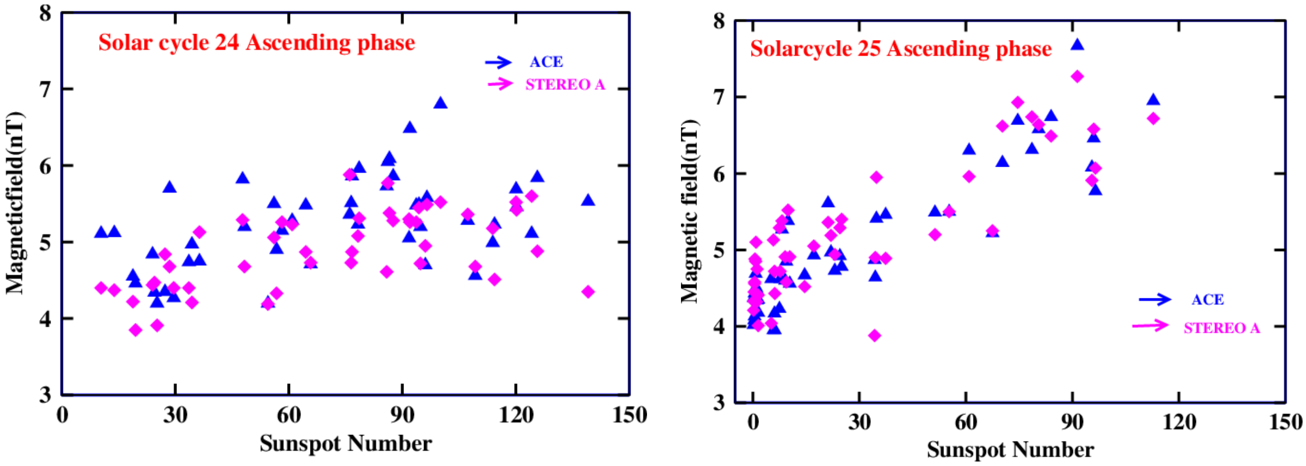

Fig 10: Solar wind magnetic field Vs sunspot number in 24 and 25 solar ascending.

The dynamics of the sun's outer layer are significantly impacted by the fluctuation of the magnetic field, which is measured by a variety of solar metrics, including the sunspot number, frequency of CME occurrences, solar wind plasma temperature, and solar wind speed. Figure 10 depicts the sun during the start of solar cycles 24 and 25, when it is quite calm and has fewer sunspots and solar activity. The magnetic field in 24 SC had a vertical range of around 7 nT during the solar ascending phase, while the magnetic field in 25 SC had a vertical range of about 8 nT. The magnetic field progressively rises with the number of sunspots throughout the rising phase. At the beginning of the rising phase, the magnetic field showed predictable fluctuations with the sunspot number. Low activity during the first part of solar cycles 24 and 25 was seen. The magnetic field is weak, and the sunspot region is modest right now. Here, the sunspot movement and area are at their highest, and the magnetic field is strongest. The relative sunspot number correlates with an increase in the solar magnetic field's strength. However, when the sunspot grows during the latter portion of the rising phase, the magnetic field weakens. The intensity of the solar cycle is established by the quantity, darkness, and field strength of sunspots, according to [24]. Because of how powerful these magnetic fields are, some of the sun's heat is prevented from rising to the surface.

In comparison to the parameters in the solar cycle 25 ascending, all of the parameters in the solar cycle 24 ascending were significantly smaller in quantity and magnitude, including solar wind velocity, temperature, density, magnetic field, and sunspot number. This is most likely caused by the 24 solar cycles' weaknesses. According to [25], solar cycle 24 is incredibly feeble, as shown by sunspot numbers, and little solar activity is seen on the Sun during this rising period of the solar cycle. In terms of disturbances seen in the heliosphere and on the solar surface, Cycle 24 is shown to be weaker than Cycle 23 [26-27].

5. Conclusion

Variations in the sun's surface activity lead to differences in the solar wind produced around the corona. The solar wind characteristics during the 24th and 25th solar ascending phases were obtained by cross-analysing the interdependence of solar wind parameters and sunspots. ACE and STEREO spacecraft observed similar types of variations in solar wind parameters in the 24 and 25 solar ascending phases. In comparison to the solar wind parameters in the ascending phase of solar cycle 25, the parameters related to solar wind, including temperature, density, magnetic field, and velocity, exhibited lower levels of activity in solar cycle 24. The smaller activity was due to the weak solar cycle. Owing to the density profile's proportionality to the magnetic field, variations in the magnetic field are associated with the sunspot trend observed during the solar cycle.

The characteristics of solar wind speed, magnetic field, density, temperature, and sunspot number did not depend on each other when compared to the data recorded by the 24 solar ascending phases. The traits shown in the 25 solar ascending were more numerous than those in the 24 solar ascending, suggesting that the 24 solar cycle is weaker. Along with the charge exchange rates of interstellar neutral species within the heliosphere, the solar wind representation depicts the development of solar wind density and speed. A weak cycle with few sunspots and little solar activity is predicted for the 24th solar cycle. A low quantity of sunspots was found in the equatorial area, where the number was uniformly distributed during the ascending phase. When comparing solar cycles 24 and 25, the total magnetic activity of cycle 24 was less.

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