



ORIGINAL RESEARCH PAPER

Physics

EVOLUTION OF SOLAR WIND PARAMETERS DURING SOLAR CYCLE 25 (2019-2025)

KEY WORDS: Solar Cycle 25, Solar Wind, Imf, Proton Density, Proton Temperature, Dynamic Pressure, Space Weather.

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ABSTRACT

In this paper we investigate the near Earth solar wind environment during Solar Cycle 25 using measured annual averages. Parameters are IMF magnitude, proton temperature, proton density, solar-wind speed and dynamic pressure. From 2019 solar minimum reference to 2025, B increased from 4.5 to 7.6 nT, Solar wind speed from 398 to 490 km/s and dynamic pressure from 1.70 to 2.62 nPa. Proton density did not increase monotonically while proton temperature reached 135,437 K in 2025.

1. Introduction

The solar wind is a magnetized plasma from the solar corona that continuously interacts with Earth's magnetosphere. Its speed, density, temperature, magnetic field strength and dynamic pressure provide the upstream conditions controlling magnetospheric compression and energy transfer. Solar Cycle 25 followed the December 2019 solar minimum and developed into an active cycle. NASA and NOAA announced the solar maximum period in October 2024. The near Earth solar wind record provides an independent plasma-based description of this evolution. Here in this paper, we will discuss annual changes in major solar wind parameters, identify systematic and non-monotonic trends, interpret changes in relation to Solar Cycle 25 and provide reproducible data tables and figure. [1]

Data Analysis and Results

The main objective of this work is to (i) quantify annual changes in major solar wind parameters (ii) identify systematic and non-monotonic trends (iii) Changes in Solar Cycle 25. For data analysis in the present study, we define flow pressure approximately as,

$$P_{dyn} = (1.67 \times 10^{-6}) NpV_{sw}^2 (1 + 4Na/Np) \text{ nPa}$$
 when the alpha /proton ratio is available. It is approximately $2.0 \times 10^{-6} N_p V_{sw}^2$ nPa.

In this study we used OMNI yearly average product directly. The annual product is appropriate for cycle scale changes, while hourly and 27-day products should be used for event level analysis. The principal comparison is between 2019 and 2020-2025. The '*' indicates 2026 row is current partial year indication and hence not to consider for study. [2][3]

Solar-Wind Data

Table 1. Solar wind data.

Year	IMF B(nT)	Proton Temp. Tp (K)	Density Np(cm-3)	Speed (Vsw) km/s	Pressure Pdyn(nPa)	Status
2019	4.5	67,061	6.4	398	1.70	Reference
2020	4.3	59,888	6.4	378	1.52	Complete
2021	5.0	73,201	6.7	403	1.84	Complete
2022	6.4	112,749	5.7	443	1.86	Complete
2023	6.5	103,614	5.8	429	1.93	Complete
2024	6.9	87,276	7.1	400	2.27	Complete
2025	7.6	135,437	6.1	490	2.62	Complete
2026*	6.6	107,928	5.6	454	2.17	Partial

Change from 2019-2025

From the data tabulated above we analyze change from the 2019 minimum reference to the complete 2025 year.

Table 2. Change in Parameters from 2019 to 2025.

Parameter	2019	2025	Change
IMF magnitude	4.5 nT	7.6 nT	68.9%
Proton Temperature	67,061 K	135,437 K	102.0%
Proton density	6.4 cm-3	6.1 cm-3	-4.7%
Solar-wind speed	398 km/s	490 km/s	23.1%
Dynamic pressure	1.70 nPa	2.62 nPa	54.1%

RESULTS AND DISCUSSION

Solar-Wind Speed

Annual mean V_{sw} decreased from 398 km/s in 2019 to 378 km/s in 2020, then increased to 403 km/s in 2021, 443 km/s in 2022 and 429 km/s in 2023. It decreased to 400 km/s in 2024 and rose to 490 km/s in 2025. This evolution is therefore variable rather than monotonic. [4][5]

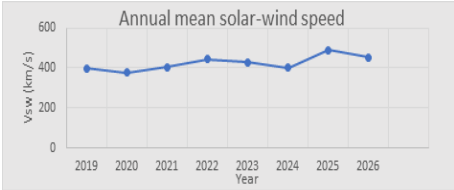


Figure 1. Annual mean solar-wind speed.

IMF magnitude and dynamic pressure

Annual mean IMF magnitude increased from 4.5 nT in 2019 to 7.6 nT in 2025. Dynamic pressure increased from 1.52 nPa in 2020 to 2.62 nPa in 2025. Since pressure depends approximately on NpV_{sw}^2 , speed changes can have a strong influence on P_{dyn} .

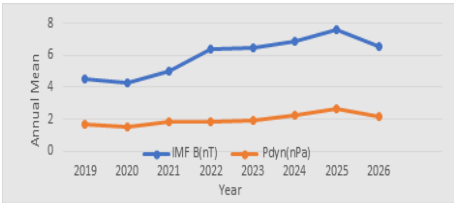
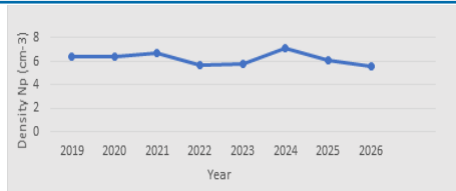


Figure 2. Annual mean IMF magnitude and dynamic pressure.

Proton density and temperature

Proton density remained near 6.4 cm⁻³ in 2019-2020, rose to 6.7 cm⁻³ in 2021, declined to 5.7-5.8 cm⁻³ in 2022-2023, increased to 7.1 cm⁻³ in 2024 and declined to 6.1 cm⁻³ in 2025. This non monotonic behavior shows that density cannot be treated as a simple proxy for solar cycle phase. Proton temperature was 67,061 and 59,888 K in 2020. It rose to 73,201 and 112,749 K in 2022, remained high in 2023 at 103,614 K, decreased to 87,276 K in 2024 and reached 135,437 K in 2025. This variability is consistent with changing contributions from fast wind, compression regions and transient structure.

Figure 3. Annual mean proton density.



The measured values show that different evolution differently during Solar cycle 25. IMF magnitude and dynamic pressure show pronounced increases toward 2024-2025, while density varies without a simple trend. Solar-wind speed also fluctuates, consistent with contributions from high-speed streams as well as transient disturbances.

Annual averages suppress short lived CME extremes. For geomagnetic storm research, Bz, speed, pressure and their duration should be examined at hourly or higher resolution products for this purpose.[5][6][7]

Conclusions

From the table 2 it is clear that the measurements show a substantial strengthening of near-Earth solar wind magnetic and pressure environment from the 2019 minimum reference to 2025. IMF magnitude increased by 68.9%, solar wind speed by 23.1% and dynamic pressure by 54.1%. Proton temperature approximately doubled, whereas proton density changed only slightly overall and remained non monotonic. These results show a multiparameter interpretation of Solar cycle 25.

Acknowledgement

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Data Availability Statement

The data used in this study are publicly available freely. The result presented in this paper are based on NASA/OMNI Web yearly averages.

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