RESEARCH PAPER

Solar Parameter Characterization Using In-Situ Measurements from the ACE Spacecraft

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Abstract
Solar wind variability plays a crucial role in shaping the near-Earth space environment and influencing space weather phenomena that affect modern technological systems. This study aims to characterize key solar wind plasma and magnetic field parameters using in-situ observations and to examine their statistical behavior and interrelationships over a selected time period. Plasma parameters such as proton density, solar wind speed, proton temperature, and alpha-to-proton ratio, along with magnetic field components, were analyzed. Data preprocessing was performed to remove non-physical values, followed by statistical, time-series, and correlation analyses. The results show that the mean solar wind speed was 445.91 km/s, while proton density averaged 5.63 cm^{-3}. Proton temperature exhibited wide variability, ranging from 5,840.60 K to 853,867.40 K. The magnetic field magnitude had an average value of 6.12 nT and reached a maximum of 35.74 nT. A strong positive correlation was observed between solar wind speed and proton temperature ($r = 0.762$), indicating that faster solar wind is associated with higher thermal energy. In contrast, proton density showed a moderate negative correlation with solar wind speed ($r = -0.411$), suggesting lower density in high-speed streams. These findings demonstrate that in-situ measurements effectively capture both quiet and disturbed solar wind conditions and provide valuable insight into plasma–magnetic field interactions, contributing to improved understanding of solar wind dynamics and space weather characterization..

Keywords: Solar wind, Plasma parameters, Magnetic field, Heliosphere, space weather

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1. Introduction

Solar wind is a continuous flow of charged particles that are released by the Sun and occupy the heliosphere and greatly affect the near-Earth space environment. Its variability is critical in the study of the processes of the heliospheric plasma and reducing the effects of space weather on the modern technological systems. Solar weather events are a world concern because they have the potential to disrupt satellite operations, communications networks, and power grids due to solar wind conditions and solar transients (Schrijver et al., 2015). The near-Earth space is very dynamic, and it is characterized with the fluctuations of plasma density, velocity, temperature, and magnetic field structures that all contribute to the complex interactions with the magnetosphere of Earth (Opgenoorth et al., 2024). Moreover, the heliospheric radiation environment significantly contributes to the development of the space conditions and is a risk to the spacecrafts and human activity (Guo et al., 2024).The innovations in space-based observations over the past decades have contributed greatly to our knowledge of the solar and heliospheric processes. Ultraviolet and visible radiation methods of remote sensing have facilitated the time series observation of atmospheric and solar processes (Abad et al., 2019). The polarimetric techniques have also increased the capacity to extract finer details about radiation interactions and particle characteristics

(Dubovik et al., 2019). The use of observational missions with the aim of measuring the plasma and magnetic fields has given valuable information on turbulence and particle dynamics in near-Earth space (Pollock et al., 2018). Moreover, the high-energy astrophysical investigations have been used to know about the energetic processes that take place in the heliosphere (De Angelis et al., 2021). The research on the variability of solar wind has also been enhanced by the access to sophisticated data analysis tools and observational campaigns. Systems that can be used to facilitate the efficient access and processing of large amounts of heliospheric data include automated multi-dataset analysis systems (Génot et al., 2021). The methods of interplanetary scintillation have been employed to study the structures of solar wind and their movement in space (Jackson et al., 2023). The relevance of studying space plasma interactions and environmental conditions to a broader context is emphasized in experimental studies dedicated to the radiation effects (Dalla Pria et al., 2024).
The in-situ spacecraft measurements are among the most accurate methods of sampling directly the solar wind plasma and magnetic field properties through the various observational techniques. The Advanced Composition

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Explorer (ACE) spacecraft in the L1 Lagrange point offers real time data on the solar wind prior to hitting the earth. This stance enables ACE to act as a preemptive surveillance system of solar wind disruptions that are coming in. Solar wind speed, proton density, temperature, and interplanetary magnetic field components are some of the key parameters measured on board ACE, which are important in characterizing the behavior of the solar wind.The parameters of solar wind are important in the processes of solar-terrestrial coupling. The magnetic field density, solar wind density and speed vary and regulate the energy and momentum transfer into the magnetosphere of the Earth. Specifically, the efficiency of magnetic reconnection at the magnetopause depends on the orientation of the interplanetary magnetic field, particularly, the Bz component, and has a significant effect on geomagnetic activity (Opgenoorth et al., 2024). These are essential processes to the answer of how the near Earth environment can react to the solar forcing.

Although there has been a lot of advancement, systematic analyses, which involve statistical characterization and correlation based analyses with consistent datasets, are still required. A large number of works are devoted to detailed event-based analysis or large-scale modeling, and less are available with combined statistical evaluation of solar wind parameters during particular periods of time. Thus, the purpose of the research is to conduct a statistical and correlation analysis of the parameters of solar wind plasma and magnetic field based on in-situ ACE measurements during the years 2015-2017. Through investigation of the relationships between the major variables that include solar wind speed, proton temperature, density and magnetic field components, this work will help in the enhancement of the current understanding of the solar wind dynamics and enable the generation of more precise space weather prediction models.

2. Methodology

2.1 Data Description and Parameter Selection

The present study is based on in-situ observations obtained from the Advanced Composition Explorer (ACE) spacecraft for the period 2015–2017. A combined dataset consisting of plasma parameters from the SWEPAM instrument and magnetic field parameters from the MAG instrument was used. The plasma parameters analyzed include proton density (Np), solar wind speed (Vp), proton temperature (Tpr), alpha-to-proton ratio, and velocity components in Geocentric Solar Ecliptic (GSE) coordinates. The magnetic field parameters include the total magnetic field magnitude (|B|) and its components Bx, By, and Bz. These parameters were selected because they represent the key physical properties required for solar wind characterization and heliospheric analysis.

2.2 Data Preprocessing

Before analysis, the dataset was carefully preprocessed to ensure accuracy and consistency. The original dataset contained missing or invalid values represented by fill values (e.g., -1.0E31), which were removed from the analysis. Data cleaning was performed separately for each parameter to retain only physically meaningful observations. After removing missing values, the dataset was checked for consistency in time resolution, and all parameters were aligned at an hourly scale. This preprocessing step ensured that the analysis was not affected by data gaps or non-physical entries.

2.3 Statistical Analysis

Statistical methods were applied to describe the overall characteristics of the solar wind and magnetic field parameters. Basic statistical measures such as mean, median, minimum, and maximum values were calculated for each parameter to understand their general behavior over the study period. In addition, distribution analysis was carried out to examine how the values of solar wind speed and other parameters are spread across different ranges. This helped in identifying typical solar wind conditions as well as extreme events present in the dataset.

2.4 Time-Series Analysis

Time-series analysis was used to investigate the temporal variation of solar wind and magnetic field parameters. The hourly dataset was examined over the entire period from 2015 to 2017 to observe changes in solar wind speed, proton density, temperature, and magnetic field strength over time. This analysis allowed the identification of recurring patterns, such as high-speed solar wind streams, as well as transient disturbances. The temporal behavior of these parameters provided insights into the dynamic nature of the solar wind environment near Earth.

2.5 Correlation Analysis

To understand the relationships between different solar wind parameters, correlation analysis was performed using the Pearson correlation coefficient. This method was used to quantify the strength and direction of linear relationships between selected parameter pairs. The analysis focused on key relationships such as solar wind speed and proton temperature, proton density and solar wind speed, and proton density and magnetic field magnitude. The correlation results helped in identifying how different plasma and magnetic field properties are interrelated.

2.6 Derived Parameters and Physical Interpretation

In addition to the primary parameters, derived quantities were considered to enhance the physical interpretation of the results. These include dynamic pressure, plasma beta, and Alfvén speed, which are important for understanding the interaction between solar wind plasma and magnetic fields. These derived parameters provide additional insight into whether the plasma or magnetic field dominates the solar wind conditions and how energy is transferred within the system.

2.7 Classification of Solar Wind Conditions

Finally, the dataset was analyzed by distinguishing between different solar wind conditions. Periods with moderate values of speed, density, and magnetic field were classified as quiet solar wind conditions, while intervals with high speed, enhanced magnetic field strength, and strong fluctuations in Bz were considered disturbed conditions. This classification helped in interpreting the results in terms of normal solar wind behavior and event-driven variations, such as high-speed streams or transient solar disturbances.

3. Results

3.1 Overview of the Dataset

The dataset contains hourly in-situ observations from the ACE spacecraft for the period 2015–2017. It includes solar wind plasma parameters from SWEPAM and magnetic field parameters from MAG. The main plasma variables are proton density, solar wind speed, proton temperature, alpha-to-proton ratio, and velocity components. The magnetic field variables include total magnetic field magnitude and the Bx, By, and Bz components. Some missing values were present in the dataset, especially in proton density and alpha-to-proton ratio. These missing values were removed before interpretation.

3.2 Statistical Characteristics of Solar Wind and Magnetic Field Parameters

The mean solar wind speed was 445.91 km/s, showing that the dataset contains mostly moderate solar wind conditions, with some high-speed intervals reaching 773.50 km/s as shown in Table 1. Proton density had a mean value of 5.63 cm^{-3}, which is consistent with typical near-Earth solar wind conditions. The proton temperature showed large variation, ranging from 5,840.60 K to 853,867.40 K. This indicates that both quiet solar wind and disturbed solar wind intervals are present in the dataset. The magnetic field magnitude had a mean value of 6.12 nT, but reached a maximum of 35.74 nT, suggesting the presence of strongly disturbed magnetic field conditions during some intervals.

Table 1. Descriptive statistics of the ACE dataset

Parameter	Valid Data Points	Mean	Median	Minimum	Maximum
Proton density, Np (cm^{-3})	14,908	5.63	4.36	0.24	51.00
Solar wind speed, Vp (km/s)	23,132	445.91	426.26	253.83	773.50
Proton temperature, Tpr (K)	22,786	92,995.54	71,237.20	5,840.60	853,867.40
Alpha/proton ratio	14,166	0.032	0.031	0.002	0.160
Magnetic field magnitude, B (nT)	23,160	6.12	5.43	0.78	35.74
Bx (nT)	23,160	-0.26	-0.62	-20.86	16.29
By (nT)	23,160	0.43	0.62	-22.95	24.13
Bz (nT)	23,160	0.04	0.08	-29.24	20.76

3.3 Solar Wind Speed and Temperature Variation

The solar wind speed showed broad variability during the study period. Most values were concentrated around moderate speeds, but several intervals exceeded 500 km/s as shown in Fig 1. These high-speed intervals may be related to high-speed solar wind streams. The proton temperature followed the solar wind speed pattern. Higher solar wind speeds were generally associated with higher proton temperatures. This behavior is expected because fast solar wind is usually hotter than slow solar wind.

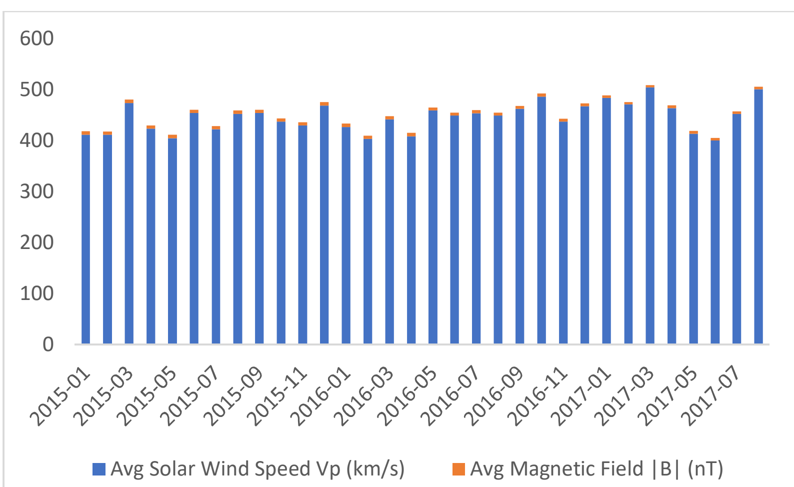

Figure 1. Monthly variation of solar wind speed and magnetic field strength

3.4 Distribution of Solar Wind Speed

The distribution of solar wind speed shows that most observations fall within the moderate-speed solar wind range as shown in Fig 2. However, the presence of values above 600 km/s confirms that the dataset also includes high-speed solar wind streams.

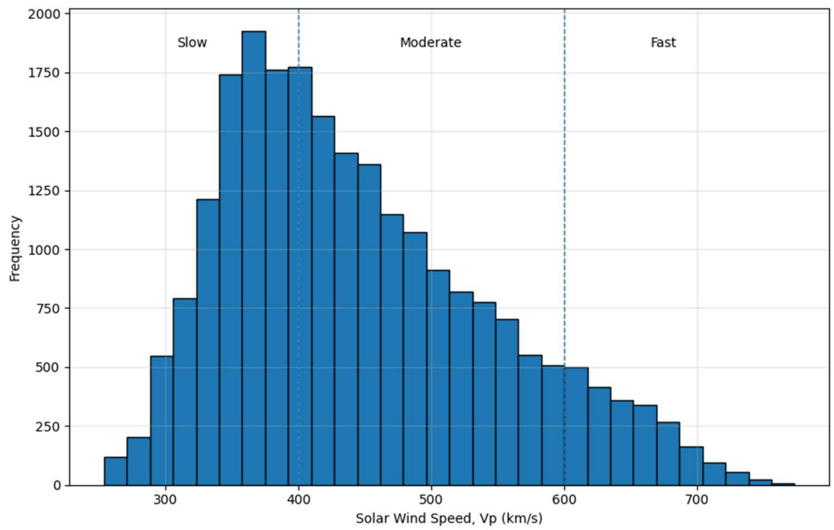

Figure 2. Distribution of solar wind speed

3.5 Relationship Between Solar Wind Speed and Proton Temperature

A strong positive relationship was found between solar wind speed and proton temperature. The correlation coefficient between solar wind speed and proton temperature was **0.762**, which indicates that faster solar wind is generally associated with higher proton temperature as shown in Fig 3.

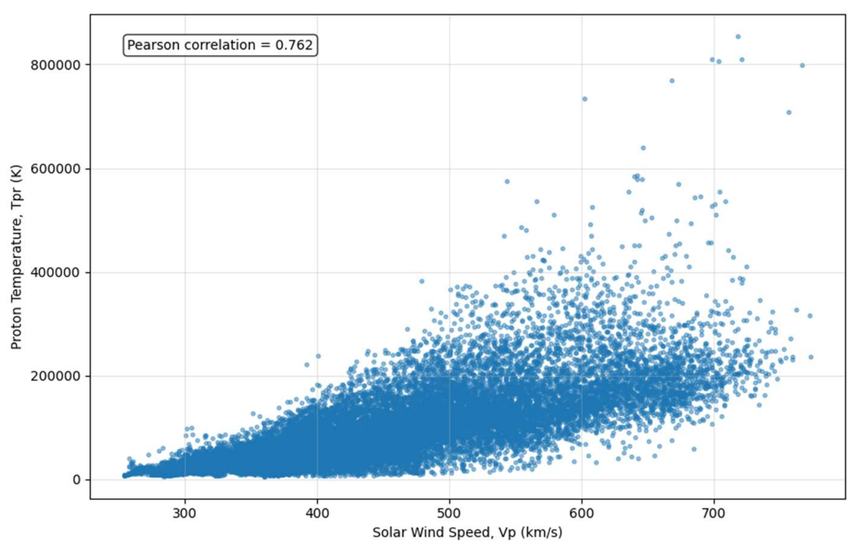

Figure 3. Relationship between solar wind speed and proton temperature

3.6 Correlation Between Solar Wind Parameters

The strongest relationship was observed between solar wind speed and proton temperature, with a correlation value of 0.762 as shown in Table 2. This confirms that high-speed solar wind intervals are generally hotter. A moderate negative correlation was found between proton density and solar wind speed with a value of -0.411. This means that faster solar wind tends to have lower density. A moderate positive correlation was found between proton density and magnetic field magnitude with a value of 0.403, suggesting that denser solar wind regions are often linked with stronger magnetic field conditions. The correlation between solar wind speed and magnetic field magnitude was weak, indicating that magnetic field strength does not increase directly with speed in a simple linear manner.

Table 2. Correlation between selected plasma and magnetic field parameters

Parameter Pair	Correlation
Solar wind speed vs proton temperature	0.762
Proton density vs magnetic field magnitude	0.403
Proton density vs solar wind speed	-0.411
Proton temperature vs magnetic field magnitude	0.239
Solar wind speed vs magnetic field magnitude	0.047
Bz vs solar wind speed	-0.006

3.7 Magnetic Field Behaviour

The magnetic field magnitude varied from 0.78 nT to 35.74 nT. The high maximum value shows that the dataset includes disturbed magnetic field intervals. The Bz component varied between -29.24 nT and 20.76 nT. The negative Bz values are important because southward Bz can enhance solar-terrestrial coupling and may contribute to geomagnetic activity.

4. Discussion

The findings of the ACE dataset give an idea of how solar wind plasma and magnetic field parameters behave in the close to the Earth atmosphere. The variation of solar wind speed which is observed between slow and high-speed regimes is an indication of dynamic characteristics of the solar wind streams. The positive correlation between the speed of solar wind and the temperature of protons is strong and positive, which means that rapid solar wind can be linked to the high thermal energy, which is expected given the known mechanisms of solar wind expansion (Zheng et al., 2024; Ishii et al., 2025). The speedy solar wind, which is usually caused by coronal holes, is warmer whereas the slow solar wind is more dense and colder. The changes in the proton density and magnetic field suggest compression zones and short-lived perturbations like stream interaction zones and interplanetary shocks (Temmer et al., 2023). The increase and decrease in the Bz component, especially southward excursions, indicate that the interaction with the magnetosphere of the Earth increases due to the magnetic reconnection processes (Grimmich et al., 2025).

The findings are in agreement with earlier research of solar wind variability and near-Earth plasma conditions. These statistical trends and associations can be related to the general account of the heliospheric plasma (Zheng et al., 2024). The correlation between wind speed and temperature of the sun has been frequently reported and indicates underlying acceleration processes (Ishii et al., 2025). High-speed streams and short-lived disruptions are consistent with the dynamics of coronal mass ejections and structures of the solar wind reported in previous literature (Temmer et al., 2023). The variation of magnetic fields and Bz can also be aligned with the magnetopause dynamic research, in which the conditions of the solar wind have a strong impact on the magnetosphere (Grimmich et al., 2025). Moreover, the contribution of solar wind activity to geomagnetic activity agrees with predictive models including PAGER project (Shprits et al., 2026). The significance of the solar wind characterization in space operations and mission design research (Opromolla et al., 2024; Wang et al., 2025), in studies of impacts of the space environment on human health (Derobertmause et al., 2025) also matters.The implications of these findings include the dynamics of solar winds, solar-terrestrial coupling, and space weather prediction. The fact that slow, moderate, and fast regimes of solar wind coexist proves the organized structure of the solar wind flow and the reliance on the solar sources and interplanetary interactions (Zheng et al., 2024; Temmer et al., 2023). The Bz component variations contribute to the solar-terrestrial relationship whereby southward Bz increases energy to the magnetosphere and provides geomagnetic activity (Grimmich et al., 2025; Ishii et al., 2025). The relationships that were observed between the parameters of plasma and magnetic field offer valuable clues that can be used when detecting disturbed conditions of the solar wind. These parameters play a vital role in enhancing space weather forecasting models and predict geomagnetic storms and radiation hazards (Shprits et al., 2026). Satellite operations, communication, and space missions are vital systems that require accurate prediction (Opromolla et al., 2024; Wang et al., 2025).

In spite of these contributions, there are limitations of dataset. The absence of values, especially those of the proton density and the ratio of alpha to protons, have a detrimental impact on the completeness of the data and can influence the statistical accuracy. The 20152017 period does not encompass a complete solar cycle, so it cannot be interpreted in the long term (Ishii et al., 2025). Also, the analysis of short-duration events including shocks and small-scale structures is limited due to the hourly resolution (Temmer et al., 2023). Thus, even though the dataset could be used to characterize solar winds, these limitations must be taken into account when interpreting the data and using it to study space weather in general.

5. Conclusion

This paper demonstrated a statistical and correlation-based investigation of the solar wind plasma and magnetic field parameters (measurements taken in-situ by the ACE spacecraft) during the 20152017 period. The measurements indicated that the speed of solar wind, the density of protons, temperature, and the components of the magnetic field had definite variations, meaning that there were both quiet and disturbed states of the solar wind. There was a high positive correlation between solar wind speed and proton temperature which confirmed the fact that the higher the speed of solar wind the higher the thermal energy. Fluctuations in the strength of magnetic field and Bz component further emphasized the dynamic nature of the heliospheric environment and its contribution to the interactions between the sun and the earth. The scientific value of the work is that it offers a statistical and correlative characterization of the parameters of solar winds with a unified collection of data. The combination of plasma and magnetic field measurements enhances the body of knowledge on the correlation of important variables that determine the behavior of solar wind and conditions in the immediate space around the earth. To conduct further research, the analysis should be extended to a complete cycle of the sun and data with a higher temporal resolution should be used to gain more knowledge on the transient events and long-term variability. More datasets and modeling methods would improve the quality of space weather forecast and would enhance the knowledge of the heliospheric dynamics.

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