Comparative Response of Auroral Electrojet Indices (AE, AL, and AU) to Variations in Solar Wind Density During 2025

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Abstract
The object of this study is to evaluate the comparative response of auroral electrojet indices (AE, AL, and AU) to changes in solar wind density during 2025 using the descriptive statistics, timescales, box plots, and scatter plots, in addition to correlation analysis to examine the nature of the relationship between these variables. The timescales indicated that all variables experienced significant fluctuations throughout the year, but the patterns of change in the auroral electrojet indices no strong directly correlate with changes in solar wind density when the full dataset was considered. When the data were separated according to the direction of the interplanetary magnetic field (IMF) component Bz, the correlation between solar wind density and all three indices (AE, AL, and AU) was consistently stronger during the southward Bz compared to the northward Bz, which is consistent with enhanced coupling of the solar wind to the magnetosphere through magnetic reconnection under southern interplanetary magnetic field conditions.

Keywords: Solar wind density; Auroral electrojet indices; Geomagnetic activity; Space weather; IMF Bz component
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1. Introduction

Solar wind density is one of the most important physical properties of solar plasma, because it represents the number of charged particles (protons and electrons) per unit volume and it is measured in (particles/cm³) [1-6]. Solar wind density continuously varies depending on the solar activity and the source of the solar wind emission from the corona. This variation leads to changes in the amount of matter and energy that reaches Earth's magnetosphere. Increases in solar wind density contribute to increased dynamic pressure on the magnetosphere, resulting in changes to its structure and the response of electric currents in the ionosphere [7]. Therefore, solar wind density is a crucial parameter for researchers studying the interactions between the solar wind and Earth's magnetic environment, and for analyzing the response of geomagnetic activity indicators, including the auroral electrojet indices (AE, AL, and AU) [8].

The auroral electrojet indices are among the most important geomagnetic indices used to explain the intensity and variations of these currents in polar regions. These indices are derived from measurements of the Earth's magnetic field recorded by a network of high-latitude magnetometers [9]. They are used in space physics research to monitor geomagnetic activity, study the dynamics of electrojet activity, and assess the impact of changes in solar wind characteristics on Earth's magnetic system. Therefore, the AE, AL, and AU indices are main tools to understanding the mechanism of energy transfer from the solar wind to the magnetosphere and for analyzing the geomagnetic response to various solar disturbances [10].

This study aims to analyze and compare the effect of solar wind density on the auroral electrojet indices during 2025, in order to assess how differently each index responds to changes in solar wind density.

2. Methodology

This study Investigated how the auroral electrojet indices (AE, AL, and AU) react to monthly changes in solar wind density (SW density) throughout 2025. The daily values of SW density in (N/cm^3) (N is the number of particles), IMF Bz, AE, AL, and AU indices (nT) were obtained from the NASA OMNIWEb Data Explorer (https://omniweb.gsfc.nasa.gov/form/dx1.html). To understand which of these three indices (AE, AL, and AU) is most strongly associated by SW density, we calculated the mean, standard deviation, minimum, maximum, range, kurtosis, and skewness for each of the four variables separately, for the daily observations throughout 2025. These descriptive statistics gives a basic understand of the data variability, distribution, and general characteristics. Then, the Pearson correlation coefficient (r) and linear regression analysis to determine the (R^2) values were calculated between SW density and each auroral electrojet indices (AE, AL, and AU), separately to understand the strength and type of relationship between solar wind density and auroral electrojet indices (AE, AL, and AU). All these statistical analyses were performed by using the Microsoft Excel 2021.

3. Results and Discussion

After the data were collection and statistical processing, it was analyzed using a number of descriptive and inferential statistical indicators to describe the characteristics of the data and measure the strength and direction of the relationship between SW intensity and auroral electrojet indices (AE, AL, and AU) during the study period. Table 1 shows the descriptive statistics for SW Density and the auroral electrojet indices (AE, AL, and AU) during 2025.

Figure (1) shows the scatter plot of relationship between solar wind density and the AU index during the year 2025. The scatter plot shows a wide distribution of points without a clear linear trend, while the regression line exhibits a positive slope. The low value of the coefficient of determination (R^2 = 0.01) indicates that solar wind density explain a very limited proportion of the AU index values, reflecting the weak correlation between the two variables during the study period.

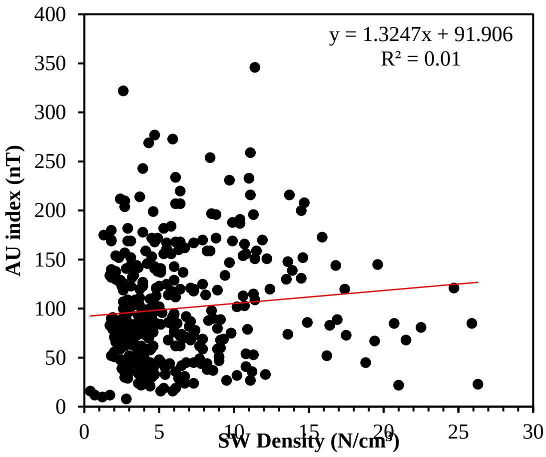

Fig. (1) The scatter plot of the relationship between the solar wind density and AU index for 2025

To further investigate the dependence of the auroral electrojet response on the direction of the interplanetary magnetic field (IMF), the analysis was extended to include the IMF Bz component. The data were divided into cases with a southerly direction of the Bz component (Bz < 0) and cases with a northerly direction (Bz > 0) to examine whether the relationship between solar wind density and the auroral electrojet indices (AE, AL, and AU) differs with the direction of the interplanetary magnetic field. This analysis provides further comparison of the statistical relationships under the southerly and northerly Bz conditions, using Pearson correlation coefficients (r), coefficients of determination (R^2), and p-values, as shown in table (2).

The table illustrates the different responses of the auroral electrojet indices (AE), (AL), and (AU) to solar wind density under southward and northward Bz conditions. Under southward Bz conditions, AE showed a weak positive correlation with solar wind density (r = 0.148), and this correlation was statistically significant (p-value = 0.0486). AU also showed a weak positive correlation (r = 0.204) with stronger statistical significance (p-value = 0.0063). AL, however, did not show a statistically significant relationship (r = −0.103, p-value = 0.1712).

Under the northward Bz conditions, all relationships were insignificant, with p-values of 0.9490 for AE, 0.5353 for AL, and 0.1934 for AU. Furthermore, the R^2 values were very low, indicating that solar wind density explains a very limited proportion of the variance in auroral electrojet coefficients. The highest R^2 value was observed in the southward Bz for the AU index (R^2 = 0.0416), suggesting that solar wind density explains approximately 4.16% of the variance in AU.

The results indicate that the effect of solar wind density on auroral electrojet indices is more pronounced under southern Bz conditions, particularly for AE and AU, while no statistically significant relationships were observed under northern Bz conditions. This may suggest that the orientation of the Bz vehicle plays a significant role in determining the auroral current's response to variations in solar wind density, although other physical factors may also contribute to controlling the auroral current's behavior.

Figures (2) and (3) compare the relationship between solar wind density and the three indices AE, AL, and AU under two different orientations of the IMF Bz component. Figure 8 shows the relationship during periods when Bz is oriented southward, while Figure 9 shows the relationship during periods when it is oriented northward. The R^2 coefficients of determination in both figures are very low. Also, the AU index was the most responsive to changes in solar wind density in both cases compared to the AE and AL indices, while the AL index showed the weakest correlation overall. Accordingly, these results support the hypothesis that the direction of Bz is the governing factor in determining the extent to which the density of the solar wind affects the Earth's magnetic activity, as the relationship, although statistically weak overall, appears more clearly during southern Bz conditions compared to northern ones.

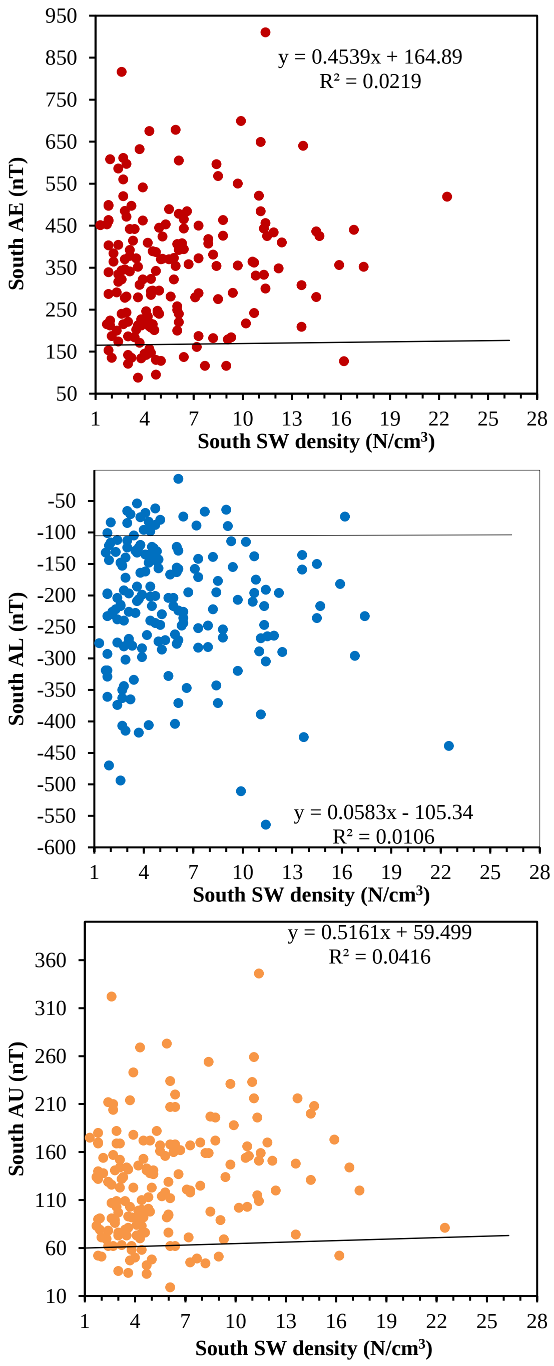

Fig. (2) The relationship between the solar wind density and the auroral electrojet indices (AE, AL, and AU) under southward Bz conditions during 2025

4. Conclusion

In conclusion, the direction of the interplanetary magnetic field (IMF) component Bz, the correlation between solar wind density and all three indices (AE, AL, and AU) was consistently stronger during the southward Bz compared to the northward Bz, which is consistent with enhanced coupling of the solar wind to the magnetosphere through magnetic reconnection under southern interplanetary magnetic field conditions These results show that solar wind density alone cannot predict how the variability of auroral electrojet indices will behave, and they are affected by other physical factors like solar wind speed. So, it important to include these factors in future studies.

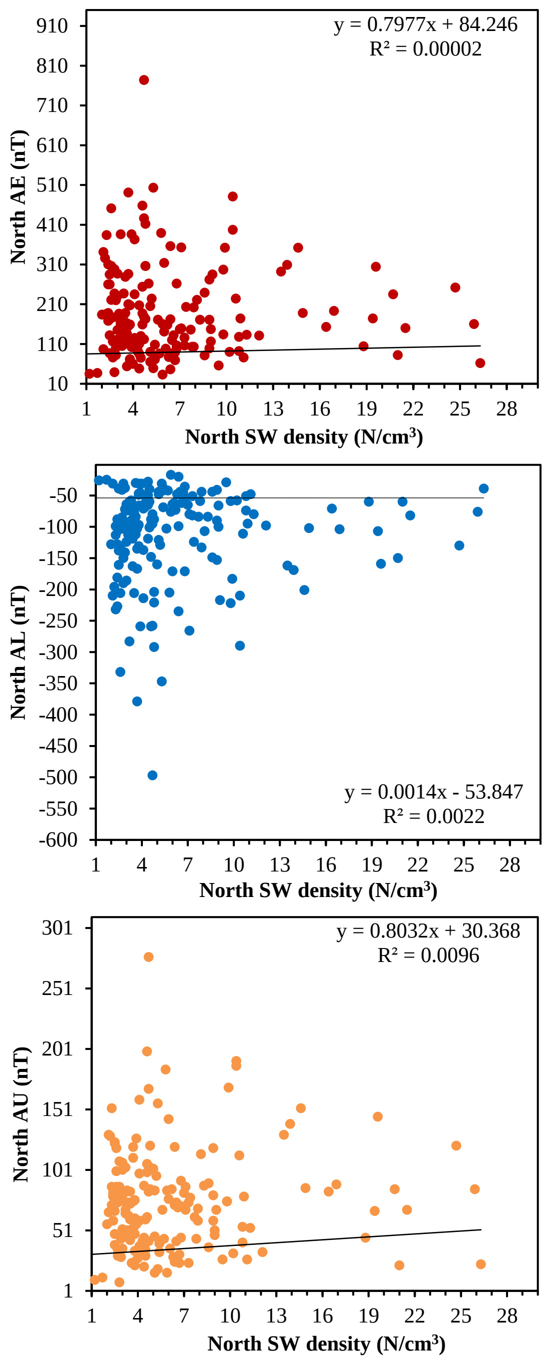

Fig. (3) The relationship between the solar wind density and the auroral electrojet indices (AE, AL, and AU) under northward Bz conditions during 2025

References

[1] Bingxian Luo et al., "Prediction of the AU, AL, and AE indices using solar wind parameters", *J. Geophys. Res.: Space Phys.*, 118 (2013) 7683-7694.

[2] J.-H. Shue et al., “A systematic study of effects of solar wind density onauroral electrojets”, *Geophys. Res. Lett.*, 32 (2005) L14112.

[3] C. Larrodera and C. Cid, “Bimodal distribution of the solar wind at 1 AU”, *Astro. Astrophys. J.*, 635 (2020) A44.

[4] Bunting et al., “Constraints on Solar Wind Density and Velocity Based on Coronal Tomography and Parker Solar Probe Measurements”, *The Astrophys. J.*, 961 (2024) 64.

[5] R. Gonzálezet et al., “Exploration of dependencies of space weather and geomagnetic proxies with thermospheric density enhancement during geomagnetic storms from 2020 to 2024”, *Adv. Space Res.*, 77 (2026) 9633-9650.

[6] M.J. Owens et al., “Annual Variations in the Near-Earth Solar Wind”, *Solar Phys.*, 298 (2023) 111.

[7] R. Schwenn, “Solar Wind Sources and Their Variations Over the Solar Cycle”, *Space Sci. Rev.*, 124 (2007) 51-76.

[8] L. Kepko et al., “Periodic Mesoscale Density Structures Comprise a Significant Fraction of the Solar Wind and Are Formed at the Sun”, *J. Geophys. Res.: Space Phys.*, 129 (2024) e2023JA031403.

[9] T.N. Davis and M. Sugiura, “Auroral electrojet activity index AE and its universal time variations”, *J. Geophys. Res.*, 71 (1966) 785-801.

[10] G. Rostoker, “Geomagnetic indices”, *Rev. Geophys.*, 10 (1972) 935-950.

[11] S.E. Milan et al., “Overview of Solar Wind–Magnetosphere–Ionosphere–Atmosphere Coupling and the Generation of Magnetospheric Currents”, *Space Sci. Rev.*, 206 (2017) 547-573.

[12] H.N. Tyssøy et al., “The Predictive Capabilities of the Auroral Electrojet Index for Medium Energy Electron Precipitation”, *J. Front. Astro. Space Sci.*, 8 (2021) 714146.

Table (1) Descriptive statistics of SW density and auroral electrojet indices (AE, AL, and AU) for year 2025

Variable	Mean	SD	Min.	Max.	Range	Kurtosis	Skewness
SW Density (N/cm^3)	6.11	4.33	0.4	26.3	25.9	4.38	1.91
AE Index (nT)	262.11	154.35	32	910	878	0.81	0.91
AL Index (nT)	-162.09	102.87	-564	-15	549	0.82	-0.99
AU Index (nT)	99.99	57.42	8	346	338	1.15	0.98

Table (2) Statistical analysis of the relationship between solar wind density and auroral electrojet indices (AE, AL, and AU) under southward and northward IMF Bz conditions

Bz condition	Index	Correlation coefficient (r)	R^2	P-value	Significance
Southward Bz	AE	0.148	0.0219	0.0486	Significant
Southward Bz	AL	-0.103	0.0106	0.1712	Not significant
Southward Bz	AU	0.204	0.0416	0.0063	Significant
Northward Bz	AE	0.0048	0.00002	0.9490	Not significant
Northward Bz	AL	0.0469	0.0022	0.5353	Not significant
Northward Bz	AU	0.0982	0.0096	0.1934	Not significant