PROCEEDINGS OF SCIENCE

Observational Study on the Near-Ground Fair Weather Electric Field and Its Variations at LHAASO

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Based on the near-ground Fair Weather Electric Field data recorded by the High-Altitude Cosmic Ray Observatory in Daocheng, Sichuan, from January 2020 to December 2021, this study analyzes the long-term variations and diurnal characteristics of the near-ground Fair Weather Electric Field in the Daocheng region, as well as its correlation with meteorological factors. The analysis of meteorological effects reveals that the long-term trends of the near-ground Fair Weather Electric Field in this region are largely consistent with three meteorological parameters (atmospheric pressure, temperature, and absolute humidity). The relationships between wind speed, aerosols, and the Fair Weather Electric Field are also discussed. The overall level of the Fair Weather Electric Field varies across seasons: approximately 0.13 kV/m in spring, 0.17 kV/m in summer, 0.14 kV/m in autumn, and 0.11 kV/m in winter. The Fair Weather Electric Field intensity is relatively higher in summer and lower in winter. The diurnal variation of the Fair Weather Electric Field exhibits a single-peak and single-trough pattern, with the peak occurring at 18:00 Beijing time and the trough at 7:00. The timing of these peaks and troughs varies slightly depending on the month. Additionally, the distribution characteristics of the diurnal variations of the Fair Weather Electric Field differ across months. These variations are related to meteorological parameters. Specifically, from November to February, the Fair Weather Electric Field primarily varies with temperature and wind speed, while from March to October, its distribution characteristics become more complex, influenced by other meteorological factors such as humidity. This study provides a comprehensive understanding of the Fair Weather Electric Field in the Daocheng region, highlighting its seasonal and diurnal patterns as well as its dependence on meteorological conditions. These findings contribute to advancing knowledge of atmospheric electricity and its interactions with local environmental factors.

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1. Introduction

Cosmic rays (CRs) are one of the most important components in the interstellar medium, mainly consisting of protons[1]. Thunderstorms can impact ground-based cosmic ray experiments, making it essential to understand the Fair Weather Electric Field at the site beforehand[2]. Since the late 18th century, researchers have conducted continuous studies on the characteristics and variation patterns of atmospheric electrical parameters. In the 1920s, the discovery of the highly conductive ionosphere marked the beginning of a rapid development era in atmospheric electricity research, providing a convenient gateway for the study of the global electric circuit[3]. Atmospheric electrical parameters are influenced not only by factors such as cosmic ray radiation, solar ultraviolet radiation, and global thunderstorm activity but are also closely related to local climate and environmental conditions[4]. The Fair Weather Electric Field is one of the important atmospheric electrical parameters, resulting from the combined effects of the Earth's ionosphere and the global electric circuit[5]. Observations indicate that a vertically downward and relatively stable Fair Weather Electric Field always exists, meaning the atmosphere carries a positive charge relative to the Earth, while the Earth carries a negative charge[6,7]. Due to the presence of atmospheric ions, the atmosphere exhibits weak conductivity. Under the influence of the Fair Weather Electric Field, a conduction current is generated[8], continuously neutralizing the charges carried by the atmosphere and the Earth, thereby gradually weakening the Fair Weather Electric Field[9,10]. To maintain a stable Fair Weather Electric Field during experimental observations, other atmospheric electrical processes must also exist[11]. Although extensive data on the Fair Weather Electric Field has been accumulated, it is affected by various factors, such as meteorological conditions, environmental pollution, and human activities, making a comprehensive analysis of the variation patterns of the Fair Weather Electric Field still challenging[12].

2. Data

Located at Haizi Mountain in Daocheng County, Sichuan Province, China, the LHAASO experiment (at 4,410 meters altitude) includes three sub-arrays: the 1 km^2 ground particle detector array (KM2A), the water Cherenkov detector array (WCDA), and the wide-field air Cherenkov telescope array (WFCTA). To monitor the observatory's environment, researchers installed a 20-meter meteorological tower to track temperature, wind speed, humidity, and rainfall at intervals of 1 minute, 10 minutes, and half an hour. An EFM-100 atmospheric electric field meter was installed on the roof of the WCDA's No. 2 pool, measuring up to 100 kV/m at 0.5-second intervals to track changes in intensity and polarity. Additionally, a sun photometer is used to measure aerosol content hourly during the day. This study analyzes atmospheric electric field and environmental data to explore its distribution under clear skies and its relationship with meteorological factors.

Studying the Fair Weather Electric Field requires filtering experimental data to select data that meet the conditions of clear weather. According to observational results, during clear weather, the atmosphere carries a positive charge relative to the Earth, with low electric field values and minimal fluctuations. The steps for selecting atmospheric electric field data that meet clear weather conditions in this study are as follows:

1.On non-thunderstorm days, exclude days with precipitation, as shown in Figure 1, where the blue represents the retained data days.

2.The distribution of the atmospheric electric field under clear skies where positive values account for 95.13% and negative values account for 4.66%. The polarity of the Fair Weather Electric Field is predominantly positive, and in data processing, we consider the positive values.

3.The atmospheric electric field intensity values range between 0 and 4.22 kV/m, with a mean value of 1.34 kV/m.

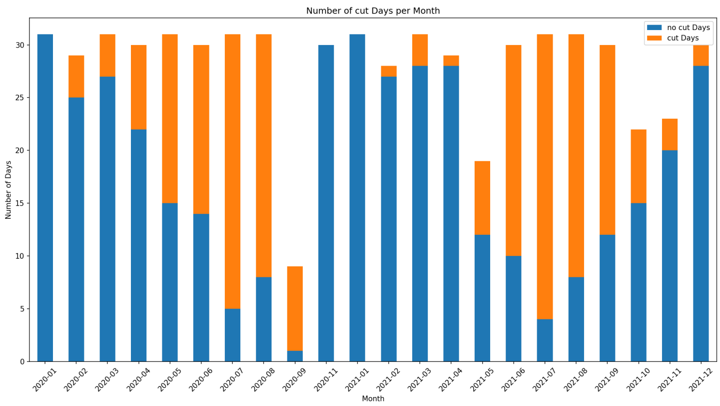

Figure 1: Proportion of days excluding precipitation.

3. Results

The variations in the Fair Weather Electric Field depend on both global factors, such as thunderstorm activity and cosmic ray radiation, and local factors, including atmospheric conductivity and columnar resistance, influenced by climate and environment. We analyze meteorological data from the LHAASO site.

3.1 Daily variation across months

The diurnal variation of the Fair Weather Electric Field is a focal point in research. Using data (EFM) from each month of 2021, an hourly average diurnal variation was calculated and compared with various meteorological factors, including temperature (temp), humidity (ah), pressure (p), wind speed (ws), and aerosols (AOD), to investigate the relationship between meteorological factors and the Fair Weather Electric Field. The characteristics of the troughs and peaks vary across different months.Due to space limitations, we select a few months as examples for analysis.

As shown in Figure 2,in January 2021, temperature and wind speed were low at night and high during the day. From 0:00 to 8:00, both temperature and humidity were decreasing, with a small peak at 1:00 possibly related to humidity, reaching a trough at 8:00. Starting at 8:00, meteorological factors began to rise, and the Fair Weather Electric Field increased accordingly. Around 11:00, humidity and atmospheric pressure reached high values, with increased water vapor in the air and a lower air column. In the afternoon, as temperature and wind speed continued to rise, aerosol concentrations increased, and the Fair Weather Electric Field gradually strengthened. By 17:00, due to the continuous increase in temperature, convection intensified, and wind speed increased, leading to higher aerosol concentrations, reduced atmospheric conductivity, and an enhanced Fair Weather Electric Field, which reached its peak at 16:00. After 16:00, the Fair Weather Electric Field declined. In March 2021, new changes were observed. From 0:00 to 8:00, both temperature and humidity were decreasing. Starting at 8:00, meteorological factors began to rise, and the Fair Weather Electric Fieldincreased accordingly. Around 10:00, humidity and atmospheric pressure reached high values, with increased water vapor in the air and a lower air column, causing a small peak in the Fair Weather Electric Field at 9:00. As humidity began to decrease gradually, water vapor reduced, and atmospheric pressure dropped, the Fair Weather Electric Field weakened. With the continuous increase in temperature and wind speed, aerosol concentrations remained relatively stable, and the Fair Weather Electric Field rose slowly, reaching its peak at 18:00. After 18:00, as temperature and wind speed weakened, aerosols diminished, and the Fair Weather Electric Field declined.

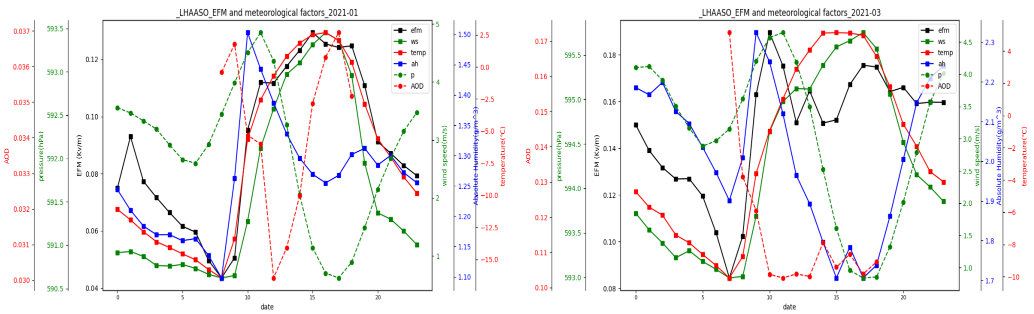

Figure 2: Left: The diurnal variations of the Fair Weather Electric Field and meteorological factors in January 2021, Right: March 2021

As shown in Figure 3,in May 2021, from 0:00 to 6:00, temperature and humidity decreased. After 6:00, meteorological factors rose, increasing the Fair Weather Electric Field. Rising temperature and wind speed caused aerosol concentrations to peak at 12:00 and 19:00. By 17:00, increased temperature intensified convection and wind speed, raising aerosol concentrations, reducing atmospheric conductivity, and enhancing the Fair Weather Electric Field, which peaked at 16:00. After 18:00, it declined as temperature, wind speed, and aerosols decreased. In June, the peak occurred between 17:00 and 16:00. In August 2021, from 0:00 to 6:00, temperature and humidity decreased. After 6:00, meteorological factors rose, increasing the Fair Weather Electric Field. By 9:00, humidity and atmospheric pressure peaked, with higher water vapor and a lower air column, causing a small peak in the Fair Weather Electric Field at 9:00. As humidity decreased, water vapor and pressure dropped, weakening the Fair Weather Electric Field. Rising temperature and wind speed kept aerosol concentrations stable. Enhanced ultraviolet radiation increased the Fair Weather Electric Field by 16:00. By 17:00, increased temperature intensified convection and wind speed, raising aerosol concentrations, reducing atmospheric conductivity, and enhancing the Fair Weather Electric Field, which peaked at 17:00. After 17:00, it declined as temperature, wind speed, and aerosols decreased.

As shown in Figure 4,in September 2021, from 0:00 to 7:00, temperature and humidity decreased, with wind speed fluctuations aligning with the Fair Weather Electric Field. After 8:00,

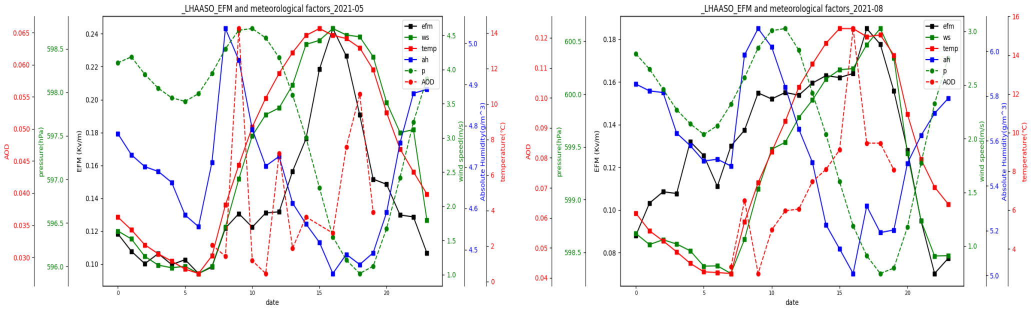

Figure 3: Left: The diurnal variations of the Fair Weather Electric Field and meteorological factors in May 2021, Right: August 2021

meteorological factors rose, increasing the Fair Weather Electric Field. By 10:00, humidity and atmospheric pressure peaked, with higher water vapor and a lower air column, causing a small peak in the Fair Weather Electric Field at 10:00. As humidity decreased, water vapor and pressure dropped, weakening the Fair Weather Electric Field. Rising temperature and wind speed kept aerosol concentrations stable. Enhanced ultraviolet radiation increased the Fair Weather Electric Field by 16:00. By 17:00, increased temperature intensified convection and wind speed, raising aerosol concentrations, reducing atmospheric conductivity, and enhancing the Fair Weather Electric Field, which peaked at 18:00. After 18:00, it declined as temperature, wind speed, and aerosols decreased. In November 2021, from 0:00 to 7:00, temperature and atmospheric pressure decreased, reducing the Fair Weather Electric Field. After 7:00, meteorological factors rose, increasing the Fair Weather Electric Field. Rising temperature and wind speed increased aerosol concentrations by 14:00, causing the Fair Weather Electric Field to rise by 16:00. By 17:00, increased temperature intensified convection and wind speed, raising aerosol concentrations, reducing atmospheric conductivity, and enhancing the Fair Weather Electric Field, which peaked at 15:00. After 16:00, it declined as temperature, wind speed, and aerosols decreased.

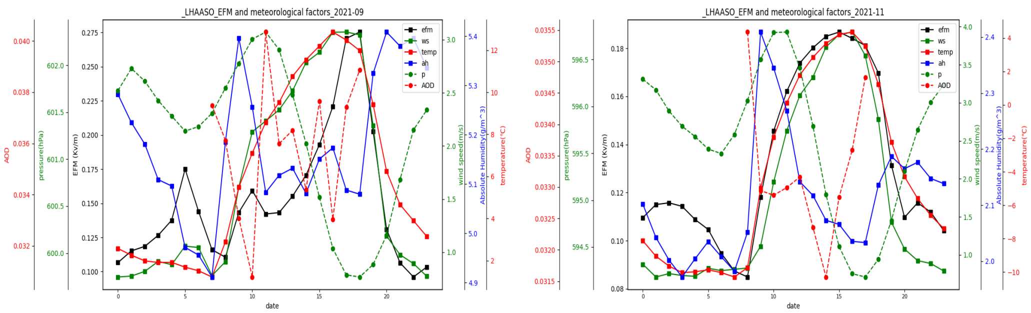

Figure 4: Left: The diurnal variations of the Fair Weather Electric Field and meteorological factors in September 2021, Right: November 2021

It was observed that from October to February, between 0:00 and 8:00, the Fair Weather Electric Field decreased by approximately 10%-15%, while the temperature dropped by about 10%-20%. In contrast, from March to September, although the temperature decreased by 20%, the mean value of the Fair Weather Electric Field showed little variation. This indicates that in colder months, temperature predominantly drives the changes in the Fair Weather Electric Field. In warmer months, when humidity is also higher, the contribution of humidity to the Fair Weather Electric Field increases. From October to February, the Fair Weather Electric Field closely followed the temperature trend, while from March to September, although it roughly aligned with the temperature profile, there were more variations. However, these variations did not alter the primary trend of the Fair Weather Electric Field being influenced by temperature. This demonstrates that temperature is the main meteorological factor affecting the Fair Weather Electric Field.

3.2 Daily variation acrosss seasons and years

To more clearly illustrate the periodic patterns of annual diurnal variations, this study analyzed the diurnal variations of the Fair Weather Electric Field for the years 2020 and 2021, with the results shown in Figure 5. As depicted in the figure, the average diurnal variation of the Fair Weather Electric Field at the LHAASO observatory exhibits a single-peak and single-trough structure. The peak occurs at 17:00 Beijing time, while the trough appears at 7:00.

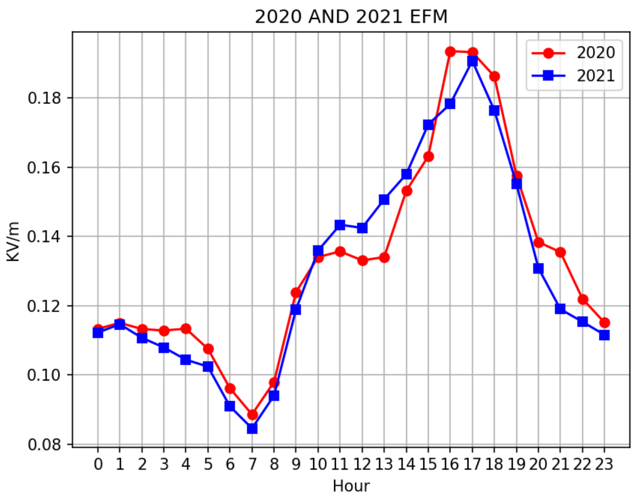

Figure 5: Diurnal variations of the Fair Weather Electric Field in 2020 and 2021.

Although the overall trends in 2020 and 2021 are similar, as shown in Figures 6, the distribution characteristics of the Fair Weather Electric Field across the four seasons differ. Generally, the diurnal variation features a single peak and single trough, but the characteristics of the Fair Weather Electric Field intensity vary by season. In the winter and spring of 2020, the Fair Weather Electric Field intensity was relatively low, while in the summer and autumn, it was significantly higher than in the winter and spring. Notably, the summer of 2020 exhibited a distinct double-peak and double-trough pattern. Compared to the winter and spring, the diurnal variations in the summer and autumn were more complex, primarily due to differences in human activity patterns influenced by local climatic conditions. In the winter and spring, the weather in the Tibetan region is extremely cold, with minimal human activity and low air pollution levels. In contrast, human activity increases during the summer and autumn, leading to higher air pollution. In 2021, the Fair Weather Electric Field in winter was even lower (0.05–0.13 kV/m). Across different seasons, the timing of the peaks and troughs in the diurnal variation of Fair Weather Electric Field intensity slightly varies due to seasonal changes. The main trough in summer occurs earliest, around 6–7 a.m., while in winter, it appears latest, around 8 a.m., primarily due to seasonal variations in sunrise times. The peak occurs in the evening between 17:00 and 18:00.

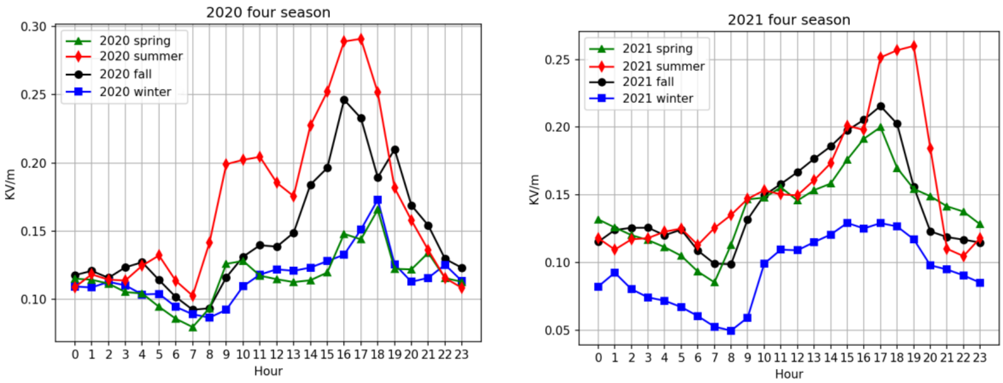

Figure 6: Left: Quarterly diurnal variations of the Fair Weather Electric Field in 2020, Right:Quarterly diurnal variations of the Fair Weather Electric Field in 2021.

4. Summary

Using the atmospheric electric field intensity data recorded by the high-altitude cosmic ray observatory in Daocheng, this study investigated the meteorological effects and temporal variations of the near-ground Fair Weather Electric Field at LHAASO. The focus was on the diurnal variation characteristics of the atmospheric electric field under clear skies and their meteorological and seasonal effects. The following conclusions were drawn:

1. The diurnal variation of the near-ground Fair Weather Electric Field at LHAASO exhibits a single peak and single trough. The trough and peak occur at 7:00 and 18:00 Beijing time, respectively. There is a certain seasonality: in summer, the trough appears around 6:00, while in winter, it appears around 8:00, with the peak consistently occurring around 15:00 in the evening.

2.The diurnal variation distributions across different months highlight the meteorological effects on the Fair Weather Electric Field. From October to February, when humidity and temperature are relatively low, Fair Weather Electric Field is primarily influenced by changes in temperature and wind speed. From March to September, as various meteorological conditions enter a period of increase, the distribution of the atmospheric electric field under clear skies becomes more complex. A small bump around 10:00 is mainly driven by changes in temperature and pressure, while the summer months are more likely to exhibit significant double-peak and double-trough patterns.

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