The Enhancement of the High Energy Electron Flux and the Variation of the Atmospheric Electric Field in the Antarctic region (Postprint)

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Abstract

High-energy electron precipitation in the high latitude regions enhances the ionization of the atmosphere, and subsequently increases the atmospheric conductivities and the vertical electric field of the atmosphere near the ground as well. The High-Energy Electron Flux (HEEF) data measured by the Fengyun-3 meteorological satellite are analyzed together with the data of nearsurface atmospheric vertical electric field measured at the Russian Vostok Station. Three HEEF enhancements are identified and it is shown that when the HEEF increases to a certain level, the local atmospheric vertical electric field near the ground can increase substantially than usual. The response time of the electric field to HEEF enhancement is about 3.7 to 4 days.

Full Text

Preamble

The Enhancement of the High Energy Electron Flux and the Variation of the Atmospheric Electric Field in the Antarctic Region

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Abstract: High-energy electron precipitation in high-latitude regions enhances atmospheric ionization and increases atmospheric conductivity, thereby causing a substantial increase in the vertical electric field near the ground compared to normal conditions. This study analyzes high-energy electron flux (HEEF) data measured by the Feng-Yun III meteorology satellite together with near-surface atmospheric vertical electric field data from Russia' s Vostok Station, identifying three HEEF enhancement events. The results demonstrate that when HEEF increases to a certain level, the local atmospheric vertical electric field near the ground increases substantially. The delay time for the electric field to begin responding to HEEF enhancement is approximately 3.7 days.

Keywords: high-energy electron flux (HEEF), polar precipitation, atmospheric electric field
Classification Index: P353

0. Introduction

It has been demonstrated that solar energetic particles can affect the mesospheric electric field and, consequently, the atmospheric vertical electric field near the ground. Solar proton events (SPE) are capable of creating measurable changes in the electric field at ground level (~5% change) [?]. One result of SPE incidence in the middle atmosphere is the generation of enhanced charged particle densities and a substantial increase in middle and upper atmospheric conductivities [?]. Holzworth and Reagan expressed that the atmospheric electric field changes because the atmospheric conductivities have changed [?, ?]. Frank suggested that the interplanetary magnetic field could also alter the vertical atmospheric electric field [?].

A working model linking the ground to the atmosphere is the global electric circuit (GEC), which results from thunderstorm activity [?]. This model is illustrated in Figure 1 [Figure 1: see original paper] [?]. Thunderstorms act as a voltage source, V, driving current upward from the ground through the upper atmosphere. The current path extends through the stratosphere and is completed via downward currents in the fair-weather atmosphere in regions well away from the storm [?].

The vertical electric field of the atmosphere near the ground is mainly determined by the current density. There are many independent ways in which the solar wind modulates the flow of current density in the GEC [?, ?, ?], such as: (a) galactic cosmic rays [?, ?], for which many complex numerical simulations have been conducted [?, ?]; (b) relativistic electron precipitation [?, ?]; and (c) changes in the ionospheric potential distribution due to magnetosphere-ionosphere coupling [?, ?, ?]. Farrell and Desch found that SPE can decrease the current in the thunderstorm region, thereby increasing the fair-weather current [?]. According to Ohm' s law, if the conductivity near the ground remains constant and the current density increases, the vertical electric field of the atmosphere near the ground will increase absolutely.

Relativistic electron precipitation effectively enhances stratospheric ionization by generating X-rays. With increased ionization in the stratosphere, the local resistance between the stratosphere and troposphere decreases, thereby increasing the current density. Consequently, the vertical electric field of the atmosphere near the ground is affected—it will increase. Even the weather in storm regions could be affected. Relativistic electrons can excite X-rays in the atmosphere, and these X-rays increase ionization in the lower atmosphere [**?**, **?**], as shown in Figure 2 [Figure 2: see original paper].

According to the Gauss equation, the space charge generated by the electric field gradient changes the distribution of charge in clouds, affects cloud microphysics, and subsequently alters weather and climate parameters [**?**, **?**, **?**], such as atmospheric vortices [**?**, **?**, **?**, **?**], cloud cover [**?**, **?**], and atmospheric transparency [**?**, **?**].

1. Data Presentation

The HEEF data measured by the Feng-Yun III satellite in 2012 and the vertical electric field of the atmosphere near the ground measured at Russia’ s Vostok Station in 2012 have been analyzed. The HEEF data from satellite passes over Vostok Station were selected, and a data-fitting method was used to determine the trend of HEEF. Three HEEF enhancement events were identified. Figures 3 [Figure 3: see original paper] through 5 [Figure 5: see original paper] demonstrate that when HEEF increases to a certain level, the vertical electric field of the atmosphere near the ground increases substantially. The delay time between HEEF enhancement and the electric field increase is about 3 to 4 days.

In Figures 3 to 5, panels ‘a’ through ‘d’ show HEEF data at different energies. The black dashed lines represent the HEEF trend obtained using the data-fitting method, while the left red vertical line indicates the approximate time when HEEF begins to increase, and the right line marks when the electric field begins to enhance. Panel ‘e’ shows the vertical electric field of the atmosphere near the ground.

Event 1 occurred from January 19 to January 31, 2012, representing a clear HEEF enhancement. Before the electric field began to enhance, it varied gently with no other factors affecting it. After HEEF returned to normal levels, the electric field began to enhance substantially at the right dashed line. This event featured two enhancements: the first lasted approximately 12.5 hours, and the second about 15.3 hours. The time between the two red dashed lines was approximately 3.7 days.

Event 2 occurred from May 15 to May 24, 2012. Some fluctuations appeared before HEEF began to increase, possibly caused by other factors such as winds. However, the electric field varied gently during the HEEF change and started to enhance at the red dashed line. The enhancement lasted about 10.7 hours, after which the electric field returned to normal.

Event 3 occurred from September 2 to September 11, 2012. In this event, HEEF increased only slightly, and the electric field showed no enhancement.

In these three events, panels ‘a’ through ‘d’ display HEEF data at different energies, the black dashed lines represent the HEEF trend from data fitting, and the left red vertical line indicates when HEEF starts to increase. The right line represents when the electric field begins to increase, and panel ‘e’ shows the vertical electric field near the ground. Event 1 is the most representative and obvious case.

Before the right red dashed line, the electric field varied gently at a magnitude of about 120 V/m with no other factors affecting it. Approximately 3.7 days after HEEF began to enhance, the electric field started to increase substantially. The first fluctuation peaked at about 1200 V/m and lasted approximately 12.3 hours; the second enhancement peaked at about 1400 V/m and lasted about 15.3 hours. Afterwards, the electric field returned to normal.

In Event 2, some enhancements occurred before HEEF began to increase, probably caused by wind (as verified from weather data). However, the electric field varied gently during the HEEF change and started to increase at the red dashed line. The enhancement lasted about 10.7 hours, after which the electric field became normal.

Although Event 3 showed some HEEF enhancements, the electric field exhibited no fluctuations, possibly because HEEF did not reach the threshold level required to cause electric field enhancement. We also considered that HEEF may not be the only factor causing electric field enhancement. Nevertheless, when HEEF increases to a certain level (flux approaching 10^4 in the data analysis), the electric field enhances substantially, with a delay of 3.7 days between the onset of HEEF increase and the electric field enhancement.

Through the transport path of high-energy electrons shown in Figure 1, the physical processes can be understood: high-energy electron flux first enhances in Earth’ s radiation belt during magnetic storms; after some time, electromagnetic waves diffuse these high-energy electrons and lead to precipitation, which produces abundant X-rays. These X-rays increase ionization in the middle-upper atmosphere at high-latitude regions, decrease local resistance, increase current density, and consequently cause the vertical electric field of the atmosphere near the ground to increase substantially.

2. Discussion and Conclusion

The HEEF data from the Feng-Yun III satellite and the vertical electric field data from Russia’ s Vostok Station have been analyzed to investigate how HEEF affects the vertical atmospheric electric field near the ground. HEEF data from satellite passes near Vostok Station were selected, revealing three HEEF enhancements. Comparison with the vertical electric field shows that while HEEF is not the only factor causing electric field increases, when HEEF rises to a certain level, the electric field enhances substantially. The delay time between HEEF enhancement and electric field increase is approximately 3.7 days.

This work uses the model shown in Figure 1 to explain how HEEF affects the vertical electric field near the ground. Event 1 demonstrates that HEEF is essentially the only factor affecting the atmospheric electric field (excluding wind induction). HEEF and associated X-rays increase stratospheric ionization, enhance conductivity, decrease resistance, increase the ionosphere-earth current density, and consequently cause fluctuations in the vertical electric field near the ground. This mechanism is illustrated in Figure 6 [Figure 6: see original paper].

Changes to the GEC are associated with conductivity changes linked to energetic particles, and the solar wind may influence the GEC through inferred effects on cloud microphysics, temperature, and dynamics in the troposphere. Meteorological effects show correlations with changes in the vertical electric field and cloud microstructure. The varied static electric field affects the electro-scavenging process near droplets, air ions, and aerosol particles. Reconstruction of the space charge surface of clouds due to precipitation-associated changes in the vertical electric field leads to potential variations in cloud microstructure, which may affect ambient temperature evolution with consequences for weather and climate at various scales. In any case, electric field variations might cause changes in space charge at cloud boundaries, and there may be several ways in which this affects cloud microphysics, producing correlated changes in weather and climate [**?**].

The phenomenon of atmospheric vertical electric field modulation by HEEF has been revealed, providing a better understanding of how the GEC is influenced by high-energy particles. This paper presents a qualitative study explaining how HEEF affects the vertical electric field near the ground. Future work will involve quantitative studies on the relationship between them and on how weather and climate respond to precipitation-associated changes in the vertical atmospheric electric field.

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