

Investigation of the Electromagnetic Field Response in the Global Ionosphere During Substorms

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During Substorms
(サブストームに伴う全球電離圏の電磁場応答の解明)

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論 文 内 容 の 要 旨

Electromagnetic Energy is accumulated in the nightside magnetosphere through interactions between the solar wind and the dayside magnetosphere. The phenomenon, in which energy is suddenly released into the ionosphere via field-aligned currents FACs, is called a substorm. This results in explosive auroral emissions in the high-latitude ionosphere. However, its effect is not limited to high latitudes alone. It has been suggested that substorms could trigger global magnetosphere-ionosphere coupling. Despite these, it is still not fully understood how the magnetospheric current systems that develop during substorms impact electric field variations at the mid and low latitudes, as well as the global current system.

This study aims to clarify the development of high-latitude current systems during substorms and their global electromagnetic field responses. We approach this by combining data from ground-based geomagnetic observations, FM-CW radar measurements, and AMPERE observations of high-latitude FACs. Specifically, the study focuses on the electromagnetic response in three key areas:

(i) **Nightside mid-latitude electric field response:** Using geomagnetic data and ionospheric electric field data from an FM-CW radar located in Paratunka, Russia (PTK), we examined the electric field responses at mid-latitudes at the nightside hemisphere. From 1,934 isolated substorms occurring between 2006 and 2013, we identified 50 events that exhibited clear electric field variations. For these events, we analyzed the distribution of electric field strength and direction. The analysis revealed two key findings: (1) the magnitude of electric field variations correlates with the intensity of auroral electrojet (AEJ), and (2) the direction of the electric field was found to depend on the relative location to the substorm current wedge (SCW, a current system formed during substorm onset that connects the nightside magnetosphere to the auroral electrojet). The temporal and spatial development of the SCW was captured in geomagnetic data from the nightside mid-latitude region. Specifically, we observed that westward electric fields were dominant at the center of the SCW, while eastward fields appeared outside the SCW. This suggests that the potential formed at the foot of the SCW extends to the mid-latitudes. Additionally, eastward electric fields were frequently observed near the upward FAC of the SCW. This tendency may be influenced by potential twisting caused by Hall currents.

(ii) **Dayside equatorial electric field response:** To investigate electric field responses extending to the dayside equatorial region, we analyzed low-latitude and equatorial geomagnetic data at the equatorial region.

Previous studies have shown that when electric fields penetrate the dayside equatorial region, the Cowling effect amplifies variations in the north-south components at the magnetic equator. By comparing north-south component variations at low latitudes and the equator, we examined the electric field responses during 170 isolated substorms from 2009 to 2011 using superposed epoch analysis. Our results revealed that both variations decreased to about the same amplitude, and there was little difference between them. This suggests that the electric field penetration associated with substorms generally does not reach the equatorial region on the dayside. In contrast, prior studies have reported cases where substorm-associated electric fields and currents extend into the equatorial region. These cases are often observed under specific conditions, such as during storms or certain frequency variations. However, the results of our study suggest that for isolated substorms, electric field penetration into the dayside equatorial region, while possible, is rare.

(iii) Comparison of polar FACs and electric field responses: Although electric field penetration on the dayside is rare, some events were observed. Comparing the timing of electric field responses on both the dayside and nightside revealed differences in their response times. This suggests that the sources driving these electric fields may differ between dayside and nightside. Using AMPERE data, we tracked the development of FACs on both the dayside and nightside, comparing them with electric field variations. Our results indicated that the timing of FAC development and decay differed between the two regions, aligning with the timing of electric field variations in each region. Furthermore, while previous studies have linked electric field responses to geomagnetic disturbances such as the auroral electrojet (measured by the AE index) and nightside positive bays, the electric field responses in the events we analyzed occurred earlier than these geomagnetic disturbances. This suggests that mid-to-low-latitude electric fields may be more sensitive to the development of polar FACs than to ground-based magnetic field variations.

In summary, this study systematically clarified the global electromagnetic field responses during substorms. We highlighted the differences between day and night responses and the influence of polar current systems. Notably, we found that electric field penetration into the dayside equatorial region is statistically rare. Additionally, the variations in electric fields between the dayside and nightside appear to be driven by different current sources. These findings deepen our understanding of magnetosphere-ionosphere coupling during substorms and provide important insights into the mechanisms driving electric and current penetration from high latitudes to the equator. In this presentation, we will discuss how these findings contribute to our understanding of the coupled magnetosphere-ionosphere mechanism, and discuss prospects for further research.

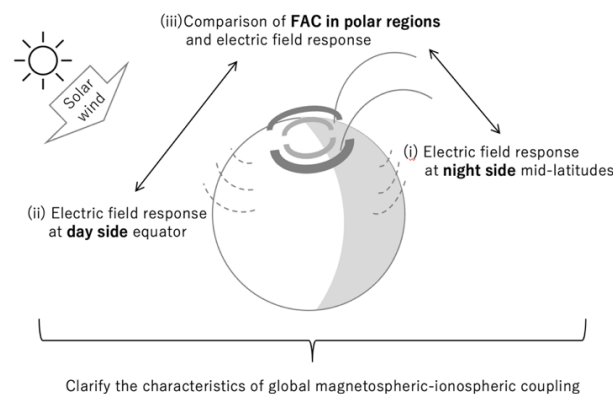


Figure 1. Schematic overview of this study.