# S11-3 Magnetosphere-Ionosphere-Thermosphere Coupling
# 磁気圏—電離圏—熱圏結合

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Magnetosphere-ionosphere-thermosphere (M-I-T) coupling is one of the most fundamental physical processes in the solar-terrestrial physics. Unlike previous studies, this paper focuses on the active role of the ionosphere on M-I-T coupling. Statistical studies based on data from EISCAT radar measurements show that sunlit/shade ionospheric conditions significantly regulates electromagnetic energy from the magnetosphere to the ionosphere and that the thermosphere, i.e., neutral wind, plays a crucial role to dissipate the electromagnetic energy.

## 1. Introduction

The magnetosphere and the ionosphere strongly couple each other with exchanging energy either in the form of electromagnetic energy flux accompanied by currents and electric fields, in the form of particle fluxes associated with plasma precipitation and outflow, or in the form of plasma waves. It is the ionosphere and thermosphere that dissipate energy input from the magnetosphere. The ionosphere is a weakly ionized plasma region, in particular, the E-region of which, where collisions with neutrals dominate and most of the energy dissipation thereby occurs, is of only 0.00001% ionization rate, while the magnetosphere is a 100% ionized collisionless plasma region. This actually means that two plasma regions of different states in terms of the ionization rate stay in contact with each other. Understanding the physical processes of the energy transfer between the magnetosphere, ionosphere and thermosphere (M–I–T) is one of the key issues not only for the M–I–T coupling but even also for the solar-terrestrial physics, since some planets such as Jupiter and Saturn have more or less same situation to the Earth and others have rather different situations from it.

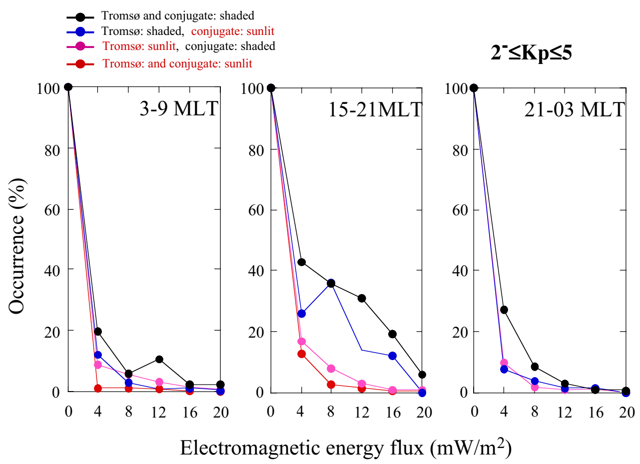
It was received wisdom that the ionosphere played a somewhat passive role in M-I-T coupling in comparison to the magnetosphere where plasma motion, electric fields and currents were driven. Recent observations have clearly shown, however, that the ionosphere plays a much more active role on the M-I coupling processes than we considered before. Indeed, observations with the FAST and Freja satellites have shown that ionospheric thermal electrons are sometimes greatly accelerated into field-aligned upward directions by downward-directed parallel electric fields existing in the lower magnetosphere, carrying downward field-aligned currents (e.g., [1]). These downward field-aligned currents were indeed thought to be secondary and merely return currents of the primary upward field-aligned currents carried by precipitation electrons from the magnetosphere. Such upward moving electrons were observed almost exclusively in a winter hemisphere, suggesting that the ionosphere must play an indispensable role in their formation. On the other hand, Newell et al. [2] indicated that the ionosphere played an essential role on the occurrence/intensity of auroras, that is, energetic electron precipitation. One of the outstanding problems is then how the ionosphere actively regulates the electromagnetic energy input from the magnetosphere to the ionosphere.

Another key issue is to understand how the ionosphere and the thermosphere interact, in particular, how the electromagnetic energy from the magnetosphere is distributed to Joule heating that heats up both ions/electrons and neutrals and to dynamical energy of neutrals, which in turn give energy to ions/electrons. The rate of the electromagnetic energy transfer is expressed by $\mathbf{J}\cdot\mathbf{E}$ ($\mathbf{J}$ is the electric current and $\mathbf{E}$ is the electric field), which is, as mentioned above, further converted in the lower ionosphere both to the Joule heating rate $\mathbf{J}\cdot\mathbf{E}'$ and to the mechanical energy transfer rate of the neutral gas $\mathbf{U}\cdot(\mathbf{J}\times\mathbf{B})$, where $\mathbf{U}$ is the neutral wind velocity and $\mathbf{E}'=\mathbf{E}+\mathbf{U}\times\mathbf{B}$. Hence, the estimate of the Joule heating rate and the mechanical energy transfer rate is not possible without determining the neutral wind velocity. Measuring the neutral wind velocity, which is highly height dependent, is a very difficult task, however, which can be derived observationally only from incoherent scatter (IS) radar measurements with good altitude resolution, covering the whole *E* and lower *F* region height range (e.g., [3]). Quantitative characteristics of **J**·**E**, **J**·**E**' and **U**·(**J**×**B**) based on observations that are not yet determined will certainly contribute to the further understandings of the M–I–T coupling processes.

This paper is going to address the above mentioned two issues using long-term European Incoherent Scatter (EISCAT) radar measurements

## 2. Active Role of Ionosphere on M-I Coupling

Based on a statistical analysis of EISCAT KST (Kiruna-Sodankylae-Tromsoe) tri-static radar data we have quantitatively investigated how actively the ionospheric conditions relate to the M-I coupling. The electromagnetic energy **J**·**E** from the magnetosphere to the ionosphere and the electric field relate strongly to the sunlit/shade condition of the ionosphere not only at the local observation point above the EISCAT radar but also at its magnetic conjugate point in the southern hemisphere. Both **J**·**E** and the electric field strength are enhanced more frequently when both of or either of the local and conjugate ionospheres are in the shade than when these two regions are sunlit, suggesting strongly that the ionosphere is not passive at all but regulates the magnetosphere to some extent.




. Figure 1. Histograms of **J**·**E** in the dawn, dusk and night regions. The occurrence is normalized, with the largest occurrence for each region set to 100%.

## 3. Ionosphere-Thermosphere Interaction

We have studied characteristics of the energy coupling processes between the lower thermosphere, ionosphere and magnetosphere through an analysis of **J**·**E**, **J**·**E**' and **U**·(**J**×**B**), based on EISCAT radar data obtained from 1989 to 1991.

The present study shows that the electromagnetic energy input from the magnetosphere to the ionosphere is distributed to both Joule heating **J**·**E**' and the mechanical energy **U**·(**J**×**B**). **J**·**E**' is generally larger than **U**·(**J**×**B**), but the latter one is generally not negligible and becomes comparable when the magnetosphere is disturbed. It is also noted that **U**·(**J**×**B**) can be negative, meaning that the energy is transferred from neutral wind to plasmas.

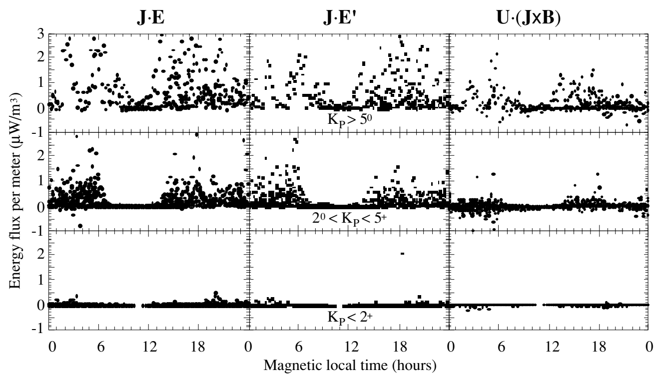



Figure 2. The magnetic local time (MLT) distribution of the electromagnetic energy transfer rate **J**·**E** (left), the Joule heating rate **J**·**E**' (middle) and the mechanical energy transfer rate **U**·(**J**×**B**) (right) under four geomagnetic disturbance levels: $K_P > 5$ (top), $2 < K_P \leq 5$ (middle), and $K_P \leq 2$ (bottom)

## References

[1] Carlson et al., Geophys. Res. Lett., **25** (1998) 2017.
[2] Newell et al., Nature, **381** (1996) 766.
[3] Fujii *et al.*, J. Geophys. Res., **104** (1999) 2357.