Cowling channel formation through the ionosphere-magnetosphere coupling via Alfven waves

Akimasa Yoshikawa (1), Olaf Amm (2), and Ryoichi Fujii (3)

(1) Kyushu University, Earth and Planetary Sciences, Fukuoka, Japan (yoshi@geo.kyushu-u.ac.jp), (2) Finnish Meteorological Institute, Arctic Research Unit, Helsinki, Finland (Olaf.Amm@fmi.fi), (3) Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, Japan(rfujii@stelab.nagoya-u.ac.jp)

An inclusive formulation of Magnetosphere-Ionosphere (MI) coupling system, which enables to describe the Cowling channel formation through the MI-coupling via the shear Alfven wave, is proposed. By applying the Walen-relation [Walen, 1944] to the Alfvenic disturbance near the ionosphere, arbitrary incompressible MHD fields ($\mathbf{b},\mathbf{v}$) can be separated into the incident component to the ionosphere and the reflected component from the ionosphere. The separated incident component gives an electromotive force (emf) for the excitation of the MI-coupled system. In addition, the thermospheric wind dynamo also becomes a source of "emf" in the ionosphere, while the reflected components are generated as a result of the MI-coupling process. Using this separation, we clarify that the MI-coupling processes are composed of the "direct reflection" process for incident MHD field, the "radiation" process for the thermospheric wind-driven dynamo, and the "polarization" process for the charge separation originating from conductivity gradients. Clearly, the "reflection" and the "radiation" processes are caused by the cancellation process of the divergence of the primary Pedersen current (primary current means directly driven current by the "emf" field). The "polarization" process is caused by the both the divergent part of the primary Pedersen and of the primary Hall current.

Since the direction of the primary Pedersen current and the direction of the primary Hall current are perpendicular to each other, the reflected fields generated to cancel out these two irrotational parts of the primary currents are also expected to be perpendicular to each other. Thus, the MI-coupled ionospheric current system can be separated into two orthogonal irrotational current systems, the first channel originating from the primary Pedersen current divergence (generator-channel) and the second channel from the primary Hall current divergence (loading-channel). A combination of these two channels forms so-called the Cowling channel. The generator-channel is directly coupled to the external generator of the system, which supplies the "emf" for generating the MI-coupled system. In this channel, the Pedersen and the Hall currents flow in the same direction, and the reflected Alfvenic potential Φ_P is generated. On the other hand, the loading-channel does not directly couple to the external generator, but couples to the internal Cowling-generator, which mediates electromagnetic energy between the generator and the loading channels. In the loading channel, the Pedersen and the Hall current flows in the opposite direction to each other, and the reflected Alfvenic potential Φ_H is produced.

Our theoretical framework proposed in this paper uniquely describes how much of field-aligned currents (FACs) are closed in the generator-channel and in the loading-channel, respectively, and how these channels are coupled to each other in the context of energy conservation. Simulation results show that significant rotation and elongation of the potential structure is caused by the Hall polarization field Φ_H which is generated in regions of steep conductivity gradients. We will present the theory in detail and show some numerical results of the formation process of the Cowling channel via Alfven waves.