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Generation mechanism of Region 1 field-aligned current and energy transfer from solar wind to the Earth

Yusuke Ebihara[1], Takashi Tanaka[2]
[1] Research Institute for Sustainable Humanosphere, Kyoto University, Japan,
[2] i-SPES, Kyushu University, Japan
e-mail (speaker): ebihara@rish.kyoto-u.ac.jp

Field-aligned currents (FACs) are known to exchange momentum between space and Earth, giving rise to major disturbances in the magnetosphere and the ionosphere. For example, when substorms take place, a large amount of energy exceeding 10^{11} W is consumed in the polar ionosphere of the Earth. The energy is supposed to be carried by the FACs, but the generation mechanism is not well known.

The Region 1 FAC is a large-scale and large-amplitude FAC that appears to flow in the polar region. In the early 1960s, the solar wind-originated plasma is suggested to penetrate into the magnetosphere, generating the formation of the FACs. Since then, the low-latitude boundary layer and the high-latitude boundary layer are thought to be the generation regions of the Region 1 FACs. If this is the case, this type of process will be basically independent of the interplanetary magnetic field (IMF). This contradicts the observational facts that the magnitude of the Region 1 FAC system increases when IMF is southward. Previously, the origin of the Region 1 FAC has been investigated by tracing magnetic field lines modeled. The magnetic field lines reach the distant magnetotail, or the magnetopause. Tracing the current line has also been performed.

We used a global magnetohydrodynamics simulation and identified the generation region by a new approach [1]. We introduced "packets" that are supposed to carry perturbations associated with FACs, and traced them backward in time from the ionosphere in a frame of reference moving with bulk flow of plasma. The generation region is assumed to satisfy the following conditions. The first condition is related to the generation of the Alfvén wave, that is,

$$\mathbf{V}\cdot\mathbf{F}_t < 0, \qquad \mathbf{F}_t \equiv \frac{B^2}{\mu_0}\left(\mathbf{b}\cdot\nabla\right)\mathbf{b}, \tag{1}$$

where $\mathbf{V}$ is the plasma bulk velocity, $\mathbf{B}$ is the magnetic field, $\mathbf{b}$ is the unit vector of $\mathbf{B}$, and μ_0 is the magnetic constant. The second condition comes from Faraday's law and Ampère law, that is,

$$\frac{\partial J_\parallel}{\partial t} \neq 0 \tag{2}$$

$$\begin{aligned}\frac{\partial J_\parallel}{\partial t} &= -\frac{1}{\mu_0}\left[\nabla\times\nabla\times\mathbf{E}\right]_\parallel \\ &= -\frac{\nabla_\parallel\left(\nabla\cdot\mathbf{E}\right)}{\mu_0} + \frac{\left(\nabla^2\mathbf{E}\right)_\parallel}{\mu_0}.\end{aligned} \tag{3}$$

where $J_\parallel$ is the FAC, and $\mathbf{E}$ is the electric field. The major results can be summarized as follows.

1. The flank (low-latitude) boundary layer is found to be a major generation region, in which the plasma originating in the solar wind pulls Earth's magnetic field lines that are newly reconnected with the IMF. The generation regions are indicated by G_1 and G_2 in Fig. 1.
2. The generation regions (G_1 and G_2) are far from the original magnetic field line (the thick line in Fig. 1) because of relatively slow Alfvén speed in the outer magnetosphere and beyond.
3. The finite travel time enables Region 1 FACs to extend to latitudinal and longitudinal directions. This is consistent with the observations that Region 1 FACs develop well for southward IMF.

The Region 1 FACs are expected to play a central role in the transfer of the magnetic energy to the ionosphere [2].

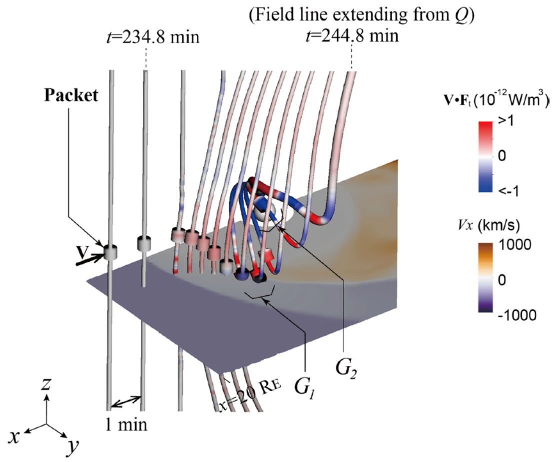

Fig. 1: The whitish sphere indicates the Earth. The Small cylinders indicate positions of the "packets" that are supposed to carry perturbations associated with the FACs. The tubes indicate the magnetic field lines extending from the "packets". The color code on the tubes and "packets" indicate the value of $\mathbf{V}\cdot\mathbf{F}_t$, Color on the equatorial plane indicates x-component of the bulk velocity of plasma (positive to the Sun). G_1 and G_2 denote the generation regions of the Region 1 FACs [1].

References

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