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Energy transfer from solar wind to ionosphere: Global MHD simulation results

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A substorm is one of the most severe disturbances that occur in the magnetosphere. A large amount of energy, more than 10^{11} watts, is consumed in the auroral ionosphere during the substorms. The ultimate source of the energy consumption in the ionosphere is the solar wind, but an immediate question is how the energy comes from. We analyzed the results of the global magnetohydrodynamics (MHD) simulation that is capable of reproducing the auroral features that manifest the substorm expansion, including westward traveling surge, sudden intensification of the Region 1-sense field-aligned current and subsequent auroral electrojet. First, we focused on the solar wind kinetic energy. A large amount of the solar wind kinetic energy is converted to the electromagnetic energy in the cusp/mantle region when the interplanetary magnetic field is southward. Then, the electromagnetic energy is transported to the lobe. During the growth phase, a part of the electromagnetic energy is stored in the lobe because of a partial stagnation of the flow. The magnetosphere starts to change its topology when near-Earth reconnection takes place. The electromagnetic energy that had been stored in the lobe during the growth phase is released, and is found to proceed toward the Earth. Electromagnetic energy steadily supplied from the cusp/mantle region is merged. A part of the electromagnetic energy is converted to the kinetic energy and the internal energy, followed by the electromagnetic energy. This final energy conversion takes place in the near-Earth region on the nightside, and leads to the generation of the field-aligned current that manifests the expansion onset of the substorm. We introduced an integral curve of the Poynting flux (S-curve) to show a pathway of the electromagnetic energy (Figure 1). The S-curve shows a spiral with its center moving toward the ionosphere. The earthward transport of the electromagnetic energy results from the large-scale field-aligned current. We focus on 4 key regions that is closely related to the energy transfer, the solar wind, the cusp/mantle region, the lobe region and the ionosphere. Power at the 4 key regions is also provided for different solar wind speed and southward component of the interplanetary magnetic field.

References

Ebihara, Y., & Tanaka, T. (2017). Energy flow exciting field‐aligned current at substorm expansion onset. Journal of Geophysical Research: Space Physics, 122, 12,288–12,309. https://doi.org/10.1002/2017JA024294

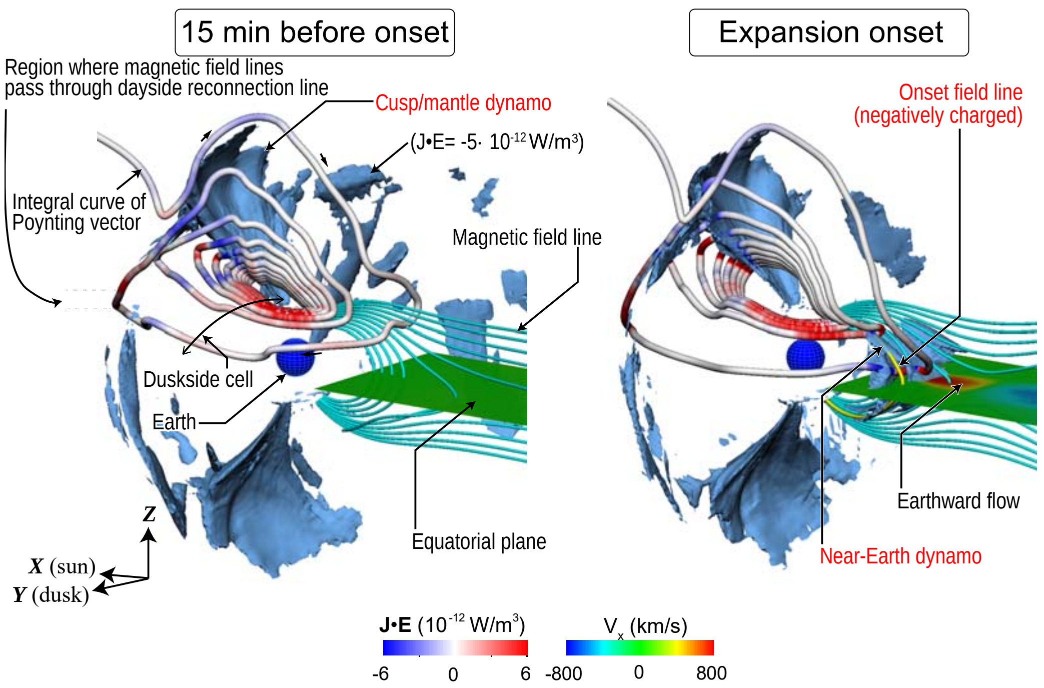

Figure 1: Principal pathway of electromagnetic energy in the magnetosphere (white line) at 15 minutes before the onset and at expansion onset. The blue shade indicates the region where J•E < 0 (dynamo region). The light blue line indicates magnetic field line. The plane indicates the equatorial plane with color given by the X-component of the plasma flow. The yellow line stands for the magnetic field line extending from the onset location in the ionosphere (adapted from Ebihara and Tanaka, 2017)