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Convection and Birkeland currents associated with theta auroras: MHD modeling

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When the interplanetary magnetic field (IMF) is northward, there occasionally occurs a peculiar auroral configuration which is called the theta aurora. The theta aurora consists of a ring of auroral luminosity (auroral oval) and the transpolar arc that crosses the polar cap from the nightside to the dayside. One mechanism that describes the theta aurora formation is the IMF By (dawn-dusk component) variation. When the IMF By polarity switches, the theta aurora is formed during the reconfiguration of the magnetosphere-ionosphere system. There are many observational studies that supports this idea, and global magnetohydrodynamic (MHD) simulations do reproduce the theta aurora configuration. However, details of the magnetosphere-ionosphere coupling process are not well known. Also, because of the observational constraints, it is not straightforward to advance the research deductively from observations. The purpose of this paper is, using numerical MHD simulations, to investigate the detailed processes of the magnetosphere-ionosphere coupling associated with the theta aurora formation and to show the evolution of convection and field-aligned currents (FACs) in a form to permit comparison with observations.

We set the IMF magnitude to 10 nT and switched the IMF clock angle from -45 to +45 degrees and vice versa. In this paper we define the theta aurora as the ionospheric projection of the closed field line region in the magnetotail (i.e., the plasma sheet). When IMF By switches from negative to positive, in the northern ionosphere, the theta aurora is detached from the dawnside auroral oval and drifts duskward in the polar cap. In the southern hemisphere, the dawn-dusk relation reverses. The characteristics of ionospheric convection and FACs are summarized as follows.

(1) In general, when IMF By is significant, quasi-stationary ionospheric convection exhibits the basic round/crescent cell pattern. In the theta aurora formation, the round cell plays a crucial role. Twenty minutes after the IMF By switch, the new round cell associated with the new IMF By is established. The theta aurora drifts with this round cell. The convection speed is faster in the rear side of the theta aurora motion (the new-lobe side) than the foreside (the old-lobe side). After the full development of the theta aurora, sunward convection occurs only at the dayside tip of the theta aurora (the theta crossbar is not connected to the dayside auroral oval). In the nightside part of the theta aurora, the round cell flow turns its direction from antisunward to sunward, so both sunward and antisunward convection coexist. The theta is often attributed to sunward convection; however this picture is not necessarily correct.

(2) The FAC reconfiguration precedes the convection reconfiguration. Fifteen minutes after the IMF By switch, the NBZ system associated with the new IMF By is already established. An FAC system with the same current polarity as the NBZ system extends antisunward along the rear side (with respect to the drift motion) portion of the theta aurora. If we trace the current lines to the magnetosphere, the FAC region is mapped to the foreside part of the protruded plasma sheet boundary (the old-lobe side). There the dot product of the current vector and the electric field vector is negative, meaning that that region is (part of) the dynamo of the FAC system. In addition, in the plasma sheet boundary on the old-lobe side, Dungey-type reconnection associated with the old IMF still continues to supply closed magnetic flux, which is one factor of the theta aurora growth. In the ionosphere, on the other hand, the FAC associated with the theta aurora largely closes with the region 1 FAC associated with the new crescent cell. This ionospheric closure of FACs drives the fast flow in the rear side of the theta aurora drift motion. That is, in the ionosphere, the theta aurora is ”pushed” from the rear side by the round cell convection.

Keywords: theta aurora, field-aligned current, ionospheric convection, MHD simulation