The influence of IMF cone angle on invariant latitudes of polar region footprints of FACs in the magnetotail: Cluster observation

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Field-aligned currents (FACs) were detected by satellites in the 1960s for the first time [*Zmuda et al.*, 1966; *Cummings et al.*, 1967], and they have been observed at both low [*Iijima et al.*, 1978] and high [*Frank et al.*, 1981] altitudes in different regions in geospace. The large scale (from the magnetotail to the ionosphere) FACs are involved in many important physical processes, including field-aligned particle acceleration [*Morooka et al.*, 2004; *Shi et al.*, 2014], magnetic reconnection in the magnetotail [*Ma and Otto,* 2013], development of the substorm current wedge [*Hesse and Birn*, 1991], and auroral activity [*Elphic et al.*, 1998; *Xiong et al.*, 2014].
In solar wind-magnetosphere-ionosphere interactions, the large scale FACs play a crucial role in transferring the solar wind energy and momentum from interplanetary space to low altitude ionosphere. The solar wind and interplanetary magnetic field (IMF) affect the energy transfer process and the associated FACs directly. In the magnetosphere, the importance of the IMF cone angle is not controversial because it is closely concerned with many important physical phenomena. Some studies show that the IMF cone angle effects geomagnetic pulsations (Pc2-5 pulsations) [*Takahashi et al.*, 1984]. *Kavosi and Raeder* [2015] found that the occurrence rate of the Kelvin–Helmholtz waves (KHWs) in the magnetopause increases with the IMF cone angle. Also, the IMF cone angle can control the efficiency of reconnection at the subsolar point [*Scurry et al.*, 1994]. Some authors have suggested that the IMF cone angle can even influence the magnetopause location [*Dušík et al.*, 2010]. In the magnetotail, both IMF cone angle and clock angle are the important factors and have great influences on the FACs. *Cheng et al.* [2013] found the FAC occurrence in the magnetotail increases monotonically with the IMF cone angle. The FAC is a large scale phenomenon in the magnetosphere-ionosphere system. The FACs in the Plasma Sheet Boundary Layers (PSBLs) connected with those in the polar region through the magnetic field lines [*Wild et al.*, 2004] and they are important for the energy flows in the solar wind-magnetosphere-ionosphere system. How the solar wind affects the large scale FACs from the magnetotail to the polar region is still an open question. And no study on the relationship between the IMF cone angle and the invariant latitudes of the FACs in the PSBLs in the magnetotail has been done. This study is focused on the influence of the IMF cone angle on the projection locations of the observed FACs by Cluster in the northern PSBL in the magnetotail. We performed a statistic study of 542 FAC cases observed by the four Cluster spacecraft in the northern hemisphere. The results show that the large FAC (>10 nA/m^2) cases occur at the low ILATs (<71 º) and mainly occur when the IMF cone angle θ >60º, which implies the footprints of the large FACs mainly expand equatorward with large IMF cone angle. The equatorward (poleward) boundary of the FAC footprints decreases (increases) with the IMF cone angle. The equatorward boundary is more responsive to the IMF cone angle. This is the first time a correlation between FAC projected location and IMF cone angle has been determined.

Keywords: FAC in magnetotail, Footprints in polar region, IMF cone angle