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Model of the evolution of the plasmasphere during a geomagnetic storm

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Abstract

The morphology of the plasmasphere during a geomagnetic storm is simulated by considering the two dimensional $\boldsymbol{E} \times \boldsymbol{B}$ drift motion of plasmaspheric charged particles in the equatorial plane. Assuming a time-independent dipolar magnetic field and a corotation electric field plus, a spatially uniform dawn–dusk convection electric field varying with K_p index, the spatial distributions of charged particles at different time during a geomagnetic storm are obtained. Our results show that if K_p increases with time, some particles inside the original plasmapause will convect into the magnetopause, forming a long tail that stretches from the plasmasphere to the magnetopause in the afternoon region. The particle convection weakens as K_p decreases, and as K_p returns to its normal value, the plasmasphere develops a thin tail that wraps around the Earth.

Keywords: Plasmasphere; Plasma convection

1. Introduction

The plasmasphere is a part of the inner magnetosphere populated with high density cold plasma, bounded by plasmapause where an abrupt transition to much lower density occurs. In past decades, ground-based and in situ measurements of the plasmasphere have provided much information on the properties of the plasmasphere, but do not reveal the global structure. Now, the Extreme Ultraviolet Imager of the IMAGE mission is providing the global images of the plasmasphere, revealing features such as convection tails, depleted regions (Sandel et al., 2001; Burch et al., 2001; Dent et al., 2003). It offers new perspectives and opportunities for understanding. The interpretation and analysis of such global images require a reliable model for the plasmasphere morphology.

The plasmasphere and the shape of the plasmapause have been investigated theoretically by many researchers (e.g., Chen and Wolf, 1972). Results indicate that the density in the plasmasphere and the formation of the plasmapause are determined by two factors. One is the ionosphere as the source of the cold plasma; the other is the magnetospheric convection and its associated large-scale electric field. The location of the plasmapause is determined by the interplay between the large-scale electric field and the corotation electric field (Nishida, 1966). The plasmapause may be quite stationary and well-defined during periods of constant magnetic activity, but it often moves and develops irregular structure during periods of variable activity (Grebowsky, 1971). The evolution of the plasmasphere in the equatorial plane under the time-varying convection field was modeled by Chen and Wolf (1972), giving the integrated plasma density in a flux tube. Most of the recent work based on hydrodynamic or kinetic theories was focused on the density structure of the

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plasmasphere itself (e.g., Rasmussen et al., 1993; Reynolds et al., 1999). The evolution of the convection tail during the geomagnetic storm is less well known.

By tracing the equatorial motion of test particles in the plasmasphere, Xu and Li (2005) discussed the morphology of the plasmasphere after a sudden increase or decrease in the convection electric field. In the present paper, the global structure of the plasmasphere under different geomagnetic conditions will be investigated. The plasmasphere is basically a magnetic field aligned structure that can be traced all the way from the equatorial plane to the ionosphere. Although only the transport of the plasma particles in the equatorial plane is considered in our present work, we believe it is possible to give us an insight into the behavior of plasmasphere under the joint influence of the convection and corotation electric fields.

2. Model

A particle moving in the inner magnetosphere will gyrate about the magnetic field line, bounce along the field line and drift perpendicular to the magnetic field. For plasmaspheric particles, plasma drift resulting from the gradient in the magnetic field or curvature of the field lines can be ignored in a zeroth-order approximation, because the gradient or curvature drift velocity is proportional to the random plasma energy, which is of order several eV or less. In our two dimensional model, it is assumed that the plasmaspheric particles have zero, first and second adiabatic invariants, and that the only motion they have is the $\boldsymbol{E} \times \boldsymbol{B}$ drift in the equatorial plane, with drift velocity defined by

$$\boldsymbol{v} = \boldsymbol{E} \times \boldsymbol{B}/B^2. \quad (1)$$

Here, $\boldsymbol{B}$ is the earth's magnetic field. In the region occupied by the plasmasphere, we believe a dipole model is adequate. It is also assumed that the dipole axis is the earth's rotational axis. $\boldsymbol{E}$ is the electric field in the magnetosphere, $\boldsymbol{E} = \boldsymbol{E}_c + \boldsymbol{E}_r$.$\boldsymbol{E}_r$ is the earth's corotation electric field in the radial direction, decreasing with $1/L^2$. Acting along, this electric field will have plasma particles rotate around the earth. $\boldsymbol{E}_c$ is the convection electric field, in the dawn–dusk direction in the equatorial plane. The convection field will have the particles move toward the sun. It is assumed that the convection electric field is spatially uniform in our model; its intensity is time-dependent and is associated with magnetic activity parameterized by K_p index (Tu, 1988), that is

$$\boldsymbol{E}_c = E_0(1 - 0.1K_p)^{-2}, \quad (2)$$

where E_0 is the magnitude of $\boldsymbol{E}_c$ at quite time in kV/R$_e$.

From Eq. (1), we can see that the particles will drift along equipotential lines of the electric field. The drift trajectories in the equatorial plane are shown by solid lines in Fig. 1, where x points to the sun and y points to the local dusk. Near the earth, the corotation electric field dominates, and the particles move around the earth along closed trajectories. In the region far away from the earth, the corotation field is small compared with the convection field and the particles move along open trajectories toward the sun. The boundary between closed and open trajectories is the plasmapause (the thick solid line in Fig. 1). The influences from the convection and the corotation fields are balanced here; at X point in local dusk, the drift velocity equals zero, which implies that X corresponds to the point where $\boldsymbol{E}_c$ and $\boldsymbol{E}_r$ have the same magnitude but in opposite directions. The y coordinate of X is

$$y_X = 9.56\boldsymbol{E}_c^{-1/2}(\mathrm{R_e}) \quad (3)$$

Therefore, if the convection electric field intensifies, the corotation region will become smaller, and the X point, as well as the plasmapause, will move toward the earth. Outside the plasmapause, stretching from X, the open trajectory serves as a separatrix between different drift regions. Below the separatrix, dayside particles drift directly toward the magnetopause in the afternoon region; while nightside particles first drift around the earth, changing their direction, and finally move toward the dayside magnetopause. Above the separatrix, particles drift sunward almost along straight trajectories.

Particle drift velocity contours are also shown in Fig. 1 by dashed lines. There are two velocity minima. One is located at X as indicated above; the other is at the center of the earth. There are two sets of contours around the two minima, which merge and develop into "8" shaped

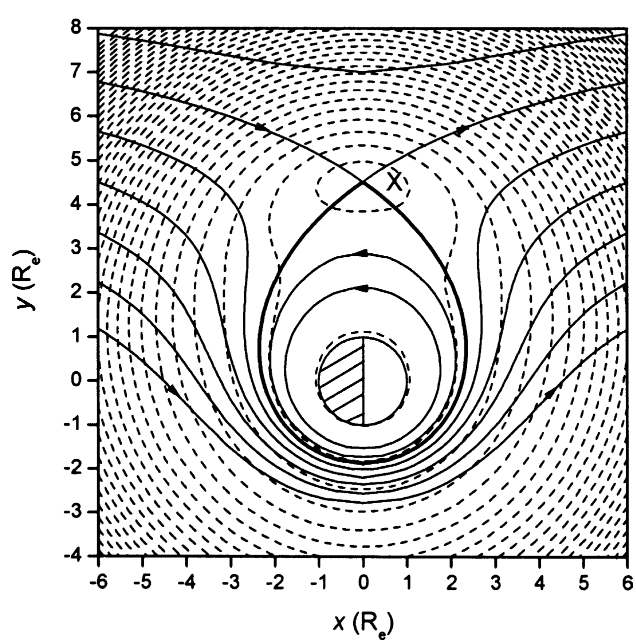

Fig. 1. The plasmaspheric particle drift orbits and drift velocity contours in the equatorial plane.