PLASMA PARTICLES DRIFTING IN THE EQUATORIAL PLANE OF QUANTITATIVE MAGNETOSPHERIC MODEL AND RELATED MAGNETOSPHERIC PHENOMENA

Tadanori ONDOH and Kazuhiro AIKYO

Radio Research Laboratories, 2–1, Nukui-Kitamachi 4-chome, Koganei-shi, Tokyo 184

Abstract: Using the quantitative magnetospheric model derived by MEAD and FAIRFIELD (J. Geophys. Res., **80**, 523, 1975) from satellite observations of the magnetic field, we have computed equatorial profiles of the total geomagnetic field, electric equipotential lines and drift paths of plasma particles with pitch angle of 90° in the magnetosphere under the superquiet (SQ) and superdisturbed (SD) conditions in case of the magnetospheric tilt angle of 0°. The uniform dawn to dusk electric field used is 0.1 mV/m for a quiet time and 0.4 mV/m for a disturbed time. All particles start from geocentric circles of 17 earth's radii (R_E) in the equatorial plane of the tail region.

Electric equipotential lines in the equatorial plane of the Mead-Fairfield (MF) model are concave on the dawn and dusk sides since the geomagnetic field lines of the MF model in the equatorial plane are curved greatly tailwards on the dawn and dusk sides compared with the radial field lines of a dipole model. The Alfvén layer or the boundary of the forbidden region for the zero-energy particles computed in the MF magnetospheric model is compared with the average location of the plasmapause in the equatorial plane. The computed drift paths of zero-energy particles for the uniform dawn to dusk electric field of 0.1 mV/m show a stagnation region in the late evening sector which agrees well with the plasmapause bulge observed by ground whistlers. The trapped particle region for zero-energy particles and energetic electrons in the late-evening outer magnetosphere seems to be produced by the particle drift motion in the late-evening outer magnetosphere, where the geomagnetic field lines are greatly curved tailwards under a weak dawn to dusk electric field of 0.1 mV/m.

The dayside extent of equatorial drift paths for electrons with 0.5 keV/nT in the MF-SQ and MF-SD geomagnetic fields for the dawn to dusk electric field of 0.4 mV/m corresponds well with the hard electron precipitation region associated with the active mantle aurora.

1. Introduction

The Mead-Fairfield (MF) magnetospheric model is a power series expansion whose coefficients are derived from a least squares fit to vector magnetic fields obtained by Explorer-33, -34, -41 and -43 in the solar magnetic coordinates (MEAD and FAIRFIELD, 1975). The data set consists of 12616 vector field averages over one-half earth radii (R_E) intervals between 4 and 17 R_E, taken from 451 satellite orbits between 1966 and 1972. This model includes four sets of coefficients for geomagnetically superquiet (SQ), quiet (Q), disturbed (D) and superdisturbed (SD) conditions. They are the

MF-SQ for $Kp=0$, 0+, the MF-Q for $Kp<2$, the MF-D for $Kp\geqq 2$ and the MF-SD for $Kp\geqq 3$. This model is very useful to compare the field configuration and to trace drift trajectories of plasma particles in the magnetosphere at different geomagnetic activities.

As for drift trajectories of plasma particles in the magnetosphere, ALFVÉN (1939, 1940, 1955) showed that plasma particles will drift to infinity or to be stably trapped inside an egg-shaped forbidden region when a uniform electric field is superimposed on the equatorial plane of a magnetic dipole. Since then many authors have discussed trajectories of plasma particles drifting through a dipole magnetic field under the influence of assumed electric field (KARLSON, 1962, 1963; TAYLOR and HONES, 1965; BLOCK, 1966; BRICE, 1967; KAVANAGH *et al.*, 1968; CHEN, 1970; STERN, 1975; COWLEY and ASHOUR-ABDALLA, 1976; EJIRI, 1978). However, there is no drift path of plasma particles computed for a quantitative geomagnetic field model based on satellite magnetic field measurements.

In this paper, tracing three-dimensional field lines of the quantitative Mead-Fairfield magnetospheric model, we present projection of constant latitude circles at the earth's surface onto the equatorial plane along the model field lines and electric equipotential lines in the magnetospheric equatorial plane, and we discuss geophysical implications of these computed results.

Then we compute drift paths of electrons or protons with zero-energy and various energies at particle pitch angle of 90°, and compare the computed results with various magnetospheric and auroral phenomena.

2. Some Characteristics of Mead-Fairfield Model in the Equatorial Plane

The four sets of the MF model include 882 points for the superquiet data, 2368 points for the quiet data, 2206 points for the disturbed data and 1334 points for the superdisturbed data over regions of four-dimensional space with similar distance, latitude, longitude and tilt angle of the geomagnetic axis. The MF model is described in the solar magnetic coordinates. The Z-axis is aligned with the magnetic dipole, the X–Z plane contains the sun-earth line, positive values of X are on the dayside, and the Y-axis is in the dawn meridian. The solar wind-dipole tilt angle, T is the complement of the angle between the Z-axis and the sun-earth line. We treat only the case of $T=0°$ in this paper. In the MF model, the dawn-dusk symmetry and north-south symmetry conditions which are automatically satisfied for a dipole field are taken into account to reduce the number of the coefficients of power series expansion.

MEAD and FAIRFIELD (1975) gave contours of constant total magnetic field magnitude in the equatorial plane for the quiet and disturbed conditions with $T=0°$. We compute also the equatorial contours of the same quantity for the superquiet and superdisturbed conditions with $T=0°$ as shown by Fig. 1, using the coefficients of power series expansion given by MEAD and FAIRFIELD (1975).

The apparent increase in field magnitude beyond 13 R_E is not a real effect. The contours inside 8 R_E are circles centered at the earth like a dipole field, while the

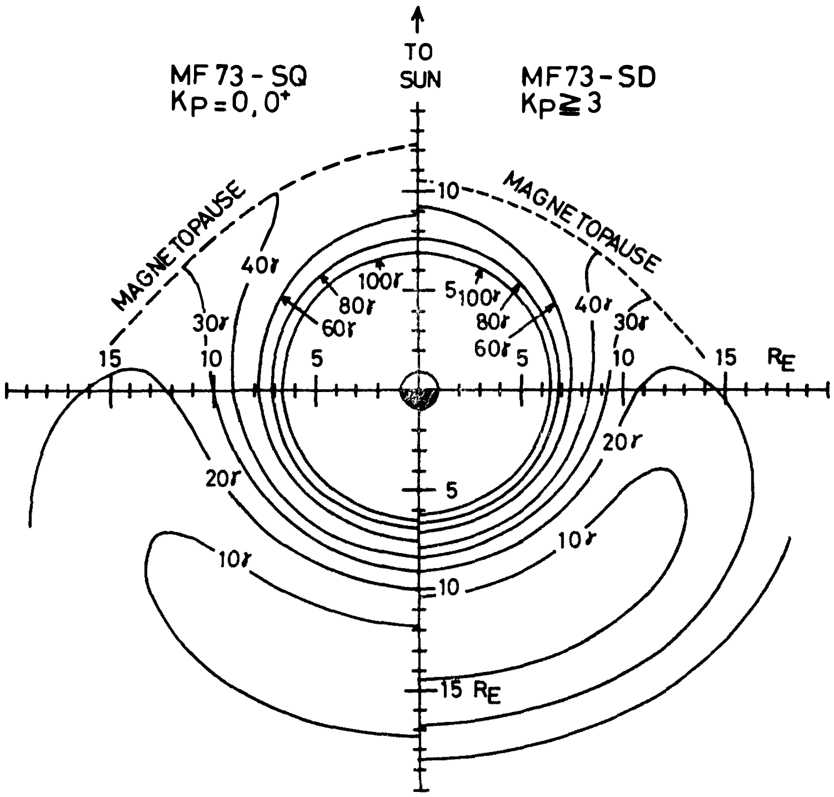


Fig. 1. Contours of constant total magnetic field magnitude in the equatorial plane for the super-quiet and superdisturbed conditions of the Mead-Fairfield geomagnetic field model.

contours outside 8 R_E are displaced toward the sun in the MF-SQ and MF-SD field models. This displacement indicates that the magnetic field is stronger on the dayside than the nightside. The subsolar magnetopauses of the MF-SQ and MF-SD models are located at 12.3 and 10.5 R_E respectively. Between 7 and 10 R_E, the nightside gradient of the magnetic field for the MF-SD model is steeper than that for the MF-SQ model. This may be a real effect associated with an enhanced plasma convection in a disturbed period.

Here we define the magnetospheric electric field in the equatorial plane by the vector sum of the uniform dawn to dusk electric field and the magnetospheric corotation electric field. We assume that the electric equipotential is kept along the geomagnetic field lines. The corotation electric field is given by $\boldsymbol{E}_c = -\text{grad}\,\phi$, where $\phi = -\phi_0 \cos^2\theta$ is the corotation electric potential on the earth's surface caused by the rotation of the earth's magnetic dipole and θ is the geomagnetic latitude. The equatorial corotation potential in the dipole magnetic field is expressed by $\phi_0 = \Omega \cdot B_0 \cdot R_E^2 \simeq$ 90 kV where B_0 is the geomagnetic field strength at the equator, R_E the earth's radius and Ω the angular velocity of the earth's rotation.

The plasma inside the plasmapause corotates with the earth as well as the dipole field lines. The geomagnetic field lines swept back by the solar wind traverse across the magnetotail as the earth rotates. The geomagnetic field lines extending into the tail do not corotate with the earth. The corotation electric field in the tail region will be given by the equatorial projection of the corotation potential at the earth's surface,

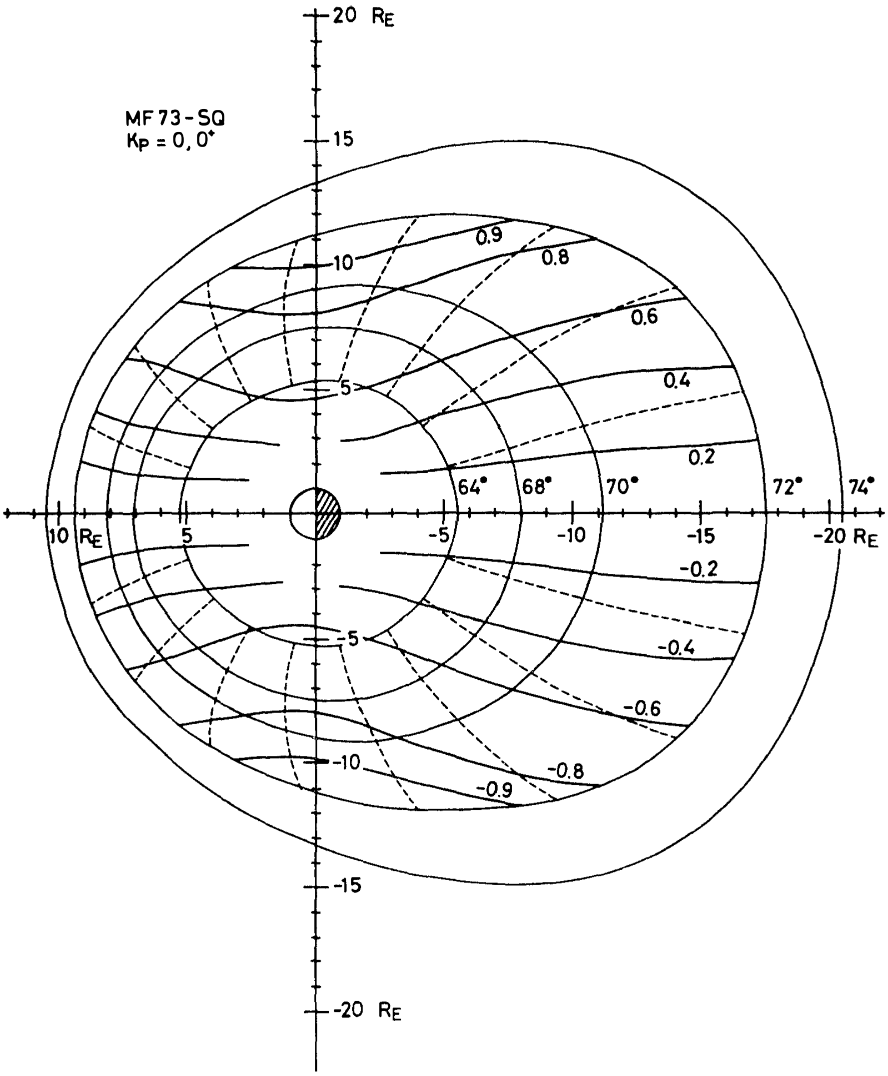


Fig. 2a.

Figs. 2a, b. *Relative electric equipotential lines normalized by a potential difference between dawn and dusk magnetospheric boundaries in the equatorial plane of the Mead-Fairfield geomagnetic field for the superquiet (2a) and superdisturbed (2b) conditions.*

$-\phi_0 \cos^2 \theta$ along the geomagnetic field lines of the MF model. The corotation electric field vectors in the equatorial plane of the tail are not in the radial direction since they are normal to the equatorial projection of constant latitude circles on the earth's surface.

Then we conduct the three-dimensional field line tracing between the outer magnetosphere and the earth's surface, integrating the expansion equation derived by MEAD and FAIRFIELD (1975). And we map the contours of constant geomagnetic latitudes at the earth's surface and electric equipotential lines over the polar cap onto the equatorial plane along geomagnetic field lines of the MF magnetospheric model as shown in Figs. 2a and 2b.

Geomagnetic field lines from the polar caps are assumed to move, at least par-

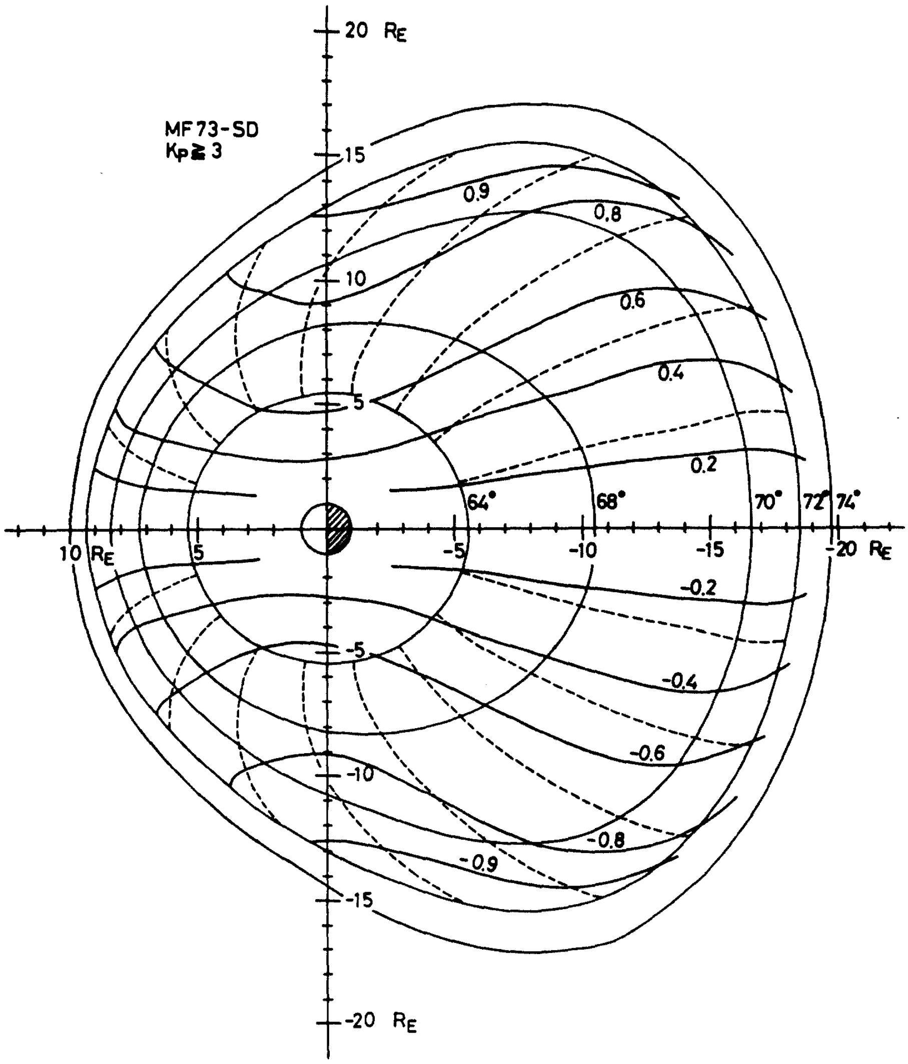


Fig. 2b.

tially, with the solar wind and so the uniform dawn to dusk electric field is also assumed to exist over the polar cap. The electric potential on the polar cap boundary approximated by a circle of constant latitude is given by $\phi(\theta, \psi)=\phi_p \sin\psi$ at $\theta=72°$ where ψ is the longitude measured eastward from the midnight meridian and ϕ_p is a constant (VASYLIUNAS, 1970). The electric potential on the polar cap boundary is positive on the dawn side and negative on the dusk side. Solid lines in Figs. 2a and 2b illustrate respectively the relative electric equipotential lines normalized by a potential difference between the dawn and dusk magnetospheric boundaries or plasma flow lines in the equatorial plane for the MF-SQ and MF-SD models. The relative electric equipotentials are very convenient for use since products of the relative equipotentials by an electric potential difference between the dawn and dusk boundaries give real electric equipotentials.

Circles and dashed lines in Figs. 2a and 2b show contours of constant latitude and constant local time at the earth's surface as projected along the model field lines onto the equatorial plane, respectively. The equatorial contours of latitude 68° and

70° in the MF-SD model are greatly displaced toward the tail and expand toward the both flanks compared with those in the MF-SQ model. The former effect may be caused by an increase of the southward magnetic field of cross-tail current in the near-tail region in a disturbed period. An increase of the solar wind velocity at a disturbed time may cause an expansion of the magnetospheric flank and also a contraction of the dayside magnetopause as shown in Fig. 2b. The electric equipotential lines in the MF-SD model are more concave toward the earth than those in the MF-SQ model around the dawn-dusk meridian, while the electric equipotential lines in the dipole model have no concave part. An equipotential point given on the radial geomagnetic field line of the dipole model in the dawn and dusk sectors corresponds to the inner and more tailward point on the curved geomagnetic field line of the Mead-Fairfield model in the dawn and dusk sectors. The geomagnetic field lines of the MF-SD model in the dawn and dusk sectors are curved more tailward than those of the MF-SQ model by an enhanced solar wind. These may account for the concave part of the electric equipotential lines.

3. Drift Paths of Plasma Particles in the Equatorial Plane of the Mead-Fairfield Magnetospheric Model

We discuss here drift paths of plasma particles with energy below about 200 keV in the MF geomagnetic field model in relation to the plasmapause and hard electron precipitation associated with active mantle auroras.

Basic assumptions on the motion of plasma particles are the guiding center approximation of plasma particles for a sufficiently slow variation of the electric field and magnetic field, and the conservation of the first and second adiabatic invariants. In general the drift velocity of charged particles in the electric and magnetic fields is given by

$$V=\frac{\boldsymbol{E}\times\boldsymbol{B}}{B^2}+W_{\perp}\frac{(\boldsymbol{B}\times\nabla B)}{eB^2}+2W_{\parallel}\frac{(\boldsymbol{B}\times\boldsymbol{R})}{eB^2R^2}\,, \tag{1}$$

where $\boldsymbol{E}$ denotes the electric field, $\boldsymbol{B}$ the magnetic field, $\boldsymbol{R}$ the radial vector, e the electric charge, $W_{\perp}$ the particle energy perpendicular to the magnetic field, $W_{\parallel}$ the particle energy parallel to the magnetic field, respectively.

Here we treat only drift paths of plasma particles with pitch angle of 90° mirrored in the equatorial plane in order to obtain a difference of particle drift paths in the quantitative MF geomagnetic field model from those in the dipole magnetic field. The plasma particles with pitch angle of 90° are subject to the magnetic field gradient drift and the electric field drift since $W_{\parallel}(=1/2\,\mathrm{mV}^2\cos^2\alpha)=0$ in the expression eq. (1), where α denotes the particle pitch angle to the geomagnetic field line.

KIVELSON (1976) has given an extensive review of the magnetospheric electric field models. She has pointed out that the analytic electric-field models do not produce self-consistent relations between the electric field and *Kp*. She has also suggested that the uniform electric field model seems reasonably consistent with most observations. Hence, as a first step, we adopt the uniform dawn to dusk electric field in computing drift paths of plasma particles in the magnetospheric equatorial plane, since our main aim is to discriminate a difference of the geomagnetic field models on the particle's drift trajectories. Empirical relations between the convection electric field, E, and geomagnetic activity, Kp, have been proposed by many authors as follows: The both relations of $E(\mathrm{kV}/R_E)=0.46/(1-0.082Kp)^2$ given by CARPENTER and PARK (1973) and of $E(\mathrm{kV}/R_E)=0.44/(1-0.097Kp)^2$ given by KIVELSON (1976) give $E=0.07$ mV/m for $Kp=0$. The relations of $E(\mathrm{kV}/R_E)=0.795(1+2Kp/3)$ by CHEN and GREBOWSKY (1974) and of $E(\mathrm{kV}/R_E)=0.87(1+0.71Kp)$ by KUZNETSOV (1972) give $E=0.37$ and 0.43 mV/m for $Kp=3$, respectively, and they also give $E=0.12$ and 0.14 mV/m for $Kp=0$, respectively. The electric potential between the dawn and dusk magnetopauses is of the order of 25 kV during quiet conditions and of 100 kV during disturbed conditions (VOLLAND, 1978). Thus the uniform dawn to dusk electric fields of $E=0.1$ and 0.4 mV/m seem to be appropriate for computation of equatorial drift paths of plasma particles in the MF-SQ and MF-SD geomagnetic field models, respectively. Then we take vector sums of the uniform dawn to dusk electric field and corotation electric field as the total magnetospheric electric field in the equatorial plane.

ALFVÉN (1939, 1940, 1955) showed that when a uniform dawn to dusk electric field is applied in the equatorial plane of the magnetic dipole field corotating with the earth, charged particles will be forced either to drift to the infinity or to be stably trapped inside an egg-shaped forbidden region, the so-called Alfvén layer. BRICE (1967) identified the location of whistler knee, the so-called plasmapause with the boundary between terrestrial and solar-wind plasmas showing electric equipotential lines due to the uniform dawn to dusk electric field and corotation electric field in the equatorial plane of the dipole magnetic field. KAVANAGH *et al.* (1968) applied the Alfvén layers of the zero-energy particles and of the non-zero-energy particles to the plasmapause

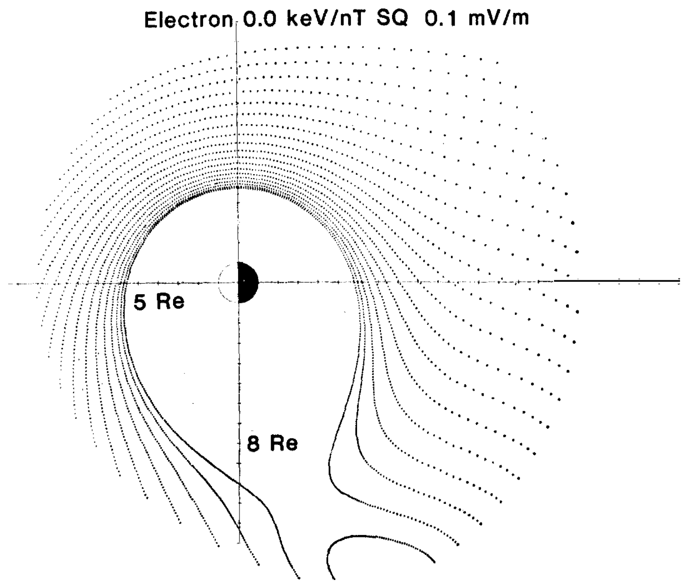


Fig. 3. Equatorial drift paths of zero-energy electrons or protons in the MF-SQ geomagnetic field for uniform dawn-dusk electric field of 0.1 mV/m. The time interval between solid points is 300 s.

and the inner edge of the plasma sheet, respectively, by computing drift paths of charged particles with various energies in the equatorial plane of the dipole magnetic field for the uniform dawn to dusk electric field and corotation electric field. The stagnation point of all these results lies in the dawn or dusk meridian (06 or 18 MLT) since they used the dipole magnetic field.

Figure 3 shows drift paths of zero-energy electrons or protons in the equatorial plane of the MF-SQ field model ($Kp=0, 0+$) for the uniform dawn to dusk electric field of $E_w=0.1$ mV/m. Figures 4a and 4b show respectively equatorial drift paths of zero-energy electrons or protons in the MF-SD field model ($Kp \geqq 3$) for $E_w=0.1$ and

Fig. 4a.

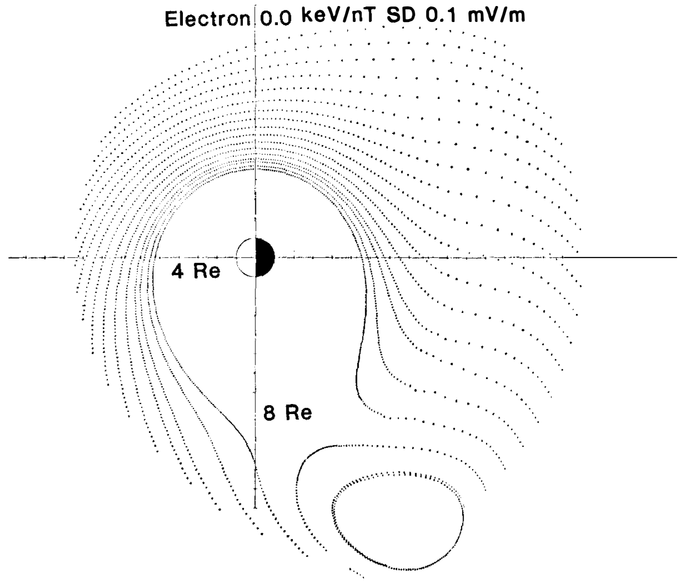
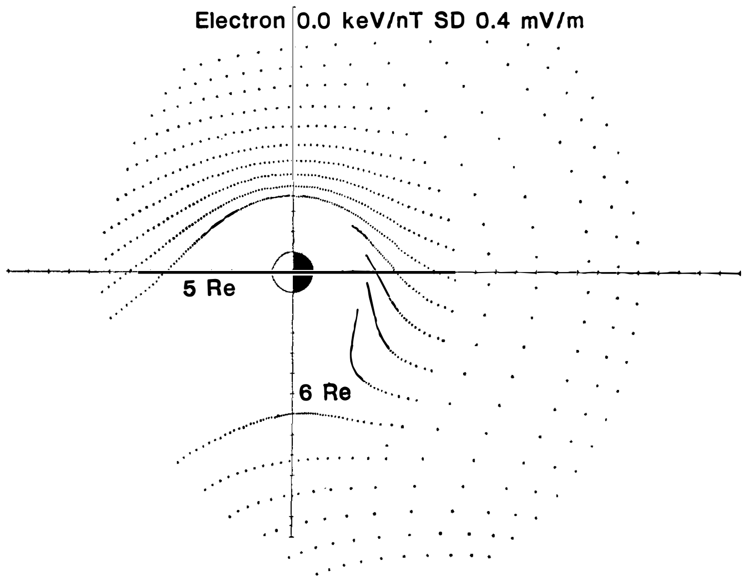


Fig. 4b.



Figs. 4a, b. Equatorial drift paths of zero-energy electrons or protons in the MF-SD geomagnetic field for uniform dawn-dusk electric field of 0.1 mV/m (4a) and 0.4 mV/m (4b).

0.4 mV/m. Both equatorial drift paths of the MF-SQ model (Fig. 3) and MF-SD model (Fig. 4a) for $E_w=0.1$ mV/m have a stagnation region in magnetic local time of 19–20 hours at geocentric distance of about 12 R_E and about 10 R_E, respectively. The plasmapause bulge, the region of large plasmapause radius was most frequently found for 19–20 hours MLT from ground-based whistler observations at Eights and Byrd, Antarctica (CARPENTER, 1970). Further the bulge position was observed near 18 MLT under more or less steady geomagnetic conditions, and near 19–20 MLT during periods preceded by 6–8 hours of quieting. The equatorial inner drift paths of zero-energy particles for $E_w=0.4$ mV/m in the MF-SD geomagnetic field show a stagnation region near 18 MLT at radial distance of about 6 R_E. Thus the stagnation region of zero-energy particles calculated for the MF geomagnetic field model can explain well the observed plasma bulge position and also an observation of the plasmapause bulge displacement toward the afternoon side with increasing geomagnetic activity, since the magnetospheric convection electric field becomes generally larger with increasing geomagnetic activity. The sunward displacement of the stagnation region is caused mainly by an inward shift of equatorial drift paths of particles due to an enhancement of electric field from 0.1 to 0.4 mV/m, because there is little difference between the geomagnetic field of the MF-SQ and MF-SD models inside geocentric distance of about 8 R_E. An abrupt end of the computed inner drift paths of zero-energy particles in the MF-SD model for $E_w=0.4$ mV/m is an artificial effect caused by giving no corotation electric field within 3.5 R_E, since the MF geomagnetic field model has no observed data inside about 4 R_E. A time interval between solid points along equatorial drift paths of plasma particles is 300 s for all figures in this paper. We choose particle's magnetic moments, $W_\perp/B$ of 0, 0.005, 0.05 and 0.5 keV/nT in the drift path calculation of plasma particles. The corresponding initial energy of these particles is 100 eV, 1 keV and 10 keV respectively for a typical magnetic field of $B=20$ nT in the geomagnetic tail. The general features of computed drift paths for particles with 0.005 keV/nT are very similar to those of the corresponding cases for zero-energy particles.

Equatorial drift paths of zero-energy particles for $E_w=0.1$ mV/m in the MF-SQ (Fig. 3) and MF-SD (Fig. 4a) models show a trapped particle region or closed path region which does not circle around the earth. This is located at geocentric distance beyond 10 R_E between 19 and 21 MLT respectively, while those for $E_w=0.4$ mV/m in the MF-SD model (Fig. 4b) show no trapped region in the late evening sector. The trapped particle region in the MF-SD model develops more than that in the MF-SQ model for the same electric field of $E_w=0.1$ mV/m.

The stagnation region of zero-energy particles in Fig. 4b lies around the evening meridian (18 MLT), since the zero-energy particles invade deeply into the magnetosphere of the dipole field for $E_w=0.4$ mV/m. The main cause of the trapped particle region may be the geomagnetic field lines curved tailward and the corotation electric field directed almost dawnward in the late evening outer magnetosphere, since the corotation electric field vector must be normal to the distorted equatorial contours of constant latitudes as shown by contours of latitude above 70° in Figs. 2a and 2b. The trapped particle region beyond the stagnation region in the late evening sector may associate with frequent occurrence of the magnetospheric whistler ducts observed in

Fig. 5a.

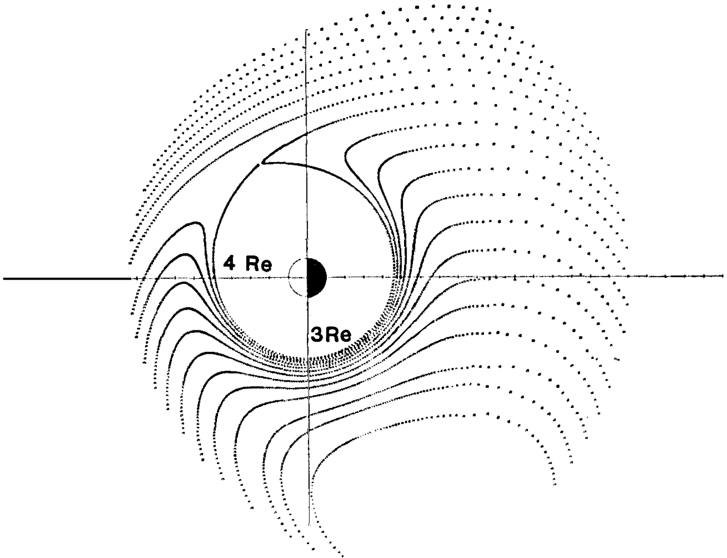
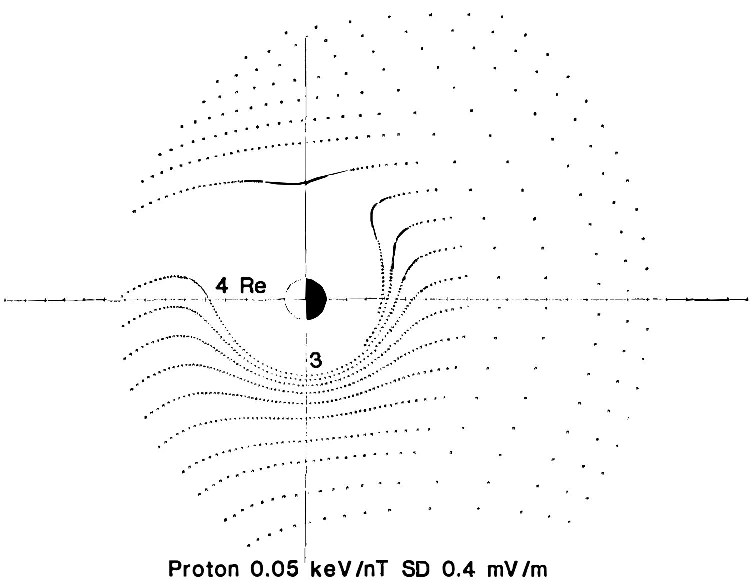


Fig. 5b.



Figs. 5a, b. Equatorial drift paths of protons with 0.05 keV/nT in the MF-SD geomagnetic field for uniform dawn-dusk electric field of 0.1 mV/m (5a) and 0.4 mV/m (5b).

the vicinity of the plasmapause bulge (CARPTENTER, 1966).

Figures 5a and 5b show respectively equatorial drift paths of protons with 0.05 keV/nT for E_w=0.1 and 0.4 mV/m in the MF-SD geomagnetic field. These figures clearly demonstrate the clockwise drift of protons and the stagnation region located in the late morning or morning sector, since the protons with 0.05 keV/nT can invade into a region of dipole gomagnetic field where the clockwise field-gradient drift is larger than the counterclockwise corotation drift. In case of the MF-SD model, the stagnation region for protons of 0.05 keV/nT lies at geocentric distance of about 5.7R_E around 0615 MLT for E_w=0.4 mV/m and at about 5.8 R_E around 0730 MLT for E_w=

Fig. 6a.

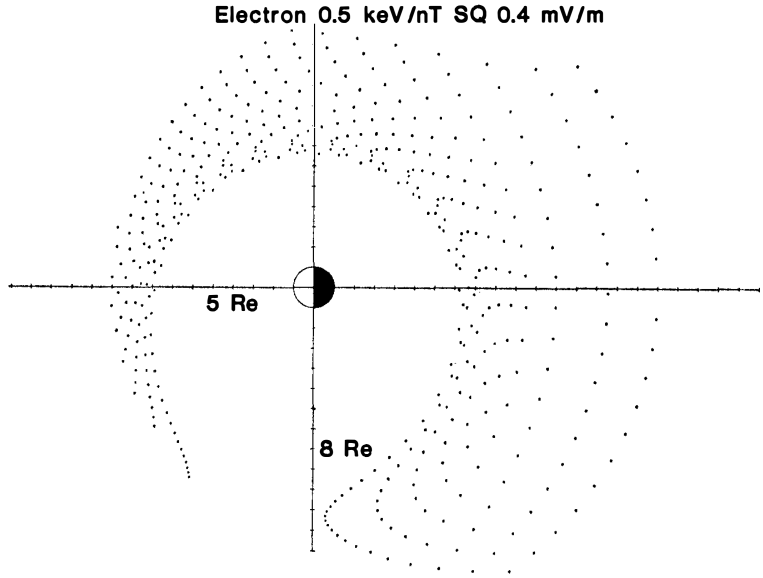
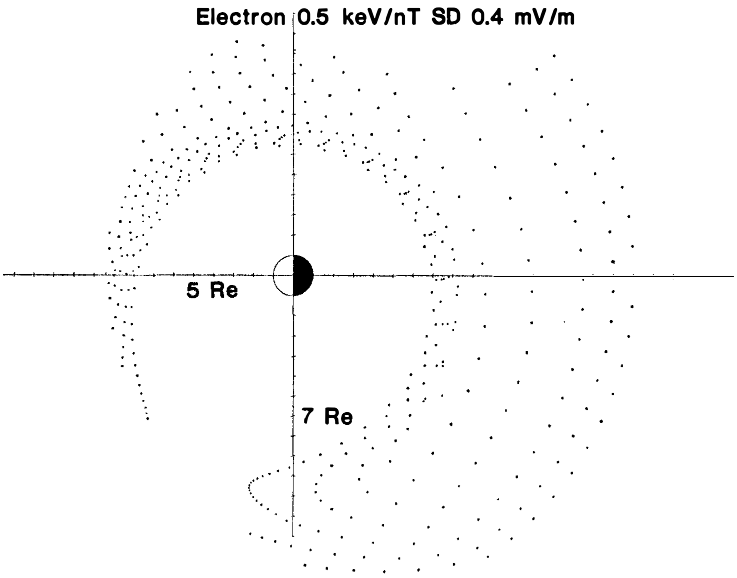


Fig. 6b.



Figs. 6a, b. Equatorial drift paths of electrons with 0.5 keV/nT in the MF-SQ (6a) and MF-SD (6b) geomagnetic fields for uniform dawn-dusk electric field of 0.4 mV/m.

0.1 mV/m. This implies that, for E_w=0.4 mV/m, protons with 0.05 keV/nT can invade deeply into the magnetosphere of dipole field, since the stagnation point for energetic protons lies just in 06 MLT meridian for the dipole geomagnetic field.

Figures 6a and 6b show equatorial drift paths of electrons with 0.5 keV/nT for E_w=0.4 mV/m in the MF-SQ and MF-SD geomagnetic field models, respectively. For E_w=0.4 mV/m, the stagnation region for 0.5 keV/nT electrons lies around 1710 MLT in the MF-SQ geomagnetic field (Fig. 6a) and around 1630 MLT in the MF-SD geomagnetic field (Fig. 6b), respectively. So the sunward displacement of the stagnation region for 0.5 keV/nT electrons may be caused by the distorted geomagnetic field.

MENG and AKASOFU (1983) have identified the patchy aurora in the midday and late morning sectors as the active mantle aurora found by SANDFORD (1964) during geomagnetically active periods. The patchy aurora occurs simultaneously with hard precipitating electrons of energies greater than several keV. This hard electron precipitation extends from the morning sector to only early afternoon (13–14 MLT) along the geomagnetic latitude circle of about 65°–70°. MENG and AKASOFU (1983) have compared the hard electron precipitation region with drift paths of 10 keV electrons in the equatorial plane of the dipole magnetic field when a uniform dawn to dusk electric field is 0.47 mV/m ($=3$ kV/R_E). In case of $E_w=0.1$ mV/m, equatorial drift paths for electrons with 0.5 keV/nT in the MF-SQ and MF-SD geomagnetic fields encircle only around the earth from the evening to the morning at geocentric distance beyond about 9 R_E.

Referring to the projection of constant geomagnetic latitudes at the earth's surface onto the equatorial plane (solid circles in Fig. 2b), the dayside extent of equatorial drift paths of electrons (0.5 keV/nT) for $E_w=0.4$ mV/m in the MF-SQ (Fig. 6a) and the MF-SD geomagnetic field (Fig. 6b) is very similar to the precipitating electron region (above several keV) associated with the active mantle aurora. Therefore, energetic electrons which produce the mantle aurora in high latitudes on the dayside seem to drift from the plasma sheet during geomagnetically active periods.

4. Conclusion

Equatorial magnetospheric profiles of the total geomagnetic field, electric equipotential lines and drift paths of plasma particles in the superquiet and superdisturbed conditions are computed for a quantitative geomagnetic field model which is derived from satellite observations of the magnetic field by MEAD and FAIRFIELD (1975). The magnetic field contours in the superdisturbed conditions have the sunward displacement outside geocentric distance of 8 R_E and a steep field gradient on the night side. The dayside magnetopause contracts and the equatorial magnetospheric flank expands in the superdisturbed conditions compared with those in the superquiet conditions.

The corotation electric potential at the earth's surface and the electric potential on the circular polar-cap boundary are projected onto the equatorial plane along the MF geomagnetic field lines. Computed electric equipotential lines in the equatorial plane are concave toward the earth on the dawn and dusk sides, since the geomagnetic field lines of the MF model are curved tailward in the dawn and dusk sectors where they deviate most from the radial dipole field lines.

Using the magnetospheric electric field defined by vector sums of the corotation electric field and uniform dawn to dusk electric field, we calculate drift paths for electrons or protons with pitch angle of 90° mirrored in the equatorial plane of the MF-SQ and MF-SD geomagnetic field. Magnetic moments of particles treated are 0, 0.005, 0.05 and 0.5 keV/nT. The particles with these magnetic moments have the initial energy of 100 eV, 1 keV and 10 keV, respectively, for magnetic field of 20 nT in the tail region. The uniform dawn to dusk electric fields used are 0.1 mV/m for a quiet time and 0.4 mV/m for a disturbed time.

The general features of equatorial drift paths for particles with 0.005 keV/nT are almost the same as those for the zero-energy particles.

The boundary of the forbidden region for zero-energy particles agrees with the observed plasmapause in local time and geocentric distance. Especially, for $E_w=$ 0.1 mV/m, the local time of the stagnation region of zero-energy particles in the SQ and SD geomagnetic fields is the late evening (19–21 MLT) which coincides well with the local time of the plasmapause bulge observed by whistlers. Also, in case of $E_w=$ 0.1 mV/m, drifting zero-energy particles or electrons with 0.05 keV/nT form a trapped particle region or closed path region, which does not circle the earth, in the late evening sector beyond the stagnation region for the SQ and SD geomagnetic fields.

While, in case of $E_w=0.4$ mV/m, the stagnation region for zero-energy particles or electrons with 0.05 keV/nT in the SQ and SD geomagnetic fields lies near the evening beyond about 5 R_E like that for the dipole magnetic field. The stagnation region for protons with 0.05 keV/nT lies in the late morning for $E_w=0.1$ mV/m and in the morning for $E_w=0.4$ mV/m at geocentric distance beyond about 5 R_E for the SQ and SD geomagnetic fields.

The trapped particle region for zero-energy particles and electrons occurs only for a weak cross-tail electric field of 0.1 mV/m, hence their main origin seems to be the geomagnetic field lines curved tailward and the corotation electric field directed almost dawnward in the late-evening outer magnetosphere.

The hard electron precipitation region associated with the active mantle aurora is explained well by the dayside extent of computed equatorial drift paths of 0.5 keV/nT electrons in the MF-SQ and MF-SD geomagnetic fields for $E_w=0.4$ mV/m.

We describe only the time-independent model of particle's drift trajectories in the magnetospheric equatorial plane. But the real electric field in the magnetosphere changes quickly corresponding to the electromagnetic state in the magnetosphere and the surrounding solar wind. So, the calculation of particle drift trajectories in the time-dependent model of the electric field and magnetic field is essentially required to elucidate the magnetospheric phenomena.

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