

ENERGETIC PARTICLE DRIFTS IN THE MULTI-FACTOR MODEL OF THE MAGNETOSPHERE

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Abstract. The drift trajectories of the particles with different pitch angles are calculated for the empirical model of the magnetic field by *Ostapenko and Maltsev* [1997]. The model is valid for distances from 3 to 10 R_E and depends on the Dst and Kp indices as well as on $IMF B_z$, solar wind dynamic pressure, and tilt of the Earth dipole. The particle trajectories are computed for quiet and disturbed conditions. The first and second adiabatic invariants are considered to be conserved. Splitting of drift shells occurred at distances $>5 R_E$ appears to be intermediate between the splitting in the models of *Mead* [1964] and *Tsyganenko* [1989]. The splitting is affected mainly by the solar wind dynamic pressure.

Introduction

The motion of charged particles in a trapping field geometry under stationary conditions can be described by two adiabatic invariants of motion, i.e. the magnetic moment M and the second invariant J :

$$M = p_{\perp}^2 / 2m_0B, \quad (1)$$

$$J = \int p_{\parallel} ds. \quad (2)$$

In these equations p_{\perp} and p_{\parallel} are the components of the momentum perpendicular and parallel to the magnetic field vector, respectively; B is the magnetic field intensity at the instantaneous position of the guiding center; and m is the rest mass. In (2) the integration is performed along the field line for a complete bounce oscillation; ds is the element of the field line.

Besides, the energy is conserved

$$p_{\perp}^2 + p_{\parallel}^2 = \text{const}. \quad (3)$$

If the magnetic field were axially symmetric the drift trajectories mapped to the equatorial plane would be concentric circles. The noon-midnight asymmetry of the magnetosphere leads to strongly asymmetrical drift shells dependent of pitch-angle of particles. *Roederer* [1967] studied the drift trajectories in the magnetic field model of *Mead* [1964]. *Shukhtina and Sergeev* [1991] examined the trajectories in a more realistic model of *Tsyganenko* [1989] which is parameterized by two factors: the Kp index and tilt of the Earth dipole.

Recently a more precise model of *Ostapenko and Maltsev* [1997] has been developed. It depends on 5 parameters: the Dst and Kp indices, $IMF B_z$, solar wind dynamic pressure p_{sw} , and tilt of the Earth dipole ψ . At distances $3 R_E < r < 10 R_E$ it yields a smaller residual error than the T89 model does. The aim of our paper is to examine the drift trajectories in the model of *Ostapenko and Maltsev* [1997].

Splitting of the drift shells under average conditions

Figure 1 shows an example of the particle trajectories in the equatorial plane. All the particles start off from the same point located at the night side at the distance of $6.5 R_E$ but have different pitch-angles, with the cosines being indicated near the trajectories. The geophysical conditions are assumed to be average ($Dst = -17$ nT, $Kp = 2.3$, $IMF_z = 0$, $p_{sw} = 2.3$ nPa, $\psi = 0$).

One can see that the greater pitch-angle, the farther noon distance. The particles with large pitch-angles ($\cos \alpha_e \sim 0$) do not reach the noon meridian at all due to the bifurcation phenomenon. The particles with $\alpha_e = 90^\circ$ drift along those points of the magnetic field lines where the magnetic field is minimum. Far from the magnetopause this corresponds to the contours $B = \text{const}$ in the equatorial plane (providing there is no dipole tilt). Near the magnetopause the B -minimum surface bifurcates into two separate sheets, one of them being in the northern hemisphere, the other one in the southern hemisphere [*Shabansky*, 1971]. For the model of *Mead* [1964], the thickness of the bifurcation region mapped to the equatorial plane is about $2 R_E$ [*Schulz*, 1975].

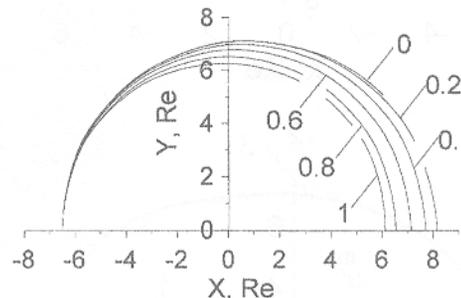


Figure 1. Trajectories of the particles starting at the night side at the distance of $6.5 R_E$ under average geophysical conditions ($Dst = -17$ nT, $Kp = 2.3$, $IMF_z = 0$, $p_{sw} = 2.3$ nPa, $\psi = 0$). The cosines of the initial pitch-angles are equal to 0, 0.2, 0.4, 0.6, 0.8, and 1.0.

The drift shell splitting for different starting pitch-angles and distances is shown in Figure 2. The solid lines correspond to the model of *Ostapenko and Maltsev* [1997] for average conditions. The dashed lines computed by *Roederer* [1967] correspond to the *Mead* [1964] model.

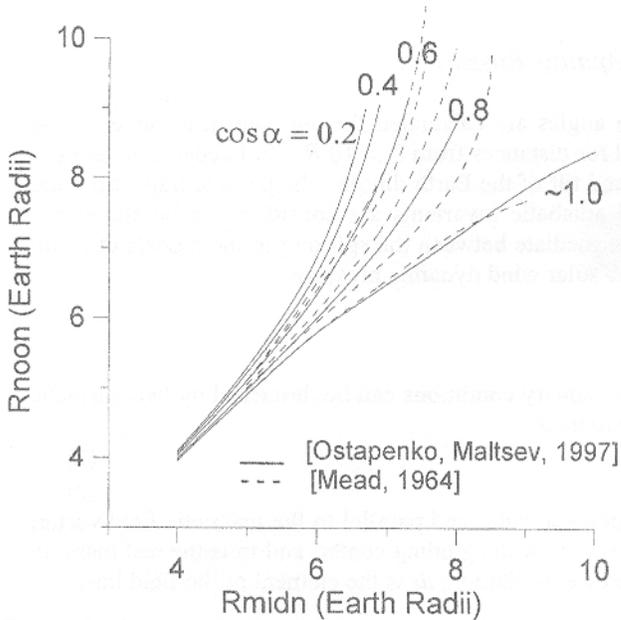


Figure 2. Comparison of the drift shell splitting in the *Mead* [1964] and *Ostapenko and Maltsev* [1997] models. α is the pitch-angle of the particle in the equatorial plane at the midnight meridian. The particles starting at the midnight meridian at the field line extended to R_{midn} will cross the noon meridian on the field line reaching out to R_{noon} .

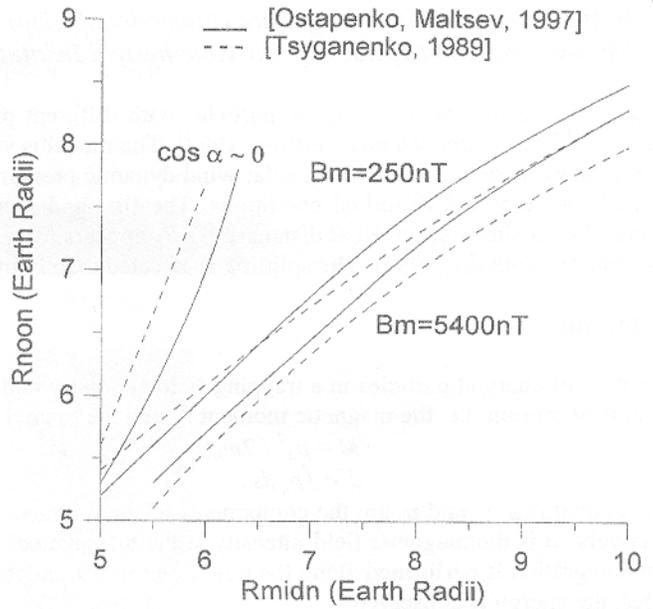


Figure 3. Comparison of the drift shell splitting in the *Tsyganenko* [1989] and *Ostapenko and Maltsev* [1997] models. B_m is the magnetic field in the mirror point. The particles starting at the midnight meridian in the field line extended to R_{midn} will cross the noon meridian on the field line reaching out to R_{noon} .

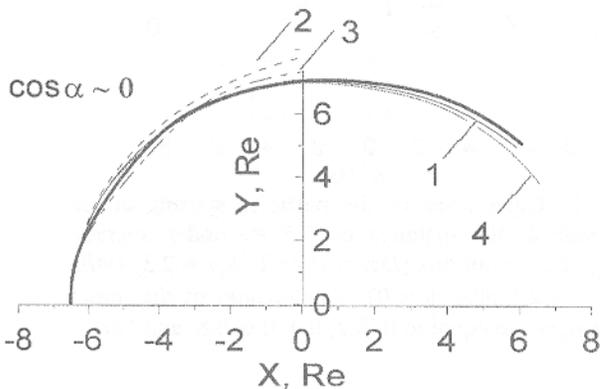
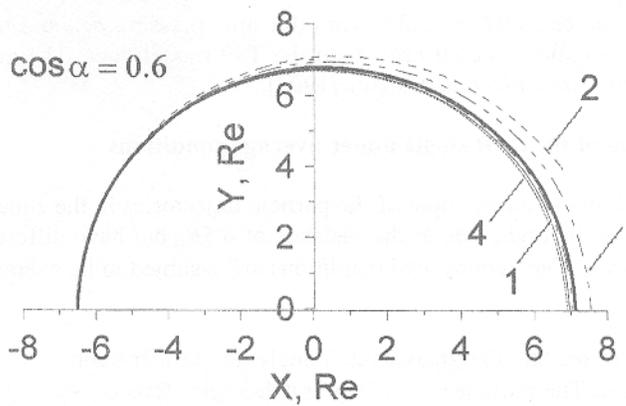
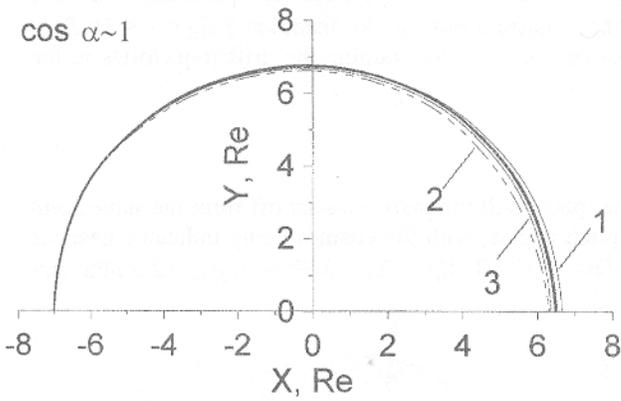


Figure 4. Trajectories of particles starting from the midnight distance of $6.5 R_E$ with different pitch-angles α under various geophysical conditions: the bold line corresponds to average conditions, the other ones correspond to the situation when one of the geophysical parameters deviates by two values of its dispersion, the other parameters keeping invariable. The curve 1 corresponds to $Dst = -67$ nT, the curve 2 to $p_{sw} = 6$ nPa, the curve 3 to $Kp = 4.9$, the curve 4 to $IMF_z = -7.4$ nT.

In Figure 3 are compared the drift splitting in the *Tsyganenko* [1989] model, $Kp = 3$ (the dashed lines) as computed by *Shukhtina and Sergeev* [1991], and in the model of *Ostapenko and Maltsev* [1997], $Kp = 3$, the other parameters being average (the solid lines). The splitting is presented as a function of the magnetic field in the mirror point, B_m .

One can see that the splitting in the *Ostapenko and Maltsev* [1997] model is intermediate between those in the *Mead* [1964] and *Tsyganenko* [1989] models.

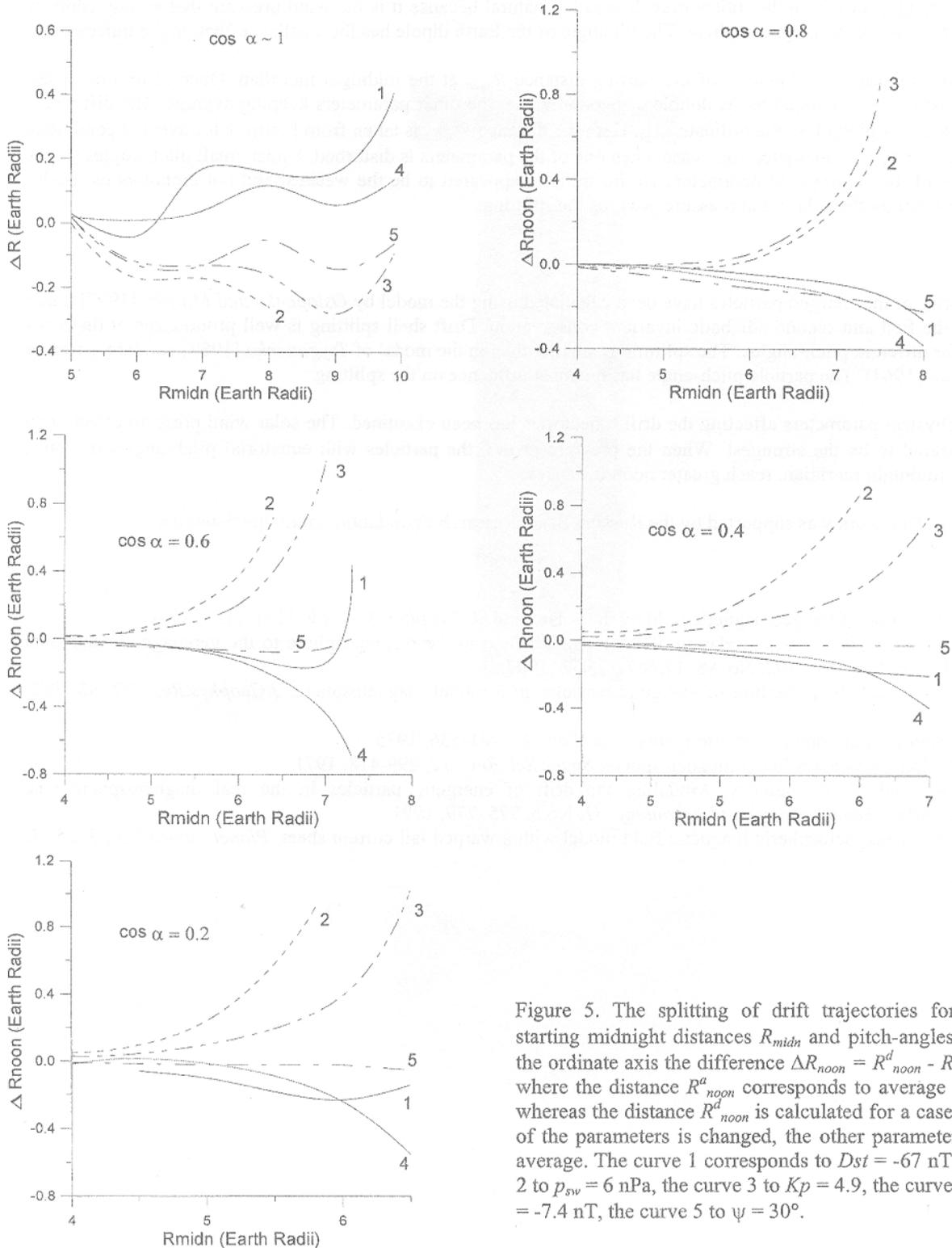


Figure 5. The splitting of drift trajectories for different starting midnight distances R_{midn} and pitch-angles α . Along the ordinate axis the difference $\Delta R_{noon} = R_{noon}^d - R_{noon}^a$ is put where the distance R_{noon}^a corresponds to average conditions whereas the distance R_{noon}^d is calculated for a case when one of the parameters is changed, the other parameters keeping average. The curve 1 corresponds to $Dst = -67$ nT, the curve 2 to $p_{sw} = 6$ nPa, the curve 3 to $Kp = 4.9$, the curve 4 to $IMFz = -7.4$ nT, the curve 5 to $\psi = 30^\circ$.

Drift shell splitting under disturbed conditions

We have computed the drift trajectories when one of the geophysical parameters was changed by its double dispersion value, the other parameters keeping average. The trajectories for three pitch-angles are shown in Figure 4. The bold solid lines correspond to average conditions.

One can see that the greater pitch-angle, the stronger dependence on the geophysical parameters. The solar wind dynamic pressure has the strongest effect on the trajectories. It is rather natural because it is the wind pressure that mainly controls the azimuthal asymmetry of the magnetosphere. The tilt angle of the Earth dipole has the smallest effect on the trajectories.

Figure 5 shows the splitting as a function of the starting distance R_{midn} at the midnight meridian. Once again one of the geophysical parameters was changed by its double dispersion value, the other parameters keeping average. The difference $\Delta R_{noon} = R_{noon}^d - R_{noon}^a$ is plotted on the ordinate axis. Here the distance R_{noon}^a is taken from Figure 1 for average conditions whereas the distance R_{noon}^d is calculated for a case when one of the parameters is disturbed. Under small pitch-angles ($\cos \alpha \sim 1$) the influence of the geophysical parameters on the splitting appeared to be the weakest and not monotonous. Under larger pitch-angles mainly the solar wind pressure governs the splitting.

Conclusions

The drift trajectories of the charged particles have been calculated using the model by *Ostapenko and Maltsev* [1997] under the condition of the first and second adiabatic invariant conservation. Drift shell splitting is well pronounced at distances exceeding $5 R_E$ for different pitch-angles. The splitting is smaller than in the model of *Tsyganenko* [1989] and larger than in the model by *Mead* [1964]. The particle pitch-angle has the most influence on the splitting.

Each of the geophysical parameters affecting the drift trajectories has been examined. The solar wind pressure effect upon the splitting appeared to be the strongest. When the pressure grows, the particles with equatorial pitch-angles $\alpha > 40^\circ$, starting from the midnight meridian, reach greater noon distances.

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