

THE STRONG PRECIPITATION BOUNDARY OF VARIOUS ENERGY PARTICLES UNDER THE TSYGANENKO-89 MAGNETOSPHERE MODEL

S.N. Kuznetsov, A.Yu. Rybakov (*Institute of Nuclear Physics, Moscow State University, Moscow, Russia*)
kuznets@srdlan.npi.msu.su

Abstract. We determined nonadiabatic conditions of energetic particle motion in the framework of Tsyganenko-89 magnetosphere model for Kp=1; 3; 5. In our calculations we used central trajectory (CT) as a model of the guide center trajectory. CT is such the trajectory along which a particle can come the dipole center. We analyzed dependencies of strong particle precipitation along drift trajectory on invariant latitude, MLT, particle energy. The results obtained were compared to experimental data on low energy cosmic ray penetration and trapped particle strong precipitation.

Introduction

If any system has independent oscillations in differ degree of freedom, oscillation can ever be characterized by an adiabatic invariant. In axial dipole magnetic field we have two oscillate motions: rotation around the guide center trajectory and oscillation along the guide center trajectory of which, the first adiabatic invariant $\mu = p^2 \sin^2 \alpha / 2mB = \text{const}$ and the second is adiabatic invariant $J = \oint p \cos \alpha dl = \text{const}$ corresponds. p is momentum of a particle, m is its mass, α is pitch-angle of particle, B is magnetic field. We use $I = J/p$ as a measure of second invariant. Invariants are retained if $\chi = \rho_L / \rho_B < \varepsilon \ll 1$. ρ_L is the full Larmor radii of a particle, ρ_B is the radii of magnetic line at the equator. We can use next expressions for receiving χ in the Earth's dipole field.

$$\chi_d = 0.0022 \sqrt{E_p} \cdot L^2 = 0.0022 \sqrt{E_p} / \cos^4 A \quad (\text{for nonrelativistic protons})$$

$$\chi_d = 5.04 \cdot 10^{-5} \sqrt{(E_e^2 + 1.02 E_e)} \cdot L^2 = 5.04 \cdot 10^{-5} \sqrt{(E_e^2 + 1.02 E_e)} / \cos^4 A \quad (\text{for electrons})$$

E_p and E_e are kinetic energy of protons and electrons in MeV. A is invariant geomagnetic latitude $\cos A = 1/\sqrt{L}$, L is particle drift shell in the inner source magnetic field.

In papers /Ilyina et al, 1993; Dmitriev et al, 1996/ empirical model of magnetic moment relation was made. We used a trajectory of the particle which was launched along the magnetic line from the dipole to equator (Central Trajectory (CT)) as a model of a guide center trajectory first branch. Second branch of CT describes motion in guide center from an equator to the dipole. If we launch a particle along CT it will begin to rotate after equator intersection around the second branch of CT in the event of nonadiabatic motion. The particle will mirror in some B and we can find the angle between two branches of CT. The angle between the particle velocity and CT we call quasipitch-angle α^* . For describing particle motion we must use μ^* and J^* . The angle A between two branches of CT is middle scattering angle for little quasipitch-angles and it Δ is a function of χ_d .

$$\Delta = 2.76 \cdot \exp(-0.965/\chi_d) \quad (\Delta \text{ is in radians}).$$

In real magnetosphere a field of inner sources is distorted by interaction with the solar wind. This disturbance is described in different model for example in models by Tsyganenko-89, / Tsyganenko, 1989/ or Tsyganenko-96 / Tsyganenko, 1996/. The magnetic field in the magnetosphere is made nonaxial. The trapped boundary of energetic electrons was analyzed in /Alotman, 1998/ in Tsyganenko-96 model. Authors suggested that χ_{cr} equal 0.1. A preliminary analysis of particle motion conditions was made on Tsyganenko-89 Model for Kp=1 /Kuznetsov, 2000/.

Computing results

We shall analyze the particle motion in Tsyganenko-89 model for Kp=1, 3 and 5 in the range where we can suppose that the disturbance is little enough addition to the main field. We used CT as a model of a guide center trajectory. We analyzed the particle motion in invariant latitudes A 58°–68° in the night side and in 58°–72° in the day side. Conditions of particle motion depend from the latitude and MLT. We computed with steps of 1° of A and 1h of MLT the following parameters: χ , Δ , B_{eq} , α_c , B_{eq} is a magnetic field in the equator in Tsyganenko-89 model. α_c is a real loss cone. Then we construct approximations $\chi/\chi_d = F(A, \text{MLT})$, $A = F_1(\chi, A, \text{MLT})$, In Fig 1 we presented in the upper panel dependencies of Δ from χ for MLT 0 and 12h, for $A=68^\circ$, for Kp=1, 3 and 5. We presented also a dipole dependence Δ from χ_d . In the night side Δ has more value for equal χ then in the dipole field. In the day side dependence Δ from χ is more complex and differ for different Kp. In bottom panel we presented dependencies χ/χ_d from A in night and day sides. We see that in the night side the real χ is more than χ_d . The type of χ/χ_d changing shows that in $A > 66-68^\circ$ the magnetotail is beginning. In the day side χ is equal χ_d in $A < 66^\circ$, then χ/χ_d decreases. In

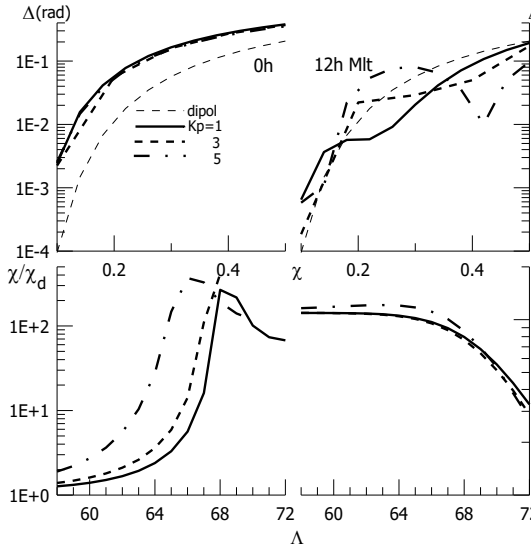


Fig.1

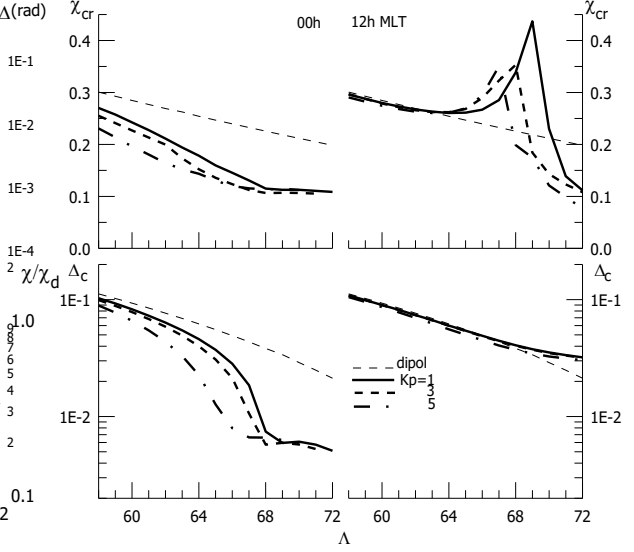


Fig. 2

Fig. 1 Upper panel. Dependence of Δ from χ for $A=68^\circ$ in the night side (left part), in the day side (right part). Bottom panel. Dependence of χ/χ_d from A in the night side (left part), in the day side (right part).

Fig. 2. Upper panel. Dependence of χ_{cr} from A in night side (left part), in day side (right part). Bottom panel. Dependence of α_c from A in the night side (left part), in the day side (right part).

Fig. 2 we presented in the bottom panel a loss cone α_c dependence from A in night and day sides. In night side α decreases more quickly then in dipole field when A increases. Magnetotail current causes such effect. In day side α decreases more quickly then in dipole field when A increases. In the upper panel we present dependence of χ_{cr} (χ for which $\Delta=\alpha_c$) from A . In the night side χ_{cr} is less then in dipole field. In the day side χ_{cr} is more then than in dipole field in $A<68-70^\circ$. χ_{cr} decreasing in $A>68-70^\circ$ connected with the cusp range approaching. We must compute a family of I for particles mirroring near Earth ($B=0.303\text{Gs}$) to analyze conditions of particle motion in drift orbits. Particles are drifting in a shall with $I=\text{const}$. We computed such families for $Kp=1, 3, 5$.

In Fig. 3, In the left part we present changing of $I=\text{const}$ latitude with changing of MLT, in the right part we present changing of $\lg\Delta$ (Δ is in radian) for drifting 1MeV protons along drift shells. We see that particles drift practically along $A=\text{const}$ in $A<60^\circ$. Drift shells in latitudes $A>60^\circ$ are asymmetric and their A increases in day hours. In the right part of Fig. 3 we see middle variation of pitch-angle of one MeV proton drifting around the Earth. Δ decreases thousand times during the drift from the night side to the day side. Now we shall use this results for the analysis of penetrating the low energy range of cosmic rays and trapped electrons.

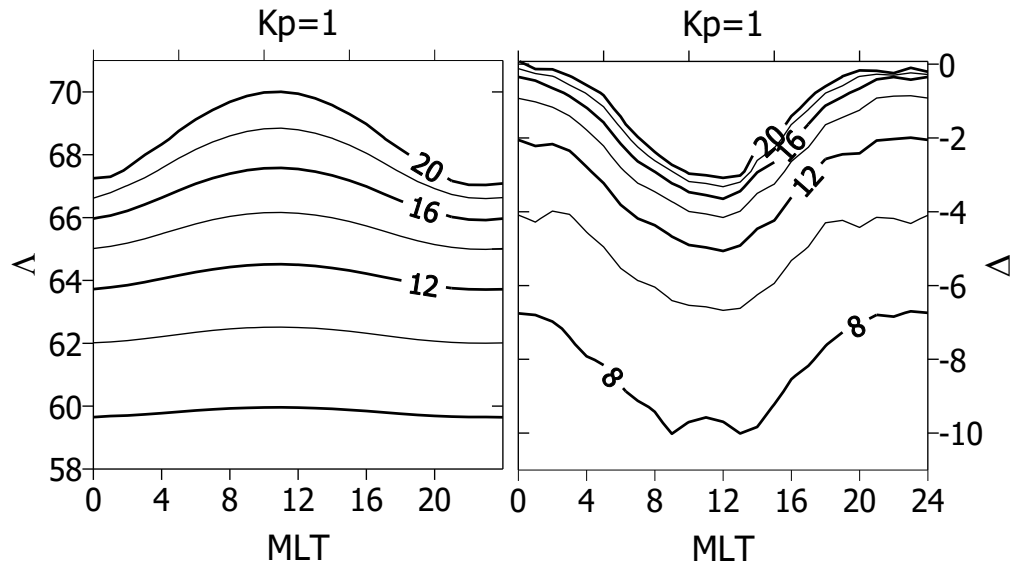


Fig. 3. The left part. MLT- A distribution of $I=\text{const}$. The right part. MLT- $\lg\Delta$ distribution of $I=\text{const}$.

Compare with experiment

In Fig. 4 we presented penetrating boundary of cosmic ray protons with energy $>1\text{MeV}$ /Ivanova, 1985/ (line 1), $>10\text{MeV}$ /Biryukov, 1983/ (line 10), strong precipitation boundary $\Delta=\Delta_c$ for protons with energy $>1\text{MeV}$ (line 1') and with energy $>10\text{MeV}$ (line 10'). We also show drift shells with $I=13$ and $I=23$. We see that penetrating boundary of $>1\text{MeV}$ protons is in higher latitudes in the night side then a strong precipitation boundary. Such phenomena is observed for $K_p=3$ and 5. In the day side the penetrating boundary is in $\Lambda\sim 74^\circ$ and the strong precipitation boundary is in $\Lambda\sim 72^\circ$. Such difference in the day side may be explained the fact that the penetrating boundary was measured in $K_p\sim 0$. For $K_p=3$ and 5 the penetrating boundary of protons coincides with the strong precipitation boundary. We also see that drift trajectory with $13<I<23$ are hybrid trajectories. In the night part of a trajectory they are situated in the range of strong precipitation $\Delta\geq\Delta_c$. In day part of a trajectory they are situated in range of weak precipitation $\Delta\leq\Delta_c$. A drift trajectories with $I>23$ are situated in range of strong precipitation. The penetrating boundary of $>10\text{MeV}$ protons are situated in range of strong precipitation.

In Fig. 5 we presented a latitude (a left part of Fig. 5) and I (a right part of Fig. 5) distributions of electron fluxes for $K_p=5$. In upper panel we presented the data received at ~ 21 h. MLT, and in the bottom panel we presented the data received at ~ 11 h. MLT. The B are equal in $\Lambda=64-65^\circ$, in less latitudes in the night time B is less then in the day time. We see that the latitude distributions of fluxes in the day side are wider then in the night side. I distributions have equal boundaries in the day and night sides, $I=15$ for electrons with $E_e>6\text{MeV}$ and $I=16-17$ for electrons with $E_e>2\text{MeV}$. In the left part of the upper panel presented with the vertical solid line the boundary of strong precipitation electrons $E_e>6\text{MeV}$, with the vertical dashed line a boundary of strong precipitation electrons $E_e>2\text{MeV}$. We can see that the boundary of trapped electrons is less of strong precipitation boundary in $\sim 0.5^\circ$. We conclude that the boundary of trapped particles is defined by nonadiabatic effects.

Conclusion

We analyzed nonadiabatic effects in model Tsyanenko-89 compared to the Earth dipole model. We received that peculiarities of cosmic ray penetrating boundary and trapped electron boundary can be explained by nonadiabatic motion agree Tsyanenko-89 model.

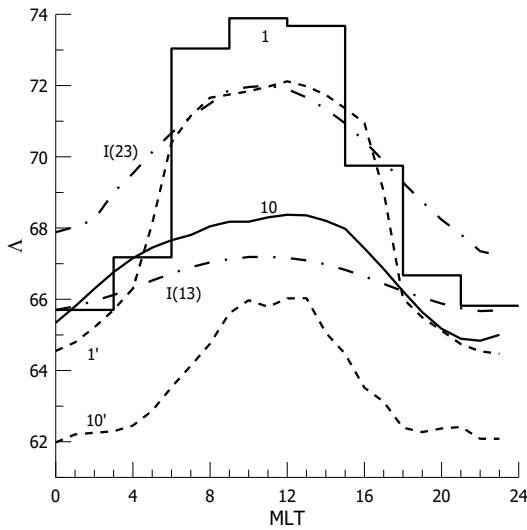


Fig. 4

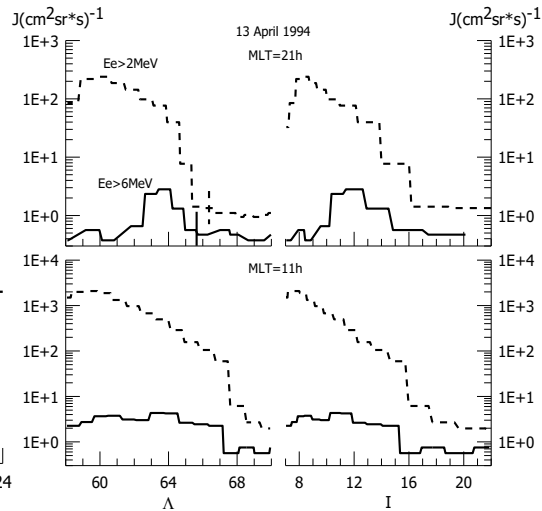


Fig. 5

Fig. 4 MLT distributions of cosmic rays $>1\text{ MeV}$ and $>10\text{ MeV}$ penetration boundary and boundaries of strong precipitations are presented. Drift orbits with $I=13$ and $I=23$ are also presented.

Fig. 5 Latitude and I distributions of trapped electrons with $E_e>2$ and $>6\text{MeV}$ are presented for day and night intersection of radiation belt by CORONAS-I.

Acknowledgements. This paper was supported by the RFFI grant No 00-02-16404

References

- Alothman M.J., Fritz T.A., A model for high latitude isotropic boundary, Polar Cap Boundary Phenomena, edited by J. Moen, A. Egeland, M Lockwood, 1998, 343-354.
- Biryukov A.S., Ivanova T.A., Kovrygina L.M., Kuznetsov S.N., Sosnovets E.N., Tverskaya L.V., Kudela K., SCR penetrating boundary to Earth magnetosphere in magneto-quiet time, *Geomagnetism i Aeronomy* (Russian), 23, 1983, No 6, p. 897-906.
- Dmitriev A.V., Ilyin V.D., Kuznetsov S.N. and Yushkov B.Yu., Formation of the Radiation Belts by Anomalous Cosmic Rays and Similar phenomena, in *Radiation belts Models and Standards*, edited by J.F. Lemaire, D. Heynderickx, and D.N. Baker, h. 43-48, 1996.
- Ilyina A.N., Ilyin V.D., Kuznetsov S.N., Yushkov B.Yu., Amirkhanov I.V. and Ilyin I.D., Model of nonadiabatic charged-particle motion in the field of a magnetic dipole, *JETP*, 77, 246-252, 1993.
- Ivanova T.A., Kuznetsov S.N., Sosnovets E.N., Tverskaya L.V., Dynamics low latitude penetrating boundary of solar low energy protons to magnetosphere, *Geomagnetism i Aeronomy* (Russian), 25, 1985, No 1, p.7-12.
- Kuznetsov S.N., Rybakov A.Yu., Destroy of energetic particle motion adiabaticity in trapped boundary in Earth magnetosphere. *Vestnik Moscow University. Ser. Physics. Astronomy*, No 5, 2000, p.
- Tsyganenko N.A., A Magnetospheric Magnetic Field Model with a Warped Tail Current Sheet, *Planet. Space Sci.* 37, 5-20, 1989.
- Tsyganenko N.A., Effects of the solar wind conditions on the global magnetospheric configuration as deduced from data-based field models, *European Space Agency Spec. Publ. ESA SP-389*, 181-185, 1996.