COSMIC RAY GEOMAGNETIC CUT-OFF COMPUTATIONS: INFLUENCE OF SELECTED PARAMETERS ON THE RESULT.

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SUMMARY.
The impact of selected parameters of cosmic ray trajectory computations in model geomagnetic field, namely the length of elementary step, total number of steps and the approach to the shape of Earth body, is examined.

Keywords: cosmic ray trajectory, cutoff´s rigidities

1. INTRODUCTION.

Cosmic ray transport in the geomagnetic field is studied for long time (e.g. McCracken, Rao and Shea, 1962 and many others). Recent progress in this topic is reviewed by Shea, Smart and Flueckiger (2000). Numerical trajectory tracing in the model field is done in several papers by using Bulirsch-Stoer numerical integration technique (e.g. Smart and Shea 2001).

Our method, originally described by Kaššovicová and Kudela (1998) is using Runge-Kutta method of the 6th order for numerical integration of the equation of motion. There are two major tasks for better understanding of the cosmic ray trajectories in the magnetosphere, namely improvements of the geomagnetic field models and checking the impact of parameters of computations on the result. Both are important for many applications, among them for peneteration of cosmic ray particles on ISS as well as for magnetospheric transmissivity of solar cosmic rays at the airplanes (e.g. recent GLE reported by Spurný and Dachev, 2001).Here we discuss some aspects of the second task.

2. METHOD.

The computer code is solving the motion of the charged cosmic ray particle in the geomagnetic field adjusted analytically. The sign of the charge and velocity vector of particle accessing a given point near Earth are reversed and trajectory is approached by sequence of large number of small linear steps starting from the point of observation. The „history“ of particle trajectory either stops on the Earth’s surface (forbidden), or crosses the model boundary of magnetosphere (allowed), or it remains „unresolved“ after large number of steps of integration. Especially at low rigidities (rigidity is the ratio of momentum and charge of particle) the complicated trajectories are met mainly of drifting or quasitrapped character. For each allowed trajectory the asymptotic directions in GEO coordinate system are obtained. In the following all trajectories are examined from vertical directions in the internal geomagnetic field model only.

3. RESULTS.

The parameters of the computations are: elementary length of the step (time or distance controlled by 1/n of the period of gyromotion or of Larmor radius in the local magnetic field), smoothness of the trajectory (maximum angle between two subsequent short lines of trajectory) and total number of the steps (N) after which the computation is closed (unresolved trajectories are adjusted as forbidden). The cutoff rigidities according to definition by Cooke et al. (1991) are obtained.
The Earth’s body is approached (i) by the sphere with the radius R_e = 6 371,2 km and (ii) by the Hayford elipsoid (Ochaba, 1986).
Lower cutoff rigidity R_l is the rigidity value of the forbidden transition observed in a set of computed trajectories. Upper cutoff rigidity R_u is the rigidity value of the highest detected allowed/forbidden transition among a set of computed trajectories. Effective cutoff rigidity R_c represents the total effect of the penumbral structure in a given direction. R_c may be either linear averages of the allowed rigidity intervals in the penumbra.

Table 1 shows the impact of length of elementary step on computations of cutoffs for two particular cosmic ray stations, namely Lomnický štít and Tsumeb. Their effective cutoff rigidities R_c for epoch 1995 are 3.88 GV for Lomnický štít and 9.06 GV for Tsumeb according to Shea and Smart (2001).
The allowed rigidities are seen to be shifted to higher values. The decreasing length of the step the amount of forbidden trajectories is increasing.

Tab.1. Cutoff rigidities obtained for internal geomagnetic field, two stations:
Lomnický štít (Slovakia, 49.20^o N, 20.22^o E) and Tsumeb (Namibia, 19.20^o S, 17.58^{o}E) at various lengths of elementary step for N = 200 000. Epoch 1995, altitude 20 km above the surface of Earth.

	Lomnický štít			Tsumeb		
n	R_l [GV]	R_u [GV]	R_c [GV]	R_l [GV]	R_u [GV]	R_c [GV]
100	2,18	3,78	3,02	6,27	9,02	7,98
500	3,05	4,19	3,83	7,80	9,24	8,71
1 000	3,11	4,22	3,91	7,82	9,27	8,78
5 000	3,32	4,24	3,99	7,88	9,30	8,85
10 000	3,67	4,24	4,03	7,81	9,29	8,84
20 000	3,68	4,26	4,09	7,71	9,29	8,89
50 000	4,17	4,26	4,24	7,93	9,31	8,97

For the same two stations the computations were done with an additional condition for the smoothness of the trajectory. The angle between two subsequent linear segments was checked by the declination of the velocity vector. If the latter was exceeding a given value ϕ_o, the length of the step on the first segment was shortened by a factor of 2 and declination was checked again. For higher values ϕ_o, (i.e. for longer elementary step) there is a larger amount of allowed trajectories in the low rigidity range. With the decreasing ϕ_o a larger portion of particles in low rigidity range remains either drifting around the Earth or forbidden. The value ϕ_o = 0.06 rad corresponds to the step length approximately n = 100. Table 2 is showing the effect.

Tab.2. Cutoff rigidities obtained for internal geomagnetic field, two stations:
Lomnický štít (Slovakia, 49.20^o N, 20.22^o E) and Tsumeb (Namibia, 19.20^o S, 17.58^{o}E) at various maximum angle between two subsequent short lines of trajectory, for starting elementary step for n_o=100, resp. n_o = 1000. Epoch 1995, altitude 20 km above the surface of Earth.

n_o=100	Lomnický štít			Tsumeb		
ϕ_o [rad]	R_l [GV]	R_u [GV]	R_c [GV]	R_l [GV]	R_u [GV]	R_c [GV]
0,06	2,17	3,80	3,11	5,62	9,04	7,92
0,01	2,17	3,80	3,11	6,36	9,26	8,67
0,006	3,08	4,20	3,83	7,02	9,28	8,78
0,001	3,39	4,24	3,94	7,71	9,30	8,84
n_o=1000	Lomnický štít			Tsumeb		
ϕ_o [rad]	R_l [GV]	R_u [GV]	R_c [GV]	R_l [GV]	R_u [GV]	R_c [GV]
0,06	3,11	4,22	3,91	7,82	9,27	8,78
0,01	3,11	4,22	3,91	7,83	9,27	8,78
0,006	3,17	4,23	3,92	7,68	9,27	8,79
0,001	3,52	4,23	3,95	7,77	9,30	8,85

The effect of the limiting total number of steps (N) was examined too. Table 3 shows the changes of cutoff rigidities for the two stations depending on N and n. The limit N= 200 000 is sufficient and increasing N above this value is not affecting the results significantly.

Tab.3. Cutoff rigidities obtained for internal geomagnetic field, two stations:
Lomnický štít (Slovakia, 49.20^o N, 20.22^o E) and Tsumeb (Namibia, 19.20^o S, 17.58^{o}E) at various total number of the steps (N) after which the computation is closed , for elementary step for n = 100. Epoch 1995, altitude 20 km above the surface of Earth.

	Lomnický štít			Tsumeb		
N	R_l [GV]	R_u [GV]	R_c [GV]	R_l [GV]	R_u [GV]	R_c [GV]
10 000	2,18	3,78	3,05	6,27	9,02	7,98
50 000	2,18	3,78	3,02	6,27	9,02	7,98
100 000	2,18	3,78	3,02	6,27	9,02	7,98
200 000	2,18	3,78	3,02	6,27	9,02	7,98
1 000 000	2,18	3,78	3,02	6,27	9,02	7,98
2 000 000	2,18	3,78	3,02	6,27	9,02	7,98

4. CONCLUSIONS.

Checking the influence of selected parameters of the numerical computation for cosmic ray trajectories at a middle- and a low-latitude station was done. The importance of the length of elementary step is indicated.

Using the proposed method controlling the smoothness of the trajectory, a relatively good correspondence with the values of cutoff rigidities reported by Shea and Smart (2001) is found for n = 1000. The differences may be caused by using different methods of numerical integration of the equation of motion of charged particle in geomagnetic field.

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