SH 3.6.29

Calculated Vertical Cutoff Rigidities for the International Space Station During Magnetically Active Times

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Abstract

We have calculated a world grid of cosmic ray cutoff rigidities each 5 degrees in latitude and 15 degrees in longitude at 450 km altitude. Geomagnetic cutoff rigidity values have been calculated employing the Tsyganenko magnetic field model combined with the International Geomagnetic Reference Field for 1995. The cutoff rigidities were calculated by the trajectory-tracing method for particles arriving from the vertical direction during magnetically active conditions. These cutoff rigidity values are intended to be a basic reference for charged particle access to the International Space Station.

1 Introduction:

A world grid of vertical cutoff rigidities has been calculated each 5° in latitude and 15° in longitude for a spacecraft orbiting at 450 km altitude employing the Tsyganenko (1989) magnetospheric field model combined with the International Geomagnetic Reference Field for epoch 1995.0 (Sabaka et al., 1997). The orbit of each particle was traced backwards through a model of the magnetosphere, to ascertain if the particle access from space was allowed or forbidden at each location. The results presented in this paper are for magnetically active conditions represented by Kp activity levels of 5 and with a Dst index of -300.

2 Method:

The cosmic ray trajectory calculations were initiated in the vertical direction from a distance of 6821.2 km from the geocenter, (450 km altitude above the average earth radius of 6371.2 km). The "sensible" atmosphere of the earth is considered to extend 20 km above the international reference ellipsoid, and any trajectory path that came lower than this distance is considered to be re-entrant and hence forbidden. In this work, "vertical" is the direction radial from the earth center. The magnetic fields in the magnetosphere were a combination of the IGRF 1995 internal magnetic field (Sabaka et al., 1997) and the Tsyganenko (1989) magnetospheric model combined by the method described by Flückiger and Kobel (1990). The Boberg et al. (1995) extension was used to describe the magnetospheric fields for magnetic activity levels exceeding Kp values of 5. The trajectory-tracing technique employed was developed by Kobel (1990) and utilizes the Bulirsch-Stoer numerical integration technique (Stoer and Bulirsch, 1980; Press et al., 1989) to minimize the number of steps required in a charged particle trajectory computation.

The cutoff rigidities were determined by calculating charged particle trajectories at discrete rigidity intervals starting with a rigidity value high above the highest possible cutoff and decreasing the rigidity to a value that satisfied our criteria that the lowest allowed trajectory had been calculated. As these calculations progress down through the rigidity spectrum, the results change from the easily allowed orbits to a complex structure of allowed, forbidden, and quasi-trapped orbits (loosely called penumbra) and finally to a set of rigidities where all trajectories intersect the solid earth. As a result of these trajectory calculations we determined the calculated upper cutoff rigidity (R_U) which is the rigidity value of the highest allowed/forbidden pair of adjacent cosmic ray trajectories, the calculated lowest cutoff rigidity (R_L) which is the rigidity value of the lowest allowed/forbidden pair of adjacent cosmic ray trajectories, and an "effective cutoff rigidity" (R_C) that allows for the transparency of the penumbra. (See Cooke et al., 1991, for definitions of cosmic ray cutoffs.) Rigidity intervals of 0.01 GV were used for trajectories between R_U and R_L to provide a reasonable sample of the cosmic ray penumbra. The effective cutoff rigidity R_C was found by summing the allowed orbits through the penumbra as described by Shea et al. (1965).

3 Results and Discussion:

These results are intended to be a reference for estimating the cosmic ray geomagnetic cutoffs at the International Space Station during active geomagnetic conditions. Iso-rigidity contours of the calculated effective vertical geomagnetic cutoff rigidities at 450 km for active magnetic conditions represented by a Kp value of 5 are shown in Figure 1. Figure 2 illustrates the iso-rigidity contours of the calculated effective vertical geomagnetic cutoff rigidities during disturbed conditions represented by a Kp value of 5 with an additional magnetic perturbation due to a ring current equivalent to a Dst index of -300. A reduced (for the lack of space) tabulation of effective vertical cutoff rigidities (R_C) are given in the tables. These results, for an internal field epoch of 1 January 1995, are the average of cutoff calculations for 00, 06, 12 and 18 UT.

A comparison of the figures and tables shows an equatorward movement of the cutoff rigidity contours as the magnetic activity increases. The changes are particularly evident when compared with the cutoff rigidities for a quiet magnetosphere presented in the previous paper (Smart et al., 1999a). Note the disappearance of the 15 GV contour for magnetically active times. Also note in Figure 2, the closure of the 11 GV contour during disturbed times. Further discussion of these changes with magnetic activity is contained in Smart et al., (1999b).

We have found that Störmer theory, in a coordinate system using a magnetic vertical direction (a radial direction from the offset dipole position), and a “proper” magnetic north direction, can be used to extend vertical cutoff rigidities to other directions. Smart and Shea, (1967) found that the cutoff change with radial distance is proportional to L^{-2}, and the McIlwain (1961) L parameter is useful in interpolating cutoff rigidities to other altitudes.

4 Conclusions:

These cutoff rigidity values derived from the Tsyganenko magnetic field model for magnetically active conditions, combined with the International Geomagnetic Reference Field for 1995, are intended to be a basic reference for charged particle access to the International Space Station.

Acknowledgments:

These calculations were performed at the Maui High Performance Computer Center. EOF acknowledges support by the Swiss National Science Foundation, grant NF 20-050697.97

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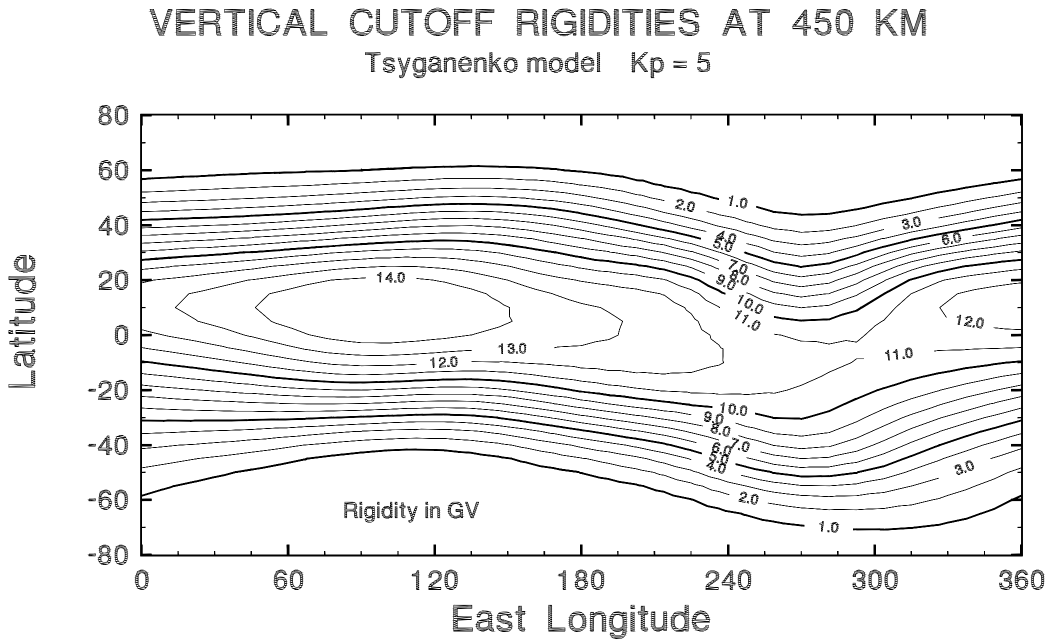

Figure 1. Cutoff rigidity contours at 450 km altitude for active (Kp = 5) magnetic conditions.

Table 1. Effective Vertical Cutoff Rigidities in GV at 450 km (Epoch 1995; Kp = 5)

	Geographic East Longitude											
Lat	0	30	60	90	120	150	180	210	240	270	300	330
90	0.00											
85	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
80	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00
75	0.02	0.03	0.04	0.05	0.05	0.05	0.03	0.01	0.00	0.00	0.00	0.00
70	0.04	0.07	0.09	0.10	0.10	0.10	0.08	0.04	0.01	0.00	0.00	0.01
65	0.09	0.19	0.27	0.35	0.40	0.42	0.27	0.09	0.03	0.01	0.01	0.04
60	0.44	0.70	0.84	1.00	1.15	1.25	0.90	0.34	0.07	0.02	0.03	0.12
55	1.29	1.62	1.82	2.03	2.30	2.48	1.99	0.99	0.21	0.06	0.07	0.58
50	2.50	2.85	3.09	3.38	3.73	3.97	3.29	1.94	0.72	0.22	0.41	1.47
45	3.92	4.27	4.57	4.92	5.35	5.54	4.50	3.16	1.61	0.74	1.06	2.69
40	5.68	6.10	6.58	7.25	7.74	7.91	6.44	4.46	2.76	1.52	2.04	4.22
35	8.00	8.09	8.83	9.21	9.81	9.41	7.73	6.24	4.18	2.50	3.25	6.29
30	9.47	9.97	10.76	11.42	11.76	11.09	9.51	7.93	5.58	3.56	4.45	8.54
25	10.89	11.56	12.35	13.04	13.12	12.22	11.03	9.69	7.83	4.95	6.44	9.90
20	11.88	12.67	13.50	14.21	14.04	13.04	11.93	10.98	8.98	6.34	7.59	10.90
15	12.43	13.17	14.05	14.78	14.53	13.52	12.57	11.70	10.02	7.04	9.58	11.50
10	12.51	13.30	14.26	14.96	14.70	13.83	12.72	12.09	10.94	9.21	10.58	11.77
5	12.26	13.08	14.08	14.92	14.68	13.90	13.16	12.47	11.59	10.36	10.99	11.71
0	11.76	12.56	13.72	14.50	14.32	13.67	13.24	12.71	11.92	10.83	11.12	11.45
-5	11.01	11.82	13.02	13.77	13.48	13.12	13.02	12.70	12.10	11.13	11.11	11.00
-10	10.14	10.84	12.03	12.71	12.33	12.22	12.40	12.43	11.90	11.34	10.91	10.38
-15	8.87	9.59	10.51	11.02	10.61	10.82	11.55	11.74	11.81	11.19	10.54	9.63
-20	7.54	8.00	8.62	8.97	8.82	8.71	10.16	10.81	11.42	10.90	10.08	8.63
-25	6.15	6.59	6.91	6.16	6.12	6.94	8.24	9.34	10.83	10.48	9.46	7.59
-30	5.10	5.04	4.72	4.33	4.22	4.72	6.47	7.42	9.76	9.91	8.67	6.49
-35	4.06	3.63	3.43	2.71	2.61	3.21	4.55	6.59	8.00	9.20	7.84	5.51
-40	3.20	2.71	2.19	1.48	1.30	1.86	3.18	4.55	6.84	8.34	6.97	5.02
-45	2.54	1.86	1.22	0.60	0.45	0.80	1.90	3.43	4.96	7.14	6.20	3.99
-50	1.90	1.20	0.60	0.15	0.09	0.20	0.90	2.20	3.66	5.29	4.93	3.15
-55	1.37	0.70	0.19	0.06	0.04	0.06	0.28	1.21	2.51	3.78	3.59	2.47
-60	0.88	0.33	0.08	0.03	0.01	0.02	0.08	0.54	1.52	2.56	2.66	1.76
-65	0.46	0.14	0.05	0.01	0.00	0.01	0.04	0.16	0.78	1.50	1.65	1.12
-70	0.22	0.07	0.03	0.00	0.00	0.00	0.02	0.06	0.27	0.70	0.81	0.56
-75	0.09	0.05	0.01	0.00	0.00	0.00	0.01	0.04	0.09	0.18	0.27	0.18
-80	0.05	0.03	0.01	0.00	0.00	0.00	0.01	0.02	0.05	0.08	0.09	0.08
-85	0.03	0.02	0.01	0.00	0.00	0.00	0.01	0.01	0.02	0.03	0.04	0.04
-90	0.01											

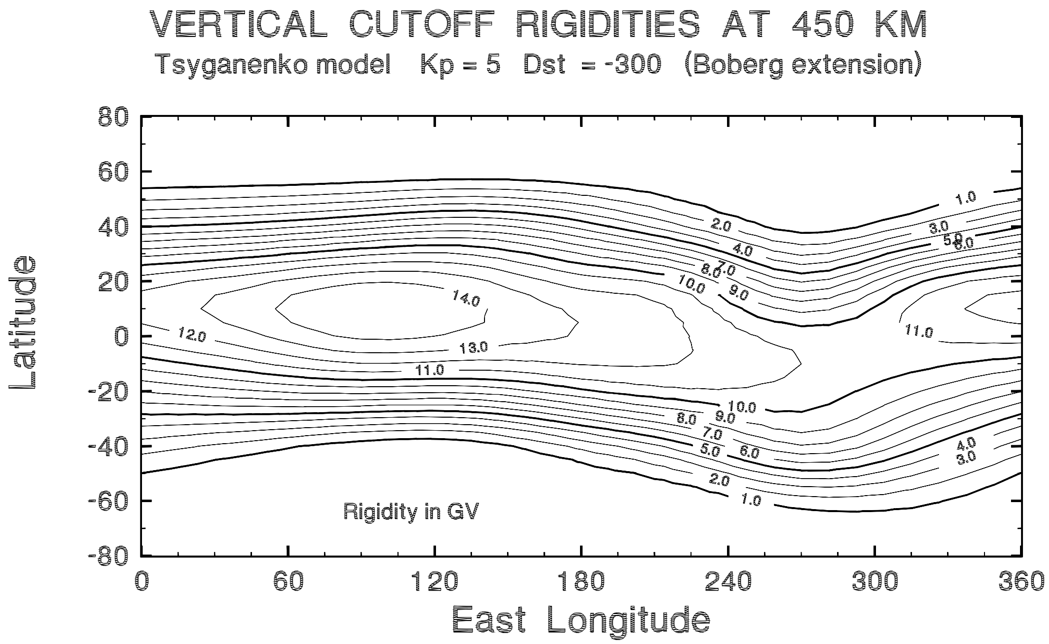

Figure 2. Cutoff rigidity contours at 450 km altitude for disturbed (Kp = 5, Dst = -300) magnetic conditions.

Table 2. Effective Vertical Cutoff Rigidities in GV at 450 km (Epoch 1995; Kp = 5, Dst = -300)

	Geographic East Longitude											
Lat	0	30	60	90	120	150	180	210	240	270	300	330
90	0.00											
85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
80	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00
75	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.00	0.00	0.00	0.00
70	0.02	0.03	0.04	0.04	0.05	0.05	0.04	0.02	0.00	0.00	0.00	0.01
65	0.04	0.06	0.07	0.08	0.09	0.09	0.07	0.04	0.01	0.00	0.00	0.02
60	0.08	0.11	0.14	0.16	0.23	0.27	0.12	0.08	0.03	0.01	0.01	0.04
55	0.28	0.56	0.76	1.00	1.27	1.45	0.90	0.16	0.06	0.03	0.03	0.07
50	1.50	1.92	2.13	2.54	2.89	3.15	2.36	0.93	0.11	0.05	0.06	0.37
45	3.23	3.60	3.94	4.29	4.70	4.85	3.83	2.27	0.58	0.10	0.21	1.75
40	4.96	5.40	5.88	6.62	7.30	7.26	5.69	3.73	1.83	0.55	1.01	3.51
35	7.53	7.71	8.44	8.73	9.35	9.00	7.29	5.43	3.50	1.69	2.29	5.41
30	9.12	9.53	10.37	11.02	11.39	10.73	9.08	7.49	4.97	3.02	3.75	8.07
25	10.57	11.21	12.01	12.72	12.75	11.89	10.64	9.25	7.32	4.36	5.58	9.53
20	11.54	12.30	13.16	13.90	13.72	12.70	11.55	10.65	8.74	5.91	6.83	10.58
15	12.13	12.86	13.73	14.46	14.21	13.21	12.21	11.40	9.77	6.80	9.06	11.17
10	12.18	12.97	13.95	14.66	14.38	13.51	12.45	11.80	10.69	8.81	10.12	11.43
5	11.93	12.76	13.78	14.61	14.37	13.59	12.85	12.16	11.25	9.99	10.63	11.38
0	11.42	12.24	13.40	14.19	13.99	13.37	12.91	12.39	11.60	10.55	10.78	11.12
-5	10.67	11.46	12.69	13.44	13.16	12.80	12.69	12.38	11.77	10.76	10.76	10.63
-10	9.73	10.46	11.66	12.33	11.99	11.90	12.07	12.10	11.57	11.00	10.57	10.04
-15	8.45	9.12	10.09	10.52	10.24	10.45	11.25	11.47	11.48	10.87	10.21	9.27
-20	7.02	7.51	8.11	8.37	8.33	8.25	9.78	10.51	11.03	10.58	9.75	8.29
-25	5.60	6.02	6.27	5.44	5.45	6.23	8.00	8.90	10.47	10.16	9.11	7.20
-30	4.53	4.21	4.00	3.58	3.57	4.12	5.79	7.01	9.34	9.60	8.37	6.11
-35	3.34	2.84	2.50	1.77	1.67	2.31	3.91	5.86	7.53	8.90	7.52	5.19
-40	2.48	1.71	1.16	0.43	0.30	0.80	2.27	3.97	6.32	7.90	6.66	4.44
-45	1.65	0.84	0.28	0.10	0.08	0.12	0.90	2.55	4.19	6.53	5.83	3.31
-50	0.95	0.28	0.09	0.05	0.04	0.06	0.15	1.18	2.88	4.37	4.17	2.52
-55	0.38	0.11	0.06	0.03	0.02	0.03	0.07	0.25	1.58	3.01	2.95	1.57
-60	0.14	0.08	0.04	0.01	0.01	0.01	0.04	0.09	0.47	1.51	1.66	0.76
-65	0.10	0.05	0.02	0.00	0.00	0.00	0.02	0.05	0.11	0.47	0.60	0.23
-70	0.07	0.03	0.01	0.00	0.00	0.00	0.01	0.03	0.07	0.11	0.15	0.11
-75	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.02	0.04	0.07	0.08	0.07
-80	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.04
-85	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.02
-90	0.01											