Calculated Vertical Cutoff Rigidities for the International Space Station Using the Tsyganenko Magnetospheric Model For Every Two Hours in UT

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Abstract

We have calculated world grids of vertical cutoff rigidities at 5° intervals for a spacecraft orbiting at 450 km. These cutoff rigidity values were determined from tracing cosmic ray trajectories through the Tsyganenko [15] magnetospheric field model combined with the International Geomagnetic Reference Field (IGRF) for epoch 1995.0 [7]. This paper summarizes the results of these calculations for all magnetic conditions represented by Kp indices ranging from super quiet (Kp=0) to extremely disturbed ($Kp=9^+$). We have improved the time resolution and now have world grids of vertical cutoff rigidities at 450 km for every two hours in universal time. From these results we have assembled a dynamic vertical cutoff rigidity model based on the Tsyganenko magnetospheric model that includes all integer magnetic activity levels specified by the Kp magnetic index.

1. Introduction

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 was considered to extend 20 km above the international reference ellipsoid, and any trajectory path that came lower than this distance was considered to be re-entrant and hence forbidden. The magnetic fields in the magnetosphere were the IGRF 1995 internal magnetic field [7] and the Tsyganenko [15] magnetospheric model as combined by Flueckiger and Kobel [3]. The Boberg et al. [1] extension was used to describe the magnetospheric fields for magnetic activity levels exceeding Kp values of 5. The magnetic fields utilized were defined for an Epoch of 1 January 1995.

The trajectory calculations and cutoff rigidity determination method is described in [8]. We determined the calculated upper cutoff rigidity (R_U), the calculated lowest cutoff rigidity (R_L), and an "effective cutoff rigidity" (R_C) that allows for the transparency of the penumbra. (See [2] for definitions of cosmic ray

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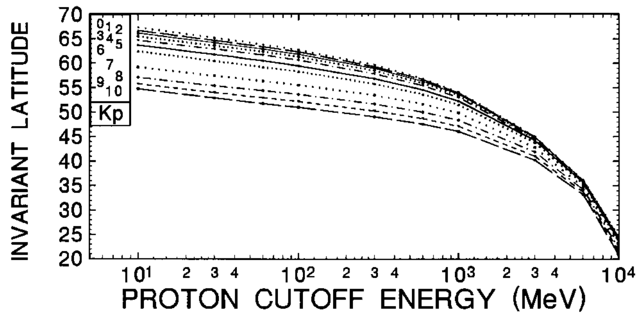

Fig. 1. Proton cutoff energy as a function of invariant latitude and magnetic activity.

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.

2. Results and Discussion

We find that the inclusion of the external magnetospheric current systems results in a systematic reduction of the geomagnetic cutoffs from values determined using only the internal field. Previously published results using the magnetospheric model but with preliminary $5° \times 15°$ world grids [9,10,11] give the general trends of the changes in cutoff with magnetic activity. The cutoff contours move equatorward with increasing magnetic activity, (see Figure 1), and the 15 GV cutoff rigidity contour disappears at magnetic activity levels of Kp values ≥ 8.

Rigidity is not the most convenient unit for use in comparing with energetic particle data since most energetic particle measurements are in units of energy. For comparison purposes, we have used the invariant latitude calculated from the internal geomagnetic field as a common parameter. We interpolated through our world grids of vertical geomagnetic cutoff rigidities for each magnetic activity level to determine the proton cutoff energy contours as a function of invariant latitude and obtained a time-averaged invariant latitude for selected energies. The curves in Figure 1 show the relation between the proton cutoff energy with latitude. The change in latitude is non-linear with magnetic activity.

3. Comparison with "Measured" Data

We have used the cutoff change with radial distance as proportional to L^{-2} [13] and the McIlwain [6] L parameter as an interpolation aid in extrapolating these calculated cutoff rigidities to other altitudes. Using this interpolation procedure, we have compared these computed average invariant latitudes of the predicted average solar proton cutoff latitudes with the SAMPEX spacecraft measured cutoff latitudes published by Leske et al. [5]. Figure 2 shows that the cutoff

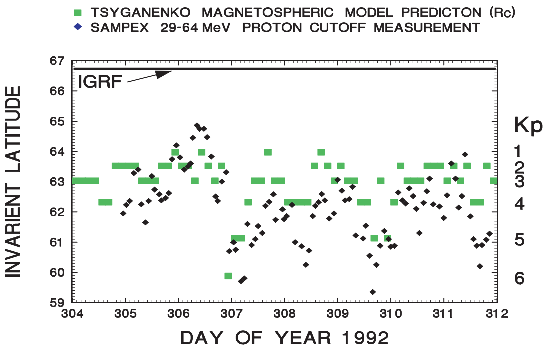

Fig. 2. The proton cutoff energy variations vs. the Kp index. The dark line is the cutoff latitude from the IGRF internal magnetic field. The solid diamonds are the cutoff latitudes of [5]. The solid squares are the cutoff latitudes for 46.5 MeV obtained by interpolation through our world grids of cutoff rigidities.

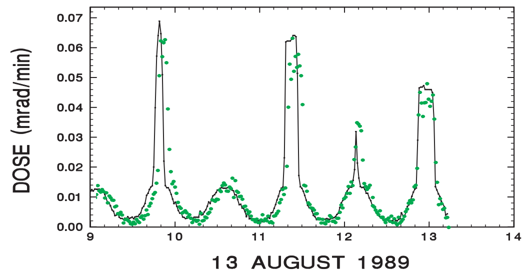

Fig. 3. Comparison of the one-minute observed radiation dose rate (dots) with the computed dose rate (solid line) during the 13 August 1989 solar proton event.

latitudes derived from interpolation through our library of magnetospheric cutoffs and measured cutoff latitudes exhibit the same general pattern. During magnetically active times the "measured" cutoff latitudes are slightly lower and show more detailed structure than the interpolated vertical geomagnetic cutoffs.

We have used the dosimetry data acquired during the STS28 space shuttle flight in August 1989 as a method to evaluate the accuracy of these cutoff rigidities. For this analysis we also applied Störmer [14] theory, in corrected geomagnetic coordinates [4] (or invariant latitude) to extrapolate our vertical trajectory-derived cutoff rigidities to other azimuth and zenith angles. Employing the observed GOES solar proton flux spectrum and the appropriate Kp magnetic activity indices enabled the computation of the solar particle flux to the minute-by-minute position of the space shuttle (latitude, longitude and altitude) during its encounter with the solar proton event. This solar particle flux was used as input to the NASA/JSC PDOSE code. It was necessary to include the effect of the lower cutoffs in the western direction (derived by the application of Störmer theory) to reproduce the observed radiation dose intensity/time profile. Employing our dynamic cutoff rigidity model with a proper selection of the magnetic activity index resulted in a one-to-one correspondence between the time periods of computed radiation dose rate due to solar protons being allowed through the magnetosphere to the position of the space shuttle and the measured dose rate in the vehicle, even for very small doses. The comparison between the computed and measured dose rate is given in Figure 3. A more detailed description is given by [12].

4. Conclusions

Cutoff rigidity values derived from the Tsyganenko magnetic field model combined with the IGRF for various magnetic conditions show non-linear changes in geomagnetic cutoff as a function of magnetic activity. From these results we have assembled a library of vertical cutoff rigidities that includes all integer magnetic activity levels specified by the Kp magnetic index. These results are intended to be a basic reference for charged particle access to the International Space Station.

5. Acknowledgments

This research was funded by NASA DPR W19,990. EOF acknowledges support by the Swiss National Science Foundation, grant NF 20-67092.01. These calculations were performed at the DOD Maui High Performance Computing Center.

6. References

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