Geomagnetic Cutoff Rigidity Calculations at 50-Year Intervals Between 1600 and 2000

D.F. Smart and M.A. Shea[1]
(1) CSPAR, University of Alabama in Huntsville, Huntsville, AL 35899, USA

Abstract

We have calculated a world grid of geomagnetic cutoff rigidities in the vertical direction every 50 years to establish the long-term changes in the geomagnetic cutoff rigidities over the past 4 centuries. We have utilized the International Geomagnetic Reference Field Models for these calculations for epochs between 2000 and 1900 and the British Geological Survey models (restricted to degree and order 5) for epochs between 1850 and 1600. The cosmic ray trajectory-tracing method was used to determine the geomagnetic cutoff rigidity parameters for a set of world grids every 5 degrees in latitude and 15 degrees in longitude.

1. Introduction

The geomagnetic cutoff rigidity is a concept that describes the geomagnetic shielding provided by the earth's magnetic field against the arrival of charged cosmic ray particles from outside the magnetosphere. It is commonly believed that geomagnetic cutoff rigidities are static. This is a misconception. In fact they are rapidly evolving, and, as detailed below, changing in a non-linear and non-uniform manner. The dipole and non-dipole components of the magnetic field are rapidly changing. The non-dipole terms contribute about 18 percent of the total magnetic field. These changes affect the geomagnetic cutoff rigidity and hence the magnitude of the cosmic radiation incident on the atmosphere at a specific location as a function of time. Shea and Smart [7,8] have shown that the geomagnetic cutoff rigidities are rapidly changing in several areas of the world with increases of the order of 1% per year in the North Atlantic Ocean area and decreases $> 0.5\%$ per year in the South Atlantic. Furthermore the changes are non-linear in time. Various analyses have shown that for precise cosmic ray measurements the geomagnetic cutoff rigidities must be calculated using a field model appropriate for the time of the measurement [8,9].

At our current point in geological time the earth's magnetic field is rapidly decreasing. The magnitude of the dipole term alone has changed by 39% over 400 years (from 1600 to 2000). This change is so rapid and non-uniform that the magnetic field Working Group 8 of IAGA Division V provides updates to the International Geomagnetic Reference Field every five years [6]. See [4] for a

pp. 4201–4204

discussion of the temporal changes in the geomagnetic field.

There has been considerable interest in constructing models of the earth's magnetic field in the past [5]. Through various international research efforts, models of the earth's magnetic field extending back centuries [1,2] and even millennia in time [3] have been derived, albeit with decreasing confidence in the model accuracy.

2. Geomagnetic Cutoff Rigidity Calculations

We have calculated a world grid of vertical geomagnetic cutoff rigidities every 50 years in order to establish the long-term changes in the geomagnetic cutoff rigidities. We have utilized the International Geomagnetic Reference Field Models to calculate world grids of vertical geomagnetic cutoff rigidities for epochs 2000, 1950, and 1900. These IGRF magnetic field models are recognized as being the contemporary standard for today's technology. Our objective is to establish the trend over the past four centuries. We have used the Barraclough [1,2] geomagnetic field models (restricted to degree and order 5) for 1850, 1800, 1750, 1700, 1650, and 1600 to establish the initial long-term trend. We adopted this set of magnetic field models into our cosmic ray trajectory-tracing computer program and by the trajectory-tracing method determined the vertical geomagnetic cutoff rigidity parameters for a complete world grid every 5 degrees in latitude and 15 degrees in longitude. An illustration of the geomagnetic cutoff rigidities derived from the use of these models is presented in Figure 1 where we show the cutoff rigidity contours. The contour intervals in each of the panels are in 1 GV intervals. In this figure, IGRF is a generic abbreviation for International Geomagnetic Reference Field. The prefix I designates an interim model; the prefix D signifies a definitive model of the International Geomagnetic Reference Field. We use BGS to designate the models developed by the British Geological Survey [1,2].

An inspection of these results shows patterns consistent with the consensus secular variation of the earth's geomagnetic field. The position of the eccentric dipole from the center of the earth changed at the rate 0.8 km per year from 1650 to 1800 increasing to a rate of 0.9 km per year from 1800 to the present. The north dipole axis position had a steady movement of 0.11 degree per year westward and 0.03 degree southward per year from 1650 to 1850. After 1850 the southward drift became very small.

3. Summary

We have calculated a world grid of vertical geomagnetic cutoff rigidities every 50 years in order to establish the long-term changes in the geomagnetic cutoff rigidities over the past 400 years. It is noted that in 1600 the highest vertical cutoff rigidity values were over South America whereas in 2000 the highest vertical

cutoff rigidity values were close to India. This is consistent with the migration of the north geomagnetic polar axis from over Northern Europe to over North America.

4. Acknowledgements

This research was funded by grant NAG5-10943. The trajectory calculations were made at the Maui High Performance Computer Center.

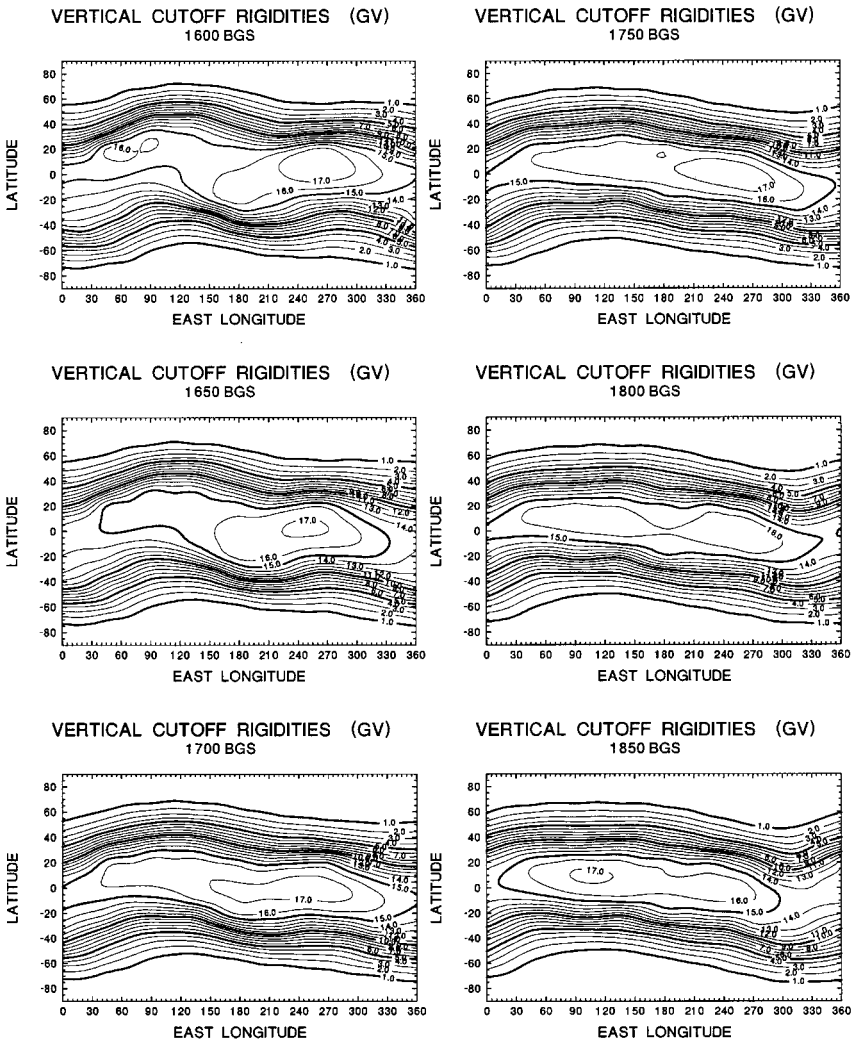

Fig. 1. Geomagnetic cutoff rigidity contours at 50 year intervals.

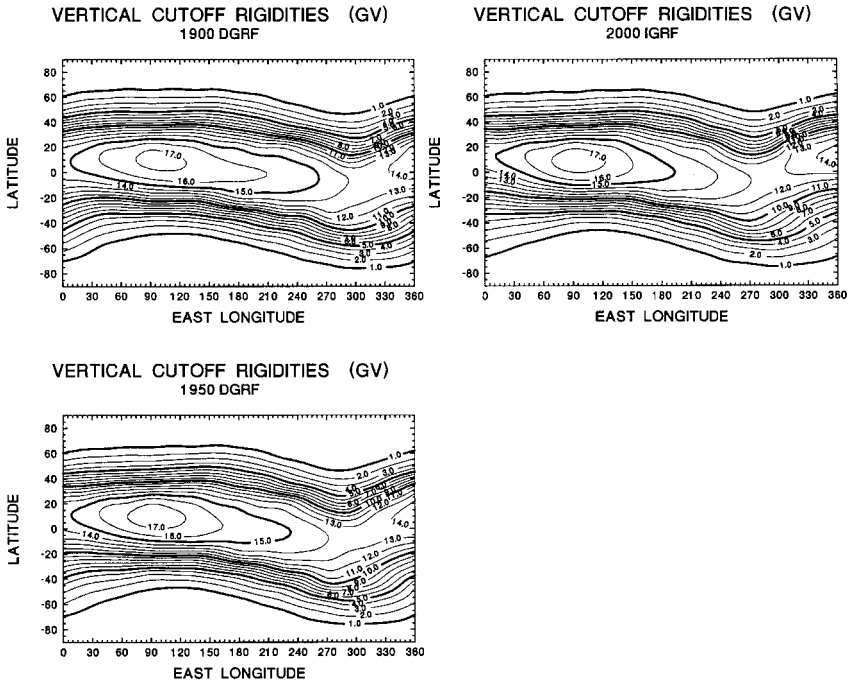

Fig. 1. (continued). Geomagnetic cutoff rigidity contours at 50-year intervals.

5. References

1. Barraclough, D.R., 1974, *Geophys. J., R. Astro. Soc.*, **36**, 497.
2. Barraclough, D.R., 1978, *Spherical Harmonic Models of the Geomagnetic Field*, Geomagnetic Bulletin 8, Her Majesty's Stationery Office.
3. Constable, C.G., et al., 2000, *Phil. Trans, R. Soc.*, Lond, A., **358**, 991.
4. Langel, R.A., et al., 1986, *J. Geomag. Geoelectr.*, **38**, 573.
5. Merrill, R.T., et al., 1997, *The Magnetic Field of the Earth: Paleomagnetism, the Core and the Deep Mantle*, Academic Press, San Diego, CA.
6. Sabaka, T.J., et al., 1997, *J. Geomag. Geoelect.*, **49**, 157.
7. Shea, M.A., Smart, D.F., 1977, 15$^{\text{th}}$ ICRC, **4**, 204.
8. Shea, M.A., Smart, D.F., 1990, *J. Geomag. Geoelectr.*, **42**, 1107.
9. Shea, M.A., Smart, D.F., 1997, 25$^{\text{th}}$ ICRC, **2**, 393.