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Cutoff Variability for the Antarctic Laboratory for Cosmic Rays (LARC: 1955-1995)

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Abstract

Vertical cutoff rigidities were computed for LARC station (Geographic Coordinates: deg. 62.20 S, deg. 301.04 E; altitude 40 m a.s.l.) using the Definitive Geomagnetic Reference Field for 1955 to 1990 and the International Geomagnetic Reference Field for 1995. Long-term rigidity changes were evaluated in five-year increments. We have found a steady decrease in LARC cutoffs over this 40-year period, with clear evidence of the change in the secular variation of the magnetic field that has it's origin inside the Earth (e.g. geomagnetic jerks).

1 Introduction:

The Antarctic Laboratory for Cosmic Rays (acronym: LARC) has been operating with a 6-NM-64 detector on King George Island since January 19, 1991 (Cordaro & Storini, 1992). A preliminary evaluation of the vertical cutoff rigidity for charged particles reaching the LARC location was made for geomagnetic epoches 1980 and 1990 (Storini et al., 1995) using approximate geographic coordinates. Recently the exact coordinates were determined as 62° 12' 09" (62.20) S and 58° 57' 42" (58.96) W. Hence the cutoff rigidity calculations for LARC were repeated. In addition to the cutoff values determined using the International Geomagnetic Reference Field appropriate for Epoch 1995 (IGRF95), we also used the Definitive Geomagnetic Reference Field models to determine vertical cutoff rigidity values every five years from 1955 (DGRF55) through 1990 (DGRF90). In this paper we present the results of these calculations.

2 Charged-particle access at LARC:

As a first step of our investigation, the geomagnetic field Synthesis program (version 3.0) made available by NOAA Web pages, was run for the period 1955.0-2000.0 using one-year increments. Figure 1 shows the strength of the magnetic field and its components at LARC for this interval.

The evolving field at the LARC location is clearly evident. To evaluate its long-term effects on charged particle access at the LARC station, a quiescent geomagnetic field model without the inclusion of external currents on the magnetosphere was used. We started trajectory calculations at the top of the atmosphere (assumed to be 20 km), and, working backward, traced a negative proton out through the field. This corresponds to the trajectory of a positive proton coming from the interplanetary medium through the magnetosphere hitting the atmosphere at 20 km above the station site and then creating a nuclear cascade to the detection location on the earth's surface.

Calculations for particle access from the vertical direction were made for particles having rigidities between 20.00 GV and 0.02 GV. The following rigidity intervals were used: 1 GV intervals between 20.00-10.00 GV; 0.10 GV intervals between 9.30-6.30 GV, 0.05 GV intervals between 6.25 - 5.40 GV and 0.01 GV intervals for the remaining lower rigidities. Figure 2 illustrates the results of these calculations where allowed particle rigidities are shown as dark areas and forbidden particle rigidities are shown by white areas.

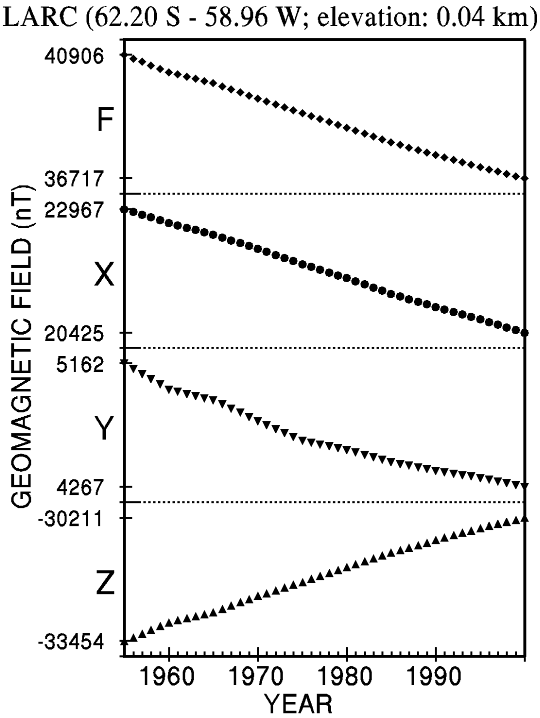

Figure 1: Field intensity (F) and its components (X, Y and Z) evaluated for LARC from 1955 t0 2000.

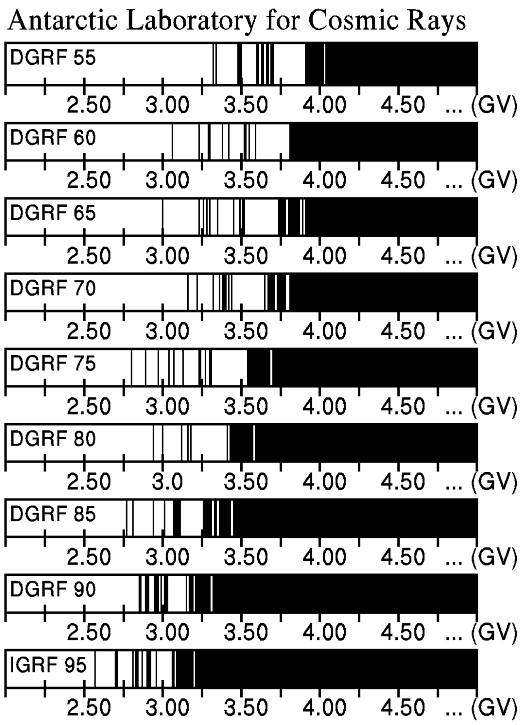

Figure 2: Charged particle access at LARC location. Allowed particle rigidities are reported as dark areas and the forbidden ones by white areas.

As expected from the decreasing geomagnetic components shown in Figure 1, there is a decreasing trend in the LARC cutoffs. The linear fit of the upper rigidity cutoffs (R_U, first allowed/forbidden pair) shown by the solid circles in Figure 3 suggests a steady change in R_U about -0.02 GV per year. An overall similar decrease is evident in the effective cutoff rigidity (R_C, solid squares in Figure 3). However, in this case the slope is not uniform throughout the 40-year period. While R_U decreases nearly steadily from 1965 to 1995, the R_C values oscillate somewhat around the decreasing trend. This oscillation is much more prominent in the values of R_L, the lower cutoff rigidity, shown as solid triangles in Figure 3.

The cosmic ray penumbra, defined as the region between the first allowed/ forbidden pair of trajectories (in rigidity space) and the last allowed/forbidden pair, is generally chaotic in

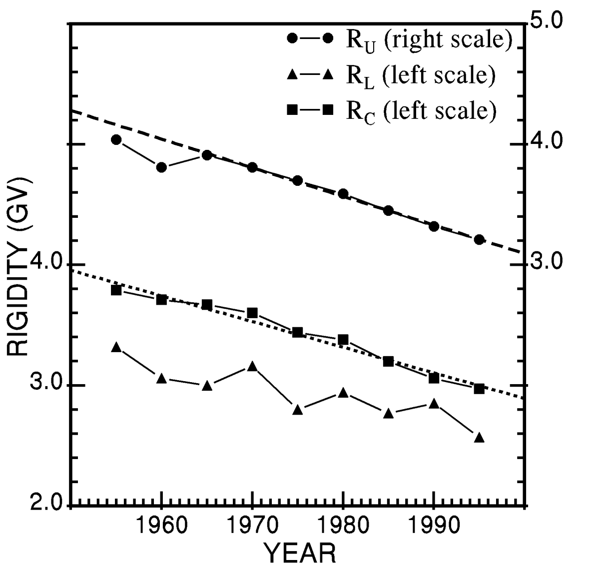

Figure 3: Time variability of R_U (upper), R_L (lower) and R_C (effective) cutoff rigidities at LARC location.

nature. Moreover, most of the allowed particles in the penumbra region are associated with trajectories that traverse large longitudinal ranges in transit between outer space and their arrival at a specific location at the top of the atmosphere. While we note apparent discontinuities in the R_L values at 10-year intervals (i.e. 1970, 1980, 1990), these discontinuities may be a consequence of geomagnetic effects and/or the sampling procedure through the cosmic ray penumbral region.

3 Are geomagnetic jerks affecting cutoff rigidity values?:

The study of the long-term variability of the geomagnetic field has revealed the existence of rapid changes or "jerks" in the slope of the curve of the annual secular variation (e.g. Sabaka et al., 1997 and references therein). These "jerks" behave as step-functions in the rate of secular change. Previous studies indicate the occurrence of three world-wide jerks during the second half of the 20th century: in 1969, 1978, and 1991. However, it is noted that the intensity of the "jerks" is not only different with respect to the components of the magnetic field at any specific location, but also the occurrence may not be concurrent throughout the world. Geomagnetic data from many locations must be evaluated to determine if the observed changes are local or part of a world wide perturbation in the earth's magnetic field.

Recently, De Michelis, Cafarella & Meloni (1998) analysed the "jerks" in 1969, 1978 and 1991, and derived the time interval in which each jerk should have occurred. Figure 4 shows the annual Y-component for the geomagnetic field at the LARC location and the difference for successive years where Y' = (Y_i-Y_{i-1}) for i = 1960 to 2000. The horizontal lines in the lower part of this figure show the time period of each world wide "jerk". The dotted lines illustrate the changes in the Y component at the LARC location coinciding with the world wide magnetic "jerks". However, the Y' trend presents other changes, even more prominent than those associated with the world wide geomagnetic "jerks". These would be local variations related perhaps with the South-American geomagnetic anomalies and should only affect cosmic ray trajectories during their final path to their arrival at the top of the atmosphere above the station location.

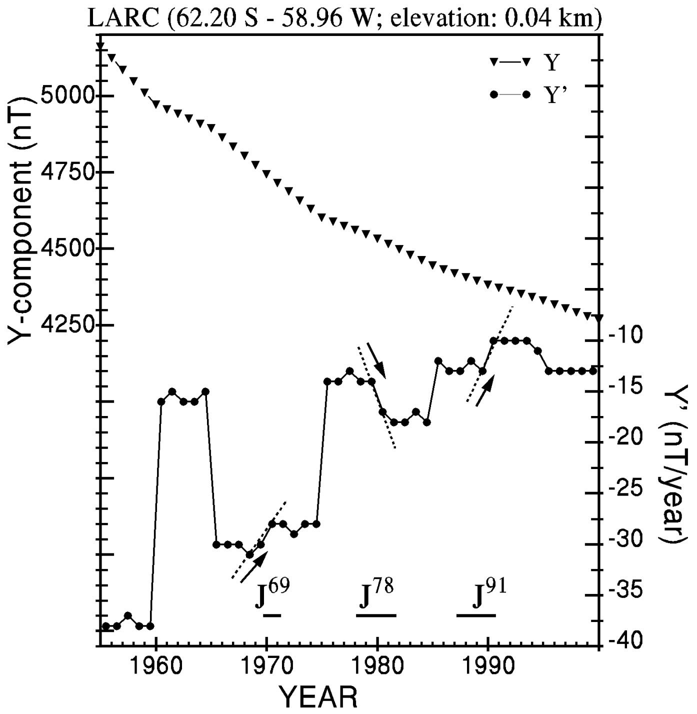

Figure 4: Long-term variation of the Y component of the geomagnetic filed and its derivative (Y') at LARC location. The time occurrence of 1969, 1978 and 1991 world-wide geomagnetic jerks (**J**^{69}, **J**^{78}, **J**^{91}) is shown (see the text for details). Arrows indicate the corresponding Y' changes at LARC location.

It is possible that the world wide geomagnetic "jerks" might explain some of the variability in the cosmic ray penumbral structure over a long period of time.

This must be confirmed by yearly rigidity studies for several geographic locations. If these world wide geomagnetic discontinuities appreciably affect the trajectories of cosmic ray particles, it would primarily be for those lower rigidity particles that encircle the Earth with very long complicated paths. This effect would not be evident for near-equatorial locations where the penumbra is extremely small or, in most cases, does not exist.

4 Conclusion and remarks:

The study of the cutoff rigidities at the LARC location (South Shetlands – King George Island – Fildes Bay – Ardley Cove; Storini & Cordaro, 1997; Storini et al., 1998) over a period of 40 years has been initiated, and while the overall lowering of the vertical cutoff rigidity coincides with a decrease in the geomagnetic field components at the same location, deviations from a smooth decrease have been identified. These deviations tend to coincide within the time intervals of the world wide geomagnetic jerks which is believed to arise from short-term (when compared with secular changes) internal variations of the Earth's core. Additional studies are necessary to ascertain if (1) the changes in cutoff rigidity values can be isolated to time periods smaller than five year intervals, and (2) if similar cutoff rigidity changes are present at comparable geomagnetic locations around the world.

5 Acknowledgements:

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