Time variation of the vertical magnetic cutoff rigidities over the South Atlantic Magnetic Anomaly

Everton Frigo[(*1)], Igor I. G. Pacca[(1)], Gelvam A. Hartmann[(1)]

[(1)] Departamento de Geofísica, IAG/USP, Brazil

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Abstract

The South Atlantic Magnetic Anomaly (SAMA) is one of the most interesting features of the Earth's magnetic field. Its region is characterized by extremely low magnetic field intensity but with a strong presence of non-dipolar components. The SAMA also coincides with the region of highest charged particle cosmic ray flux however this phenomenon is not satisfactorily explained by the existing vertical magnetic cutoff models. The IGRF (International Geomagnetic Reference Field) has been used to investigate possible causes for this discrepancy. Our results indicate that the disagreement between models predictions and experimental data may be connected with local field factors such as the horizontal field component and the presence of non-dipolar components.

Introduction

The Earth's magnetic Field is a natural protection barrier against the incidence of cosmic ray charged particles that may give rise to several physical and chemical effects as they penetrate the Earth's atmosphere.

The lowest energy an incident particle should have to be able to penetrate the geomagnetic field is called the magnetic cutoff rigidity, that is usually represented in terms of the vertical magnetic rigidity cutoff (P_c). These P_c values will depend on the geomagnetic time and space variations. There are several models such as those by Shea et al., 1987 and Bhattacharyya and Mitra, 1997 that describe how P_c varies with geographical coordinates and time. However these models do not agree with charged particle flux data obtained with satellites, especially over the SAMA region.

In this paper we present an analysis of the geomagnetic field and the vertical cutoff rigidity time variations for the SAMA region.

The SAMA time evolution

The SAMA region is characterized by the lowest magnetic field intensity on the Earth's surface as shown on Figure 1. In the period between 1600 and 2005 the lowest geomagnetic field region drifted from Africa to South America, according to the analysis by Hartmann (2005), using the models of Barraclough (1974) and the IGRF.

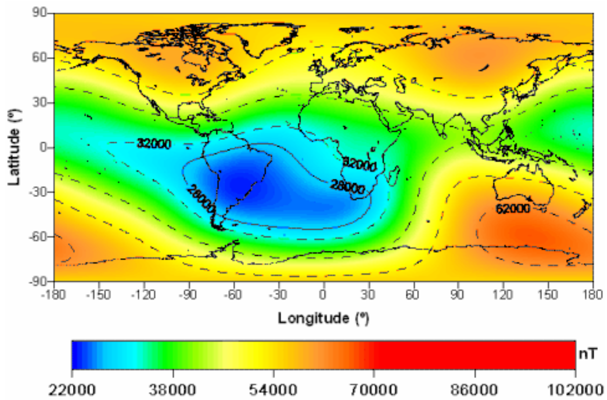

Figure 1: Total intensity of geomagnetic field obtained from IGRF 2005 [Hartmann, 2005].

Furthermore the geomagnetic Field in the SAMA region is characterized by a strong presence of non-dipolar components as shown on Figure 2.

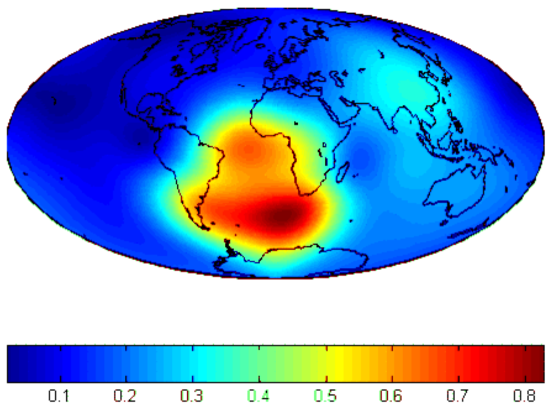

Figure 2: Non dipolar to dipolar field ratios obtained from IGRF 2005 [Hartmann, 2005].

These non dipolar components show a westward drift that is similar to that of the SAMA intensity. It is interesting to notice the differences between the SAMA shape as defined by total intensity (Figure 1) and by the percentage of non-dipolar components (Figure 2).

On the other hand, the SAMA region coincides with that of charged particles maximum flux, as shown on Figure 3, drawn after NASA model AE-8, that includes electron flux data obtained by 20 satellites from the early sixties to the mid-seventies.

The SAMA time evolution as defined by charged particle flux between 1960 and 2003 has been studied by Grigorian et al. 2008 using space research data. Results indicate characteristics that are similar to those shown by Hartmann (2005).

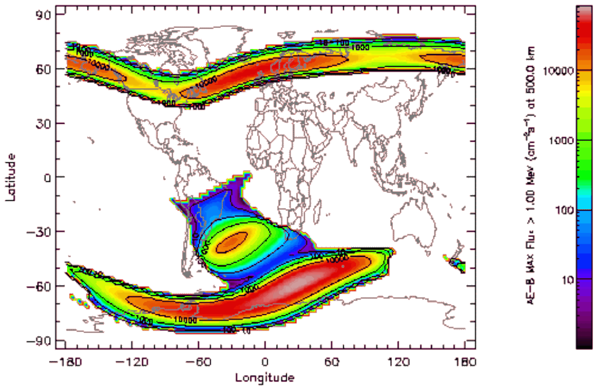

Figure 3: World map of the AE-8 MAX integral electron flux > 1 MeV at 500 km altitude. [Heynderickx, 2002].

Low particle flux regions must coincide with those with high P_c values whereas high particle flux must coincide with low P_c regions like those of the geomagnetic poles and the SAMA.

Vertical magnetic rigidity cutoff models

The classical equation for calculating P_c is that of Störmer approximation:

$$P_c \approx 1.9M\cos^4\lambda_G \qquad (1)$$

Where P_c is expressed in GV, *M* is the geomagnetic dipole moment and λ_G is the local geomagnetic latitude defined in terms of geographic coordinates (λ, ϕ) and geomagnetic pole coordinates (λ_P, ϕ_P)

$$\lambda_G = \arcsin(\sin\lambda_P \sin\lambda + \cos\lambda_P \cos\lambda\cos(\phi_P - \phi)) \qquad (2)$$

Later on other methods were proposed to compute P_c like that of Shea et al. (1965), that uses a computational code for tracing the trajectories of individual particles in the geomagnetic field according to the IGRF model with coefficients up to degree 10. Results of this model for 1985 are shown on Figure 4 but one disadvantage was the long time that was required for computation.

Bhattacharyya and Mitra (1997) proposed a model that is based on an eccentric dipole approximation and they calculated P_c variations due to the geomagnetic secular variation since 1835. Results with their model are very similar to those obtained by Shea et al. (1965) but with a much faster method.

P_c models are extremely important for calculating ionization induced by cosmic radiation in a certain region of the atmosphere. This ionization is directly dependent on the cosmic ray flux and the P_c values, as shown by the results of Usoskin et al. (2004). These ionization processes are very relevant to investigations of a possible connection between cosmic ray flux and climate variations (Usoskin and Kovaltsov, 2008).

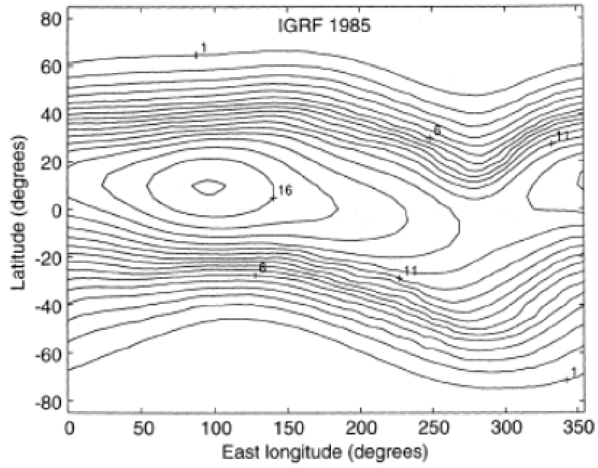

Figure 4: Isorigidity contours of vertical cosmic ray cutoff rigidities (in GV), at an altitude of 100 km, computed by Shea et al., 1987 [Bhattacharyya and Mitra, 1997].

Data and Analysis

IGRF data at Earth's surface for total intensity, horizontal and vertical components of the geomagnetic field covering the time interval between 1905 and 2005 have been used. With dipolar magnetic field classical equations, dipole moments corresponding to the main field, horizontal or vertical components were calculated for a certain latitude. Non dipolar to dipolar field ratios (*r*) as shown on Figure 2 for 2005 were calculated for the 1905 to 2005 interval so that the fraction of dipolar field was *f=1-r*. All these parameters were then used for obtaining the time variation of P_c with equation 1.

Results

Figures 5 and 6 show the geomagnetic field time variation for two geographical positions, the first at (23S,46W) corresponds to a minimum field intensity in 2005, located in the SAMA region and the second at (38S,30W) corresponds to a maximum electron flux according to Figure 3.

Figures 5 and 6 show differences between local geomagnetic behavior under the influence of SAMA. Figure 5 shows a constant decrease in *FI* and *HI* intensity and a constant increase of *ZI*. The *HI* decrease becomes stronger around 1940 as a consequence of the SAMA approximation.

On the other hand, Figure 6 does not show this sudden change in *HI* variation rate because since 1905 when observation started, SAMA was already having a strong influence on that region. The figure also shows that the local field *FI* is higher at (38S,30W) than at (23S,46W) although here the horizontal component *HI* is higher.

Field intensities at figures 5 and 6 were used for calculating dipole moments and the corresponding P_c values through equation (1).

Since P_c is related to vertically incident particles, it can be assumed that the horizontal geomagnetic component is the most important or even the only one that is important. Therefore we calculated *Pc* values associated to the global dipole moment and also related to the field horizontal component.

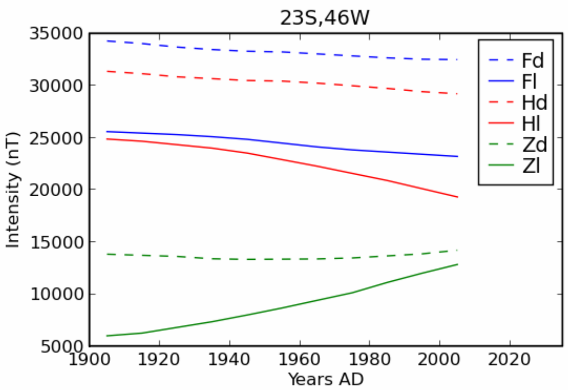

Figure 5: Geomagnetic field intensity for location (23S,46W) where *Fd*, *Hd* and *Zd* are the total field, horizontal component and vertical component generated by an exclusively dipolar field IGRF. *Fl*, *Hl* and *Zl* are total field, horizontal and vertical components generated by IGRF considering a multipolar field.

Pc values that were calculated for (23S,46W) are shown on Figure 7 while Pc values for (38S,30W) are presented on Figure 8.

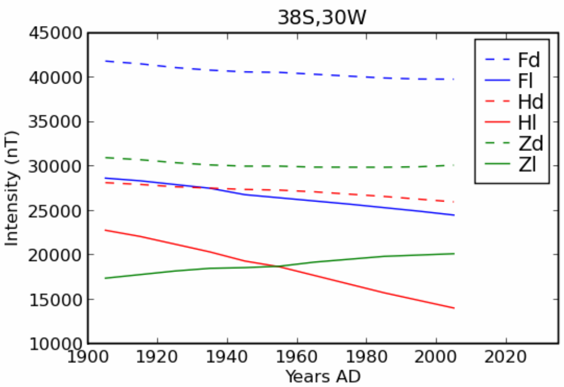

Figure 6: Geomagnetic field intensity for location (38S,30W). Symbols are the same as in Figure 4.

Comparing Pc values obtained with Md and Mdf for at (23S,46W), Figure 7, with those at Figure 4 we see that the value associated to *Mdf* (~7.5 GV) is the one that is closest to that calculated by Shea et al. (1965), of approximately 10 GV. However, these rigidity values are too high for this place (see Figure 3). However *Mhl* and *Mhlf Pc* values are much lower, especially for *Mhlf* (about 5 GV), what may indicate that a more realistic value would depend on *Hl* and *f*.

When we compare *Pc* values obtained for locality (38S,30W), Figure 8, with those at Figure 4 (approximately 6 GV) we see that values associate to *Md* are much higher than those of Shea et al. (1965), while the value associated to *Mdf* is lower. In this case highest agreement is with that associated to *Mhl*. However, taking into consideration again that this locality is close to the SAMA region with highest particle flux, *Pc* values should be lower, similar to those that are expected for the geomagnetic poles. Once more the best correspondence between calculated *Pc* values and the observed particle flux was found for *Mhlf*, similarly to what had been found for the other locality (23S,46W).

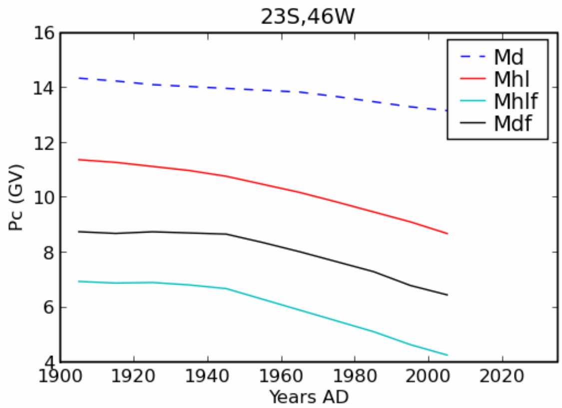

Figure 7: Vertical cutoff magnetic rigidity for location (23S,46W) as a function of different parameters, where: *Md* corresponds to the global dipole moment; *Mhl* is associated to dipole moment relationship to local horizontal field; *Mhlf* is the product of *Mhl* and *f*; *Mdf* is the product of *Md* and *f*.

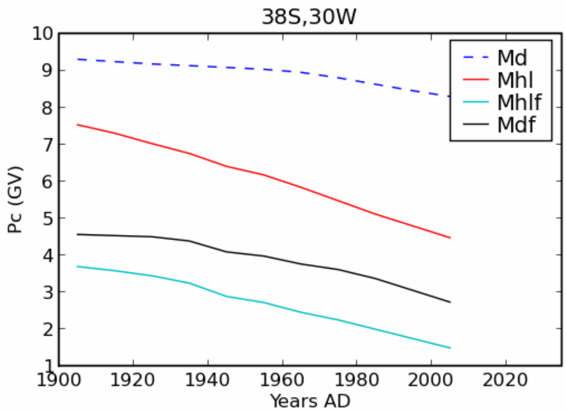

Figure 8: Vertical cutoff magnetic rigidity for location (38S,30W) as a function of different parameters. The symbols are the same as on Figure 7.

Conclusions

Existing models for the calculation of vertical cutoff magnetic rigidity for the incidence of cosmic rays are not satisfactory for regions like that of the South Atlantic Magnetic Anomaly with a high presence of non dipolar components in the geomagnetic field.

Corrections that take into account the peculiarities of the geomagnetic field in these regions are proposed to obtain agreement with experimental data.

The data is intended to be used to investigate ionization caused by cosmic rays in the atmosphere and its relation with climate factors.

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