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LONG-TERM TRENDS IN COSMIC RAYS AND GEOMAGNETIC FIELD SECULAR VARIATIONS

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Abstract. Cosmic rays are modulated by solar and geomagnetic activity. In addition, the flux that arrives to the Earth is sensitive to the inner geomagnetic field through its effect on the geomagnetic cutoff rigidity, Rc. This field has been decaying globally at a rate of ~5% per century from at least 1840. However, due to its configuration and non-uniform trend around the globe, its secular variation during the last decades has induced negative and positive Rc trends depending on location. In the present work, the database from the World Data Center for Cosmic Rays (WDCCR) is used to analyze long-term trend variations linked to geomagnetic secular variations. This database includes more than 100 stations covering, some of them, almost seven decades since the 1950's. Those stations spanning more than 20 years of data are selected for the present study in order to adequately filter solar activity effects.

Introduction. The Earth's magnetic field of internal origin has been decaying at a rate of ~5% per century, at least since the 1840's, with evidences suggesting that this decay began much earlier. This behavior led us to think of an undergoing reversal or excursion, even though the possibility of a recovery without the occurrence of these extreme events is feasible as well (*Panovska et al.*, 2019; *Brown et al.*, 2018). Nevertheless, the intensity of the global field will most likely continue to decrease in the near future with consequent changes in our planet's magnetic shield (*Tarduno*, 2018).

The cutoff rigidity (Rc) can be thought of as a quantitative measure of this shielding since it corresponds to the minimum energy needed by a charged particle coming from outer space to reach a given location at the Earth. This parameter can be obtained calculating charged particle trajectories in the Earth's magnetic field, which requires numerical solutions of differential equations due to the field complexity. There are also analytical approximations considering that 80% of the field can be described by a pure dipolar component using Störmer theory (*Störmer*, 1955).

Considering Rc tabulated values by *Gvozdevskii et al.* (2016), obtained from trajectory calculations based on the equation of motion of charged particles in the geomagnetic field given by the IGRF (*Thebault et al.*, 2015), *Comedi et al.* (2020) obtained the secular variation spatial pattern of Rc for the period 1900-2020 in a 5°×15° latitude-longitude grid by estimating the linear trend α at each grid point from

$$Rc = \alpha\, t + \beta \qquad (1)$$

where t is time, and regression coefficients α and β are estimated with least squares. Negative, as well as positive Rc trends are obtained according to location.

A decrease in Rc would imply that particles with energies that before were not enough to enter the atmosphere, now they do. This could suggest a flux increase, like for example in cosmic rays' case. With this assumption, cosmic ray time series are analyzed in order to detect long term trends and its possible association with the geomagnetic field secular variation effects on Rc.

Data and methodology. Cosmic ray flux (CR) from the World Data Center for Cosmic Rays (WDCCR, http://cidas.isee.nagoya-u.ac.jp/WDCCR/) database is used, which includes more than 120 stations covering, some of them, almost seven decades since the 1950's. 74 stations were selected according to their time span (2 to 3 solar cycles minimum, ~20 to 30-year), data completeness and homogeneity. These CR time series were checked for outliers, and even though their number in percentage was low they were eliminated.

CR is modulated by solar activity level being weaker for low levels and vice versa. Using the sunspot number, Rz, as a solar activity proxy, the linear correlation coefficient between CR and Rz results higher than -0.8 in almost all the cases. This means that most of CR variance is explained by solar activity, which turns necessary filtering its effect before estimating the trends we are looking for. We do this by estimating the residuals from the linear regression between the 12-month running means of CR and Rz, through

$$CR_{residual} = CR - (a\,Rz + b) \quad (2)$$

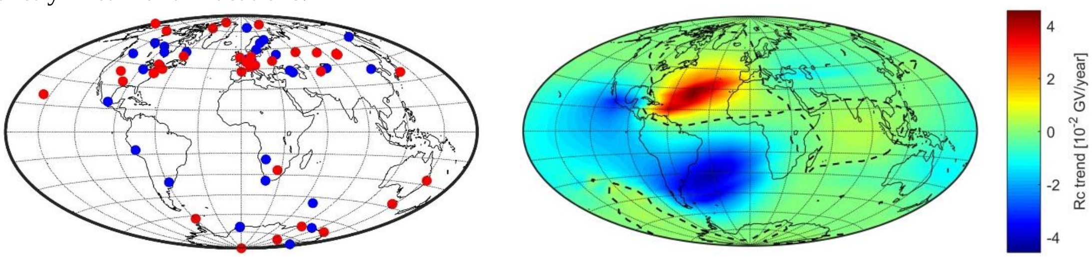
where a and b are the least square coefficients of CR vs. Rz.

Finally, the linear trend α' of these residuals was assessed through the linear regression

$$CR_{residual} = \alpha'\,t + \beta' \quad (3)$$

where regression coefficients α' and β' are estimated with least squares as in the case of Rc in Equation (1).

Results. As a preliminary result we present the α' sign (positive or negative) in Figure 1 of all stations analyzed without discriminating the period over which each trend value is estimated. It should be noted that the period covered by each station included in this analysis is different and in many cases there is not even overlap. In addition, although we performed a linear estimate for the whole period 1900-2020 in the case of α (shown also in Figure 1) it is not strictly linear for all locations.



(a) (b)

Figure 1. (a) Cosmic ray trends according to their sign: negative (red) and positive (blue) for 74 stations from the World Data Center for Cosmic Rays (WDCCR) database (http://cidas.isee.nagoya-u.ac.jp/WDCCR/). (b) Rc trends obtained from trajectory based estimations from *Gvozdevskii et al.* (2016) (black dashed line indicates α=0) (figure from *Comedi et al.*, 2020).

Discussion. The expected result for α' is: positive values (blue dots in Figure 1a) in regions where α is negative (green-blue areas in Figure 1b), and negative values (red dots in Figure 1a) in regions where α is positive (yellow-red areas in Figure 1b). There seems to be limited global agreement between CR and Rc long-term trends. However, there is a hint of consistency around the strong positive and negative patches in the western hemisphere, which may be due to the actual rotation and displacement of the Earth's dipole axis with a stronger effect due to rotation (*Comedi et al.*, 2020).

Several reasons could be mentioned to explain our results, and the main are regarding our methodology, which will be considered in a future work: trends are not entirely linear and trend periods are not homogeneous in the first place, and secondly bad filtering of solar activity effect, taking into account that estimating the residuals from a linear regression with Rz for the whole period may not be enough. The effect of additional trend sources may be thought of as well.

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