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Inferred secular variation of the heliospheric magnetic field

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There is a considerable interest in the long-term influence of solar activity on terrestrial climate. Earlier work, by using correlation between geomagnetic aa index and galactic cosmic ray counts, inferred that the radial component of the interplanetary magnetic field at 1 A.U. increases secularly. However, our results show that there is no correlation between the geomagnetic aa index and galactic cosmic ray counts for time periods 1964-1986, 1986-1996 and 1997-2010. Averaging has to be very carefully dealt with when examining the aa index and other parameters that depend upon the sign of interplanetary magnetic field as averaged values and the most probable values may not be the same. Low values of the correlation coefficients between cosmic ray counts and the CME rate for time period 1996-2009 also has been obtained. This low values of the correlation coefficients is due to high frequency of CMEs

Keywords: Galactic cosmic ray, Coronal mass ejection, Interplanetary magnetic field

1 Introduction

The solar coronal magnetic field is inferred to have increased by approximately a factor of 2 during this century by Lockwood *et al*. and Stamper *et al*.[1,2]. However, Richardson *et al*.[3] and Laptukhov *et al*.[4] found that the solar coronal magnetic field increased by not more than 10% during the last century.

Richardson[3] argues that the increase in the interplanetary magnetic field (IMF) and galactic cosmic rays (GCR) intensity in 1964-1996 do not indicate true long-term trends because the trends are sensitive to the end points of the relatively short period of data fitted. According to Laptukhov[4], it is difficult to compare geomagnetic activity indices like the aa index[5] with solar wind parameters and IMF vector components. According to authors, aa index is frequently used as a representative of geomagnetic activity as compared to other indices due to the length of database (from 1868). But the aa index is an inhomogeneous series because many aa values existing in the interval $0<aa<aa_{max}$ are never observed. Laptukhov[4] also suggested a new method of performing statistical analysis regarding the relation between the aa index and the interplanetary solar wind parameters by transforming the integral values of the aa index to another integer index LA, using the formula:

$$LA = [1+4\ln((aa+4)/6] \quad \ldots(1)$$

where square bracket means that the integer part of a number within these brackets is taken. Thus, it is possible to pass to a more consistent series of numbers (with respect to continuity) than the series of the real aa index. Hence, one of the aims of present study is to explore the relation between galactic cosmic rays and LA numbers.

Laptukhov[4] also stressed the importance of the time scale used for averaging the analyzed values while searching for correlation between geomagnetic indices and other solar wind parameters because the sign of the IMF strongly affects geomagnetic activity. Thus, our study also aims to find relation between the geomagnetic aa index, LA numbers and galactic cosmic rays at different time resolutions[5].

Our study of the relation between geomagnetic activity and galactic cosmic ray intensity is expected to provide us with information of the heliosphere near Earth condition. To make our study complete, we also need to study the correlation between galactic cosmic rays and (CME) coronal mass ejection rate. The potential role of CMEs in perturbing galactic cosmic rays is well known[6,7]. CMEs are large scale phenomena that change the configuration of the IMF and clearly modulate the cosmic rays intensity on shorter time scales. Thus, it is natural to think that CMEs may also contribute to longer term modulation, by forming global merged interaction regions (GMIRs) which are a major contributor for long term modulation[8-10].

Lara *et al* .[10] found high anti-correlation (~ 0.88) between the GCR intensity and the CME rate. However, when the CME rate is divided into low and high latitude regimes and then compared to the GCR

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intensity during the ascending phase of solar cycle 23, a lower anti-correlation between the low latitude CME rate and the GCR intensity is found (~ 0.71). A very high anticorrelation between the CME rate and the GCR intensity (~ 0.94) is also found at high latitude. Thus, in general, CMEs can cause significant decrease in the GCR flux in the inner heliosphere.

2 The Data

We first consider the report by Laptukhov [4] that the analysis of the relationship of the geomagnetic activity using hourly data differs significantly from an analysis performed using daily average or annual observations. This is because the IMF parameters change sign on time intervals shorter than a year. Laptukhov[4] also argued that to perform a statistical analysis between aa index and other parameters, this index must be transformed to logarithmic aa numbers using the formula (1) to get a more homogeneous series. These numbers change from 1 to 20 with a change in aa numbers from the minimum $aa_{min} = 2$ to the maximum $aa_{max} = 715$. This homogeneity is an advantage of LA numbers over aa numbers.

The geomagnetic aa index[5] from 1965 to 2010 for the present study is obtained from UK Solar System Data centre at three data frequencies, hourly, daily and annual averages. We divide our study in three groups of time period namely 1965-1986, 1986-1996 and 1997-2010. This time periods are chosen as they coincide with time period of solar cycle.

This aa index is transformed to LA numbers using formula (1).

Galactic cosmic ray counts for the similar time period and with similar time resolution are obtained from the Moscow neutron monitor. The neutron monitor with a geomagnetic cut off rigidity of 2.43GV is situated 20 km south-west from Moscow in the Troitsk town at 200m elevation above sea level.

Long term studies of CMEs are now possible due to sufficient data in the CME catalogue[11]. The acceleration, speed, angular width, and angular position of each CME as observed by SOHO LASCO since 1996 are available in the CME catalogue. Using this catalogue, we obtained the CME rate of each month for the years 1996-2008.

3 Results and Discussion

Our study is divided into three groups of time intervals from 1964-1986, 1986-1996 and 1997-2010. The first time interval from 1964-1986 is of 23 years and is chosen to match the length of a solar cycle; usually ~ 22 years. Other two time intervals namely from 1986-1996 and 1997-2010 are of the order of 11 years each and is chosen to coincide with periodicity of the 11 year sunspot cycle.

Figure 1 shows the 3-hourly geomagnetic aa index and the 3-hourly galactic cosmic ray counts from 1964 to 1986. It is clear from the figure that there is no correlation between the aa index and the cosmic ray counts. Fig. 2 shows the LA numbers as a function of the galactic cosmic ray counts for the same time period and similar time resolution. Poor correlation between the two parameters is again found. A noteworthy feature here is that the transformation of the aa index to the LA numbers brings homogeneity in data in agreement with Laptukhov[4] but this homogeneity did not change the results regarding correlation between two parameters.

Table 1 shows anti-correlation coefficient of the geomagnetic aa index and the LA numbers with the

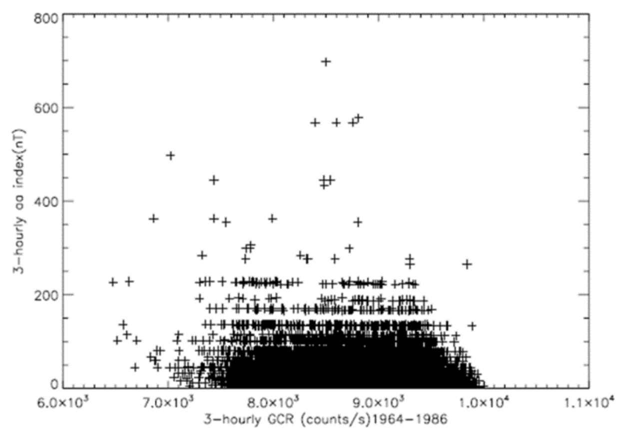

Fig. 1 — Scatter plot of the 3-hourly geomagnetic aa index as a function of galactic cosmic ray counts obtained from the Moscow neutron monitor for the time period 1964-1986.

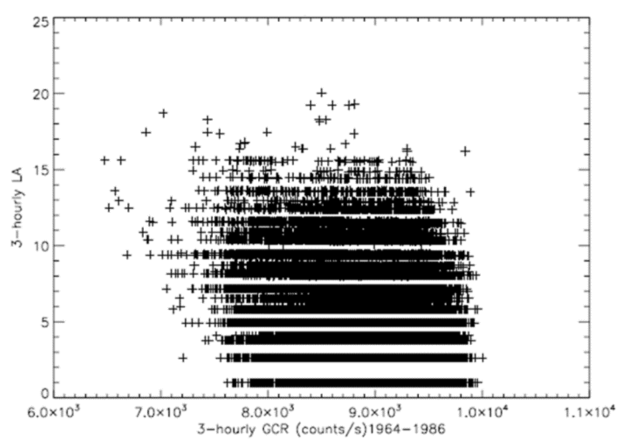

Fig. 2 — Scatter plot of the 3-hourly LA numbers and the galactic cosmic ray counts obtained from the Moscow neutron monitor for the time period 1964-1986.

Table 1 — Comparison of the anti-correlation of the geomagnetic aa index and the LA logarithmic aa numbers with galactic cosmic ray counts at different time scales for different time periods 1964-1986, 1986-1996 and 1997-2010.

Cross-correlation coefficient of Galactic Cosmic rays (GCR) with geomagnetic aa index and LA numbers for different time periods

Data Interval►	1964-1986		1986-1996		1997-2010	
Data frequency▼	aa	LA	aa	LA	aa	LA
Hourly	0.15	0.17	0.22	0.22	0.25	0.28
Daily	0.18	0.20	0.29	0.28	0.39	0.45
Annual average	0.52	0.52	0.80	0.80	0.84	0.89

galactic cosmic ray counts at different time scales for different time periods 1964-1986, 1986-1996 and 1997-2010. The annual average of the geomagnetic aa index and the cosmic ray counts suggests high anti-correlation between the two but may be misleading because of the fact that sign of IMF strongly affects geomagnetic activity. With increasing time resolution, the cross correlation coefficient between the geomagnetic aa- index and the cosmic ray counts decreases as derived from daily and hourly measurements of the geomagnetic aa- index and the cosmic ray counts. Similar trends are seen in LA numbers. Thus, we see that there is absence of any correlation between GCR counts and the aa index or LA numbers. The reason for this can be attributed to the fact that aa-index or LA numbers are both affected by the sign of the IMF but GCR counts are affected by only magnitude of IMF in observed time scales. So, we cannot expect any correlation between the aa-index/LA numbers and the GCR counts. This is confirmed by low anti-correlation values obtained with hourly and daily data. Hence, little significance can be given to the strong correlation seen in annual averaged data.

Thus, averaging has to be very carefully dealt with and the number of measurements should be large for high degree of accuracy. This shows that each measurement of the aa index and the interplanetary parameters play a crucial role in finding possible correlation between the parameters. Use of annual averaged data may lead to incorrect inferences.

Figure 3 shows correlation values between GCR counts and the CME rate for different years ranging from 1996 to 2009. Low values of the correlation coefficients between cosmic ray counts and the CME rate is quite surprising and in contrast to the results

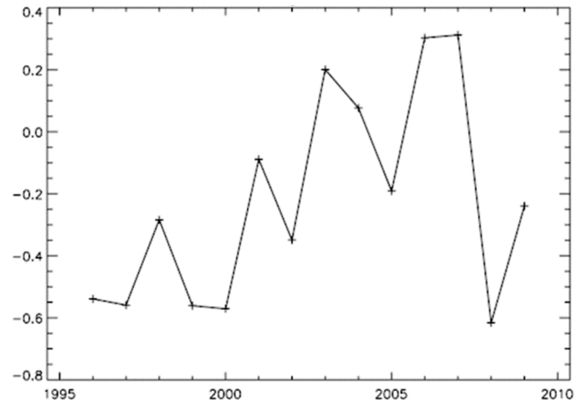

Fig. 3 — The correlation coefficient when comparing coronal mass ejection rate and the galactic cosmic ray counts for the time period 1996-2009.

presented by Lara[10] who found high correlation between the two parameters. We note that this type of low correlation is manifested by the high frequency of CMEs in 2007 in spite of very low sunspot numbers. It appears that high numbers of CMEs do not disturb the cosmic rays which lead to a normal behaviour of cosmic ray counts in the same time period. Since the CMEs of the solar minimum period are mostly from the eruptions of quiescent filaments, which result in slow CMEs[12], these slow CMEs are unlikely to produce significant perturbations of the solar wind parameters. This conjecture can be tested using data of the CME velocities and will be the topic of a further research.

4 Conclusions

Low values of the correlation coefficient between the hourly geomagnetic aa index and GCR count lead us to conclude that there is no significant correlation between the aa index and GCR counts. This is also supported by the fact that the sign of the interplanetary magnetic fields over short time intervals, affects the geomagnetic aa index but galactic cosmic ray counts do not depend on sign of interplanetary magnetic field at observed time scale. Previous results of the secular increases in the IMF were based on analysis with annually averaged data and hence needs to be re-investigated. It is required to analyse those parameters again with the finest available time resolution i.e. hourly data as we have shown that averaging can lead to incorrect results. The high frequency of CMEs in spite of low solar activity in 2007 resulted in a low value of the correlation coefficient between GCRs and the CME rate. It will be interesting to investigate which type of CME affects GCR and which does not.

Acknowledgement

Geomagnetic aa index was taken from http://www.ukssdc.ac.uk and galactic comic ray counts were taken from http://helios.izmiran.troitsk.ru/cosray/main.htm. CME data are available in the SOHO LASCO CME catalogue.

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