Cosmic ray intensity variation upto recent solar cycle 23

S. K. SHRIVASTAVA [1], RAJESH K. MISHRA [2], REKHA AGARWAL MISHRA [1]
[1] *Department of Physics, Govt. Model Science College (Autonomous), Jabalpur (M.P.) 482 001, India*
[2] *Computer and IT Section, Tropical Forest Research Institute, P.O.: RFRC, Mandla Road, Jabalpur (M.P.) 482 021, India*
contact. rm_jbp@yahoo.co.in

Abstract: Systematic correlative studies have been performed since long to establish a significant relationship between cosmic ray intensity and different solar/heliospheric activity parameters and study is extended to recent solar cycle 23. In the present work yearly average of sunspot number (Rz), interplanetary magnetic field (B) have been used to correlate with yearly average cosmic ray intensity derived from the data of Moscow neutron monitor. It is noticed that for four different solar cycles 20-23 the cosmic ray intensity is found to anti-correlated with sunspot numbers (Rz) and interplanetary magnetic field (B) with some discrepancy. However, the interplanetary magnetic field B shows a good positive correlation with Rz for four different solar cycles. The IMF, B shows a weak negative correlation (-.35) with cosmic rays for the solar cycle 20, whereas show a good anti-correlation for the solar cycles 21-23 (-0.76, -.69).

Introduction

Cosmic rays are energetic particles that are found in space and filter through our atmosphere. Ground based neutron monitors at several locations on the Earth for the last several decades are regularly monitoring cosmic rays. Observations so far indicate a clear solar cycle effect, with largest reductions in cosmic ray neutron monitor intensity during sunspot maximum years, a good anti-correlation for long-term variation [1-2 and references therein]. The structure of the recovery in the 11-year cycle of cosmic ray in relation to the state of interplanetary magnetic field have been studied in detail by Jokipii and Thomas [3] and further by Ahluwalia [4].

Galactic cosmic ray intensity data have been analyzed by Stozhkov et al. [5] and by Ahluwalia [4] for 4 consecutive solar activity minima for the period 1963 to 1998. Data obtained with a variety of detectors located at the global sites as well as the balloon altitudes are used in both the studies. A systematic decrease is observed in all data sets, near solar minimum epochs for the period 1965 to 1987. The observed decrease is ascribed to a supernova explosion in the near interstellar medium by Stozhkov et al. [5]. This is disputed by Ahluwalia's study [4]. He ascribed it to the long-term modulation of galactic cosmic ray flux within the heliosphere by the solar wind.

The intensity of galactic cosmic rays measured on Earth is related to the Sun's cycle of activity, which is well known. The solar magnetic field flips every 11 years and the number of sunspots and 'coronal mass ejections' rises and falls twice in each complete 22-year cycle. The cosmic ray intensity on Earth also peaks twice every 22 years in time with the solar cycle. Cliver and Ling [6] have discovered a quirk in this pattern - and they believe that coronal mass ejections could be to blame.

The intensity of cosmic rays varies at different time scales, from minutes to decades and even beyond. These variations can be studied using data from ground based neutron monitors. Berezhko et al. [7] found a significant solar cycle variation in the cosmic ray fluctuation magnitude for 1980-1990 using 5-min. data from the Tixie Bay neutron monitor. A solar cycle change was also found in the spectrum of small-scale turbulence [8]. The solar cycle variation in cosmic ray fluctuations was verified for two solar cycles (1980-2002) using data from two remote polar neutron monitor, Oulu and Tixie Bay [9].

The study of modulation of galactic cosmic rays is important because of its potential for revealing the subtle features of energetic charged particles transport in the tangled fields that permeate the heliosphere and in part as a means of remotely probing the heliosphere, as well as for learning about the physics of the processes operating on the Sun.

Eleven year galactic cosmic ray modulation has been studied quite aggressively since the work of Forbush [1]. He discovered an anti-correlation between cosmic ray intensity and the sunspot numbers. We know now that sunspots are the sites of intense magnetic fields on the Sun's photosphere. Moreover, a case has been made that the local value of the interplanetary magnetic field (B) plays a significant role in controlling cosmic ray modulation at an observing site [10-12].

The long-term cosmic-ray (CR) modulation cycle has a well known ~11-year variation with solar cycle, and a 22-year cycle coinciding with the polarity cycle of the solar magnetic field.

The cosmic ray time profiles are more flat-topped (sharply peaked) around solar minimum when the interplanetary magnetic fields have a positive (negative) polarity in the northern hemisphere. This phenomenon is likely due to CR gradient, curvature and current sheet drift transport, which depends on the sign of the magnetic field polarity [13-14]. In the beginning of a positive polarity cycle, the cosmic-ray intensity can increase quickly over a 1-2 year time scale so that relatively early in the cycle, the CR intensity and associated radiation hazard reach maximum levels.

Data and analysis

The temperature and pressure corrected hourly data (counts of neutrons) of cosmic ray intensity from Moscow neutron monitor have been used, where the long-term change from the data has been removed by the method of trend correction. The days of Forbush decreases have also been removed from the analysis to avoid their influence in cosmic ray variation. Interplanetary magnetic field and solar wind plasma data have been taken from the interplanetary medium data book.

Results and Discussion

Figure 1 (a-e) shows the plots of sunspot number (Rz), interplanetary magnetic field (B), Bz component of IMF, Disturbance time index (Dst) and cosmic ray intensity normalized in a suitable manner so that they are juxtaposed to represent

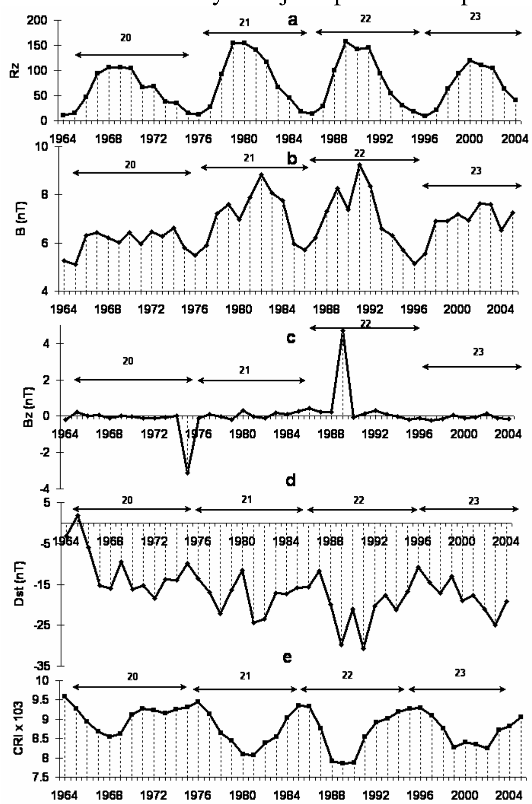

Fig 1: Annual variation of cosmic rays alongwith (a) sunspot numbers (Rz), (b) interplanetary magnetic field (B), (c) north south component of interplanetary magnetic field (Bz) and (d) disturbance storm time index (Dst) during solar cycle 20 - 23.

the continuous temporal variations of cosmic rays alongwith different parameters over the four decades (1964-2004). The curve 1 (a, b) for cosmic ray intensity and Rz tracks each other in an impressive manner. A major discrepancy is seen for the period 1972-1973. As depicted in the Fig 1 there is an inverse correlation between cosmic ray intensity and solar activity measured by sunspot numbers (Rz), as one would expect from Forbush's original analysis. However the maximum of cosmic ray intensity does not always occur at

sunspot minima. This behaviour was noted previously for the neutron monitor counting rate [15].
Further one can see a linear positive correlation between sunspot number (Rz) and interplanetary magnetic field (B). However the maximum of IMF, B does not always occur at sunspot maxima. The IMF, B is found to inversely correlate with cosmic ray intensity variation. To identify a possible correlation between these parameters, we have also calculated the correlation coefficient between these data strings for different solar cycles 20-23. We observe a significant inverse correlation between cosmic ray intensity and Rz for all the four solar cycles 20-23 (-0.78, -0.95, -0.86, -0.95). The IMF, B shows a weak negative correlation (-.35) with cosmic rays for the solar cycle 20, whereas show a good anti-correlation for the solar cycles 21-23 (-0.76, -0.69). The IMF, B found to positively correlated with Rz (0.53) and significantly correlated for rest of the solar cycles 21-23 (0.68, 0.90, 0.61).
Thus from the above findings one may conclude that for four different solar cycles the cosmic ray intensity is found to anti-correlated with sunspot numbers (Rz) and interplanetary magnetic field (B) with some discrepancy. However, the interplanetary magnetic field shows a good positive correlation with Rz for four different solar cycles.
Barbara Popielawska [16] used the neutron monitor data from two pairs of cosmic ray stations, Kiel/Tsumeb and Climax/Huancayo, to study the rigidity dependence of solar modulation during the solar activity cycle 22. They noticed a long-term decrease in cosmic ray intensity during the ascending phase of cycle 22 is characterized by the same rigidity dependence as for the long-term recovery during the descending phase of cycle 21.
Özgüç and Ataç [17] studied the hysteresis effect between the solar flare index and cosmic ray intensity for the period from January 1, 1965 to December 31, 2001 on a daily basis. They show that smoothed time series of flare index and the daily Calgary Galactic Cosmic Ray intensity values exhibit significant solar cycle dependent differences in their relative variations during the studied period and the shapes of these differences vary from cycle to cycle.
Van Allen [18] showed that a plot of annual averages of sunspot numbers versus Climax cosmic-ray intensity produced different patterns in even- and odd-numbered solar cycles (broad ovals in cycles 19 and 21, narrow ovals [straight lines to first order] in cycles 20 and 22). Van Allen did not consider the tilt angle in his analysis. An earlier study by Nagashima and Morishita [19] used the same technique as Van Allen using ionization chamber data from Huancayo. Those authors found that the even-odd pattern in the relationship between sunspots and cosmic rays is also present (although not as clear) in data from cycles 17 (peak sunspot number in 1937) and 18 (1947).
The cosmic-ray intensity curve also appears to follow a 22 yr cycle with alternate maxima being flat-topped and peaked [20], as predicted by models of cosmic-ray modulation based on the observed reversal of the Sun's magnetic field polarity every 11 yr and curvature and gradient drifts in the large-scale magnetic field of the heliosphere [21-22]. During the course of a recent study into the causes of the 11 yr modulation cycle [23], it is noted that the cosmic-ray curve for solar cycle 21 (~1980 peak) lagged the sunspot curve while for cycle 22 (~1990 peak) the cosmic-ray and sunspot variations were more closely synchronized.

Conclusions

- An inverse correlation between cosmic ray intensity and solar activity measured by sunspot numbers (Rz), as one would expect from Forbush's original analysis.
- The interplanetary magnetic field, B shows a weak negative correlation (-0.35) with cosmic rays for the solar cycle 20, whereas B shows a good anti-correlation for the solar cycles 21-23 (- 0.76, - 0.69).
- The interplanetary magnetic field B shows a good positive correlation with sunspot numbers for four different solar cycles.

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