Galactic cosmic ray modulation during last four solar cycles

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Abstract. Cosmic ray neutron monitor counts observed by different ground based detectors have been used to study the galactic cosmic ray modulation during the last four solar activity cycles. Since long systematic correlative studies have been performed 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 10.7-cm solar radio flux, interplanetary magnetic field strength (B) have been used to correlate with yearly average cosmic ray intensity derived from the different neutron monitors. It is noticed that for four different solar cycles 20-23 the cosmic ray intensity is found to anti-correlated with 10.7-cm solar radio flux and interplanetary magnetic field strength (B) with some discrepancy. However, the interplanetary magnetic field strength (B) shows a good positive correlation with 10.7-cm solar radio flux for four different solar cycles. The IMF, B shows a weak correlation with cosmic rays for the solar cycle 20, whereas show a good anti-correlation for the solar cycles 21-23.

Keywords: cosmic ray, solar cycle, interplanetary magnetic field

1 Introduction

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 monitors, Oulu and Tixie Bay [9].

2 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.

3 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 the continuous temporal variations of cosmic rays along with 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 sun-spot minima.

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

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 (-0.35) 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. The behaviour of cosmic ray and solar activity correlation shows a qualitatively different behaviour during the descending phase of solar cycle 20. The intensity of cosmic ray was found to independent on solar activity during 1973-1976. The correlation between IMF B and cosmic ray was also found very weak during solar cycle 20. The cosmic ray modulation is controlled by the global solar activity affecting the conditions of cosmic ray propagation in the heliosphere. The very low solar activity of the solar cycle 20 may be responsible for the unusual behaviour of cosmic ray and IMF parameters. This implies that the perturbations of the heliosphere is weaker and less widely spread during solar cycle 20 than during other solar cycles. This might lead to a situation where the heliospheric perturbations are relatively small for cosmic ray particles allowing these particles to reach the Earth as if it was a minimum solar activity period. This implies that the heliospheric perturbations caused by solar activity in the descending phase of solar cycle 20 were quite local and could not result in global modulation of cosmic rays.

Özgüç and Ataç [10] 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 [11] 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 [12] 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).

4 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 high anti-correlation for the solar cycles 21-23 (-0.76, -0.69).

The interplanetary magnetic field strength (B) shows a good positive correlation with sunspot numbers for four different solar cycles.

5 References