Solar cycle variation of cosmic ray intensity alongwith interplanetary and solar wind plasma parameters

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Abstract: Galactic cosmic rays are modulated through their propagation in the heliosphere by the effect of the large-scale structure of the interplanetary medium. A comparison of the variations of the cosmic neutron monitor intensity with variation of geomagnetic disturbance Dst, solar wind velocity (V), interplanetary magnetic field (B), their product (V x B) near the Earth for the period 1964-2004 has been presented so as to establish a possible correlation between them. We used the hourly averaged cosmic ray counts observed with neutron monitor at Moscow. It is noteworthy that a significant negative correlation have been observed between interplanetary magnetic field (B), product (V x B) and cosmic ray intensity during the solar cycle 21 and 22.The solar wind velocity has a good positive correlation with cosmic ray intensity during solar cycle 21, whereas it shows weak correlation during cycle 20, 22 and 23. The interplanetary magnetic field, B shows a weak negative correlation with cosmic rays for the solar cycle 20, whereas B shows a good anti-correlation for the solar cycles 21-23 with cosmic ray intensity**.** The cosmic ray intensity shows good positive correlation with disturbance time index (Dst) index during the solar cycle 21 and 22, whereas shows weak correlation for the cycle 20 and 23..

Introduction

The study of the long- and short-term modulation of galactic cosmic rays above ~ 3 GV has relied for many decades upon the world-wide network of neutron monitors, which measures the nucleonic cascades in the Earth's atmosphere and provides the only long-term measurements of the high-energy cosmic rays.

Cosmic rays are being regularly monitored by ground-based neutron monitors at several locations on the Earth for the last several decades. Observations so far indicate a clear solar cycle effect, with largest reductions in cosmic ray neutron monitor intensity during sunspot maximum years [1-2].

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 [3] 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. [4] 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 [5]. 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 [6].

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

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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 [7-10].

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 [11-12]. 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 cosmic ray intensity (neutron monitor count rates for Moscow neutron monitor, interplanetary magnetic field (B), disturbance storm time index (Dst), solar

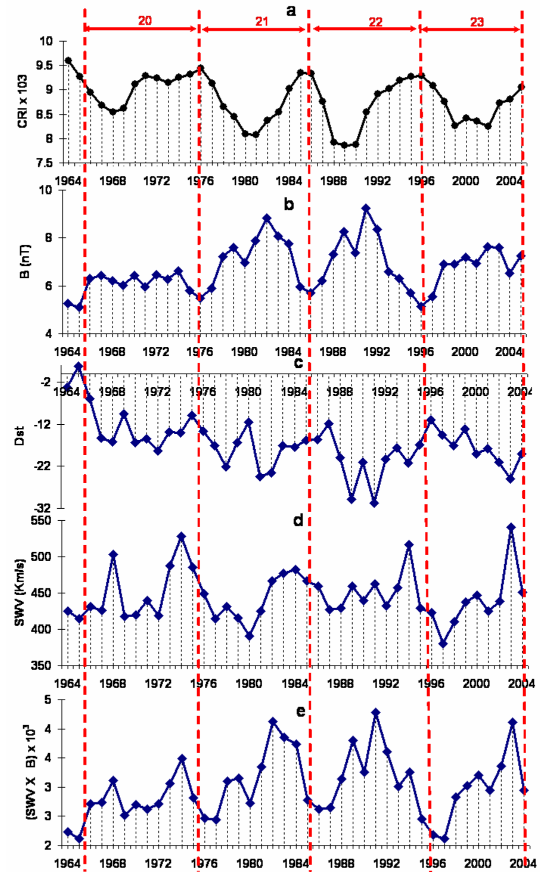

Fig 1: Annual variation of cosmic rays alongwith interplanetary magnetic field (B), disturbance storm time index (Dst), solar wind velocity and the product (V x B) during solar cycle 20 - 23.

wind velocity (V), the product (V x B) and cosmic ray intensity normalized in a suitable manner so that they are juxtaposed to represent the continuous temporal variations of cosmic rays alongwith different parameters over the four decades (1964-2004).

As depicted in the Fig 1 there is an inverse correlation between cosmic ray intensity and interplanetary magnetic field strength (B). However the maximum of cosmic ray intensity does not always occur at IMF B minima. One can see from the plots that increase in the values of interplanetary magnetic field (B) and the product (V x B) produce significant decrease in the cosmic ray intensity during the years 1982 and 1990-91. A significant negative correlation have been observed between IMF B, product (V x B) and cosmic ray intensity during the solar cycle 21 and 22, whereas the disturbance time index and solar wind velocity seems to be positive correlated with cosmic ray intensity with some deviations during these cycles.

Further one can see a linear positive correlation between the product (V x B) and interplanetary magnetic field (B). However, the maximum of IMF, B does not always occur at (V x B) maximum. 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 that the solar wind velocity have a good positive correlation (0.45) during solar cycle 21, whereas it have weak correlation (0.06, 0.15, -0.21) during cycle 20, 22 and 23 with cosmic ray intensity. The cosmic ray intensity shows good positive correlation (0.39, 0.57) with Dst index during the solar cycle 21 and 22, whereas shows weak correlation (0.10, 0.12) for the cycle 20 and 23.

The IMF, 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) with cosmic ray intensity.

Thus from the above findings one may conclude that for four different solar cycles the cosmic ray intensity is found to anti-correlated the product (V x B) and interplanetary magnetic field (B) with some discrepancy. However, the interplanetary magnetic field found to linearly correlated with the product (V x B) for four different solar cycles.

Barbara Popielawska [13] 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 [14] 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 [15] 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 [16] 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 [17], 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 [18-19]. During the course of a recent study into the causes of the 11 yr modulation cycle [20], it is noted that the cosmic-ray curve for solar cycle 21 ($\sim$1980 peak) lagged the sunspot curve while for cycle 22 ($\sim$1990 peak) the cosmic-ray and sunspot variations were more closely synchronized.

Conclusions

From the present investigations following conclusions may be drawn:

- A significant negative correlation have been observed between interplanetary magnetic field (B), product (V x B) and cosmic ray intensity during the solar cycle 21 and 22.
- The solar wind velocity has a good positive correlation with cosmic ray intensity during solar cycle 21, whereas it shows weak correlation during cycle 20, 22 and 23.
- The interplanetary magnetic field, B shows a weak negative correlation with cosmic rays for the solar cycle 20, whereas B shows a good anti-correlation for the solar cycles 21-23 with cosmic ray intensity.
- The cosmic ray intensity shows good positive correlation with disturbance time index (Dst) index during the solar cycle 21 and 22,

whereas shows weak correlation for the cycle 20 and 23.

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