Study of Hysteresis Effect between Cosmic Ray Intensity and Solar Indices

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***Abstract*. In order to perform the study of cosmic ray long-term modulation, we have used six monthly averaged cosmic ray data from Oulu (Rc = 0.78GV) and Rome (Rc = 6.32GV) neutron monitoring stations for three solar cycles. (21 - 23) with solar activity index (sunspot numbers). The detailed analysis of hysteresis effect between these two parameters has been done. The area of hysteresis loops and time lag with correlation coefficient between cosmic ray intensity and sunspot numbers have also been calculated and noticeable differences have been found during odd and even number solar cycles. Area of odd cycle loops is much larger than even cycle loop. Each hysteresis loop consists of a small secondary loop near solar maxima. Time lag between cosmic ray intensity and sunspot numbers is different in odd and even cycles. Implication and consequences of observed differences have been discussed in this paper.**

***Keywords*: Hysteresis loop, Solar cycle, Sunspot numbers.**

I. Introduction

Correlative study between solar indices and cosmic ray intensity has been extensively studied in the past. The cause of time lag between solar activity and cosmic ray intensity and their variation has also been the matter of great interest. The 11-year solar cycle variation in cosmic ray intensity observed at Earth is anti-correlated with solar activity with some time lag. The investigation of the hysteresis phenomenon, caused by the large dimension of modulation region, between long term variation of cosmic ray intensity observed at the Earth and solar activity cycle done by Forbush (1954) first and demonstrated that cosmic ray variations lagged behind sunspot activity by 6 to 12 months. The hysteresis phenomenon was analysed by Dorman and Dorman (1968) on the basis of neutron monitor data for about one solar cycle in the frame of convection-diffusion model of CR global modulation in the Heliosphere; it was shown that the dimension of the Heliosphere couldnt be smaller than 50 AU and greater than 200-300 AU. This result is in good agreement with modern information on the possible position of terminal shock wave bounding the Heliosphere.

In most of earlier studies of hysteresis effect, yearly averaged value of cosmic ray intensity and solar activity index have been used. These plots show differences in features during different solar cycles. Munendra et. al. (2005) determined the average time-lag between the 10.7 c.m. solar flux and cosmic ray intensity in order to decide about a suitable period over which the data may provide better insight of hysteresis phenomenon . In this paper, the study of hyteresis effect between long term variation in cosmic ray intensity and solar activity during the period of 21, 22 and 23rd solar cycles has been performed.

II. Data Analysis

In the present study we have selected cosmic ray intensity data from Oulu neutron monitoring station (cut off = 0.78GV) and Rome neutron monitoring station (cut off = 6.32GV) for the period of solar cycles 21, 22 and 23rd (minimum solar activity expected in 2006). Hysteresis curves have been plotted between cosmic ray intensity and sunspot number (SSN) by taking six monthly mean values and the area of each hysteresis loop is calculated. Time-lag and correlation coefficient between these two parameters have also been calculated.

III. Results and Discussion

We plotted the hysteresis curves for solar cycles 21,22 and 23 by taking six monthly mean of cosmic ray intensity and sun spot number. Fig 1 illustrates the hysteresis loops between six monthly-averaged cosmic ray intensity for Rome neutron monitoring station and SSN for SAC- 21, 22 and 23. These hysteresis loops show similar patterns during odd and even solar cycles. The size of each hysteresis loop is determined by calculating the area of each loop for each cycle, given in Table 1.

TABLE I: Area of hysteresis loops (x 103)

Solar Cycle	Rome (Area)	Oulu (Area)
21	28.8	63.5
22	13.3	23.63
23	16.0	39.58

A small secondary loop of intensity is also observed in each hysteresis loop. This additional feature may be due to Gnevyshev gap effect- double peak structure in the maximum phase of solar activity cycles or due to peculiar particle drift effect at solar maxima. Munendra et.al. (2005) also observed such small secondary loops (cyclic changes) of intensity for Climax neutron

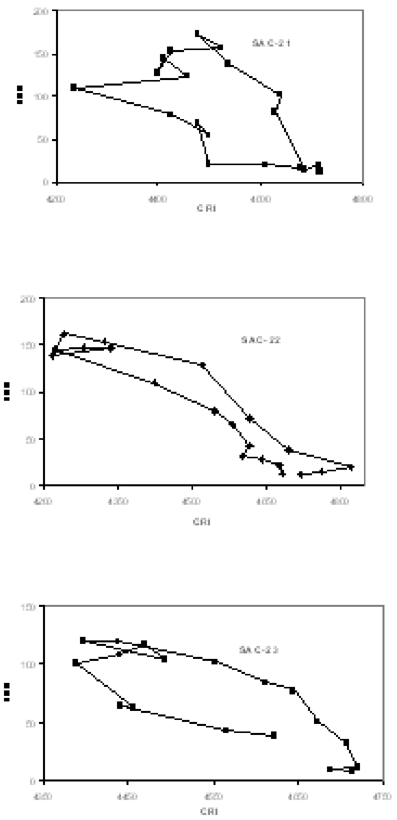

Fig. 1: Hysteresis plots of six monthly-averaged cosmic ray intensity for Rome neutron monitor versus sunspot number for solar cycle 21, 22 and 23.

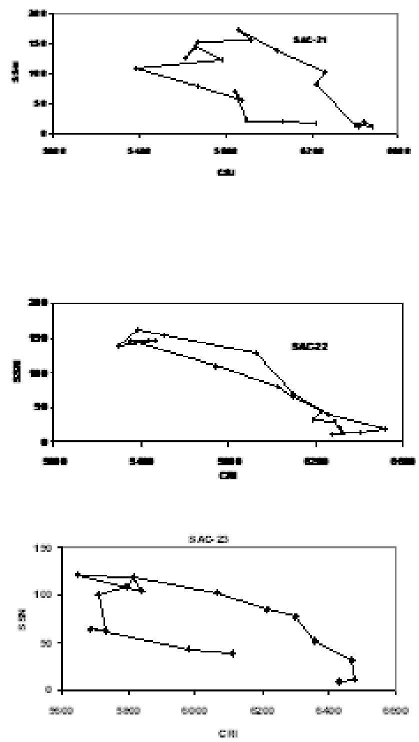

Fig. 2: Hysteresis plots of six monthly-averaged cosmic ray intensity for Oulu neutron monitor versus sunspot number for solar cycle 21, 22 and 23.

monitor, superimposed at/near the solar maximum when solar polarity reversal takes place. Hysteresis effects between cosmic ray intensity of low-low rigidity neutron monitoring station and low-high rigidity station for the SAC-22 has been studied and mini loops are also obtained by Tripathi et.al,(2005). In fig. 2 hysteresis curves between cosmic ray intensity from Oulu station and SSN has been shown. These curves are similar in patterns as obtained for Rome station. The area of these loops is also given in the Table 1. It is clear from this table that the area of odd cycle loops are much larger than even cycle loops for both the stations. Similar odd-even asymmetry of cosmic ray cycles is observed earlier Allen (2000). Otaola et. al. (1985) discussed such differences in behavior of cosmic ray intensity during odd and even numbered solar cycles, on the basis of hypothesis by Mavromichalaki et.al.(1998) that when polar magnetic field of the Sun is nearly parallel to the galactic magnetic field, they can easily connect, so that galactic cosmic rays, especially those of low rigidities, could enter more easily into the Heliosphere along the field lines of force, as compared to anti parallel states of the magnetic fields.

IV. CONCLUSION

The analysis of hysteresis loops obtained for different solar cycles shows differences between odd and even solar cycles. The area of hysteresis loops for odd solar cycles is larger than that for even cycles for both neutron monitoring stations, suggests that cosmic ray intensity behavior for even and odd solar cycles may be due to parallel and anti parallel states of solar polar magnetic field relative galactic magnetic field. A small secondary loop in each hysteresis loop may be due to peculiar particle drift effect of solar maxima.

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