29th International Cosmic Ray Conference Pune (2005) **2,** 61-64

Cosmic Ray Intensity Variations During Carrington Rotation Periods in Low Solar Activity Conditions

Vivek Gupta and Badruddin
Department of Physics, A.M.U., Aligarh-202 002, India
Presenter: V. Gupta (nucleus12@rediffmail.com), ind-gupta-V-abs1-SH32-poster

Temporal evolution of cosmic ray intensity during Carrington rotation periods has been analyzed. Average oscillations in the intensity during the course of Carrington rotation in low solar activity conditions and in different polarity states of the heliosphere ($A < 0$ and $A > 0$) have been determined. It has been shown that the nucleonic intensity, as recorded by neutron monitors, oscillates during the course of Carrington rotations. The average amplitude of oscillation is found to be larger during $A > 0$ than $A < 0$. Observed oscillations in intensity are compared with the simultaneous variations of solar wind parameters such as solar wind speed and interplanetary magnetic field strength. Amplitudes of intensity oscillations in each Carrington rotation have also been calculated. Regression analysis between intensity oscillations and heliospheric current sheet tilt angle in each rotation has also been done. This analysis shows that the amplitude of oscillation changes at almost same rate with tilt angle during $A > 0$ and in $A < 0$ polarity epochs.

1. Introduction

Two basic kinds of recurrent phenomena in the solar wind and interplanetary magnetic field have been found in the inner heliosphere; one is the tilted heliospheric current sheet (HCS). The other recurrent phenomenon, the corotating interaction region (CIR), is the result of compression between slow and fast solar wind streams. Since the slow wind mainly originates from the equatorial zone and the fast wind streams come from polar coronal holes, equatorial extension of a polar coronal hole will produce the CIR as observed by an interplanetary spacecraft. Both the HCS and the CIR are expected to modulate galactic cosmic rays (GCR) and produce ~26-day recurrent variations in the cosmic ray flux. However, it is not clear whether the primary cause of recurrent cosmic ray modulation is tilted HCS or CIR. Although the effects of HCS and CIR on recurrent modulation of GCR cannot be easily distinguished, there are evidences supporting one or the other [1-13] and more studies are needed to resolve this question.

The heliospheric current sheet evolves during the course of a Carrington rotation. As the sun rotates, the heliomagnetic latitude at the earth or spacecraft changes periodically. In this paper we have studied the GCR modulation during Carrington rotation periods separately during two low solar activity periods: 1983-86 ($A < 0$) and 1993-96 ($A > 0$); these include the periods when high speed corotating streams are more prominently observed, 2-3 years prior to and during solar activity minimum.

2. Discussion

For the study of GCR variations during Carrington rotation periods, we have adopted the method of superposed epoch analysis; epoch corresponds to the Carrington rotation start time. Analysis has been performed using neutron monitor data from Oulu and Climax and OMNI heliospheric plasma and field data. In Fig. 1 we have plotted the superposed epoch analysis results of daily averaged GCR intensity (I), solar wind velocity (V), interplanetary magnetic field (B), it's variance (σ_B) and the product V.B during two low solar activity periods.

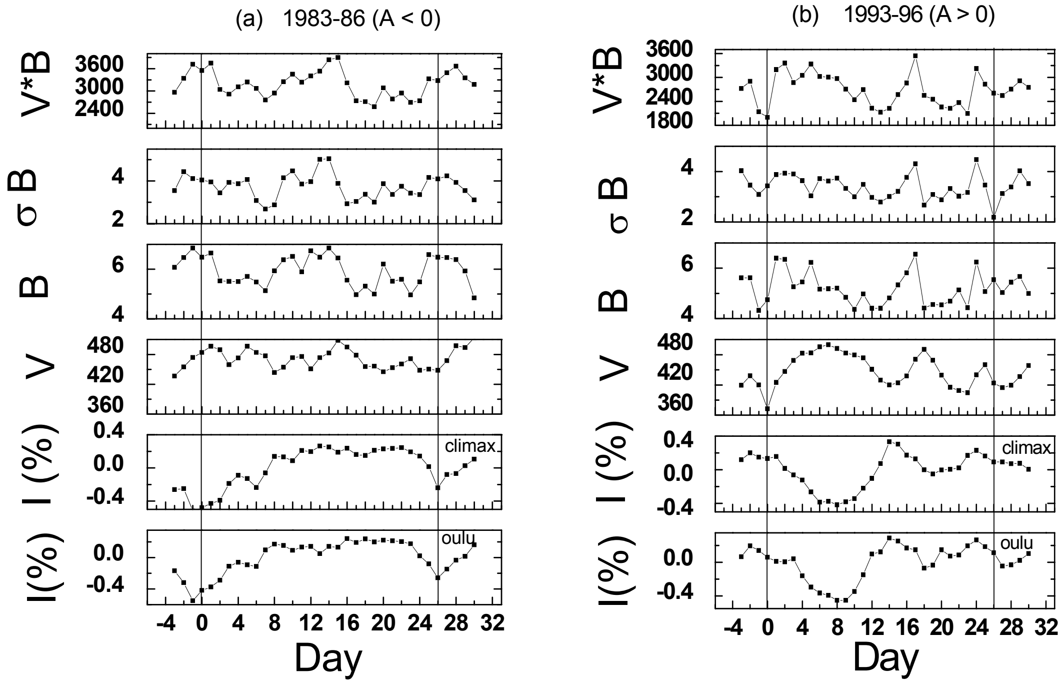

Figure 1. Superposed epoch analysis results of variations in GCR intensity I (%), solar wind velocity V (Km/sec), B (nT), σ_B (nT) and product VB; Zero day corresponds to first day of Carrington rotation.

GCR modulation processes, convection and adiabatic deceleration, are related to solar wind velocity (V) and diffusion/scattering of particles is related to parameters B and σ_B. Particle drift in large-scale heliospheric magnetic field is a process of modulation that depends on solar magnetic polarity. A comparison of Figs. 1(a) and 1(b) shows that the GCR intensity oscillates during the course of Carrington rotation, that the intensity is larger during A > 0 than A < 0, that intensity oscillations do not closely follow the variation in the solar wind parameters V, B, σ_B and V.B in A < 0, and that the solar wind velocity appears to be related (in anti-phase) with the intensity oscillations during the course of Carrington rotation in A > 0.

We have calculated the correlation coefficients between the GCR intensity and solar wind parameters. The best correlation is obtained between variation in GCR intensity and solar wind velocity, that too only in A > 0 epochs (Table-1). Further, scatter plots along with best fit curve between averaged GCR intensity and solar wind speed variations during the course of Carrington rotations are plotted in Fig. 2 (a, b). From the results presented in Table-1 and in Fig. 2 (a, b), one may conclude that either the cosmic ray response to solar wind speed variations is reduced in A < 0 periods [10] or some other effect/process "obscures" the response of solar wind velocity in A < 0 epochs. Burger and Hitge [14] developed a divergence free Fisk–Parker hybrid heliospheric magnetic field and studied the effect of hybrid field on GCR by solving the 3-D steady state Parker transport equation. They investigated the 26-day recurrence for both protons and electrons. They have shown that hybrid field reduces intensities compared to Parker field when A > 0; when A < 0, the global effect of hybrid field is almost negligible. Their model predictions are consistent with earlier observed

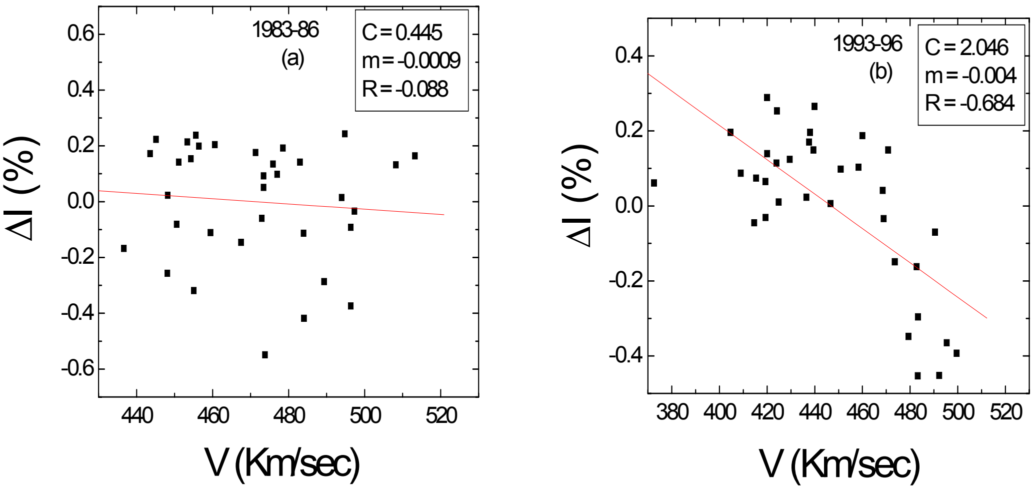

Figure 2. GCR intensity oscillation ΔI (%) versus solar wind velocity V (Km/sec) scatter plot along with the best fit curve and parameters.

results [12,13] only when drift effects are included, indicating that drifts are important for the corotating modulation. Badruddin et al. [1] suggested possibility of displacement of HCS to explain GCR variation near the HCS. A 3-D drift model with asymmetrically placed HCS has also been proposed [15] to explain the recurrent decrease in GCR.

Tilt angle of the HCS is an important parameter of drift models. We have studied the relationship between amplitudes of GCR oscillation and the tilt angle of HCS during Carrington rotations. The scatter plot between tilt angle and GCR oscillation during Carrington rotation periods along with the best fit curve is shown in the Fig. 3(a, b) for 1983-86 and 1993-96. The regression coefficient (R), density gradient with

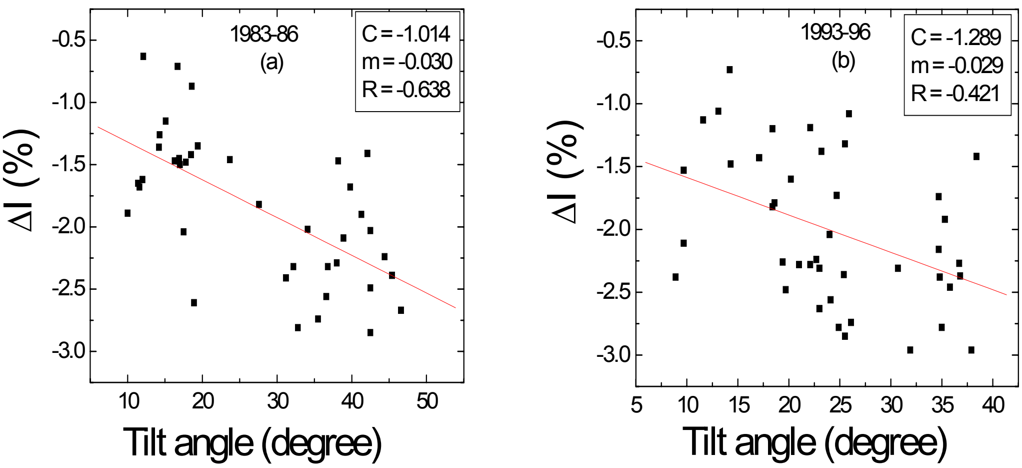

Figure 3. Relation between GCR intensity oscillation and tilt angle in Carrington rotation periods.

respect to tilt angle of HCS (m) and intercept (C) are given on the top of figure during A < 0 (1983-86) and A > 0 (1993-96). Although the regression is better during A < 0, GCR density gradient with tilt angle is nearly same in both the epochs.

Table1: Correlation coefficients between GCR intensity (I) and various solar wind parameters V, B, σ_B and V.B.

Period	I Vs. V	I Vs. B	I Vs. σ_B	I Vs. (V.B)
1983-86 (A < 0)	-0.08	-0.44	-0.32	-0.42
1993-96 (A > 0)	-0.68	-0.29	-0.02	-0.27

3. Conclusions

We find that the amplitude of GCR oscillation is larger in A > 0. The GCR intensity tends to be (anti) correlated with the solar wind speed during A > 0 but not during A < 0. Further, the amplitude of oscillations in GCR intensity during Carrington rotations shows some dependence on the tilt angle of the heliospheric current sheet. However, this dependence is similar for both polarity epochs, A < 0 and A > 0, with almost same density gradient with tilt angle.

4. Acknowledgements

We acknowledge with thanks the use of Oulu and Climax neutron monitor data. ISRO grant to Badruddin (P.I.) through it's RESPOND program is also acknowledged.

References

[1] Badruddin et al., Planet. Space. Sci. 33, 191 (1985).
[2] Badruddin, Astrophys. Space Sci. 246, 171 (1997).
[3] Badruddin and A.G. Ananth, 28th ICRC, Tsukuba (2003) 3909.
[4] G. Newkirk and L.A. Fisk, J. Geophys. Res. 90, 3391 (1985).
[5] N. Iucci et al., Nuovo Cim. 2, 421 (1979).
[6] M. V. Alania et al., Adv. Space Res. 27, 619 (2001).
[4] G. Newkirk and L.A. Fisk, J. Geophys. Res. Lett. 8, 619 (1981).
[5] N. Iucci et al., Nuovo Cim. 2, 421 (1979).
[6] M. V. Alania et al., Adv. Space Res. 27, 619 (2001).
[7] A.C. Cummings and E.C. Stone, Int. Solar Wind Conf. (1988) 2, 599.
[8] H. Kunow et al., Space Sci. Rev. 72, 397 (1995).
[9] D.V. Reames and C.K. Ng, Astrophys. J. 563, L179 (2001).
[10] I.G. Richardson et al., J. Geophys. Res. 104, 12,549 (1999).
[11] I.G. Richardson, Space, Sci. Rev. 121, 267 (2004).
[12] G.M. Simnett and H. Kunow et al., Space Sci. Rev. 83, 215 (1998).
[13] M. Zhang, Astrophys. J. 484, 841 (1997).
[14] R.A. Burger and M. Hitge, Astrophys. J. 617, L76 (2004).
[15] J. Kota., and J.R. Jokipii, 27th ICRC, Hamburg (2001) 9, 3577.