EFFECT OF SOLAR HELIOSPHERIC PARAMETERS ON DIFFERENT COMPONENTS OF DAILY VARIATION IN COSMIC RAY INTENSITY

Rekha Agarwal Mishra[1] and Rajesh K. Mishra[2]
(1) Govt. Autonomous Model Science College, Jabalpur (M.P.) India 482 001
(2) Tropical Forest Research Institute, Jabalpur (M.P.) India 482 001

Abstract

The data of three different neutron monitoring stations, Deep River, Inuvik and Tokyo located at different geomagnetic cutoff rigidities and altitudes has been harmonically analysed for the period 1980–95 to investigate for a comparative study of diurnal, semi-diurnal and tri-diurnal anisotropies in cosmic ray (CR) intensity in connection with the change in IMF (Bz) component and solar wind velocity on 60 quietest days (60 QD). It is observed that the amplitudes of all the three harmonics increases during the period 1982–84 at all the stations during the high speed solar wind stream (HSSWS) epoch and remains low during the declining phase of the stream. The amplitudes of the three harmonics have not any obvious characteristics associated with the time variation of magnitude of Bz component. The phases of all the three harmonics have not time variation characteristics associated with solar wind velocity and Bz.

1. Introduction

Cosmic ray (CR) intensity exhibits a daily variation composed of a prominent diurnal component and also a semi-diurnal component of lesser amplitude. The diurnal, semi-diurnal as well as the tri-diurnal variation play an important role in constructing the whole picture of the modulation mechanism of the cosmic ray intensity in interplanetary space. The CR variations observed near the Earth are an integral result of numerous solar and heliospheric phenomena, so any parameter alone cannot determine the behavior of CR. Ballif et al. (1969) correlated Kp and Ap with the mean fluctuations in amplitude of interplanetary magnetic field (IMF), which in turn is related to diffusive component of convection-diffusion theory. Ap is also found to be related with solar wind velocity, V; which is related to convective component of convection-diffusion theory.

CR modulation is a complex phenomena which occurs all over the heliosphere and depends on many factors. No single solar index can be responsible for CR variations. Numerous theoretical and experimental works discuss a strong influence of the heliospheric tilt and the polarity of the general magnetic field on the long-term CR variations (Jokipii and Thomas, 1981; Smith and Thomas, 1986). An existence of relation between solar wind velocity, IMF module and

pp. 3937–3944

long-term CR variations has been established (Chirkov, 1985; Cane et al., 1999; Belov et al., 1999).

Long-term cosmic ray modulation can be studied by the global network of cosmic ray stations located at different geomagnetic cut-off rigidities and altitudes. Neutron monitors are sensitive to cosmic rays of about 0.5–20 GeV which, coincides with the energy range of most effective solar modulation. NM records are a unique data set to study the detailed time behavior of modulation since 1950s. Present study deals with the relation of solar wind, Bz component of IMF and polarity of solar poloidal magnetic field to the solar daily variation (diurnal/semi-diurnal/tri-diurnal) for three different NM stations. Since any location on the Earth is characterized by its own asymptotic cone of acceptance, the different cosmic ray stations are expected to show a different response to a certain form of anisotropy.

2. Experimental data analysis

A comparative study of diurnal, semi-diurnal and tri-diurnal anisotropies performed over a period $\approx$ 14 years for the three different neutron monitoring stations Deep River, Tokyo and Inuvik in connection with the change in IMF (Bz) component and solar wind velocity.

3. Results and discussion

Solar wind and IMF plays an important role in controlling the electrodynamics of the heliosphere (Parker, 1963). Solar wind speed, V and IMF parameters, such as vector **B**, spiral angle and tilt are important for the transport of energetic cosmic ray particles in the heliosphere, for the modulation of CR and creation of CR anisotropy in the interplanetary space. The solar wind velocity determines two components of the CR modulation mechanism: the convection and the adiabatic energy changes. The high velocity solar wind fluxes associated with coronal holes give rise to both isotropic and anisotropic variations in CR intensity (Iucci et al., 1979a; Kaminer et al., 1981). Changes of the solar wind velocity near the Earth may have not only local but also the global character (Sheeley et al., 1991; Richardson et al., 1999). Kondoh et al. (1999) found that the peak solar wind velocity has good anti-correlation with the high-energy galactic cosmic ray intensity. Recent enhancements of solar wind velocity are closely associated with the long-term decreases in the galactic cosmic ray intensity. The IMF magnitude and fluctuations are responsible for the depression of CR intensity during high speed solar wind events (Sabbah, 2000a). The IMF magnitude reaches the highest value during declining phase of solar activity (Sabbah, 1996). The correlation between cosmic ray intensity and solar wind velocity is statistically significant, especially in the period of the maximum solar activity. The regression coefficients obtained on yearly basis depend on sunspot number and are ~ -0.8 and ~ -0.2

per 100 km/s at the solar maximum and minimum, respectively (Fujiimoto et al., 1983a). Duggal and Pomerantz (1977) and Iucci et al. (1979b) pointed out that the effect of HSSWS on CR intensity is -0.5% per 100km/s in the case of high-speed wind emerging from the coronal holes. The relation of CR intensity to solar wind velocity is, in general, dependent on physical conditions in the interplanetary space varying with the solar activity. The year to year variation of the effect of solar wind upon CR intensity is dependent on solar activity and the decrement of CR intensity due to the variation of solar wind velocity is proportional to sunspot number (Fujiimoto et al., 1983b).

Yearly average values of the amplitudes and phases of the first three harmonics of daily variation in CR intensity alongwith the solar wind velocity and the magnitude of Bz component of IMF on 60 QD has been plotted for three different NM stations Deep River, Inuvik and Tokyo in the Figures 1, 2, 3, 4, 5 and 6 respectively. Usually the solar wind velocity is about 300 km/s. Solar wind velocity increases from 1980–83. The significant enhancements in the velocity are seen during 1982–84 when the velocity is over 400 km/sec. The period of 1982–84 is the period of high-speed solar wind stream (HSSWS). Diurnal amplitude R_1 has low values during 1983 when the wind speed is high but attains gradually high values during 1983–85 at all the stations, which includes the epoch of HSSWS. Semidiurnal (R_2) as well as tri-diunal (R_3) amplitudes increased gradually at all the stations during 1982–84 except that tri-diurnal amplitude decreased during 1984 at Tokyo. The diurnal amplitude R_1 attains its lowest in 1987 at Deep River and in 1986 at Tokyo and Inuvik, closer to the period when the values of solar wind speed and Bz are low. During 1991 when Bz has high value R_1 decreases at Deep River and remains constant at Inuvik. Diurnal amplitude is generally most sensitive to the IMF direction and the solar wind velocity (Sari, 1978). R_2 decreases sharply during 1989–90 at Inuvik and Tokyo and increases sharply at Deep River during 1991. R_3 remains low at Deep River during 1991 but has quite large values at Inuvik. Thus, the amplitude of all the three harmonics increases during 1982–84 at all the stations during the HSSWS epoch and remains low during the declining phase of the stream. The amplitudes of the three harmonics have not any obvious characteristics associated with the time variation of magnitude of Bz component.

Iucci et al. (1981) observed that the amplitude of the first and second harmonics during the initial part of the fast stream are large on a day-to-day basis, particularly incase of the high speed solar wind stream interaction region whereas during the declining phase of the stream the harmonics are found to be particularly low. An analysis using groups of days with high and low solar wind speeds shows greater amplitude of both the tri-diurnal and semi-diurnal waves for the group of days with high wind speed (Agrawal et al., 1981; Agrawal, 1981). Agrawal et al. (1981) suggested that the solar polar coronal holes could influence

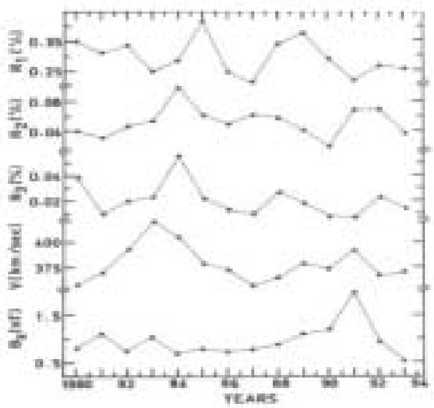

Fig. 1. Plots showing the average values of the amplitudes (%) of the first three harmonics of daily variation in cosmic ray intensity alongwith the solar wind velocity and the magnitude of Bz component of IMF on 60 QD for the Deep River NM station

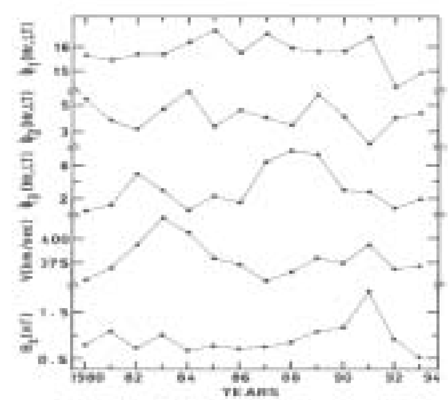

Fig. 2. Plots showing the average values of the phases (Hr) of the first three harmonics of daily variation in cosmic ray intensity alongwith the solar wind velocity and the magnitude of Bz component of IMF on 60 QD for the Deep River NM station

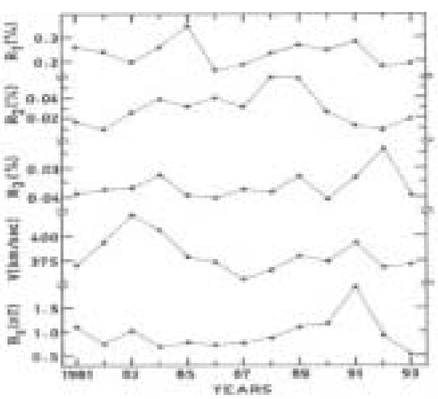

Fig. 3. Plots showing the average values of the amplitudes (%) of the first three harmonics of daily variation in cosmic ray intensity along with the solar wind velocity and the magnitude of Bz component of IMF on 60 QD for the Inuvik NM station

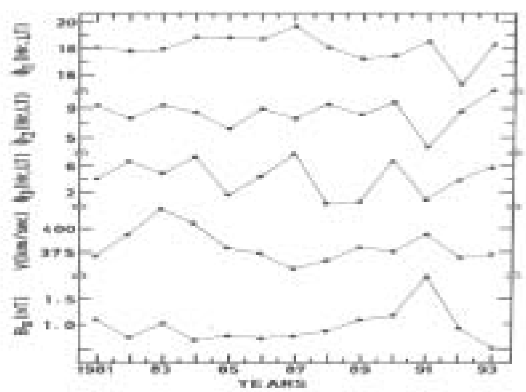

Fig. 4. Plots showing the average values of the phases (Hr) of the first three harmonics of daily variation in cosmic ray intensity alongwith the solar wind velocity and the magnitude of Bz component of IMF on 60 QD for the Inuvik NM station

both semidiurnal as well as tri-diurnal variations. Ahluwalia (1992) showed that a subsidary maximum appears in the annual mean solar diurnal anisotropy data "when the solar wind bulk speed V $>$ 470 km/s or when **B** has large values. Sabbah (1996) also observed that the days characterized by high IMF magnitude

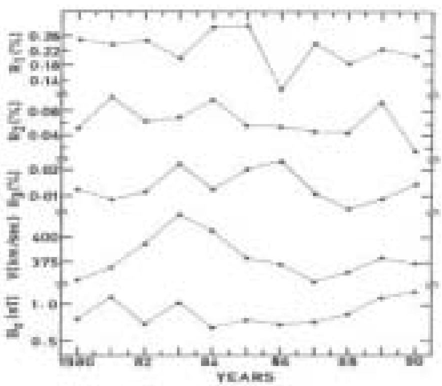

Fig. 5. Plots showing the average values of the amplitudes (%) of the first three harmonics of daily variation in cosmic ray intensity alongwith the solar wind velocity and the magnitude of Bz component of IMF on 60 QD for the Tokyo NM station

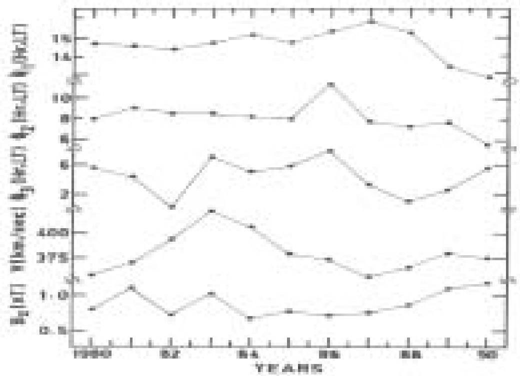

Fig. 6. Plots showing the average values of the phases (Hr) of the first three harmonics of daily variation in cosmic ray intensity alongwith the solar wind velocity and the magnitude of Bz component of IMF on 60 QD for the Tokyo NM station

are associated with higher diurnal variation amplitudes as well as higher solar plasma parameters.

High speed solar wind streams have an effect on diurnal variation observed with neutron monitors (Snyder and Neugebauer, 1963). Munakata et al. (1987) studied the characteristics of solar diurnal anisotropy in HSSWS originating from polar coronal holes using neutron monitor data for 17 stations and muon telescope data from 17 directions. They found that the amplitude of the diurnal anisotropy depends on the location of the coronal holes and hence IMF source in constantly high and declining portion of the solar wind stream. Iucci et al. (1983) with 33 well-defined events of HSSWS found that the semi-diurnal amplitude depends on the Earth's position inside the stream. Munakata et al. (1987) found that the modulation of the anisotropy is less dependent on the solar wind speed which is different from the results obtained by Iucci et al. (1983) and Dorman et al. (1984, 85).

The phase ϕ_1 of the diurnal component of daily variation is observed to be statistically constant at all the stations during the period 1980–86. Iucci et al. (1983) have studied the changes observed in phase of the diurnal anisotropy during different portions of HSSWS and observed that the phase is almost constant at $\sim$ 18 Hr. Values of Bz are small for the period 1980–90. IMF magnitude B is enhanced during the declining phase of solar activity (Sabbah 1994, 96). During 1992 when Bz drops to half of its value and solar wind velocity decreases, shift to earlier hours in the value of ϕ_1 is steeper at Deep River and Inuvik NM stations.

The direction of diurnal anisotropy is found to be more sensitive to IMF. It responds not only to ecliptic component of IMF but to total magnetic field of the Sun (Gonchar et al., 1983). The modulation effect of solar wind speed to the solar diurnal anisotropy is rigidity dependent and the most sensitive rigidity of modulation is around 50 Gv (Munakata et al., 1990). From May 1987, the cosmic ray intensity started to decrease rapidly and the rate of decrease is rigidity dependent (El-Borie and Thoyaib, 2001).

Phase ϕ_2 of the semi-diurnal component remains statistically constant at Tokyo till 1985. The variations in the phase are similar for Deep River and Inuvik NM stations. A large shift to early hours has been observed during 1985 at Deep River and during 1987 at Tokyo. ϕ_2 has significantly shifted to earlier hours during the year 1991 at Deep River and Inuvik when Bz has large value and solar wind velocity attains its peak. Semi-diurnal phase has shifted to later hours during 1992 when both Bz and the solar wind velocity decreases. The long-term variation in the amplitude and phase of the semi-diurnal anisotropy has been studied for the periods 1964–76 (Kumar et al. 1981b), 1968–79 (Agrawal et al., 1983) and 1968–84 (Pathak and Agrawal, 1987). An increase in the amplitude of the semi-diurnal anisotropy during the years 1973–74 is observed when high-speed streams are frequent; the phase remained constant throughout the epoch of study.

Phase ϕ_3 of the tri-diurnal variation has shifted largely to later hours at Tokyo during 1983 and to earlier hours at Inuvik during 1985 and 1988 as compared to the previous year. Solar wind velocity decreases continuously from 1983 till 1987. During 1991–92 when the two heliospheric parameters i.e., V and Bz decrease ϕ_3 has shown a shift towards earlier hours during 1991 and to later hours during 1992 at Inuvik.

Snyder et al. (1963) and Mavromichalaki et al. (1988) correlated the solar wind speed to the geomagnetic activity. The geomagnetic activity is correlated with the southward magnetic field component (Crooker and Gringauz, 1993). Geomagnetic activity results from magnetic reconnection between IMF and the Earth's magnetic field and this process is most effective when the IMF is southward. Sabbah (1999) obtained an inverse correlation between cosmic ray intensity and the geomagnetic activity and observed the enhancement in upper cut-off rigidity, Rc and the geomagnetic activity resulting from variation in the solar plasma parameters. Upper cut-off rigidity correlates well with the product VB rather than with magnetic field B since VB reflects both diffusion by the IMF and convection with solar wind. The product VB is more important for both cosmic rays and geomagnetic activity modulation rather than IMF alone. The amplitude of 27-day variation of GCR is also linearly correlated with the IMF strength B, the z-component Bz of the IMF vector and the product VB (Sabbah 2000b). Burlaga and Ness (1998) argued that it is ultimately the strong magnetic field and their associated fluctuations that produce the modulation of cosmic rays. Coupling between the IMF strength B and the CR transport parameters leads to a simple modulation model in which the modulation process is linked to global variations of B. Belov (1999) suggested that the local value of the IMF place a significant role in controlling the GCR modulation at an observing site. The high values of Rc, V and Bz during 1991 and their sharp decrease during 1992 might have resulted in shifting the anisotropy vectors of diurnal and semi-diurnal anisotropies.

The Bz component of IMF does not usually contribute significantly to the solar modulation of cosmic rays since the long-term average of this component near the Earth is ~ 0. However, Swinson et al. (1981) have demonstrated that on occasions it can contribute to a field dependent anisotropy especially to the extended trains of enhanced solar diurnal variation observed in 1974. They contend that this enhancement resulted from the constructive interference of the regular solar diurnal variation, $B_y \times \nabla N_y$ streaming where B_y is the y component of IMF and ∇N_y is the radial heliocentric cosmic ray density gradient.

4. Conclusions

On the basis of above investigation following conclusions may be drawn:

- The amplitude of all the three harmonics increases during 1982–84 at all the stations during the HSSWS epoch and remains low during the declining phase of the stream. The amplitudes of the three harmonics have not any obvious characteristics associated with the time variation of magnitude of Bz component.
- The phases of all the three harmonics have not time variation characteristics associated with solar wind velocity and Bz.

5. Reference

1. Ballif J.R., Jones D.E., Coleman P.J. 1969, J. Geophys. Res. 74, 2289
2. Jokipii, J.R., Thomas, B.T. 1981, Astrophys. J. 243, 1115
3. Smith, E.J., Thomas B.T. 1986, J. Geophys. Res. 91, 2933
4. Chirkov N.P. 1985, 19^{th} Int. Cosmic Ray. Conf. 4, 489
5. Cane V., Wibberenz G., Richardson L.G., Von Rosenvinge T.T. 1999, Geophys. Res. Lett. 26, 565.
6. Belov A.V., Guschina R.T.,Yanke V.G. 1999, 26^{th} Int. Cosmic Ray Conf., Utah 7, 175
7. Parker E.N. 1963, Interplanetary Dynamical Process-Wiley Inter Science, Nework.
8. Iucci N., Parisi M., Storini M., Villoressi G. 1979a, Nuovo Cimento 2C, 421.
9. Kaminer N.S., Kuzmicheva A. E., Mymrina N.V. 1981, Geomag. and Aeronomy 21, 424.
10. Sheeley N.R., Swanson E.T., Wang T.M. 1991, J. Geophys. Res. 96, 861
11. Richardson J.D., Paularena K.I., Wang C. 1999, Solar Wind Nine
12. Kondoh K., Hasebe N., Doke T., Kikuchi J., Kobayashi M. N., Medina J., Sequeiros J., Takashima T., Yanagimachi T., Wilken B., 1999, 26^{th} Int. Cosmic Ray Conf.,

Utah 7, 179
13. Sabbah I. 2000a, Can. J. Phys. 78, 293
14. Sabbah I. 1996, J. Geophys. Res. 101, 2485
15. Fujimoto K., Mori S., Ueno H., Nagashima K. 1983a, 18th Int. Cosmic Ray Conf., Bangalore 3, 295
16. Duggal S.P., Pomerantz M.A. 1977, 15th Int. Cosmic Ray Conf., Plodiv 4, 370.
17. Iucci N., Paris, M., Storin, M., Villoressi G. 1979b, 10th Int. Cosmic Ray Conf., Tokyo 3, 491.
18. Fujimoto K., Kojimatt, Munakami K. 1983b, 18th Int. Cosmic Ray Conf., Bangalore 3, 267.
19. Sari J.W., Venkatesan D., Lanzerotti J.J., Maclennan C.G. 1978, J. Geophys. Res. 83, 5139.
20. Iucci N., Parisi M., Storini M., Villoressi G. 1981, 17th Int. Cosmic Ray Conf., Paris, **10**, 238.
21. Agrawal S.P., Mishra B.L., Pathak S.P., Yadav R.S., Kumar S., Badruddin 1981, 17th Int. Cosmic Ray Conf., Paris 4, 119
22. Agrawal S.P. 1981, J. Geophys. Res. 86, 10115
23. Ahluwalia H.S. 1992, Geophys. Res. Lett. 19, 633.
24. Sabbah I. 1996, J. Geophys. Res. 101, 2485.
25. Snyder C.W. Neugebauer M., Rao U.R. 1963, J. Geophys. Res. 68, 6361.
26. Munakata K., Mori S., Ryu J.Y., Agrawal S.P., Venkatesan D. 1987, 20th Int. Cosmic Ray Conf., Moscow 4, 39.
27. Iucci N., Parisi M., Storini M., Villoressi G. 1983, 18th Int. Cosmic Ray Conf., Bangalore 3, 354.
28. Dorman L I., Kaminer N.S., Kuj'micheva A.E., Mymrina N.V. 1984, Geomagnetism and Aeronomy 24, 452.
29. Dorman L I., Kamur N.S., Kuj'micheva A.E., Hymrina N.V. 1985, Geomagnetism and Aeronomy 24, 554.
30. Sabbah I, 1994, Annal. Geophys.12, 279.
31. Gonchar G.A., Kolomeets E.V., Slyunyaevea N.V. 1983, 18th Int. Cosmic Ray Conf., Bangalore 10,197.
32. El-Borie M. A., Al-Thoyaib S.S. 2001, 27th Int. Cosmic Ray Conf., Hamburg SH 3.2, 3780.
33. Kumar S., Yadav R.S. 1981, 17th Int. Cosmic Ray Conf., Paris 10, 242.
34. Agrawal S.P., Pathak S.P., Mishra B.L. 1983, 18th Int. Cosmic Ray Conf., Bangalore 3, 304.
35. Pathak S.P., Agrawal S.P. 1987, 20th Int. Cosmic Ray Conf., Moscow 4, 129.
36. Snyder C.W., Neugebauer M., Rao U.R. 1963, J. Geophys. Res. 68, 6361.
37. Mavromichalaki H., Vassilaki A., Marmatsouri E. 1988, Solar Physics 115, 345.
38. Crooker N.U., Gringauz K.I. 1993, J. Geophys. Res. 98, 59.
39. Sabbah I. 1999, Solar Physics 188, 403
40. Burlaga L.F., Ness N.F. 1998, J. Geophys. Res. 103, 29719.
41. Sabbah I. 2000b, Geophys. Res. Lett. 27, No.13.
42. Swinson D.B., Saito T., Mori S. 1981, J. Geophys. Res. 86, 8845.