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Third harmonics of cosmic ray intensity on quiet days at Deep River Neutron Monitoring Station

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Abstract. The cosmic ray (CR) intensity data recorded in Deep River Neutron Monitoring Station have been investigated on quietest days (QD) for third harmonics of daily variation during solar cycles 21 and 22. It has been observed that in spite of abrupt change in the amplitude and phase of tri-diurnal anisotropy in CR intensity, the amplitude is quite significant throughout the period of investigation with larger amplitude during the years 1980 and 1985. Thus, tri-diurnal anisotropy clearly shows 11-year variation at the mid latitude neutron monitoring station.

Keywords. Cosmic rays; higher harmonics; geomagnetically quiet days.

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1. Introduction

The spatial anisotropy of the galactic cosmic ray intensity in the interplanetary space manifests itself as daily variation with a period of 24 h (and its higher harmonics) due to the rotation of the Earth in the course of a day. The power spectrum analysis as well as the Fourier analysis of the long-term data of the 24-h values of cosmic ray (CR) intensity observed by Earth-based detectors have provided confirmatory evidence along with the characteristics of the first three harmonics of daily variation of extraterrestrial origin [1,2]. However, the amplitude of the fourth harmonics is still controversial [3–7].

2. Analysis of the data

Solar daily variation has been studied in terms of helio-magnetic activity. A new concept of data analysis has been introduced for studying the long/short-term daily variation in CR intensity recorded with neutron monitors. Fourier technique has been applied on different groups of days chosen according to their different geomagnetic conditions.

1. All days: This means all the 365/366 days in a year. Thus, these days are termed as AD. Of course the days with abrupt changes are ignored.
2. Quiet days: Those days in which the transient magnetic variations are regular and smooth are said to be magnetically quiet or Q days. The criteria are based on *Ap* and *Kp* values. There are two types of days.

(a) 60 Quiet days: According to solar geophysical data (SGD) lowest mean order number are the five quietest days in a month. Thus, 60 Q days in a year is termed as 60 QD.

(b) 120 Quiet days: First ten quiet days in a month. Thus, 120 Q days in a year is termed as 120 quiet days.

The pressure-corrected hourly CR intensity data (corrected for meteorological effects) on five geomagnetically quietest days (QD) in every month from Deep River (Lat: 46.06°N; cut-off rigidity: 1.02 GV; longitude: 282.5°E; altitude: 145 m) and Goose Bay (Lat: 53.33°N; cut-off rigidity: 0.52 GV; longitude: 299.58°E; altitude: 46 m) neutron monitoring stations for the period 1978–94 have been used in Fourier analysis. After applying the trend corrections, such a set of data have been subjected to harmonic analysis for each day [8]. Average values of the amplitude and phase (local time of the station) of the third (tri-diurnal) harmonics on yearly basis have been obtained. According to solar geophysical data five quietest days are selected in a month. Thus 60 quietest days are obtained in a year. These days are called international quiet days (QD). The days with extra ordinary large amplitude if any, have not been considered. Further, the variation in the tri-diurnal anisotropy with the reversal of polarity of solar magnetic field (PSMF) on 60 QD has also been investigated. Also all those days having more than three continuous hourly data missing are discarded.

3. Results and discussion

The percentage occurrence of days during the years 1985, 1986 and 1987 for the amplitude (%) and phase (Hrs) of tri-diurnal anisotropy of CR intensity for Deep River on (A) five most quiet days (QD), (B) ten quiet days and (C) all days have been plotted on histograms in figures 1A, B, C, 2A, B, C and 3A, B, C respectively. It is quite apparent from figure 1 that the distribution of the phase of third harmonics for 60 QD, the peak is quite sharp; most of the days occur in the interval of 2–3 h. The distribution of phase for 120 QD and for all days are broader in contrast. Nevertheless, the peak remains statistically significant. Similar conclusions are drawn from the plots of histogram of the phases for the above three types of days during the years 1986 and 1987 from figures 2 and 3. Thus three types of studies performed with different approaches lead to the same conclusion. However, this also brings out the fact that five most quiet days are better suited to study the daily variation of CR intensity on long-term basis as well as short-term basis.

The yearly average amplitude and phase of the third harmonics of daily variation along with average values of *Ap* indices on quiet days, solar wind velocity and PSMF in the northern and southern hemisphere of the Sun from Deep River

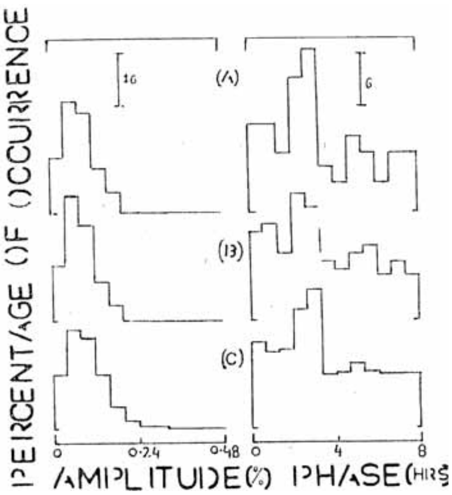

Figure 1. The histographic plots of (A) 60 quiet days (B) 120 quiet days and (C) all days for the amplitude (%) and phase (h) of third harmonics of CR intensity at Deep River Neutron Monitoring Station during the year 1985.

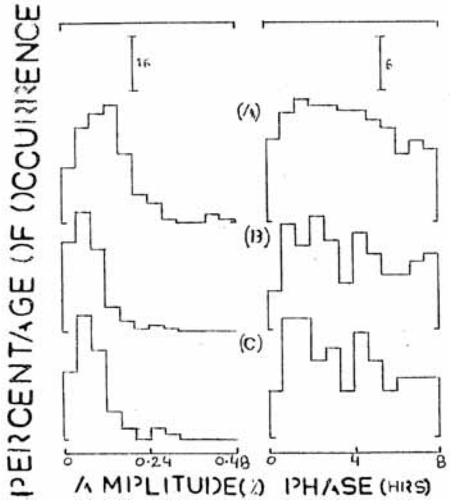

Figure 2. The histographic plots of (A) 60 quiet days (B) 120 quiet days and (C) all days for the amplitude (%) and phase (h) of third harmonics of CR intensity at Deep River Neutron Monitoring Station during the year 1986.

Neutron Monitoring Station have been plotted in figure 4 during the period 1978–94 on quiet days. It is quite apparent from figure 4 that the amplitude of third harmonics of daily variation has quite abruptly increased during the years 1980 and 1985. The likely cause for such variation could be the change in geomagnetic threshold cut-off rigidity from 1.02 GV to 1.15 GV in 1980 and from 1.02 GV to 1.12 GV in 1985 respectively [9–11] as it has been discussed in the case of change of diurnal anisotropy of cosmic ray intensity on QD [12]. The amplitude of tri-diurnal anisotropy on QD has shown an exceptionally small value during 1987 and 1994, which is a period of minimum solar activity [13]. The amplitude of third harmonics of daily variation on QD is observed to be significantly low during 1981 as well as in 1990, which coincides with phase reversal of the solar poloidal magnetic field [14,15]. Further, during the years 1985 and 1986, the years of minimum solar activity, the amplitude of third harmonics on QD is significantly high, which support the earlier finding [15]. The yearly error @ 0.006% contained in the amplitude of third harmonic on QD. It is also observed from figure 4 that there is no systematic change in the phase of third harmonics of daily variation in cosmic ray intensity on quiet days. However, a slight change in the tri-diurnal phase is observed, when the polarity of solar magnetic field reversed its polarity during the periods 1979–80 and 1990–91 [14]. It shows that the phase of tri-diurnal anisotropy on quiet days has nearly the same value on both sides of reversal period. But in both the cases during the succeeding years, i.e., 1980–81 and 1991–92, the change in the phase of tri-diurnal anisotropy of CR intensity has been found to be quite significant [16]. It is clear that there exists a 11-year variation in third harmonics of CR intensity

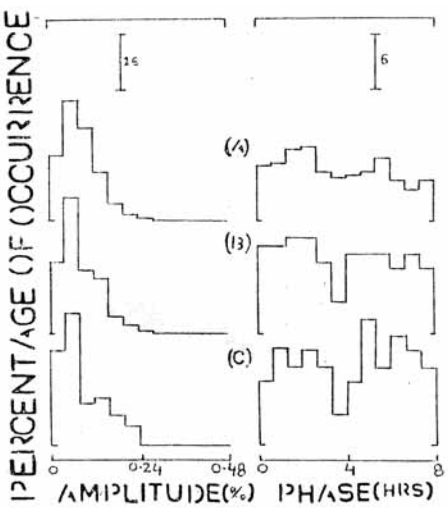

Figure 3. The histographic plots of (A) 60 quiet days (B) 120 quiet days and (C) all days for the amplitude (%) and phase (h) of third harmonics of CR intensity at Deep River Neutron Monitoring Station during the year 1987.

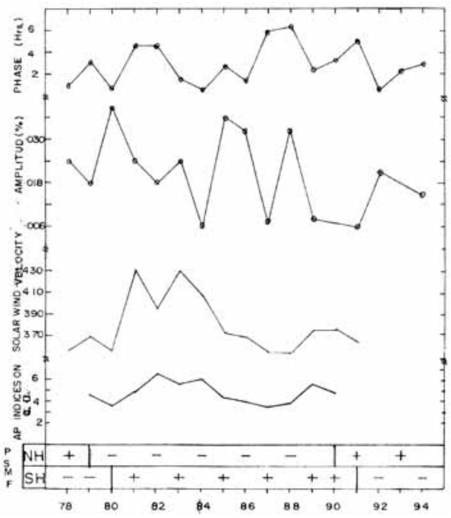

Figure 4. Amplitude (%) and phase (h) of third harmonics along with average values of *Ap* indices on quiet days. Solar wind velocity and PSMF in the Northern and Southern hemispheres of the Sun at Deep River Neutron Monitoring Station during 1978–94.

on QD due to the variation of solar activity [17]. The polarity dependence of the change in phase-shift has been interpreted as due to the change of CR density distribution in space caused by the difference of CR drift motion in the positive and negative polarity states [18–21].

It is apparent from figure 5 that no systematic variation is observed in the amplitude and phase of the third harmonics of daily variation. However, some of the significant observations are such that the amplitude has decreased during the year 1990, which coincides with phase reversal of the solar poloidal field [14]. It is observed that the amplitude is statistically neatly constant high value during the years 1986–88. The amplitude of the tri-diurnal anisotropy of CR intensity has been observed almost equal during the two consecutive solar maximum activity periods, i.e., years 1979 and 1991, of solar cycles-21 and 22 supporting 11-year variation in the tri-diurnal anisotropy of CR intensity on quiet days [22]. Further, the amplitude of third harmonics during the years 1982 and 1994 (difference of 11 years) have the same value, which again confirm the 11-year variation in third harmonics of daily variation. The yearly error @ 0.005% contained in the amplitude of third harmonic on quiet days. Furthermore, it is also apparent from figure 5 that the phase has been observed during the year 1987–90 into later hours. However, a significant change towards earlier hours is observed in the phase of tri-diurnal anisotropy, when the polarity of solar magnetic field is reversed during the period 1990–91 [16].

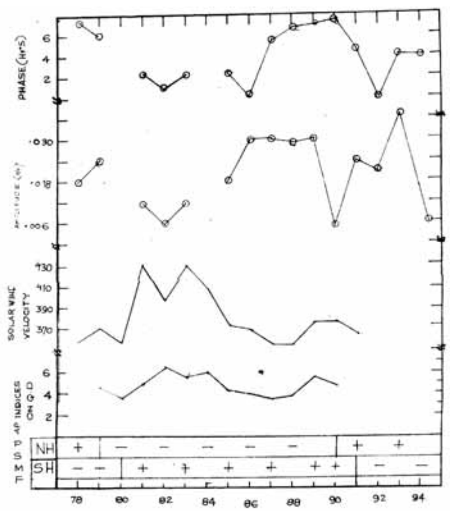

Figure 5. Amplitude (%) and phase (h) of third harmonics along with average values of *Ap* indices on quiet days. Solar wind velocity and PSMF in the Northern and Southern hemispheres of the Sun at Goose Bay Neutron Monitoring Station during 1978–94.

4. Conclusions

The following conclusions may be drawn from the present investigation of cosmic ray intensity data recorded in Deep River Neutron Monitoring Station.

1. The amplitude of tri-diurnal anisotropy of CR intensity on QD has abruptly increased due to change in threshold cut-off rigidity of the station.
2. The amplitude of tri-diurnal anisotropy on QD have small value during the years 1987 and 1994, which is the period of minimum solar activity.
3. The amplitude of third harmonics of daily variation on QD during 1981 and 1990 is significantly low, which coincides with the phase reversal of solar poloidal magnetic field.
4. The tri-diurnal anisotropy of CR intensity on QD has shown long-term variation, i.e., 11-year variation.
5. The tri-diurnal phase is shifted to later hours during the negative polarity of PSMF in NH whereas it is shifted to early hours during positive polarity of PSMF in NH. Since the phase-shift of tri-diurnal anisotropy towards early/later hour has been attributed to the change in the polarity of the PSMF, it may be derived from here that this phase-shift is due to drift effect.

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References

[1] A Fujii, K Nagashima, K Fujimoto, H Ueno and I Kondo, *12h ICRC, Hobart Tasmania* **2**, 666 (1971)
[2] H S Ahluwalia and S Singh, *Proc. 13th Int. Cosmic Ray Conf. Australia*, vol. 2, p. 948 (1973)
[3] H S Ahluwalia and S Singh, *Proc. 13th Int. Cosmic Ray Conf. Australia*, vol. 5, p. 3129 (1973)
[4] M A Pomerantz and S P Duggal, *Space Sci. Rev.* **12**, 75 (1971)
[5] U R Rao, *Space Sci. Rev.* **12**, 719 (1972)
[6] D Venkatesan and Badruddin, *Space Sci. Rev.* **52**, 121 (1990)
[7] S P Agrawal, *J. Geophys. Res.* **86**, 10115 (1981)
[8] S Kumar, R Agrawal, R Mishra and S K Dubey, *Bull. Astron. Soc. India* **30**, 451 (2002)
[9] M A Shea and D F Smart, *18th Int. Cosmic Ray Conf., Bangalore*, vol. 3, p. 411 (1983)
[10] D F Smart and M A Shea, *20th Int. Cosmic Ray Conf., Moscow* (1987) vol. 4, p. 204
[11] M A Shea and D F Smart, *27th Int. Cosmic Ray Conf., Hemberg* (2001) vol. 3, p. 4063
[12] S Kumar, U Gulati, D Khare and M K Richharia, *Bull Astron. Soc. India* **21**, 395 (1993)
[13] S Kumar, M K Richharia, M L Chauhan, U Gulati, D K Khare and S K Shrivastava, *24th Int. Cosmic Ray Conf., Rome, Italy* (1995) vol. 4, p. 623
[14] S Kumar, S K Shrivastava, S K Dubey, M K Richharia and U Gulati, *Ind. J. Radio and Space Phys.* **27**, 236 (1998)
[15] S Kumar, M K Richharia and S K Shrivastava, *Proc. Natl. Acad. Sci. India* **69A**, II, 231 (1999)
[16] El Borie, M A Sabbah, A A Darwish and A A Bishra, *24th Int. Cosmic Ray Conf., Rome, Italy* (1995) vol. 4, p. 619
[17] El Borie, M A Sabbah, A A Darwish and A A Bishra, *24th Int. Cosmic Ray Conf., Rome, Italy* (1995) vol. 4, p. 603
[18] K Munakata and K Nagashima, *Planet Space Sci.* **34**, 99 (1986)
[19] K Nagashima, R Tatsuoka and K Munakata, *Planet Space Sci.* **34**, 469 (1986)
[20] S Kumar, R Agrawal, R Mishra, S K Dubey and M K Richharia, *Indian J. Phys.* **76B(3)**, 259 (2002)
[21] K Nagashima and K Fujimoto, *Planet Space Sci.* **37**, 1421 (1989)
[22] M K Richharia, S K Shrivastava and S Kumar, *Pure Appl. Phys.* **11(1)**, 11 (1999)