Average Anisotropy Characteristics of High Energy Cosmic Ray Particles and Geomagnetic Disturbance Index Ap

C. M. Tiwari[1], D. P. Tiwari[1], Ajay K. Pandey[1] & Pankaj K. Shrivastava[2]
[1]*Department of Physics, A.P.S. University, Rewa (MP) 486 003, India.*
e-mail: tiwaricm123@rediffmail.com
[2]*Department of Physics, Govt. Model Science College, Rewa (MP) 486 001, India.*
e-mail: pankaj_in_2001@rediffmail.com

Abstract. The average characteristics of the diurnal and semi-diurnal anisotropy of cosmic ray intensity at relativistic energies have been obtained by using data from the worldwide grid of neutron monitor for the period 1989 to 1996. The complex behaviour of the diurnal amplitudes and time of maxima (phase) and its association with the Ap index on a long-term and day-to-day basis have been studied. Even though the general characteristics, on a yearly average basis, have not changed significantly during this period, both the diurnal and semi-diurnal amplitudes and phases vary significantly, besides significant changes being observed for different interplanetary conditions on a short-term basis. It is found that the relationship between the Ap index and the diurnal vector is out of phase during the period 1991 to 1995. On a long-term basis, the correlation of diurnal variation with Ap index has been found to vary during the solar cycle. On a short-term basis, it has been observed that the high Ap days are usually associated with higher amplitudes with phase shifted to earlier hours.

Key words. Cosmic rays—anisotropic variation—geomagnetic disturbances.

1. Introduction

Long-term variability (11 yr/22 yr) periodicity in diurnal variation of cosmic ray intensity was proposed as early as in 1953 (Thambyahpillai & Elliot 1953). Changes in amplitudes and time of maxima (phase) have been studied by a number of investigators (Rao 1972; Forbush 1973; Agrawal 1983; Shrivastava 1990; Tiwari 2001; Tiwari *et al.* 2003). Characteristics of daily variation were also investigated on a day-to-day basis for different interplanetary conditions using Ap index for the interval period 1968 to 1974 (Sharma *et al.* 1978). Ap value is a geomagnetic disturbance index, which is recorded by magnetometers/magnetograms. The quantitative values of the geomagnetic field are obtained by formulating the geomagnetic indices. A characteristic of the study of geomagnetic field variation of magnetic activity over the earth surface is a complicated task. However, this has been done through the use of magnetic indices (Mayaund 1980). Ap and Kp are examples of such indices, which provide physical

significance of field variation. Shrivastava & Shukla (1993) have reported a significant influence of high-speed solar wind streams on geomagnetic activity enhancement. Further Shrivastava & Shukla (1996) reported that there is a high correlation between solar wind velocity and Ap index. As we know from convection diffusion approximate theory, solar wind velocity plays an important role in cosmic ray modulation. In the absence of solar wind data, one can use the daily values of Ap index. Since Ap values are well correlated with solar wind velocity, we can use Ap values to explain the anisotropic variation in border areas. High- and low-Ap values also indicate disturbed and quiet interplanetary medium. In this paper, we have critically examined the relationship of diurnal/semi-diurnal amplitude and phases with geomagnetic disturbance index (Ap) for the period 1989 to 1996.

2. Results and discussion

The temperature and pressure corrected hourly data (counts of neutrons) of cosmic ray intensity from two neutron monitors have been used to obtain the amplitude and phase of the harmonic component for each day by Fourier techniques, where the long-term change from the data has been removed by the method of 24-hour moving average. The days of Forbush decreases have also been removed from the analysis to avoid associated superposed variation in cosmic rays. A complete computer program is made to calculate the harmonics of every day for the period 1989 to 1996. The yearly mean values with their standard errors have been obtained from these daily vectors. Geomagnetic disturbance index Ap is found to be a very good proxy of the interplanetary conditions. The low values of Ap index of geomagnetic activity indicate quiet periods, thereby signifying quiet conditions of the interplanetary medium. For this we have chosen (1) days for which Ap ≤ 8 and derived the amplitude and phases for such days, which are again averaged to get the yearly mean value. Likewise other criteria are Ap values ranging between 9–17, 18–26, 27–53 and Ap ≥ 54. Higher Ap groups are an indicator of disturbed interplanetary medium.

As mentioned earlier the statistical relationship between Ap and amplitude (r_1) and also with time of maximum (ϕ_1) of diurnal variation of all on a day-to-day basis was found to change drastically, during the period 1968 to 1973 (Sharma *et al.* 1978; Agrawal *et al.* 1995). In fact, it has been demonstrated that the Ap index is highly correlated with the mean fluctuations in the amplitude of the interplanetary magnetic field, which in turn is related to the diffusive component of the convection–diffusion theory. Moreover, Ap is also found to be related to the solar wind velocity, which is related to convective component (Sabbah *et al.* 1996). It is therefore, natural to look for the relationship between Ap and diurnal/semi-diurnal variation for the recent period also.

To obtain the relationship between Ap index with diurnal and semi-diurnal anisotropy on a day-to-day basis, we have taken the cosmic ray data from two stations Kiel (cut-off rigidity $\approx 2.32\,\text{GV}$) and Tokyo (cut-off rigidity $\approx 11.50\,\text{GV}$) covering the high and low cut-off rigidity. The vector average of diurnal and semi-diurnal variation has been obtained by dividing all good days in five groups of Ap values. To understand the variational effects of the solar output during the period of study, the analysis has been extended on a day-to-day basis by using the daily geomagnetic Ap index as the proxy for interplanetary disturbances. For each year, the averages for the diurnal variation for five groups of Ap days have been calculated, and are shown in Fig. 1, for each year from 1989 to 1996. Hourly count rates of cosmic ray neutrons
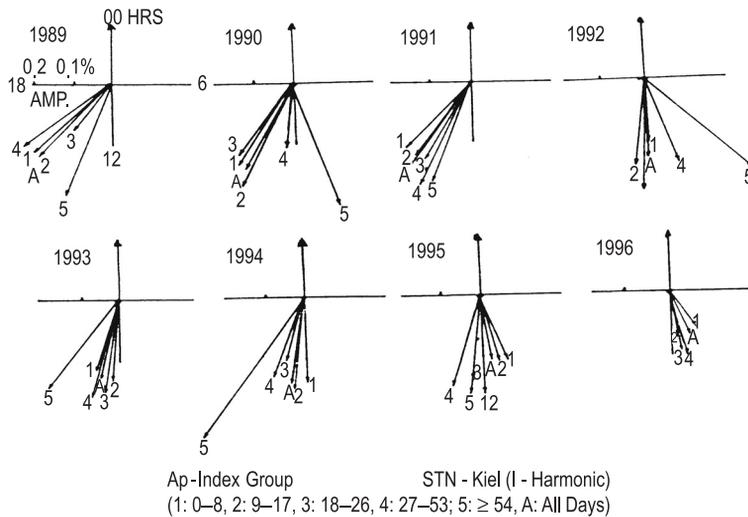
Figure 1. Shows the harmonic dial representation of the diurnal vectors (first-harmonic) for various groups of Ap days, for each year from 1989 to 1996. Group 1 of Ap days comprise of most quiet days, whereas Ap days in group 5 are mostly disturbed days. The average diurnal vectors for each year for all "good days" represented by "A" are for Kiel neutron monitoring station.

are monitored at Kiel and Tokyo neutron monitor stations. These 24-hour counts are used to derive the amplitude and time of maxima by adopting the harmonic analysis techniques. The divisions of days are according to increasing values of Ap index (0–8, 9–17, 18–26, 27–53, and Ap $\geq$ 54). However, there is no significance of the fifth group as these days are highly disturbed days. Figure 1 shows the change in diurnal variation with Ap for Kiel station and demonstrates exactly similar variation except the years 1992 and 1996. Further it reveals a complete reversal of the vector from 1 to 4 as the period of maxima to minima approaches. It is seen that in the years 1989 to 1992 and with the increasing values of Ap index the time of maximum shifts to earlier hours, with amplitudes remaining almost constant (except for the group of most disturbed days – group 5), whereas during 1993 to 1995 the situation is just reverse. Such behaviour was also reported during the interval 1968 to 1974. It was reported that in the year 1969 (high sunspot activity period), with the increasing value of Ap index, the time of maximum shifts to earlier hours, whereas during 1973, it was found to shift to later hours (Agrawal & Singh 1975). This indicates that once again the interplanetary conditions must be drastically changing during this period of our study. Figure 2 shows the result of similar analysis for Tokyo stations. The vector average values for each group and for each year from 1989 to 1996 for Tokyo stations are plotted in this figure. It is observed that for low Ap group the dispersion from one period to another is least in both the amplitude and phase. However, the dispersion is large for two higher Ap index groups particularly for Ap, 27–53 and Ap $\geq$ 54 (groups 4 and 5). It is also noticed that the amplitude (r) increases with Ap result consistent with earlier findings (Sharma *et al.* 1978). Nevertheless, it appears that the vectors associated with high Ap values having large amplitude and large scatter-diagrams are composed of real extra-terrestrial anisotropy and that the variation of terrestrial origin which could be due to universal time variations, cut-off rigidity changes correlated
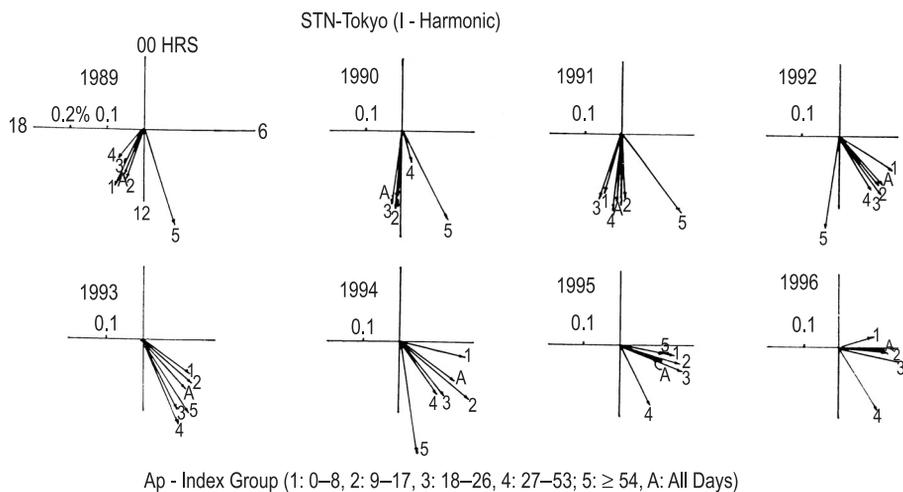
STN-Tokyo (I - Harmonic)

Ap - Index Group (1: 0–8, 2: 9–17, 3: 18–26, 4: 27–53; 5: ≥ 54, A: All Days)

Figure 2. Similar to Fig. 1, but for Tokyo neutron monitor data.

STN - Kiel (II - Harmonic)
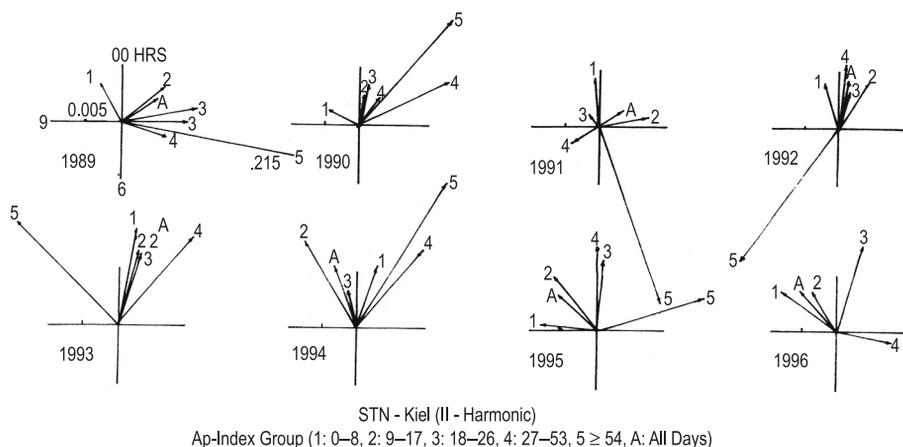Ap-Index Group (1: 0–8, 2: 9–17, 3: 18–26, 4: 27–53, 5 ≥ 54, A: All Days)

Figure 3. Shows the harmonic dial representation of the semi-diurnal vectors (second-harmonic) for various groups of Ap days, for each year from 1989 to 1996. Group 1 of Ap days comprises of most quiet days, whereas Ap days in group 5 are mostly disturbed days. The average diurnal vectors for each year for all "good days" represented by "A" are for Kiel neutron monitoring station.

with geomagnetic field variations, and/or due to inadequate atmospheric pressure correction. During the year 1989–1992, the diurnal time of maximum is found to shift to earlier hours with the increasing values of Ap index, which is in complete agreement with earlier findings (Agrawal & Singh 1975). The complete reversal of the nature of Ap and ϕ_1 during the years 1989–1992 and earlier, is not very suppressing due to the fact that Ap has increased during 1989–1992 though it was expected to decrease in this period, and that ϕ_1 has shown a large change is not seen. It may be noted that the relationship is not so clear during most of the years. Figure 3 shows the similar harmonic dial for semi-diurnal vectors in all five groups for Kiel stations cosmic ray data. Similarly, Fig. 4 shows the results for Tokyo neutrons. Large variations in
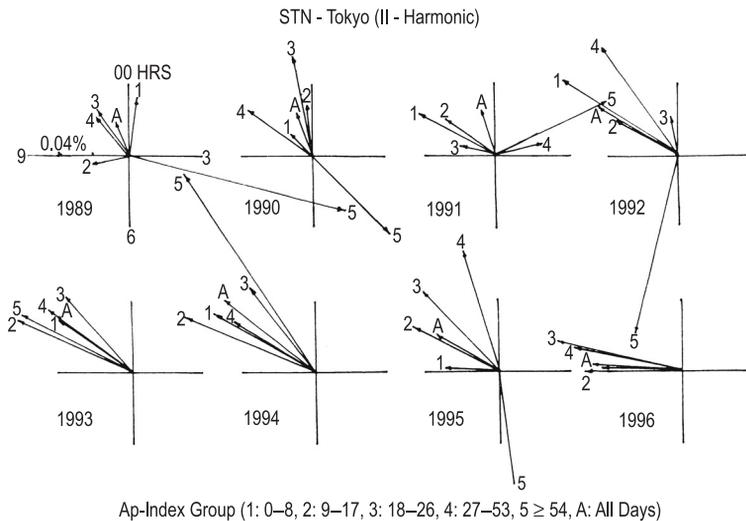
STN - Tokyo (II - Harmonic)

Ap-Index Group (1: 0–8, 2: 9–17, 3: 18–26, 4: 27–53, 5 ≥ 54, A: All Days)

Figure 4. Similar to Fig. 3, but for Tokyo neutron monitor data.

average vectors for all the five groups are seen. Moreover, no definite trend in the semi-diurnal variation with Ap is established. However, increase in its amplitude is found with the increasing value of Ap index. The results of the analysis reported here has two components: firstly the long-term variation of the diurnal anisotropy, i.e., the change in the overall values of the annual average diurnal amplitude and phase. It is observed that in a typical high/middle latitude neutron monitor station such as Kiel, the diurnal amplitude is substantially high during the maximum phase of the sunspot cycle, whereas the diurnal amplitude is quite small during decreasing phase and more so in the minimum phase of the sunspot cycle. Secondly, when the days are distributed as per the degree of interplanetary disturbances (proxy based on Ap), one finds that the behaviour of the diurnal variation is quite different during the two periods mentioned above. The diurnal time of maximum rotates to earlier hours during maximum phase whereas it rotates to later hours during the declining phase of the solar activity. The two contradictory situations can be qualitatively understood in terms of two different types of interplanetary conditions prevailing during different phases of the sunspot activity cycle.

In this context, it is now well known that there are two types of solar wind streams, one associated with solar flares and the other associated with solar coronal holes occurring in exclusion with each other, i.e., the first occurring abundantly during maximum phase of sunspot activity, whereas the other, coronal holes associated streams, abundantly occurring during declining phase of the solar activity. Such a difference can be associated with the peculiar observations reported here, however, the mechanism is not yet fully understood.

In this context, it is also pertinent to note that the short-term cosmic ray intensity variations have been reported to be quite different for the two types of solar wind streams. The coronal hole associated high speed solar wind streams do not produce any large decrease in cosmic ray intensity, in contrast to very large Forbush type cosmic ray decreases associated with high velocity solar flare streams (Venkatesan *et al.* 1982; Shrivastava & Shukla 1994, 1996). The spectral exponent of

the cosmic ray variation was also reported to be quite different in the two cases. As such the nature of observed anomalous changes in the diurnal variation and their relation with Ap index does not reveal the exact mechanism, which is operative during the period of study.

The results may lead to an easy way out to predict the occurrence of the solar phenomena from ground-based cosmic ray observations.

3. Conclusions

The analysis presented leads to the following conclusions:

- It is found that in diurnal anisotropy for low Ap group of dispersion from one year to another is least particularly in amplitude (Ap values ranging between 27 to 53 and Ap $\geq$ 54). However, the dispersion is large for high Ap values (groups 4 and 5).
- Time of maxima (phase) for diurnal anisotropy shifts to earlier hours for the period 1992 to 1996.
- The semi-diurnal amplitude and phase have not changed very significantly except in later periods associated with high values of Ap index (groups 4 and 5).
- The semi-diurnal amplitude and phase associated with low Ap values are more coherent and are probably representative of the true extra-terrestrial anisotropy, whereas large increase in amplitudes and variability during high Ap days could be related to terrestrial origin.

Acknowledgements

References

Agrawal, S. P., Shrivastava, P. K., Shukla, R. P. 1995, *Proc. 24th Int. Cos. Ray Conf. Italy*, **4**, 932.
Agrawal, S. P. 1983, *Space Sci. Rev.*, **34**, 127.
Agrawal, S. P., Singh, R. L. 1975, *Proc. 14th Int. Cos. Ray Conf. Munich*, **3**, 1253.
Forbush, S. E. 1973, *J. Geophys. Res.*, **78**, 7933.
Forman, M. A., Gleeson, L. J. 1975, *Astrophys. & Space Sci.*, **32**, 771.
Mayaund, P. N. 1980, Geographical Monograph, 22 AGU, Washington, D.C., USA.
Rao, U. R. 1972, *Space Sci. Rev.*, **12**, 719.
Sabbah, I., El-Borie, M. A., Pandey, A., Shrivastava, P. K. 1996, *Indian J. Phys.*, **70B(5)**, 367.
Sharma, R. M., Nigam, S. K., Singh, R. L., Agrawal, S. P. 1978, *Indian J. Radio & Space Phys.* **7**, 210.
Shrivastava, P. K., Shukla, R. P. 1996, *Bull. Astr. Soc. India*, **24**, 663.
Shrivastava, P. K. 1990, *Proc. 21th Int. Cos. Ray Conf. Adelaide*, **6**, 353.
Shrivastava, P. K., Shukla, R. P. 1993, *Proc. 23rd Int. Cos. Ray Conf. Calgary, Canada*, **3**, 590.
Shrivastava, P. K., Shukla, R. P. 1994, *Sol. Phys.*, **154**, 177.
Shrivastava, P. K., Shukla, R. P. 1996, *J. Astron. Astrophys.*, **16**, 297.
Tiwari, C. M. 2001, Ph.D. Thesis, A.P.S. University, Rewa, India.
Tiwari, C. M., Agrawal, S. P., Tiwari, D. P., Elbori, M. A., Shrivastava, P. K. 2003, *Curr. Sci.*, **3(1)**, 219.
Thambyab Pillai, T., Elliot, H. 1953, *Nature*, **171**, 918.
Venkatesan, D., Shukla, A. K., Agrawal, S. P. 1982, *Sol. Phys.*, **81**, 375.