COMPARATIVE STUDY OF DIURNAL AND SEMIDIURNAL ANISOTROPIES IN CR INTENSITY FOR THE PERIOD 1964–95

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 Deep River neutron monitor data has been harmonically analysed for the period 1964–95 covering three solar cycles 21, 22 and 23 for looking the long term trend of the diurnal and semi-diurnal anisotropies of cosmic ray intensity on geomagnetically 60 quiet days. The amplitude of both the harmonics remains statistically constant during 1964–70. The amplitudes of the first harmonic is found to be low during 1965, 1976–77, 1987 and 1995 which are the periods of minimum solar activity. The amplitude of diurnal anisotropy acquired exceptionally large value in 1985 whereas semi-diurnal anisotropy acquired large values in 1974–75 and in 1984, which are the epochs of high speed solar wind stream (HSSWS). The phase of the diurnal anisotropy has shifted to earlier hours in 1973 and 1995 whereas the phase of semi-diurnal anisotropy has significantly shifted to earlier hours during 1967, 1977, 1981–82, 1990–91 and 1995, the periods close to minimum solar activity. The phase shows a shift to later hours during 1964, 1979 and 1986.

1. Introduction

A number of physical mechanisms for causing different harmonics of daily variation have been proposed from time to time. The diurnal anisotropy is caused by the streaming of particles in interplanetary space, due to convection, diffusion, adiabatic deceleration and particle drifts. Subramanian and Sarabhai (1967) and Quenby and Lietti, (1968) both attributed the origin of semi-diurnal anisotropy to symmetric latitudinal cosmic ray density gradient in the heliosphere with particle density rising on both sides of the equatorial plane (Kota, 1975). According to Nagashima et al. (1972a) semi-diurnal anisotropy arises mainly as a result of the contribution from the pitch angle scattering rather than in the manner suggested by Subramanian and Sarabhai (1967) and Quenby and Lietti (1968). Recent data acquired by Ulysses spacecraft during its fast heliolatitude scan shows that the latitude distribution of GCR has both symmetric and asymmetric components (Simpson et al. 1996, Heber et al., 1996). According to Ahluwalia and Fikani (1996a, b) the contribution of the symmetric transverse gradient to semi-

pp. 4011–4019

diurnal anisotropy is minimal and the larger contribution comes from some other source(s). Nagashima's treatment also implies that semi-diurnal and tri-diurnal anisotropies have common features. This is observed by many workers (Ahluwalia, 1977; Agrawal, 1981; Ahluwalia and Fikani, 1991). Bieber and Pomerantz (1983) proposed the unified theory of cosmic ray diurnal variation. A careful investigation of the characteristics of the different components of the daily variation is therefore important in contributing towards understanding the mechanism.

2. Experimental data and analysis

Pressure corrected data of Deep River neutron monitoring (NM) station (cutoff rigidity 1.02 GV; latitude 46.1° N; longitude 282.5° E; altitude 145 M) has been Fourier analysed after applying trend corrections to obtain the first and second harmonics at ground for the period 1964–95. According to solar geophysical data five quietest days are selected in a month; thus 60 quietest days in a year. These are called International Quiet Quiet days or QQ days. The study of diurnal and semi-diurnal variation has been performed on 60 QQ for the period 1964–95. The justification for the selection of only geomagnetic quiet days for the analysis purpose has been discussed elsewhere. The days with extraordinarily large amplitude, if any, have not been taken into consideration. Also all those days are discarded having more than three continuous hourly data missing.

3. Results and Discussion

The average annual diurnal and semi-diurnal phases ϕ_1 and ϕ_2 (Hr, LT), amplitudes R_1 and R_2 (%), Ap index, resolved components of R_1 and R_2 along the two perpendicular directions on 60 QD for Deep River neutron monitoring station and the polarity of SPMF in the northern hemisphere (NH) and southern hemisphere (SH) of the Sun for the period 1964–95 have been plotted in Fig 1 and 2.

It is observable from Figs 1 and 2 that the amplitudes R_1 and R_2 is smaller during the years 1964–65, 1976–77, 1986–87 and 1995 as compared to its preceding two years. These are the periods of minimum solar activity. Ahluwalia et al. (1990) observed large values of diurnal amplitude during high solar activity and low values when the activity is low. The amplitude of semi-diurnal variation is found to be proportional to the solar activity (Fujii, 1971). El-Borie et al. (1995b) observed low values of semi-diurnal variation near the years of solar activity minimum. Pransky et al. (1991) using ionization chamber data for the period 1954–89 obtained similar results of decrease in amplitude during 1964, 76 and 86 i.e. the years of minimum solar activity. They also noticed the decrease in amplitude during magnetic field inversion of the Sun. The decrease in amplitude during solar activity minimum may be explained by decrease in regular component of

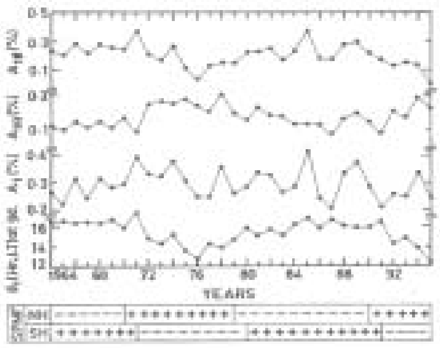

Fig. 1. The phase ϕ_1 (Hr, LT), amplitude R_1 (%), radial component R_{1R} (%) and east-west component $R_{1\phi}$ (%) at ground of the annual diurnal anisotropy in cosmic ray intensity on 60 QD plotted alongwith SPMF polarity in NH and SH for the period 1964–95

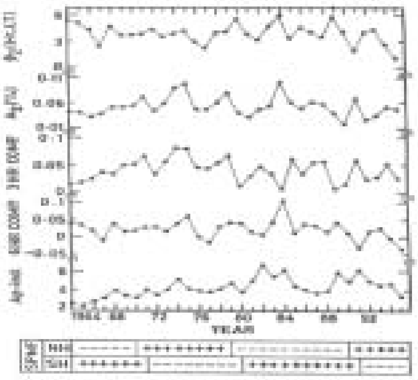

Fig. 2. The phase ϕ_2 (Hr, LT), amplitude A_2 (%), 6 Hr component, 3 Hr component alongwith values of Ap-index on 60 QD and polarity of SPMF in NH and SH has been plotted for the period 1964–95

the interplanetary magnetic field intensity. The reason for decrease in amplitude during magnetic field inversion has been thought to be due to increase of IMF irregularities originated from solar polar coronal holes. On the contrary Ahluwalia and Fikani (1991) using the muon telescope data for the period 1966–88 observed increase in the amplitude after the epochs of SPMF reversal. They also observed the amplitudes to be smaller when the solar activity is low, which is in agreement with the findings of Pransky et al. (1991). Pandey et al. (1990) observed the diurnal vectors to be composed of, a static vector with its amplitude 0.47% from the 16.8 hour direction, the ∼11- year wave and the ∼22-year wave for the period 1955–84. Krivoshapkin et al. (1973) found that the main contribution in diurnal anisotropy is made by convection-diffusion mechanism with the maximum time 17–18 hour. The contribution of the anti-symmetric diurnal variation is negligibly small whereas the radial source contributes much larger percentage.

The amplitude of both the harmonics remains statistically constant during 1964–70. The small changes in the diurnal amplitude may be attributed to the variation of maximum cutoff rigiditity R_{max} (Agrawal and Singh, 1975a). The regime of invariant diurnal anisotropy prevails all through the period 1957–70 i.e., for 14 years. Charged particle drifts do not make any identifiable contribution to the diurnal anisotropy during this period (Ahluwalia, 1988).

The amplitude of diurnal and semi-diurnal anisotropy is observed to be high during declining phase of SAC 20, 21. Ahluwalia and Riker (1987) observed large values of diurnal amplitude during 1973–75; whereas, Ahluwalia et al. (1990) observed similar large values of diurnal amplitude for the period 1984–85 at Deep

River. Pathak et al. (1983) reported an increase in the amplitude of semi-diurnal as well as tri-diurnal anisotropy during the period 1973–75 by a factor of two. Fikani et al. (1991) using the Deep River NM data for 1966–88 observed a broad enhancement in the amplitude for the year 1973 through 1976. Agrawal (1981) has pointed out that the amplitudes of semi-diurnal as well as tri-diurnal anisotropies increase during 1973–75. It has been suggested that such an increase is associated with the days of high-speed solar wind streams (HSSWS) originated from solar polar coronal holes. The interaction between HSSWS and Earth's magnetosphere transfers a vital information to the magnetosphere, which manifests itself in changes in geomagnetic activities as monitored by its geomagnetic indices Ap and aa (Schatten et al., 1978, Schatten and Pensell, 1993). A relationship exists between solar wind velocity, Ap and southward component of IMF. The present study performed on 60 QD leads to high value of amplitude of diurnal and semi-diurnal anisotropy during the years 1973–74 and 1984–85 which is in agreement with the findings of Ahluwalia et al. (1990) for diurnal anisotropy and El-Borie et al. (1995b) for semi-diurnal anisotropy. Nigam et al. (1983) have observed the semi-diurnal amplitude to be low during 1973, which has been attributed to HSSWS from the coronal holes, in contradiction to the findings of Ahluwalia et al. (1990). Kudo and Mori (1990) showed the 11-year periodicity of the amplitude enhancement in the solar diurnal variation of cosmic rays in the declining periods of solar activity. Using the data from the world-wide neutron monitors including Deep River for the period 1957 to 1987 they found that observed amplitudes show minimum in 1954, 64, 76 and 86 when the sunspot numbers are minimum. They noticed the enhancement in amplitudes in 1962–63, 1973–74 and 1984–85 and suggested that these enhancements may be correlated with the interplanetary plasma parameters and the structure of the heliomagnetic fields. Diurnal amplitude depends on IMF magnitude, direction and the solar wind velocity (Sari et al., 1978; Sabbah, 1999a, b). The amplitude of the total diurnal anisotropy varies by 30% following a polarity reversal of IMF — with the cosmic ray anisotropy vector in free space, $A>0$ values less than those when $A<0$ (Potgieter and Van Staden, 1990). The amplitude of diurnal anisotropy has large value during 1971, 78 and 89 which are the periods of polar reversal or lies in proximity of them. The amplitude of semi-diurnal anisotropy increases during the years 1971, 1979 and 1991 followed by the decrease for all the three consecutive epochs of SPMF inversions. The changes in amplitude are significantly high during the polarity reversal of 1979–80 and 1990–91, however they are less prominent during the polarity reversal of 1970–71. On the contrary, Ahluwalia and Fikani (1996b) denied the effect of the polarity of IMF on semi-diurnal anisotropy parameters (amplitude as well as direction).

There is a sharp decrease in diurnal amplitude during the year 1986 as compared to that during 1985 and remains low during the year 1987; which is in accordance with the findings of Ahluwalia et al. (1990) for Deep River neutron monitor for the period 1980–87. It remains almost constant for the period 1988–90. It again falls to lower values during 1991 and gradually attains higher values during 1992–94. Le Roux and Potgieter (1990) observed four global merged interaction region (GMIR) during 1977–87. Each simulated GMIR affected cosmic ray intensity for a maximum of two years so that long term modulation for the first and last 2–3 years of the 1977–87 cycle is totally controlled by the changing heliospheric neutral sheet (HNS). Le Roux and Potgieter (1990) according to their 2D model illustrated that the incorporation of GMIR gave a natural and convincing explanation for the observed large step decreases in long term modulation. They concluded that long-term modulation is a process determined by the interplay between the changing waviness of the HNS and the outward propagating GMIRs that originate beyond 10 AU. During times of lower solar activity the HNS controls the modulation because of the absence of large GMIR in the heliosphere; while during times of larger solar activity successive GMIRs dominate the HNS in determining the time variation in long term cosmic ray modulation.

Krainev and Webber (1993) supported the combined MIR-Drift picture of modulation whereas Potgieter and Le Roux (1992) concluded that drifts are of primary importance as long as the waviness of the HNS is moderate (Le Roux and Potgieter, 1990) i.e., tilt angle, $\alpha \leq (35 \pm 5)^\circ$, α is a good indicator of solar activity and this strongly suggests that several years around solar maximum modulation may not be drift dominated. The transition may happen either gradually (1984–87.3; increasing drift effects) or rapidly (after 1987; decreasing drift effects), depending on the rate of change in global solar activity and therefore on global modulation conditions. The rapid increase in solar activity after minimum modulation in 1987 favors a situation where drift occurred progressively less, simply because conditions had deteriorated to the extent that drifts could no longer accumulated on the large time scales required for major long term modulation (Potgieter, 1993). There has been a little increase of diurnal amplitude during 1994 after a decrease observable for all type of days during 1991 which is period of maximum solar activity. Large shock associated flux increases in late 1991.

A high correlation has been noted between the current sheet tilt angle and the neutrons recorded during May–June of 1987, which seems to be directly responsible for the intensity decrease (Webber and Lockwood, 1988). The variation in the amplitude of the diurnal anisotropy $\sim$7% when the neutral sheet tilt angle varies from 0° to 60° when $A<0$ and only 2 % when $A>0$ (Potgieter and Van Staden, 1990).

Ahluwalia (1994b) computed the mean values of the transverse particle density gradient in the heliosphere G_θ for the period 1965–90. The sign of G_θ changes with a change in the solar magnetic polarity. Its computed annual mean value is positive for $qA > 0$ epochs and negative for $qA < 0$ epochs, in accordance with predictions of the drift hypothesis. The magnitude of the transverse gradient is nearly zero for 1973–76, 1981–82 and 1984–85 but has a larger value during 1977–80. Asymmetric gradients become unstable after 1973 (Ahluwalia and Sabbah, 1993). Ahluwalia and Fikani (1996b) observed the high value of the amplitude of semi-diurnal anisotropy during 1972–77 and low values for the period 1978–80. The semi-diurnal anisotropy is most persistent during the period when transverse gradients (symmetric as well as asymmetric) are unstable or non-existent. They suggested that the contribution from the symmetric transverse gradients ($G_{\theta s}$) to semi-diurnal anisotropy appears to be minimal and a major contribution comes from pitch angle scattering. According to Nagashima et al. (1972a) the existence of a negative symmetric gradient enhance the effect of pitch angle scattering. G_θ has large negative value for the years 1986–87. The present study on 60 QD leads to high values of the semi-diurnal amplitude during 1974–75 and 1984 while values obtained during 1977, 1980 and 1986 being $R_2 < 0.05\%$. The results are partially in agreement with findings of Ahluwalia and Fikani (1996b) and Nagashima et al. (1972a). Subramanian and Sarabhai (1967) and Quenby and Lietti (1968) attributed the symmetric latitudinal gradients for the origin of semi-diurnal anisotropy. Thus, it appears as if there are more than one processes active or responsible for the origin of semi-diurnal anisotropy.

The latitudinal cosmic ray gradient contributes to the cosmic ray solar diurnal variation (Swinson et al., 1986). Asymmetric gradients contribute to diurnal and not to semi-diurnal anisotropy (Ahluwalia and Fikani, 1996b). The amplitude of the diurnal anisotropy is determined by many factor besides the transverse gradient. The asymmetric transverse gradient, $G_{\theta a}$ is well behaved over an intermediate rigidity range ($10\text{Gv} \leq R_m \leq 67\text{Gv}$) where it is inversely proportional to the rigidity of the GCR protons. The direction of $G_{\theta a}$ changes consistently immediately after a solar polar field reversal (Ahluwalia and Dorman, 1997). In the real world, both symmetric as well as asymmetric gradients may be present $G_\theta = G_{\theta a} + G_{\theta s}$ (Ichinose et al., 1983). For the period 1965–68, a persistent southward pointing gradient exists. From 1969–73, it points northward. The gradient becomes southward again in 1974, 81, 84, 92 and reverts to being northward in 1975, 79–80, 82–83, 87, 89. The gradient disappears for the period 1976–78, 1985–86, 88. The gradient has large magnitude during the years 1968(s), 1973(n), 1984(s), 1987(n) (Ahluwalia and Dorman, 1997). It is observable from the plots of diurnal anisotropy that the amplitude is high. In 1971, 74, 78, 85, 89, which are the periods close to the periods when the transverse asymmetric gradient has large magnitude in 1975–76. $G_{\theta s}$=0 and have large negative values in 1986–87 when obtained diurnal amplitude found to be very low.

The amplitude of the semi-diurnal variation depends upon the primary rigidity whereas the amplitude of the diurnal anisotropy is independent of the primary rigidity upto a limiting rigidity Rc (Subramanian and Sarabhai, 1967;

Quenby and Lietti, 1968; Pathak, 1972). The amplitude and phase of semi-diurnal variation are rigidity dependent (Ueno et al., 1990). The variational spectrum applicable to semi-diurnal anisotropy may be represented by a double power law, with exponents γ_1 for a range of primary rigidities R $\leq$ Rp and γ_2 for R $>$ Rp; Rp being the peak rigidity. Ahluwalia and Fikani (1996a) found $\gamma_1 = 0.7 \pm 0.3$ and $\gamma_2 = -0.4 \pm 0.2$. The upper cut-off rigidity Rc applicable to diurnal and semi-diurnal anisotropy has higher values near solar activity maxima and low values around solar activity minima. During the epoch when the solar wind speed is high (1973–75, 1982–85) the value of the upper cut-off rigidity is also high when the high amplitudes of diurnal and semi-diurnal amplitudes are observed. A close correspondence exists between the magnitude of IMF and the value of Rc and the peak rigidity Rp. Both exhibits the solar as well as the hale cycle variation (Ahluwalia and Fikani, 1996a). Ahluwalia and Fikani (1996a) with 39 globally distributed detectors and Sabbah (1999a) for Deep River NM coupled with underground meson telescope independently calculated the value of Rc. Rc has low values during 1965, 76–77, 86–87, 1995 and large values during 1968–70, 78–80, 89 and 1991. From the plots of Fig 6.7 it is observable that diurnal amplitude is low in 1964–65, 76–77, 86–877, 91, 95 and has quite large values during 1971, 78 and in 1989. Further, semi-diurnal amplitudes have low values during 1966, 76–77, 90. Thus, a close relationship seems to exist between the amplitude of daily variation and Rc as suggested by Sabbah (1999a). The amplitude of the semi-diurnal variation depends on the azimuthal direction of arrival of the particles incident at an angle of 45° to the zenith; whereas, it is three times larger for the particles coming from south than for those coming from north (Elliot and Dolbear, 1950, 51).

It is observable from Fig 1 that the phase of the diurnal anisotropy remains constant during 1964–70 and then it has started shifting towards earlier hours till 1976. The shift to earlier hours is larger in 1973 and 1995 which are the periods close to minimum solar activity, confirming a ∼22-year periodicity in the phase of diurnal anisotropy. The direction of the diurnal anisotropy is quite variable and rigidity dependent during the epoch that lasted from 1971–79 (Ahluwalia, 1988). The phase of diurnal anisotropy recovered gradually to 18-Hr/ azimuthal/corotational direction from 1976 to around 1986 which is in agreement with the findings of Fujii and Ueno (1990). The long-term behaviour of the diurnal anisotropy especially the phase shift from one solar minimum period to another depends on the polarity of IMF (Van Staden and Potgieter, 1991). During positive IMF polarity (when the IMF pointed away from the Sun above the neutral sheet) period, the phase of the diurnal variation shifts closer to the noon hour than in the case during the negative IMF polarity (when the IMF pointed towards the Sun above the neutral sheet) period (Swinson, 1986). In 1982–85 the IMF pointed towards the Sun above the neutral sheet; while in 1972–78 the

IMF pointed away from the Sun above the neutral sheet. Again during 1992–95, the positive IMF polarity appears which may be associated with a large shift in phase of diurnal anisotropy towards early hours during 1994–95. The phase of the diurnal anisotropy shows a shift to early hours when the polarity of the solar magnetic field in the northern hemisphere changes from negative to positive (Kumar et al., 1998). The polarity of the solar magnetic field changes from positive to negative during 1979–80. During the period from 1981–87 the phase of the diurnal anisotropy recovered to its usual direction of corotation. For the period 1993–95, NH has positive polarity and a large shift in phase of diurnal anisotropy towards early hours is observed.

It is apparent from Fig 2 that the semi-diurnal phase decreases gradually from 1964–67. It is statistically constant for the period 1968–74. The phase shifts to much earlier hours during 1967, 77, 91 and 95. During the polarity reversal of 1979–80 it has shifted to later hours; whereas, during 1990–91 reversal it has shifted to much earlier hours. In the year 1991 the shift in phase is accompanied by large change in the amplitude of the anisotropy.

4. Conclusions

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

1. The amplitude of semi-diurnal anisotropy acquired large value in 1974–75 and in 1984, which are the epochs of HSSWS.
2. The amplitude of diurnal anisotropy acquired exceptionally large value in 1985 and very low value in 1986–87, which may be attributed to the combined HNS and drift effect (Le Roux and Potgieter, 1990).
3. The amplitude of the first harmonic is found to be low during 1965, 1976–77, 87, 95, which are the periods of minimum solar activity or close to it.
4. The phase of the diurnal anisoropy has shifted to earlier hours in 1973 and 95 the periods close to minimum solar activity confirming once again the periodic nature of diurnal anisotropy.

5. References

1. Subramanian G., Sarabhai V. 1967, Astrophys. J. 149, 417.
2. Quenby J.J., Lietti B. 1968, Planet. Space Sci. 16, 1209.
3. Kota J. 1975, J. App. A. 8, 1349.
4. Nagashima, K., Ueno, H., Fujimoto, K., Fujii, Z., and Kondo, I., 1972a, *Rep. Inos. Space Res.*, Japan, **26**, 1.
5. Simpson, J. A., Zhang, M. and Bame, S., 1996, *Astrophys. J.*, **465**, 69.
6. Heber B., Droge W., Kunow H., Muller-Mellin R., Wibberenz G. 1996, Geophys. Res. Lett. 23, 1513.
7. Ahluwalia H.S., Fikani M.M. 1996a, J. Geophys. Res. 101, 11075.
8. Ahluwalia H.S., Fikani M.M. 1996b, J. Geophys. Res. 101, 11087.
9. Ahluwalia H.S. 1977, 15th Int. Cosmic Ray Conf., Plovdiv 11, 298.

10. Agrawal S.P.1981, J. Geophys. Res. 86, 10115.
11. Ahluwalia H.S., Fikani M.M. 1991, 22nd Int. Cosmic Ray Conf., Ireland 3, 461.
12. Bieber J.W., Pomerantz M.A. 1983, Geophys. Res. Lett. 10, 920
13. Kumar S., Agarwal Rekha, Mishra Rajesh, Dubey S.K. 2001, 27th Int. Cosmic Ray Conf., Hamburg SH 3.4, 3966.
14. Ahluwalia H.S., Sabbah I. S., Riker J.F., Fikani M.M. 1990, 21st Int. Cosmic Ray Conf., Adelaide 6, 303.
15. Fujii K., 1971, Iono. Space Res., Japan 25, 242.
16. El-Borie M.A., Sabbah I., Darwish A., Bishara A. 1995b, 24th Int. Cosmic Ray Conf., Rome 4, 619.
17. Pransky I.A., Krivoshapkin P.A., Grigoryev V.C. 1991, 22nd Int. Cosmic Ray Conf., Ireland 12, 21.
18. Pandey P.K., Pathak S.P., Agrawal S.P. 1990, 21st Int. Cosmic Ray Conf., Adelaide 6, 318.
19. Agrawal S.P., Singh R.L. 1975a, 14th Int. Cosmic Ray Conf. 3, 1253.
20. Ahluwalia H.S. 1988, Geophys. Res. Lett. 15, 287.
21. Ahluwalia H.S., Riker J.F. 1987, Planet Space Sci. 35, 39.
22. Ahluwalia H.S., Sabbah I.S., Riker J.F., Fikani M.M. 1990, 21st Int. Cosmic Ray Conf., Adelaide 6, 303.
23. Pathak S.P., Shrivastava P.K., Awasthi D.S., Agrawal S.P. 1983, 18th Int. Cosmic Ray Conf., Bangalore 3, 304.
24. Fikani M.M., Ahluwali, H.S., Sing, S., Sabbah I. 1991, 22nd Int. Cosmic Ray Conf., Ireland 3, 465.
25. Schatten K.H., Scherrer P.H., Svalgaard L., Wilcox J.M. 1978, Geophys. Res. Lett. 5, 411.
26. Schatten K.H., Pensell W.D. 1993, Geophys. Res. Lett. 20, 2275.
27. Nigam S.K., Mishra K.N., Tiwari D.P., Mishra P. Ramesh, Singh R.L., 1983, 18th Int. Cosmic Ray Conf., Bangalore 3, 342.
28. Kudo S., Mori S. 1990, 21st Int. Cosmic Ray Conf., Adelaide 6, 307
29. Sari J.W., Venkatesa, D., Lanzerott, J.J., Maclennan C.G. 1978, J. Geophys. Res.83, 5139.
30. Sabbah I. 1999a, 26th Int. Cosmic Ray Conf., Utah 7, 272.
31. Sabbah I. 1999b, Solar Physics 188, 403.
32. Potgieter M.S., Van Staden M.L. 1990, 21st Int. Cosmic Ray Conf., Adelaide 6, 326.
33. Le Roux J.A., Potgieter M.S. 1990, Ap. J. 361, 275.
34. Krainev M.B., Webber W.R. 1993, 23rd Int. Cosmic Ray Conf., Calgury 4, SH 6.5.3.
35. Potgieter M.S., Le Roux J.A. 1992, Ap. J. 392, 300.
36. Potgieter M.S, 1993, Adv. Space Res. 13, 239.
37. Webbe, W.R., Lockwood J.A. 1988, J. Geophys. Res. 93, 8735.
38. Ahluwalia H.S. 1994b, J. Geophys. Res. 99, 23515.
39. Ahluwalia H.S., Sabbah I. 1993, Ann. Geophys. 11, 763
40. Swinson D.B. 1986, Planet. Space Sci. 34, 752.
41. Ahluwalia H.S., Dorman L.I. 1997, J. Geophys. Res. 102, 17433.
42. Ichinose M., Nagashima K., Morishita I., Ishida Y. 1983, 18th Int. Cosmic Ray Conf., Bangalore 10, 182.
43. Pathak P.N. 1972, Planet. Space Sci. 20, 533.
44. Ueno H., Fujii Z., Yamada T. 1990, 21st Int. Cosmic Ray Conf., Rome 6, 376.
45. Eliot H., Dolbear D.W.N. 1950, Proc. of Phys. Soc. A 63, 137.
46. Eliot H., Dolbear D.W.N. 1951, J. Atoms. Terr. Phys. 1, 205.
47. Fujii Z., Ueno H. 1990, 21st Int. Cosmic Ray Conf., Adelaide 6, 314.
48. Van Staden M.L., Potgieter M.S. 1991, Planet. Space Sci. 39, 1237.
49. Swinson D.B, 1986, Planet. Space Sci. 34, 752.
50. Kumar, S., Shrivastava, S.K., Dubey, S.K., Richhariya, M.K. and Gulati, U., 1998, *Ind. J. Radio and Space Phys.*,**27**, 150.