1989EM&P...47...61M

APPLICATION OF DIFFUSION – CONVECTION MODEL TO DIURNAL ANISOTROPY DATA

H. MAVROMICHALAKI

Nuclear and Particle Physics Section, Physics Department, University of Athens, Greece

(Received 27 July, 1989)

Abstract. The diurnal anisotropy of cosmic-ray intensity observed over the period 1970–1977 has been analysed using neutron-monitor data of the Athens and Deep River stations. Our results indicate that the time of the maximum of diurnal variation shows a remarkable systematic shift towards earlier hours than normally beginning in 1971. This phase shift continued until 1976, the solar activity minimum, except for a sudden shift to a later hour for one year, in 1974, the secondary maximum of solar activity.

This behavior of the diurnal time of maximum has been shown to be consistent with the convective-diffusive mechanism which relates the solar diurnal anisotropy of cosmic-rays to the dynamics of the solar wind and of the interplanetary magnetic field. Once again we have confirmed the field-aligned direction of the diffusive vector independently of the interplanetary magnetic field polarity. It is also noteworthy that the diurnal phase may follow in time the variations of the size of the polar coronal holes. All these are in agreement with the drift motions of cosmic-ray particles in the interplanetarty magnetic field during this time period.

1. Introduction

The large variation observed in phases and amplitudes of cosmic-ray diurnal anisotropy on a day-to-day basis cannot be explained by the corotational concept (Parker, 1964; Axford, 1965). Therefore many scientists (Rao *et al.* 1972; Kane, 1974; 1975; Owens and Kash, 1976) attempted to understand this variation in terms of a convective-diffusive mechanism (DCM). This mechanism of cosmic-ray transport (Axford, 1966; Forman and Gleeson, 1975) is generally accepted as providing an adequate description of the physical processes occurring in the heliosphere. It was initially used to explain the apparent corotation of the net cosmic-ray flux with the Earth during solar activity cycle 20 (Jokipii and Parker, 1969); fortunately, it also incorporates mechanisms for producing anisotropies in other directions. The standard picture for the diffusion of cosmic-rays at neutron monitoring energies in the solar system involves diffusion which is essentially field-aligned (Jokipii, 1971). Later Kane (1974) showed that on a day-to-day basis the diffusion vector deviates from the interplanetarty magnetic field (IMF) direction in the ecliptic plane by more than 30° on about 35% of the quiet days. Ananth *et al.* (1974) comparing the diffusion vector with the magnetic field vector pointed out that this simple concept holds good on more than 80% of days. On the rest 20% of days the diurnal anisotropy characteristics seem to indicate the presence of a significant component of a transverse diffusion current in addition to the normal convection and diffusion flow. Such days are found to be present in the form of trains of consecutive days and to be associated with abrupt changes in

Earth, Moon, and Planets **47**: 61–72, 1989.

the interplanetary field direction. The value of the diffusion coefficients ratio $K_\perp / K_\parallel$ which is normally about $\leqslant 0.05$ for field-aligned days, is found to be ~ 1.0 on non-field aligned days. It has been shown (Kane, 1974) that on many days the interplanetary field seems to stick to the garden-house direction, while the diffusion vector deviates significantly from the garden-house direction and on some other days the reverse situation obtains. Owens and Kash (1976) selecting only those days in which there are no complication from changing magnetic sectors and eliminating days with a poorly determined anisotropy or mean magnetic field direction, showed that the diffusion is field aligned on essentially all well-determined days. Rao *et al.* (1972). Mavromichalaki (1980a, b) have shown that the diffusion vector is field aligned during days exhibiting enhanced diurnal variation, the diffusion current on an average basis being driven by large cosmic-ray gradients in the ecliptic plane.

So, even though the average picture of the diurnal variation has now been explained quite satisfactorily in terms of a good physical model, the detailed picture of the diurnal variation, on a day-to-day basis, is still not clearly understood.

In this work we present a detailed analysis of diurnal anisotropy on a day-to-day basis using neutron monitor data for the period 1970–1977 in order to test the validity of the convective-diffusive mechanism to different trends of the diurnal phase and to demonstrate that on most of the days this concept is valid. It is interesting to note that the observed diurnal anisotropy in space has shifted to earlier hours than the corotation direction from 1970 to 1976 where the solar activity minimum is. Further, we also attempt to determine the detailed characteristics of the few days on which the observed diurnal anisotropy shows departures from the simple convection and diffusion picture.

2. Data Analysis

In order to examine the cosmic-ray diurnal variation on a day-to-day basis in a statistically meaningful way we used neutron monitor data of the Deep River (1.02 GV) and Athens (8.72 GV) stations over the period January 1970–December 1977 without any exclusion of Forbush characterized periods. Interplanetary magnetic field data were used from IMP–AMP satellites (Interplanetary Medium Data book, 1977; 1979).

The procedure for resolving the observed diurnal vector into the convective and diffusive components was as follows:

The amplitude δ and the hour of maximum φ_1 of the observed diurnal anisotropy of Athens and Deep River neutron monitor data were evaluated for each day of the above-mentioned period. These values were corrected for geomagnetic bending according to the relation (see Barnden, 1972; Owens and Kash, 1976)

$$\varphi = \varphi_1 - 5 + 2.4 \quad \text{(for the Deep River station)} \qquad (1)$$

TABLE I

The free space anisotropy amplitude and phase for the years 1970–1977 for the two stations

	Deep River		Athens	
Year	Amp. %	Phase hr	Amp. %	Phase hr
1970	0.29	14.8	0.51	19.8
1971	0.33	14.3	0.54	19.0
1972	0.30	14.0	0.50	18.9
1973	0.29	13.4	0.49	18.4
1974	0.30	14.1	0.50	19.1
1975	0.28	13.3	0.47	18.3
1976	0.25	12.7	0.42	17.8
1977	0.26	13.2	0.42	18.2

and

$$\varphi = \varphi_1 + 2 + 4.4 \quad \text{(for the Athens station)} \tag{2}$$

where φ is the hour of maximum intensity of diurnal variation in interplanetary space. The first term is the observed diurnal hour of maximum (UT), the second term changes from Universal time to local time and the third one corrects for geomagnetic bending, since Deep River's mean asymptotic viewing cone is 36° east of its geographic longitude, and the Athens' one is 66° west of its geographic longitude (Shea *et al.*, 1968). The vector (δ, φ) was then considered as the vector observed at ground but corrected for geomagnetic effects (Free space anisotropy vector).

The size of the convective anisotropy δ_c for each day was calculated by the expression (Forman and Gleeson, 1970; Rao *et al.*, 1972)

$$\delta_c = 3CV_P/v\,, \tag{3}$$

where C is the Compton–Getting factor (which is 1.5 for neutron monitor energies), V_P is the solar wind velocity and v is the particle velocity.

The diffusive anisotropy vector for each day was obtained by vector subtraction of the convective anisotropy δ_c from the observed anisotropy δ (pointing in the direction given by φ) according to the relation

$$\delta = \delta_c + \delta_d\,, \tag{4}$$

Then the diffusive vectors were compared day-by-day with the interplanetary magnetic field ecliptic component. So, the solar wind data and the magnetic field data were hourly averages taken from the magnetometers aboard the geocentric IMP–AMP satellites in Earth orbit in interplanetary space (Wolf and King, 1977).

For the plasma averages we assumed the solar wind to be always streaming radially outward from the Sun in the ecliptic plane, while for the IMP data the averages are calculated vectorially (taken into account B, φ and θ). The hourly averages were resolved into Cartesian coordinates and the amplitude Bxy and the direction φ_B of the daily average magnetic field in the ecliptic plane were calculated (Figure 1).

3. Diurnal Anisotropy in Space

From the hourly cosmic-ray data corrected for the geomagnetic bending of the primaries according to equations (1) and (2) for the two stations, respectively. The free space anisotropy vectors were calculated for the time period 1970–1977. The annual mean diurnal anisotropy vectors in space observed at Athens and Deep River stations are displayed on a harmonic dial in Figure 2. A remarkable systematic change of the diurnal time of maximum and the diurnal amplitude during this period is noted. A phase shift of the time of maximum to earlier hours during the years 1970–1976 is obvious. An exception is observed during the year 1974 where the secondary solar activity maximum is. On the other hand, the diurnal amplitude presents a similar behaviour during this period. In the year of solar minimum (1976) the diurnal amplitude becomes extremely small, to the point that one wonders whether the variation persists all year round. From all this it results that the solar diurnal variation undergoes dramatic changes in amplitude and phase during the solar activity cycle, as many authors have found in the past (Ahluwalia, 1977; Mavromichalaki and Geranios, 1981).

The occurrence frequency histograms of the diurnal anisotropy phase in free space for each day as derived from the data of the Athens and Deep River stations

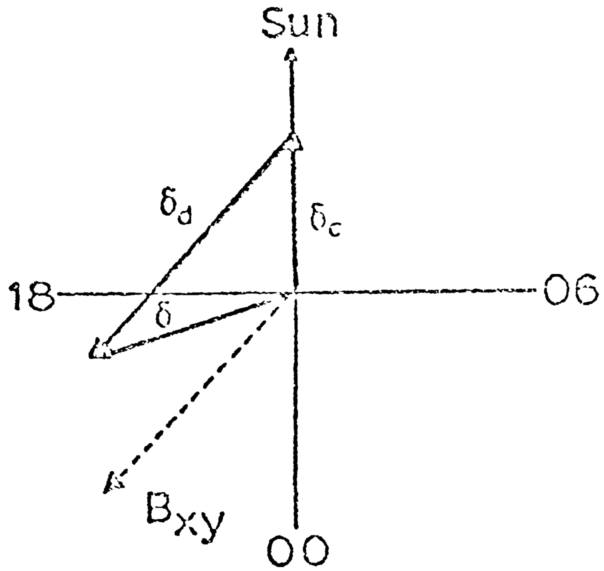
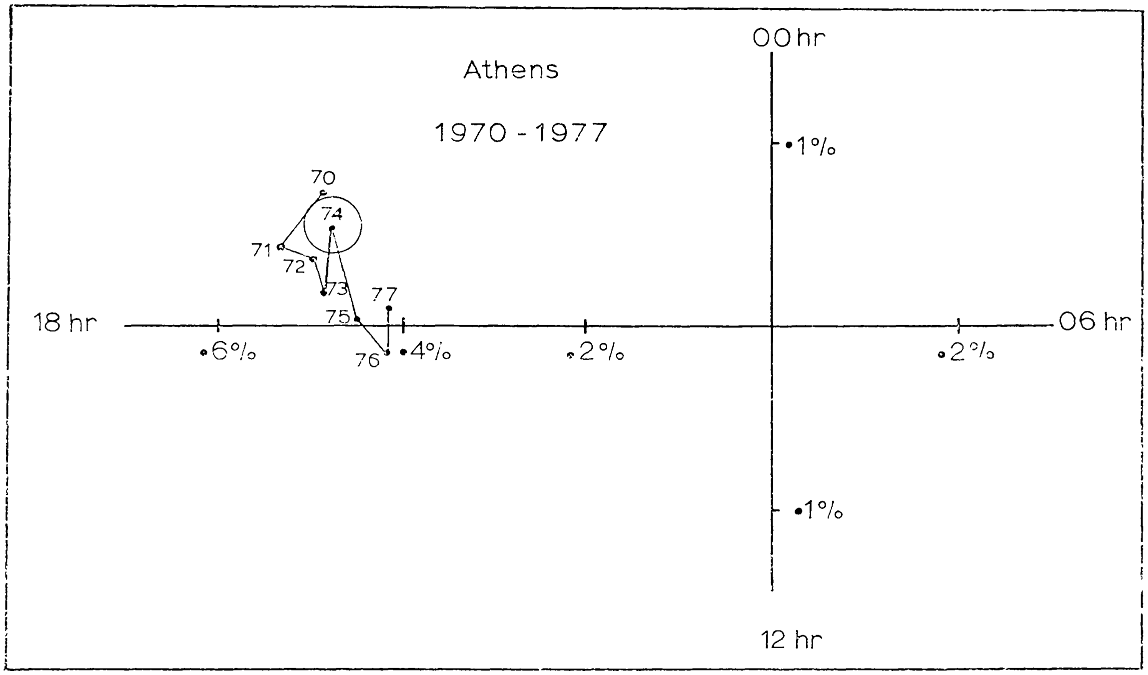
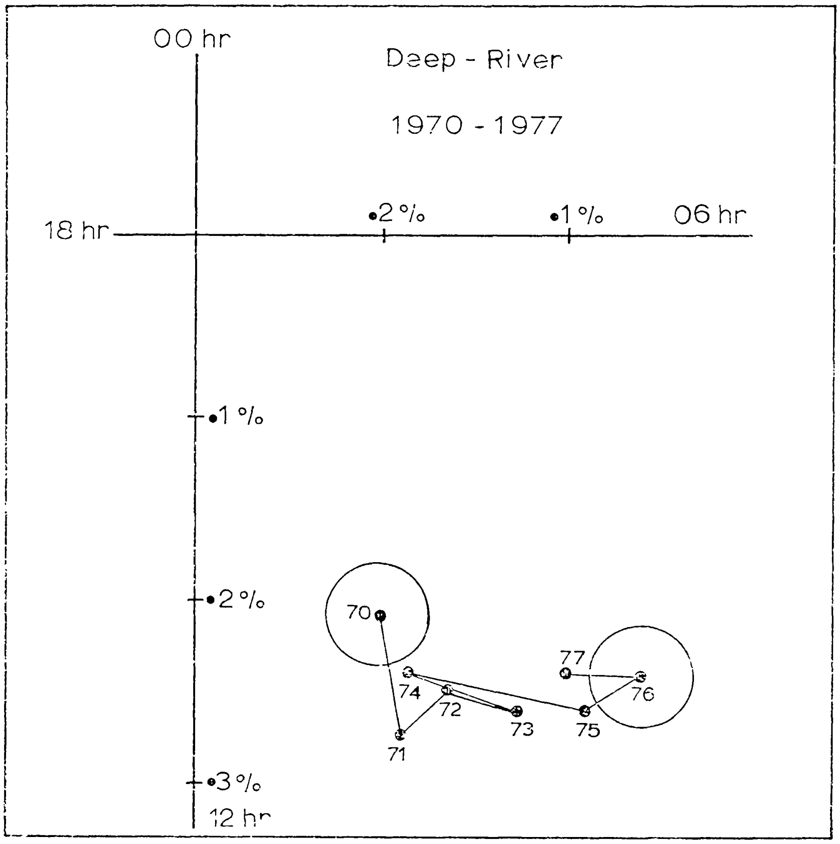


Fig. 1. Observed (δ), convective (δ_C) and diffusive (δ_D) anisotropy vectors for a typical day. The IMF vector in the ecliptic plane (B_{xy}) is also indicated.



(a)



(b)

Fig. 2. Annual mean diurnal anisotropy vectors in space observed at (a) Athens and (b) Deep River stations on a harmonic dial. The errors are also indicated.

1989EM&P...47...61M

is displayed in Figure 3. The good correspondence between the two histograms demonstrates that the method of obtaining diurnal anisotropy vectors in space using the variational coefficient techniques developed by Rao *et al.* (1963) and McCracken *et al.* (1965) provides the true anisotropy vector in space with improved statistics.

A detailed examination of the Figure 3 and the neutron monitor data of the two stations shows that the direction of maximum cosmic-ray intensity in space is shifted to an earlier time than the 18.00 hr, direction predicted by the corotation theory. The mean diurnal anisotropy of the two data sets displays a maximum intensity at approximately the 16.00 hr direction over the time period 1970–1976, that is the declining phase of the 20th solar cycle.

In the Athens data there appeared a second small maximum around the early morning hours. Mavromichalaki (1980a,b) has noticed a shift of the diurnal phase to earlier hours than the corotation phase during large amplitude wave trains of cosmic-ray intensity in the year 1973. Also Agrawal and Singh (1975), who examined the mean characteristics of ten neutron monitor stations for the period 1968–1974, showed that the time of maximum intensity has significantly shifted to earlier hours since 1971. This phase shift was expected to increase further during the years 1975–1976 where the sunspot minimum happened.

A significant decrease of diurnal time of maximum has also been observed from 1953 to 1954, the year of the 19th solar cycle minimum (Agrawal and Singh, 1975).

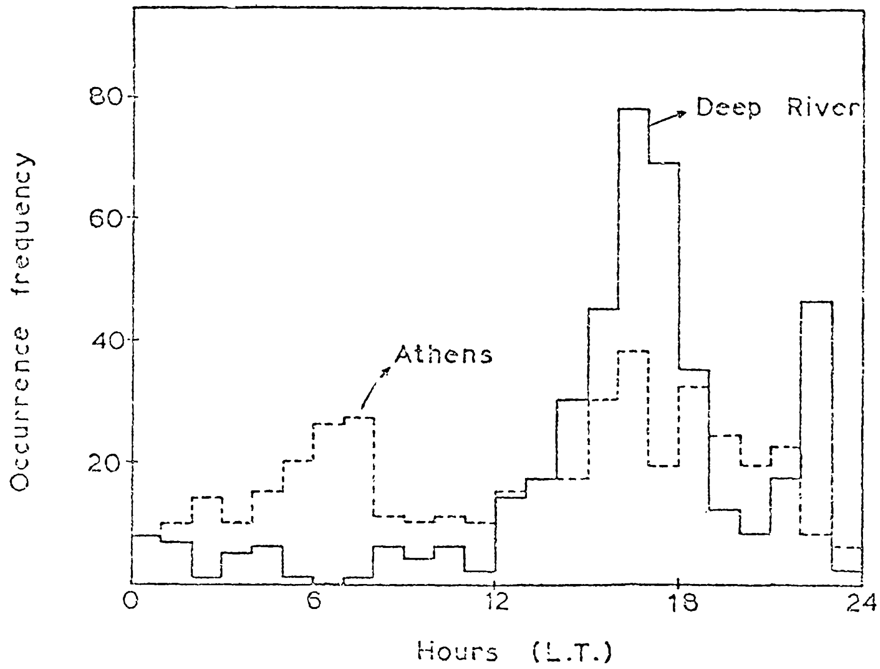


Fig. 3. Histogram showing the hour of maximum of diurnal anisotropy for the two stations for the period 1973–1976.

Recently Bekalaeva *et al.* (1987) showed that a 22-year component of solar diurnal anisotropy changing its direction during the periods of reversal of solar total magnetic fields exists. It means that in addition to variations of anisotropy from maximum to minimum of solar activity related to variations of upper cutoff rigidity of rigidity spectrum of solar diurnal anisotropy, we also have 22-year variations resulting from a heliomagnetic cycle. Moreover except for variations of anisotropy resulting from changes of title of neutral sheet are observed. Latitudinal extent of neutral sheet and its Northern–Southern asymmetry is considerably greater during 1971–73 than the ones during 1974–78 (Korhrov *et al.*, 1986).

4. Heliosphere Transport Theory

The diffusion-convection model of cosmic-ray transport has been used here in order to explain the observed phase shift of the diurnal anisotropy to earlier points and to provide an adequate description of the physical processes occurring in the heliosphere.

In this work we have examined in detail the behaviour of the diffusive component with the orientation of the interplanetary magnetic field. The frequency distribution of the diffusion vector direction φ_d for Deep River and Athens stations in various local time intervals is shown in Figure 4. The corresponding frequency distribution of the direction φ_B of the interplanetary magnetic field ecliptic component is shown as superposed dashed lines. The anti-garden hose direction (21.00 LT) for the two stations shows fairly narrow peaks of about ±2 hours width for both φ_d and φ_B. However there is a small additional peak for φ_d at about 00.00 LT especially in the Athens neutron monitor data (Kane, 1974). Also the garden-hose direction (09.00 LT) shows a second peak for φ_B as expected.

It is observed that the diffusion vector δ_D and the ecliptic magnetic field vector Bxy are very well aligned along the 45° line, as the anti-garden hose direction is concerned. However, when Bxy is pointing outward ($\varphi_B = 09.00$ LT) it deviates more from the 45° direction than φ_D does. Thus the diffusion vector seems to have a memory of the anti-garden hose direction independently of the interplanetary magnetic field polarity and even though φ_B may deviate from it (Kane, 1974).

The fact that φ_D and φ_B may not deviate from the mean in the same way has resulted in the rather broad distribution of $(\varphi_D - \varphi_B)$ shown in Figure 5. When φ_D and φ_B both range from 00.00 to 23.00 LT, the difference $(\varphi_D - \varphi_B)$ will range from −23.00 to +23.00 hours. To this we added (or subtracted) 12.00 or 24.00 hours to bring $(\varphi_D - \varphi_B)$ into a physically significant range of −6 to +6 hours. Thus values of the difference $(\varphi_D - \varphi_B)$ very close to zero would indicate field-aligned diffusion, while large values of $(\varphi_D - \varphi_B)$ nearing ±6 hours would indicate highly non-field aligned diffusion. As is shown in Figure 5 the difference $(\varphi_D - \varphi_B)$ is close to zero for the two stations. Note that the standard deviation for the 'Athens' distribution is three times larger than those of the Deep River.

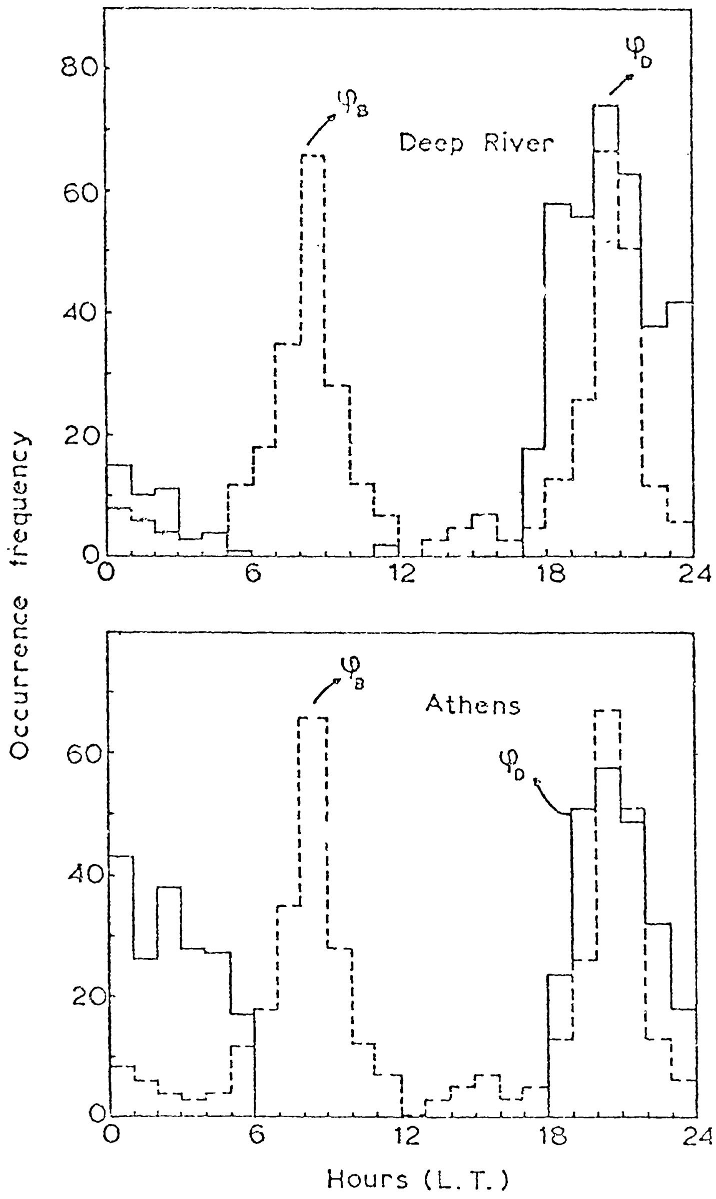


Fig. 4. Frequency distribution of diffusive phase φ_D and of azimuth angle φ_B of IMF ecliptic component for the years 1970–1977.

5. Discussion and Conclusions

According to the transport theory of cosmic-rays in a spherical coordinate system centred on the Sun the diurnal anisotropy in the ecliptic plane can be written as

$$A = A_C - 3(K_{\|}/v)G_{\|} - 3(K_{\perp}/v)G_{\perp} - 3(K_T/v)(G_P B/B) ,$$

where A_c is the convective component; G is the cosmic-ray gradient with components $G_{\|}$ and $G_{\perp}$ in the ecliptic plane and G_P perpendicular to it; $K_{\|}$ and $K_{\perp}$ are the diffusion coefficients parallel and perpendicular to B_{xy} and K_T is a transverse diffusion coefficient. In this approximation, if there are no drifts ($K_T = 0$), then

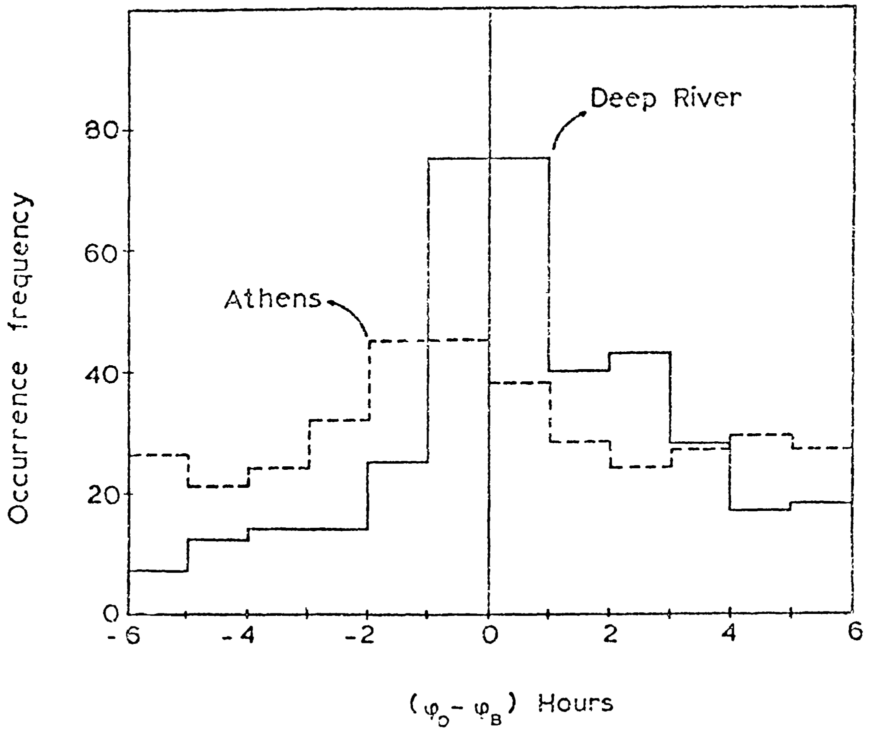


Fig. 5. Frequency distribution of the difference ($\varphi_D - \varphi_B$).

only the azimuthal component of the anisotropy exists and cosmic-rays appear to co-rotate with the Sun. When the diffusion vector is field aligned, $K_\perp/K_\parallel$ and K_T are negligible and the first two terms can adequately explain the anisotropy (Forman and Gleeson, 1975). Rao *et al.* (1972) and Mavromic halaki (1980a, b) have shown that the ratio of the average diffusion vectors is $K_\perp/K_\parallel \approx 0.2$. Ananth *et al.* (1974) have shown that on average this ratio is ≤ 0.05 for field-aligned days and ≈ 1.0 for non-field aligned days. Recently Ahluwalia and Riker (1987) takes $K_\perp = 0.15K_\parallel$ for the period 1965–1970.

The results of this investigation can be summarized as follows:

The observed diurnal vector in space of cosmic rays is shifted to an earlier time than the 18.00 hr direction over the time period 1970–1977. This phase shift increased during the years 1975–76, the year of sunspot minimum. Ahluwalia (1988) has also showed that during 1971–79 the diurnal anisotropy consists of two components. One is in east west direction and the other is the radial component with direction along 12.00 hour LT. The latter attains a maximum amplitude in 1976.

The diurnal time of maximum has also been continuously shifting to earlier hours as we go back to 1954 from 1957. A large phase shift to earlier hours from the year 1953 to 1954, the year of minimum solar activity as well as from 1972 to 1973–74 has been observed by Agrawal and Singh (1975). The phase shift is found to be larger in stations with high cut-off rigidity. Ahluwalia and Ericksen (1971) have suggested that the solar cycle dependence of the amplitude and the phase of the diurnal variation during the ascending part of solar activity cycle, too, can be explained in terms of the changes of the cut-off rigidity.

The observed diurnal vector of cosmic rays has been resolved into a convection vector and a diffusion vector. The direction of the diffusion vector with the ecliptic component of the IMF is studied for about 2100 days during 1970–1977 for the two neutron monitoring stations Deep River and Athens. It came out that for the Deep River stations on 59% of the days the two vectors differ 0–2 hours and on 27% of the days 2–4 hours. On about 14% of the days the difference is 4–6 hours. Especially the difference is almost ±6 hours on about 6% of the days. Similar results have been reported by Kane (1974) and Ananth *et al.* (1974) for the years 1965–1968. They mention that on about 4% of the days the deviations are as large as 90°.

For the Athens station the two vectors differ 0–2 hours on 43% of the days and 4–6 hours on 28% of the days. Thus on a substantially large fraction of days the net diffusion is almost perpendicular to the interplanetary magnetic field. It is noteworthy that days of Forbrush decreases of geomagnetic storms are not omitted from our data.

Whereas the gross tendency of the magnetic field and the diffusion vector is to be in the garden-hose and antigarden-hose directions, deviations from these directions in both vectors do not always occur in the same sense. Thus (a) when φ_D deviates from the 21.00 LT direction, φ_B seems to stick to the garden-hose direction (09.00 LT and 24.00 LT); to explain the observed diurnal vector on such days, large values of the perpendicular and transverse diffusion vectors are needed and (b) when φ_B deviates from the garden-hose direction φ_D seems to stick to it. This result is very interesting indeed and implies that even though the magnetic field may meander, cosmic-rays still retain memory of the garden-hose direction. A possible explanation could be that the deviations in φ_B are very localized, whereas the cosmic-rays gradients are still seeing a gross garden-hose structure and respond to it for diffusion.

On a very few occasions the magnetic field is perpendicular to the garden-hose direction. Again, very large transverse gradients are needed to explain the observed vectors.

The shift of diurnal time of maximum to earlier hours on an average basis can be qualitatively understood in terms of simple convection-diffusion theory either as an enhancement in the convective vector due to an increase in solar wind velocity accompanied by an increase in the value of diurnal anisotropy amplitude or as a decrease in the diffusive vector due to the increase in the value of $K_\perp/K_\parallel$ accompanied by a decrease in diurnal anisotropy amplitude. If both of them operate simultaneously, the diurnal amplitude may remain constant. From the present set of the observed average diurnal vectors and with the increasing trend in the value of A_P index from 1970 to 1974 it can be speculated that either of the mechanisms mentioned above may be operative. An increase in the average value of A_P index might in general have increased the solar wind velocity thereby increasing the convection vector. Or the increase in A_P might have increased the interplanetary magnetic field fluctuations thereby increasing $K_\perp/K_\|$ which reduces the diffusive vector. Indeed King (1981) has reported that long-term variations in IMF magnitude include enhancements in 1973–1974 and 1978–1979 and a decrease in 1975–1976. These variations are to be understood in terms of varying levels of both spiraling of IMF lines and radial magnetic flux density at 1 AU in the ecliptic plane. The first two years have enhanced radial flux density which, of IMF magnitude, is offset (fully in 1973 and partly in 1974) by the decreased IMF spiraling. But we have not yet attributed definitively the 1973–1974 radial flux density increase to a specific source. We note that solar polar magnetic fluxes from 1972 to 1974 but they show no decrease through 1976 (Svalgaard and Wilcox, 1978). On the other hand the 1978–1979 enhancement of radial flux density has a likely source in enhanced levels of solar flux being drawn from solar active regions. Also Feldman *et al.* (1978) and Mavromichalaki *et al.* (1988) have shown that the years 1973–1976 were marked by recurrent high-speed streams not found in the years immediately preceding or following. It is known that these high-speed solar-wind streams during the solar minimum are emitted by coronal holes.

Indeed Ahluwalia and Riker (1981) have tried to correlate the systematic shift of the diurnal time of maximum from 1971 to the size of the polar coronal holes (Hundhausen *et al.*, 1981; Xanthakis *et al.*, 1981). One can see from the diagram of evolution of coronal holes that the polar coronal holes grow in size from their birth in 1971 until 1976. After that they begin to shrink. Ahluwalia and Riker (1981) suggested that after 1971 electromagnetic conditions in the solar corona make it easier for off-ecliptic cosmic-rays to be transported from high-heliolatitudes to low-heliolatitude locations in the solar corona. These particles give a field-aligned flow in the neighbourhood of the Earth. This contribution is in addition to the corotational anisotropy which has a free-space direction along 18.00 LT. Here it is noted that there is an abrupt rearrangement of the large-scale solar field in 1974 where the secondary maximum of solar activity at the 20th solar cycle happens. There occurs a worldwide transient shift of the diurnal time of maximum to a later hour which does not result from the coronal transport of the off-ecliptic cosmic-rays. It nearly chokes off the field-aligned flow of the particles permitting this time-shift. A rearrangement of the solar field in 1975 resumes the field-aligned flow of particles and the time of maximum again shifts to an earlier hour. Moreover the off-ecliptic cosmic-ray contribution is very much reduced in 1980 which allows the diurnal time of maximum to return to normal hour.

A further study of the diurnal time of maximum through the whole period of different solar cycles will help us to understand the two modes of the cosmic-ray intensity from the eleven-year variation, during the solar maximum and during the solar minimum.

Acknowledgements

Thanks are due to the Cosmic-ray colleagues of Deep River (Canada) for the support with their neutron-monitor data. Thanks are also due to Mrs. P. Tatsi for her technical help.

References

Agrawal, S. P. and Singh, R. P.: 1975, *Proc. 14th Int. Conf. Cosmic-Rays* (*München*) **4**, 1193.

Ahluwalia, H. S.: 1977, *Proc. 15th Int.Cosmic-Rays* **11**, 298.

Ahluwalia, H. S.: 1988, *Geophys. Research Letters* **15**, 287.

Ahluwalia, H. S. and Riker, J. F.: 1981, *Proc. 17th Int. Conf. Cosmic-Rays* (*Paris*) **10**, 230.

Ahluwalia, H. S. and Riker, J. F.: 1987, *Planet. Space Sci.* **35**, 45.

Ahluwalia, H. S. and Ericksen, J. H.: 1971, *J. Geophys. Res.* **76**, 6643.

Ananth, A. G., Agrawal, S. P., and Rao, U. K.: 1974, *Pramana* **3**, 74.

Axford, W. I.: 1965, *Planet. Space Sci.* **13**, 115.

Axford, W. I.: 1966, *Planet. Space Sci.* **13**, 115.

Barnden, L. R.: 1972, Preprint, Rome, LPS-72-8.

Bekalaeva, Nik., Kolomeets, E. V., and Slyunyseva, N. Y.: 1987, *Proc. 20th Int.Conf. Cosmic-Rays* **4**, 134.

Feldman, W. C., Asbridge, J. R., Bame, S. J., and Gosling, J. T.: 1978, *J. Geophys. Res.* **83**, 2177.

Forman, M. A. and Gleeson, L. J.: 1970, Preprint, Monash University.

Forman, M. A. and Gleeson, L. J.: 1975, *Astrophys. Space Sci.* **32**, 77.

Hundhausen, A. J., Hansen, R. T., and Hansen S. F.: 1981, *J. Geophys. Res.* **86**, 2079.

Jokipii, J. R.: 1971, *Rev. Geophys. Res.* **81**, 3471.

Jokipii, J. R. and Parker, E. N.: 1969, *Astrophys. J.* **155**, 777.

Kane, R. P.: 1974, *J. Geophys. Res.* **79**, 1321.

Kane, R. P.: 1975, *J. Geophys. Res.* **80**, 3509.

King, J. H.: 1981, NASA Technical Memoradum 82075.

Korhrov, N. N. and Variatzii, K. I.: 1986, *Issledovanic Kosmosa M.*, p. 53.

Mavromichalaki, H.: 1980a, *Astrophys. Space Sci.* **68**, 137.

Mavromichalaki, H.: 1980b, *Astrophys. Space Sci.* **71**, 101.

Mavromichalaki, H. and Geranios, A.: 1981, *Proc. 15th Int. Conf. Cosmic-Rays* **4**, 130.

Mavromichalaki, H., Vassilaki, A., and Marmatsouri, E.: 1988, *Solar Physics* **115**, 345.

McCracken, K. G., Rao, U. K., and Fowler, B. G.: 1965, IQSY Instruction Manual No. 10.

Owens, A. J. and Kash, M. M.: 1976, *J. Geophys. Res.* **81**, 3471.

Parker, E. N.: 1964, *Planet. Space Sci.* **12**, 735.

Rao, U. R., McCracken, K. G., and Vankatesan, D.: 1963, *J. Geophys. Res.* **68**, 345.

Rao, U. R., Ananth, A. G., and Agrawal, S. P.: 1972, *Planet. Space Sci.* **20**, 1799.

Riker, J. F. and Ahluwalia, H. S.: 1987, *Planet. Space Sci.* **35**, 1117.

Shea, M. A., Smart, D. F., McCracken, K. G., and Rao, U. R.: 1968, Supplement to IQSY Instruction Manual, No. 10.

Svalgaard, L. and Wilcox, J. M.: 1978, *Ann. Rev. Astrophys.* **16**, 429.

Wolf, J. and King, H.: 1977, Interplan. Medium Data Book NSSDC/NDC-A Greenbelt Maryland.

Xanthakis, J., Mavromichalaki, H., and Petropoulos, B.: 1981, *Astrophys. Space Sci.* **74**, 303.