DIURNAL ANISOTROPY DURING SOLAR ACTIVITY CYCLE TWENTY AND DIFFUSION-CONVECTION MODEL

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ABSTRACT

Underground muon telescope data obtained at Embudo and Neutron monitor data obtained at Deep River are divided into two sets; one covers the ascending phase of the cycle (1965-70) and the other covers the descending phase (1971-76). The amplitude of diurnal anisotropy calculated from the data does not agree with the value predicted by the simplified version of the Diffusion-Convection Model (DCM); the discrepancy is worse for neutron data.

INTRODUCTION. We report here an extension of our earlier study (Ahluwalia and Ericksen, 1970, 1971). Coupling functions (W) given by Murakami et al. (1979) and those given by Lockwood and Weber (1967) are used to calculate the amplitude of diurnal anisotropy. Median rigidity of response $(R_m) \sim 16$ GV for Deep River neutrons and ~ 134 GV for Embudo muons. Unlike Subramanian (1971) we are not able to reconcile our calculations with the predictions of the simplified version of Diffusion-Convection Model (Forman and Gleeson, 1975).

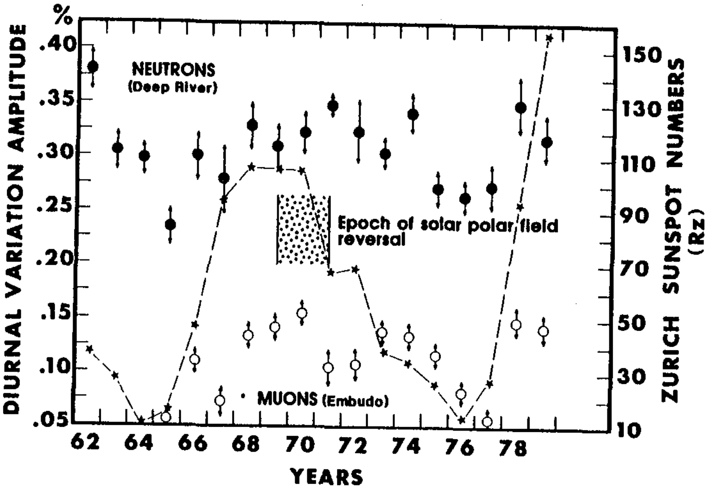

Fig 1

DATA. Figure 1 summarizes the available data on the annual mean amplitudes of the diurnal variation observed at Embudo (open circles) for the period 1965-79 and at Deep River (solid dots) for the period 1962-79. The flags indicate the standard deviation, computed from the observed scatter in the data for a given year. Zurich sunspot numbers (R_z) indicate the level of solar activity. Epoch of solar polar field reversal is also shown; after 1970 the solar polar field is directed out of the sun in the northern hemisphere. In general the amplitudes have the lowest values during activity minima and large values during activity maximum. In particular, we wish to point out that the amplitudes at Embudo have large values for the years 1973, 1974 and 1975 during which the mean level of the solar activity is only about one third of the maximum value in 1968. Bulk velocity (V) of solar wind is high during these years.

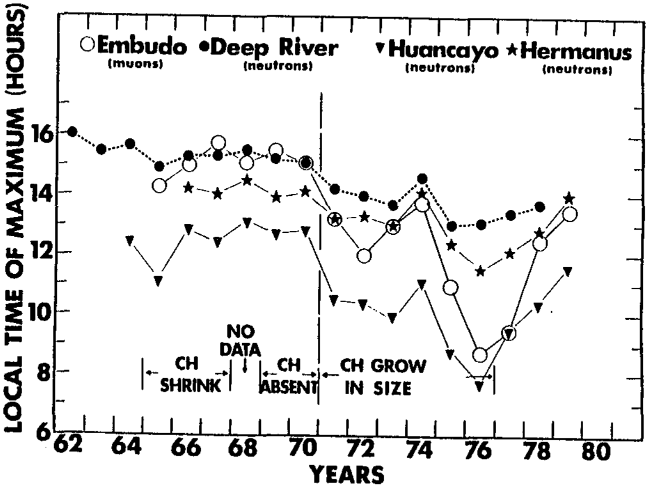

FIG 2

Another important feature of the dependence of the diurnal variation on the solar activity is shown in Figure 2. It gives the annual mean time of maximum of the diurnal variation observed at Embudo, Deep River, Hermanus ($R_m \cong 20$ GV) and Huancayo ($R_m \cong 30$ GV). The data exhibit a remarkable, worldwide, systematic, rigidity-dependent shift of the time of maximum of diurnal variation to early hours, during the period 1971-76. The data for Huancayo and Hermanus are staggered in time, with respect to Deep River, to minimize an overlap. The rigidity dependent nature of this effect was emphasized by us elsewhere (Ahluwalia, 1976). Note that prior to 1971 the observed time of maximum at Embudo is nearly steady at about 15 hours (LT) but in 1976 the time of maximum is at 8.7 hours (LT). The diurnal times of maximum return to pre-1971 values by about 1979, at all stations. Agrawal (1983) has reported similar behavior for neutron and surface-level muon detectors at sites in Canada. Also summarized in Figure 2 is the information about the size of the coronal holes during solar activity cycle (SAC) 20.

<u>ANALYSIS</u>. We subdivide the data into two sets; one set covers the period 1965-70 and the other set covers the period 1971-76. The reader is reminded that the observed diurnal variation is rather steady, on a year to year basis, during the first period and undergoes a remarkable systemmatic change during the second period. The characteristics of the annual mean diurnal variation observed at Embudo and at Deep River for the two periods are displayed in Fig. 3 on the harmonic dial. The error circles are for 2σ. One can see that the amplitudes for the two periods remain the <u>same</u> for both Embudo muons and Deep River neutrons. However, the time of maximum is significantly early for both detectors, for the second period (1971-76). The fact that the ampli-

tudes are the same for muons as well as neutrons, implies that upper cut-off rigidity R_c has the same average value for both periods; in fact $R_c \sim 70$ GV. Also the fact that the vectors for the two periods, for both detectors, are well-resolved implies that some new effects contribute to the observed diurnal variation during 1971-76 period.

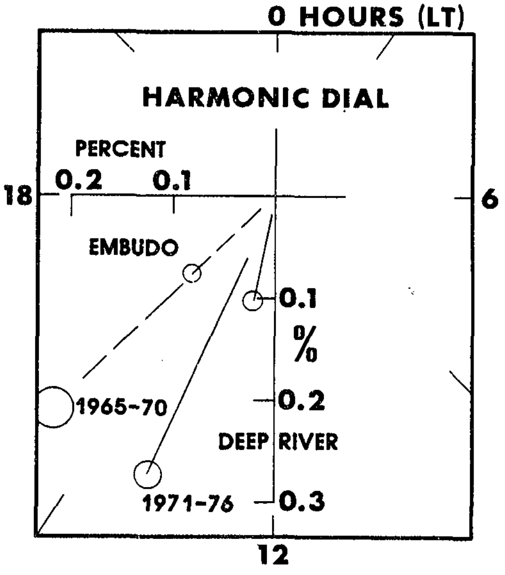

FIG 3

Diffusion-Convection Model (DCM) predicts that if $K_\perp = 0$ and there is no net radial streaming (S_r) and if perpendicular gradient is zero, cosmic rays undergo corotation. In this case the anisotropy (δ) recorded by a detector with a mean asymptotic latitude λ of viewing is given by

$$\delta = 0.6 \cos \lambda, \%$$

So we expect that δ should be independent of solar wind bulk velocity (V). An obvious limitation of the model is that it does not contain the concept of R_c. Somehow the diffusion coefficients $K_{||}$, $K_\perp$ must depend upon primary rigidity (R) in such a way as to lend some physical significance to the concept of R_c. The theory in its present state is obscure on this point. Let us assume that,

$$\delta_{theo} = \begin{cases} 0.6 \cos \lambda \,\%, & \text{if } R \leq R_c \\ 0.0, & \text{if } R > R_c \end{cases}$$

This form of variational spectrum is consistent with the results obtained in our analyses earlier, for the first period (1965-70). Table 1 gives a summary of results for the two detectors, for the three periods, assuming R_c=70 GV. The direction of anisotropy in free space is calculated after applying corrections for the "orbital-effect" and for the "geomagnetic bending" of the primaries. These corrections are model independent.

RESULTS. (1) Diurnal Anisotropy in free-space is in the direction of 18 hours (LT) for the first (1965-70) and third periods (1965-76), but the direction is significantly earlier for the second period (1971-76).

(2) Within errors of observations the amplitudes of diurnal variations for the two detectors, for the three periods, are the same. The amplitude of the anisotropy, calculated from the data for the two detectors, is tabulated in the last column of Table 1. The calculated value is about 33% less for neutrons and about 8% less for muons when compared to the theoretical value. So our results do not

TABLE 1

Station	λ	$\int_{R_o}^{R_c} W dR$	Free Space Direction of Diurnal Anisotropy			δ calc
	deg	%	hours (LT) 1965-70	1971-76	1965-76	%
Deep River	11.8	0.78	18.21 ± 0.12	16.87 ± 0.12	17.54 ± 0.12	0.43 ± 0.01
Embudo	19.1	0.28	17.83 ± 0.11	16.87 ± 0.11	17.74 ± 0.11	0.55 ± 0.02

agree with the predictions of the simplified DCM, for SAC 20. However in practice we may not have $K_\perp = 0$. Also $K_\perp$ may be inversely proportional to the square of the particle rigidity (Jokipii, 1971). If we follow Jokipii's suggestion and take $(K_\perp/K_{||}) \approx 0.15$ and further note that median primary rigidity of response for muons is about a factor of <u>eight</u> larger than for neutrons, the calculated values agree much better with the theoretical value. <u>But this does not explain why the direction of anisotropy is significantly earlier in the second period</u> (1971-76). Also it is hard to believe that the ratio $K_\perp/K_{||}$ is invariant in time.

(3) In recent years Jokipii has emphasized very strongly that drifts should play an important role in the modulation of cosmic rays (Kota and Jokipii, 1983 and references therein). It would be interesting to see if one obtains a better agreement between theory and observations by invoking charged particle drifts.

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