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LARGE AMPLITUDE WAVE TRAINS OF COSMIC RAYS

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The large amplitude wave trains of cosmic rays observed during June,July and August 1973 were analysed. These events exhibit the same characteristics as the event of May 1973. The phase of the enhanced diurnal anisotropy during these days is shifted to earlier hours than the corotation direction or the anti-garden-hose direction. For this analysis data from high and middle latitude neutron monitors and from the satellites HEOS-2, IMP-7 and -8 were used. This diurnal variation is well understood in terms of a radially outward convection and a field-aligned inward diffusion yielding a diurnal anisotropy vector along about 16.00hr in space.

1. Introduction. In an attempt to understand the diurnal variation on individual days a lot of work has been performed so far to find the possible origin of the large amplitude wave trains of cosmic ray neutron intensity. These variations last many days and exhibit large amplitudes of diurnal variation. These amplitudes cannot be explained by the corotation effect predicted usually values of 0.4%. Moreover the maximum intensity of the diurnal anisotropy is not appeared in the direction of the 18.00hr, which is the nominal corotation phase.

Hashim and Thambyahpillai (1969) and Rao et al (1972) have shown that the enhanced diurnal variation of large amplitude events shows a maximum intensity in space aroud the anti-garden-hose direction (20.00hr) and a minimum intensity around the garden-hose direction (9.00hr). Kane(1970) and Bussoletti(1973) have noticed that there are very often large reinforcements from the corotation direction. In all these cases the observed diurnal anisotropy is well understood in terms of convective-diffusive mechanism (Forman and Gleeson, 1975). Recently it has been shown (Mavromichalaki, 1977) that the enhanced diurnal vatiation observed over the period of May 22 to June 4, 1973 was caused by a source around the 16.00 hr or by a sink at about the 4.00 hr. It was pointed out that this diurnal variation is caused by the superposition of convection and field-aligned diffusion due to an enhanced density gradient of ~ 8 % / AU.

In the present work detailed analysis of another three large amplitude events is presented. The events studied exhibit the same characteristics to the ones of the event mentioned above. Similar results have been obtained namely the phase of this diurnal variation in space is shifted to earlier hours (16.00 hr) which is explainable very well with the convective-diffusive mechanism. So, a new class of large amplitude wave trains of cosmic rays intensity is appeared. The phase of these events is shifted to earlier hours than the antigarden-hose direction or the corotation direction. The satisfactory explanation with the convective-diffusive mechanism supports this model in the study of the enhanced diurnal variation.

The sequences of the large amplitude events observed over the periods 11-18

June, 11 - 20 July and 9 - 18 August 1973 have been selected for analysis here.

2. Data analysis The spatial characteristics of the cosmic ray anisotropy during these events have been determined from the analysis of a few high and middle latitude neutron monitor stations data (Table 1). In order to correct the cosmic ray intensity from the North-South anisotropy data from the two polar stations, Alert and McMurdo, were also used. The mean intensity three days prior to the commencement of each enhanced diurnal wave train was used for normalization of each station. The selected large amplitude events as observed at the Deep River neutron monitor station are shown in fig. 1.

Station (NM-64)	Symbol	Geographic coord.		Threshold	Mean asymptotic coord	
		Latitude (Deg)	Longitude (Deg)	rigidity (GV)	Latitude (Deg)	Longitude (Deg)
Sanae	SA	-70.30	357.7	1.06	-21	19
Leeds	LE	53.8	358.5	2.20	4	52
Utrecht	UT	52.1	5.1	2.76	-2	62
Kiel	KI	54.3	10.1	2.29	3	64
Oulu	OU	65.0	25.4	0.81	30	63
Kerguelen	KE	-49.4	70.2	1.19	-26	87
Novosibirsk	NO	54.8	83.0	2.91	10	130
Magadan	MA	60.1	151.0	2.10	12	191
Inuvik	IN	68.4	226.3	0.18	47	233
Calgary	CA	51.1	245.9	1.09	28	269
Climax	CL	39.4	253.8	3.03	26	296
Deep River	DR	46.1	282.5	1.02	27	319
Swarthmore	SW	39.9	284.6	1.92	-10	331
Durham	DU	43.1	289.2	1.41	25	332
Goose Bay	GB	53.3	299.6	0.52	35	339
Alert	AI	82.5	297.7	<0.05	77	331
Mc Murdo	MC	-77.9	166.6	<0.05	-74	261

Table 1 Stations whose data have been utilised in the present analysis.

From the hourly intensity of each station the mean intensity of Alert and McMurdo neutron monitor stations was substracted. Combining these intensities from all the stations at each azimuthal direction relative to the Sun-Earth line in space, three dimensional space-time maps of cosmic ray intensity in space were constructed.(Mercer and Wilson, 1968 ; Hashim and Thambyahpillai, 1969 ; Rao et al, 1972 ; Mavromichalaki, 1977). Such maps are plotted on an hour to hour and on a day to day basis, but space limitations prevent us from presenting them here. The amplitude and the phase of the equatorial diurnal anisotropy for each

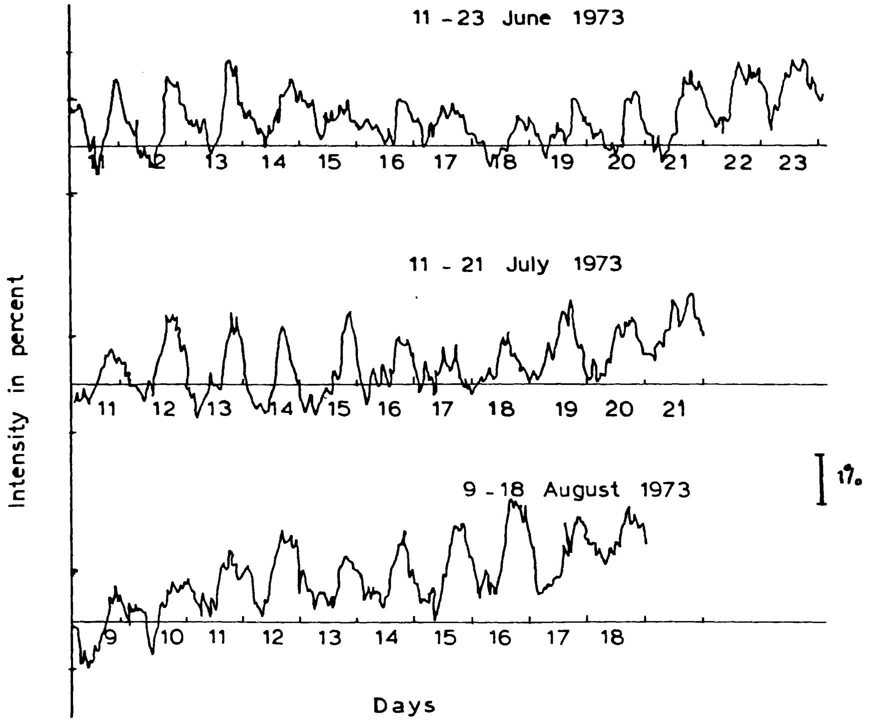

Fig.1 Intensity-time diagrams of the three events as observed at the Deep River neutron monitor.

day were estimated by the method developed by Bussoletti et al (1972).

The interplanetary field parameters for each of these days were obtained from HEOS-2, IMP-7 and -8 satellites measurements for comparison with the diurnal anisotropy vectors.

3.Experimental results The events analysed here seem to be a repetition of the large amplitude event occured from May 22 to June 4, 1973 with the difference that the amplitude of this diurnal anisotropy is smaller. Anyway the half-peak amplitude of the anisotropy detected at the ground is equal to or greater than 0.80%.So, it is assumed that the diurnal variation of these days is "enhanced". These time periods are not connected with Forbush decreases and the general conditions in interplanetary space are quiet.

It is very useful to underline here the similarities between the morphology of these wave trains and that of May 1973 previously analysed (Mavromichalaki, 1977). The study of the space-time maps of these events has shown that the corotative component of the diurnal variation has a far from constant pattern. In fact, the amplitude of the diurnal anisotropy in interplanetary space is greater than the nominal corotation amplitude and the direction of maximum intensity is shifted to earlier hours than the direction of the 18.00hr predicted by the corotation theory. The diurnal anisotropy maximum and the time of maximum for each day are shown in fig. 2. The mean observed phase of the diurnal anisotropy in space for the events of June, July and August is the direction of 16.00hr, 15.00hr and 16.00hr respectively.During these events the enhanced diurnal anisotropy is caused by an increase of the cosmic ray intensity in a broad cone of directions around the 16.00hr. It is noticed that the intensity in the garden-hose and anti-garden-hose directions is practically unaffecte

4. Field-aligned diffusion during days of enhanced diurnal variation. The observed

cosmic ray anisotropy vector δ was resolved into two components

$$\delta = \delta_c + \delta_d$$

where δ_c is the convective vector and δ_d is the diffusive vector.

The calculated diffusive anisotropy vectors of each day were compared with the ecliptic component of the interplanetary magnetic field. The solar wind data were obtained from IMP-7 and -8 satellites measurements and the interplanetary magnetic field data from magnetometers in the HEOS-2 satellite. The observed diurnal anisotropy vector, the convective vector, the diffusive vector and the interplanetary magnetic field vector for each day of the three events are given in the tables 2,3 and 4. The diffusive anisotropy vector for the three events day to day is shown in fig. 3. The ecliptic component of the magnetic field $B_{x\psi}$, is also shown in the same figure. It is noted the good agreement between the field azimuth and the direction of the diffusive vector throughout the duration of the events except of the 14th of July and the 16th of August where there is a deviation from the anti-garden-hose direction. Anyway the field aligned nature of the diffusion on a day to day basis during these events is confirmed. During these days the magnetic field was continously directed outwards ftom the Sun. So, it is not possible to have results about the days which are influenced by magnetic sector boundaries or when the magnetic field is directed towards the Sun.

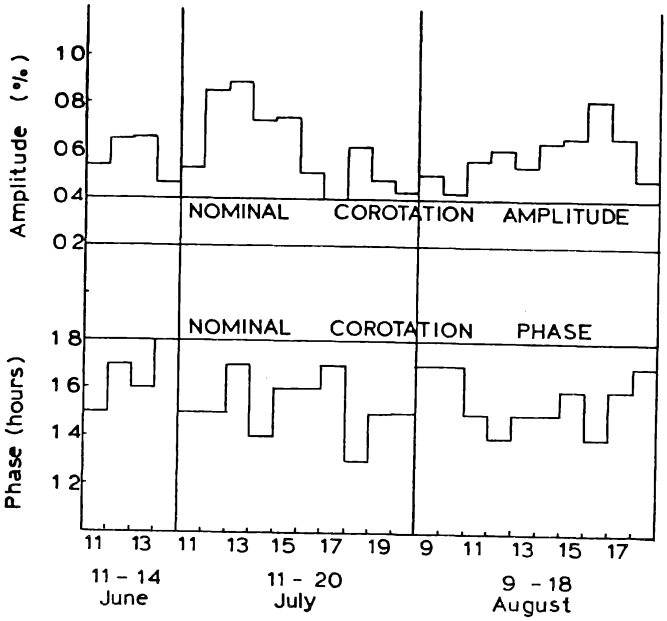

Fig.2 The amplitude and phase of the diurnal anisotropy in space on each day.

5. Discussion and conclusions. From the above anlysis the following conclusions are derived:

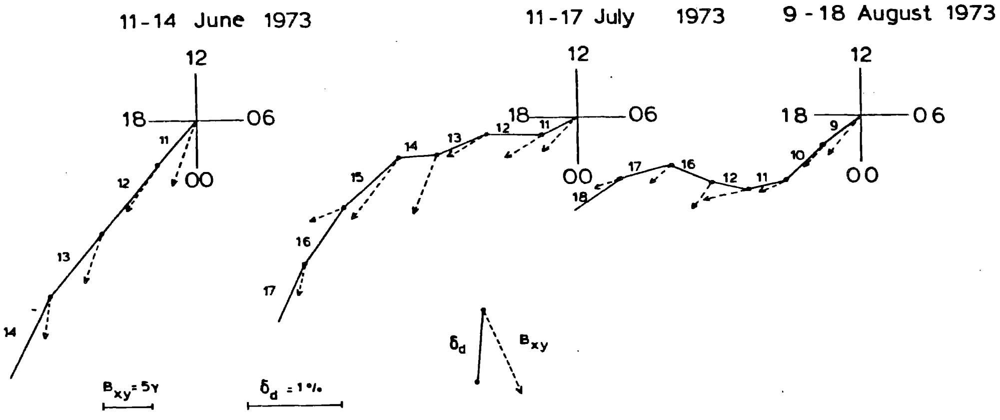

Fig.3 The ecliptic domponent of the magnetic field for each day is plotted alongside the diffusion vector for each day.

June 1973	Diurnal anisotropy vector		Convective vector	Diffusive vector		Magnetic field vector	
	amp. (%)	phase (Deg)	amp. (%)	amp. (%)	phase (Deg)	amp. (γ)	phase (Deg)
11	0.54	225	0.81	0.57	310	7.26	340
12	0.65	255	0.93	0.98	321	5.43	325
13	0.67	240	1.02	0.90	330	5.38	340
14	0.47	270	0.92	1.03	333	4.22	342

July 1973	Diurnal anisotropy vector		Convective vector	Diffusive vector		Magnetic field vector	
	amp. (%)	phase (Deg)	amp. (%)	amp. (%)	phase (Deg)	amp. (γ)	phase (Deg)
11	0.53	225	0.55	0.41	296	4.98	316
12	0.85	225	0.53	0.60	263	4.36	301
13	0.89	255	0.58	0.66	293	4.47	297
14	0.73	210	0.66	0.37	275	7.12	338
15	0.74	240	0.94	0.85	312	8.26	322
16	0.51	240	0.86	0.75	324	3.37	290
17	0.39	255	0.69	0.70	327	3.61	346
18	0.62	195					
19	0.48	225					
20	0.43	225					

August 1973	Diurnal anisotropy vector		Convective vector	Diffusive vector		Magnetic field vector	
	amp. (%)	phase (Deg)	amp. (%)	amp. (%)	phase (Deg)	amp. (γ)	phase (Deg)
9	0.50	255	0.51	0.62	308	5.13	323
10	0.42	255	0.49	0.56	313	2.68	314
11	0.56	225	0.47	0.40	282	2.60	294
12	0.61	210	0.45	0.31	255	4.10	291
13	0.54	225				3.42	323
14	0.64	225				5.53	339
15	0.66	240				4.60	331
16	0.32	210	0.53	0.45	246	3.36	325
17	0.67	240	0.48	0.60	284	2.71	313
18	0.49	255	0.46	0.58	305	2.51	290

Tables 2,3 and 4 Diurnal anisotropy vector, convective vector, diffusive vector and interplanetary magnetic field vector (ecliptic component) for the events of June, July and August respectively.

a) The observed enhanced diurnal variation can be well understood in terms of a outward convection and a field-aligned diffusion yielding a diurnal anisotropy vector along about 16.00hr in space.

b) The diffusion follows in time the anti-garden-hose direction of the magnetic field. Moreover it has been shown (Mavromichalaki, 1977) that the diffusion keeps the anti-garden-hose direction irrespectively of the direction of the magnetic field with respect to the Sun.

c) According to the convective-diffusive mechanism(Kane, 1974) the ratio $k_\perp/k_\parallel$ of the perpendicular to parallel diffusion coefficient with respect to the ecliptic magnetic field as well as the transverse diffusion coefficient are negligible in a field-aligned diffusion vector. The anisotropy is then well explained in terms of convection and diffusion. Ananth et al (1974) have shown that on average this ratio $k_\perp/k_\parallel$ is $\leq$ o.o5 for field-aligned days and $\sim$1.0 for non field-aligned days. During these days the ratio $k_\perp/k_\parallel$ was 0.24 for the June, 0.30 for the July and 0.36 for the August. It means that the transverse gradients are negligible and the diffusion vector is field-aligned.

d) During these events the radial density gradients in the ecliptic plane which correspond to the average diffusion vectors are 9% /AU for June, 6% /AU for July and 4.5% /AU for August. In other words large cosmic ray gradients seem to be existed especially during the event of June.The enhanced gradients during these events are caused by an increase of the cosmic ray intensity along the direction of the 16.00hr or by a decrease along the direction of the 4.00hr.

e) The phase shift of the enhanced diurnal anisotropy to earlier hours is explained by the convective-diffusive mechanism either as an enhancement in the convective vector or as a decrease in the diffusive vector (Agrawal and Singh, 1975).

The analysis of these events and the previous analysed event of May 1973 led us to the conclusion that these events constitute a new class of large amplitude wave trains where the enhanced diurnal variation may be caused by a source at about 16.00 hr or by a sink at about 4.00hr. This diurnal anisotropy is not correlated with the garden-hose or the corotation direction. Anyway the simple picture of the outward convection and the field-aligned diffusion is explained well and this diurnal anisotropy.

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