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TRANSIENT MODULATION

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TRANSIENT MODULATION

Rapporteur paper read at the 12th International Conference on Cosmic Rays, Hobart, Australia, 1971

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ABSTRACT

Papers dealing with the subject of transient modulation and presented at the 12th International Conference on Cosmic Rays are reviewed.

KIVONAT

A 12. Nemzetközi Kozmikus Sugárzási Konferenciára benyujtott, a tranziens moduláció témakörébe vágó tudományos dolgozatok áttekintése.

РЕЗЮМЕ

Обзор трудов, занимающихся проблемами транзиентной модуляции, и поданных на I2-ую Международную Конференцию по космическим лучам.

1. INTRODUCTION

This is a summary of and comments on Conference papers dealing with problems of Forbush decreases or cosmic ray intensity variations due to large scale quasi persistent azimuthal asymmetry in the solar wind. The section "Forbush decreases" /abbreviated as FD in what follows/ will include all kinds of cosmic ray storms /not only those beginning with a sharp decline/, and the term "azimuthal asymmetry variations" /AAV/ will cover in particular the 27 day variation and other recurrent variations with a time scale more than a few days and less than a few months.

The number of papers may be read in Table 1 together with the analogous figures relating to the Budapest Conference.

Table 1.

The number of papers presented on "Transient Modulation"

Topics	Budapest, 1969	Hobart, 1971
Mainly FD	7	15
Mainly AAV	5	6
Very short term variations	5	-

Whereas there is a conspicuous growth of the number of papers in the field of FD during the last two years leading to a better understanding of the processes involved, there is no large development in the field of AAV and it is regrettable that no paper has been presented on very short time variations, i.e. with time scales less than a few hours, a field which may contribute much to get insight into small scale irregularities of the solar wind and/or the magnetosphere.

2. FORBUSH DECREASES

2.1 Morphology

Classifications of FDs were introduced independently by Bachelet and Sandström [1] who distinguished four and five groups of FDs, respectively.

A less detailed but physically well founded grouping is given in MOD-45 by Verschell and al. According to their classification there are two types of FDs. A Type I decrease shows a sharp decline, has usually an amplitude $\gtrsim 5$ per cent and is initiated by a solar flare. Characteristic for Type I decreases is the lag of the recovery of low energy particles behind those of higher energies. A typical example of a Type I. decrease is given in Fig. 1, where the relative counting rate of the air borne New York University neutron monitor /mean energy of primaries between 1 and 2 GeV/n/ is plotted against the relative counting rate of the Inuwik neutron monitor /mean energy of primaries between 10 and 15 GeV/n/. A Type II. decrease has a gradual onset, an amplitude usually less than 5 per cent, is not associated with a solar flare, and

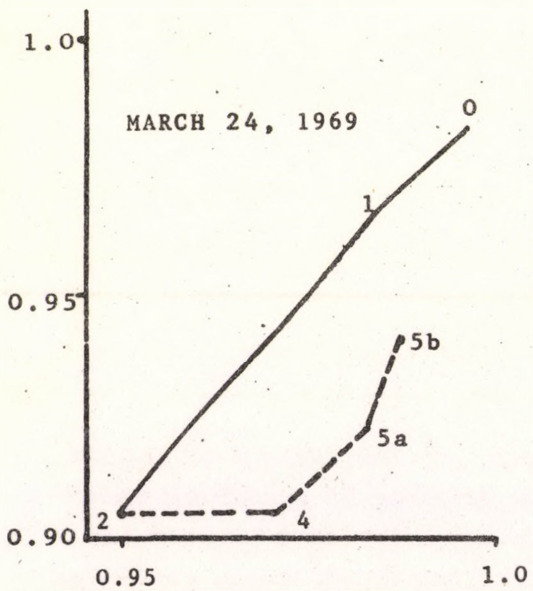


Fig. 1

Regression curve, type I. FD., Mar. 24, 1969. (Paper MOD 45)

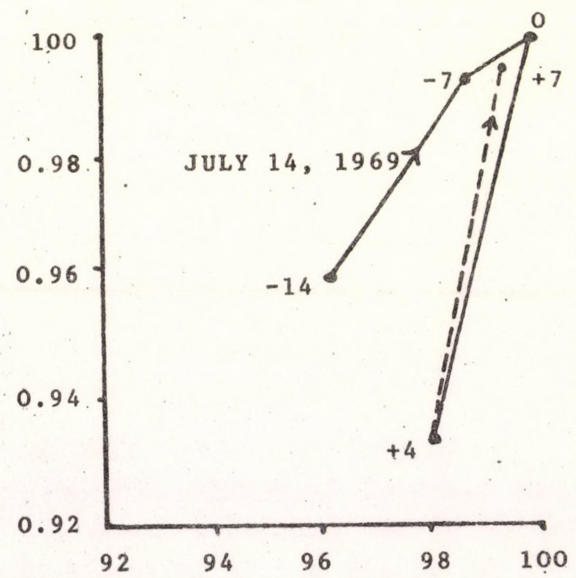


Fig. 2

Regression curve, type II. FD, July 14, 1969. (Paper MOD 45)

Positive numbers along the regression lines indicate days after the beginning of the FD, negative numbers indicate days before the FD.

the speed of recovery does not depend on energy, at least in the interval 1-10 GeV/n. /Fig.2./

It seems to be appropriate to mention here that an interesting description of FDs in terms of their duration was given in a paper not presented at this Conference. Blanariu and al. [2] have gone through the neutron monitor data obtained at Alert in the years 1966-67 and have plotted the distribution of FDs according to their duration /Fig. 3/. The hystogramm clearly indicates that there are many short time FDs with durations less than two and a half days. Since these decreases have a mean amplitude of only 1,4 per cent, they can easily pass

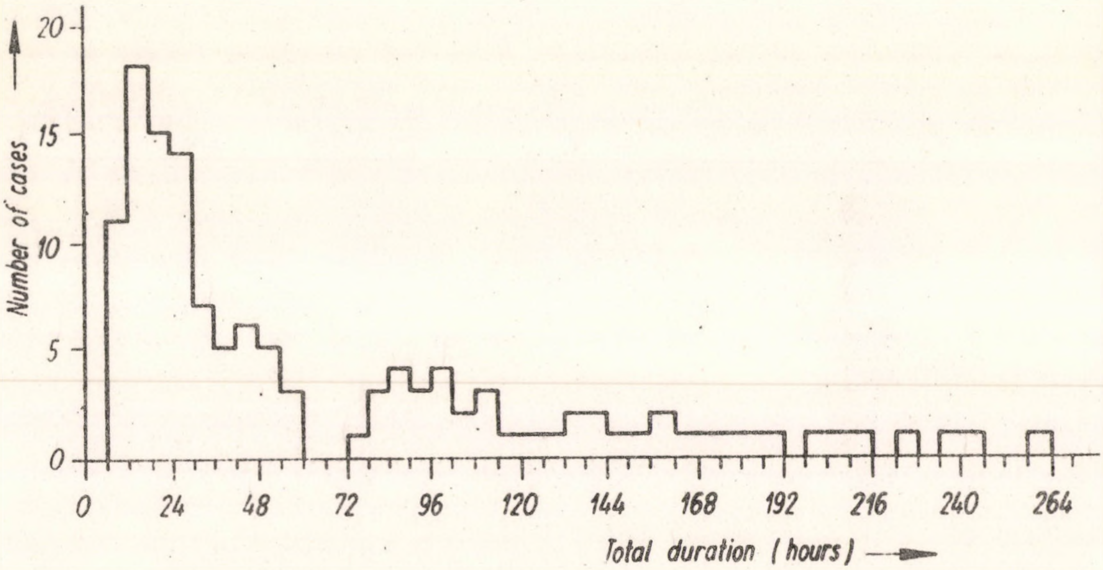


Fig. 3

The distribution of FDs with sharp decline according duration, as observed in neutron monitor data obtained at Alert. (Ref. [2].)

undetected at stations with large solar daily variations. /The Alert data show practically no solar daily variation./ The suggestion put forward by the authors to distinguish two distinct groups of FDs with durations less and more than say 2.5 days, respectively, needs further support by observation. The gap in the hystogram between 60 and 72 hours, as it is at present, may be due to statistical fluctuation.

2.2 Analysis

2.2.1 The influence of the variation of the geomagnetic cutoff

When analyzing FDs it is very important to separate the decrease due to variation of the geomagnetic cutoff from that due to other /i.e. interplanetary/ causes. An interesting method to solve this problem was put forward by Dorman and al. in paper MOD-114. Starting with the relative intensity variation

$$\frac{\delta I}{I} = -\delta P_c \cdot W(P_c) \left[1 + \left(\frac{\delta D}{D}\right)_{P_c} \right] + \int_{P_c}^{\infty} \left(\frac{\delta D}{D}\right)_P W(P)dP, \qquad /1/$$

where P_c denotes the cutoff rigidity, W(P) the coupling function (differential response function) and $\delta D/D$ the relative variation of the differential rigidity spectrum. They have measured the value of $\delta I/I$ at three different heights above sea level at the station near Irkutsk during the FD which took place from 5 to 9 Nov. 1970. Since $W(P_c)$ depends on the height of observation, they have got three equations to determine the value of δP_c , K , and α , where K and α are the parameters characterizing the dependence of $\delta D/D$ on P, a function usually written as

$$\delta D/D = K.P^{\alpha} \qquad /2/$$

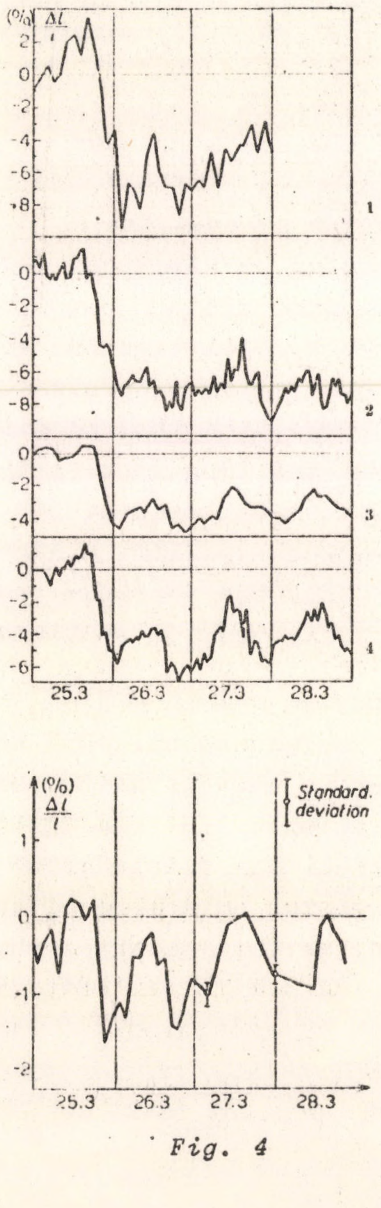
The values of α obtained in MOD 114 were - 1,2 and -1,9 on the second and first day <u>before</u> the FD, respectively, furthermore -3,8 and -1,2 during the rapid decline and the recovery, respectively. δP_c was determined to be +0,3 GV and -0,7 GV before and during the FD, respectively. However interesting the method seems to be, it is difficult to judge its value without a precise estimation of the statistical and systematic errors involved. Unfortunately the uncertainties of the results were not calculated by the authors.

A similar problem has been dealt with by Iucci and Villoresi in MOD 44 who have calculated the influence of the change of the geomagnetic field upon the geomagnetic cutoff and have found that a change of 300 γ in the horizontal field strength gives rise to a change of 0,5 GV in the cutoff at midlatitudes. It would have been interesting to know what the change of the horizontal field strength was during the period investigated in MOD 114 and to compare the changes obtained experimentally with those which could have been predicted on the basis of MOD 44.

2.2.2 The rigidity spectrum of FDs

It may be interesting to recall that the observation of a FD underground /at 40 m w.e./ indicating an extension of the modulation spectrum to rigidities as high as 100 GV was reported by the Budapest group in [3] as early as 1958 /Fig.4./. Since then many quantitative determinations of the rigidity spectrum have been made which, however, show a very large variability with values of the exponent α ranging from zero to -2. /For the definition of α see Eq. (2)/.

This problem has been given special attention to by F. Bachelet and al./MOD 66/ who arrived at the conclusion that the spectrum averaged on many FDs shows a curious shape which cannot be characterized by a single power function. The exponents pertaining to the various rigidity intervals, as obtained in MOD 66, are shown in Table 2 together with the exponents of the spectrum of the long term /11 year/ variation. It is interesting to note that, according to the paper MOD 66, both spectra show a considerable flattening in the rigidity range 5-12 GV, and that the spectrum of the FDs falls off, at high energies, considerably slower than that of the 11 year modulation, whereas at



The FD on 25.3.1958 as measured by means of (1) IGY neutron monitor in Praha (2) IGY neutron monitor on the Lomnicky peak (3) cubical muon telescope in Praha (4) cubical muon telescope on the Lomnicky Peak, and (figure at the bottom) semicubical muon telescope 40 m w.e. underground in Budapest. (Ref. [3]).

Fig. 4

Table 2.

Values of the exponent $-\alpha$ pertaining to various rigidity intervals according to paper MOD66

Rigidity, GV	FD	11 year modulation
2 - 5	1.7	1.7
5 -12	0.6	0.7
> 12	1.0	1.9

rigidities 2 - 12 GV both spectra have similar shapes. The flattening around 5 - 12 GV has gained additional support by Iucci and al. /MOD 109/ who have derived α =-0.7 on the basis of multiplicity measurements in neutron monitors.

A further comparison of the spectra of FDs and long term variation was made in the paper of Baixeras-Aiguabella /MOD 43/ who has analyzed the data obtained by the OGO-V monitor system. The analysis was carried out separately on data relating to electrons (energies E > 500 MeV), protons (E >400 MeV) and α particles (E > 400 MeV/n). In fact, this paper seems to be the first to deal with FDs of electrons and to separate FDs of α particles from those of protons. The statistical errors involved are still very large, and thus no difference could be found between the spectra of FDs and long term variation in the cases of electrons and α particles. In the case of protons, where the statistical uncertainties are much smaller, a significant difference was found, the FDs showing a flatter spectrum than the long term variation, again in agreement with the results mentioned above /MOD 66 and 109/.

The spectral behaviour of FDs enabled Roelof and al. /MOD 63/ to draw conclusion on the rigidity dependence of λ, the diffusion mean free path of protons and α particles. Starting with the transport equation of Gleeson and Axford they concluded that time independence during a FD of the ratio of the counting rates of two detectors with different rigidity sensitivities involves, under certain assumptions, the independence of λ on rigidity in the rigidity interval subtended by the two detectors. As an example, the FD with an exceptionally long recovery during the period 2nd July - 25 Sep. 1969 /Fig.5/ was analyzed and a fairly good constancy of the ratio of the counting rates of the

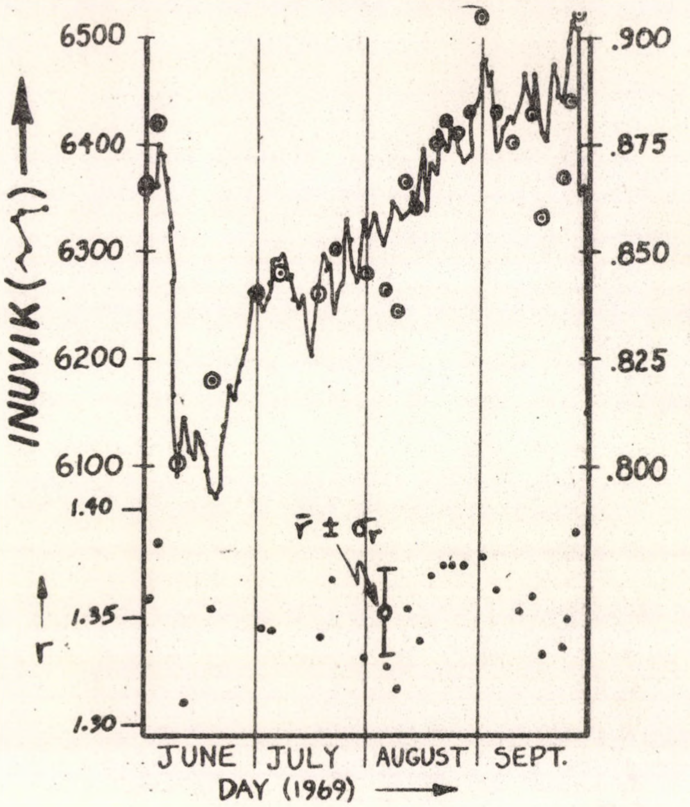


Fig. 5

Daily averages of the Inuvik neutron monitor /continuous curve/, flight averages of the NYU airborne detector /circles/, and the ratio /r/ of the NYU to Inuvik in arbitrary units /dots/. The average ratio /r/ and standard deviation /σ_r/ for the plotted points are shown by error bars. /Paper MOD 63/.

Inuvik neutron monitor and the New York University airborne neutron monitor was found. This would indicate an independence of λ of P in the interval 1.5 GV $\lesssim P \lesssim$ 15 GV. This, however, seems to be strange since this would involve the power spectrum M(k) of the magnetic irregularities in terms of the wave number, k, to be $M(k) \sim k^{-2}$, whereas observations show rather a dependence $M(k) \sim k^{-1}$. The authors of paper MOD 63 are inclined to think that perhaps one of the assumptions made, especially that requiring the separability of $\lambda(r, P, t)$ into $\lambda_1(r,t) \cdot \lambda_2(P,t)$, does not hold.

It would have been nice to give a statistically well founded upper limit of the coefficient of regression /in time/ of the ratio of the counting rates involved and to show how large variations of λ

with P can be excluded on the basis of this upper limit. Without such an analysis the conclusions drawn seem to be of a qualitative character.

2.2.3 Anisotropy during FDs

Since the early work of A.G. Fenton and al. showing the existence of North-South anisotropies during FDs [4] many papers have dealt with this type of anisotropy.

The method given in [5] and applied in [6] was developed and very extensively applied by the original authors, Duggal and Pomerantz, in MOD 48. The new conclusions as compared to those reached in [6] are the following:

a/ A more thorough analysis has shown that ≈ 90 per cent of all FDs show North-South anisotropies.

b/ There were several cases the N-S anisotropy was of a very long duration /a week or more/. An example is shown in Fig.6.

c/ Several cases were observed when the anisotropy changed its direction. A brilliant example of this phenomenon is shown in Fig.7.

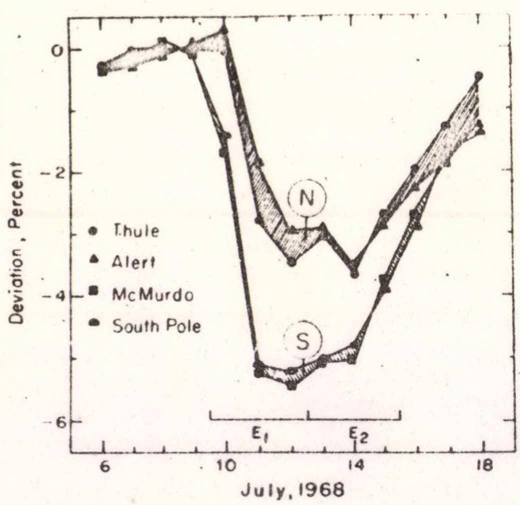


Fig. 6

Comparison of the nucleonic intensity deviations recorded at a pair of northern and a pair of southern stations in July, 1968./Paper MOD 48/

According to the theory developed in [5] the relative change of intensity, dI/I, as observed at stations with various "effective latitudes", λ^* /defined in paper [5]/, should be a linear function of sin λ^*. This was observed in a large fraction of the cases /see e.g. Fig.8/, but there were several cases, when the dI/I values showed no tendency at all to be arranged along a straight line when plotted as a function of sin λ^*. These latter cases deserve thus special interest.

Another paper /MOD 47/ was presented by Mercer and al. mostly along the same lines. They have found that all FDs show anisotropies

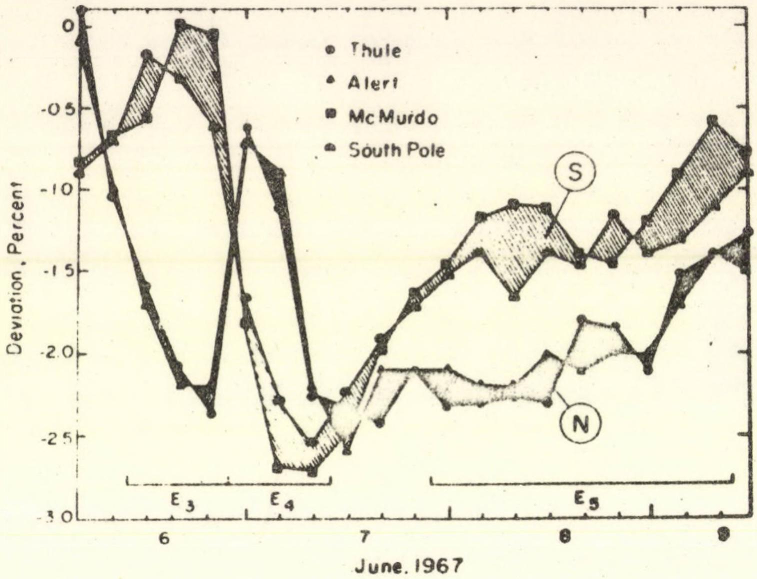


Fig. 7

Observation of phase inversion event in which the direction of the North-South asymmetry reversed abruptly./Paper MOD 48/

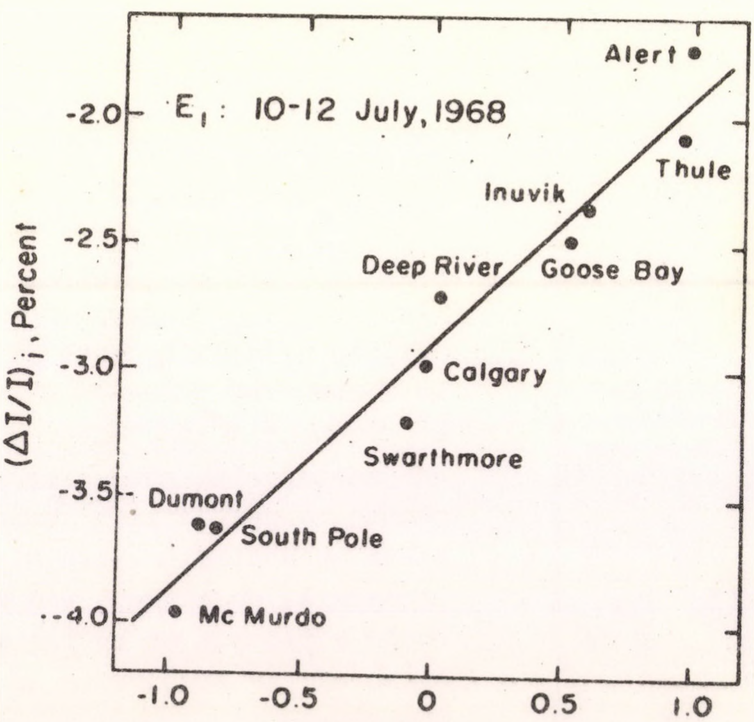


Fig. 8

$\Delta I/I$ plotted as a function of $\sin\lambda^*$ during 10-12 July, 1968. An example of a good fit of points to a straight line. There are other cases, when the fitting to a straight line is not possible. /Paper MOD 48./

in the beginning phase and more than 43 per cent of the FDs show anisotropies during the whole period of depression. It is interesting to note that the authors of paper MOD 47 have found a N-S anisotropy also during quiet days. In fact some 35 per cent of the quiet days investigated by them showed a N-S anisotropy, most of them with a relative amplitude of 0.5 to 0.7 per cent.

In a talk given at the session of most recent results [7] it has been pointed out by Somogyi that a considerable fraction of the quiet time N-S anisotropy can be explained by the fact that the equatorial plane is inclined by 23.5 degrees to the plane of the ecliptic. This inclination gives rise to other interesting effects /half yearly variation of the amplitude of the solar daily variation, yearly wave in the intensity/ as well.

It has been known for a long time that the solar daily variation is likely to show an enhanced amplitude during FDs with a phase generally different from that observed during quiet times. Enhanced amplitudes during FDs may be observed at energies as large as 10^{11} eV as is shown in the bottom figure in Fig.4 representing one of the earliest observations at these energies.

Razdan and Bemalkheddar /MOD 42/ analyzing data obtained at 15 stations during 1965-1967 have found seven cases in which enhanced solar daily variation took place during the recovery phase of a FD. Three of these cases may be seen in Fig.9. The amplitudes ranged from 0,67 to 0,95 per cent and the phases were grouped around the morning hours /8-10 hours a.m./. The rigidity spectrum of the amplitude could be best fitted by a constant value /i.e. with an exponent $\gamma = 0$/. Whereas various geomagnetic and solar phenomena connected with these anomalous anisotropies were studied in detail, no attempt was made to build a picture as to the mechanism of the production of the anomaly.

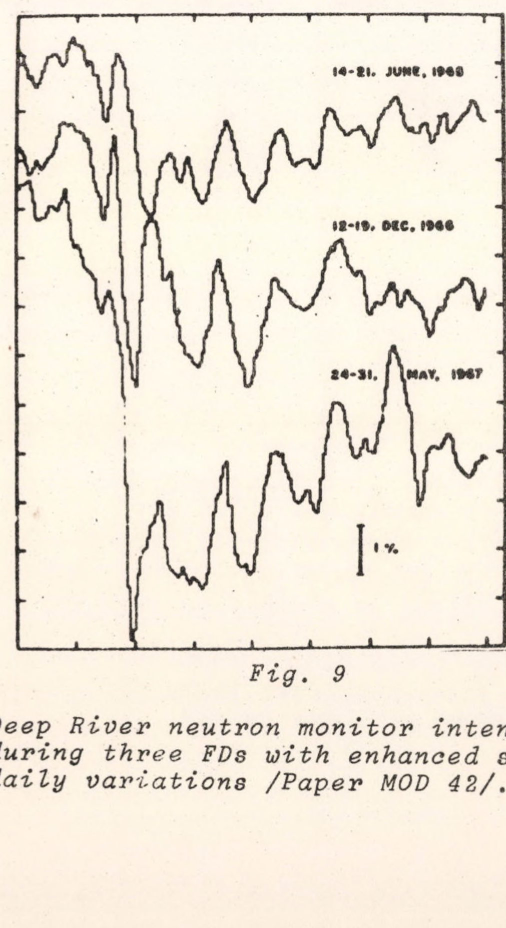


Fig. 9

Deep River neutron monitor intensity during three FDs with enhanced solar daily variations /Paper MOD 42/.

Quiet time enhanced anisotropies were studied by Ananth and al. /MOD 32/ in the world wide grid of neutron monitors in the years 1965-69. Four cases with amplitudes ranging from 0.89 to 1.17 per cent and with maxima between 19,2 and 19,8 hours were found. The profiles of these events may be seen in the upper part of Fig.10. The rigidity spectrum again showed independence of rigidity. The authors interpret these events as consequences of extra streams or sinks along the garden hose field lines in the direction towards or from the sun, respectively. It is interesting to note the difference, almost 12 hours, of the time of maxima in the cases of FD and quiet time events.

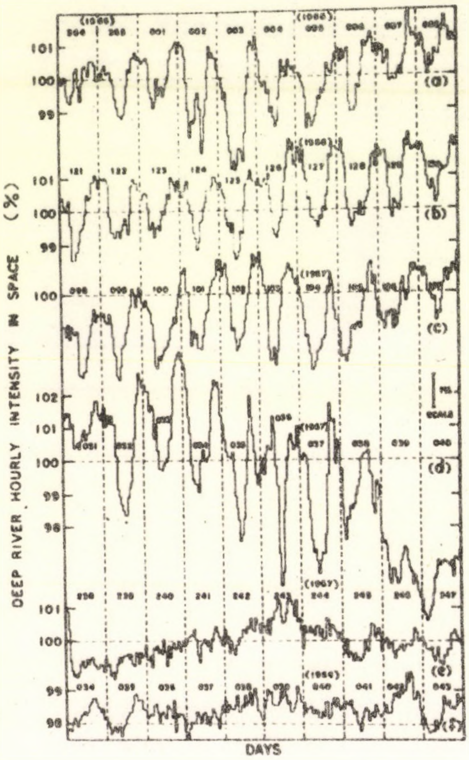


Fig. 10

Four events showing enhanced solar daily variations during quiet days /top four curves/. /Paper MOD 32/.

2.2.4 Pre-increases before FDs

Dorman and al. /MOD 51/ have continued their interesting work which they have reported on already at the Budapest Conference. In accordance with Razdan and Bemalkheddar /MOD 42/ they have found that FDs are mainly produced by solar flares at the eastern limb. They have also found that the amplitude of the pre-increase is proportional to that of the FD and both increase with the heliolatitude of the flare producing them. On the basis of the duly corrected time lag between the onset of the solar flare and the pre-increase the place of production of the shock wave can be located.

2.3 Synthesis

A few of the papers dealt with above /e.g. MOD 32, 42, 63, etc/ have attempted to fit theories or at least put forward special assumptions to give a better understanding of the results of the analysis reported on in the paper itself. There is, however, only one paper /Quenby, MOD 50/ presented which aims at a refinement of our basic concepts on FDs. In this excellent paper MOD 50, a systematic and quantitative confrontation of the theories of FD with the basic features of the FD has been made. The theories invoked were a/ the perturbation of the basic modulation process b/ the shock wave theory c/ the theory of the magnetic tongue with tangential discontinuity.

a/ The perturbation of the basic modulation process leads to an additional decrease by a factor of $\exp(-0.12\ P^{-1} \beta\ .\ \delta R)$, where P stands for particle rigidity in GV, β is the enhancement factor of the parameter w^2/K with w being the solar wind velocity and K the coefficient of diffusion parallel to the field lines, and $R_1 = 1 + \delta R$ is the distance in astronomical units for which w^2/K is enhanced by the factor of β.

This model can account for a decrease as large as 6 per cent in neutron monitor intensities developing during some 3-4 days, is, however, unable to explain any sudden decrease, like 1,5 per cent in 2 hours.

b/ The maximum decrease which may be produced by a shock wave has been calculated to be

$$\frac{\Delta n}{n} = \frac{4w}{v\ \cos\vartheta}\left(1 - \frac{B_o}{B}\right)$$

where v is the particle velocity, ϑ is the angle of the field lines to the radial direction inside of the shock wave, B_o and B are the magnetic field outside and inside of the shock wave, respectively. Direct observations of w show that although the sharp drop of the intensity may well be understood in terms of this theory, too large values of ϑ /i.e. $\vartheta \approx 90^o$/ would be required to explain FDs with amplitudes of about 10 per cent. In the case indicated in Fig.11. the position of the shock front was determined by means of various spacecrafts. The orientation of the shock near the earth as determined by HEOS yields $\vartheta \approx 64^o$ which cannot explain a FD larger than 0,7 per cent. The shock position at Pioneer 9 with $\vartheta \approx 81^o$ gives also rise to a low value of a FD, i.e. 2 per cent.

c/ Magnetic tongues /double shock waves/ with large scale tangential discontinuities can involve decreases as large as

$$\frac{\Delta n}{n} \approx 1 - \frac{v_{d,o}}{v_d}$$

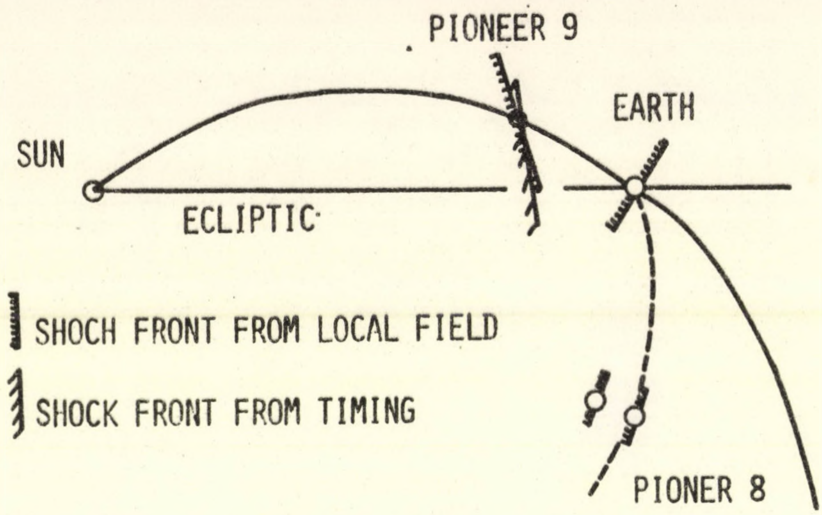


Fig. 11

Positions of shock fronts as seen at Pioneers 8 and 9, and HEOS A-1 on 26 Feb 1969. /Paper MOD 50/.

where $v_{d,o}$ and v_d stand for the drift velocities outside and inside of the shock, respectively. Since $v_{d,o}/v_d$ may be as low as 30 per cent, FDs as large as 70 per cent may be accounted for in terms of tangential discontinuities stretching along a substantial part of the surface of a sphere around the sun. The existence of a tangential discontinuity is made very probable by observation of the magnetic field components carried out on Pioneers 8 and 9. /See the decrease of B and the change of sign of Θ at about 7 a.m. in Fig.12./

The author concludes that the initial cause of large decreases is mechanism c/ (magnetic bottles with tangential discontinuities) and the later stages of the events may be controlled by mechanism a/ (perturbation of the long term modulation).

A mechanism giving rise to enhanced anisotropies is also dealt with in MOD 50.

3. AVV, I.E. VARIATIONS DUE TO LARGE SCALE AZIMUTHAL ASYMMETRIES OF THE SOLAR WIND

Long lived active centres on the sun may produce azimuthal asymmetries in the solar wind persistent through several solar rotations.

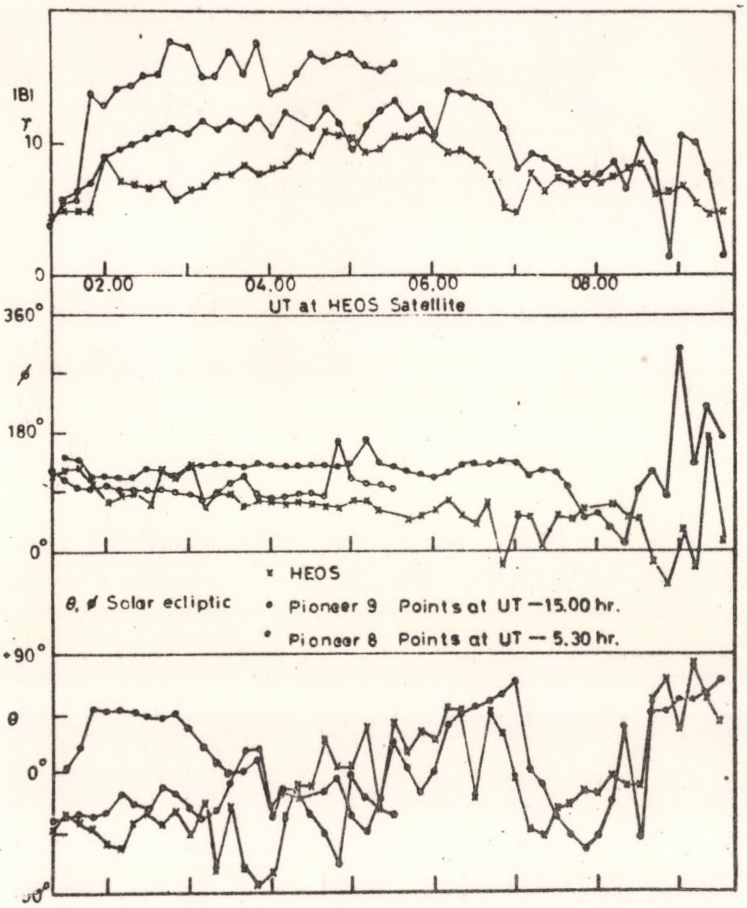


Fig. 12

/B/, Θ, and Ø values of the interplanetary field /solar ecliptic coordinates/ from Pioneers 8 and 9, and HEOS A-1 shifted in time so that the shock onset coincides on each graph. /Paper MOD 50/.

The existence of such centres and the correlation of their passage through the central meridian, with decreases of the Deep River neutron monitor intensity data was clearly demonstrated by Antonucci and al. /MOD 27/

The effect of active solar centres may be observed at energies as high as about 100 GeV by means of underground telescopes like that at the Station Monte dei Cappuccini at a depth of 70m w.e. /Antonucci and al., MOD 28/. The data obtained at this station was compared with those of Hobart /40 m w.e./. The Hobart data show a much less pronounced response to the solar events which may perhaps be explained by the excess of activity of the northern solar hemisphere as compared to the southern one. This is also reflected in the presence of a 27 day wave in the Monte dei Cappuccini data obtained between Sep. 1969 and May 1970, and the absence of a similar wave in the Hobart data obtained during the same period. For an early measurement of the 27 day wave at about 100 GeV see [8].

The presence of a North-South anisotropy at such high energies is the most remarkable feature of these phenomena. From this point of view it is of great importance that a new underground station will be put into operation at Mawson, Antarctica, yielding, among others, the possibility to study the high-energy north-south asymmetry to a greater precision.

A study of the spectral composition of the Deep River neutron monitor variations in the frequency range 0.05 - 0.5 cycles/day was carried out by Ruthberg /MOD 53/ for each year separately from 1958 to 1969. A peak corresponding to the 27 day period was visible on all graphs except of those corresponding to the years 1961 and 1964. /See Fig. 13/. The shape of the background was a power function with an exponent -1,5.

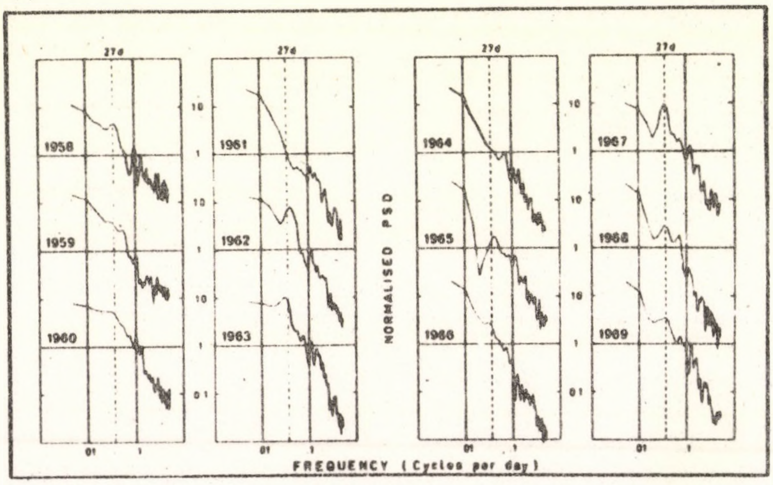


Fig. 13

Normalized power spectra of the galactic cosmic ray intensity /Deep River neutron monitor data/, 1958-1969. The spectra are plotted in log-log scale. /Paper MOD 53/.

It is interesting to compare this result with those of Martinic /MOD 60/a/ who has found exponents of the power spectrum density function varying from -1.3 to -2.0 and has found no significant peak corresponding to a 27 day variation in the Deep River neutron monitor data in the year 1967. /Figs. 14 and 15/.

One is inclined to think that the divergence of the results as

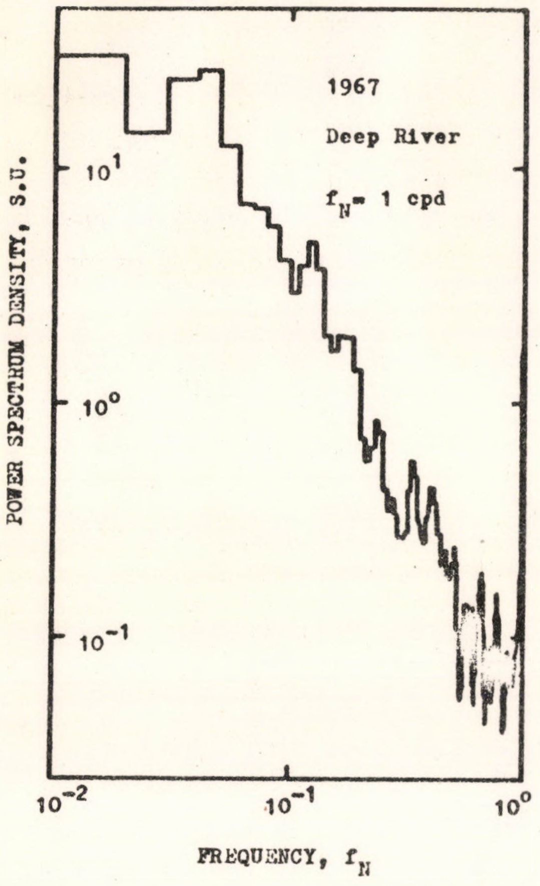


Fig. 14

Power spectrum of cosmic ray intensity from data recorded at Deep River. Frequency range 0.01-1 cycles/day. /Paper MOD 60a/.

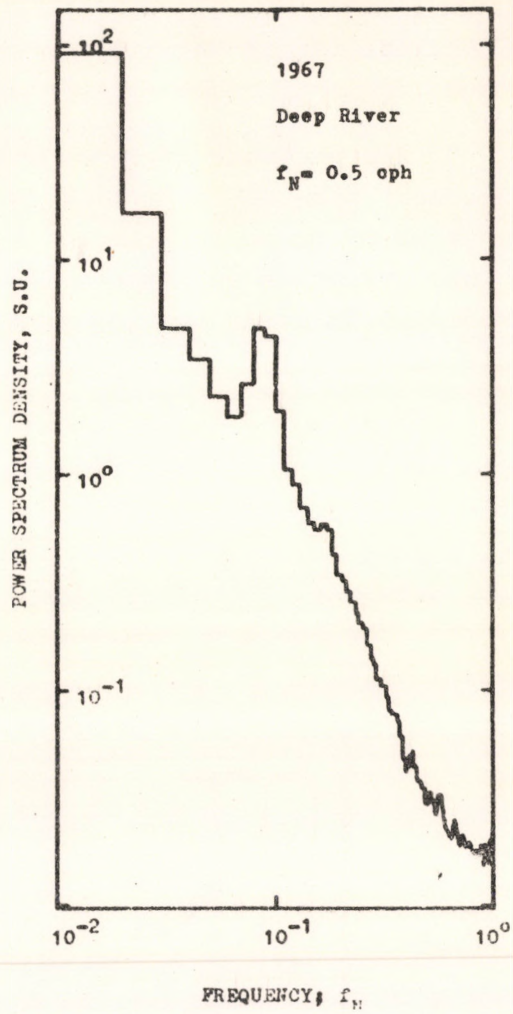


Fig. 15

Power spectrum of cosmic ray intensity from data recorded at Deep River. Frequency range 0.12-12 cycles/day. /Paper MOD 60a/.

to the existence of a 27 day wave in the Deep River data in 1967 might be due to the methods of analysis employed. In fact, the power spectrum analysis, however good insight it might give as to the general spectral composition of a time series, is difficult to interpret when the problem consists of determining the values of certain parameters, like the amplitude of a suspected 27 day wave. The proof of the existence of a wave cannot be done otherwise than by proving that its estimated amplitude is significantly different from zero and to do this it is inevitable to have a correct quantitative estimate of the amplitude together with an estimate of the statistical uncertainty of the estimated amplitude.

In paper MOD 54 an attempt is made by Alaniya to determine the

27 day variation of the amplitude of the solar daily variation based on Chree diagrams constructed on the basis of observations carried out by means of six neutron monitors during July 1957 - February 1958. The existence of the 27 day wave in question was made very probable, no quantitative results were, however, reported.

4. CONCLUSION AND A FEW QUESTIONS

The most interesting result brought out on this Conference in the field of modulation dynamics is the general character of North-South asymmetries, i.e. the fact that in almost all cases when the equilibrium of the interplanetary space is disturbed, a marked gradient perpendicular to the ecliptic plane is produced. There is some indication that this holds not only in violent cases such as shock waves but also in weak perturbations like those giving rise to a 27 day wave.

A lot of interesting questions arises. First of all: Is the extra gradient perpendicular to the ecliptic a quasi static one? There are cases when the gradient changes its direction in periods as short as a few hours. One is inclined to think of oscillations around an equilibrium state. In other cases the extra gradient fades out gradually as if the oscillations were damped very strongly giving rise to an aperiodic case. What are the physical causes of this damping and why it is less effective in some cases then in others?

Furthermore, a great deal of information can be obtained by extending the energy range of the investigations of dynamic effects. Allowing for a very few exceptions, all papers presented were concerned with primary energies of a few GeV, i.e. mainly neutron-monitor energies. Both the low energy end /satellite observations/ and the high energy end /underground observations/ of the dynamic modulation spectrum are but very crudely known. What is the value of the N-S anisotropy at very high energies, say 100 GeV?

In addition to the N-S anisotropy, the dynamic behaviour of the general anisotropy /i.e. the component lying within the ecliptic plane/ needs a more detailed theoretical study. About these and other open questions like the problem of short term /less than one hour/ variations we shall certainly learn in the course of the next Conferences.

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In conclusion, the author of this rapporteur paper wishes to express his sincere gratitude to the Organizing Committee of the 12th International Conference on Cosmic Rays for the kind invitation and facilities which helped him to take part in the activities of the Conference.

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The following papers presented at this Conference have been dealt with in this rapporteur talk: MOD 27, 28, 32, 42, 43, 44, 45, 47, 48, 50, 51, 54, 55, 60a, 63, 66, 109, and 114.

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