Dissertation on

The Study of Time Variation of Cosmic Rays
at the geomagnetic equator

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by

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STATEMENT

A study of the time variation of meson intensity has been made by the author at Trivandrum ($\lambda = -1.13^\circ$, sea level) with narrow angle and wide angle telescopes during the period August 1957 to April 1960. The main conclusions of the investigations are presented below.

1. During 1958 or 1959 there is no statistically significant difference in the amplitudes of the 12 month mean daily variation recorded by telescopes of different opening angles in the east-west plane. The amplitudes of the diurnal and semidiurnal components of the daily variation when studied on a day to day basis also do not exhibit any dependence on the opening angle of the telescope in the east-west plane.

2. The amplitude and the time of maximum of the daily variation are constant during 1957 and 1958 at Ahmedabad, Kodaikanal and Trivandrum. The amplitude of the average daily variation during 1959 is larger than in the previous years largely due to the smaller variability of the time of maximum on individual days.

3. The amplitudes of the daily variation at Ahmedabad and Trivandrum are comparable, whereas the amplitude at Kodaikanal having a lower mean energy of response is smaller than at the sea level stations. The lower

amplitude at Kodaikanal is attributed to the large variability of the time of maximum of the low energy component of cosmic radiation.

4. An examination of the average daily variation at Kodaikanal and Trivandrum when the diurnal amplitudes at both the stations are significant at the 2σ level shows that Kodaikanal having a lower mean energy of response has an earlier diurnal time of maximum compared to Trivandrum. This is consistent with the average daily variation being caused by an anisotropy of primary radiation.

5. The semidiurnal component of the daily variation at Trivandrum and Ahmedabad after correcting for meteorological effects is about 90° out of phase with the semidiurnal component of the barometric pressure. This indicates that the semidiurnal component of the daily variation observed at equatorial stations, particularly at low altitudes, is associated with an anisotropy of primary radiation.

6. During the period 1957 - 1960, no marked dependence of the amplitude of the daily variation related to the index of geomagnetic disturbance is observed. However, the time of diurnal maximum is found to be earlier on geomagnetically disturbed days in narrow angle telescopes.

7. Even though the form of the 12 month mean daily variation has not changed from 1957 to 1959 at Trivandrum, Kodaikanal and Ahmedabad, the diurnal time of maximum has shifted to later hours at all three stations. The results are in agreement with the long term changes observed by Sarabhai et al.

8. An extensive study is made of the cosmic ray intensity changes following polar cap absorption events. The events have been classified into two types depending on their association with cosmic ray decreases. Type A events which are not accompanied by cosmic ray decreases are found to be associated with flares on the western half of the sun and, on the average, with shorter time lags than type B events. Type A PCA events which do not produce significant changes of daily mean cosmic ray intensity or of geomagnetic field are nevertheless found to be effective in producing anisotropy of cosmic rays 3 to 5 days after the flare.

9. The decreases of neutron and meson intensities at different latitudes following type B PCA events, cosmic ray storms and low east-west asymmetry epoch are studied and the results are compared with the observations of other workers. It is shown that in order to explain the global distribution of the changes of intensity, we have to assume a variational spectrum of the type aE^{-x} and in addition an increase in the geomagnetic cut-off following the cosmic ray storms. 'a' the strength of

the source has to be anisotropic, being largest at $= 80^\circ$ and minimum at $= 0^\circ$. The results are discussed in the light of different models proposed and it is shown that all the currently prevalent models are inadequate to explain cosmic ray storms.

These conclusions have been discussed in chapters IV, V and VI and a list of references consulted by the author has been included at the end of the thesis.

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C O N T E N T S

CHAPTER I. INTRODUCTION 1

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CHAPTER I

INTRODUCTION

There is today a great interest in the study of the time variations of cosmic rays. Apart from having a bearing on the theories of the origin of cosmic rays, the studies permit the use of high energy primary particles as probes of electric and magnetic fields in the exosphere, in interplanetary and in inter-stellar space. For the International Geophysical Year about 110 continuous cosmic ray recording stations were set up at different parts of the world. Studies have been made with standard neutron monitors as well as with cubical meson telescopes. Investigations have been made on mountain tops, in aeroplanes, in balloons and with satellites and rockets. Intensive work has been undertaken to study the solar, terrestrial and interplanetary relationships of cosmic ray variations.

Progress in the study of the time variations of cosmic radiation has been reviewed by Elliot[1], Sarabhai and Nerurkar[2], Rose[3] and Singer[4]. Dorman[5] has dealt with this subject in a most exhaustive manner in his book "Cosmic Ray Variations". Moreover, individual authors such as Simpson[6], Forbush[7] and Sarabhai et al[8] have reviewed particular aspects of this field with special reference to the work done by their own groups.

Time variations of cosmic radiation can arise from various factors such as

(a) atmospheric changes altering the multiplicity function linking primary with secondary intensity,

(b) changes of primary intensity including those due to new sources,

(c) changes in the primary energy spectrum,

(d) changes in the geomagnetic cut-off due to disturbances in the geomagnetic field, and

(e) anisotropy of primary radiation, as viewed by an instrument fixed to the spinning earth.

This thesis deals mainly with the experimental study of long and short term changes of solar daily variation and the variations of daily mean intensity of cosmic ray mesons recorded by narrow and wide angle telescopes at the equatorial sea level station of Trivandrum during the period August 1957 to April 1960.

In order to interpret time variations of secondary cosmic ray intensity in terms of the variations of primary intensity, it is necessary to apply corrections for geomagnetic effects and take into account the transition effects in the atmosphere. In this introduction a summary of the work relating to geomagnetic effects, the transition effects and the meteorological effects in the atmosphere is first presented. The subject of time variations is next surveyed with particular reference to our present investigation.

1.1. Geomagnetic effects.

Stormer[9] has made extensive computations of the trajectories of charged particles in the earth's dipole field in an attempt to explain aurora. The extension of the Stormer theory to cosmic ray physics has been made by Lemaitre and Vallarta[10,11] by applying Liouville's theorem to an isotropic distribution of cosmic rays. By taking into account the earth's shadow effect, they have shown that there are directions excluded for particles of certain energy that the simple Stormer theory allows to enter. These results have been summarised by Janossy[12], Johnson[13], Montgomery[14] and Alpher[15].

For the interpretation of the effects such as the solar flare effect where the isotropy of cosmic rays is not observed, it becomes necessary to calculate the actual trajectories of the individual particles. Schluter[16], Firor[17], Jory[18], Lust et al[19], Lust[20], Gall and Lifshitz[21] and Malmfors[22] have computed individual orbits for primary particles of energy upto 10 Bev. Brunberg and Dattner[23] have used a model terrella experiment where a well collimated beam of electrons of variable velocity is ejected from a miniature gun mounted on a magnetized model of the earth. The asymptotic coordinates of velocity vectors for protons of energy greater than 2 Bev which can arrive at specified angles to the zenith in the north-south and east-west planes at various latitudes are experimentally determined. In figure 1 we have reproduced Brunberg and Dattner's diagram for Kodaikanal showing the asymptotic coordinates on the celestial sphere for protons of various rigidities and directions of arrival.

The results of Brunberg and Dattner's study presented in convenient graphical form for various stations have been extremely valuable in the interpretation of the effects caused by anisotropic radiation.

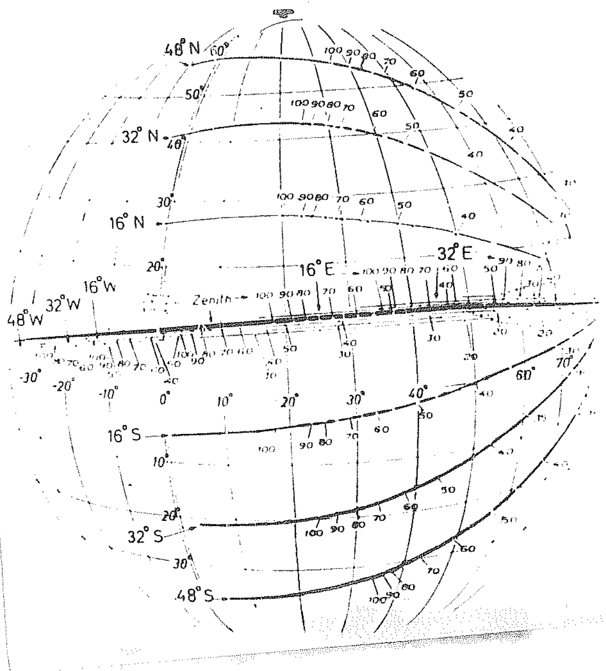

Fig. 1 - Diagram showing the asymptotic coordinates of velocity vectors of protons incident at Kodaikanal.

Evidence presented by Rose et al[24], Kodama and Miyazaki[25], Rothwell and Quenby[26], Skorka[27], Simpson[28] and McDonald[29] have shown that the cut-off momenta as predicted by Stormer theory with an eccentric dipole representing the earth's field and the corresponding values derived from the intensities of cosmic rays at various latitudes and longitudes are often not in good agreement. Rothwell and Quenby[29] attribute the discrepancies to the regional anomalies in the earth's field. Kellogg and Schwartz[30] have theoretically calculated the cut-off rigidities using an approximation to the earth's magnetic field which includes all moments upto octupole and find that the results agree fairly well with the observed cosmic ray intensity at various places. Their results show that the deviations of observed cosmic ray intensity from the calculated value on the basis of the dipole approximation may be ascribed to higher moments of the earth's field. Recently, Quenby and Webber[31] have taken into consideration the dipole as well as the nondipole parts of the field and deduced the cut-off energies at various latitudes. Cogger[32] has calculated for a large number of stations the magnetic cut-off rigidities following Quenby and Webber's method. In table 1 are presented these values along with the cut-off rigidities according to the centred dipole field for a few stations.

1.2 Methods of relating primary cosmic ray intensity variations to secondary cosmic ray intensity variations.

Primary cosmic rays incident at the top of the atmosphere undergo complicated transition effects before

Table 1

Magnetic cut-off rigidities according to centred dipole field and the modified field as suggested by Quenby and Webber.

Station	Geo. Coordinates Lat. °	 Long. °	Geomag. Lat. °	Magnetic cut-off rigidities in GV Centred dipole.	 Quenby & Webber.
Kodaikanal	10.23	77.48	0.55	14.90	17.53
Trivandrum	8.48	76.95	-1.13	14.89	17.48
Lae	- 6.72	147.00	-15.72	12.79	14.80
Ahmedabad	23.02	72.60	13.78	12.35	14.58
Makerere	0.33	32.62	- 2.18	14.85	14.61
Huancayo	-12.06	284.67	- 0.60	14.80	14.18
Climax	39.37	253.82	48.17	2.95	2.77
Mt.Welling-ton	-42.87	147.33	-51.40	2.22	1.71
Chicago	41.83	272.33	52.90	1.97	1.54
Mawson	-67.60	62.88	-73.22	1.00	0.97
Resolute	74.68	265.05	82.99	0.33	0.00

they are detected by a recorder in the lower atmosphere. The spectrum of observed secondary particles has been related to the primary spectrum through a function named 'multiplicity function', 'generating function' or 'yield function' by various workers (Treiman[33], Fonger[34], Nagashima[35], Simpson et al[36], Olbert[37] and Dorman[6]). Almost all workers have made use of experimental data on latitude effect for estimating the function. The advantage of this method is that no assumptions have to be made regarding the nature of the complicated processes involved in the transformation of the primaries into secondaries, but the limitation is that the function can be calculated only in the range covered by field sensitive primaries. The function has to be extrapolated for non-field sensitive cosmic rays.

For an observing station situated at a latitude λ and longitude f and level with pressure h_o, the total vertical intensity $N^i_{\lambda,f}(h_o)$ of the i^{th} component (mesons, neutrons, soft component, etc.) produced by the primary energy spectrum $D(E)$ is given by Dorman[5] as

$$N^i_{\lambda,f}(h_o) = \int_{E^{min}_{\lambda,f}}^{\infty} D(E)\, m^i(E, h_o)\, dE \qquad \ldots (1)$$

where $m^i(E, h_o)$ is the multiplicity function which represents the number of type i particles produced by a single primary particle of energy E at the pressure level h_o in the atmosphere. $E^{min}_{\lambda,f}$ is the geomagnetic cut-off at the observing station.

By varying equation (1) with respect to all parameters, we get the cumulative variation of the observed intensity.

$$\frac{\delta N^{i}_{\lambda,r}(h_o)}{N^{i}_{\lambda,r}(h_o)} = -\delta E^{min}_{\lambda,r} \cdot W^{i}_{\lambda,r}(E^{min}_{\lambda,r}, h_o)$$

$$+ \int_{E^{min}_{\lambda,r}}^{\infty} \frac{\delta D(E)}{D(E)} \; W^{i}_{\lambda,r}(E, h_o) \, dE$$

$$+ \int_{E^{min}_{\lambda,r}}^{\infty} \frac{{}'\delta \, m^{i}(E,h_o)}{m^{i}(E,h_o)} \cdot W^{i}_{\lambda,r}(E,h_o) \; dE$$

$$\text{.......} \quad (2)$$

where

$$W^{i}_{\lambda,r}(E,h_o) = \frac{D(E)\; m^{i}(E,h_o)}{N^{i}_{\lambda,r}(h_o)} \qquad \text{.......} \quad (3)$$

The function $W^{i}_{\lambda,r}(E, h_o)$ has been named "coupling coefficient" by Dorman.

The first term on the right hand side of the equation (2) represents the variation due to the variations of the geomagnetic threshold $E^{min}_{\lambda,h}$. This variation in $E^{min}_{\lambda,h}$ may be due to the combined influence of various geomagnetic disturbances.

The second term represents the variation in the observed intensity of cosmic rays due to the variation of the differential energy spectrum of the primary particles. The relative variation of primary flux $\frac{\delta D(E)}{D(E)}$ may be called the energy spectrum of variation of cosmic rays or in short the primary variations of cosmic rays. It is clear that with the help of the function $W^{i}_{\lambda,r}$ (E, h_o) we can determine the observed variation of the i^{th} component from a known value of $\frac{\delta D(E)}{D(E)}$; or conversely, from the observed data of various secondary variations, having substantially different coupling coefficients, primary variation of cosmic rays $\frac{\delta D(E)}{D(E)}$ can be determined.

The third term represents the variations due to the variation of the multiplicity function for a fixed primary flux. The variation of $m^{i}(E,h_o)$ can be due to a variation in the experimental conditions (for example, the change in the thickness of the shield) or due to the variation in the atmospheric conditions. Thus, we include essentially the meteorological effects on the measured secondary intensity. If the data are corrected for meteorological effects, this term can be neglected.

To determine the coupling coefficient, we differentiate equation (1) with respect to $E^{min}_{\lambda,r}$.

$$\frac{\delta N^{i}_{\lambda,r}(h_o)}{\delta E^{min}_{\lambda,r}} = - D(E^{min}_{\lambda,r})\, m^{i}(E^{min}_{\lambda,r}, h_o)$$

and substituting this in equation (3) we get

$$W^{i}_{\lambda,r}(E^{min}_{\lambda,r}, h_o) = - \frac{1}{N^{i}_{\lambda,r}(h_o)} \cdot \frac{\delta N^{i}_{\lambda,r}(h_o)}{\delta E^{min}_{\lambda,r}} \quad ...(4)$$

The right hand side of equation (4) represents essentially the geomagnetic effect at the given point for the i^{th} component and may be obtained from the results of extensive experiments on geomagnetic effects for the given component. Thus the coupling coefficient can be obtained from the results of empirical data on geomagnetic effects.

Dorman has presented his results in graphical form from which coupling coefficients can be read out for total ionising component, hard component and neutron intensity at sea level and at 700 gm/cm^2 for latitudes 0°, 30°, 50° and 80° for primary energies upto 1000 Bev. His results are reproduced in figure 2 for $\lambda = 0°$. Direct values have been obtained upto 20 Bev, beyond which the curves have been extrapolated.

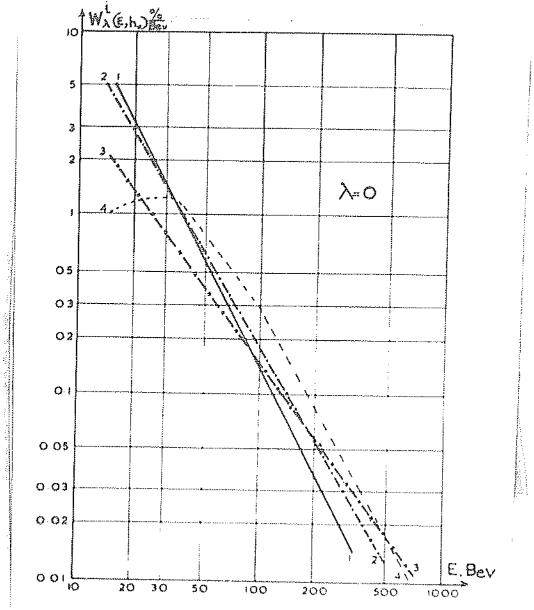

Fig. 2 - Coupling coefficients (1) for total intensity (ionising component) at high altitude; (2) for sea level neutron intensity; (3) for total intensity at 700 gm/sq.cm and (4) for hard component at sea level.

With reference to the proposed changes of cosmic ray geomagnetic coordinates, Webber and Quenby[38] have made more accurate calculations of Fonger's 'yield functions' taking into account the new cut-off rigidities obtained by considering the higher moments of the earth's magnetic field as well.

1.3 Variations of atmospheric origin.

Duperier[39] was the first to represent the variations of atmospheric origin in the form of the regression equation

$$100 \frac{\Delta I}{I} = \alpha_P \Delta P + \alpha_H \Delta H + \alpha_T \Delta T \quad ....(5)$$

connecting the percent change in the mean intensity of cosmic rays with change of barometric pressure ΔP at the station, the change in the height of 100 mb level ΔH and the change ΔT in the mean temperature between the 100 and 200 mb levels. Since then, many workers such as Barret et al[40], Olbert[41], Maeda and Wada[42], Wada and Kudo[43], Trefall[44,45,46,47], Bachelet and Conforto[48], Hayakawa et al[49], Mathews[50] and others have tried to explain the cosmic ray variations of atmospheric origin. For the meson component in the lower atmosphere, the important physical processes to be considered are the rates of creation and absorption and the survival probability of the unstable π and μ mesons.

Dorman and Feinberg[51] have worked out the complete theory of the atmospheric effects on the same basis as that of Maeda and Wada[42]. The final results of the derivation have been expressed by them in the form

$$\frac{\delta N_\mu}{N_\mu} = \beta \delta h_0 + \int_0^{h_0} W_T(h)\, \delta T(h)\, dh \qquad \dots (6)$$

where δh_0 is the change in barometric pressure h_0 at the station level, β is the barometric coefficient (pressure coefficient) which arises from the mass absorption effects and $\delta T(h)$ is the change in temperature of the isobaric level at pressure h. The function $W_T(h)$ is designated as the temperature coefficient density and has been calculated and tabulated by them for a variety of experimental conditions.

Equation (6) can be written in the following form after approximation:-

$$\frac{\delta N_\mu}{N_\mu} = \beta \delta h_0 , + \sum_{i=0}^{i=10} K_i \, \delta T_i \qquad \dots. (7)$$

where K_i is the partial temperature coefficient for the i^{th} isobaric layer obtained by integrating W(h) over the corresponding layer. Dorman has pointed out that it is sufficient to sum up the temperature effects over eleven standard atmospheric layers from 1000 mb to 50 mb. The main difficulty in applying this method for correcting daily variation of cosmic ray intensity lies in the accurate determination of δT_i from radio sonde observations which may have inherent errors due to improper radiation shielding of the temperature element.

Glokova[32], Kuzmin[33] and others have shown, following Dorman's method of corrections for cosmic ray data, that the seasonal variation of daily variation and daily mean intensity vanish if proper temperature corrections are applied. For high latitude Russian stations they have found that the amplitude of diurnal variation of meson intensity is almost doubled with time of maximum near noon after temperature correction. Maeda[34] has shown that the temperature variations give rise to a diurnal variation of only 0.05 % amplitude with a time of maximum near 1400 hours.

Miyazaki[35] has worked out a method of applying temperature correction to the low energy portion of cosmic rays by comparing the cosmic ray intensities measured by identical instruments at two stations lying almost on the same latitude and longitude, but at different altitudes. With the assumption that the temperature variations over a corresponding isobaric level above the two stations are exactly alike, he has shown that the difference in the intensity at the two stations has to be corrected only for the temperature changes of the mean atmosphere between the two stations.

Simpson et al[36] and Dorman[6] have shown that the effect of atmospheric temperature variations on the neutron intensity is negligible; the temperature coefficient being -0.02 %/°C at $\lambda = 0$, and -0.006 %/°C at $\lambda = 50°$ and above. The main contribution to the variations of atmospheric origin in this case is due to barometric pressure changes. Simpson et al[55] have obtained a pressure coefficient of -0.94 % per mm of Hg. This value agrees well with those calculated by Adams and Braddick[56], Van Heerden and Thambyahpillai[57] and Bose and Kataman[58]. The pressure coefficient is constant over the geomagnetic latitude range $\lambda = 0$ to $\lambda = 54^{\circ}$ and for atmospheric depths greater than 600 gms.

Sarabhai and Rao[59] have recently summarised experimental evidence which shows that the diurnal variation of temperature has negligible amplitude above 2 Km. They have thus stated that it is enough to correct for the temperature variations upto 2 Km. in studying the daily variation of cosmic rays. Since radio sonde data for the daily variation of temperatures at 1 Km and 2 Km are difficult to obtain, they have estimated the temperature variations at 1 Km and 2 Km above the ground level according to Boers' relation. The amplitudes are 0.22 and 0.11 times the amplitude at surface. Thus, by using Dorman's temperature coefficients for layers upto and including 2 Km and making use of Boers' relation they have estimated the temperature coefficient to be -0.0284 %/°C change of temperature at ground level. Thambyahpillai and Quenby[60], however, believe that by correcting daily variation of meson intensity for daily variation of atmospheric temperature upto 2 Km above ground level, by using Dorman's formula, only 2/3 of the temperature effect is accounted for.

1.4 Modulation of cosmic ray intensity.

1.41 Long term variations.

The change in the general mean intensity of cosmic radiation with the change in solar activity as reflected by the sun-spot numbers has been studied by many authors. A decrease of about 4 to 5 % for the meson intensity at sea level and about 22 % in the neutron intensity from maximum to minimum solar activity have been reported from the studies of Forbush[7], Glokova[61], Lockwood[62] and Fenton et al[63]. This change in mean intensity has the same magnitude from Huancayo (0°S) to Godhavn (80°N) and is negatively correlated with the sun-spot numbers. The magnitude of the change practically remains the same for magnetically quiet and disturbed days.

Fenton et al[63] from a study of the intensity variations of mesons as well as neutrons at Ottawa and Resolute during the period 1955-1957 have shown that there is a decrease of 5 to 6 per cent in meson intensity and 22 % in nucleonic component and that these changes are not due to transient decreases, thus proving that the 11 year variation in the intensity with solar activity is not due to a cumulative effect of Forbush decreases.

The occurrence of similar changes at high altitudes have been provided by balloon experiments conducted by Neher[64,65], Meyer and Simpson[66], Pomerantz et al[67,68] and others. Neher[64,68] has shown that at the latitude $85^\circ - 88^\circ$N, at 70,000 feet elevation above sea level, there is a change of about 50 % in the total ionizing component corresponding to a change of 4 % at sea level from sun-spot maximum year of 1937 to sun-spot minimum year of 1954. Neher's[69,70] results for the present solar cycle also confirm the above values. The results of Winckler et al[71,72] show that the effect in the present solar cycle is more than the change observed in the previous solar cycle and that the major part of the change is occurring near the peak of the solar activity. They conclude that there exists a triggering mechanism rather than a proportional relationship between solar activity and mean intensity changes. The results of Freier et al[73] and Neher and Anderson[74] for flux and heavy nuclei also indicate the same relation.

Forbush[75] has shown that the decrease in intensity recorded by the ionization chamber from its maximum near the sun-spot minimum lags an year or more behind the increase of solar activity following the sun-spot minimum. This lag does not appear in the results obtained by Neher at high altitudes nor is it obtained by Rose from the neutron monitor data at Ottawa.

Katzman[76] on the other hand has reported an increase of about 12 % in the intensity of meson component measured at Ottawa by a narrow angle telescope of solid angle 11.5×10^{-4} steradians with increase of solar activity for the period September 1956 to February 1957, the reference level of intensity being that recorded in July 1958. This large increase has been observed to accompany a large and sustained increase in solar activity as determined by means of critical frequency of the F_2 layer.

Simpson et al[77] from the cosmic ray intensity measurements at ground level by neutron monitors and at great distances upto 8×10^{6} Km by detectors carried by satellite Explorer VI and space probe Pioneer V have shown that any mechanism changing the cosmic ray intensity over 11 years is centred about the sun and the scale size is greater than one astronomical unit for the volume of the space in which the cosmic ray intensity is reduced at this period of solar activity (August 1959 - April 1960).

It has been shown by Simpson[78] that the energy spectrum of relativistic particles upto at least 20 Bev changes approximately from $E^{-2.7}$ in 1954 to $E^{-2.0}$ at maximum solar activity in 1957-1958, with the intensity being reduced by a factor in excess of 4 for the integral flux down to nearly 100 Mev for protons.

McDonald and Webber[79] have shown that the variations in primary rigidity spectrum can be represented as

$$\frac{\Delta j}{j_o} = - c(t)P^{-\gamma} \qquad ..... \quad (8)$$

from which the primary rigidity spectrum at time t in terms of the spectrum at time t_o is given as

$$J(P,t) = j_o\,(P,t_o) \left\{ 1 - c(t)\,P^{-\gamma} \right\} \qquad ... \quad (9)$$

Here $c(t)$ is a function of time in the solar activity cycle. Thus the long term changes can be represented by a modulation of the primary spectrum by $(1 - c(t)\ P^{-\gamma})$. $\gamma = 1$ gives good agreement with $1 \leq c(t) \leq 2.5$. Lockwood[20] has shown for the present cycle of solar activity $c(t) = 2.5$ and $\gamma = 1$ explains very well the observed changes in intensity, when $j_0(P, t_0)$ is taken to represent the primary rigidity spectrum at the solar activity minimum in 1954.

1.42 Changes in the 'knee' of the latitude effect.

An important result has emerged out of high altitude studies conducted by Neher[21] and others during the last solar minimum of activity. Experiments have revealed the absence of low energy cut-off in cosmic rays beyond a latitude of $53^0 - 55^0$, even at the highest altitudes reached by balloons. During other periods of the solar cycle a sharp cut-off of the primary spectrum at about 0.8 Bev for protons corresponding to the 'knee' is found to exist.

In order to avoid the errors due to day to day changes in the cosmic ray intensity, Neher et al[22,23] have made simultaneous flights with balloon borne instruments at different latitudes. The results show that the 'knee' for an atmospheric depth of 15 gm/cm^2 shifted to higher latitudes from 1957 to 1961. Meyer and Simpson[26] have reported that the 'knee' of the latitude effect at an altitude of 30,000 feet for the nucleonic component has shifted by 3° from 55° to 58° during the period 1948-1951. The low energy cut-off for protons at 0.8 Bev in 1951 vanished in 1954 when protons of energy as low as 0.13 Bev were detected.

Ellis et al[84] have pointed out that there exists cut-off for heavy primaries also at about the same latitude as for protons in 1953. This result indicates a cut-off dependent on rigidity rather than on energy of the primaries which favours a mechanism involving magnetic fields responsible for the cut-off.

Van Allen[85] and Meredith et al[86] have made investigations with counters sent aloft in rockets from stations extending upto the pole. They find that there is no increase in flux, in the energy range of 170 to 20 Mev and thus conclude that the cut-off extends to as low as 20 Mev for protons. These results have to be taken with reservations due to the uncertainty in the contribution of the albedo and of the geomagnetic effects as applied to streams of low energy particles at very high latitudes.

Katzman and Rose[88] from studies at ground level from 15° to 60°N geomagnetic latitudes in 1954 have got a value for the 'knee' for neutron component as 52°N, the 'knee' for the meson component being not well defined.

Neher's[87] experiments during this solar cycle have shown that the low energy cut-off has reappeared in 1956. Neher et al[68] have reported that the 'knee' of the latitude versus intensity curve exists in the southern hemisphere as well. In October 1958 it is at 53° as revealed from observations made at atmospheric heights of 30 gm/cm^2.

Storey[69] from studies conducted with aircraft borne neutron monitors in July 1957 and July 1958 at 475 gm/cm^2 reports the northward shift of the south latitude 'knee' between July - August 1957 and July 1958 to be about 1.5° from 52.3°S to 50.8°S.

Winckler et al[72] and Freier et al[73] at Minnesota have shown that even in 1957, when the sun was at its peak activity, low energy particles down to 150 Mev/nucleon were present on some occasions at balloon heights. They conclude that the reduction in flux in 1957 is due to the reduction in both high as well as low energy particles. Major part of the decrease occurs in 1956 - 1957 which again suggests a triggering mechanism responsible for the change.

Meyer and Simpson[66] have estimated that the power law spectrum for the differential primary intensity changed from $J = c(P/Z)^{-2}$ in 1948 to $J = c(P/Z)^{-2.7}$ in 1954 for particles of rigidity 1 to 4 Bev. This was accompanied by a 13 % increase in the total intensity during the same period. Thus a close relationship between the shift of the 'knee' and the 11 year cycle of changes in cosmic ray intensity is evident.

1.43 Variations of intensity during magnetic storms.

The world-wide nature of cosmic ray intensity decreases, sometimes accompanying magnetic storms, has been shown as early as 1937 by Forbush[90]. Many authors have studied this phenomenon in relation to its various aspects. The main features of such events known as 'Forbush decreases' or 'cosmic ray storms' are the initial sharp decrease in cosmic ray intensity sometimes even upto 10 %. Many cosmic ray storms are associated with the main phase of magnetic storm and their recovery (following the decrease) lasts several days.

Tandberg-Hanssen[91] and many others have shown that all magnetic storms are not accompanied by cosmic ray decreases and cosmic ray storms sometimes occur without corresponding magnetic storms. The relation between the two types of events is therefore not a direct one. Even when magnetic storms are followed by cosmic ray decreases, the ratio of the change of magnetic field strength to the change in cosmic ray intensity does not remain the same for all storms. Chasson[92] has shown that there are instances when decreases in cosmic ray intensity have occurred considerably earlier than the occurrence of any measurable geomagnetic disturbance. Magnetic storms with a dominant positive peak and a small negative peak have been shown by Trefall[93] to produce no change in cosmic ray intensity. Kitamura[94] has shown that cosmic ray storms associated with sudden commencement magnetic storms are larger than those associated with other type of magnetic storms. From a study of world-wide storms, Trumpy[96] has shown that the magnetic storms of short duration correspond to cosmic ray storms of lower intensity. A small increase of amplitude of cosmic ray storms with increase in geomagnetic latitudes has been shown to exist in general by Forbush[96], Yoshida and Kamiya[97], Glokova[82], Kodama and Miyazaki[26] and Brown[98].

An exhaustive study of the relation between cosmic ray storms and magnetic storms has been made by Sekido et al[99]. They have divided the magnetic storms into two groups namely, S type and M type, effective and non-effective respectively in producing cosmic ray storms. S type storms follow the 11 year cycle of solar activity and are closely related to the central meridian passage of large sun-spot groups. M type storms do not follow the 11 year cycle, but exhibit a sharp 27 day recurrence tendency. The authors attribute S storms to large magnetic corpuscular clouds ejected from sun-spot groups and M type to be caused by non-magnetic narrow corpuscular beams from the M regions of the sun.

The investigations of Kamiya and Wada[100] have brought out the intimate relation between cosmic ray storms and type IV outbursts on the sun. They have shown that during the period July 1957 to December 1958, every cosmic ray storm occurs after a solar flare accompanied by radio outburst of type IV. The dependence of the magnetic storm on the meridian distance of the solar flare is very clear, whereas the dependence of cosmic ray decreases on the meridian distance of the flare is rather poor. The type IV outbursts are evidence of synchrotron radiation from the coronal region of the sun. Hence at the time of type IV outburst, solar corpuscular clouds which contribute to the cosmic ray storms may be emitted.

Venkatesan[101] analysing the neutron monitor and meson telescope data for the Canadian stations for October 1956 to December 1957 has found that cosmic ray storms exhibit 27 day recurrence tendency, though the amplitude of recurrence is highly variable. However, very large cosmic ray storms do not recur.

McCracken[102] has analysed the anisotropy of a large number of cosmic ray decreases. He has found that the cosmic ray storm does not occur simultaneously in all directions at the same station. The intensity in the direction between 90° - 120° west of the sun-earth line is the first to decrease and is the one that suffers maximum depression. The intensity from the direction 0° - 90° east of the earth-sun line is the last to be affected and shows the least depression.

Sarabhai and Palmeira[103] have analysed the finer features of the storm of February 11, 1958. They find two small increases in intensity, one about four to five hours before the arrival of solar plasma indicated by the commencement of the storm and, the second, essentially during the main phase of the storm. These two increases which are observed only at equatorial stations are characteristic of the high energy component of cosmic radiation. The second increase also exhibits a strong north-south and east-west asymmetry, being very small in the southern hemisphere and absent in the longitude range 147° - 182°E. It is suggested that the pre-storm increase is caused by magnetic fields in the shock front of the moving plasma as suggested by Dorman[104].

Lockwood[105] studying neutron monitor data for this event for different stations has pointed out that the main decrease occurring simultaneously all over the earth is relatively energy insensitive. The subsequent temporary recovery appears to be associated with spatial anisotropy confined principally to directions perpendicular to the geomagnetic equatorial plane. He has suggested that the slight increase of intensity between 0030 and 0100 U.T. at Climax, Deep River and Mount Wellington could be produced by the albedo of the particles from a moving solar gas cloud. The unusual intensity changes during this event is suggestive of a model in which it is assumed that the outer geomagnetic field is disordered by the increase of solar wind. As a result of the penetration of the geomagnetic field by clouds of ionized gas, the field at large distances will be no longer a dipole field, thus causing the anisotropy observed in the intensity changes.

Yoshida and Wada[106] and Kondo et al[107] who studied in detail the cosmic ray storms associated with magnetic storms of September 13, 1957 and February 11, 1958 find that there is a pronounced increase superposed on the intensity decrease, associated with the cosmic ray storm. These increases are not due to solar flare effect as they are found to be more pronounced in lower latitudes as reported by Sarabhai and Palmeira[103]. These increases are also not due to pronounced anomalous diurnal variations, as they are present simultaneously at the day and night sides of the globe. A lowering of the cut-off rigidity during the magnetic storm may be the probable cause of these increases.

Steljes and Carmichael[108] have reported a decrease upto 6 % in the neutron intensity on February 11, 1958 relative to a smaller decrease in meson flux. The decrease in neutron flux started about 6 minutes earlier than the magnetic storm and was complete about 30 minutes sooner than the main meson decrease.

Bachelet et al[109] have studied in detail the cosmic ray storm of May 12, 1959, which revealed a large and sharp drop followed by a slow recovery in intensity.

McDonald and Webber[110] have studied the changes in the low energy particles by balloon observations on May 12, 1959 and have compared the results with those of Deep River neutron monitor. They have suggested that the rigidity dependence of the Forbush mechanism is similar to that of the long term variation.

Lockwood[80] has repported that for this event the recovery rate of neutron detectors is very much greater for stations with high cut-off rigidities than for stations with low cut-off rigidities indicating that the higher rigidity particles returned earlier.

Nansano et al[111] have studied in detail the intensity changes in mesons as well as neutrons associated with the magnetic storm of May 24, 1959. This Forbush decrease showed a strong longitude dependence.

Simpson et al[112,113] have reported recent observations of cosmic ray intensity changes during the magnetic storms of August 19, 1959 and March 30, 1960, by recorders in satellite Explorer VI and space probe Pioneer V. They have been able to show that simultaneously with the Forbush type decrease observed on the earth, the cosmic ray intensity is depressed even at distances upto 8 x 10^6 Km from the earth. Thus they conclude that the mechanism causing the Forbush decrease is not geocentric and that one should not invoke the presence of the earth and its magnetic field for explaining Forbush decreases.

MacAnuff[114] has shown that during the magnetic storm of January 24, 1940, when the sea level meson intensity decreased by about 6 %, no perceptible change occurred at 60 m.w.e. underground. Neher and Forbush[115] have reported the decrease in intensity at 17,000 feet elevation to be 4 times that at sea level.

Appreciable differences in the onset times of Forbush decreases have been found by Fenton et al[116] at four widely spaced stations. Murakami and Kudo[117] have pointed out that the onset time is earlier for the nucleonic component than for the hard component for the cosmic ray storms. Kitamura and Kodama[118] show that the low energy component recovers later than the high energy component and the energy spectrum becomes flatter while the cosmic ray storm is in progress in agreement with the findings of Bloch et al[119].

Many authors have given the energy spectrum for the variation of intensity during Forbush decreases. Dorman[5] has suggested that the primary spectrum of variation for these events can be represented as

$$\frac{\delta D(R)}{D(R)} = \left[\begin{array}{ll} -a & \text{if } R \lesssim 40 \text{ Bev} \\ 0 & \text{if } R \gtrsim 40 \text{ Bev} \end{array} \right]$$

where $a \simeq 0.3$ if the depression in the meson component at $\lambda = 50^{\circ}$ is nearly 10 %. His calculations are mainly based on the data for the meson component.

The primary rigidity spectrum for the Forbush decrease has been represented by McDonald and Webber[110], Lockwood[80] and many others by modulating the undisturbed primary rigidity spectrum of intensity. Thus the differential rigidity spectrum at time t_p can be written in the most general form

$$\frac{d_j\,(P,t_p)}{dP} = \frac{d_j\,(P,t_0)}{dP}\left[1 - C(t_p)P^{-1} + K_p\right] \quad ..(10)$$

where $\frac{d_j\,(P,t_0)}{dP}$ is the unmodulated primary spectrum.

Studying a large number of Forbush decreases individually, Lockwood has shown that for the Forbush decrease $0 \leqslant K_p \leqslant 4$ percent for neutron detectors at sea level and at mountain altitudes and $0.8 < c(t_p) \leqslant 2.2$.

1.44 Day to Day Changes of cosmic ray intensity.

The world-wide nature of the day to day changes both in meson and neutron components of cosmic rays has been brought out by the studies of Fonger[34], Neher and Forbush[118], van Heerden and Thambyahpillai[57] and others.

An important type of day to day change of cosmic ray intensity is having a 27 day recurrence tendency, corresponding to the synodic period of rotation of the low latitude region of the sun. Glokova[61,120] analysing the Carnegie stations' data for the period 1937-1950 has pointed out that the 27 day variation is most pronounced in the years of maximum solar activity and is completely absent during years of minimum solar activity in agreement with the results of Rola[121], Broxon[122], Meyer and Simpson[123] and Venkatesan[124]. Glokova et al[125] have shown that there is practically no 27 day recurrence tendency in meson intensity after proper temperature correction during the minimum solar activity period of 1953-1954. Meyer and Simpson[123] and Simpson and Babcock[126] have shown that the peak to peak amplitude of 27 day variation associated with nucleonic component is 4 to 5 times that of the hard component. Vernov et al[127] show that the total ionising component at 30 Km shows an amplitude of the 27 day variation 8 to 10 times that at the surface. Kuzmin[128] has shown that the 27 day variation is more pronounced in the case of low energy particles. He has found that the amplitude of recurrence at 60 m.w.e. is only of the order of 1/3 that at 30 m.w.e.

Simpson et al[129] have shown that many quasi-periodic increases of intensity are associated with the central meridian passage of active solar regions and regions of enhanced green coronal emission on the sun. Simpson et al[126] have also shown that in 1953 the intensity increases of 27 day periodicity are associated with the central meridian passage of the unipolar regions (UM regions) and are followed by K_p maxima 4 days later.

The close relation between 27 day variation and geomagnetic activity has also been studied by many workers. van Heerden and Thambyahpillai[67], Simpson[130], Kane[131] and others have shown that the minimum of 27 day variation in the cosmic ray intensity occurs 3 to 5 days earlier than K_p maximum. Venkatesan[101] and Trumpy[98], however, do not find this relation to always hold good. They have given instances of K_p maxima preceding cosmic ray minima. Van der Walt[132] concludes that during the period of solar minimum, cosmic ray intensity minimum generally precedes K_p maximum and, during solar maximum, K_p maximum occurs a day or two earlier to cosmic ray minimum.

The exact relation between the 27 day variation in cosmic ray intensity and geomagnetic and solar activity changes is yet to be established. Even the aspect whether it is an increase or decrease is also not quite certain. van Heerden and Thambyahpillai[97], Brown[133], Dorman[8] and Kamain[130] believe that the 27 day variations belong to the same group of phenomena as do the 11 year cyclic changes and the magnetic storm effects, and that the decrease is due to the screening of part of the primary cosmic radiation by some modulating effect. Kodama[134] on the other hand suggests that some emission of low energy particles from the sun should be taken into account in addition to the decrease of intensity due to magnetic clouds to explain the 27 day recurrence tendency at sun-spot minimum period.

1.5 Solar flare effects in cosmic ray intensity.

1.51 Effects of large solar flares.

The characteristics of solar flare effects on cosmic rays are represented by a sudden increase in the intensity and a comparatively slow decline in intensity to reach the pre-flare level. These rare increases provide direct evidence that the particles can acquire energies of several Bev somewhere on the sun or near it. The study of these bursts gives information about the condition of the sun, the interplanetary magnetic fields and the influence of the earth's magnetic field on charged particles.

The solar flare effects in the cosmic ray intensity during the first five great bursts have been revealed from the studies of Forbush et al[135], Biermann and Schlüter[136], Sekido and Murakami[137], Sarabhai et al[138], Simpson[139] and many others. The main features are:-

(1) The increase in cosmic ray intensity may be delayed even upto one hour after the visible sighting of the solar flare.

(2) Except for the very large flare of February 23, 1956, no appreciable increase in intensity has been observed at equatorial stations, showing that the primary particles responsible for the increases in the first four cases were of energy less than 15 Bev.

(3) The magnitude of the effect largely depends on the longitude, latitude and altitude of the place and also on the type of detector used. The magnitude of the effect at mountain elevations is about 4 times that at sea level. The effect in the case of nucleonic component is several tens of times as great as that of the ionising component.

On the basis of the assumption that the particles responsible for the flare increases are generated on the sun and propagate rectilinearly outwards, Schluter[16] and Firor[17] have calculated the trajectories of such particles in the geomagnetic field. They have shown that the particles, assuming them to be protons, responsible for increases arrive in distinct impact zones of 0900, 0400 and 2200 hours local time, out of which the first one is the most important. But this cannot explain the increases observed at polar regions which lie in the forbidden zone. Sekido and Murakami[137] have suggested that these less steep polar type increases of longer duration can be explained as due to the scattering of the particles by an outer trapping field extending a little beyond the earth's orbit. Kraushaar[140] explains this in terms of the deflection of particles in the galactic field.

The very large solar outburst of magnitude 3+ which occurred on February 23, 1956, was associated with cosmic ray intensity increases for the first time at the equatorial stations of Huancayo, Kodaikanal and Trivandrum as reported by Forbush[141] and Sarabhai et al[138]. The latter authors have estimated that particles of energy 30-67 Bev were emitted from the sun during the flare. Marsden et al[142] observed an increase of 4500 % in the neutron monitor at Leeds which was in the 0400 hours impact zone, and Meyer and Simpson[143] have reported an increase in neutron intensity of 2000 % at Climax, even though it was not in any favoured impact zone. Winckler[144], 13 hours after the onset of the flare found an increase of 180 % in the neutron intensity at 10 gm/cm^2 over Chicago when sea level intensity was only 26 % higher. The absence of any increase in the extensive air showers as reported by Sittkus et al[145] puts an upper limit of 10^{12} ev for the energy of the particles emitted during this flare. The development of the flare and the associated events have been described in great detail by Simpson[139].

Kusmin et al[146] at Yakutsk ($\lambda = 51^\circ N$) and Brunberg and Eckhartt[147] at Stockholm ($\lambda = 58^\circ N$) found that the north pointing telescopes recorded relatively a greater increase compared to the south pointing ones. They have interpreted this as due to solar protons which have suffered deflection in the mean magnetic field of the order of 6×10^{-6} gauss before reaching the north pointing telescope. Ehmert[148] after making a detailed study of the time differences in the onset and the decay of the increases for stations all over the world, came to the conclusion that the high latitude effect and the midnight effect can be satisfactorily explained in terms of the deflection of the flare particles in the interplanetary magnetic field of the order of 3×10^{-6} gauss.

Meyer et al[149] from a study of the neutron monitor data, have shown that the flare radiation had a steep momentum spectrum given by a power law with an exponent $n \sim 7$ and that the increase decayed with a time roughly as $t^{-3/2}$. They believe that a heliocentric field free cavity ($B < 10^{-6}$ gauss) of radius 1.4 A.U exists. This is surrounded by a shell of disordered magnetic fields which reflects the flare particles back into the field free regions. The slow decline of intensity is explained as due to the escape of cosmic ray particles into the galaxy.

Eckhardt[150] has pointed out that the earlier onset time of increase at Hobart which lay outside the impact zone may be explained as due to the particles which arrived from the direction of the solar beam which produced the magnetic storm two days later.

McCracken[151] has pointed out that the most energetic flares that produce appreciable cosmic ray increases are also observed in white light. However, a white light flare of importance 3^+ on March 23, 1958, has not produced any cosmic ray increase. This is given as evidence to show that the cosmic rays produced from flares occurring on the east limb fail to reach the earth. Cocconi et al[152] have suggested that there are elongated magnetic bottles or magnetic tongues extending from the vicinity of the sun which will serve as guides for the flare particles. If the earth is within this bottle, the particles travelling along the lines of force will arrive at the earth resulting in the sharp initial increase. The slow diffusion of the radiation out of the bottle would account for the gradual decay of the flare effect. On the other hand, if the earth is outside the tongue, it will receive particles only after they have diffused from the tongue and there will not be such a rapid rise in intensity. The solar rotation and the resulting trailing of the outer portion behind the inner one of the tongue originating as a result of the flare on the east limb explains why no flare effect is observed in such cases.

1.53 Effect of small flares.

Relatively smaller increases in cosmic ray intensity have been reported in a few cases in association with small flares. Firor[18] observed a small increase in cosmic ray intensity during a flare of magnitude 1^{+}. McCracken[153] has reported an increase of 2 % in the neutron monitor at sea level at Hobart during the flare of August 31, 1956. The increase has been recorded both in U.S.A. and Australia, but meson telescopes at Mawson did not record any increase. Corrigan et al[154] have reported an increase of $\sim$ 30 % at $\lambda = 65^{\circ}$N at a height of 25,000 feet during a 1^+ flare on August 9, 1957. Neher et al[82] during a flight made one hour after the occurrence of a flare of 1^+ on July 23, 1951 observed an increase in intensity. Anderson[155] found an increase by a factor of 10 in the ion chamber at 10 gm/cm^2 on August 22, 1958, about 70 minutes after the occurrence of a flare of importance 3. He has concluded that protons of energy of the order of 170 Mev have been emitted and found that the flare particles were detected at least for two days. Charakhchian et al[156] have given direct evidence for the early arrival of particles from the solar flare at 2000 hours on 10th May 1959 at high latitudes at balloon heights. A considerable increase of the order of 20 times in the rate of a single counter was observed in this case. Ney et al[157] found that the integral flux of the particles at the top of the atmosphere at 10 gm/cm^2 increased by $\sim$1000 times above that of the cosmic rays at 0400 hours on 12th May 1959. This increase in flux (mainly protons) is explained as due to the distortion of the incoming solar beam by geomagnetic fields. The arrival of solar magnetic cloud lowered the low energy cut-off and allowed the normally forbidden particles to arrive. Winckler and Bhavsar[158] also observed an increase in intensity at balloon heights on 12th May 1959.

Freier et al[159] have reported an increase by a factor of 2 of the integrated flux of protons at the top of the atmosphere on 26th March 1958 in the vertical direction, corresponding to a solar flare on 23rd. They have tried to explain this as due to the particles accelerated in the flare and stored in the solar corona which were then propagated to the earth through a magnetic channel.

Palmeira and McCracken[100] have observed a very abrupt and short lived cosmic ray increase of about 6 % in the M.I.T. meson monitors corresponding to the solar flare of importance 2 occurring on the western limb of the sun on 4th May, 1960. During this event impact zones were very pronounced and there was very little time dispersion between high and low energy particles and the effect observed by stations outside the impact zones was small. The short time scale has been explained in terms of a model in which the earth is within an essentially radial field rooted in the active region of the sun.

1.23 July 1959 events.

A group of events of great interest occurred during the month of July 1959. There were three solar flares of importance 3^+ which occurred on

July 10, 1959 0210 U.T.
July 14, 1959 0342 U.T. and
July 16, 1959 2115 U.T. respectively.

In all these cases solar flare increases were observed in the cosmic ray intensity especially at high altitudes, giving strong evidence for the solar emission of particles during the flare. Corresponding to the flare events, radio fade outs, radio noise storms of type III and type IV outbursts were also observed and these were followed by SC type magnetic storms and characteristic Forbush type decreases in cosmic ray intensity. The cosmic ray intensity reached a minimum at 0300 hours on 10th, the lowest value recorded during recent years (Carmichael and Steljes[101]).

Several authors have reported detection of enhanced intensity at balloon heights immediately after the flares, the intensity increases were observed even upto 13 hours after the occurrence of the flares.

Brown and D'Arcy[102] find 68 % increase in intensity at 17 gm/cm^2 over College Alaska 10 hours after the flare on 10th, but the intensity at 10 gms/cm^2 as reported by Leinbach at Minneapolis was normal. Kuzmin et al[103] have reported a predecrease at Yakutsk about 4 - 5 hours before the beginning of the Forbush decrease on 11th. Ehmert et al[104] find that on July 15th, at 15 gm/cm^2 the cosmic ray intensity is 40 % in excess of the normal value and conclude that if the particles are protons their energy range extends upto 40 Mev which is not allowed by Stormer theory at 51° N. They suggest that either the particles must have been brought in by some mechanism controlled by the ionised clouds ejected from the solar flare regions on 14th or are not protons.

Solar radiation from the flare of 16th July was first detected at 2305 hours U.T. at 30 gm/cm² about 2 hours after the onset of the flare[162]. The intensity increased and at about 0000 hours U.T. on 17th, the flare radiation had increased to 3.5 times the background at 10 gm/cm². Winckler[165] has reported that at 2000 U.T. on 17th, the total ionization at 10 gm/cm² over Minneapolis also increased greatly, though the intensity was only slightly above normal during the earlier hours on that day.

Steljes and Carmichael[161] have observed at 2330 U.T. on 17th near the end of the third Forbush decrease a sudden decrease of about 7 % and an equally sudden increase after about 30 minutes in the neutron intensity at Deep River.

Evidence for the solar emission of low energy particles have been given by Bailey and Pomerantz[166] from ionospheric monitor of signal intensity at 38 Mc/s. Leinbach and Reid[167] from polar cap absorption studies suggest that the greatest contribution to the observed absorption comes from solar protons of energies < 150 Mev, which are normally restricted to geomagnetic latitudes $> 62^{\circ}$.

Wilson et al[168] studying the neutron monitor and meson data from 57° to 88° geomagnetic latitude describe the series of events as follows:-

(1) A large Forbush decrease occurred on 11th followed by a slow recovery.

(2) Before recovery to the pre-storm level of intensity, a second event starts by about 1000 U.T. on 15th.

(3) This is followed by an unusually rapid increase by 0000 U.T. on 17th, then again the intensity falls and slowly recovers. There is a sudden increase at about 0100 hours on 18th which persists only for a few minutes resembling a flare type increase, which has also been reported by Carmichael and Steljes[161]. The increase on 17th is considered to be due to either the increase in the number of incoming particles or due to a collapse of the modulating system which causes the Forbush decrease.

McCracken and Palmeira[159] studying the neutron monitor data at high latitudes show that the cosmic ray particles of rigidity >1 Bev were produced by the solar flare of 18th July. The temporal dependence of the flare radiation was unlike that of the earlier flare effects, the intensity taking ~7 hours to reach its maximum value. No impact zone was observed.

Comparing the results with the flare increases in cosmic rays during the previous flares and a later flare of May 4, 1960, they conclude that:-

(1) the time scale of the solar flare effect is a highly variable quantity, varying from event to event by a factor as great as 36.

(2) the ratio of the rise time of the solar flare increase to the 50 % decay time is roughly constant; that is, the shape of the intensity versus time curve is roughly the same in all cases.

(3) the flares resulting in flare effects with the shortest time scales occurred on the western solar limb, while those with longest time scales occurred near the centre of the solar disc. No impact zone was observed at the time of the flare effect which showed the greatest time scale.

Charakhchian et al[169] suggest that the great increases in intensity of cosmic rays (flares) which occur in stratospheric heights in the northern latitudes are brought about by primary protons of solar origin of energy > 100 - 120 Mev, with a differential energy spectrum with index 6.0.

Solar radio outbursts of intensity 3 and type IV burst recorded at Fort Davis in 580 - 24 Mc/s range have been reported by Hughes[170] to start at 0101 U.T. on 16th July, 1959, and to last upto 0243 U.T. on 17th. Thompson and Maxwell[171] are of the opinion that this type of solar radio outburst originate in the synchrotron process in the solar atmosphere and is related to the ejection of low energy cosmic rays from the sun.

Carmichael and Steljes[172] studying the data from 33 neutron monitors and 18 meson telescopes scattered all over the world for July 1959 have found that the overall latitude effect of the three decreases also holds for each of them, but that there are significant differences in the recoveries especially from the third decrease. Equatorial neutron monitors and all meson telescopes show more rapid recovery than high latitude neutron monitors. There is also an indication that the recovery from the third Forbush decrease in the southern hemisphere is more rapid than in northern. Injection of solar cosmic rays have been found to be present on 17th. It is found that the eccentric dipole cut-off rigidities and Rothwell values are unsuitable, Quenby and Webber values giving consistent results. It is concluded that the formation is dependable in the vicinity of magnetic latitudes 60°N and south. Hence the rigidities of the particles responsible for the ground level signal are found to be between 0.8 and 1.2 Bev/c, corresponding to an energy of protons around 400 Mev.

1.54 Polar cap absorption events.

The measurement of the ionospheric absorption of high frequency cosmic radio noise near the arctic regions is a sensitive method for the detection of low energy cosmic rays associated with solar flares. Solar protons of energies 130 Mev or less will be stopped at atmospheric heights of 30 Km and upwards; the ionisation they produce may be sufficiently dense to severely absorb the radio waves passing through the ionosphere. However, protons of these energies are confined to geomagnetic latitudes > about 62° by the earth's magnetic field. Hence these events are known as polar cap absorption events (PCA).

The polar cap absorption can quite readily be distinguished from the more common high latitude absorption associated with auroral and magnetic disturbances. The latter absorption is localised to the auroral zone and usually shows strong intensity variations within periods of some tens of minutes or less. On the other hand, polar cap absorption besides occurring over the entire polar region, may last for many days with only smooth and gradual changes in intensity.

Little and Leinbach[173] have perfected a technique for the measurement of cosmic noise absorption continuously at a preselected frequency using a riometer. Multi-station observations of 27.6 Mc/s cosmic noise obtained by these instruments helped Reid and Leinbach[174] to report 24 polar cap absorption events associated with solar cosmic ray outbursts in the period May 1957 to July 1959. Four more weak events were detected later by Leinbach[175], one occurring in August 1959. No polar cap absorption events occurred during the period September 1959 to the last week of March 1960. Eight more polar cap absorption events have been reported to have occurred during the period 31st March, 1960 to 31st May, 1960.

Magneto-ionic theory shows that the absorption in decibels is proportional to $\int \frac{N\nu}{\nu^2 + \omega^2}$ dh where N is the electron density, ν the electron collisional frequency and ω is the angular frequency of the radio waves at a height h. This expression is integrated through the absorbing region and over the solid angle subtended by the antenna. It is assumed that ν remains constant during solar cosmic ray bombardment, thus the variations of absorption being attributed to the changes of the electron density. It is well known that the time required for the electron production by a constant flux of bombarding particles to come to equilibrium with the electron loss process is of the order of minutes throughout the absorbing region. Thus, the variations of polar cap absorption are interpreted as representing the variations of the flux of bombarding particles.

Many workers such as Anderson[155,176], McCracken and Palmeira[160], Freier et al[157,180] and others have reported at balloon heights, especially at high latitudes, detection of enhanced cosmic ray intensity after the flares. These observations coincide well with the detection of low energy solar cosmic rays following flares and giving rise to polar cap absorption.

Reid and Leinbach[174] have described the sequence of events occurring in connection with solar flares as follows:-

(1) A major solar flare occurs usually accompanied by short wave fade outs over the sunlit hemisphere of the earth; these fade outs are caused by electromagnetic radiation from the flare and are recorded by the riometer if

it happens to be on the sunlit hemisphere. These are referred to as sudden cosmic noise absorption (SCNA).

(2) The flare is almost without exception followed by a strong low frequency solar noise storm often lasting for several hours. This is also recorded by the riometer if the sun is above the horizon.

(3) Within a few hours of the flare the type III absorption (polar cap absorption) sets in over the entire polar cap, the actual onset often being obscured by the solar noise storm, the absorption reaching a maximum within a few hours, and then decaying in the following few days.

(4) After a day or two, a sudden commencement magnetic storm almost invariably occurs, often accompanied by intense auroral activity.

Studying the corresponding solar flares in the case of the first 24 events, Reid and Leinbach have shown that out of 18 cases, where flares could be distinctly recorded, 12 occurred on the west of the solar central meridian giving a clear indication that solar cosmic rays originating on the west half of the visible disc can reach the earth more readily than those originating on the eastern half. Obayashi and Hakura[177] have studied the varied aspects of the polar cap blackouts, type IV outbursts and magnetic storms associated with solar flares. They have shown that larger number of polar cap blackouts are associated with flares on the western half of the solar disc and the time delay for the absorption events is smaller than for the events connected with flares on the eastern half of the sun. The western excess of the events and the inequality of their time delays indicate the existence of some modulation mechanism for the solar cosmic rays propagated through the interplanetary space. Solar cosmic rays originating on the western side of the disc reach more or less directly along the magnetic lines of force; but for those originating on the eastern side, some scattering mechanism due to irregularities in the field may operate so that the large delay in this case for the particles to reach the earth may be due to the time required for them to reach and follow the magnetic lines of force connected with the earth which originate from somewhere on the western side of solar disc.

McCracken and Palmeira[109] have studied the delay observed between the occurrence of the flare and the first indication of the arrival of cosmic rays at the earth. Plotting this delay against the position of the flare on the solar disc they have concluded that the delays tend to be greatest for the flares on the eastern half of the solar disc and least for the flares near the west limb. The four events of September 21, 1957; September 2, 1957; February 10, 1958 and March 23, 1958 showed great deviations from these general features and they have remarked that these cases become suspicious. The abnormally long delay of September 2, 1957 event (of the order of 7½ hours) might be possibly due to the fact that it occurred when the terrestrial cosmic ray intensity was greatly depressed by a Forbush decrease. The conclusions of McCracken and Palmeira[169], Reid and Leinbach[174] and Obayashi and Hakura[177] favour the Parker's model[178] of the outward extension of a solar magnetic field by low velocity charged particles travelling radially outward from the sun. The sun's rotation gives a curvature to the particle streams convex towards the west and protons originating to the west of the central meridian of the sun can thus reach the earth more easily than those from the east.

Leinbach[175] has attempted to explain the polar cap absorption in relation to solar flares on the basis of the "magnetic tongue" model postulated by Gold[179]. The material ejected from the sun during the flare contains a frozen in magnetic field, the ends of which remain connected to the source on the sun. Thus, as the cloud of material expands outward from the sun, a magnetic tongue is formed which will be the source of a trapping region for high energy particles accelerated at the sun; at the same time it will serve to exclude galactic cosmic rays after the tongue has engulfed the earth, thus leading to the Forbush decreases.

Let us suppose that the magnetic tongue is dragged out by the slow corpuscular (auroral) stream with velocities of the order 1000 to 2000 Km/sec consistent with the observed delay of the magnetic storms. The front of the stream is a region of trapping of high energy (10 - 1000 Mev) protons, some of which are scattered out of the region and bombard the earth well before the arrival of the second corpuscular stream. As a slow stream approaches the earth, it expands, lowering the field intensity and increasing the possibility of diffusion and scatter. Thus, the polar cap absorption is observed to increase at a slow and constant rate after the arrival of the initial particles. Onset of the recovery represents the passage of the trapping front beyond the earth. The subsequent recovery of the absorption may represent the degree of diffusion and scatter of the high energy particles on the inside of the tongue towards the sun.

Hultqvist[120] interprets the ionisation in the lower atmosphere occurring at high latitudes on both the day and night sides of the earth in a few hours after the flare as being caused by a high energy ion beam of very small density emitted from the sun and moving in Stormer orbits.

1.6 Anisotropy of cosmic rays.

1.61 Daily variation.

A solar anisotropy of cosmic rays outside the geomagnetic influence of the earth shows up as a daily variation of cosmic ray intensity in an instrument fixed to the spinning earth. A daily variation with an amplitude of 0.2 % obtained from time averaged data in the early studies of Hogg[121], Lange et al[122] and others could not lead to any definite conclusions about the anisotropy of cosmic rays because of the uncertainty of meteorological corrections applicable to secondary meson intensity. To overcome this difficulty Malmfors[123] and Elliot and Dolbear[124] made studies with directional telescopes equally inclined to the vertical. At middle latitudes (λ~45°), a north pointing telescope inclined at 45° to the vertical would always point to the same direction of the sky, whereas a south pointing telescope would sweep a plane close to the ecliptic. Since particles entering both telescopes would have to pass through the same atmosphere, the difference between the variations recorded by them would reflect the effects of primary anisotropy. Such a study led them to conclude that there existed an anisotropy of primary cosmic radiation.

Elliot and Rothwell[125] at London (λ = 52°N) in 1954 and Parsons[126] at Mawson (λ = 73°S) during May 1955 to February 1956 obtained results with directional telescopes which at first appeared to be inconsistent with the daily variation being caused by an anisotropy of primary radiation. They have taken the mean energy of the particles in calculating the directional response of the telescopes, whereas the integrated effect has to be taken. Thambyahpillai and Quenby[60] have shown that application of proper temperature correction to Parsons' data for Mawson yields results in agreement with the daily variation being caused by an anisotropy of primary radiation.

A study has been conducted by Sarabhai and Rao at Ahmedabad ($\lambda = 14^{0}$) during 1957 and 1958 of the time variations of meson intensity incident from east and west directions at 45^{0} to the vertical. A characteristic difference of about 6 hours in the diurnal time of maximum for east and west directions is observed to occur on many days and this has been interpreted as signifying an anisotropy of primary radiation caused by a source outside the influence of the geomagnetic field. However, there are many days on which the daily variation has a maximum near noon for both directions. On such days the predominant influence is that of a local source situated within the influence of the geomagnetic field. The local source is associated with geomagnetically disturbed days. Long term changes in the daily variation are found to be similar for east, vertical and west directions.

1.63 Energy dependence of daily variation.

MacAnuff[114], Sherman[137], Barrot et al[40] and Farley and Storey[188] have shown that the amplitude of solar daily variation becomes quite small at great depths. Recently Kuzmin[128] has made a detailed study of the solar daily variation with semi-cubical telescopes at surface and at 7, 20 and 60 m.w.e. during 1957 and 1958. He finds the average amplitudes during this period in the four cases to be 0.30 %, 0.25 %, 0.18 % and 0.06 % respectively, showing that the amplitude of daily variation decreases with increasing energy of the primary particles.

Anisotropy of heavy primaries have been studied in balloon experiments by Anderson et al[189], McClure and Pomerantz[190], Yngve[191], Lord and Schein[192] and Ney and Thon[193]. Anisotropy of very low energy part of the primaries has been investigated by balloon observations by Bergstralh and Schroeder[194] and Dowton and Elliot[195]. These experiments are very difficult to perform and present greater difficulties of interpretation. The great variability of intensity at high altitudes from day to day prevent the direct comparison of these results pertaining to different periods and with ground level experiments.

Firor et al[196] found an amplitude of solar daily variation of nucleonic component at Climax 5 times that found by counter telescopes of wide aperture or ionisation chambers. Comparing Huancayo and Climax neutron intensity variations, they have shown that the ratio of the amplitudes at the two places was about 1.4 ± 0.2 and shows only small variation from event to event.

By comparing the amplitudes of time averaged daily variation for a number of stations, Dorman[5] has concluded that the diurnal amplitude of extra atmospheric origin in the hard component at sea level or at mountain altitudes is of the order of 0.3 % at equator and in temperate latitudes (upto $\lambda \approx 50^0$) and of the order of 0.1 % in high latitudes. For the nucleonic component the diurnal amplitude apparently increases with latitude

Huancayo showing an amplitude of about 0.4 to 0.5 %, Climax about 0.6 %. He has observed that the diurnal variation of cosmic rays is mainly due to primary particles of moderate energies, of the order of 1×10^{10} ev and, perhaps, higher.

1.63 Dependence of solar daily variation on the geometry of the detector.

In an attempt to increase the statistical accuracy in the measurement of time variation of cosmic ray intensity, it is desirable to use instruments of high counting rates. Often this is achieved by measuring the intensity over a wide range of directions. In the study of primary anisotropy, it is, however, important to restrict the geometrical sensitivity of the instrument.

As early as 1950, Sekido et al[107] pointed out that the amplitude of the daily variation increased from 0.19 % to 0.34 % as the semiangle of the telescope in the east-west plane was reduced from 40° to 12°. Ehmert and Sittkus[108] revealed from studies made in 1950 that the amplitude of daily variation measured with a vertical counter telescope of limited directional sensitivity was higher than that measured by an ion chamber of omnidirectional sensitivity. Sarabhai et al[109] have made simultaneous studies during July 1954 to August 1955 with counter telescopes with different semiangles of opening from 2.5° to 15° in the east-west plane. They have shown that the amplitude of daily variation at low latitudes increases from 0.6 % to 1.2 % with a decrease in the semiangle of opening from 15° to 5°. However, Elliot and Possener[200] at $\lambda = 50°$ in 1954-1955 and Razdan[201] at 14°N in 1957-1958 did not find any change in the amplitude of time averaged daily variation recorded with narrow and wide angle telescopes.

A time averaged amplitude of daily variation can be different either because the amplitude of daily variation on individual days has changed or the day to day variability of the time of maximum of the daily variation is different in the two periods. Razdan[201] has therefore analysed not only the time averaged effects, but also the daily variation on a day to day basis from 1954 to 1958. He finds that while the amplitude of the daily variation measured with a narrow angle telescope has become significantly smaller from 1954 to 1957, the amplitude of the diurnal component measured with a wide angle telescope has remained more or less the same.

The author has done similar studies at the equatorial station of Trivandrum with narrow and wide angle telescopes during the period August 1957 to April 1960. The results obtained are presented in detail in chapter IV.

Recently Brunberg[202] has worked out in great detail the dependence of the amplitude of daily variation on the assumption that the solar daily variation is caused by extra-terrestrial anisotropy. He points out that what we actually observe from our measurements of daily variation is the ratio of the source to the background intensity and not the source intensity itself. If we assume the source which causes daily variation to subtend an infinitely small solid angle at the detector, then the amplitude measured by the wide angle telescope will be smaller as it records a higher background.

Brunberg[203] has numerically calculated the amplitude of daily variation which will be observed by telescopes of different apertures taking only the atmospheric spreading of particles into consideration and for the first approximation neglecting geomagnetic bending. Here, he also assumes that there exists an infinitely small source in space with the same source spectrum as that of the background. The results are graphically shown in figure 3, giving for the telescopes of different apertures the amplitudes of daily variation to be expected from cosmic ray particles coming from different zenith angles. For a vertical narrow angle telescope, the major contribution comes from the particles coming along the zenith. If we assume a ratio of 1 % between the counting rate of the source and the background, for particles coming along zenith, the narrow angle telescope of 2.5° measures the full 1 % whereas the wide angle telescopes will measure much smaller amplitudes.

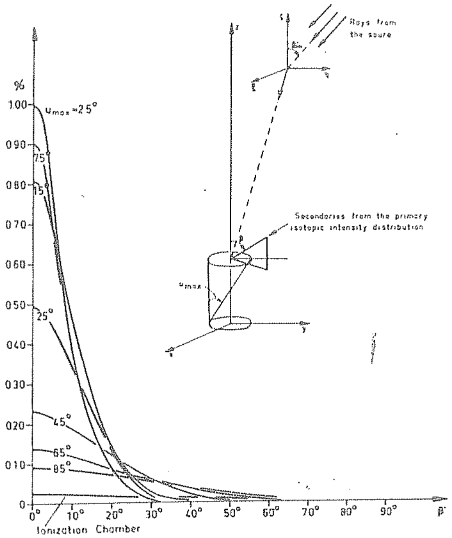

Fig. 31. The percentage increase of the counting rate when measuring a very small source element with telescopes of different apertures. The $\cos^2 \beta$ law is assumed to hold at sea level for the intensity distribution of the "background".

Fig. 3 - The percentage increase of the counting rate when measuring a very small source element with telescopes of different apertures.

Brunberg has also examined the effect of geomagnetic bending on the amplitude of daily variation. The polar diagram along Ø = 0 (geographic latitude) for telescopes with different apertures at sea level in Huancayo has been reproduced in figure 4 from Brunberg's paper.

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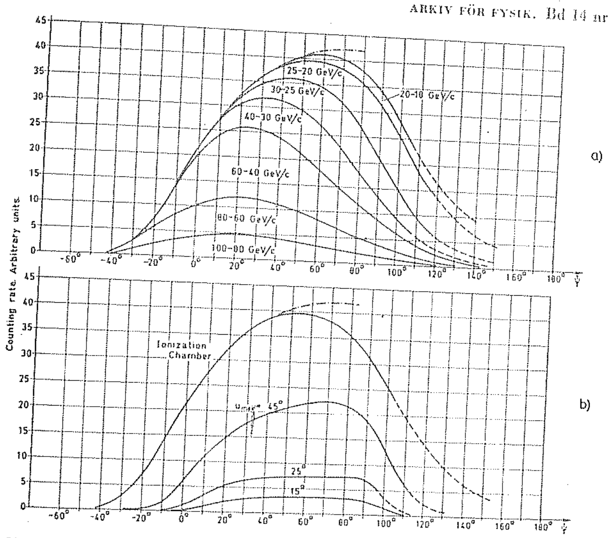

Fig. 33. (*a*) The contributions of different primary momentum intervals to the polar diagram along Φ = 0 of an ionization chamber at sea level in Huancayo. (*b*) The polar diagrams along Φ = 0 for telescopes with different apertures at sea level in Huancayo.

Fig. 4 - The polar diagrams along Ø = 0
for telescopes with different
apertures at sea level in Huancayo.

Brunberg has also shown that the narrower the aperture of the detector, the more faithful is the reproduction of the first and higher harmonics of the profile of the extra-terrestrial anisotropic flux of primaries which causes daily variation. A conclusion that emerges from Brunberg's work is that while a narrow and wide angle telescope both respond reasonably well to the diurnal component, the semidiurnal component is considerably attenuated in the wide angle telescope.

1.04 Long term changes of daily variation.

From an extensive study of the data for the hard component of the Carnegie Institution Stations at Huancayo, Cheltenham and Christchurch for the period 1937-1952, Sarabhai and Kane[203] and Sarabhai et al[204,8] have shown that the twelve month mean daily variation undergoes large long term changes of world-wide character. It has been shown that there is relationship of the diurnal component with the 11 year cycle of solar activity. The change of time of maximum of the diurnal variation is correlated with the change of intensity of solar 5303°A coronal line, the relation with the sun-spot number being somewhat weaker. Significant variations are also found to take place in the semidiurnal component. When the daily variation is considered as a whole instead of resolving it into its harmonic components, they have shown that a remarkable sequence of changes take place in the case of Huancayo data (figure 5). It is clearly seen from the figure that the 12 month mean daily variation which exhibited one maximum near noon from 1937 to 1942, changes over by 1952 to a variation exhibiting one maximum early in the morning. In the intervening period, there is clear evidence of progressive increase of an early morning maximum followed by a decrease of the noon maximum. During the period 1948 to 1950, the 12 month mean daily variation exhibits two maxima instead of one. Only half the cycle of changes appears to have been completed in 11 years. They have also shown that the daily variation can be considered in terms of the contributions of two distinct types of variations, the 'd' and 'n' type showing maxima near 1200 hours and 0300 hours respectively. In general, the 'd' and 'n' type of

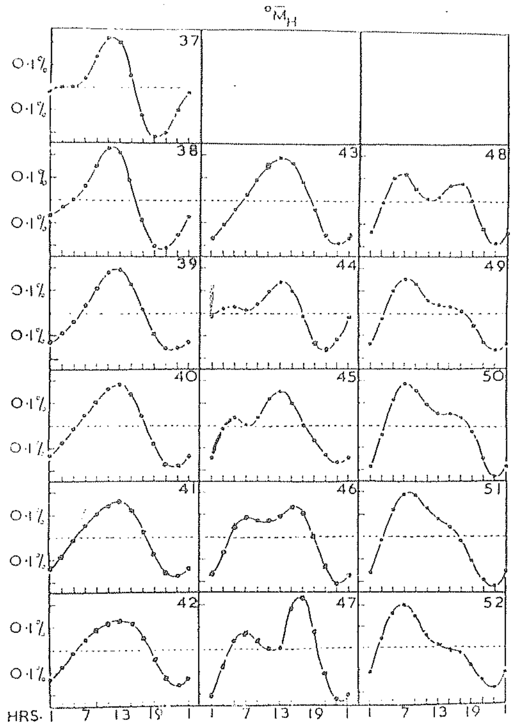

Fig. 6 - The 12 month mean daily variation of meson intensity at Huancayo during different years.

variations are simultaneously added or attenuated. Just preceding sun-spot minimum, there is a brief period when only 'd' type variation predominates, which is followed immediately by an equally brief period when 'n' type contribution is more. The pattern of addition and attenuation of the contributions appears to be reversed after 11 years. They have shown that these two components are not clearly seen in the middle latitudes (Cheltenham), which agrees with the conclusions of Feinberg[205].

Thambyahpillai and Elliot[206] from an examination of cosmic ray data of various stations from 1932 to 1952 have shown the world-wide changes of the time of maximum of the diurnal component and have pointed out that the changes probably follow a 22 year cycle of activity. Steinmaurer and Gheri[207] also have come to a similar conclusion from a study of Hafelekar ion chamber data for 23 years. They have shown that during the sun-spot minimum of 1933, the time of maximum of the diurnal component was about 0700 hours comparable with that in 1953-1954, but was earlier than the time of maximum 11 years later in 1944, indicating a relationship with the 22 year cycle of solar activity. Possener and van Heerdan[208] also found a time of maximum near midnight hours in 1953-1954 in inclined telescopes at London. Sandstrom[209] has shown that the world-wide shift of time of maximum of the diurnal component is independent of the direction of arrival of particles.

Glokova[210] has shown that during the solar activity minimum period of 1954, the amplitude of the diurnal variation of neutron intensity at Huancayo has decreased to a value not significantly different from zero. This is in agreement with the results of Conforto and Simpson[211].

Venkatesan and Dattner[212] from a study of cosmic ray data from different stations for the period 1937-1955 show that the long term changes in the diurnal amplitude are more closely related to changes in the geomagnetic activity than those in solar activity. They have also indicated that whereas the secular changes in the mean annual vector of the diurnal component are world-wide in character, those of the semidiurnal component are not. Katzman and Venkatesan[213] have shown from the study of Ottawa neutron monitor data for 1965-1969 that the semidiurnal component is mainly a pressure effect. However, studying the world-wide nature of daily variation in neutron intensity, they have shown that the daily variation at the equatorial stations of Kodaikanal, Ahmedabad and Makerere show significant semidiurnal component even after applying pressure correction.

Sarabhai et al[214] have shown that the changes in the semidiurnal components are similar at equatorial stations of Kodaikanal and Huancayo. Huancayo data shows a semi-diurnal component with hour of maximum following a 22 year cycle indicating its relationship with solar activity.

Sarabhai and Rao[90] have conclusively shown from directional telescopes at Ahmedabad that the daily variation at a low latitude station associated with a primary anisotropy has got a significant semidiurnal component.

1.66 Day to day changes of daily variation.

The highly variable nature of the daily variation of cosmic rays is at least partly of extraterrestrial origin.

Remy and Sittkus[215] and Firor et al[196] have studied daily variation on groups of days. There are some groups of days with large amplitudes of diurnal variation with time of maximum during day and some others with maximum occurring in the night. Sittkus[216] studying ionisation chamber data found that the days with large diurnal amplitude and time of maximum near noon occurred in groups and showed a 27 day recurrence tendency but did not show any special association with significantly high magnetic character figure compared to the rest of the days.

Sarabhai et al[199] studied this problem with narrow angle telescopes in 1954-1955. On about 75 % of the days, the daily variation exhibited only one maximum either occurring near 12 hours ('d' type) or 0300 hours ('n' type) local time. They have shown that the 'd' type days occurred in groups and exhibited 27 day recurrence tendency. Sarabhai et al[217] have further shown that the daily variation of 'd' type is associated with an increase in daily mean intensity, whereas the 'n' type is linked with decrease of the daily mean intensity. The 's' type of days showing two maxima in daily variation are generally associated with almost normal mean intensity.

0 A The strong 27 day recurrence tendency of the amplitude of diurnal variation was shown by Yoshida and Kondo[218] from the study of the ion chamber data at Huancayo for the period 1936-1946. Kane[190] studying the neutron monitor data from several stations for the period

1951-1953 also found the 27 day recurrence tendency of the diurnal amplitude. Glokova et al[125] did not find any perceptible 27 day recurrence tendency of the amplitude of diurnal variation for the nucleonic component during the minimum solar activity period of 1954.

The relation between the daily variation and magnetic disturbances has been studied in detail by many workers. Sekido and Kodama[219] found that the amplitude of diurnal variation increased and its time of maximum shifted to earlier hours for geomagnetically disturbed days. This effect was shown much more clearly in narrow angle telescopes. Sekido and Yoshida[220] show that the semidiurnal component which is generally present in quiet day variations gets reduced on magnetically disturbed days. Sandstrom[221] also has shown that with increasing magnetic activity (increasing K_p), there is a progressive shift of the time of maximum to earlier hours and an increase in the amplitude of diurnal variation. This effect has been found to be more pronounced in case of vertical telescopes and telescopes inclined at 30° to the vertical and pointing south than in the north pointing ~~30° inclined~~ telescopes inclined at 30°. He has also indicated that the daily variation can be represented as arising out of the 18 hour or tangential component and 12 hour or radial component of anisotropy in the solar system as envisaged by Alfven[222]. Then with increasing K_p, the 18 hour component increases whereas the 12 hour component practically remains constant in accordance with Alfven's theory. The 12 hour component is non-existent or of reversed sign when geomagnetic activity is low. Satyaprakash[223] has found that in 1957, there is no distinct relationship between the parameters characterising the daily variation of nucleonic component at Kodaikanal and the geomagnetic activity (C_p). Yoshida[224] explains this type of difference as due to the changes in the disturbance vector in step with the 11 year cycle of solar activity.

Sekido et al[225] have made an extensive study of the mean storm type vector representing the difference in the diurnal components during geomagnetically disturbed and quiet periods during each year. They have shown that the disturbance vector representing a storm type anisotropy points on an average towards the radially outward direction from the sun and undergoes a long term change from year to year, broadly in step with the 11 year cycle of solar activity.

The dependence of diurnal variation amplitude on C_p has been studied during the period 1955-1962 by many workers (Satyaprakash[223], Duggal[226], Sastry[227], Ahluwalia[228], Rao[229] and Razdan[201]) at equatorial stations for meson as well as nucleonic component. They were not able to prove conclusively the dependence of the diurnal amplitude and time of maximum on C_p. C_p which has been interpreted as indicative of solar particle radiation in the vicinity of the earth does not specify adequately the electro-magnetic state of the interplanetary space in the vicinity of the earth which affects cosmic ray intensity.

Katzman and Venkatesan[212] studying the neutron data for 15 stations (from 73°S to 83°N) have reported a systematic progressive shift of the time of maximum of the diurnal variation towards earlier hours as we proceed from the pole to the equator.

Venkatesan[230] has studied the daily variation of cosmic ray intensity as measured by Huancayo ionization chamber corresponding to 60 most geomagnetically disturbed days each year for the period 1937 to 1958. It has been found that the diurnal time of maximum follows K_p changes much better than the solar activity represented by relative sun-spot number. However, the semi-diurnal time of maximum follows solar activity in rough measure.

Sarabhai and Satyaprakash[231] from a study of the daily variation of neutron intensity recorded at Kodaikanal during 1956-1957 find that on days of high geomagnetic disturbance the daily variation exhibits abrupt changes indicative of the source being situated at a distance shorter than the range of the geomagnetic field. On geomagnetically quiet days, the daily variation has a form consistent with its being related to an anisotropy in the interplanetary space. On days of moderate geomagnetic disturbance, the daily variation has changeable characteristics.

1.66 Correlated changes of daily variation and daily mean intensity.

From a study of the hard component intensity measured with narrow angle telescopes at Ahmedabad during 1956, Sarabhai and Bhavsar[217] have shown that 'n' type days (with diurnal time of maximum near 0300 hours) are associated with low daily mean intensity and 'd' type days (with time of maximum for diurnal component near 1200 hours) with relatively high mean intensity. A detailed study by Sarabhai and Satyaprakash[231] of bihourly intensities of neutron component at Kodaikanal during 1957 has revealed that there exist correlated changes of the daily mean intensity and of the magnitude of bihourly deviations at particular hours. They have shown that large negative deviations at 2200 hours are associated with decreases in mean intensity and large negative deviations at 0600 hours are associated with increases in daily mean intensity. It is, therefore, possible to separate days associated with an increase or decrease of daily mean intensity by using significant negative deviations at important hours.

1.67 Location of the source of daily variation and its energy spectrum.

Using the extensive experimental data on solar daily variation for different components of cosmic radiation measured at different latitudes from the geomagnetic equator to 60°, Dorman and Feinberg[51] have deduced the spectrum of variation of the primaries causing these variations. They have made use of the coupling coefficients to connect the secondary variations with the variations in the primaries. They find that the primary spectrum for diurnal variation can be represented as

$$\frac{\delta n(E)}{D(E)} = \begin{cases} 0 & \text{if } E < E_1 \\ a(\phi)E^{-1} & \text{if } E > E_1 \end{cases}$$

where

$$E_1 = \begin{cases} 7.5 \pm 0.5 \text{ Bev} & \text{if } E_1 > E_\lambda^{min} \\ E_\lambda^{min} & \text{if } E_1 < E_\lambda^{min} \end{cases}$$

$a(\phi)$ is known as the Strength ~~power~~ of the source of daily variation. They have studied the Strength ~~power~~ of the source as a function of ϕ, the angle between the direction of motion of the particle at infinity and the plane of the geomagnetic equator. Their analysis has revealed that

$$a(\phi = 0) = 0.17$$

$$a(\phi = 36) = 0.14$$

$$a(\phi = 75) = 0.05$$

$$a(-\phi) = a(\phi);$$ ϕ being considered as positive in the northern hemisphere. Thus, the Strength ~~power~~ of the source decreases as ϕ increases.

Calculating the effective direction of the source, they have found that the source is located to the left of the sun-earth line at almost right angles to it (82° ± 8°).

with increasing geomagnetic disturbance, the angle between the source and the sun-earth line decreases.

This spectrum has been derived on the basis of data averaged over long periods and thus does not take into account the highly variable nature of daily variation. Moreover, the diurnal component alone has been considered to represent the daily variation.

A more recent determination of energy spectrum of daily variation has been made by Sarabhai and Rao[30] using directional telescopes during 1957-1958 at Ahmedabad. They find that when the daily variation can be associated with a primary anisotropy, the spectrum of variation has the form $aE^{-0.8}$ with the source located at $115^\circ \pm 10^\circ$ with respect to the sun-earth line in agreement with Dorman and Feinberg's results. On geomagnetically disturbed days, they find that the source of the daily variation cannot be adequately represented by an external anisotropy but must be within the influence of the geomagnetic field. The spectrum of such a local source is found to be aE^0 with maximum occurring at local noon.

1.7 Interpretation of variations.

The close relationship between many of the events occurring on the sun and the major effects in cosmic rays and their periodicities may be summarised as follows:-

(1) Some of the large flares occurring on the sun release cosmic ray particles of high energy. On one

occasion the energy extended to ~~was of the order of~~ 30 - 60 Bev, so that the flare increase was seen even in the cosmic ray intensity at equatorial stations[138].

(2) There is an 11 year cycle of change in cosmic ray intensity, in the low energy cut-off of primary particles and of primary energy spectrum. During sun-spot minimum, the cosmic ray intensity is maximum and the cut-off is practically absent.

(3) The following changes occurring on the sun have a period of 22 years:-

(a) The state of the magnetic polarity of the bipolar sun-spot groups.

(b) The frequency of prominences.

(c) The probable variation of solar diameter.

(d) The diverging motion of the spot forming groups.

(e) The proper motion of the spots in latitude.

(f) The alternating character of the successive sun-spot cycles.

Corresponding to this period, we have the changes in the form of the 12 month mean daily variation of cosmic rays, as revealed by the studies of Sarabhai et al[8], the changes in the time of maximum of the diurnal component as reported by Thambyahpillai and Elliot[206] and the changes in the time of maximum of the semidiurnal component at equatorial stations found by Sarabhai et al[214].

(4) Many of the short term changes in the cosmic ray intensity and the fluctuations in the anisotropy can be directly associated with the central meridian passage of active solar regions such as sun-spot groups, unipolar regions and the regions of intense coronal emission of 5303 Å line.

(5) Some of the active regions on the sun which persist for several rotations of the sun may be responsible for the 27 day recurrence tendency of the cosmic ray intensity.

(6) The close relation existing between cosmic ray variations and geomagnetic activity points to a common source through corpuscular radiation from the sun. The geomagnetic storms associated with type IV radio outbursts are reported to produce marked cosmic ray storms.

The inverse relationship between solar activity and changes in the mean intensity and the low energy cut-off of the cosmic rays rules out the possibility of the sun being the main source of cosmic rays of high energies. Hence at present most of the theories of the variation of cosmic ray intensity and of solar anisotropy refer to the modulation of an almost isotropic intensity of cosmic rays of galactic origin. The main physical processes involved in the modulation are related to the screening or scattering by magnetic fields which may be stationary with respect to the earth, or moving with plasma clouds or streams or stretched by an outward wind emitted from the sun. These theories either refer to geocentric or heliocentric models of the magnetic fields and involve differences in the electromagnetic state of interplanetary space. Recently there have also been suggestions of some variations of cosmic rays being related to the disturbances produced in the geomagnetic field when solar plasma clouds impinge on it.

1.71 Interpretation of short term variations of intensity.

Short term variations in cosmic ray intensity are believed to be mainly decreases by many of the workers. However, Simpson et al[126], Kodama[134], Sarabhai et al[231] and Ahluwalia[228] have pointed out that there exist increases as well as decreases of short duration. Simpson et al[126] have connected the increases observed by them to the central meridian passage of unipolar regions. Kodama's[134] observations of short term increases in intensity during the solar minimum period of 1954 lead him to believe that these are caused by the actual emission of low energy cosmic rays, which can arrive at the earth due to the absence of low energy cut-off during this period. Sarabhai et al[231] and Ahluwalia[228] on the other hand have related the increases to the modulation mechanism in the solar streams emitted by the sun.

Early workers tried to explain the decreases in terms of the modulation of the cosmic ray intensity by changes in the geomagnetic field on the basis of the close relation between the two decreases. But Simpson[120] has shown that the variations in neutron intensity at latitudes above the 'knee' are similar to those observed at low and middle latitudes. This makes the explanation of the variation through the modulation of cosmic rays by geomagnetic field untenable.

Nagashima[96] has proposed a model involving a geoelectric field to explain the world-wide nature of the cosmic ray intensity variations. Even though his theory explains fairly well the altitude and latitude dependence of the variations, it is unable to explain the large variations occurring during magnetically quiet periods when no perturbing geoelectric fields are present. Moreover, the experimental observations of Simpson[120] in the range $\lambda = 45^\circ$N to 60°N of the latitude dependence of the fractional changes in the neutron intensity do not agree with the theoretical values on the basis of this model. Simpson concludes that the mechanism causing the variation should be extra-terrestrial in origin and its association with solar phenomena is independent of the earth's system. Even the very existence of a geoelectric field is doubtful because of the high conductivity of the ionosphere, of the exosphere and interplanetary space.

Alfven[232] has suggested that solar corpuscular streams which are responsible for magnetic storms and aurora can also explain cosmic ray intensity variations. These streams of ionised matter carry frozen in magnetic fields and while moving in interplanetary space appear at the earth to be electrically polarised with an electric field perpendicular to the direction of propagation of the stream and of the frozen magnetic field. The acceleration and deceleration of particles traversing this field may be expected to cause the increases and decreases in intensity on the earth.

In this model, the change of energy of the cosmic ray particles traversing the electric field is independent of the initial particle energy so that the percentage change in the energy is a decreasing function of energy. This will give rise to a marked latitude dependence of the intensity decreases.

Brunberg and Dattner[233,234], elaborating on Alfven's model, have stated that if only decreases associated with magnetic storms are to be explained, then there should exist a general magnetic field of the order of 10^{-5} gauss in the vicinity of the earth, in the same direction as the earth's field. This field is assumed to deflect cosmic ray particles sufficiently to prevent acceleration by the electric field of the beam. They have shown that for particles of energy 30 Bev, the solar magnetic field should have a value ~ 10 gauss in the same direction as the earth's field, and it should vary with distance as $r^{-2.6}$ to produce a field of 10^{-5} gauss at the earth's orbit. It can be shown that the paths of particles of energy 30 Bev do not extend upto infinity and so they must be generated within the solar system. Thus Brunberg and Dattner's theory leads to the solar origin of cosmic rays to explain Forbush decreases.

Morrison[235] has suggested a heliocentric mechanism for the explanation. He assumes the emission of large ionised gas clouds from the active regions of the sun and that these clouds have tangled magnetic fields embedded in them. When these clouds engulf the earth, they shield it from the incident galactic cosmic rays thus causing a decrease.

After a critical study of this model, Parker[236] has pointed out a number of difficulties in accepting it. He says that:-

(1) There are some drastic assumptions to be made regarding the cloud velocities and the magnitude of the field they carry to explain the decreases in cosmic ray intensity in about 4 to 5 hours. Even then it is difficult to explain the period of two to three weeks taken by the depressed intensity to recover to the predecrease level.

(2) The rate of loss of mass due to the required number of magnetic gas clouds amounts to about 10^{14} gm/sec, which is extremely high compared to the estimate of 5×10^{10} gm/sec by Biermann[237] from comet tail studies.

(3) It is necessary for the sun to eject gas clouds in all directions including the polar regions so that the outward flowing magnetic gas clouds may screen the earth in all directions from the galactic particles. Both visual as well as magnetic observations show that the violent aspects of the sun (flares, sun-spots etc.) with which the emission of gas clouds are connected, do not occur near the poles of the sun.

These and many other difficulties have induced Parker[236] to suggest a geocentric mechanism operating within a few earth radii. He envisages earth's gravitational field capturing the interplanetary magnetic clouds to form a nebulous geocentric barrier of chaotic magnetic fields which scatters the galactic cosmic ray flux. The small scale model vastly reduces the amount of magnetic gas needed, eliminates the necessity of the sun to eject clouds in directions far away from the equatorial plane, reduces the characteristic time of the decrease to the observed value of few hours for augmenting the barrier and also readily accounts for the steady low energy cut-off in face of only sporadic solar ejection of clouds. It has also been shown that the geomagnetic field is sufficiently dense to support the weight of such a barrier.

Recent evidence given by Simpson et al[112,113] from space probes shows that along with the Forbush decrease observed on earth, there is a decrease in intensity even at a distance of 8 x 10^6 Km from the earth. They are of the opinion that we should exclude invoking the presence of the earth and its magnetic field and thus geocentric models for explaining the Forbush decreases. They have strong experimental evidence that there is bulk motion outward from the sun of conducting solar plasma ejected in association with a solar flare. This plasma either carries a magnetic field within itself or manipulates an interplanetary magnetic field to convectively remove the galactic cosmic radiation from a limited volume of the inner solar system, by particle collisions with advancing magnetic field irregularities.

Dorman[6] has given a most comprehensive theory for the interpretation of most of the observed variations of cosmic rays. He starts with the basic concept of Alfven, but in contrast to Alfven's idea of the solar origin of cosmic rays, he makes the basic postulate that all cosmic ray particles, down to those of the lowest energies, originate from the galaxy where the flux is isotropic in space and constant in time. Most of the cosmic ray variations are caused by the modulation of these primaries by solar corpuscular streams carrying frozen in magnetic fields as envisaged by Alfven. Dorman has considered that, apart from the acceleration and deceleration of the particles by the electric field set up in the stream, the primary particles are also subjected to the strong influence of the magnetic fields frozen in the streams, thus leading to the scattering of low energy primaries. This aspect is not considered in Alfven's theory. Thus the decrease in cosmic ray intensity during a magnetic storm results from the scattering of the low energy primaries by the streams sweeping the earth, and the daily variation results from the acceleration and deceleration of the particles (of higher energies) by the same stream.

Elaborating this model, Dorman[228] has recently suggested that the principal peculiarities of the variation profile of cosmic ray intensity during magnetic storms are connected mainly with the different ways in which the earth enters a corpuscular stream carrying a frozen in magnetic field. The rate of decline and recovery of the intensity depends very much on the velocity of the stream in the vicinity of the earth. The inhomogeneity of the field will also affect the nature of intensity variations. An examination of a large number of storms has revealed that the magnetic field frozen in the stream is weakened when passing from the leading side edge to the lagging side edge and is sharply strengthened near the front face. Dorman also postulates the existence of two kinds of streams: those of the first kind with small fields that envelop the earth with their side edges cause 27 day variations, those of the second kind are narrow short lived streams with large field causing the changes in intensity during magnetic storms with sudden commencement. It may happen quite often that the narrow streams move inside the broad ones.

In order to explain the cosmic ray decrease from which there is only a partial recovery, Dorman proposes that along with the ejection of a stream giving rise to a magnetic storm effect, there is strong emission from the sun in other directions too. This leads to a sharp discontinuous strengthening of the solar wind and hence to a steep reduction in the general level of the cosmic ray intensity in the earth-sun Region.

1.72 Interpretation of long term changes.

Davis[239,240] has proposed a model in which he supposes a field free cavity having a mean radius of about 200 A.U. to be formed by the sweeping away of the solar and galactic magnetic fields by the ionised matter emitted from the sun. This cavity will trap cosmic ray particles of energy less than 100 Bev for periods long compared to the sun-spot cycle. He has shown that the 4 % change in the intensity in a period of 11 years as reported by Forbush can be explained in terms of one per cent change in the radius of the cavity. However, this model cannot explain the short term changes or the changes in the low energy cut-off with cycle of solar activity.

Beiser[241] has modified Davis' model on the basis that the electrical conductivity of the interplanetary space is not infinite and hence a small residual magnetic field may be left behind by the emitted matter sweeping the galactic field, thus making the cavity diamagnetic.

According to him, the field free cavity of Davis should be thus replaced by a diamagnetic spheroid of semiaxes 5×10^{15} and 5×10^{14} cm, with a residual magnetic field of the order of 10^{-9} gauss inside it. He considers the possible trajectories of particles through this spheroid and trapping of certain particles in it to explain the cut-off. He has shown that a change of about 1.6 % in the total corpuscular output of the sun over a sun-spot cycle can explain the observed 4 % change in intensity. He has also been able to explain the change in cut-off and its absence in 1954.

Chandrasekhar has criticised these models on the ground that inhomogeneities of various kinds will disrupt the cavity walls, thus enabling the trapped particles to escape.

Parker[342] has shown that the hydrodynamic outflow of gas from the sun, as inferred from studies of comet tails by Biermann[337], results in a reduction of cosmic ray intensity in the inner solar system during the years of high solar activity. The computed cosmic ray spectrum closely resembles the one from observations on the earth and he thus infers that the outflow of gas from sun can be taken to explain the 11 year cycle of cosmic ray intensity changes.

The hydrodynamic outflow of the gas from the sun will stretch out the lines of force of the solar magnetic field making it practically radial in the inner solar system.

Instabilities or magnetic turbulence sets in, in the vicinity of the earth's orbit, resulting in a shell of disordered magnetic fields of 10^{-5} gauss (this has been inferred from flare data of February 23, 1956, also). The outward moving disordered magnetic field shields the earth from the galactic cosmic rays, the effectiveness of the shield being greatest at sun-spot maximum. This is because cosmic ray particles will be swept away by the outward moving solar wind and also scattered in the presence of the shell resulting in a net decrease of intensity inside the shell and thus on the earth.

Dorman[343] has commented that Parker has under-estimated the free path length of the low energy particles and that the velocity with which the inhomogeneities are propagated in the interplanetary medium should be considered to fall off exponentially.

Singer[344] tries to explain the 27 day variation, Forbush decreases and the 11 year cycle of changes in intensity by one and the same mechanism. This involves deceleration of primary cosmic rays in interplanetary space due to the expansion of the turbulent magnetic clouds emitted by the sun as considered in Morrison's model. The detailed mechanism is based on a statistical decrease of the initially highly tangled magnetic field as the cloud expands. This corresponds to an inverse Fermi effect. The cosmic rays are reflected back and forth in a region where the turbulent energy is decreasing as the cloud expands. Thus the particles suffer deceleration by the induced electric field, causing the decrease in intensity.

Elliot[243] has recently suggested a heliocentric model which can explain the general characteristics of the cosmic ray intensity variations by the modulation processes of interplanetary magnetic fields. He assumes a large scale heliocentric field of predominantly dipole character and extending far out into interplanetary space even beyond the earth's orbit. This field contains small scale irregularities which act as scattering centres and is occasionally very seriously distorted by outward moving solar material. The strength of the field, which is generated by current systems believed to be present in the solar corona, is dependent on the level of solar activity. Elliot's theory does not explain the day to day changes of daily variation. Moreover, there is so far no evidence for the type of current systems in the corona which are required for this model.

1.73 Interpretation of daily variation.

The scanning of an anisotropic primary radiation by an instrument fixed to the spinning earth is considered to produce the daily variation of cosmic ray intensity.

Brunberg and Dattner[229] have shown that seen from a fixed coordinate system, the rotating sun is strongly polarised so that there would be a voltage difference between the poles and the solar equator of the order of 10^9 volts. The combined effect of this electric field and the solar magnetic field will make the cosmic rays reaching the neighbourhood of the sun partake in the general rotation with the sun. Thus the earth will receive an excess of particles in the 18 hour direction giving rise to tangential anisotropy and a diurnal variation with amplitude ~ 0.3 - 0.4 % at equator. Alfven[222,246] has suggested the possibility of an outward radial flow of cosmic rays, depending upon the accelerating processes within the solar system. This radial anisotropy in the 12 hour direction will change with the 11 year cycle of solar activity. Daily variation is supposed to be resulting from the contributions of the tangential and radial anisotropies, the changes in the radial component giving rise to long term changes in the amplitude and time of maximum of the diurnal variation.

Nagashima[347], extending Alfven's ideas, assumes that the frozen magnetic field in the beam is derived from the dipole field of the sun and that associated with every beam, there is a minimum energy below which no anisotropy is produced. For higher energies, the anisotropy will progressively decrease with increasing energy. He has shown that the minimum anisotropy would be produced in the direction pointing towards the sun, in agreement with the experimental evidence of storm type vector by Sekido et al[235]. This theory explains the 11 year cycle of variation of storm type anisotropy as being due to a change in the density of solar streams and of the strength of the trapped magnetic fields during the solar cycle of activity. However, his theory cannot explain the night type maximum observed on groups of days by Sarabhai et al[199].

Nerurkar[248] has extended Nagashima's ideas by considering the frozen magnetic field in the beam to be derived from the intense local sun-spot fields. Consequently, the field perpendicular to the plane of the ecliptic would have a component either parallel or anti-parallel to the solar field. He has shown that these two cases can give rise to anisotropy in the 1500 hour or 0900 hour directions respectively. Due to the effect of the geomagnetic field, these anisotropies can give rise at low latitudes to daily variation with maximum occurring either at 1200 hours or 0900 hours.

Dorman[3] has elaborated on these models and has tried to explain the diverse features of daily variation by taking into consideration the different orientations of the trapped magnetic fields in the beams. His theory, as he himself admits, has assumed the daily variation to be diurnal in character and daily variation averaged over long periods has been used for its verification.

A confirmation of the general basis of the theory is forthcoming from the experimental work of Sarabhai and Rao[60] who have demonstrated that when the daily variation can be associated with an anisotropy of the primary radiation, the anisotropy has a direction and energy spectrum of variation as predicted by theory. Moreover, the same theory can also generally explain the associated increase of east-west asymmetry. The work of these authors, however, has brought to light evidence of a local source of daily variation on geomagnetically disturbed days and for this there is as yet no adequate theory.

1.3 Statement of the problem.

Even though it is know that protons can be ejected from the sun with cosmic ray energies during some solar flares and with energies in the region 50 - 600 Mev during polar cap absorption events associated with other flares and type IV radio outbursts, it is generally agreed that the bulk of the cosmic rays measured on the earth have a galactic origin. It is also widely accepted that most variations of intensity and of energy spectrum and the solar anisotropy of cosmic radiation are connected with modulation produced by interplanetary electric and magnetic fields. However, on the question whether these fields are randomly oriented by the turbulent motion of highly ionized gas or are highly organized and frozen within moving solar stream, there is wide divergence of opinion. Similar difference exists concerning the heliocentric or geocentric character of the fields and of the nature of the solar "wind" or "breeze" which may blow through interplanetary space.

A development of our understanding of the physical processes involved in time variations of cosmic rays is dependent not only on examination of further theoretical models but in the performance of accurate experiments which can enable the application of rigorous tests to choose between the various alternative models. The investigation undertaken by the author attempts to derive fresh knowledge concerning the time variations of meson intensity observed at a station at the geomagnetic equator at a longitude where the geomagnetic cut-off rigidity is amongst the highest found anywhere on the earth. Experiments have been conducted with narrow and wide angle telescopes at Trivandrum (Geographic latitude 8.48°N, longitude 76.95°E, geomagnetic latitude -1.13°, geomagnetic longitude 147.51°, sea level) during the period August 1957 to April 1960. Radio sonde observations at Trivandrum made twice every day by the India Meteorological Department enable us to apply appropriate temperature corrections to the meson data. The data has been used to study the following aspects:-

(1) Those relating to solar anisotropy of cosmic rays.

(a) The dependence of the daily variation on the opening angle of a cosmic ray telescope in the east-west plane.

(b) Long term changes in the 12 month mean daily variation.

(c) Relationship between daily variation and geomagnetic activity.

(2) Those relating to correlated changes of intensity and of anisotropy during events like cosmic ray storms, polar cap absorption events, low east-west asymmetry, etc.

(3) Those relating to the energy spectrum of variation during changes of intensity.

While there have been many contemporary studies particularly during and after the I.G.Y. period, which relate to the analysis of data from neutron monitor stations, the present study is perhaps the only one so far reported which uses meson intensity data at the geomagnetic equator which is corrected for upper air temperature changes. The results highlight the inadequacy of some of the current concepts and an attempt is made to test the validity of alternative hypothesis.

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CHAPTER II

EXPERIMENTAL TECHNIQUE

The significance of making measurements with narrow angle telescopes at low latitudes, with different angles of opening has been already discussed in the earlier chapter. In this chapter, we shall describe in detail, the experimental set up built by the author to study the time variations of cosmic ray intensity at the equatorial station Trivandrum (sea level, geomagnetic latitude 1.13°S, geographic longitude 76.95°E).

An ideal experimental unit should have as high a counting rate as possible to enable us to study the daily variation on individual days and the day to day variations. In practice limitations are imposed by available facilities in realising this ideal. For a given geometry and size of counters, the counting rate can be increased by using several identical sets of telescopes. Since self quenching Geiger Muller counters have a limited life, counter failures are not uncommon and independent sets of telescopes not only serve to improve the statistical accuracy of the result but also enable us to standardise and normalise the rates when the counting rate is altered in one of the telescopes due to the replacement of a faulty counter by a good one.

For the study of the long term changes in cosmic ray time variations, it is necessary that the apparatus should be stable and should retain its characteristics. For this purpose, the mains A.C. voltage of 230 volts is stabilised with the help of a constant voltage transformer. All power supplies for D.C. voltages are electronically stabilised. The failure of counters is minimised by using suitable quenching units for external quenching. To avoid electrical interfeeding or 'pick up', pulses from one unit to the other are fed through properly shielded cables. All output terminals of power supplies are decoupled with the use of suitable condensers. The counters are maintained in a constant temperature enclosure for stability of working conditions.

2.1 Apparatus.

It has been shown by Sekido et al[107] that the diurnal and semidiurnal components of solar daily variation increase as the angle of opening of the telescope is decreased. Sarabhai et al[109] from a study of narrow angle units at Ahmedabad have shown that during 1954 the diurnal and semidiurnal components increase as the angle in the E-W plane is reduced upto 5°, but beyond that there is no significant increase in the amplitude as the angle is reduced still further. Keeping in mind these results and realising that the statistical error of each bihourly counting rate is increased as a given telescope is made narrower, an apparatus is designed as described below. The block diagram and the various telescopes included are indicated in figure 6.

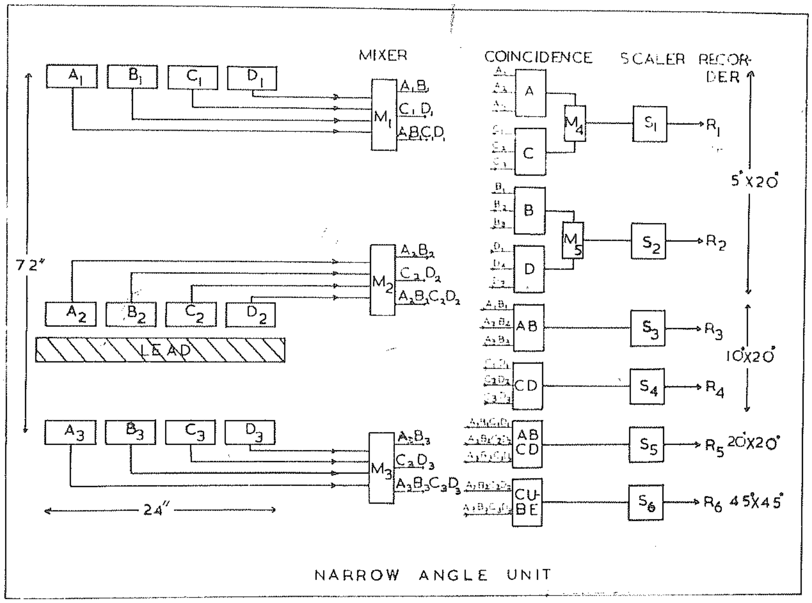

Fig.6 - Schematic diagram of the arrangement of various telescopes in the "Narrow angle unit".

The unit consists of three trays of 16 counters each, with an absorber of 8 cm of lead in between the second and the third trays to filter out the low energy particles. The counters are placed with their axes along the north-south direction. Each counter has a length of 2 feet and a diameter of 1.5 inches. The distance between the top tray and the middle tray is 4 feet.

Groups of four adjacent counters of the same tray are connected in parallel to quenching units A_1, B_1, C_1, D_1. The triple coincidence of four counters of A_1 with the corresponding counters in A_2 and A_3 corresponds to a telescope of semivertical angle of 5° in the east-west plane and 20° in the north-south plane. Thus we have 4 independent telescopes of 5° x 20°.

The outputs of the quenching units A_1, B_1, C_1, D_1 are fed to the diode mixer M_1. The diode mixer gives us the mixed outputs A_1B_1, C_1D_1 and $A_1B_1C_1D_1$. Similarly, the outputs of quenching units of tray 2 (A_2, B_2, C_2, D_2) are fed to M_2 and those of tray 3 (A_3, B_3, C_3, D_3) are fed to M_3. The mixed outputs are fed to the appropriate coincidence units to give the telescope counting rates of the combinations as given below:-

$$\text{(a)}\quad \left.\begin{matrix} A_1, A_2, A_3 \\ B_1, B_2, B_3 \\ C_1, C_2, C_3 \\ D_1, D_2, D_3 \end{matrix}\right\} \quad \text{Four } 5^\circ \text{ x } 20^\circ \text{ triple coincidence telescopes.}$$

$$\text{(b)}\quad \left.\begin{matrix} A_1B_1, A_2B_2, A_3B_3 \\ C_1D_1, C_2D_2, C_3D_3 \end{matrix}\right\} \quad \text{Two } 10^\circ \text{ x } 20^\circ \text{ triple coincidence telescopes.}$$

(c) $A_1B_1C_1D_1$, $A_2B_2C_2D_2$, $A_3B_3C_3D_3$ - One 20° x 20° triple coincidence telescope.

(d) $A_2B_2C_2D_2$, $A_3B_3C_3D_3$ - One 45° x 45° double coincidence telescope.

Triple coincidences are used in all telescopes except 45° x 45°, in which case double coincidence is used. The triple coincidence outputs of the 5° x 20° telescopes A_1, A_2, A_3 and C_1, C_2, C_3 are mixed by M_4, those of B_1, B_2, B_3 and D_1, D_2, D_3 are mixed by M_5. The mixed outputs are fed to two scale of 4 units and then to mechanical recorders. The outputs of the two 10° x 20° telescopes are also scaled down by scale of 4 units and recorded. A scaling factor of 16 is used in the case of the 20° x 20° telescope and a factor of 128 for the high counting rate cube of 45° x 45°. All units are designed to work from two stabilised supply voltages viz. +300 volts and -70 volts.

Besides the "Narrow angle unit", which started functioning properly by about the end of July 1957, the author was also in charge of another unit - "Standard unit" - with 4 identical telescopes of semiangles of opening 23° and 37° in the E-W and N-S planes respectively. The block diagram of the arrangement in this unit is given in figure 7 and is briefly described below.

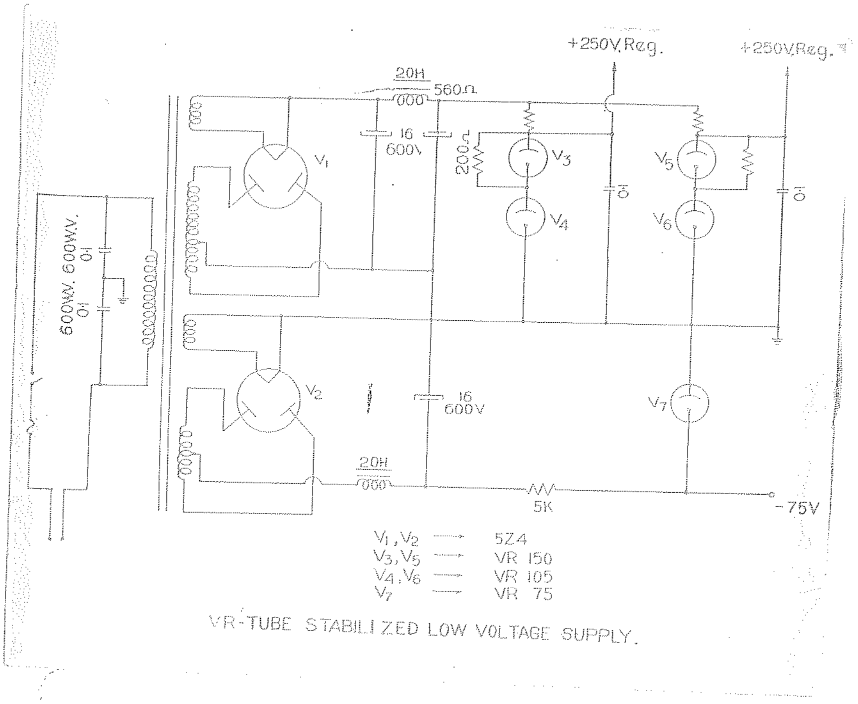

Fig. 7 - Schematic diagram of the 'Standard unit'.

The "Standard unit" (Wide angle unit) consists of 4 vertical triple coincidence telescopes. Two identical sets of four trays A, B, C, D and A', B', C', D' are mounted side by side with vertical separation of 20 cm between individual trays of each set. Each tray consists of 4 counters connected in parallel to a common quenching unit. Triple coincidences of trays ABC, A'B'C', BCD and B'C'D' are recorded after scaling down each rate by a scale of 4 unit. The length of each counter is 30 cm and diameter 4 cm with its axis aligned along the north-south direction. To eliminate the soft component, 2 cm of lead is put as absorber between trays B-B' and C-C'.

Details of the various types of telescopes included in the Narrow angle unit and the Standard unit are given in table 2.

Table 2

Details of the different telescopes working at Trivandrum in the Narrow angle unit and Standard unit.

Type of telescope. (E-W & N-S semi-angles)	No. of telescopes.	Total bihourly counting rate. (without scaler).	Scaling factor.	Bihourly standard error (%)
5° x 20°	4	3600	4	±1.67
10° x 20°	2	7000	4	±1.20
20° x 20°	1	13200	16	±0.87
23° x 37°	4	16000	4	±0.80
45° x 45°	1	83200	128	±0.35

2.3 Geiger Muller counters.

A Geiger Muller counter is essentially a diode, filled with some rare gas like argon, and operates in the region of the unstable corona discharge. The passage of a single ionising particle produces a few ion pairs in the sensitive volume of the counter. The free electrons trigger an avalanche and a discharge which rapidly spreads throughout the length of the counter. The discharge lasts only for a few microseconds and finally gets quenched due to the development of positive space charge near the central wire. As a result of discharge and quenching of the counter, a small voltage pulse is developed across the counter, which can be suitably amplified and recorded. The quenching of the discharge is helped by the addition of a polyatomic vapour such as ethyl acetate to the counter gas. The decomposition of the quenching vapour following each discharge sets a limit to the useful life of the counter. The important property of the Geiger Muller counter is that the magnitude, duration and the general character of the discharge is independent of the specific ionising power of the initial particle. Spartz[249] has estimated the life of a self quenching counter to be of the order of 10^{10} counts.

The important characteristics of a Geiger counter are (1) its threshold voltage (2) the length and slope of its plateau (3) efficiency (4) stability with use and time (5) large pulse size and short recovery time (6) temperature dependence and (7) useful life. All these features cannot be achieved simultaneously to the maximum degree. Wilkinson[250], Korff[251], Montegomery and Montegomery[252], Stever[253], Curran and Craggs[254] and Friedman[255] have studied extensively the theory of counters and the complete characteristics have been discussed.

Metal counters were used in the present investigation and all of them were prepared by the author himself at Trivandrum. The method of preparation is briefly given below:-

A thin walled brass tube of 4 cm diameter is used as the cathode and a very thin tungsten wire of 4 mils diameter is used as the anode. The brass tube is fitted at its ends with two well fitting brass discs in the centre of which holes are drilled for attaching glass bushings carrying the central wire. The glass bushings also provide for evacuation and filling of the counter.

The inside surface of the brass tube and the discs are polished well with steel wool and they are then washed with petrol and ethyl acetate to remove all dirt. The counter parts are next assembled together and a suitable length of tungsten wire is threaded through the capillary of the glass tubes.

Metal to metal and metal to glass joints are heated to about 300°F and 'araldite' type 1, a thermo-setting resin, is applied to make a leak proof coating at the joints. The technique of applying 'araldite' is very similar to that of soft soldering. The entire assembly is allowed to cool till the 'araldite' sets firmly. The thin tungsten wire is then spot welded at both ends to thicker tungsten wires which protrude outside the glass bushings. These ends are soldered to copper wires by using silver nickel alloy. The counters are then connected to the evacuating system and while they are being evacuated, they are slightly warmed to drive out moisture if any inside the counters and the central wire is heated to incandescence by passing a current through it to burn out dust and sharp points on the wire. About 24 hours after evacuation, the counters are tested for air leaks and leak-proof counters are filled with 1 cm of ethyl acetate and 9 cm of argon. The gases are then allowed to mix for two hours and the counters are tested. Those giving a plateau of more than 200 volts with a slope less than 2 % for 100 volts are sealed at the constriction in the glass tubing.

2.3 Electronic units.

2.31 Quenching unit.

The development of spurious pulses in a self quenching counter can be avoided and the spreading of the discharge limited and thereby its useful life increased by the application of a quenching pulse of well defined duration and magnitude from an external quenching unit to the central wire of the counter.

The quenching unit consists of a monostable multi-vibrator shown in figure 8. When triggered by a counter discharge pulse, it produces a rectangular negative pulse of ~ 250 volts and of duration ~ 1000 microseconds at the anode of the counter. To make the pulse acceptable for fast coincidence work, it is differentiated by the RC network having a small time constant. This differentiates the square pulse into

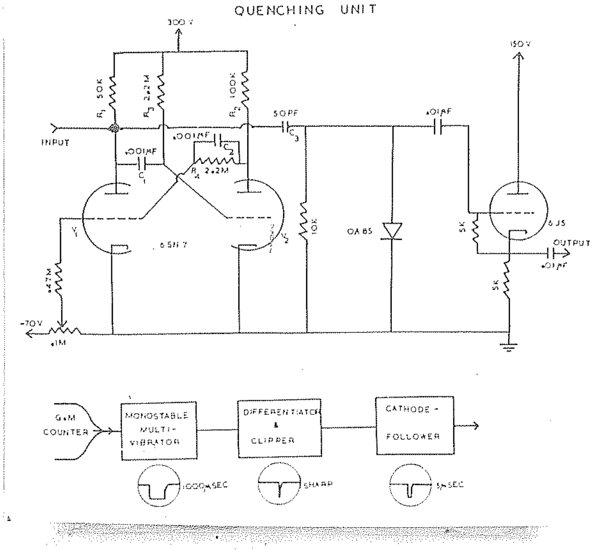

Fig. 8 - Circuit diagram of Quenching unit.

a sharp positive and a sharp negative pulse, the positive pulse being clipped off by a crystal diode and the negative pulse fed to the grid of the cathode follower. The cathode follower furnishes negative pulses to all required channels at a low output impedance, which minimises the loss of signal.

2.32 Mixer unit.

The mixer unit in the narrow angle unit is used to mix the pulses of various channels to get the appropriate combinations of telescopes. The circuit diagram of the mixer unit is given in Figure 9.

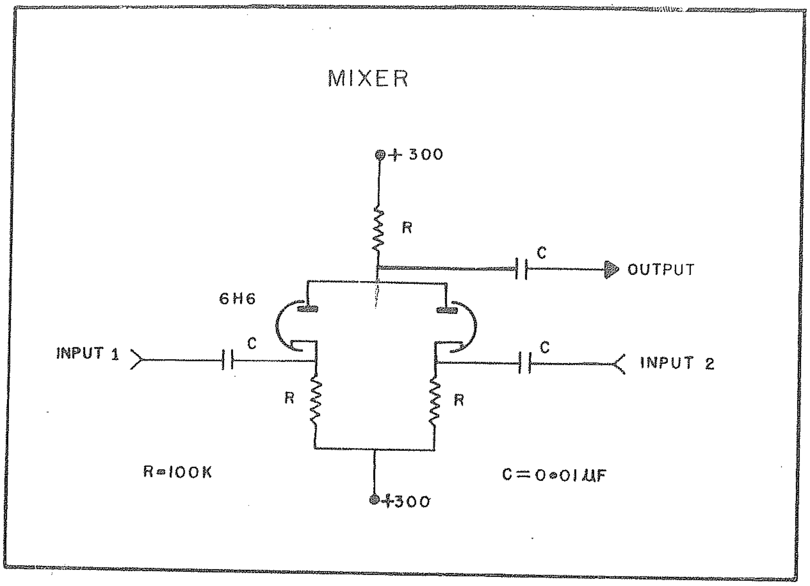

Fig. 9 - Circuit diagram of Mixer unit.

Metal diode 6H6 is used for the mixer circuit to avoid interfeeding. Mixers are used to mix output pulses from quenching units and in case of 5° x 30° telescopes after coincidence before the pulses are fed to scaling units.

2.33 Coincidence unit.

Coincidence circuit used (figure 10) is of the well known Rossi[237] type. To secure high resolution and good discrimination between partial and total coincidences, sharp cut-off pentodes (6J7) are used. The plates of the pentodes are connected together through a common resistance to the voltage supply. When negative pulses arrive in all the channels simultaneously or within a short interval of time of the order of 5 microseconds the tubes become nonconducting as a result of which a large positive pulse is developed at the common anode. This sharp positive pulse is fed to the grid of a discriminator pentode which is biased much below the cut-off. The ratio of the size of the pulses formed due to n fold (genuine) and n-1 fold (partial) coincidences is very large, of the order of 20. Thus the discriminator is not triggered by small partial coincidence pulses. It acts as a phase inverter as well and we finally get negative pulses from the plate corresponding to genuine coincidences.

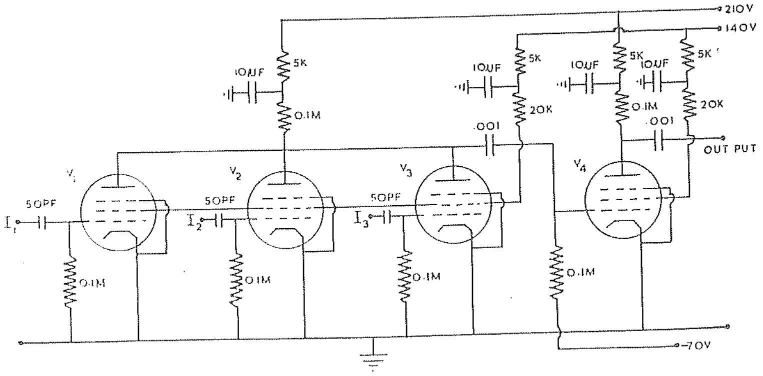

Fig.10 - Circuit diagram of a triple coincidence unit.

2.34 Scaling and Recording unit.

A scaling unit introduced between the coincidence circuit and the final recording stage reduces the input rate of pulses to the mechanical recorder and at the same time reduces the randomness in the arrival of pulses at the recorder. Thus a scaling unit usually eliminates the loss of pulses by a mechanical recorder and at the same time increases its useful life by reducing wear ~~and tare~~.

The circuit used for scaling is a bistable multivibrator of the usual type described by many authors (Freeman^{258}, Ritchie^{259} and Fitch^{260}). Figure 11 shows the basic scale of two unit.

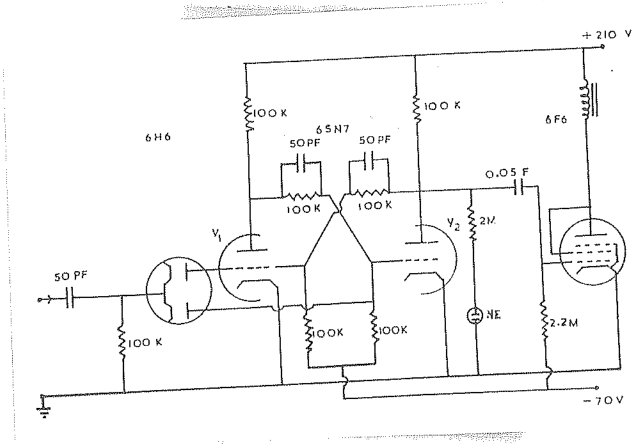

Fig.11 - Scaling and Recording unit.

Any number of such stages can be used in cascade to increase the scaling factor. The counting rates of the telescopes of 5° and 10° of 'Narrow angle unit' are scaled down by a factor of four, that of 20° by a factor of 16 and of the cube by a factor of 128. The final output pulse of the scaler is fed to the grid of a power pentode 6F6 which is biased beyond cut-off. The plate voltage of this tube is applied through the solenoid of a mechanical recorder. The arrival of a positive pulse at the grid of this tube makes the tube conducting and thus actuates the mechanical recorder.

The output pulse from the last stage of the scaler unit is a sharp one. It is fed to the biased grid of the power pentode through a large condenser so as to have sufficient broadening to give positive action to the mechanical recorder. The mechanical recorder used is of the type employed in registering the number of telephone calls made.

2.35 Automatic photographic unit.

An automatic photographic device is made use of to get the hourly records of cosmic ray intensity. Mechanical recorders of all the telescopes together with a clock and date index are mounted on one side of a light tight box with an easily detachable camera fixed on the opposite side. The shutter of the camera is permanently kept open and a short range lens is used for the camera. The camera can hold about 11 feet of 35 mm film which suffices ~~for~~ about a week. To the inside of the light tight box are fixed two electric lamps, which are made to flash for a fraction of a second with the help of a relay arrangement triggered by an electrical contact of few seconds duration made hourly by an external clock. The exposed film is automatically wound on a spool which is geared to the shaft of a low speed motor, the gearing of which is so adjusted that the film is moved through one frame after each exposure.

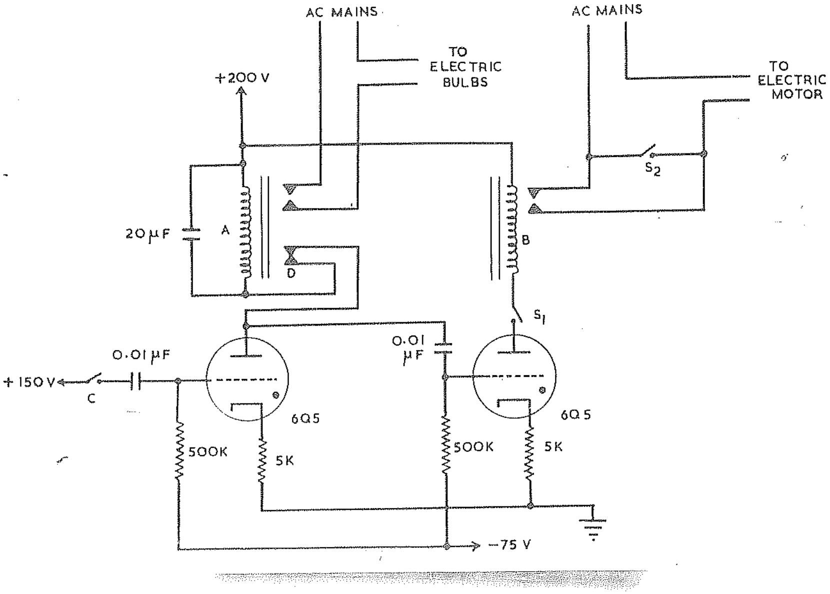

Fig. 12 - Automatic sequence control circuit.

The automatic sequence control circuit used for this purpose is shown in figure 12. It consists of two triggered thyratron switches working in succession. Every hour the clock gives a positive pulse of 150 volts to the grid of the first thyratron (left) which is normally biased negative. The current passing through this closes the relay A thereby flashing the bulbs momentarily. At the same time the plate circuit of this tube is made open and so it stops conducting. This opens the relay A, switching off the lamp circuit. The pulse from the plate of the first tube triggers the second thyratron (right), the relay B closes and hence the motor moves. An internal switch of the motor removes high tension from the plate of the second tube for a time in which the film is rotated by one frame. After these operations the circuit comes back to its initial stage.

2.36 Power supplies.

The mains AC voltage of 230 volts, 50 cycles available at Trivandrum Laboratory is stabilised by using a constant voltage transformer which gives an output of 230 volts 50 cycles for input voltages ranging from 180 volts to 250 volts. The power for the various D.C. power supplies and filament transformer for the vacuum tubes is derived from this constant voltage transformer. Hunt and Hickman[231] have discussed in detail the various types of voltage stabilising circuits and have shown that the simple degenerative type are quite satisfactory for giving a regulated D.C. power source of high stability, low internal resistance and low ripple output. The D.C. voltage supplies used are stabilised by the degenerative type of stabilising circuits.

In the Narrow angle unit, a voltage of 300 volts is used for all circuits for the plate and screen voltages and -70 volts as the bias voltage. In the case of the Wide angle unit, the arrangement is as follows:-

(1) 420 volts for quenching units and scalers.

(2) 210 volts for plate voltage of coincidence units and cathode followers.

(3) 150 volts for the screen voltage of coincidence units.

(4) -70 volts as the bias voltage in all cases.

2.321 <u>High voltage power supply.</u>

Figure 13 shows the circuit diagram of the high voltage power supply used for providing voltage to the G.M. counters. Tube 807 is used as a regulator and tube 6SJ7 as the feed-back amplifier. Since the voltage stability depends on the voltage gain of the amplifier, 6SJ7 is used in a starvation region. Walker,[232] has shown that when a pentode is used with a low screen voltage and high plate resistance, for the starvation

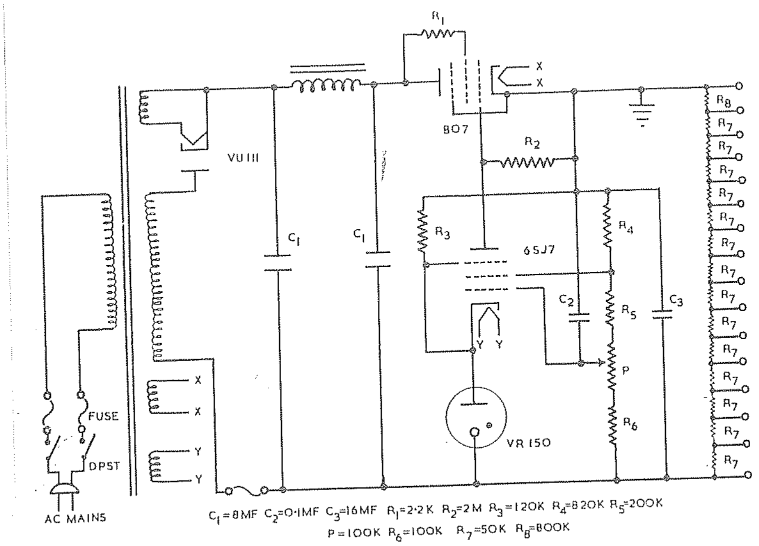

Fig.13 - High voltage regulated power supply.

amplifier, high gain upto 2500 can be obtained. The current to the reference tube is fed from the regulated side and thus more stability and better regulation is ensured. The power supply can give voltages ranging from 800 to 1400 volts and various voltage tappings are obtained in steps of 50 volts by using a suitable bleeder.

2.362 Low voltage power supply.

D.C. voltage of 300 volts, 480 volts and 510 volts were obtained from power supplies electronically stabilised using the difference amplifier circuit described by Elmore and Sands[258]. The circuit diagram of the 300 volts supply is shown in figure 14. In the 300 volts supply, both plates of 6SC7 are fed approximately to 300 volts to obtain symmetrical behaviour with respect to currents and voltages. Standard reference voltage given by VR 90 is applied to one grid of the 6SC7 tube and the other grid is connected

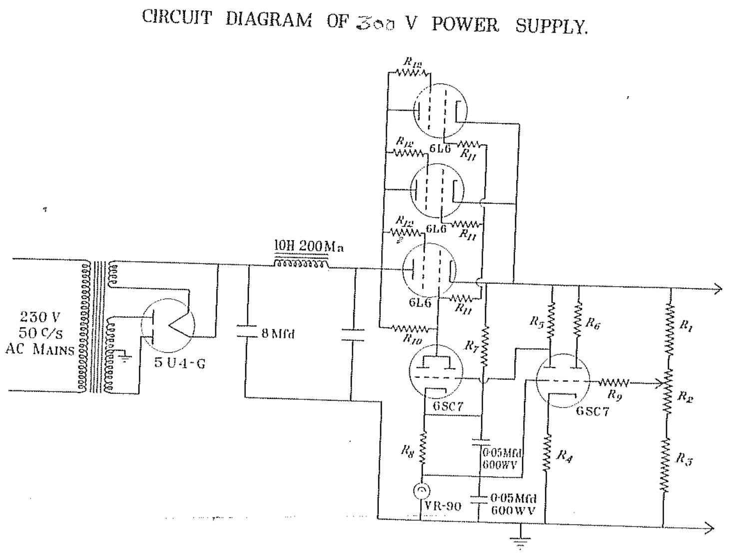

Fig.14 - Circuit diagram of low voltage power supply.

to the sampling net-work. The error voltage amplified by the difference amplifier is further amplified by a second 6SC7 before being fed to the grid of the regulating tube 6L6.

The voltage supply for 150 volts and the bias voltage supply of -70 volts are stabilized by using VR 150 and VR 75 tubes respectively.

ooo 0 ooo

CHAPTER III

METHODS OF ANALYSIS

3.1 Data processing.

From the hourly photographs of the mechanical recorders, readings for odd hours namely 2300 (previous day), 0100, 0300, 0500,....., 2300, I.S.T. are noted down daily. The difference between successive readings gives the bihourly intensity of cosmic rays centred at 0000, 0200, 0400, ..., 2200 hours I.S.T. recorded by the particular telescope. The arithmetic mean of the twelve bihourly values gives the daily mean intensity.

When more than one telescope~~s~~ of the same geometry ~~are~~ is working, an intercomparison is made to see if all of them are working alike. In an ideal case, we expect them to record the same intensity during a common period, but due to slight difference in geometry or the sensitivity of the recording apparatus, there may be some difference apart from statistical sampling errors between the number of counts recorded. To test whether the recordings for two similar telescopes are agreeing within limits of statistical errors, the difference between the corresponding bihourly counts ΔT are found out for each successive bihourly interval (say from one break to the next break in the continuous recording of the two telescopes). Mean of these differences $\overline{\Delta T}$ is calculated and a check is made to see whether about 95 % of the values lie within ± 2σ range~~s~~ of this mean $\overline{\Delta T}$, where σ is the standard deviation of the difference between the two telescope rates. σ is given by

$\sigma^2 = \sigma_1^2 + \sigma_2^2$, where σ_1 and σ_2 are the standard deviations of the bihourly counts of the two telescopes. If more values are outside this limit than statistically allowed, the data of each individual telescope are scrutinised and the one which shows erratic behaviour is eliminated.

If there are more than two telescopes of the same kind, they are thus tested in pairs and finally these pairs are intercompared. The deviations from daily mean of all properly working telescopes of the same geometry are then added together and are expressed as percent deviations with respect to the total mean for that day. Thus the cosmic ray data is reduced to 12 percentage bihourly deviations from the daily mean for each type of telescope.

From the barograph charts the pressure deviations from the mean pressure for the day are found out corresponding to the hours 0000, 0200,....., 2200, I.S.T. and a pressure coefficient of -0.17 % per mb is used as suggested by Sarabhai et al[8]. All the twelve bihourly percent deviations of cosmic ray intensity are thus corrected for atmospheric pressure variations.

Even though a coefficient of -0.17 % /mb has been used for applying corrections for barometric changes of pressure, an attempt has been made as is described in section 4.3 to determine the barometric coefficient from cosmic ray intensity.

3.11 Normalisation of mean intensity.

In this investigation, since we are having several similar telescopes, the mean intensity for a day recorded by a particular type of telescope is given by the sum of the mean bihourly counts of all telescopes of that type in operation on the day. For any particular geometry, all telescopes may not be working on a particular day. In such cases an estimate of the mean intensity is made from the rates of the properly working similar telescopes.

Let N_1^j, N_2^j,.........., N_x^j be the individual mean rates of x similar telescopes on the j th day. Then the total intensity for the day is given by

$$N^j = N_1^j + N_2^j + ... + N_x^j. \qquad ...(11)$$

If for example, the first telescope with rate N_1^j is not working on the j th day, then the intensity is normalised by making use of the data on the previous five days and the normalised intensity is given by

$$N^j = \frac{(N_2^j + N_3^j + \ldots + N_x^j) \sum_{j-1}^{j-5} N^j}{\sum_{j-1}^{j-5} (N_2^j + N_3^j + \ldots\ldots + N_x^j)} \quad \ldots \quad (12)$$

The above case is applicable when the failure of a particular recording section occurs and the sensitive area of the telescope does not change. The mean intensities before and after the j^{th} day are then directly comparable. On the other hand, if there is Geiger counter failure, it is hardly possible to replace by another counter of exactly identical characteristics. Hence the total counting rates of the telescopes before and after replacement of the bad counter by a good one are not directly comparable. In order to normalise the new series of mean intensity to the previous level, it is multiplied by a factor K which is derived from the mean intensity of the telescopes five days before and after the j^{th} day,

$$K = \frac{\sum_{j-1}^{j-5} N^j . \sum_{j+1}^{j+5} (N_2^j + N_3^j + \ldots\ldots + N_x^j)}{\sum_{j+1}^{j+5} N^j . \sum_{j-1}^{j-5} (N_2^j + N_3^j + \ldots\ldots + N_x^j)} \quad \ldots \quad (13)$$

The normalised series of mean intensity is then expressed as a percentage of an assumed standard mean intensity which is of the order of the average daily mean intensity for the particular telescope (3050 and

1725 in case of standard unit and $10^\circ \times 20^\circ$ respectively). Daily mean pressure values for the same period are represented as deviations from a fixed mean pressure (1000 mb in case of Trivandrum). The pressure deviations are multiplied by the pressure coefficient (numerical value 0.17 %/mb) and added to the percentage normalised mean intensity. The new series so obtained represents the pressure corrected normalised mean intensity.

3.12 Temperature corrections.

3.121 Temperature correction for daily mean intensity.

The mean intensity of the standard unit as well as that recorded by $10^\circ \times 20^\circ$ telescopes are corrected for atmospheric temperature effect according to the method given by Dorman[5]. As explained in section 1.3 Dorman and Feinberg[31] have shown that the contribution to mean intensity changes due to atmospheric temperature variations can be represented as

$$\frac{\delta I}{I} = \int_0^{h_0} W_T(h)\,\delta T(h)\,dh = \sum_{i=0}^{i=10} K_i \Delta T_i \qquad \ldots (24)$$

For convenience of calculation, they have shown that the entire mass of atmosphere can be divided into 11 layers as follows:-

No. 0 from h_0 (station level) to 950 mb.

No. 1 from 950 to 850 mb.

No. 2 from 850 to 750 mb.

....

No. 9 from 150 to 75 mb.

No. 10 from 75 to 25 mb.

Temperature values are taken from the radio sonde data for the middle isobaric levels of 900, 800, ..., 100 and 50 mb. The contribution ΔW_i of the i^{th} layer to the temperature correction is given by the relation

$$\Delta W_i = -K_i \, (T_i - T_i^0) = -K_i \Delta T_i \qquad \ldots \quad (15)$$

Where ΔT_i is the deviation of the observed temperature T_i from the standard temperature T_i^0 for the i^{th} layer. T_i^0 is either the most frequently encountered temperature at the isobaric level i, or the temperature at the level on the day of standardisation of the instrument.

The contribution of the first layer is calculated from the equation

$$\Delta W_0 = -K_0' \, (h_0 - 950) \, (T_0 - T_0^0) \qquad \ldots \quad (16)$$

Total temperature correction in percent to the mean intensity is given by

$$W = \sum_{i = 0}^{i = 10} \Delta W_i \qquad \ldots \quad (17)$$

In the present investigation, the standard temperature T_i^0 for the i^th isobaric level is calculated as the mean temperature at the layer observed during the whole period August 1957 to April 1960, which is under study. The temperature T_i for the i^th isobaric level is taken as the mean value obtained from two radio sonde flights at 0000 hours G.M.T. and 1200 hours G.M.T. (0530 and 1730 hours I.S.T). ΔT_i for the i^th layer is the difference between this temperature and the standard temperature T_i^0 calculated for that layer as described above.

The value of K_o for the surface layer is calculated from the value of K_o' given by Dorman et al[203] and taking h_o to be 1000 mb.

$$K_o = 0.032 \times 10^{-2} \times 50 = 16 \times 10^{-3} \% / ^\circ C \quad \ldots (18)$$

At Trivandrum the temperature data at different isobaric levels are available on most of the days only upto about 300 mb or 250 mb level. This necessitates an extrapolation of the available data to get the temperature values corresponding to 200 mb, 100 mb and 50 mb levels. Correlation analysis of temperatures at different isobaric levels for the same day carried out for a period covering a large number of days when temperature data are available upto the highest level has revealed that there exists good correlation between the temperature changes at 400 mb, 300 mb, 200 mb and 100 mb. The correlation coefficients are as high as 0.8 to 0.9. This justifies the assumption that there is an almost one to one correspondence between temperature changes occurring at different layers at least above 400 mb and that we are justified in finding out the temperature deviations by the method of extrapolation, when such values are missing. The following procedure is adopted:-

X, the ratio of the root mean square values of the temperature deviations at 300 mb to that at 400 mb is calculated as

$$X = \sqrt{\frac{\sum(\Delta T_{300})^2}{\sum(\Delta T_{400})^2}}$$

Similarly,

$$Y = \sqrt{\frac{\sum(\Delta T_{200})^2}{\sum(\Delta T_{400})^2}}$$

and

$$Z = \sqrt{\frac{\sum(\Delta T_{200})^2}{\sum(\Delta T_{300})^2}}$$

are also calculated. These factors X, Y and Z are used to extrapolate the temperature deviations corresponding to 300 and 200 mb levels from those experimentally observed for 400 mb or 300 mb as the case may be. An estimate is next made to determine the contribution to temperature correction by the layers of 100 mb and 50 mb. For this, days are selected when the original values of temperature deviations are available upto 50 mb and the ratio of the contribution due to layers upto and including 200 mb level from the station level to that due to levels of 100 and 50 mb is calculated, which gives a value 1 : 0.15. Hence, instead of depending on the scanty data of temperature for 100 and 50 mb levels, the temperature correction $\sum_{i=0}^{i=8} K_i (T_i - T_i^0)$ is multiplied by 1.15 to account for the contribution due to 100 and 50 mb levels also.

The values of the partial temperature coefficients for different levels as given by Dorman et al[263] and the standard temperatures for the corresponding levels calculated as described above are given below:-

Level	Surface 1000 mb	900 mb	800 mb	700 mb	600 mb	500 mb	400 mb	300 mb	200 mb	100 mb	50 mb
K_i in 10^{-3} % per $^{\circ}$C	16	28	27	26	27	28	29	30	28	20	12
T_i^0 ($^{\circ}$C)	27.0	21.5	16.5	10.5	3.5	-5.0	-16.5	-31.0	-52.5	-	-

The value of $\sum_{i=0}^{i=10} \Delta W_i$ thus calculated, which represents the reduction in cosmic ray mean intensity due to temperature effect for the day is added to the percent normalised pressure corrected mean intensity to get the mean intensity for the day corrected for temperature and pressure changes in the atmosphere.

3.122 Temperature correction to daily variation of meson intensity.

For adopting the method elaborated in the preceding section for applying temperature correction to the daily variation of meson intensity, it is necessary to know the daily variation of temperature at various atmospheric depths ranging from the ground upto 50 mb. It is difficult to get direct value of the daily variation of temperature at Trivandrum at different heights as there are only two flights per day. Sarabhai and Rao[39] have recently summarised the experimental evidence which shows that the diurnal variation of temperature has negligible amplitude above 2 Km from the earth's surface. Beers' relation indicates that the amplitudes of daily variation of temperature at 1 Km and 2 Km above the surface of the earth are 0.22 and 0.11 times the amplitude at the surface. Hence an estimate of the temperature correction to daily variation of meson intensity has been made using Beers' relation and the partial temperature coefficients K_t given by Dorman et al[203] for surface, 900 mb and 800 mb levels. The value of the temperature coefficient thus obtained is found to be -0.025 % per °C change of ground level temperature.

Temperature correction to the daily variation of meson intensity is expected to be of the order of 0.05 % to 0.06 % at Trivandrum since the fluctuations of temperature are small. Daily variation of meson intensity is generally studied on groups of days or on days when the amplitudes of the diurnal and semidiurnal components are significant at 2σ level (σ is the standard error associated with the amplitude and its value is of the order of 0.4 %). When the amplitude of daily variation is high, temperature correction has very little effect on the amplitude. On the other hand, when daily variation averaged over groups of days is studied for which amplitude of the order of 0.2 to 0.3 % becomes significant, temperature correction has to be applied before valid interpretation can be undertaken.

3.2 Analysis.

3.21 Fourier analysis.

In cosmic ray variation studies, it is important to know the nature of the periodicities involved in the daily variation and their relationship with known geophysical and astrophysical periodicities. It has been found in the case of most of these problems that the first and second harmonics represent the variations almost completely.

Various authors such as Thompson[284], Whittaker and Robinson[285], Bonnay[286] and Kane[287] have described elegant methods of resolving a periodic function into its harmonics. Any time dependent function F(t) can be expressed in terms of a Fourier series of the type

$$F(t) = a_0 + \sum_{n=1}^{\infty} (a_n \cos nt + b_n \sin nt) \qquad \ldots \quad (19)$$

where $0 < t < 2\pi$ and a_0, a_n, b_n .... are independent of t and are called "Fourier coefficients".

If the experimental curve, as in our case, is defined by 12 equally spaced ordinates U_0, U_1, U_2 .... U_{11} corresponding to times t_0, t_1, t_2 .... t_{11} respectively, then harmonic analysis determines the coefficients a_0, a_n and b_n such that $[U_i - F(t_i)]$ is as small as possible. If the twelve values are expressed as deviations from their mean, then $a_0 = 0$. The coefficients a_n and b_n corresponding to 12 ordinate system are then given by

$$a_n = \sum_{0}^{11} \frac{U_i \cos nt_i}{6}$$

$$\text{and} \quad b_n = \sum_{0}^{11} \frac{U_i \sin nt_i}{6} \qquad \ldots \quad (20)$$

where n represents the order of the particular harmonic component under consideration.

The function $F(t)$ can be rewritten in a more convenient form as

$$F(t) = a_0 + \sum_{n=1}^{\infty} r_n \sin (nt + \psi_n) \qquad \ldots \quad (21)$$

where $a_n = r_n \sin \psi_n$ and $b_n = r_n \cos \psi_n$. r_n and ψ_n are called the amplitude and phase of the n^{th} harmonic and are given by the relations

$$r_n^2 = a_n^2 + b_n^2 \quad \text{and} \quad \tan\psi_n = \frac{a_n}{b_n} \qquad \ldots \quad (22)$$

In the case of solar daily variation, since the twelve values are spread over an interval of 24 hours, r_1 and ψ_1 represent the amplitude and phase of the first harmonic of period 24 hours, r_2 and ψ_2 represent the amplitude and phase of the second harmonic of period 12 hours. Conversion from the phase angles ψ_1 and ψ_2 into more convenient times of maxima ϕ_1 and ϕ_2 of the first and second harmonic components is done by using the relations $\phi_1 = 90^0 - \psi_1$, $\phi_2 = 90^0 - \psi_2$. In the present investigation, the amplitude and phase of the first and second harmonics from the daily twelve bihourly deviations have been calculated by using a chart designed by Kane[207].

3.22 Standard error of Fourier coefficients.

If the standard error in each of the twelve bihourly values U_0, U_1, U_2, ..., U_{11} is e, then the errors δa_n and δb_n in a_n and b_n are given by the

$$\delta a_n = \delta b_n = \frac{e}{\sqrt{6}} \qquad \ldots \quad (23)$$

The error δr_n in the amplitude of the harmonic component r_n is given by

$$\delta r_n = \sqrt{\left(\frac{\delta R(r)}{\delta a_n}\right)^2 \cdot \delta a_n^2 + \left(\frac{\delta R(r)}{\delta b_n}\right)^2 \cdot \delta b_n^2}$$

$$= \sqrt{\frac{a_n^2}{a_n^2 + b_n^2} \cdot \delta a_n^2 + \frac{b_n^2}{a_n^2 + b_n^2} \cdot \delta b_n^2}$$

$$= \frac{\sigma}{\sqrt{N}} \qquad \ldots (24)$$

and the error $\delta\psi_n$ in phase angle ψ_n is given by

$$\delta\psi_n = \sqrt{\left(\frac{b_n^2}{a_n^2 + b_n^2}\right)^2 \cdot \frac{1}{b_n^2} \cdot \delta a_n^2 + \left(\frac{b_n^2}{a_n^2 + b_n^2}\right)^2 \cdot \frac{a_n^2}{b_n^4} \cdot \delta b_n^2}$$

$$= \frac{\delta r_n}{\sqrt{a_n^2 + b_n^2}} = \frac{\delta r_n}{(r_n)} \qquad \ldots (25)$$

3.23 "Chree" analysis.

This method of analysis, originally developed by Chree[209], is very useful for investigating any quasi-periodic phenomenon. The method is free from any preconceived ideas about the length and significance of the recurrence tendency.

Chree analysis involves the superposition of a large number of similar events chosen on the basis of some criteria. For example, in case of cosmic ray mean intensity studies in relation to other geophysical changes, the values of intensity belonging to similar types of events are written one below the other in a column 'zero', and this day is called the epoch day. The intensities for days prior to and later than each epoch are in the same way arranged one below the other in columns -1, -2, ... etc. and +1, +2, ... etc., the extent of the series preceding and following the epoch being fixed according to the nature of the problem studied. The mean value for each column is then found and plotted against the corresponding column number. By superposition of large number of epochs random and non-periodic fluctuations unrelated to the epoch get suppressed and recurrence tendency shows up quite clearly.

3.24 Correlation analysis.

Correlation analysis enables one to determine the degree of relationship between two or more variables and the correlation coefficient γ gives a measure of this relationship. If for variables X and Y, ΔX and ΔY represent the deviations from mean of X and Y over a common interval and if n is the number of pairs, then the correlation coefficient $\gamma_{X,Y}$ is given by

$$\gamma_{X,Y} = \frac{\sum^{n} (\Delta X, \Delta Y)}{\left[\sum^{n} (\Delta X)^2 \quad \sum^{n} (\Delta Y)^2\right]^{1/2}} \qquad \ldots \quad (25)$$

$\gamma_{X,Y}$ can be positive, negative or zero. $\gamma_{X,Y} = 0$ indicates that X and Y are not related to each other in any way. The regression equation between X and Y can be written in the form $\Delta X = b_{X,Y} \cdot \Delta Y$, where the regression coefficient is given by

$$b_{X,Y} = \gamma_{X,Y} \left[\frac{\sum^{n} (\Delta X)^2}{\sum^{n} (\Delta Y)^2} \right]^{1/2} = \frac{\sum^{n} (\Delta X . \Delta Y)}{\sum^{n} (\Delta Y)^2} \quad \ldots (27)$$

The standard error (σ_γ) associated with the correlation coefficient $\gamma_{X,Y}$ is given by

$$\sigma_\gamma = \pm \frac{(1 - \gamma^2_{X,Y})}{\sqrt{n - 1}} \quad \ldots (28)$$

3.25 Punch card system of data processing.

In cosmic ray time variation studies and related problems, the data have to be sorted out and grouped together on the basis of certain criteria. In this type of analysis, it is most convenient to tabulate the data on punched cards.

Each card gives full information for one type of telescope for one day. In the present investigation, Hollerith cards of 80 columns are used for tabulation of the data. The following scheme of punching is employed.

Punch-Card Tabulation of Data

Column	Information punched
1, 2	Identity number for the type of telescope.
3, 4	Year.
5, 6	Month.
7, 8	Day.
9,10	Interplanetary magnetic index C_p.
11, 12, 13	Blank.
14 - 37	The 12 bihourly pressure corrected percentage deviations. 5.0 % is added to make all of them positive and the deviations are expressed correct to one place of decimal.
38, 39	The sum of the 12 pressure corrected percentage deviations to which 5.0 % has been added to make it positive.
40	Number of bihourly values normalised if any.
41	Number of telescopes working.
42	Blank.
43 - 46	Total mean bihourly rate for the day.
47 - 50	Normalised pressure corrected daily mean intensity expressed in units of 0.1 % of a standard mean.
51, 52, 53, 54, 55, 56, 57, 58.	a_1, b_1, a_2, b_2 represented in % to which 5.0 has been added to make all of them positive and expressed in units of 0.1 %.
59, 60, 61, 62.	r_1 and r_2 expressed in units of 0.1 %.

63, 64; 65, 66.	ϕ_1 and ϕ_2 in units of 10°.
67, 68	r_1 / r_2 in ~~units~~ of 0.1.
69, 70	Ranges of significance of r_1 and r_2.
71 - 80	Blank.

3.3 Tests of significance.

3.31 Comparison of histograms.

In the statistical analysis of cosmic ray data the problem of determining whether the samples under consideration belong to the same population or not is of great significance. In the case of normal distribution or any other distribution such as Poisson's distribution, which can be approximated to normal, it is sufficient to make comparisons of the two parameters of the samples, namely, the 'mean' and the 'variance'.

This method of comparing the 'means' and 'variances' is made use of in the comparative study of the frequency distributions of the amplitudes of diurnal and semidiurnal components of the daily variation of cosmic radiation during different periods etc.

In order to determine whether the two samples with 'means' S_1 and S_2 and variances σ_1^2 and σ_2^2 are significantly different, a null hypothesis is made that they are not significantly different and the difference observed is attributed to chance. When the populations from which the two samples are independently drawn are normal populations, the sampling distribution of the difference of the means of these samples $x_1 - x_2$ is also normal, the mean of this distribution being zero, and its variance σ^2 is given by

$$\sigma^2 = \frac{\sigma_1^2}{N_1} + \frac{\sigma_2^2}{N_2} \qquad \text{.... (20)}$$

where N_1 and N_2 are the number of observations in each sample.

The ratio $t = \frac{x_1 - x_2}{\sigma}$ follows the 't' distribution, which tends to normal distribution for a large sample. Students' 't' table then gives the probability of obtaining a 't' value as large as one obtained from the sample under consideration on the basis of chance alone for the confidence level of 95 % (5 % chance). If the 't' value does not fall within the 't' distribution at 5 % level, then it can be said that the difference in the means is due to inherent difference in the populations from which the samples are derived.

In carrying out the statistical test for the difference between the variances, the first step is to set up the null hypothesis that the difference in variance is not due to specific causal factor, but only due to chance. This test is also independent of whether the means of the populations are the same or not. The statistic that is most convenient to use in the present case is the ratio of the two maximum likelihood estimates of the population variances given by

$$\frac{\sigma_1^2 \dfrac{N_1}{N_1-1}}{\sigma_2^2 \dfrac{N_2}{N_2-1}}$$

If the two populations have identical variances, the ratio will be close to 1. In other words, if pairs of samples are drawn independently from the populations with identical variances and if the ratio of the maximum likelihood estimates of variance is calculated for each pair, these ratios will have a frequency distribution that is of the form of 'F' distribution with degrees of freedom n_1 and n_2 given by

$$n_1 = N_1 - 1, n_2 = N_2 - 1.$$

To test the hypothesis, it is enough to note whether the ratio given above of the maximum likelihood estimates is greater or less than the 0.05 point of the 'F' distribution. If the value falls within the 0.05 point value of 'F' distribution, then the null hypothesis is not rejected and the difference in variance is attributed to chance. Otherwise it is attributed to real differences in the population variances.

9.32 Method of applying correction for the difference in counting rates of two telescopes when the r_1 or r_2 histograms are being compared.

In comparing r_1 or r_2 histograms of two telescopes of different geometries, we have to take into account not only the contribution due to their difference in geometry and the corresponding response functions to the daily amplitude, but also the contribution due to the difference in counting rates. r_1 and r_2 represent the amplitudes of the diurnal and semidiurnal components of daily variation of cosmic ray intensity recorded by a telescope on a particular day. Thus in comparing r_1 or r_2 histograms of $20^\circ \times 20^\circ$ and $23^\circ \times 37^\circ$ telescopes, it may appear that the amplitudes are larger in the narrower telescope than in the wider telescope on individual days. To see whether this larger amplitude is caused by the difference in the response characteristics of the two telescopes, or due to the difference in counting rates, the following method is adopted.

Let the amplitude r (diurnal or semidiurnal) observed on the j^{th} day by the two telescopes of different counting rates and geometries be represented as

$$r'_j = \epsilon'_j + \delta'_j \qquad \ldots \qquad (30)$$

$$r''_j = \epsilon''_j + \delta''_j \qquad \ldots \qquad (31)$$

where ϵ_j' and ϵ_j'' are the contributions due to the Poisson statistical errors, δ_j' and δ_j'' the contributions due to the response characteristics of the telescopes. δ_j' and δ_j'' need not be the same even if the source of anisotropy causing the daily variation is the same for the two telescopes.

Subtracting equation (31) from (30) and taking the variance of the difference $(r_j' - r_j'')$ we get

$$V(r_j' - r_j'') = V(\epsilon_j' - \epsilon_j'') + V(\delta_j' - \delta_j'')$$

$$= \sigma'^2 + \sigma''^2 - 2\sigma'\sigma''\alpha + V(\delta_j' - \delta_j'') \quad \text{.... (32)}$$

where σ' and σ'' represent the Poisson standard errors of r_j' and r_j'' and α is the correlation coefficient between r' and r''. If we now make a null hypothesis that the response functions δ_j' and δ_j'' are the same, then

$$V(r_j' - r_j'') = \sigma'^2 + \sigma''^2 - 2\sigma'\sigma''\alpha \quad \text{... (33)}$$

The left hand side of equation (33) represents the observed variance and the right hand side the expected variance when $\delta_j' = \delta_j''$. In this case, we have

$$\chi^2 = \frac{(n-1)\ \text{Observed variance}}{\text{Expected variance}} = \frac{(n-1)\ V(r_j' - r_j'')}{\sigma'^2 + \sigma''^2 - 2\sigma'\sigma''\alpha}$$

$$= \frac{(n-1) \sum (d_j - \bar{d})^2 \Big/ (n-1)}{\sigma'^2 + \sigma''^2 - 2\sigma'\sigma''\alpha}$$

$$= \frac{\sum (d_j - \bar{d})^2}{\sigma'^2 + \sigma''^2 - 2\sigma'\sigma''\alpha} \qquad \ldots \quad (34)$$

where d_j is the observed difference in amplitudes $(r'_j - r''_j)$ and $\bar{d}$ is the average difference for the total number of n days on which r' and r'' are compared.

χ^2 table will give for (n-1) degrees of freedom the theoretical value of χ^2 to be expected at the single tail of the χ^2 distribution at 5 % level. If the observed value of χ^2 is the same as the theoretical value, then the original assumption that $\delta'_j = \delta''_j$ is justified and the difference in r'_j and r''_j is attributed to the difference in counting rates of the telescopes. If, on the other hand, the value of χ^2 exceeds the theoretical value at 5 % level, then the contributions due to the difference in response characteristics are not the same and the difference in the amplitudes is caused partly by the difference in counting rates and partly by the difference in the response functions.

In this derivation we have assumed that the two telescopes are independent of each other and hence the value of γ will be very small. But if one of the telescopes forms a part of the other as is in the case of $10^\circ \times 20^\circ$ and $20^\circ \times 20^\circ$ telescopes, the wider telescope records all the particles recorded by the narrower one plus the extra particles coming in more inclined directions. Thus, the observed rates are not quite independent of each other and the value of the correlation coefficient α will not be negligible. The term $-2\sigma'\sigma''\alpha$ in the expression for the expected variance will thus take care of the contribution due to common particles recorded by the two telescopes.

3.33 Comparison of ϕ_1 or ϕ_2 histograms.

On any particular day, ϕ_1 represents the time of maximum of the diurnal component and ϕ_2 that of the semidiurnal component of solar daily variation. ϕ_1 or ϕ_2 histogram for any telescope has been drawn only for days when the corresponding amplitude r_1 or r_2 is significant at 2σ level where σ is the Poisson standard error associated with r_1 or r_2.

To see whether a maximum in a particular ϕ_1 histogram is statistically significant, say at 5 % level, we generally calculate the value of

$$\chi^2 = \sum_1^n \left[\frac{(f_o - f_e)^2}{f_e}\right]$$

where f_o is the observed frequency in a particular interval, f_e the expected frequency and n the number of intervals considered. f_e is the total frequency divided by n the number of intervals. If the observed value of χ^2 is greater than the expected value for (n-1) degrees of freedom, then we say that the distribution is not random, but statistically significant at 5 % level. Thus when χ^2 value is high, the preference shown in the histogram for particular intervals is considered to be statistically significant.

In comparing ϕ_1 or ϕ_2 histograms of two telescopes, we are just trying to see whether they belong to statistically different distributions. For this, the following method is followed[339].

Let f_o' and f_o'' represent the observed frequencies f_e' and f_e'' represent the expected frequencies in the case of the two distributions for a particular interval, say n. Then we have the following relations.

$$\text{Total frequency in case (i)} \quad N' = \sum_1^n f_o'$$

$$\text{Total frequency in case (ii)} \quad N'' = \sum_1^n f_o''$$

$$N = N' + N'' = \sum_1^n f_o$$

Where

$$f_o = f_o' + f_o''$$

$$f_e' = \frac{N'}{N' + N''} f_o$$

$$f_e'' = \frac{N''}{N' + N''} f_o \qquad = f_o - f_e' \qquad \ldots (35)$$

The values of $\chi_1^2 = \sum_1^n \left[\frac{(f_o' - f_e')^2}{f_e'}\right]$ and $\chi_2^2 = \sum_1^n \left[\frac{(f_o'' - f_e'')^2}{f_e''}\right]$ are next calculated. Then the value of χ^2 is given by the relation

$$\chi^2 = \chi_1^2 + \chi_2^2 \qquad \ldots (30)$$

The value of χ^2 is next tested for significance at 5 % level for the degrees of freedom (n-1) and if the observed value of χ^2 is greater than the theoretical value, it is concluded that the two distributions tested are different at 5 % level.

In making this statistical test, there are some points to be remembered. The first one is that the width of the n^{th} interval for any value of n should be the same for the two groups considered. The second point is that the expected frequency f_e' or f_e'' should not be less than 5 for any interval. If the expected frequency becomes less than 5, then two or more adjacent intervals are combined together for both the distributions to make the expected frequency ≥ 5. In this case for considering the degrees of freedom, the new value of n should be considered.

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CHAPTER IV

EXPERIMENTAL RESULTS

4.1 Introduction.

As described in chapter II, the author has operated at Trivandrum a 'Narrow angle unit' and a 'Standard unit' during the period August 1957 to April 1960. The 'Narrow angle unit' was constructed by the author in 1957 and it started regular recording of cosmic ray intensity by the end of July 1957. The standard unit working at Trivandrum since 1955 was revived and maintained by the author during the period mentioned above. A description of the two units has been already given in chapter II.

The Standard unit consists of four identical telescopes of semiangles of opening 23° and 37° in the east-west and north-south planes respectively. The Narrow angle unit is having four telescopes of 5° x 20°, two telescopes of 10° x 20°, one telescope of 20° x 20° and a cubical telescope of 45° x 45°, the two angles in each case representing the semiangles of opening of the telescope in the east-west and north-south planes respectively.

Table 3 shows the number of days during each month on which data are available for the different telescopes. As is evident from the table, the standard

Table 2

Number of days in each month for the period August 1957 to April 1960 for which data are available for various telescopes.

Type of telescope.	J	F	M	A	M	J	J	A	S	O	N	D
1957												
5° x 20°	-	-	-	-	-	-	-	27	27	28	29	30
10° x 20°	-	-	-	-	-	-	-	28	27	25	29	30
20° x 20°	-	-	-	-	-	-	-	29	27	21	23	26
23° x 37°	-	-	-	-	-	-	-	30	27	27	30	31
45° x 45°	-	-	-	-	-	-	-	29	27	28	29	29
1958												
5° x 20°	31	24	25	24	26	24	28	27	31	24	10	-
10° x 20°	30	24	25	24	30	22	27	28	22	24	10	-
20° x 20°	25	24	24	23	13	13	20	22	10	27	17	-
23° x 37°	31	28	30	25	31	21	29	27	28	31	27	31
45° x 45°	29	24	24	12	10	25	31	24	22	28	21	26
1959												
5° x 20°	-	3	27	17	28	30	27	27	30	28	30	30
10° x 20°	-	3	27	17	28	30	26	28	30	28	28	30
20° x 20°	-	1	21	15	27	27	26	15	27	20	27	29
23° x 37°	29	26	26	26	29	30	27	30	30	28	28	31
45° x 45°	23	9	21	16	26	27	27	22	29	28	28	29
1960												
5° x 20°	30	28	31	27								
10° x 20°	29	23	31	27								
20° x 20°	24	27	30	21								
23° x 37°	31	29	31	29								
45° x 45°	27	27	30	24								

unit operated smoothly throughout the period. In the case of the narrow angle unit, for about three months during 1968-1969, the data are missing as the unit was checked to eliminate trouble due to spurious pulses caused by leaks in some of the shielded wires. Continuous data have been collected since the end of February 1969 from this unit.

4.2 Meteorological corrections.

The cosmic ray data from each type of telescope have been corrected for barometric pressure changes as described in section 3.1. Unfortunately, for about two months (May, June 1968) the bihourly pressure data for Trivandrum are not available and hence for daily variation studies on a day to day basis the cosmic ray data of this period have not been used. However, the daily mean pressure recorded at Cochin, which is a near by sea level station, has shown a very high correlation with the daily mean pressure at Trivandrum and hence daily mean pressure of Cochin has been used to extrapolate the missing daily mean pressure at Trivandrum.

Temperature correction to the daily variation of cosmic ray intensity has been applied as described in chapter III (section 3.122). It has been found that the temperature correction to daily variation of meson component recorded at Trivandrum is comparatively small, the diurnal amplitude being of the order of 0.06 % with time of maximum at 1500 hours local time and the semidiurnal component being negligible.

The method of normalisation of daily mean intensity has been described already in chapter III, section 3.11. All intensities are normalised to a standard pressure of 1000 mb. Temperature correction is applied according to Dorman's method using temperature variation upto 50 mb level. The temperatures at different isobaric levels were obtained from the twice daily radiosonde flights at Trivandrum. The mean of the two values was used for the correction.

4.3 Determination of barometric coefficient.

Even though we have used a barometric coefficient of -0.17 % per mb as suggested by Sarabhai et al[8], an attempt has been made to determine the coefficient using data obtained during 1969 from the standard unit of 23° x 37°. The method suggested by Forbush and Venkatesan[270] has been adopted in this case.

Sequences of four days are selected within intervals characterised by large monotonic increases or decreases of pressure and by the absence of world-wide changes in the cosmic ray intensity. The values of pressure as well as the normalised daily mean intensity of the meson component uncorrected for pressure changes for these four days are then represented as deviations from mean for the respective intervals of four days. The average deviations of pressure ΔP and cosmic ray intensity ΔI are then found out for each of the four days, separately for increasing pressure and decreasing pressure. The values of ΔP and the corresponding values of ΔI are then plotted as shown in figure 15.

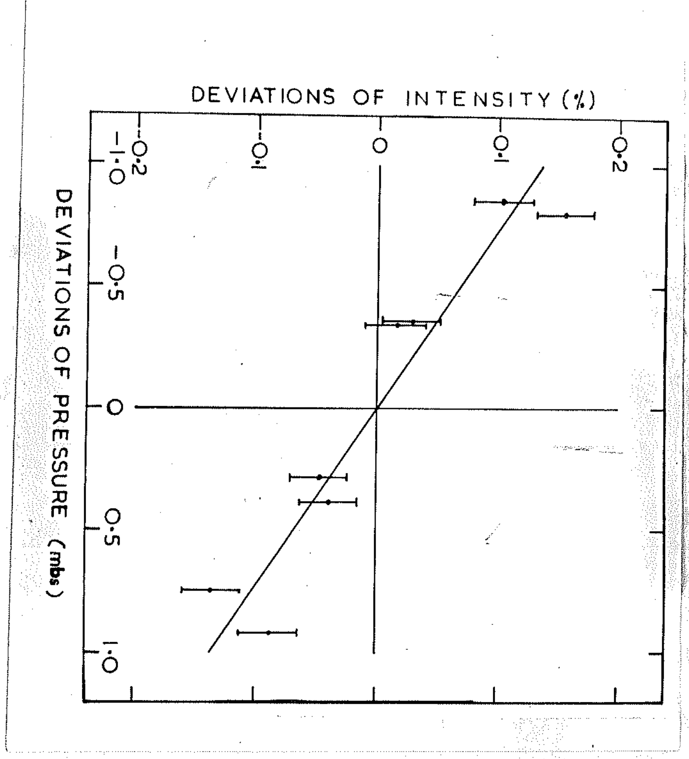

Fig. 15 - Determination of pressure coefficient.

Correlation analysis between ΔP and ΔI gave a coefficient of -0.95 which indicated high negative correlation between pressure and cosmic ray intensity. The best fit regression line was then drawn as per the relation

$$\Delta I \quad = \quad \beta \, \Delta P$$

where β the regression coefficient represents the pressure coefficient. The slope of the regression line gives the pressure coefficient β as -0.14 %/mb. This value of the pressure coefficient is in fair agreement with the value -0.17 %/mb used for correcting the cosmic ray data.

4.4 Explanation of nomenclature and symbols.

The daily variation of cosmic rays has been studied in this thesis in terms of the diurnal and semidiurnal components of the variation since these two are known to represent adequately the main features of the variation. The amplitudes and times of maxima of the diurnal and semidiurnal components on individual days (after applying proper meteorological corrections in case of cosmic rays) are represented by r_1, ϕ_1 and r_2, ϕ_2 respectively and their vectorial mean values averaged over an extended period or for groups of days selected on the basis of some criteria are represented by $\bar{r}_1$, $\bar{\phi}_1$ and $\bar{r}_2$, $\bar{\phi}_2$ respectively.

4.5 Daily variation

4.51 Dependence of daily variation on the opening angle of the telescope in the east-west plane.

The twelve month mean daily variation has been studied with telescopes of different opening angles in the east-west plane and the same angle of opening in the north-south plane. For this study, the telescopes with semiangles of opening 5°, 10° and 20° in the east-west plane and with semiangle of opening 20° in the north-south plane have been considered. These telescopes are referred to as 5° x 20°, 10° x 20° and 20° x 20°.

In figure 16 are presented the 12 month mean daily variations for these three telescopes for the years 1958 and 1959. The amplitude and time of maximum of the diurnal and semidiurnal components of the 12 month mean daily variation recorded by these telescopes are given in table 4. While there is a major difference between the 12 month mean daily variation for 1958 and for 1959, the different telescopes in each year agree within statistical accuracy of the observations. It is seen from the figure that the daily variation recorded by all telescopes show a single maximum near noon during 1958. There is a slight indication of a less prominent additional maximum in the early morning at about 0200 hours local time in the mean daily variation recorded by the above telescopes during 1959.

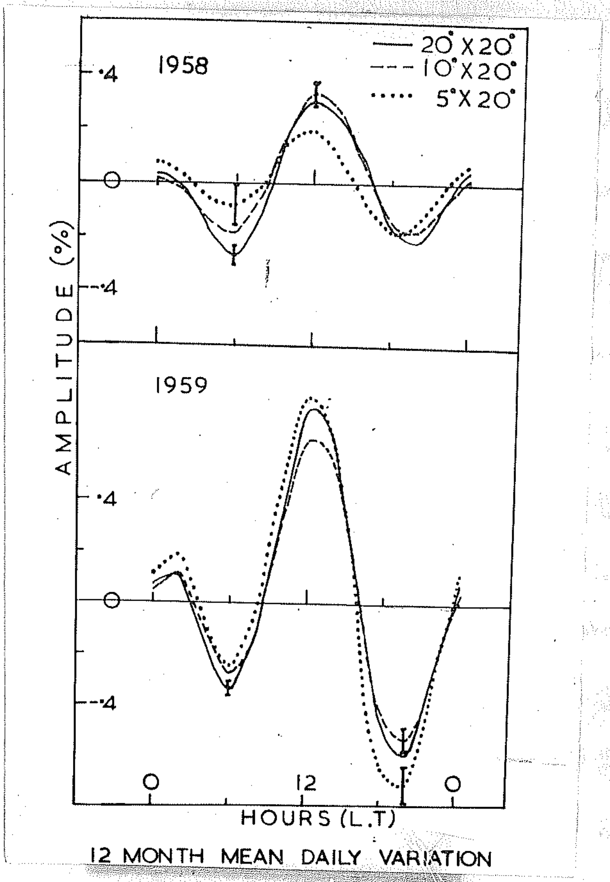

Fig. 16 - Twelve month mean daily variations for telescopes of different openings in the east-west plane for the years 1958 and 1959.

The peak to peak amplitude of the daily variation in 1959 is almost twice the value in 1958 in all the telescopes. Table 4 shows that the amplitudes of diurnal as well as semidiurnal components of the 12 month mean daily variation have increased by a factor of about two in 1959 compared to their value in 1958.

Table 4

Amplitude and time of maximum of the diurnal and semi-diurnal components of the 12 month mean daily variation recorded by telescopes of different openings in the east-west plane during the years 1958 and 1959.

Year	Telescope opening.	$\bar{r}_1\%$	ϕ_1	$\bar{r}_2\%$	ϕ_2
	5° x 20°	0.11 ± 0.04	140°	0.13 ± 0.04	357°
1958	10° x 20°	0.16 ± 0.03	106°	0.17 ± 0.03	13°
	20° x 20°	0.13 ± 0.02	105°	0.23 ± 0.02	16°
	5° x 20°	0.30 ± 0.04	130°	0.40 ± 0.04	22°
1959	10° x 20°	0.30 ± 0.03	163°	0.30 ± 0.03	30°
	20° x 20°	0.34 ± 0.02	103°	0.46 ± 0.02	25°

The present study indicates that during 1958 or 1959 there is no statistically significant difference in the amplitudes of the 12 month mean daily variations recorded by telescopes of different opening angles in the east-west plane.

Daily variation studies have been made by Sekido et al[137] during 1949-1950 with telescopes of different semiangles of opening in the east-west plane. Their results indicate an increase in the amplitude of the time averaged mean daily variation with decrease in the angle of opening of the telescope in the east-west plane. Sarabhai et al[199] have studied the daily variation at Ahmedabad (λ= 14°) with telescopes of semiangles of opening 2.5°, 5° and 15° in the east-west plane and 10° in the north-south plane. They have shown that during 1954-1955 the time averaged amplitude of daily variation increased from 0.6 % to 1.2 % as the semiangle of opening of the telescope in the east-west plane decreased from 15° to 5°.

Elliot and Possener[200] who made similar studies at λ= 50° during 1954-1955 found that there was no difference in the average daily variation recorded by the telescopes of different openings in the east-west plane. Their studies at λ= 50° and those of Sarabhai et al[199] at λ = 14° correspond to more or less the same period in 1954-1955. Elliot and Possener have suggested that the dependence of the amplitude of daily variation on the opening angle of the telescope is a function of latitude of the place of observation.

Rasdau[201] has made investigations with telescopes of 5° and 20° semiangles in the east-west plane during the high solar activity period of 1957-1958 at

Ahmedabad. His results have shown that during 1957-1958 there is no change in the amplitude of the 12 month mean daily variation as the semiangle of opening of the telescope in the east-west plane is reduced from 20° to 5°. These results which agree with the findings at Trivandrum indicate that even at the same place the large amplitude of the 12 month mean daily variation associated with narrow angle telescopes during 1954 does not persist during the solar activity maximum period of 1957-1958.

There are two possible explanations for the differences in the findings during 1958-1959 and during 1951-1955. There could be a change of the profile of the primary cosmic ray anisotropy with the solar cycle of activity. Alternatively, the scatter of the time of maximum of the diurnal component may be much greater for the narrow angle telescope during 1958-1959 than during sun-spot minimum period. For a clarification between these two possibilities, it is necessary to study the daily variation on a day to day basis.

In section 3.332, we have described the statistical procedure to allow for difference in the counting rates of instruments when making a comparative study of the histograms of the parameters of the daily variation on a day to day basis. To investigate the day to day changes of daily variation recorded by telescopes of different opening angles in the east-west plane, only the telescopes of 10° x 20° and 20° x 20° have been considered since the standard error is quite large on a bihourly basis for $5^\circ \times 20^\circ$ telescopes. The comparative study is made only on days when two telescopes of $10^\circ \times 20^\circ$ and one telescope of $20^\circ \times 20^\circ$ are working. There are 172 and 230 such days during the years 1958 and 1959 respectively.

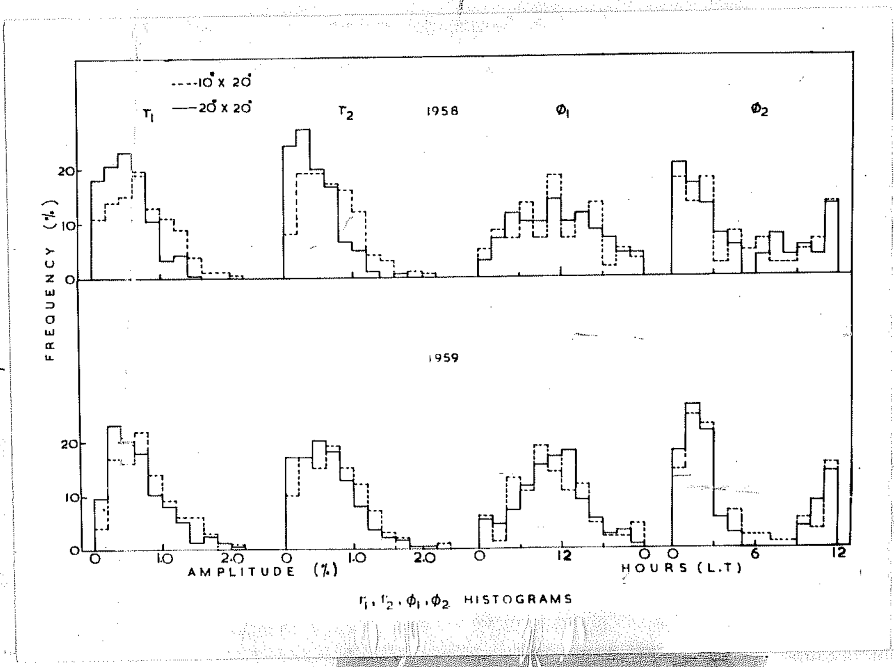

Fig. 17 - Frequency distribution of the amplitudes and times of maxima of the diurnal and semidiurnal components of the daily variation of cosmic ray intensity recorded by $10^\circ \times 20^\circ$ and $20^\circ \times 20^\circ$ telescopes on common working days during 1958 and 1959.

Figure 17 shows the distribution of the amplitudes of the diurnal and semidiurnal components of the solar daily variation during the years 1958 and 1959. The histograms of ϕ_1, the time of maximum of the diurnal component, are drawn for days on which the amplitude r_1 is significant at the 2 σ level (or $r_1 > 2\sigma$), where σ is the standard error associated with r_1 or r_2. Similarly, ϕ_2 histograms showing the distribution of the time of maximum of the semidiurnal component are drawn for days on which r_2 is statistically significant at the 2σ level. An examination of the histograms reveal the following:-

(1) In r_1 and r_2 histograms in both years, there are larger number of days on which the amplitudes are more in 10° x 20° telescope than in 20° x 20° telescope. When the histograms of r_1 or r_2 of the two telescopes are combined after making due allowance for the difference in the counting rates it is found that they do not differ at 5 % level of significance. We can, therefore, conclude that the difference in the amplitudes recorded on individual days is mainly due to the difference in counting rates.

(2) In the case of both the telescopes, the frequency of occurrence of large values of r_1 and r_2 is more in 1959 than in 1958.

(3) During 1958, the histograms of ϕ_1, the time of maximum of the diurnal variation, show a random distribution for 10° x 20° as well as for 20° x 20° telescopes. However, in 1959, the histograms show a clear maximum indicating that on a large number of days the time of maximum of the diurnal component of solar daily variation occurs near noon. The response of the two types of telescopes is in any case similar.

(4) The histograms of ϕ_2, the time of maximum of the semidiurnal component, of the solar daily variation, show a preference for early morning hours. This tendency is much more pronounced in 1959 compared to 1958.

Sarabhai and Kerurkar[271] studying the daily variation recorded by narrow angle telescopes on individual days during the period 1951-1955 at Ahmedabad have shown that there is a tendency for the occurrence of the time of maximum of the diurnal variation either at 1100 hours or at 0300 hours local time. Sarabhai and Bhavsar[219] in 1955-1958 find that this persists, but the two maxima have shifted, from 0300 hours to 0700 hours and from 1100 hours to 1500 hours respectively. They have thus characterised the diurnal variation as 'n' type and 'd' type according as the time of maximum occurs in the early morning or near noon. The structure showing two maxima in the ϕ_1 histograms is neither seen in our studies during 1958-1959 at Trivandrum nor in the studies made at

Ahmedabad during 1957-1959 by Nandan[301]. It seems that the two maxima have merged together to form a broader maximum from 1000 hours to 1400 hours in 1957-1959. The spread is less in 1960 than in 1959.

Our study indicates that the comparatively large value of the amplitude of 12 month mean daily variation during 1960 is partly due to the amplitudes on individual days being high and partly due to the smaller variability of the time of maximum of the diurnal as well as semi-diurnal components during this period.

Our study also indicates that not only does the amplitude of the daily variation and its time of maximum change from year to year and from period to period, but the relative difference in the response of the narrow and wide angle telescopes to the anisotropy also undergoes changes.

Brunberg[302] has shown that the amplitude of the solar diurnal variation would be larger when measured by a narrow angle telescope than by a wide angle telescope if the source of daily variation is a point source. Hence we may conclude that whereas the source of the daily variation during 1954-1955 was comparatively sharp, it is more diffuse and variable during 1957-1959. The possibility of the daily variation during this period being produced by more than one source cannot also be ruled out. Sarabhai and Rao[59] have recently indicated from directional studies at Ahmedabad during 1957-1962 that on some days the daily variation cannot be adequately explained in terms of external anisotropy and they conclude that the daily variation on such days is caused by a local source.

4.22 Long term changes of solar daily variation*.

The twelve month mean daily variation of the meson intensity recorded at Trivandrum with telescopes of opening 23° x 37° during the years 1953 to 1959 is shown in figure 18. For comparison the 12 month mean daily variation recorded by similar telescopes at Kodaikanal and Ahmedabad are also shown in the same figure. The twelve month mean daily variation has been obtained by the superposition of the diurnal and semidiurnal components of the variation. In table 5 are presented the values of $\bar{r}_1$, $\bar{r}_2$, $\bar{\phi}_1$ and $\bar{\phi}_2$ during various years at the three stations. In figure 19 the changes occurring at the three stations in the diurnal and semidiurnal components of the 12 month mean daily variation are presented for the period 1955-1959. An examination of the curves in figure 18 and the values in table 5 brings out the following points.

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* The author is grateful to Dr.K.S.G.Sastry, Mr.G.Subramanian, Mr.H.L.Razdan and Mr.U.D.Desai for supplying data for Kodaikanal and Ahmedabad and to Dr.S.P.Duggal for supplying data for Trivandrum for the period January 1953 to July 1957.

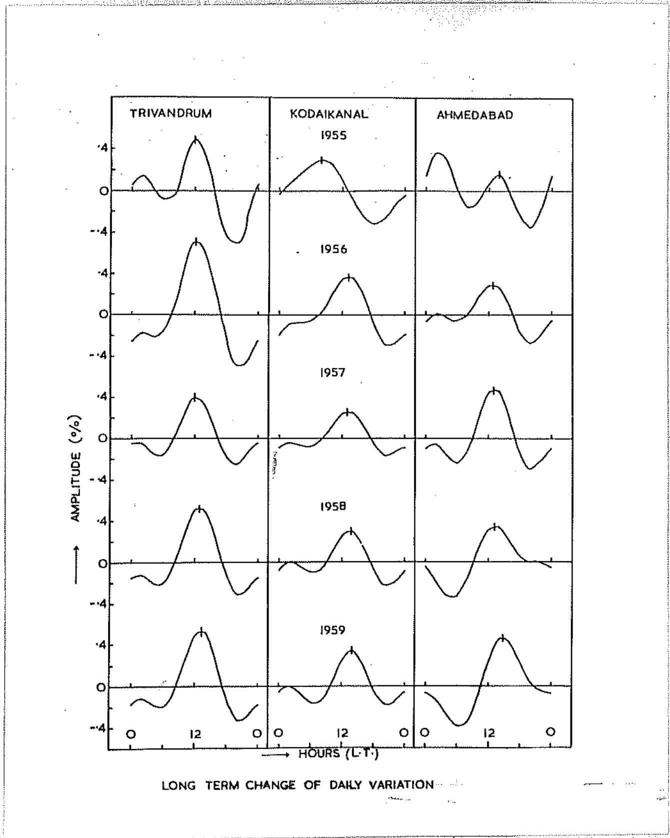

Fig. 13 - 12 month mean daily variation observed with standard telescopes at Trivandrum, Kodaikanal and Ahmedabad during the years 1955 to 1959.

(a) At Trivandrum.

(1) During the years 1955, 1956, 1957 and 1958, the principal maximum of the twelve month mean daily variation occurs at noon. From 1958 to 1959, there is a slight shift of the time of maximum from 12 hours to 14 hours local time.

The secondary early morning maximum at 0200 hours in 1955 becomes less prominent in 1956 and 1957. In 1957,

Table 5

Table showing the diurnal and semidiurnal components of the 12 month mean daily variations recorded by standard telescopes at Trivandrum, Kodaikanal and Ahmedabad for the years 1955 to 1959.

Year	Trivandrum				Kodaikanal				Ahmedabad			
	$\bar{r}_1$ (%)	ϕ_1	$\bar{r}_2$ (%)	ϕ_2	$\bar{r}_1$ (%)	ϕ_1	$\bar{r}_2$ (%)	ϕ_2	$\bar{r}_1$ (%)	ϕ_1	$\bar{r}_2$ (%)	ϕ_2
1955	0.29	138°	0.20	21°	0.29	105°	0.04	315°	0.14	73°	0.25	64°
1956	0.40	174°	0.24	26°	0.27	175°	0.15	51°	0.15	151°	0.14	35°
1957	0.22	175°	0.18	18°	0.16	184°	0.10	44°	0.23	192°	0.21	28°
1958	0.33	187°	0.19	30°	0.17	183°	0.15	53°	0.27	227°	0.17	39°
1959	0.33	193°	0.20	42°	0.17	205°	0.17	67°	0.35	244°	0.16	59°
Standard error	±0.02		±0.02		±0.02		±0.02		±0.02		±0.02	

the 12 month mean daily variation has a single maximum at noon. In 1959, there is a slight indication of the reappearance of the less prominent early morning maximum. Peak to peak amplitude of the average daily variation also shows changes during different periods. The amplitude is maximum during 1956 and minimum during 1957. In 1955, 1958 and 1959 the peak to peak amplitude is practically the same.

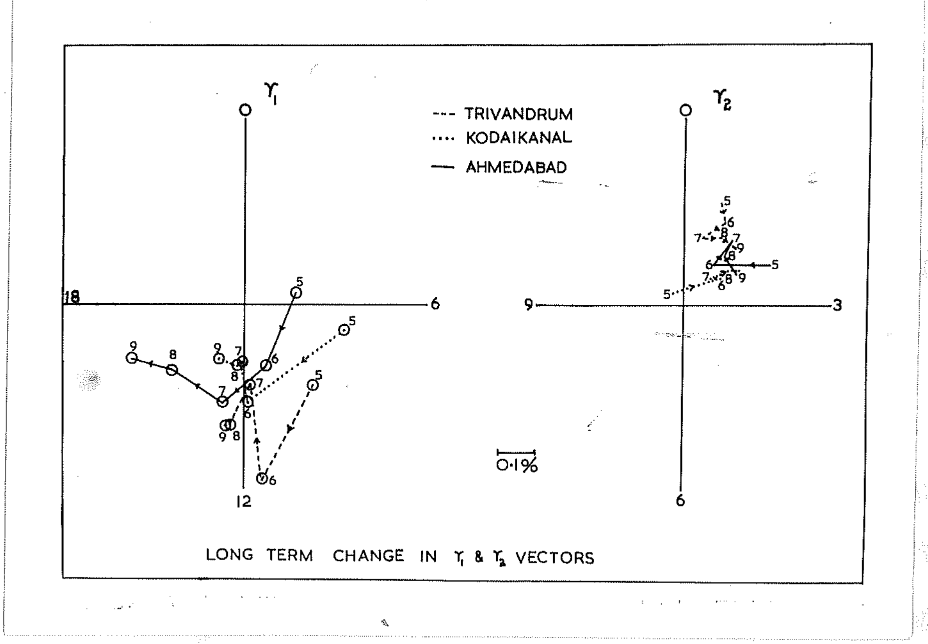

Fig. 19 - Diurnal and semidiurnal components of the 12 month mean daily variation observed with standard telescopes at Trivandrum, Kodaikanal and Ahmedabad during the years 1955 to 1959.

(2) The diurnal amplitude r_1 gradually decreases from June 1955 and reaches its minimum value in June 1957. Thereafter it shows a slow increase and attains a value of 0.30 % by the end of 1957. No statistically significant changes are found to occur after that.

(3) There is a gradual decrease in the amplitude $\bar{r}_2$ of the semidiurnal component from 1955 to 1957, thereafter the amplitude remaining practically constant.

(4) τ_1 the time of maximum of the 12 month mean diurnal component becomes significantly later from 1955 to 1956 mainly due to the changes occurring in the later half of 1955, but thereafter there is only a gradual change in the time of maximum.

(5) There is a gradual shift in the time of maximum τ_2 of the semidiurnal component also, but this cannot be established at a level of statistical significance.

(b) <u>At Kodaikanal.</u>

(1) The 12 month mean daily variation during 1955 is mainly diurnal in character with the time of maximum occurring at about 0800 hours local time. The form of daily variation changes and the time of maximum shifts to 1400 hours during 1956. Thereafter there is

not much change in the form, peak to peak amplitude or the time of maximum of the average daily variation from year to year.

(2) The diurnal amplitude $\overline{F}_1$ decreases during 1954-1955 but from 1957 onwards there is no change.

(3) Just as in the case of Trivandrum, the major shift in the time of maximum $\overline{Z}_1$ of the 12 month mean diurnal component occurs during 1955-1956. The shift of $\overline{Z}_1$ is larger at this station than at the other two.

(4) $\overline{F}_2$ is negligible in 1955, but increases and becomes comparable with F_1 in 1958.

(5) Shift in $\overline{Z}_2$ is slightly larger than at the other two stations.

(c) <u>At Ahmedabad.</u>

(1) During 1955 the average daily variation shows two distinct maxima, one at 0200 hours and the other at 1400 hours local time. It is seen that the early morning maximum is much more prominent than the maximum in the afternoon. In 1956, the early morning maximum has completely disappeared and from 1957 onwards the average daily variation is represented by a curve with a single maximum.

(2) $\bar{r}_1$ increases gradually from 0.14 % in 1955 to 0.36 % in 1959.

(3) ϕ_1 shows a shift to later hours and the shift is quite large from 1955 to 1956.

(4) The changes in the time of maximum ϕ_2 of the semidiurnal component of the average daily variation during 1955 - 1959 are comparatively small. At Trivandrum and Ahmedabad the time of maximum ϕ_2 is always found to occur between 0000 hours and 0300 hours.

It is seen from a comparative study of the 12 month mean daily variation for the three stations presented here, that at all the three stations the form of the average daily variation has not changed much during the period 1957 - 1959. The amplitude at Ahmedabad and Trivandrum are comparable, but at Kodaikanal it is significantly smaller. The time of diurnal maximum is comparable at all three stations. In the years 1955 - 1956, the differences from year to year and between the stations are quite large.

The long term changes in the form of daily variation are consistent with the occurrence of a component having maximum near noon and another with a maximum near 0300 hours local time as has been suggested by Sarabhai et al[8] from the study of the long term changes at Huancayo.

Katzman and Venkatesan[113] studying the semidiurnal component of the 12 month mean daily variation for a large number of stations both for meson and neutron component of cosmic rays have shown that at the equatorial stations of Huancayo, Kodaikanal and Makerere the semidiurnal component is significant. For neutron component at Ottawa ($\lambda=45^{\circ}$) they have shown that the semidiurnal component is mainly due to pressure effect during the period 1953 - 1959.

In figure 20, the vectors representing the semidiurnal components of the time averaged daily variation of pressure and of meson intensity corrected for the atmospheric changes of temperature and pressure, recorded at Trivandrum for the period August 1957 to April 1960, and those at Ahmedabad for the period 1955 to 1958, are shown. It is quite evident from the figure that the pressure vector is 90° out of-phase with the

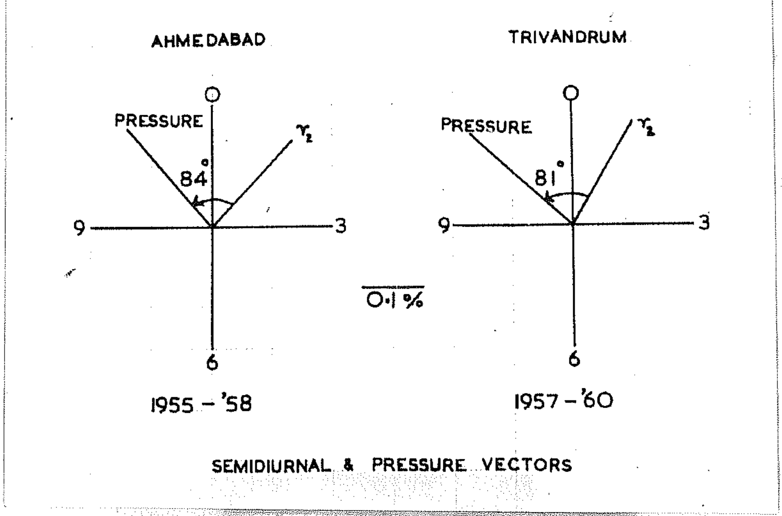

Fig. 20 - Semidiurnal vector of the time averaged daily variation of cosmic ray intensity and the corresponding barometric pressure vector for the period 1955-1958 for Ahmedabad and for the period August 1957 - April 1960 for Trivandrum.

cosmic ray vector and hence the semidiurnal component is not due to a residual barometric effect. Thus, it is seen from our studies that even after correcting for the temperature and pressure changes in the atmosphere, there is a significant semidiurnal component of daily variation. Recently, Sarabhai and Rao[59], Razdan[201] and Ahluwalia[222] have shown the significance of a semidiurnal component of solar daily variation which is not of meteorological origin.

We have already seen in section 4.5 that in 1959 the 12 month mean daily variation recorded by 20° x 20° telescope at Trivandrum is larger than that recorded during 1958. To see whether this change is occurring only at Trivandrum or at other places also, we have examined the 12 month mean daily variation recorded by 20° x 20° telescope during 1958 and 1959 at Ahmedabad also. The average daily variation is shown in figure 21 and the parameters of the harmonic components of 12 month mean daily variation are shown in table 6.

It is seen that at both places the amplitude of the diurnal component of the 12 month mean daily variation has increased in 1959 and the time of maximum has shifted to earlier hours compared to the values in 1958. The semidiurnal component of intensity measured with 20° x 20° telescope is in both years significantly larger at Trivandrum than at Ahmedabad.

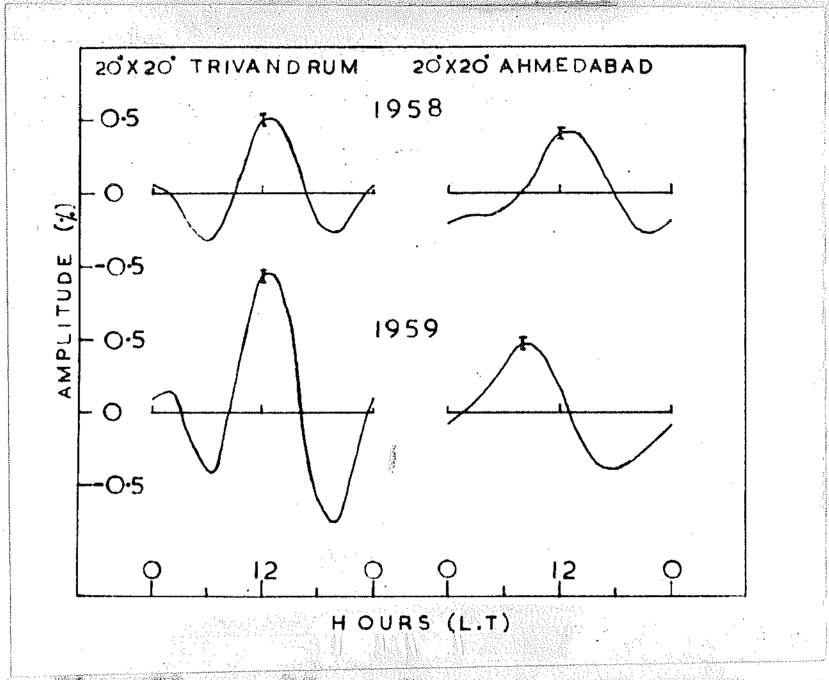

Fig. 31 - 12 month mean daily variation recorded by 20° x 20° telescopes during 1958 and 1959 at Trivandrum and Ahmedabad.

Table 6

The parameters of the amplitude and time of maximum of the diurnal and semidiurnal components of the 12 month mean daily variation recorded by 20° x 20° telescopes at Trivandrum and Ahmedabad during 1958 and 1959.

Station	Year	$\bar{r}_1$(%)	$\bar{\phi}_1$	$\bar{r}_2$(%)	$\bar{\phi}_2$
Trivandrum	1958	0.18 ± 0.02	189°	0.33 ± 0.02	16°
Ahmedabad	1958	0.34 ± 0.02	194°	0.08 ± 0.02	35°
Trivandrum	1959	0.24 ± 0.02	160°	0.46 ± 0.02	25°
Ahmedabad	1959	0.32 ± 0.01	169°	0.08 ± 0.02	321°

4.53 A comparative study of daily variation of meson intensity at Trivandrum and Kodaikanal.

For understanding the energy dependence of solar daily variation, a comparative study of the daily variation recorded by identical instruments at two places differing only in the mean energy of response is of great importance. Kodaikanal and Trivandrum satisfy these conditions in an admirable manner. The two stations are almost at the same geomagnetic latitude and geographic longitude. It is seen from table 1 that the magnetic cut-off rigidity at the two places is almost the same (17.55 GV at Kodaikanal and 17.40 GV at Trivandrum). The two stations differ only in altitude by 2343 meters and hence the difference observed in the daily variation may be attributed to the difference in the multiplicity function applicable to the two instruments.

The study has been made of daily variation recorded at the two stations with standard telescopes of semiangles of opening 23° x 37° for the period 1957-1958. Common days when all the four telescopes of the units at each station were working have been considered. This is to ensure the following:-

(1) Uniformity of counting rate of the instrument at each station. This facilitates the application of statistical tests as described in section 3.332 to make allowance for the inherent difference in counting rates at the two stations.

(2) That in the presence of day to day variability of the daily variation, the comparison between the two stations may be valid.

A total of 333 days have been thus selected during 1965 - 1968 for the comparative study. The average daily variation of meson intensity for 333 days corrected for atmospheric changes of temperature and pressure is shown in figure 22 for Kodaikanal and Trivandrum. The parameters $\bar{r}_1$, $\bar{r}_2$, $\bar{\phi}_1$ and $\bar{\phi}_2$ are given in table 7.

Table 7

Table showing the parameters $\bar{r}_1$, $\bar{r}_2$, $\bar{\phi}_1$, $\bar{\phi}_2$ of the average daily variation for 333 common days when all the 4 telescopes of the standard units are working at Kodaikanal and Trivandrum.

Station.	$\bar{r}_1$(%)	$\bar{\phi}_1$	$\bar{r}_2$(%)	$\bar{\phi}_2$
Kodaikanal	0.19 ± 0.03	174°	0.09 ± 0.02	55°
Trivandrum	0.27 ± 0.03	170°	0.21 ± 0.02	23°

It is seen from figure 22 and from table 7 that the average daily variation has an amplitude which is significantly larger at Trivandrum than at Kodaikanal. This may be due to large r_1 on individual days at Trivandrum

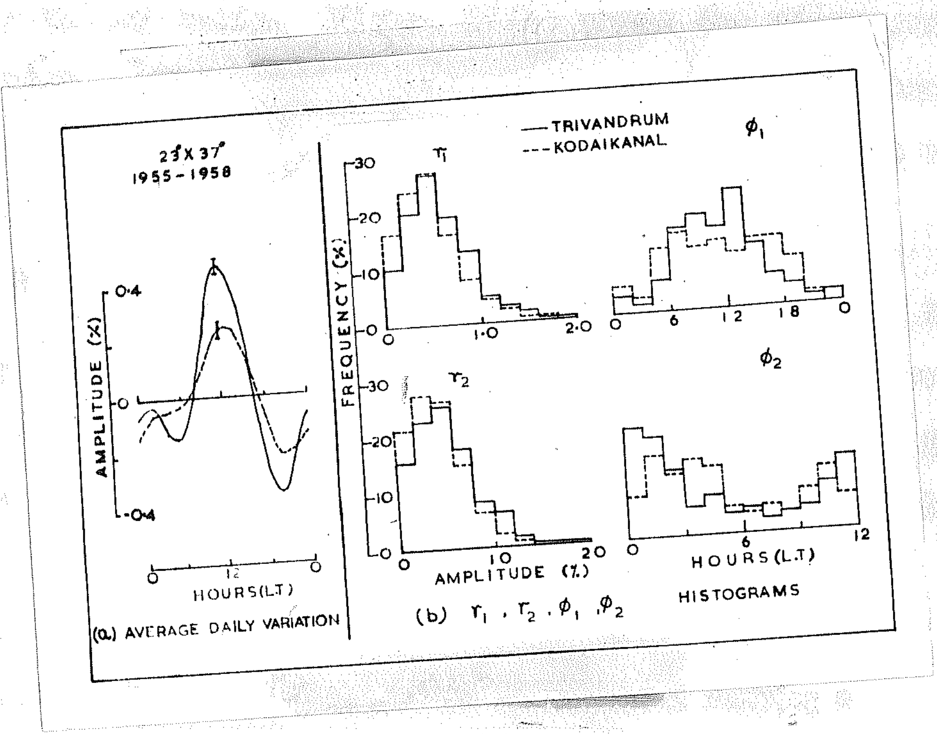

Fig. 22 - (a) Average daily variation of meson intensity corrected for atmospheric changes of temperature and pressure for 330 common days when all 4 telescopes of the standard unit are working at Kodaikanal and Trivandrum during the period 1955 - 1958.

(b) Frequency distributions of r_1, ϕ_1, r_2, ϕ_2 for 333 common working days of the standard units at Trivandrum and Kodaikanal during the period 1955-1958.

or to ϕ_1, the time of maximum of the diurnal component, having large variability at Kodaikanal. To get some insight into this, the amplitude and time of maximum of the diurnal and semidiurnal components are studied on a day to day basis. Figure 22(b) shows the histograms of r_1 and r_2. The histograms of ϕ_1 and ϕ_2 for days when the corresponding amplitudes r_1 and r_2 are significant at 2σ level are also shown in the same figure.

Applying statistical tests to take account of the counting rate at Kodaikanal being 1½ times that at Trivandrum we find that the r_1 as well as r_2 histograms are not significantly different at the two places. On the other hand, both ϕ_1 and ϕ_2 histograms have significantly greater variability at Kodaikanal than at Trivandrum. This is probably due to the telescope at Kodaikanal having a lower mean primary energy response than at Trivandrum. This hypothesis has been tested by drawing a polar histogram of $\phi_{1T} - \phi_{1K}$ making ϕ_{1T} coincide with 00 direction. Here ϕ_{1T} and ϕ_{1K} represent the time of maximum of the diurnal components of the daily variation at Trivandrum and Kodaikanal on a particular day. Only those days which have an amplitude r_1 at both stations significant at the 2σ level, are considered. For 85 such days, the polar histogram is shown in figure 23.

It is seen that ϕ_1 values at Kodaikanal are not randomly distributed in relation to the corresponding value on each particular day at Trivandrum. There is a marked tendency for the Kodaikanal time of maximum to occur 3 to 4 hours earlier than the maximum at Trivandrum.

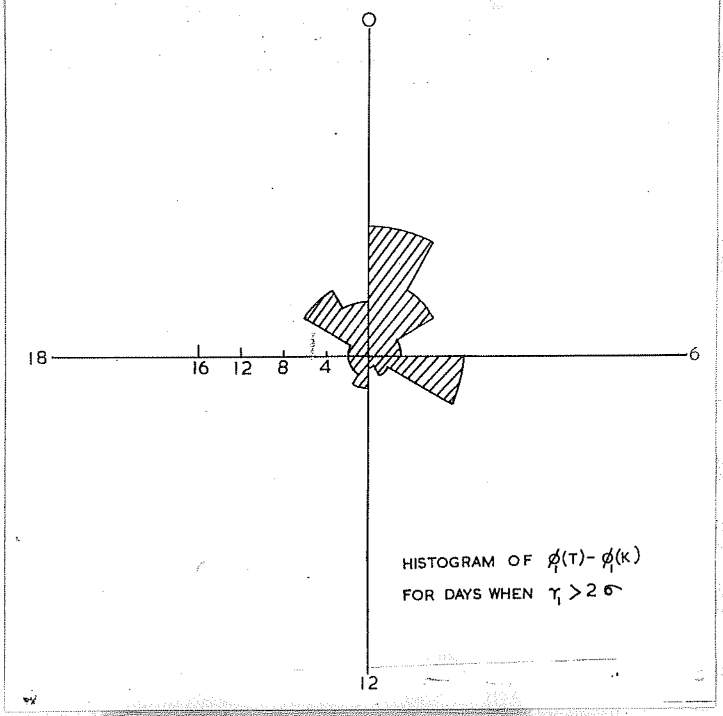

Fig. 23 - Polar histogram of $\phi_{1T} - \phi_{1K}$ for 55 days when r_1 amplitudes are simultaneously significant at Kodaikanal and Trivandrum during 1958 - 1962.

This is what should be expected if the daily variation is the result of the anisotropy of primary cosmic rays of positive charge such as protons which suffer deflection in geomagnetic field.

Rao[220] has shown by a comparative study in east and west azimuths that the daily variation for west which responds to a lower mean energy of primaries than east has got a greater variability than for the east. The comparative study of daily variation at Trivandrum and Kodaikanal confirms the findings from the directional studies at Ahmedabad.

4.64 Relationship of solar daily variation with geomagnetic activity.

In order to study the relation between the solar daily variation of meson intensity and geomagnetic disturbances characterised by the interplanetary character figure C_p the days are divided into three groups, depending upon the value of C_p. The following symbols have been used to indicate the three groups.

Group.	Symbol.	Value of C_p.
Low geomagnetic activity.	C_p^L	$0 \leqslant C_p \leqslant 0.5$
Medium geomagnetic activity.	C_p^M	$0.6 \leqslant C_p \leqslant 1.0$
High geomagnetic activity.	C_p^H	$C_p \geqslant 1.1$

Two units recording meson data, viz. the Standard unit with telescopes of semiangular opening 23° x 37° and the Narrow angle telescope of semiangular opening 10° x 20°, are selected for this study. The entire period of August 1957 to April 1960 is considered together. The mean daily variations for the two types of telescopes and for the three groups during this period are shown in figure 24.

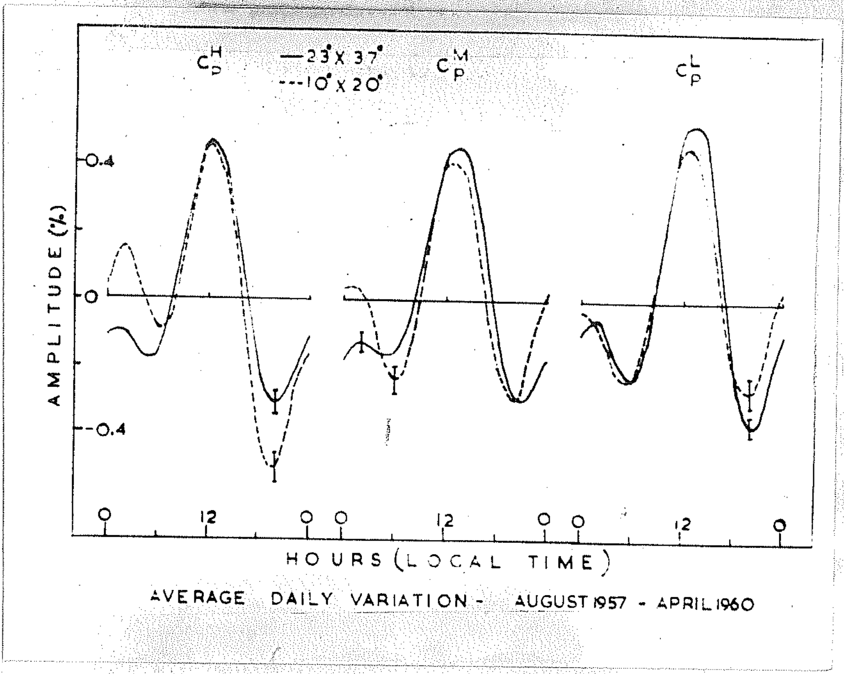

Fig. 34 - Average daily variation recorded by 23° x 37° telescope and 10° x 20° telescope on C_p^L , C_p^M and C_p^H groups of days during the period August 1957 to April 1960.

It is seen from the figure that though the peak to peak amplitude of the average daily variation is slightly more in 10° x 20° than in 23° x 37° for C_p^H group of days, in general the mean daily variation curves for each C_p group of days are similar in form and almost of comparable peak to peak amplitude for the two telescopes studied. There is no significant difference in the peak to peak amplitude of the average daily variation for geomagnetically quiet and disturbed days (C_p^L and C_p^H groups). The early morning maximum in the average daily variation appears only in the case of C_p^H group for the 10° x 20° telescope.

Table 8 gives the parameters $\bar{r}_1$, $\bar{\phi}_1$, $\bar{r}_2$ and $\bar{\phi}_2$ of the diurnal and semidiurnal components of the average daily variation for the three groups of days C_p^L, C_p^M and C_p^H for the two telescopes during the period August 1957 - April 1960.

Table 8

Average parameters $\bar{r}_1$, $\bar{r}_2$, $\bar{\phi}_1$ and $\bar{\phi}_2$ of the diurnal and semidiurnal components of solar daily variations recorded at Trivandrum for days grouped according to the degree of geomagnetic disturbances. Period considered August 1957 - April 1960.

Group	Telescope 24° x 37°				Telescope 10° x 20°			
	$\bar{r}_1$(%)	$\bar{\phi}_1$	$\bar{r}_2$(%)	$\bar{\phi}_2$	$\bar{r}_1$(%)	$\bar{\phi}_1$	$\bar{r}_2$(%)	$\bar{\phi}_2$
C_p^H	0.30±0.02	173°	0.19±0.02	21°	0.26±0.03	143°	0.23±0.03	31°
C_p^M	0.31±0.02	186°	0.14±0.02	43°	0.19±0.03	129°	0.20±0.03	27°
C_p^L	0.32±0.02	180°	0.09±0.02	36°	0.25±0.03	185°	0.23±0.03	15°

It is seen from the table that there is no significant change in the diurnal amplitude in the three groups of days. There is a significant change in the time of maximum of the diurnal component for C_p^H group of days, it being earlier by about 3 hours compared to C_p^L group of days in the 10° x 20° telescope. This shift to earlier hours of ϕ_1 in C_p^H group is not statistically significant in the case of the $23^0 \times 37^0$ telescope.

Figure 23 shows the histograms of the amplitudes of diurnal and semidiurnal components of daily variation r_1 and r_2 for the three C_p groups of days studied for the two units $23^0 \times 37^0$ and $10^0 \times 20^0$. The histograms for ϕ_1 and ϕ_2 the time of maximum of the diurnal and semidiurnal components of daily variation have been drawn for days on which the corresponding amplitudes r_1 and r_2 are significant at the 2σ level. It is seen from the figure that;

(1) The r_1 histograms for the three C_p group of days do not differ significantly from each other.

(2) r_2 histograms are also almost alike for the C_p^H, C_p^M and C_p^L groups.

(3) ϕ_1 histograms for C_p^L and C_p^H groups for $10^0 \times 20^0$ telescope differ significantly. Statistical tests made to see whether the two distributions are different have confirmed this difference. Thus the diurnal variation of meson intensity studied on a day to day basis for a large number of days show that there is a tendency of the occurrence of the time of maximum ϕ_1 of the diurnal component earlier on geomagnetically disturbed days (C_p^H group) than on quiet days (C_p^L group). The earlier time of maximum of the diurnal variation on geomagnetically disturbed days is shown much more clearly in the narrow angle telescope of $10^0 \times 20^0$ than in $23^0 \times 37^0$. In the time averaged daily variation

studies for geomagnetically quiet and disturbed days, we have seen that the time of maximum of diurnal variation is ≈ 3 hours earlier for C_p^H than for C_p^L group in $10^\circ \times 20^\circ$ telescope.

(4) ϕ_2 histograms showing the distribution of the time of maximum of the semidiurnal component of daily variation reveal statistically significant preference for early morning (0 - 3 hours) in all the cases.

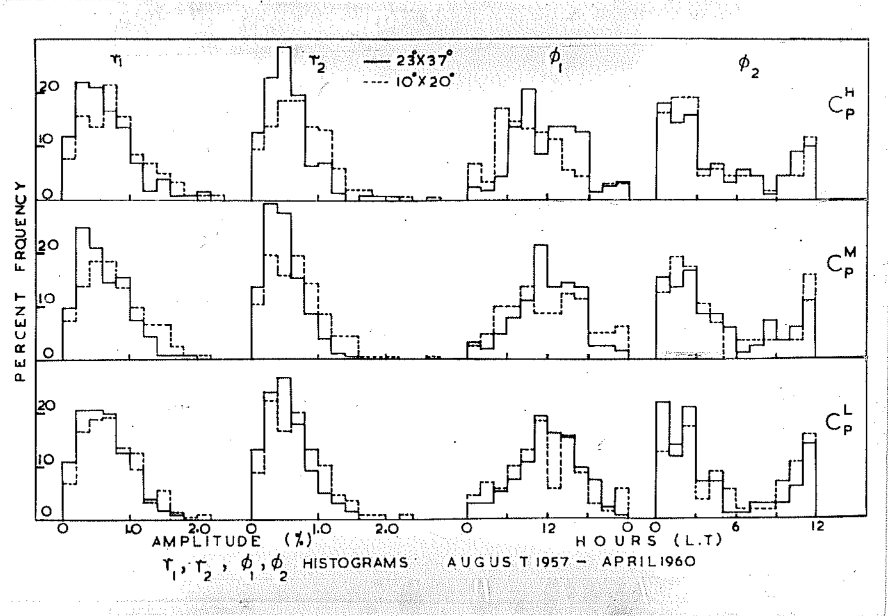

Fig. 25 - Frequency distribution of the amplitudes and times of maxima of the diurnal and semidiurnal components of daily variation for C_p^L, C_p^H and C_p^H groups of days recorded by $23^\circ \times 37^\circ$ and $10^\circ \times 20^\circ$ telescopes at Trivandrum during the period August 1957 to April 1960.

The relation between daily variation of cosmic ray intensity and geomagnetic disturbances as characterised by K_p or C_p has been studied by many workers. Sekido and Kodama[219] and many others have found that the amplitude of solar diurnal variation becomes larger and its time of maximum shifts to earlier hours on geomagnetically disturbed days compared to geomagnetically quiet days. The dependence of the amplitude of diurnal variation and its time of maximum on C_p has been studied by many workers during the period 1955 - 1959 both for meson and nucleonic components at the low latitude stations of Kodaikanal, Trivandrum and Ahmedabad. Satyaprakash[223] from a study of the nucleonic component during 1957, recorded at Kodaikanal, finds that there does not exist any distinct relationship between daily variation parameters and geomagnetic activity represented by K_p or C_p. Studying meson data from Kodaikanal during 1956, Sastry[227] has also got similar results. He finds that for geomagnetically quiet days, the amplitude of diurnal variation is more than on geomagnetically disturbed days. This is not in agreement with the results of Sandstrom[221] from a study of meson component at a high latitude station during 1947 - 1950. He has reported an increase in r_1 and a shift of ϕ_1 to earlier hours with increasing C_p.

The difference between the results relating to 1947 - 1950 and 1956 - 1957 is understandable on the observations of Yoshida[224] that the disturbance vector, which displaces the vector representing the quiet period diurnal variation, has itself an 11 year period of change in amplitude as well as time of maximum. Thus the amplitude and phase changes observed on C_p^{II} days will depend upon the period of solar activity.

The results presented in this section are in agreement with the time of maximum of the diurnal component of solar daily variation occurring earlier on geomagnetically disturbed days, as suggested by Sekido and Kodama[219], Sandstrom[221] and others. However, during August 1957 - April 1960, the amplitude of time averaged solar diurnal variation does not appear to depend very much on the value of C_p.

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Sarabhai

CHAPTER V

DAY TO DAY CHANGES OF INTENSITY

5.1 Introduction.

A striking series of day to day changes of intensity of cosmic rays takes place during cosmic ray storms. Many cosmic ray storms have been associated with type IV bursts and sudden commencement magnetic storms, but often the solar relationship is not precisely known. Dorman[5] has classified the solar streams into two kinds. According to him, streams of the first kind are rarefied and are probably connected with faculae or with high latitude formations on the sun, which do not cause an appreciable amount of decrease in cosmic ray intensity. Such streams are likely to cause cosmic ray storms with gradual onset and of long duration with a marked recurrence tendency. Streams of the second kind which are very dense probably originate within the sun's equatorial region and are most probably intimately connected with sun-spots. They are likely to cause large sudden commencement magnetic storms of short duration which show a weak recurrence tendency. Dorman believes that streams of great density causing large cosmic ray storms carry strong magnetic fields ($H \sim 10^{-4}$ gauss) whereas the streams of the first kind carry weak fields ($H < 10^{-5}$ gauss).

The discovery of polar cap absorption events (PCA) permits a relatively unambiguous interpretation of a sequence of events starting from an event on the sun followed by its effect in the polar ionosphere, geomagnetism and in cosmic rays. This study, therefore, starts by considering polar cap absorption events and their relationship with cosmic ray changes. For those events which are effective in producing cosmic ray storms, the cosmic ray intensity changes are studied at various latitudes as measured with neutron monitors as well as meson telescopes in order to get an idea of the spatial distribution of the modulating process and the change of energy spectrum it produces.

The study of the day to day changes has also been conducted

(1) Looking upon cosmic ray storms as a class regardless of their association with PCA events. The July 1959 event which is remarkable for its intensity and features is studied separately.

(2) choosing events when the east-west asymmetry of cosmic rays at Ahmedabad is significantly depressed as reported by Rao[220]. This is indicative of an alteration of the primary energy spectrum.

6.2 The data.

The cosmic ray data is derived from stations in three different latitude belts. In table 9 are listed the stations, the data of which are used in the analysis.

Table 9

Particulars of stations giving the geographic and geomagnetic coordinates, the magnetic cut-off rigidities, mean energy of response for mesons (M) and neutrons (N) and the name of the principal investigator.

Station	Geographic. Lat. °	Geographic. Long. °	Altitude. (meters)	Geomagnetic Lat. °	Geomagnetic Long. °	Magnetic cut-off rigidity. (B V Bev.		Mean energy of response (in Bev)	Investigator.
I Equatorial region.									
Trivandrum	8.48	76.95	S.L.	- 1.13	147.5	17.48	N	89.9	Dr.V.Sarabhai, India.
Lae	- 6.72	147.0	S.L.	-15.72	218.6	14.89	N	41.8	Dr.A.G.Fenton, Hobart.
Makerere	0.33	32.5	1196	- 2.18	102.6	14.51	N	41.8	Dr.D.M.Thomson, Uganda.
Huancayo	-12.05	284.6	3400	- 0.68	354.7	14.18	N	38.3	Dr.J.A.Simpson, Chicago.
II High latitude region.									
Climax	39.37	253.8	3400	48.17	317.0	2.77	N	10.3	Dr.J.A.Simpson, Chicago.
Chicago	41.83	272.3	S.L.	52.58	338.2	1.61	N	11.6	Dr.J.A.Simpson, Chicago.
Leeds	53.82	358.5	100	56.45	84.7	1.71	N	11.6	Dr.P.L.Marsden, England.
Mt.Wellington	-42.87	147.3	725	-51.40	225.8	1.71	N	11.6	Dr.A.G.Fenton, Hobart.
III Polar region.									
Resolute	74.68	265.05	17	82.99	291.3	0.00	N M	10.9 43.7	Dr.D.C.Rose, Canada.
Mawson	-67.60	62.8	S.L.	-73.22	104.5	0.57	N	10.9	Dr.A.G.Fenton, Hobart.
Churchill	58.80	265.9	30	68.71	324.3	0.11	N M	10.9 43.7	Dr.D.C.Rose, Canada.

M = Meson. N = Neutron.

The particulars of the location and the name of the principal investigator at each station through whose kindness the data have been made available to us are also indicated in the table. The geomagnetic cut-off rigidities according to Quenby and Webber's method[32] and the mean energy of response for the components calculated by using the coupling coefficients given by Dorman and adopting the method suggested by Fonger[34] are also indicated in the same table.

5.3 Polar cap absorption events.

Reid and Leinbach[174] have listed 24 intense polar cap absorption events recorded during the period May 1957 to July 1959. Of these, cosmic ray intensity data at Trivandrum and other stations are available for 21 events. Of these events on August 29, 1957; September 9, 1957; September 26, 1957; August 21, 1958; July 14, 1959 and July 16, 1959, which are preceded in each case by other PCA events within about 10 days have been eliminated from further consideration since we are interested in studying the day to day changes upto 10 days following the onset of the cosmic ray storms associated with some of these events.

Figure 26 indicates the changes in the intensity as observed by the neutron monitor at Climax for fifteen of these events. Climax has been chosen for the initial classification of PCA events in terms of their association

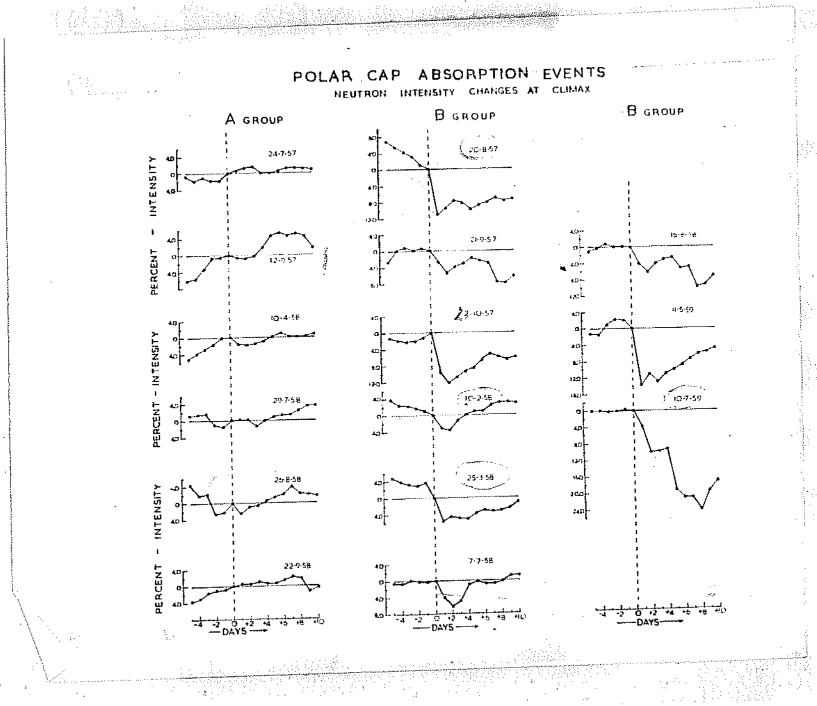

Fig. 26 - Daily mean neutron intensity changes from -5 to +10 days at Climax corresponding to each polar cap absorption event. All intensities are shown as deviations from the values on epoch day.

with cosmic ray changes since of all stations considered, Climax neutron monitor has the lowest mean energy of response and is, therefore, expected to respond most effectively to changes of primary intensity.

Six events are found not to be associated with Cosmic ray decreases exceeding 2.5 % at Climax following them within one or two days. These are referred to as 'group A' events. The other 9 events are followed by cosmic ray intensity decreases of the Forbush type exceeding 3 % at Climax within one or two days. These are referred to as 'group B' events in this section.

The relevant data of the PCA events, the probable flare and the magnetic storm are shown in table 10 for group A and group B events separately. Chree analysis has been done for the following intensities from -5 to +10 days for A and B groups separately.

(1) Daily mean intensity.

(a) Meson intensity at Trivandrum corrected for barometric pressure and atmospheric temperature changes.

(b) Meson intensity at Churchill and Resolute corrected for barometric pressure changes.

(c) Neutron intensity at Huancayo, Climax, Chicago, Leeds, Mt.Wellington, Resolute, Mawson and Churchill corrected for barometric changes.

(2) H the horizontal intensity of the earth's magnetic field at Kodaikanal.

Table showing the particulars of different events connected with polar cap absorption events.

Date of event	PCA starts at UT	Max.absor. at 27.6 Mc/s(db)	Probable Flare				Magnetic storm				Delay in events in hours	
			Time UT	Impor-tance.	Helio. Lat.	Helio. Long.	Date.	Time UT	Type	Fig.of acti-vity.	τ_1	τ_2
						GROUP A						
24- 7-57	2015	2.0	1016	3	S24	W22	-	-	-	-	03	-
12- 9-57	1200	0.5	0700	2+	S12	W15	13	0040	SC	s	05	13
10- 4-58	1130	3.0	1010	1+	N18	W73	15	0418	G	ms	01	-
20- 7-58	0405	0.7	0308	3	S14	W43	-	-	-	-	01	-
26- 8-58	0100	10.0	0005	3	N20	W54	27	0301	SC	s	01	26
22- 9-58	1830	4.0	0741	2+	S17	W12	25	0405	SC	ms	04	62
						GROUP B						
20- 5-57	1500	9.0	1031	3	S24	E22	20	1920	SC	m	02	06
21- 9-57	1930	6.0	1338	3	N10	W08	21	1006	SC	s	06	18
21-10-57	0700	6.0	1337 (20th)	3+	S26	W15	21	2235	SC	m	14	16
10- 2-58	0700	12.0	2108 (9th)	2+	S13	W14	11	0124	SC	s	10	18
25- 3-58	2230	12.0	0950 (23rd)	3+	S15	E30	-	-	-	-	61	-
7 - 7-58	0120	15.0	0039	3+	N24	W02	8	0751	SC	s	01	30
16- 8-58	0600	13.0	0433	3+	S14	W53	17	0818	SC	ms	01	26
11- 5-59	0130	15.0	2055 (10th)	3+	N23	W47	11	2330	SC	ms	05	22
10- 7-59	0700	15.0	1937 (9th)	2+	N19	E07	11	1625	SC	m	05	33

τ_1 - Delay between flare and PCA. τ_2 - Delay between PCA and magnetic storm.

(3) Ionospheric absorption at 25 Mc/s at Ahmedabad.

(4) Three hourly K_p indices (only from -5 to +5 days).

(5) Average daily variation for Trivandrum meson and for neutron intensity at Huancayo, Climax and Mt.Wellington for three day groups comprising (-3, -2, -1), (0, +1, +2) and (+3, +4, +5).

In figure 27, for group A events, the intensities, H, ionospheric absorption, etc. have been plotted as deviations from the mean value for the three days -5, -4 and -3 with respect to the epoch. For group B events, the reference level of intensities is taken as the value on epoch day. The cosmic ray intensities are shown for meson intensity at Trivandrum and neutron intensity at Huancayo, both stations at the equator, and the neutron intensity at Climax, a high latitude mountain station. Table 11 gives the results of Chree analysis of daily mean intensity of meson and neutrons for group B events.

The average daily variation studied for A and B groups separately are shown in figure 28 and the parameters of the harmonic components are given in table 12.

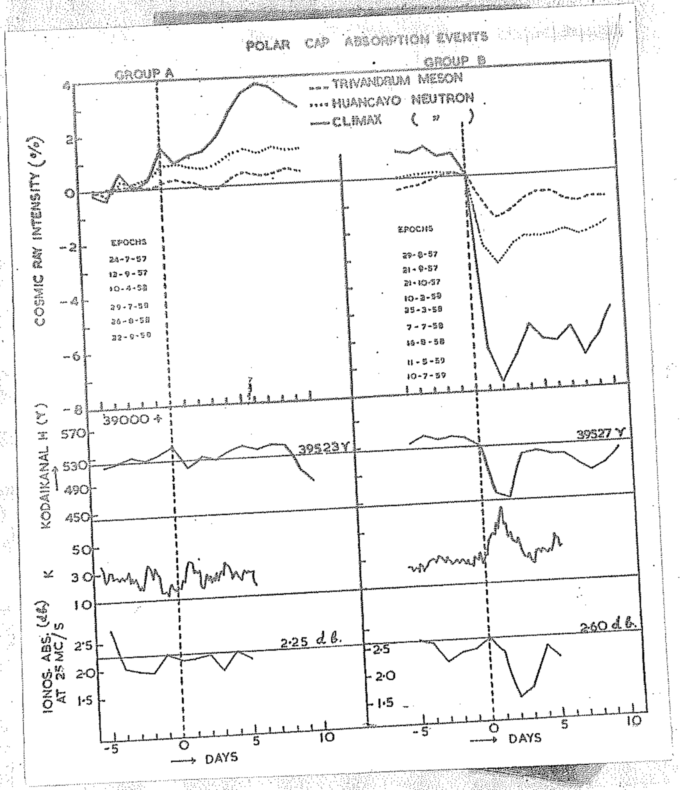

Fig. 37 - Results of Chree analysis of daily mean intensity of mesons at Trivandrum, neutrons at Huancayo and Climax, ionospheric absorption at 25 Mc/s at Ahmedabad, horizontal component of earth's field at Kodaikanal and three hourly K_p indices for group A and group B PCA events.

Characteristics of group A events.

(1) Meson and neutron intensities at various stations are above normal on epoch day. From +4 to +8 day the intensities increase. On +7th day, intensity is ~3.5 % above mean level for Climax and for some of the

Table 11

Intensity decreases with respect to the value on epoch day for 9 polar cap absorption events of group 3 studied together.

Station	Midnight or Noon	+1 day (%)	+2 day (%)	+3 day (%)	+4 day (%)	+5 day (%)	+6 day (%)	+7 day (%)	+8 day (%)	+9 day (%)	+10 day (%)	Standard Error (%)
Trivandrum	N	0.91	1.55	1.34	0.92	0.70	0.90	0.93	1.11	0.96	0.99	± 0.08
Huancayo	N	2.95	3.30	2.70	2.31	2.33	2.30	2.16	2.23	2.18	1.91	± 0.08
Climax	N	6.47	7.64	6.49	5.99	6.14	6.21	5.74	6.79	6.11	5.69	± 0.01
Ottawa	N	4.55	5.00	4.54	3.20	3.91	4.04	3.93	5.31	4.43	3.44	± 0.03
Leeds	N	4.20	5.77	5.04	4.32	4.74	4.97	4.39	5.08	4.28	3.21	± 0.05
Mt.Wellington	N	6.63	7.34	5.94	4.89	5.44	5.03	5.12	5.91	5.46	4.30	± 0.03
Resolute	N	6.06	6.94	6.10	5.46	5.34	5.04	4.74	6.84	5.94	4.60	± 0.04
Mawson	N	5.46	6.44	5.32	4.75	5.01	4.80	4.69	5.51	5.15	4.12	± 0.04
Churchill	N	5.22	5.63	4.71	3.98	4.53	3.83	4.22	5.29	4.73	3.73	± 0.05
Resolute	N	2.34	2.15	1.87	1.40	1.21	1.03	0.93	1.73	1.12	0.75	± 0.03
Churchill	N	2.59	2.49	1.98	1.53	1.82	1.72	1.34	1.83	1.53	1.34	± 0.03

polar stations. The mean intensity at Trivandrum is also above normal from +5 to +8 day.

(2) Peak to peak amplitudes of daily variation and the diurnal and semidiurnal components are high for the group comprising +3, +4 and +5 days at equatorial and high latitude stations.

(3) Kodaikanal H is slightly lower by about 30 γ on +1 day.

(4) C_p is slightly above normal value on +1 day.

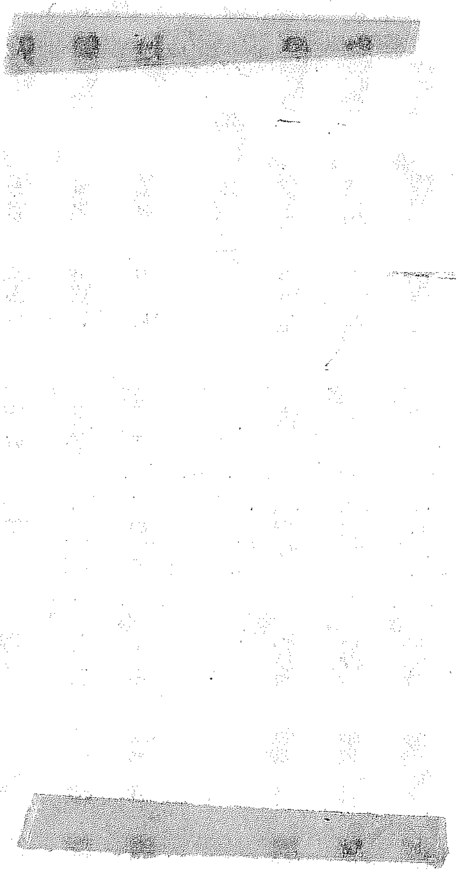

Fig. 33 - Average daily variation for group A and group B PCA events for three day groups comprising (-3, -2, -1) days, (0, +1, +2) days and (+3, +4, +5) days respectively.

Table showing the parameters $\overline{r}_1$, $\overline{\phi}_1$, $\overline{r}_2$, $\overline{\phi}_2$ of the average daily variation studied for three day groups comprising (-3, -2, -1), (0, +1, +2) and (+3, +4, +5) days with respect to the epoch for group A and group B polar cap absorption events.

Station	N or M	Days combined (-3, -2, -1)				Days combined (0, +1, +2)				Days combined (+3, +4, +5)				St. error (%)
		$\overline{r}_1$ (%)	$\overline{\phi}_1$	$\overline{r}_2$ (%)	$\overline{\phi}_2$	$\overline{r}_1$ (%)	$\overline{\phi}_1$	$\overline{r}_2$ (%)	$\overline{\phi}_2$	$\overline{r}_1$ (%)	$\overline{\phi}_1$	$\overline{r}_2$ (%)	$\overline{\phi}_2$	
							GROUP A							
Trivandrum	N	0.18	221°	0.17	40°	0.33	107°	0.17	329°	0.49	194°	0.26	7°	±0.03
Huancayo	N	0.22	201°	0.05	323°	0.23	180°	0.08	337°	0.41	193°	0.08	255°	±0.02
Climax	N	0.30	224°	0.01	225°	0.28	226°	0.08	35°	0.63	234°	0.11	63°	±0.01
Mt.Wellington	N	0.10	107°	0.22	90°	0.43	234°	0.11	85°	0.53	248°	0.23	77°	±0.04
							GROUP B							
Trivandrum	M	0.46	191°	0.17	55°	0.55	197°	0.29	35°	0.20	164°	0.23	88°	±0.05
Huancayo	M	0.24	204°	0.05	0°	0.02	178°	0.04	304°	0.19	171°	0.03	120°	±0.02
Climax	M	0.39	149°	0.15	83°	0.58	113°	0.05	301°	0.05	252°	0.06	130°	±0.01
Mt.Wellington	M	0.29	143°	0.13	105°	0.30	136°	0.14	201°	0.34	109°	0.09	122°	±0.02

N = Neutron. M = Meson.

(5) There are no clear changes in ionospheric absorption at Ahmedabad.

(6) Only three events are having SC storms following them within one or two days, out of which only one is severe.

(7) All probable flares corresponding to these events occurred on the western half of the solar disc.

(8) Absorption at 27.6 Mc/s is comparatively low, mean value for 6 events being < 3 db.

(9) The average delay between the occurrence of probable flare and PCA is small $\approx 2\frac{1}{2}$ hours for the six events.

Characteristics of group B events.

(1) Cosmic ray intensities show abrupt fall from the epoch day to +1 day and reach minimum value on +2 day. The intensity recovery is slow.

(2) Peak to peak amplitude of daily variation is maximum for the group of days comprising epoch, +1 and +2 days.

(3) Kodaikanal H is lower by about 70γ on +1 day, the depression being much larger than in group A events.

(4) C_p reaches maximum value on +1 day, the changes being considerably larger than for A group of

events. Three hourly indices of K_p are also significantly higher on +1 and +2 days.

(5) Daily variation and the daily mean ionospheric absorption at Ahmedabad are low on +2 and +3 days.

(6) 8 out of 9 events are followed by SC storms. Most of them are either moderately severe or severe.

(7) The flare has no preference for either the eastern or western half on the solar disc.

(8) Ionospheric absorption at 27.6 Mc/s is more in this case, average for 9 events being >11 db.

(9) The delay in the PCA after the occurrence of the flare is comparatively high. On one occasion, it is ~60 hours. The average time delay for the 9 events is ~12 hours and excluding the one event, the average delay is ~6 hours.

It is of interest to compare our observation with the study of Obayashi and Hakura[177], which mainly concerns with the association of geomagnetic storms, PCA and type IV solar outbursts. This is summarised in table 3 of their paper which is reproduced below:-

Solar Flares and Disturbances in the Earth's Upper Atmosphere.

	Flare	
Electromagnetic radiations.	Soft X rays Hα enhancement and major radio outbursts.	SID and crochet
	Corpuscular cloud	
Relativistic electrons	Synchrotron radiation	Type IV outbursts.
Relativistic protons	Solar cosmic ray	Unusual increase of cosmic ray
High-energy particles	Solar cosmic ray	Polar-cap blackouts
	Auroral particles (trapped in the cloud)	Auroral zone blackouts
		Auroras, polar magnetic storms
Low-energy particles	Corpuscular cavity formation	Dst of magnetic storms.

Their comments on the cosmic ray effects are as follows:-

"It is worth while to note here that the Forbush type decreases of cosmic ray intensity are usually correlated with those of the high-energy type. An intimate relation between type IV outbursts and cosmic-ray storms (Forbush decrease) has been noted by Kamiya and Wada (1959). Since it is generally believed that cosmic-ray storms are caused by the shielding of incident intergalactic cosmic ray particles due to clouds carrying tangled magnetic fields, the present results may support the idea that the corpuscular clouds of high-energy type are magnetic. As shown in Figure 8,* a large Forbush-type decrease was observed simultaneously all over the world on October 21-22, 1957, and no appreciable decrease was noticed on November 6-7, 1957. In the case of a large Dst field of the geomagnetic storm such as on February 11, 1958, the cosmic-ray intensities at middle and low latitudes show considerable storm-time increases (Kondo, Nagashima, Yoshida, and Wada, 1960), though they are usually superposed on the Forbush-type decreases. Clouds of low-energy type, on the contrary, will tend to enhance the cosmic-ray intensity observed on the earth, owing to the distortion of the outer geomagnetic field."

Since we have taken only PCA events, we have, according to Obayashi and Hakura[177], either high energy corpuscular clouds or a combination of high and low energy clouds. We find that amongst these, those with the highest energy, i.e. which generally have the shortest time as in group A, produce minor geomagnetic effects and almost no cosmic ray effects. Thus Obayashi and Hakura's classification can be extended to a third category, consisting of events where relativistic protons are emitted without any major emission of either low or high energy plasma clouds. The steadily rising cosmic ray intensity

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* Obayashi and Hakura[177]

in group A events from -2 to +7 days represents in many cases a recovery from earlier Forbush type decreases and this indicates that the conditions for the arrival of relativistic protons by themselves are most appropriate when the interplanetary magnetic fields have been stretched out towards the earth through earlier high or low energy plasma clouds.

5.4 Cosmic ray storms.

For a study of the intensity changes during cosmic ray storms, the following criterion has been used for selecting the storm dates. The daily mean intensity of the nucleonic component at Huancayo is examined for the period September 1957 to December 1959 and days are selected on which the decrease in intensity during 24 hours is more than 2 %. The twelve cosmic ray storms studied in this section occurred on the following dates:-

September	29, 1957.	February	11, 1959.
October	22, 1957.	May	12, 1959.
November	26, 1957.	July	12, 1959.
December	30, 1957.	July	15, 1959.
March	26, 1958.	September	4, 1959.
August	17, 1958.	December	9, 1959.

Some of these individual storms have been studied by various workers, following the intensity changes in short intervals, sometimes even upto a few minutes. The comparatively low counting rate of the meson telescopes at Trivandrum does not permit this type of study. Hence, an attempt is made here to examine only the gross effects of the 12 cosmic ray storms. Results of the Chree analysis of the daily mean intensity of mesons at Trivandrum and neutron intensity at Huancayo, Climax and Mt. Wellington are shown in figure 20. The intensities are represented as deviations from mean of -3, -2 and -1 day from the epoch. The Chree analysis of C_p has also been done for those days and the changes are represented in the same diagram.

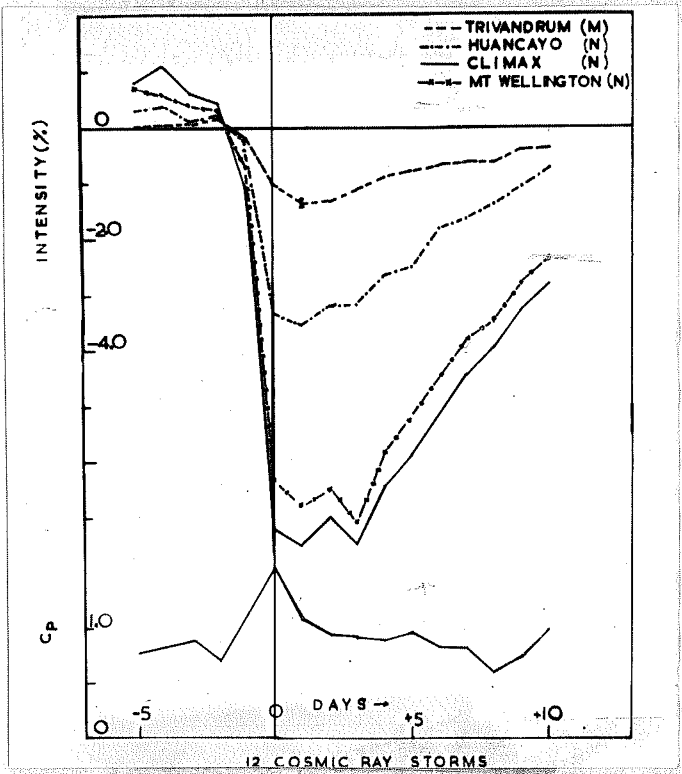

Fig.20 - Results of Chree analysis of daily mean intensity of mesons at Trivandrum, of neutron intensity at Huancayo, Climax and Mount Wellington and of C_p for 12 cosmic ray storms.

It is seen from the figure that the maximum depression in the intensity occurs one day after the epoch, even though the fall in intensity is very steep from -1 day to epoch day. The decreases in intensity from the reference level on different days are shown in table 13. It is seen from the figure that the recovery of the intensity to the prestorm level takes more than 10 days when all the storms are considered together. In the case of individual storms, it has been noted that the recovery time is much shorter than this in some cases.

The ratios of decreases of neutron to meson intensity at equatorial and polar latitudes on days following the cosmic ray storms are also shown in table 13. The sequential changes of this ratio at equatorial and polar latitudes show an almost opposite trend to each other on the epoch and the first two days after the epoch. The ratio of neutron to meson intensity at equatorial latitude is high on epoch day and decreases on +1 and +2 days after the epoch, indicative of the spectrum being steep on the epoch day and becoming flatter thereafter. The ratio again increases on +3 and +4 days after the epoch. On the other hand, the corresponding ratio at polar latitudes is low on the epoch day and increases on +1 day. It is low again on +2 day and thereafter it increases progressively till the 5th day following the epoch. The changes are indicative of the spectrum being flat on the epoch day. The dissimilar behaviour of the

Table 12

The percent decrease intensity on epoch day and on six days following the epoch for 12 cosmic ray storms during the period September 1957 to December 1959. Reference level of intensity has been taken as the mean value of -3, -2 and -1 day from the epoch.

Station	M or N	Days							Standard error
		Epoch	+1	+2	+3	+4	+5	+6	
Trivandrum	(M)	1.00	1.30	1.31	1.22	0.87	0.80	0.71	±0.06
Huancayo	(M)	3.32	3.32	3.18	3.16	2.63	2.48	1.78	±0.01
Climax	(N)	7.21	7.51	7.01	7.53	6.46	5.91	5.18	±0.01
Chicago	(N)	5.87	5.43	4.92	5.62	4.92	4.60	4.27	±0.03
Leeds	(N)	6.80	7.61	7.15	7.65	6.49	5.90	5.35	±0.05
Mt.Wellington	(N)	6.30	6.73	6.52	7.13	5.73	5.15	4.49	±0.03
Resolute	(N)	6.83	6.70	6.24	7.06	5.54	5.02	4.76	±0.04
Mawson	(N)	5.61	6.21	5.47	6.07	5.33	4.76	4.21	±0.03
Churchill	(N)	5.32	4.32	5.23	5.23	4.19	3.68	3.72	±0.05
Resolute	(M)	2.77	2.40	2.40	2.66	1.75	1.66	1.66	±0.03
Churchill	(M)	2.75	2.39	2.30	2.43	1.80	1.34	0.86	±0.03

Ratios

	Epoch	+1	+2	+3	+4	+5	+6
Resolute (N) / Resolute (M)	2.48	2.79	2.61	2.65	3.16	3.02	2.89
Huancayo (M) / Trivandrum (M)	3.32	2.55	2.43	2.58	3.02	3.10	2.50
Climax (N) / Huancayo (M)	2.17	2.13	2.20	2.39	2.46	2.43	2.89

M = Meson N = Neutron

ratios of neutron to meson at different latitudes suggests that a single spectrum cannot be fitted for all the components at different latitudes.

Maximum value of C_p occurs on the epoch day and the value is high on -1 and +1 days.

The parameters of the harmonic components of the average daily variation for the 12 storms studied together on -1, 0 and +1 days for the meson intensity at Trivandrum corrected for pressure and temperature changes are given below:-

Day	$\bar{r}_1(\%)$	$\bar{\phi}_1$	$\bar{r}_2(\%)$	$\bar{\phi}_2$
-1	0.20 ± 0.03	215°	0.18 ± 0.03	07°
Epoch	0.56 ± 0.03	112°	0.41 ± 0.03	61°
+1	0.40 ± 0.03	103°	0.11 ± 0.03	15°

It is seen that the $\bar{r}_1$ and $\bar{r}_2$ amplitudes are high and the time of maximum of the diurnal component of average daily variation is significantly earlier on epoch day.

5.5 Cosmic ray storms of July 1959.

An interesting group of events of great importance occurred during the month of July 1959. There were three solar flares of importance 3^+ which occurred at 0210 UT on

10th July, 0942 UT on 14th July and 2115 UT on 15th July respectively. The subsequent solar and terrestrial effects have been described in detail in section 1.63.

In figure 30 we have presented the changes occurring in the daily mean meson intensity at Trivandrum corrected for atmospheric changes of pressure and temperature. For comparison the intensity of the nucleonic component recorded at Huancayo, Climax and Mt.Wellington corrected for barometric changes is also shown. The value of C_p for each day has also been plotted. The intensities have been represented as deviations from the value on 10th July 1960.

The intensity falls in three steps from 10th July to reach the minimum value on 18th. At each step, there is a tendency for recovery after the Forbush decrease but the next decrease starts before the recovery is complete. The recovery from the third Forbush decrease is very slow and even by the end of July, the neutron intensity does not recover to the level on the 10th. The maximum depression in intensity on 18th with reference to intensity on 10th July is given below,-

Trivandrum	(meson)	3.7 ± 0.2 %
Huancayo	(neutron)	9.7 ± 0.1 %
Climax	(neutron)	24.1 ± 0.1 %
Chicago	(neutron)	15.7 ± 0.1 %

Leeds	(neutron)	10.7 ± 0.1 %
Mt.Wellington	(neutron)	22.3 ± 0.1 %
Resolute	(neutron)	25.3 ± 0.1 %
Mawson	(neutron)	21.1 ± 0.1 %
Churchill	(neutron)	18.4 ± 0.1 %
Resolute	(meson)	10.3 ± 0.1 %
Churchill	(meson)	8.6 ± 0.1 %

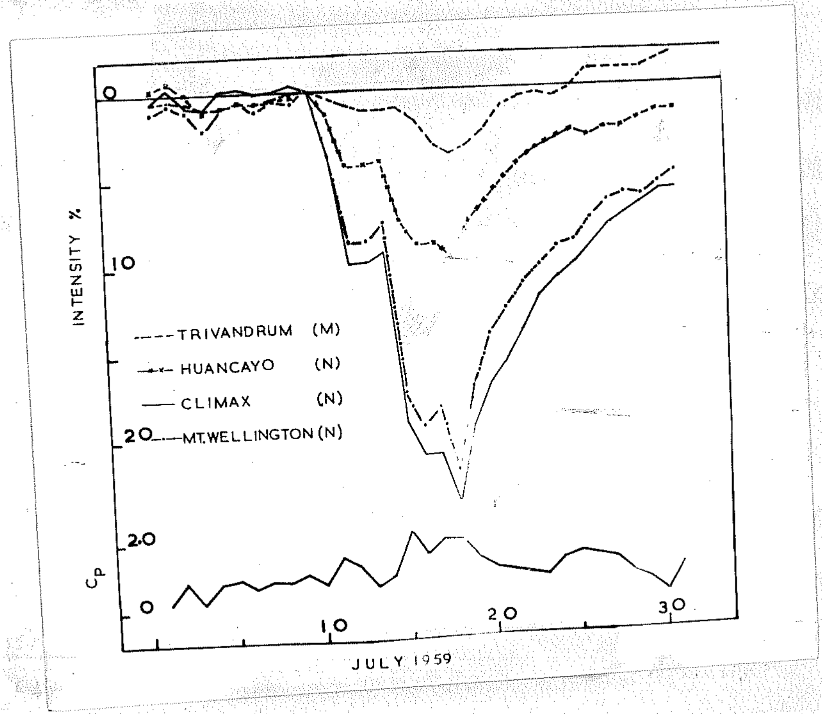

Fig. 30 - Daily mean intensity changes of meson and neutron components during the month of July 1959.

It is seen from figure 30 that Huancayo neutron intensity and Trivandrum meson intensity recover much more rapidly than the intensity recorded at high latitudes after the third Forbush decrease. The three Forbush decreases are seen very clearly in neutron intensity at high latitudes and at Huancayo. At Trivandrum, the second and the third Forbush decreases almost merge together, indicative of the small amplitude of the further changes.

The ratios of the percent decreases of the daily mean intensity for detectors of different mean energies of response are indicated in table 24 for the period July 11, 1959 to July 22, 1959. The following intensities are considered:-

(1) Mean value of the decrease in daily mean neutron intensity at Dawson, Churchill and Resolute to represent the decrease in neutron intensity at polar region [λ80 (N)].

(2) Mean value of meson intensity decrease at Resolute and Churchill to represent the decrease in meson intensity at polar region [λ80 (M)].

(3) Mean value of the neutron intensity decrease at Leeds and Chicago to represent the neutron intensity changes at sea level at ~ 50° [λ50 sea level (N)].

(4) The decrease in the neutron intensity at Climax representing the nucleonic component intensity at mountain elevation at 50°.

(5) The decrease in neutron intensity at Huancayo representing the nucleonic component at mountain elevation at equator.

(6) Meson intensity at Trivandrum.

Table 14

Table showing the ratio of the decrease in intensity from the level on July 10, 1959, at different latitude regions and for different components.

Ratio	11/7	12/7	13/7	14/7	15/7	16/7	17/7	18/7	19/7	20/7	21/7	22/7
$\frac{\text{Huancayo(N)}}{\text{Trivandrum(M)}}$	3.50	4.80	3.53	3.48	6.00	6.00	2.78	2.68	2.33	2.64	4.91	7.17
$\frac{\text{Climax(N)}}{\text{Huancayo(N)}}$	2.71	2.27	2.30	2.23	2.53	2.34	2.37	2.48	2.53	2.59	2.94	3.27
$\frac{\lambda_{50}\ (N)}{\lambda_{50}\ (M)}$	1.71	2.61	2.51	2.41	2.42	2.51	2.11	2.23	2.27	2.31	2.32	2.83
$\frac{\text{Climax(N)}}{\lambda_{50}\ \text{sea-level (N)}}$	1.65	1.54	1.55	1.52	1.31	1.36	1.31	1.32	1.31	1.32	1.30	1.36

At the equator, the ratio of neutron to meson is high on the 12th and again on the 15th and 16th in the first and second Forbush decreases respectively. Similarly the ratio of neutron to meson at $\lambda = 50^{\circ}$ increases significantly from the 11th to the 12th, but unlike at the equator it continues to increase till the 13th. After the 16th of July, 1959, the ratio decreases in a similar manner as at the equator. It is interesting to observe that the ratios of Climax neutron to Huancayo neutron and Climax neutron to λ_{50} sea level neutron do not exhibit the type of changes observed in the ratio for neutrons to mesons.

The three successive Forbush type events are different in relation to the energy spectrum of variation that is observed in each case. This is discussed in detail in chapter VI.

5.6 Low east-west asymmetry and associated changes in daily mean intensity.

Cosmic ray time variation studies have been made with directional telescopes at Ahmedabad during 1957-1958 by Rao[229]. The intensity of the meson component has been recorded with telescopes inclined at 45° to the vertical and pointing in the east and west directions. If W and E represent the intensities measured by the west and east pointing telescopes, then east-west asymmetry is defined as

$$\frac{2\,(W - E)}{(\,W + E\,)} \quad x \;100.$$

The average value of east-west asymmetry at Ahmedabad is 14.07 ± 0.55 % and days on which the asymmetry is above (> 16.1 %) or below (< 12.0 %) the 2σ level have been classified by him as days of high and low asymmetry respectively. There are 15 low east-west asymmetry days during the period November 1957 to December 1958.

The changes of daily mean intensity and geomagnetism associated with these 15 epochs have been studied through Chree analysis of

(a) Meson and neutron intensities at different stations indicated in table 9.

(b) H, the horizontal component of the earth's magnetic field recorded at Kodaikanal.

(c) C_p, the interplanetary character figure.

The Chree analysis has been extended to ±10 days. All the intensities are expressed as deviations from the value on the -6 day, which corresponds to normal intensity. The results of Chree analysis for four representative intensities, C_p and H are shown in figure 51.

An examination of the intensity changes reveal that:-

(1) The meson intensity at Trivandrum and the neutron intensity at stations in the equatorial region show minimum value on the epoch day. Huancayo neutron intensity is practically the same on epoch day and -1 day.

(2) All neutron intensities at high latitude and polar regions reach minimum value on -1 day.

(3) H, the horizontal component of the earth's magnetic field at the equatorial station Kodaikanal reaches minimum value on -2 day of the epoch and remains comparatively low even on epoch day.

(4) C_p shows maximum value on -2 day.

(5) The depressed intensity recovers to its normal value (on -6 day) in about 4 to 6 days after epoch. It is seen that at lower latitudes, the recovery is faster than at higher latitudes.

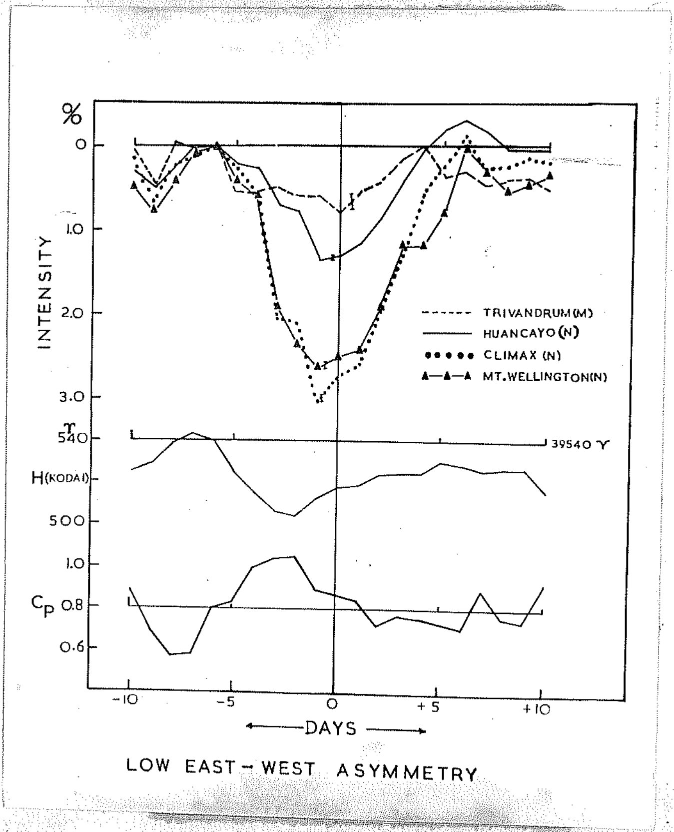

Fig. 31 - Associated changes of daily mean intensity and of geomagnetism for 15 epochs of low east-west asymmetry.

Most of these events are found to be associated with sudden commencement magnetic storms within 3 days prior to epoch.

These results are in very good agreement with those of Sarabhai and Rao[60], who have studied the associated changes for 23 low east-west asymmetry epochs during the period January 1957 to December 1958.

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CHAPTER VI

ENERGY SPECTRUM AND ISOTROPY OF COSMIC RAY STORMS

6.1 Introduction.

In chapter I, section 1.2, an analytical expression as suggested by Dorman[5] has been given to represent in the most general form the percent variation of cosmic ray intensity. In identifying a modulating mechanism to explain the time variation of intensity during a cosmic ray storm, it is important to know the energy spectrum of variation $\frac{\delta D(E)}{D(E)}$ and whether the variation is isotropic in character. Studying meson intensity changes at $\lambda = 0$ and $\lambda = 50^{0}$, during a large number of Forbush decreases, Dorman has suggested that the primary spectrum of variation can be represented as

$$\frac{\delta D(E)}{D(E)} = \begin{bmatrix} -aE^{0} & \text{if } E \lesssim 40 \text{ Bev} \\ 0 & \text{if } E \gtrsim 40 \text{ Bev} \end{bmatrix}$$

McCracken[102] has suggested a spectrum of the type $E(1+E)^{-0.8}$ or for the short term changes of intensity. Kuzmin[123] has suggested that the energy spectrum of variation for Forbush type decreases can be represented as

$$\frac{\delta D(E)}{D(E)} \propto E^{-(0.7 \text{ to } 1.0)}$$

McDonald and Webber[110], Lockwood[80] and others, studying the neutron intensity changes during cosmic ray storms, have suggested an exponent -1.0 for the differential energy spectrum.

In this chapter, we first explain the method of estimating for various assumed forms of $\frac{\delta D(E)}{D(E)}$ the time variations of intensity that could be observed in measurements made at different latitudes and elevations with neutron monitors and cubical meson telescopes. We next examine whether it is possible to reconcile the observed distribution of changes of intensity on any particular day involving only a single spectrum of variation.

Whenever the fit between the expected and observed changes is not good in terms of a spectrum of the form $\frac{\delta D(E)}{D(E)} = aE^{-x}$, we attempt to remove the discrepancy in one of the following ways:-

(1) By putting a low energy cut-off E_{min} below which $\frac{\delta D(E)}{D(E)} = 0$, or

(2) By putting a high energy cut-off E_{max} above which $\frac{\delta D(E)}{D(E)} = 0$, [Such a spectrum has been suggested by Dorman with $x = 0$, and $E_{max} \sim 40$ Bev, taking into consideration only meson intensity changes at $\lambda = 0$ and $\lambda = 50$. He gets the value of 'a' to be ~ 0.3 if the meson intensity decrease at $\lambda = 50$ is $\sim 10\%$,] or

(3) By permitting the strength 'a' of the source to have a latitude dependence, and

(4) Finally, invoking a variation produced by change of geomagnetic cut-off $E^{min}_{\lambda,t}$ in addition to variational spectrum $\frac{\delta D(E)}{D(E)}$.

We thus derive from a phenomenological stand point the basic characteristics of the modulating process~~es~~. We then examine whether the process is isotropic and study the manner in which it progressively alters after the onset of a cosmic ray storm.

6.2 Method of calculating expected changes of intensity.

Assuming that cosmic ray data is appropriately corrected for meteorological effects when a barometric correction is applied to the neutron intensity and a correction for barometric and atmospheric temperature changes is applied to meson intensity, the relative change of intensity can be expressed by the first two terms of equation (3) in section 1.2.

The coupling coefficients for neutron monitors and meson telescopes at 0^0, 50^0 and 80^0 latitudes for sea level and for mountain stations at an atmospheric depth of 700 gm/cm^2 have been given by Dorman and Feinberg[51]. These can be used directly for the stations and detectors indicated in table D in chapter V, section 5.1.

6.21 Effect of change of geomagnetic cutoff energy.

The contribution due to the changes of the geomagnetic cut-off energy in the intensity changes can be calculated

From the expression

$$- \delta E^{min}_{\lambda,f} \cdot W^{i}_{\lambda,f} (E^{min}_{\lambda,f}, h_0)$$

where $\delta E^{min}_{\lambda,f}$ is the change in geomagnetic cut-off and $W^{i}_{\lambda,f} (E^{min}_{\lambda,f}, h_0)$ is the value of the coupling coefficient at $E^{min}_{\lambda,f}$. for the particular component and station considered.

3

In figure 33 are indicated the values of the percent change of intensity $\frac{\delta N^{i}_{\lambda,f} (h_0)}{N^{i}_{\lambda,f} (h_0)}$ for each station and detector for different values of the change of geomagnetic cut-off $\delta E^{min}_{\lambda,f}$. It is seen from the figure that:-

(1) For the same change in $\delta E^{min}_{\lambda,f}$ the change of intensity for Huancayo neutrons is 3.77 times larger than for Trivandrum mesons.

(2) For neutron intensities at Climax and Huancayo the ratio of the changes is 1.83 : 1 for the same change in $\delta E^{min}_{\lambda,f}$.

(3) Comparing Climax and Chicago neutrons, it is seen that the coupling coefficients at $E^{min}_{\lambda,f}$ are 7.00 and 1.70 and the values of $E^{min}_{\lambda,f}$ 2.77 and 1.64 Bev respectively. Hence for the same change in cut-off, the ratio of the changes in intensities at Climax and Chicago is 4.12.

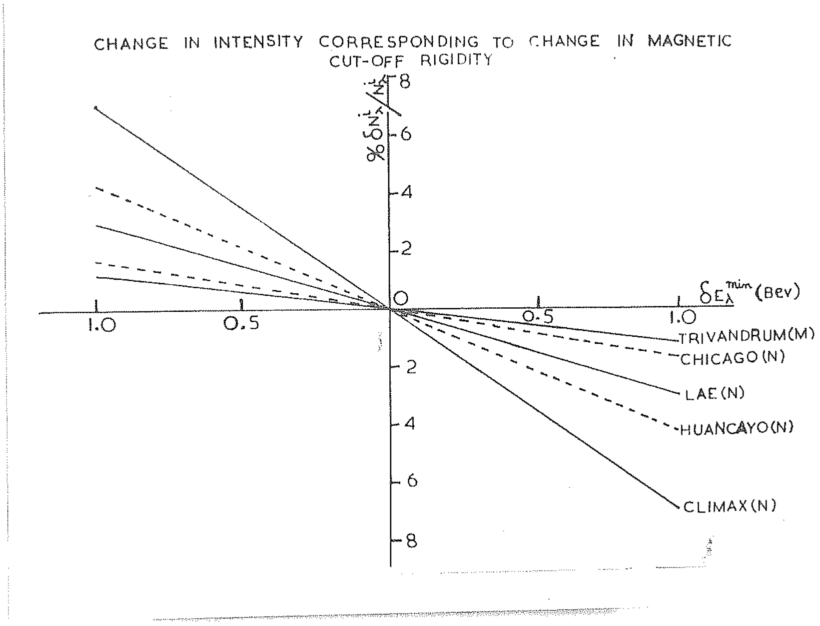

Fig. 33 - Figure showing the percent change of intensity for each station and detector for change of geomagnetic cut-off $\delta E^{min}_{\lambda,f}$.

(4) Mawson, Resolute and Churchill are in the polar region where the atmospheric cut-off is more than the geomagnetic cut-off. The geomagnetic cut-off is almost zero. Hence the change in cut-off will have an effect only if the change exceeds the atmospheric cut-off.

(6) For λ_{80} meson (Resolute and Churchill) the value of the coupling coefficient is almost zero below 6.5 Bev, whereas the geomagnetic cut-off is much lower than 6.5 Bev. Hence a change in geomagnetic cut-off upto ~ 6.5 Bev will not affect the polar meson intensity.

6.22 Effect of change of primary spectrum.

If the most general form of the primary spectrum $\frac{\delta D(E)}{D(E)} = aE^{-x}$ is chosen with values of $x = 0, 0.2, 0.4, \ldots\ldots, 2.8$, the percent change in intensity for $a = 1$ is given by

$$\frac{\delta N^{i}_{\lambda,f}(h_0)}{N^{i}_{\lambda,f}(h_0)} = \int_{E^{min}_{\lambda,f}}^{\infty} W^{i}_{\lambda,f}(E, h_0)\, E^{-x}\, dE \quad \ldots (37)$$

In calculating the contribution of this process using the curves for coupling coefficients, it is necessary to consider the summation over successive bands of energy. Table 15 indicates the percent change in various energy bands for Trivandrum meson component for range of values of the exponent. Similar tables have been constructed for meson and neutron components at other stations also. Whenever a spectrum with a particular E_{min} or E_{max} is to be considered, the contribution of the change outside the limiting value has to be neglected.

Table showing the contribution in percent due to particles in different energy bands to $\int_{E_{\lambda,t}\,min}^{\infty} F^{1}_{\lambda_0 f}(E, h_0)\, E^{-x}\, dE$ for different values of x for meson component at Trivandrum.

Energy range Mev	x = 0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.4	2.8
17.6- 20	2740	1520	850	471	282	145.7	31.05	45.04	25.04	13.93	7.75	2.398	0.7406
20- 25	9250	3350	1800	965	512	277.8	149.00	79.34	42.88	23.01	12.34	3.532	1.0225
25- 30	6850	3220	1530	835	441	227.3	117.13	60.33	30.63	16.04	8.26	2.195	0.5831
30- 35	6000	2890	1400	743	370	184.6	91.98	45.88	22.87	11.30	5.68	1.410	0.3504
35- 40	5500	2580	1290	625	303	145.7	71.05	34.42	16.67	8.07	3.91	0.918	0.2165
40- 45	5000	2380	1120	527	249	117.7	55.55	26.25	12.52	5.88	2.77	0.617	0.1380
45- 50	4150	1910	890	445	159	37.4	40.38	18.64	8.61	3.98	1.84	0.393	0.0838
50- 60	7000	3140	1410	632	284	127.3	57.09	25.61	11.49	5.16	2.31	0.435	0.0938
60- 70	5500	2390	1040	450	195	84.6	36.72	15.93	6.91	3.00	1.30	0.245	0.0462
70- 80	4400	1820	750	330	138	58.6	24.74	10.43	4.40	1.85	0.78	0.139	0.0246
80- 90	3600	1420	610	250	103	42.3	17.42	7.15	2.95	1.21	0.50	0.084	0.0144
90- 100	2900	1170	470	189	76	30.6	12.29	4.91	1.98	0.80	0.32	0.052	0.0084
100- 120	4800	1870	730	286	112	43.6	17.04	6.66	2.60	1.02	0.40	0.061	0.0091
120- 150	5040	1900	710	266	100	37.3	14.00	5.25	1.97	0.74	0.28	0.039	0.0055
150- 200	5050	1800	640	228	81	28.9	10.27	3.66	1.30	0.46	0.17	0.021	0.0025
200- 250	3400	1150	390	132	45	15.1	5.11	1.73	0.59	0.20	0.07	0.009	0.0010
250- 300	2400	780	250	83	27	8.7	2.83	0.94	0.30	0.10	0.03	0.003	0.0003
300- 400	2900	900	270	86	27	8.3	2.57	0.79	0.25	0.08	0.02	0.002	0.0003
400- 500	1900	580	160	49	15	4.2	1.24	0.37	0.11	0.03	0.01	0.001	0.0000
500- 600	1400	400	110	32	9	2.5	0.72	0.20	0.06	0.02	0.01	0.000	0.0000
600- 700	1150	310	90	24	6	1.9	0.49	0.13	0.04	0.01	0.00	0.000	0.0000
700-1000	3000	780	200	52	14	3.5	0.92	0.24	0.06	0.02	0.00	0.000	0.0000

Values given are in units of 10^{-3} %.

In table 16, the total contribution due to particles of energy above that corresponding to geomagnetic cut-off is indicated for the different values of the exponent considered for the spectrum and for the different detectors. It is seen from an examination of tables 15 and 16 that;-

(1) For the same station when the spectrum becomes steeper and the strength of the source is unchanged, the amplitude becomes less.

(2) If the spectrum becomes steep, the relative difference between neutrons and mesons is more and the relative difference between low latitude and high latitude and that between mountain and sea level neutrons increases. But though both Climax and Chicago are near $\lambda = 50^{\circ}$, a curious situation arises because Climax is higher than Chicago in elevation, but has $E^{min}_{\lambda,f}$ higher than that for Leeds and Chicago. In consequence, with increasing exponent of the spectrum, a stage is reached when even though the mean energy of response is lower at Climax than that at Chicago or Leeds, the percent decrease is higher at Chicago and Leeds than at Climax. The imposition of a low energy cut-off E_{min} at around the geomagnetic cut-off 2.7 Bev can remove this anomaly, so that the changes at Chicago and Leeds are always smaller than those at Climax.

Table 16

Table showing the values of $\int_{E^{min}_{\lambda,f}}^{\infty} W^{1}_{\lambda,f}\,(E,\,h_{0})\;E^{-x}\,dE$ in percent for different values of x and for different components at different latitudes and altitudes.

Component \ x	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.4	2.8
Trivandrum (N)	38.60	16.28	7.60	3.58	1.68	0.808	0.394	0.194	0.097	0.049	0.013	0.003
~~Lae (N)~~	~~48.10~~	~~19.64~~	~~9.53~~	~~4.76~~	~~2.43~~	~~1.262~~	~~0.666~~	~~0.353~~	~~0.189~~	~~0.102~~	~~0.030~~	~~0.009~~
Huancayo (N)	44.14	20.85	10.34	5.16	2.65	1.385	0.732	0.390	0.210	0.114	0.034	0.010
λ50 sea level (Chicago) (N)	54.86	33.04	21.00	13.87	9.44	6.617	4.739	3.467	2.581	1.955	1.171	0.737
Climax (N)	57.94	35.85	23.09	15.32	10.38	7.190	5.033	3.574	2.563	1.858	1.002	0.583
λ80 (N)	55.54	33.96	21.91	14.74	10.18	7.300	5.353	4.021	3.064	2.412	1.582	1.074
λ80 (M)	41.73	19.30	9.28	4.62	2.36	1.239	0.666	0.368	0.205	0.115	0.039	0.014

M = Meson.

N = Neutron.

6.3 Estimation of the source of variation.

In making this estimation, we have taken the succession of cosmic ray intensity changes occurring after

(1) Cosmic ray storms associated with polar cap absorption events (3 group). Of the 9 events shown in figure 26, there are 4 events of a special nature. For 3 of these, viz. on August 29, 1957, on February 10, 1958 and on March 25, 1958, the intensity starts falling even prior to the PCA event. The fourth is the July 1959 event which is well known for its very remarkable character. A study has been made of the aggregate effect of all 9 events as well as the 5 events after excluding the above mentioned 4 events.

(2) July 1959 storms.

We examine the changes occurring at the polar stations, the equatorial stations and the stations at high latitude.

6.31 Group 3 polar cap absorption events.

(a) Polar region.

In table $\overset{2}{27}$ we present the intensity changes observed on 10 days following epoch of the polar cap absorption events studied together. The details of these 9 events have been given in section 6.3. It is seen from the table that there are several significant discrepancies between meson intensities at the two stations as well as the neutron intensities at the three stations. The discrepancy is more for neutron intensities than for meson intensities. This is particularly surprising because the meson intensities are not corrected for changes of atmospheric temperature.

In selecting data representative of the particular latitude region, we impose an arbitrary limit (0.5 and 0.3 % for neutron and meson intensities respectively), for agreement between the changes at the independent stations and reject the data from any one of the stations if it differs by more than the permissible limit. The stations which have been selected on a particular day are indicated in table 17. An examination of table 17 shows that from +1 to +7 day, the ratio of $\frac{\lambda_{80}(N)}{\lambda_{80}(M)}$ rises steadily from a value 2.26 to a value 3.99. This indicates an increase in the value of the exponent x from +1 to +7 day, or if we use an exponent 0, it requires a high energy cut-off which decreases from 40 Bev on +1 day to 25 Bev on +7 day.

We can consider the implications of a change of geomagnetic cut-off taking place on a day when the spectrum is also disturbed. A low energy cut-off in the primary spectrum exists at 1.9 Bev corresponding to a latitude of 53.4° in the dipole coordinate system. This is indicated by the 'knee' of the latitude effect during the I.G.Y. period as reported by Neher and Anderson[88]. If during the cosmic ray storm, this cut-off is raised to a value E', the strength of the source and the exponent of the energy spectrum required to fit the relative changes of neutrons and mesons at $\lambda \sim 80^\circ$ are shown in table 18 for +1 day of PCA events.

Table 13

Table showing the exponent and the strength of the source required to explain the decreases of meson and neutron intensities at polar stations on the first day of PCA events for different values E'. (i) without temperature correction, (ii) with temperature correction of +0.5 % and (iii) with temperature correction of -0.5 %, for mesons.

Observed decrease $\lambda_{80}^{(N)}$ %	Observed decrease $\lambda_{80}^{(M)}$ %	$\frac{\lambda_{80}^{(N)}}{\lambda_{80}^{(M)}}$	E' assumed (Bev)	Cal $\frac{\lambda_{80}^{(N)}}{\lambda_{80}^{(M)}}$	Exponent x	Strength a λ_{80}
			(i) Without temperature correction for meson			
5.55	2.47	2.25	1.0	2.26	0.5	0.203
			1.5	2.31	0.6	0.260
			3.0	2.22	0.7	0.383
			6.0	2.31	1.0	1.030
			7.0	2.31	1.6	6.700
			9.0	2.34	2.2	48.700
			(ii) With temperature correction of +0.5 % for meson			
5.55	2.97	1.87	1.0	1.78	0.4	0.150
			1.5	1.74	0.4	0.150
			3.0	2.02	0.5	0.300
			6.0	1.93	0.8	0.624
			7.00	1.85	1.3	2.420
			9.0	1.87	2.0	21.070
			(iii) With temperature correction of -0.5 % for meson			
5.55	1.97	2.82	1.0	2.86	0.75	0.239
			1.5	2.84	0.75	0.233
			3.0	2.84	0.90	0.502
			6.0	2.79	1.20	1.601
			7.0	2.83	2.00	17.500
			9.0	2.81	2.30	56.500

It may be noted that the meson intensity at the polar stations has not been corrected for changes of upper air temperature. Without radio sonde data, it is difficult to estimate what this correction should be. The limits of error that may be introduced through neglect of this correction can nevertheless be estimated by assuming that associated with cosmic ray storms temperature changes occur so as to produce changes of meson intensity of ±0.5 %. The required spectrum for the two cases are given in table 18 for +1 day of PCA events. The principal conclusions are not altered by changes of the atmospheric temperature of the assumed magnitude.

An examination of table 15 shows that the neutron and meson intensity decreases at $\lambda = 60^{\circ}$ can be explained either

(1) by assuming a flat spectrum in which case the strength of the source will be small and E' will have a very low value, or

(2) by assuming a very steep spectrum in which case the strength of the source will have a high value and E' will also have a high value.

For reasons already mentioned earlier in section 6.21, geomagnetic cut-off changes will not have any effect in the case of polar stations unless the changes are very large.

(b) Equatorial region.

The coordinates of the stations considered in this region, namely, Trivandrum and Huancayo, have been already given in table 9. The intensity decreases on 10 days following the PCA events are shown in table 10.

Table 10

Table showing the intensity decreases on 10 days following the polar cap absorption events of group B at Trivandrum and Huancayo.

Day.	Trivandrum. (N) %	Huancayo. (N) %	$\frac{\text{Huancayo(N)}}{\text{Trivandrum(N)}}$	Exponent K	$a\lambda_0$
+1	0.91	2.65	2.91	2.4	75.50± 3.50
+2	1.56	3.30	2.12	1.8	15.20± 0.50
+3	1.34	2.70	2.01	1.6	6.19± 0.30
+4	0.92	2.31	2.51	2.0	12.80± 0.50
+5	0.70	2.33	3.33	2.8	209.00±15.00
+6	0.69	2.30	3.33	2.8	200.00±15.00
+7	0.99	2.14	2.16	1.6	5.30± 0.30
+8	1.11	2.33	2.10	1.6	5.85± 0.30
+9	0.96	2.18	2.27	1.6	4.98± 0.30
+10	0.99	1.91	1.93	1.4	2.56± 0.15
Error	± 0.03	± 0.02			

It is seen from the table that the ratio Huancayo neutron to Trivandrum meson is high on +1 day, decreases on +2 and +3 days and increases again upto +6 day. On the other hand, the ratio at the polar region is low on the first day and increases progressively upto the 7th day.

If we consider that the change in intensity is only due to a variational spectrum of the form $\frac{\delta D(E)}{D(E)} = aE^{-x}$, the value of the exponent x and the strength of the source on +1 to +10 days are indicated in table 19. We find that to explain Trivandrum meson and Huancayo neutron intensity changes on different days, the exponent of the spectrum should be high and the corresponding values of a_{λ_0} should also be high particularly on +1, +2, +4, +5 and +6 days.

If a change in the magnetic cut-off rigidity is associated with the onset of the cosmic ray storm and the effect of this change is superposed on the effect due to the variational spectrum, we can calculate alternative values of the change in magnetic cut-off rigidity and the strength of the source a_{λ_0} for different assumed values of the exponent x. Table 20 indicates the values of $\delta E^{min}_{\lambda,f}$ and a_{λ_0} required for the different values of the exponent to explain the changes in intensity at Huancayo and Trivandrum on +1 day.

Thus, neutron intensity changes at Huancayo and meson intensity changes at Trivandrum can be explained either with a steep spectrum with a high value of 'a' or a flat spectrum (x = 0.6) with a low value of 'a' and increase of the geomagnetic cut-off of the order of 0.5 Bev.

Table 20

Table showing the values of the exponent x, the change in the cut-off and the corresponding value of 'a' the strength of the source at equatorial stations for PCA events on +1 day.

Observed Trivandrum(M) Huancayo (N)	Calculated Trivandrum(M) Huancayo (N)	Exponent x	$\delta P^{min}_{\lambda_0 f}$ (Bev)	Strength of the source a_{λ_0}
0.34	0.81	0.4	0.53	0.018
0.34	0.75	0.6	0.52	0.042
0.34	0.69	0.8	0.50	0.094
0.34	0.63	1.0	0.48	0.214
0.34	0.58	1.2	0.45	0.471
0.34	0.54	1.4	0.44	1.041
0.34	0.50	1.6	0.41	2.253
0.34	0.46	1.8	0.37	5.052
0.34	0.43	2.0	0.33	11.000
0.34	0.37	2.4	0.16	58.020

M - Meson N - Neutron

(c) High latitude $\lambda \simeq 50$ region.

Table 9 gives the coordinates of stations considered in this region. Climax is taken to represent a mountain altitude station, Leeds and Chicago being sea level stations. Mean value of changes at Leeds and Chicago when the two are comparable represents the sea level neutron intensity changes. Changes of intensity are shown in table 21.

Table 21

Table showing the neutron intensity decreases on 10 days following the PCA events of group B at high latitude region.

Day.	Intensity decrease (%)				
	Leeds. (N)	Chicago. (N)	λ_{50} sea level (N)	Climax (N)	$\frac{\text{Climax(N)}}{\lambda_{50}\ \text{sea-level (N)}}$
+1	4.20	4.55	4.38 ± 0.18	6.47	1.48
+2	5.77	5.00	5.38 ± 0.38	7.64	1.42
+3	5.04	4.51	4.79 ± 0.25	6.69	1.40
+4	4.32	3.89	4.32 ± 0.05	5.59	1.29
+5	4.74	3.91	4.33 ± 0.42	6.14	1.42
+6	4.97	4.04	4.50 ± 0.46	6.21	1.38
+7	4.39	3.99	4.19 ± 0.20	5.74	1.37
+8	5.08	5.31	5.20 ± 0.12	6.79	1.31
+9	4.28	4.43	4.36 ± 0.07	6.11	1.40
+10	3.21	3.44	3.33 ± 0.12	5.09	1.53
Error	±0.05	±0.05		±0.01	

It is seen that:-

(1) The ratio Climax neutron to λ_{50} sea level neutron remains remarkably constant. The value is relatively high on +1 day and low on +4 day. The changes are, however, much less than at the other regions considered.

(2) The discrepancy between the two sea level stations is quite large on some days.

(3) To explain the average decrease at Chicago and Leeds with respect to the observed decrease at Climax, we require a steep spectrum with a low energy cut-off at 2.7 Bev or a less steep spectrum involving magnetic cut-off changes. If a steep spectrum is fitted we get values of 'a' for $\lambda = 50^\circ$ which are considerably less than those derived for an equally steep spectrum for $\lambda = 0$, using Huancayo neutron and Trivandrum mesons. Table 23 illustrates the ratio $a\lambda_0$ to $a\lambda_{50}$ for various values of the exponents on different days. Thus, a latitude dependence of the strength of the source is required. Even assuming that 'a' does not decrease further in going to higher latitudes, the magnitude of changes of mesons at $\lambda = 80^\circ$ using the value of 'a' at $\lambda = 50^\circ$ and the same exponent which is fitted to $\lambda = 0^\circ$ and $\lambda = 50^\circ$ is too small as compared to the observed value. Thus we have to reject the possibility of explaining the changes without involving the additional mechanism through the change of geomagnetic cut-off.

Table 22

Table showing the exponent of the spectrum and the strength of the source of variation for 10 days following the PCA events.

Day.	Exponent.	a_{λ_0}	$a_{\lambda_{50}}$	$\frac{a_{\lambda_0}}{a_{\lambda_{50}}}$
+1	2.4	75.50 ± 3.50	5.90 ± 0.20	12.80 ± 0.70
+2	1.8	15.20 ± 0.50	2.82 ± 0.07	5.39 ± 0.60
+3	1.6	6.21 ± 0.30	1.68 ± 0.05	3.68 ± 0.23
+4	2.0	18.30 ± 0.50	2.55 ± 0.08	7.17 ± 0.70
+5	2.8	200.00 ±15.00	10.20 ± 0.60	20.31 ± 1.30
+6	2.8	200.00 ±15.00	10.10 ± 0.80	19.80 ± 2.20
+7	1.6	5.30 ± 0.30	1.40 ± 0.07	3.86 ± 0.28
+8	1.6	5.85 ± 0.30	1.72 ± 0.05	3.39 ± 0.20
+9	1.6	4.98 ± 0.30	1.35 ± 0.05	3.60 ± 0.23
+10	1.4	2.56 ± 0.15	0.96 ± 0.04	2.67 ± 0.19

As at the equator, invoking a change in geomagnetic cut-off at $\lambda = 50^\circ$ the changes of neutron intensities at Climax and Chicago can be explained with a less steep spectrum. In table 23 is shown the changes in the geomagnetic cut-off required to explain the observed ratio of changes of intensity at Climax and Chicago on +1 day of PCA events, for various values of the exponent x. The corresponding strength of the source is also given in the same table.

Table 22

Table showing the values of the exponent x, the change in cut-off and the corresponding value $a_{\lambda_{80}}$ the strength of the source at $\lambda = 80^{\circ}$ for PCA events on +1 day.

λ_{80} $\frac{\text{sea level (N)}}{\text{Climax (N)}}$ Obs. Ratio.	Cal. Ratio.	Exponent x	$\delta E^{min}_{\lambda, f}$ (Bev)	$a_{\lambda_{80}}$
0.68	0.92	0.4	0.33	0.1154
0.68	0.91	0.6	0.33	0.1816
0.68	0.91	0.8	0.33	0.2734
0.68	0.91	1.0	0.33	0.4036
0.68	0.92	1.2	0.33	0.5763
0.68	0.94	1.4	0.35	0.7075
0.68	0.97	1.6	0.37	1.0761
0.68	1.00	1.8	0.40	1.4420
0.68	1.06	2.0	0.43	1.8454
0.68	1.19	2.4	0.49	3.0170
0.68	1.33	2.8	0.56	4.6510

(d) Explanation of global changes.

Since neither an isotropic model nor a non-isotropic model assuming a latitude dependence of the strength of the source can alone explain the observed decreases at various places, we attempt to explain these by assuming an isotropic source and invoking a change in geomagnetic cut-off. In figure 33 are plotted the graphs showing the relationship between the strength of the source and the exponent on +1 day of PCA events at $\lambda = 0$ (given in table 20) and at $\lambda = 50^{\circ}$ (given in table 23). The value of the exponent and the strength of the source corresponding to the point of intersection of these two curves with the appropriate changes in cut-off necessarily explains the decreases of neutron and meson intensities at $\lambda = 50^{\circ}$ and $\lambda = 0^{\circ}$. Similar calculations are done for other days also. Table 24 shows the value of the exponent and the strength of the

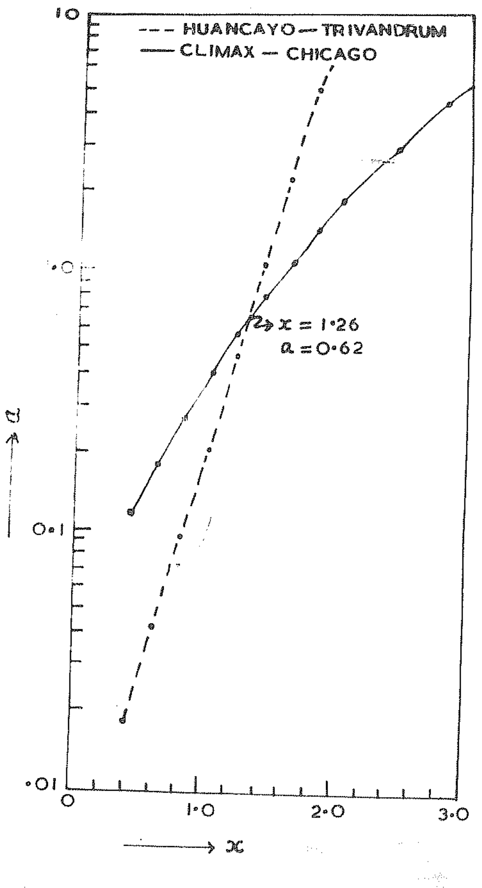

Fig. 33 - Figure showing the relation between the exponent x and the strength of the source a required to explain intensity changes at $\lambda = 0^{\circ}$ and $\lambda = 50^{\circ}$.

source corresponding to the cross-over point for various days following the PCA events. The expected decreases of neutron and meson intensities at polar latitudes for such a source are also shown in the same table. It is clear that with such a source we cannot explain the decreases of mesons at $\lambda = 80^\circ$.

Table 24

Table showing the value of the exponent, the strength of the source and the required change in cut-off which can explain the decreases at equatorial and high latitudes on different days of PCA events.

DAY.	x	Strength of the source a	$\delta E^{min}_{\lambda,f}$ at $\lambda = 50$ (Bev)	$\delta E^{min}_{\lambda,f}$ at $\lambda = 0$ (Bev)	$\lambda = 80$ Mesons Cal. I %	$\lambda = 80$ Mesons Obs. I %	$\lambda = 80$ neutrons Cal. I %	$\lambda = 80$ neutrons Obs. I %
+1	1.86	0.62	0.33	0.45	0.65	2.50	4.2	5.6
+2	0.86	0.39	0.33	0.26	1.54	2.30	6.2	6.6
+3	0.83	0.34	0.29	0.22	1.60	1.90	6.3	5.7
+6	1.71	1.32	0.31	0.46	0.35	1.35	4.7	6.2

We finally attempt to explain the various decreases by assuming a non-isotropic model of the variation spectrum as well as invoking a change in geomagnetic cut-off. We first determine the exponent and the strength of the source at $\lambda = 50^\circ$, assuming E' to be at 1.5 Bev. (low energy cut-off), which can explain the observed ratio of neutron to mesons at this latitude. For this exponent we next calculate the change in the geomagnetic cut-off required and the strength of the source at $\lambda = 50^{\circ}$ and $\lambda = 0^{\circ}$. The results are summarised in table 25. The strength of the source at $\lambda = 0$ is much smaller than the strength at $\lambda = 50$ for all the days considered. The change in cut-off required at $\lambda = 0$ is also greater than that required at $\lambda = 50^{\circ}$. Instead, if we assume the strength at all latitudes to be the same as at $\lambda = 50^{\circ}$, then the change in exponent required at various latitudes are also indicated in the same table.

We thus finally conclude that no isotropic source with or without a change in cut-off can explain the observed distributions of decreases. We have to invoke the changes in geomagnetic cut-off as well as a latitude dependence of the strength of the source or the exponent.

6.32 July 1959 events.

We have attempted to find the energy dependence of the changes of intensity for the July event. The ratios of the various observed decreases at different latitudes and their changes from day to day have already been discussed in section 5.5. To determine the energy dependence and the nature of the source of modulation, we follow the same steps as for the PCA events.

Table 23

Table showing the exponent, strength of the source at different latitudes and the geomagnetic cut-off which are required to explain the decrease.

Day	x	$\delta E^{min}_{\lambda,f}$ at $\lambda = 50$ (Bev)	$\delta E^{min}_{\lambda,f}$ at $\lambda = 0$ (Bev)	Strength of the source $a_{\lambda_{50}}$	$a_{\lambda_{30}}$	a_{λ_0}	x when $a_{\lambda_{50}} = a_{\lambda_{30}} = a_{\lambda_0}$ x_{50}	x_{30}	x_0
+1	0.60	0.33	0.32	0.360	0.182	0.092	0.60	0.80	1.05
+2	0.75	0.33	0.40	0.402	0.315	0.265	0.75	0.86	0.55
+3	0.80	0.38	0.29	0.400	0.300	0.255	0.80	0.93	0.87
+5	0.90	0.25	0.42	0.404	0.353	0.397	0.90	0.98	1.40

Using the same arguments as for the PCA events, we can show that neither an isotropic source with a change in cut-off nor a non-isotropic source by itself can explain the observed decreases at all places. Using the same method as given in the previous section, we have calculated the exponent, the changes in geomagnetic cut-off required at $\lambda = 50^{\circ}$ and $\lambda = 0^{\circ}$ and the strength of the source required to explain the decreases at $\lambda = 80^{\circ}$, 50° and 0° for some representative days. The three successive Forbush decreases have their onsets on 11th, 15th and 17th respectively.

In table 26, the change in cut-off required and the strength of the source at $\lambda = 0$, 50 and 80 for these days are given. It will be seen that on 11th, 17th and 18th we can fit parameters for 'a', 'x' and $\delta E^{min}_{\lambda,t}$ analogous to those fitted for the PCA events. The main difference is in the magnitude of these individual parameters. During the July events, the values of the change in cut-off required as well as the strength of the source at all latitudes are much higher than for PCA events. However, just as for PCA events, the value of 'a' at $\lambda = 0$ is smaller than at $\lambda = 80^{\circ}$ and the change in cut-off at $\lambda = 0$ is higher than at $\lambda = 80^{\circ}$.

An important point that arises, however, is that on 12th, 15th and 16th even the various parameters which we have considered above fail to explain the observed decreases at $\lambda = 0^{\circ}$. The decrease of meson

Table 28

Table showing the exponent, strength of the source at different latitudes and the geomagnetic cut-off which are required to explain the decreases in intensity on representative days during July 1959 events.

Date	x	$\delta E^{min}_{\lambda,c}$ at $\lambda = 50$ (Bev)	$\delta E^{min}_{\lambda,c}$ at $\lambda = 0$ (Bev)	Strength of the source		
				$a_{\lambda 60}$	$a_{\lambda 50}$	$a_{\lambda 0}$
11-7-59	0.4	0.25	0.31	0.108	0.057	0.0035
12-7-59	0.6	0.55	-	0.300	0.294	-
15-7-59	0.6	0.60	-	0.780	0.651	-
16-7-59	0.6	0.75	-	0.745	0.674	-
17-7-59	0.6	0.85	1.08	0.725	0.712	0.1670
18-7-59	0.6	0.47	1.73	1.016	0.300	0.2350

intensity being only about 1/7 the decrease of neutron intensity at Huancayo we will not get a reasonable value for the change in geomagnetic cut-off at equatorial latitude for the exponent considered. On other days, however, we can explain the global distribution of intensity changes by a non-isotropic source and invoking a change in geomagnetic cut-off.

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CHAPTER VII

DISCUSSION AND CONCLUSIONS

7.1 Significance of studying time variations of cosmic ray intensity with narrow angle telescopes.

It is now clear that during the period 1957 to 1959, at Ahmedabad as well as at Trivandrum, there is no significant difference in the daily variation recorded by telescopes of semi-angle of opening 5° x 20°, 20° x 20° and 23° x 37°. This holds not only for the 12 month mean time averaged daily variations, but for the distribution of the daily variation on a day to day basis. Considered in the context of earlier studies during 1953 and 1954, when the narrow angle telescopes showed larger amplitudes, there is a noticeable difference between observations made during a period of low solar activity and of high solar activity. This, however, requires further confirmation during the ensuing solar minimum. If geomagnetically disturbed days are compared to quiet days, the diurnal time of maximum becoming earlier is more noticeable in narrow angle telescopes than in wide angle telescopes as was found by Sekido et al[220].

7.2 The source of the daily variation.

Comparative studies of the 12 month mean daily variation at Trivandrum, Kodaikanal and Ahmedabad with telescopes of similar characteristics show that during 1957, 1958 and 1959, the daily variations at Ahmedabad and Trivandrum are comparable while the daily variation at Kodaikanal has a somewhat smaller amplitude in all three years. The time of maximum of the diurnal component at all three places is comparable. Thus, apart from the lower amplitude of the daily variation at Kodaikanal, which appears to be related to the lower mean energy of response of the meson detector at mountain elevation, the instruments at all three stations respond to the same source of the daily variation. There appears to be a greater variability in the time of maximum of the instrument at Kodaikanal responding to a lower mean energy of response, and this agrees with the observations of Rao[229] comparing the variability of the diurnal time of maximum in west pointing telescopes with east pointing telescopes.

There is no significant change in the amplitude or the time of maximum of the daily variation during 1957 and 1958, but during 1959 the amplitude of the 12 month mean daily variation increases on account of the decreased variability of the time of maximum from day to day.

At low latitudes, there is a significant semi-diurnal variation of meson intensity, which is not related to the semidiurnal variation of pressure. This is in agreement with the observation of Rao[229] from east-west directional studies made at Ahmedabad that a semidiurnal component is associated with the daily variation produced by the primary anisotropy of cosmic rays.

7.3 Polar cap absorption events.

There are several PCA events during 1957 and 1958 which are not associated with any significant change of cosmic ray intensity and produce only small effects on the geomagnetic field. If we designate these as type 'A' events, distinguishing them from type 'B' events where major changes in cosmic ray intensity and in geomagnetism occur, it is found that type 'A' events are associated with flares on the western limb and, on the average, with shorter time lags than type 'B' events. Thus one can have the ejection of relativistic protons from the sun without any major emission of either low or high energy plasma clouds as defined by Obayashi and Hakura[177]. The 'A' type PCA events which do not produce significant changes of daily mean cosmic ray intensity or of geomagnetic field are nevertheless effective in producing anisotropy of cosmic rays 3 to 6 days after the flare.

For 'B' type events, table 27 indicates the ratio of decreases of pairs of recorders differing in mean energy of response and latitude. The ratios considered are:-

(a) Equatorial region

$$\frac{\text{Neutron intensity at Huancayo}}{\text{Meson intensity at Trivandrum}}$$

(b) Polar region $\lambda = 80^\circ$

$$\frac{\text{Neutron intensity at sea level}}{\text{Meson intensity at sea level}}$$

(c) Mountain stations

$$\frac{\text{Neutron intensity at Climax}}{\text{Neutron intensity at Huancayo}}$$

Table 27

Table showing the progressive change of the ratios of different intensity from +1 to +10 days following PCA events. 1 represents the ratio of average intensity for all 9 events, 2 for average intensity for 5 events excluding the events on August 29, 1957; February 10, 1958; March 26, 1958 and July 10, 1959, and 3 represents for the intensity following the July event on July 10, 1959.

Day	Huancayo (N) / Trivandrum (N)			λ80 (N) / λ80 (M)			Climax (N) / Huancayo (N)		
	1	2	3	1	2	3	1	2	3
1	2.01	-2.60	3.50	2.26	2.48	1.71	2.44	2.51	2.71
2	2.12	1.99	4.89	2.38	2.71	2.51	2.32	2.35	2.37
3	2.01	1.92	3.38	3.01	3.17	2.81	2.48	2.57	2.30
4	2.51	2.37	3.42	3.48	3.55	2.41	2.42	2.68	2.29
5	3.33	2.67	6.00	3.57	3.56	2.42	2.64	2.91	2.53
6	3.33	3.00	5.00	3.75	3.29	2.51	2.70	2.86	2.34
7	2.16	1.83	2.78	3.99	4.05	2.11	2.68	3.24	2.37
8	2.10	2.62	2.62	3.00	4.14	2.23	2.91	3.19	2.48
9	2.27	2.57	2.33	3.72	5.28	2.27	2.80	3.29	2.53
10	1.93	1.71	2.64	3.10	3.98	2.31	2.64	2.36	2.50

The table indicates the ratios for 10 successive days after the onset of the PCA events. The first column in each case relates to the 9 B type PCA events (table 10), the second column relates to 5 of these after excluding 4 events of a special type as described in section 6.3. Column 3 relates to the July 1959 event where the first day corresponds to the 11th of July. Ratios (a) and (b) clearly demonstrate that about 5 to 6 days after epoch, a secondary disturbance makes its effects felt most prominently at the equatorial stations. Ratio (c) demonstrates that the latitude dependence of the change alters significantly after the 5th day. The secondary disturbance after 5 days is a general characteristic not related to the peculiarity of any one PCA event followed by a cosmic ray storm.

7.4 Cosmic ray storms.

Perhaps the most important conclusion that emerges from the present work relates to the consideration of the type of processes which are responsible for cosmic ray storms. Many workers have commented on the fact that during Forbush decreases, the meson intensity has a later time of onset and an earlier recovery than neutron intensity. Many have also commented on the low amplitude of changes observed at sea level stations at $\lambda = 50^\circ$ compared to mountain stations at a comparable latitude. However, the implications of these observations with respect to the models of the modulating process have been largely ignored. It is demonstrated in the present thesis that from an experimental stand point, barring a few exceptions, there is no basis for dismissing the reality of these observations and that if we attempt to take them into account, the currently prevalent models are totally inadequate to explain the global distribution of changes of intensity.

McCracken and Parsons have demonstrated the anisotropy of the initial phase of Forbush decreases with respect to the earth-sun line. Our present work demonstrates that there is a marked anisotropy perpendicular to the plane of the ecliptic. This anisotropy can be expressed either in term of change with latitude of the strength of the source or the spectrum of variation. On physical considerations the former seems to be the more likely explanation. The anisotropy is most marked on the two days immediately following the onset of the storm and again on the 5th and the 6th day.

The second important conclusion is that changes of the primary spectrum by themselves cannot explain the global distribution of decrease during a cosmic ray storm. The type of geomagnetic changes which are required involve the enhancement of geomagnetic cut-off energy. The increase in cut-off has to be larger at the equator than at higher latitudes and larger on +1 and +2 days than on +5 and +6 days. The subsidiary effect on +5 and +6 days is predominantly seen at the equator rather than at higher latitudes.

At the present moment, the explanation is based purely on phenomenological considerations and there may be alternative models. But it is important to relate our interpretation to a theoretical model involving the interaction of solar plasma streams with the geomagnetic field system. Rothwell[272] and Parker[242] suggest that geomagnetic cut-off should decrease following storms. This is necessary to explain the presence of low energy relativistic protons in the stratosphere at latitudes where they are normally forbidden. But it is possible that the relativistic protons are scattered from the solar plasma into the exosphere. However, at the present stage of theoretical and experimental studies, these considerations are largely speculative. It is the view of the author that, in any case, current theories are inadequate to explain several experimentally established features of cosmic ray storms.

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