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Dissertation

on

A STUDY OF THE TIME VARIATION OF COSMIC RAYS AT LOW LATITUDES

presented

by

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STATEMENT

The daily variation of meson intensity measured with vertical counter telescopes has been studied by the author during the years 1955, 1956 and 1957 at the equatorial sea level stations of Trivandrum (Geomagnetic latitude:- $1^{0}S$). The twelve month mean daily variation during each year and the frequency distribution of the parameters of the diurnal and semidiurnal components of the daily variation on individual days have been studied. The change of the 12 month mean daily variation in the years 1955-57 corresponding to increasing sunspot activity has the following features.

(a) The twelve month mean daily variation undergoes significant long term changes. The amplitude of the mean daily variation at Trivandrum increased from 1955 to 1956 and after that it decreased in 1957 to a value lower than that in 1955. This decrease in amplitude from 1955 to 1957 is found to be due to smaller amplitudes on individual days in 1957 compared to 1955 as also due to a high scatter in the time of maximum of first harmonic in 1957. The large amplitude in 1956 is due to a smaller scatter of the time of maximum of the diurnal component on individual days than during 1955 or 1957. Moreover the amplitudes on low and high C_p days in this year are comparable.

(b) The twelve month mean percentage daily variation of low energy component also decreases from 1955 to 1957.

(c) The time of maximum of the diurnal component becomes later from 1955 to 1957. No significant change takes place in

the time of maximum of the semidiurnal component.

(d) For a proper study of the daily variation, it is necessary to consider the semidiurnal component of the daily variation in addition to the diurnal component. The change of daily variation unresolved into its harmonic components give a true representation of the changes. The daily variation at Trivandrum (unresolved into its harmonic components) reveals significant changes. The bihourly deviation at 0200 hours in the average daily variation which is significantly positive in 1955 disappears in 1957. The amplitude of the maximum at 1000-1400 hours and the minimum at 1600-2200 hours reduces from 1955 to 1957.

(2) It has been reported by many workers that certain changes in the electromagnetic conditions of interplanetary space produce variations in the geomagnetic field and in the cosmic ray intensity. An attempt has been made in this dissertation to understand the association between Cp, the geomagnetic planetary index and the daily variations. The study shows the following noteworthy features.

(a) The relationship of Cp with the parameters of the daily variation changes from year to year.

(b) In 1955 and 1957, the days having values of Cp from 0.6 to 1.0 show smaller mean amplitude compared to days of low and high Cp. Satya Prakash in his study of data of nucleonic component at the mountain station of Kodaikanal has also reported similar result.

(c) A study of days having maximum values of Cp indicates that these days are associated with different types of changes in the daily variation depending upon whether these epoch days belong to the class of geomagnetic disturbances which show a recurrence tendency on ± 27 ± 1 days or to the nonrecurrent class. The recurrent group of epochs of maximum Cp days are associated with higher amplitudes of daily variation before the epoch, while the nonrecurrent group has significantly high amplitudes after the epoch.

(d) Bell and Glaser have reported that certain changes on or near the sun are associated with low values of Cp. Our study indicates that the days with low values of Cp are associated with smaller amplitudes in daily variation. The amplitudes are larger after the epochs than immediately before the epoch days of low Cp.

(e) A study of days having significantly higher amplitudes simultaneously at the low latitude sea level stations, Trivandrum and Ahmedabad shows that such days are associated with high values of Cp only in the year 1956.

(3) To study the nature of the source of anisotropy at low latitude stations (which have in general a larger semidiurnal component of daily variation compared to high latitude stations), a comparative study of 12-month mean daily variation measured at Trivandrum, Kodaikanal and Ahmedabad with identical instruments from 1955 to 1957 is made. The study indicates that the experimental observations in 1955 and 1956 cannot be explained by a unique source of anisotropy outside the influence of the geomagnetic field.

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CONTENTS

		Page
I.	INTRODUCTION.	1
1.1	Methods for relating the observed secondary fluctuations to primary fluctuations.	4
1.11	Geomagnetic effects.	4
1.12	Polar diagram of cosmic ray telescope	4
1.13	Methods of relating primary cosmic ray intensity changes to the secondary intensity changes.	7
1.14	Practical methods of eliminating intensity changes due to atmospheric radiations.	11
1.2	Anisotropy of primary radiation.	17
1.21	The relationship of observed daily variation to anisotropy and the determination of the spectrum of the daily variation.	17
1.211	Source of daily variation and its spectrum.	19
1.3	Long term changes in daily variation and their world wide characteristics.	21
1.31	Relationship of long term changes with solar and terrestrial phenomena.	22
1.4	Day to day changes of anisotropy.	26
1.5	Galactic anisotropy.	31
1.6	Time variations of primary radiation.	33
1.61	Variation of intensity with solar cycle.	33
1.62	Change of "knee" of latitude effect.	34
1.63	Magnetic storm type changes.	36
1.64	27 day recurrent changes of intensity.	39

		Page
1.65	Solar flare increases.	41
1.651	Solar flare of 23rd February, 1956.	43
1.652	Effects of small solar flares.	47
1.7	Interpretation of variations.	48
1.71	Geocentric and heliocentric models.	50
1.72	Modulation in interplanetary space.	58
1.8	Statement of the problem.	62
II.	EXPERIMENTAL TECHNIQUE.	64
2.1	The apparatus.	67
2.2	Geiger Muller Counter.	69
2.21	Preparation of Geiger counters.	71
2.3	Electronic units.	73
2.31	Quenching unit.	73
2.32	Coincidence unit.	75
2.33	Scaling unit.	76
2.34	Power supplies.	78
2.341	High voltage supply.	79
2.342	Low voltage power supply.	80
2.35	Automatic photographic device.	81
III.	METHODS OF ANALYSIS.	84
3.1	Cosmic Ray data.	84
3.31	Fourier analysis.	86
3.32	The harmonic dial.	88
3.33	Standard error of the Fourier coefficients.	89
3.4	Correlation analysis.	91

		Page
3.5	Chree analysis.	93
3.6	Punch card system of tabulation of data.	94
IV.	EXPERIMENTAL RESULTS.	96
4.1	Corrections for meteorological factors.	96
4.2	Long term changes.	102
4.21	Examination of 12 month mean daily variation.	102
4.22	Examination of distribution in different years of characteristics of the daily variation.	105
4.221	r_1 histogram.	106
4.222	r_2 histogram.	107
4.223	ϕ_1 histogram.	108
4.224	ϕ_2 histogram.	109
4.23	Analysis of significant positive and negative bihourly deviations of the 12 month mean daily variation.	110
4.3	Daily variation and geomagnetic activity.	111
4.31	Mean daily variation on groups of days having low, medium and high values of C_p.	111
4.32	Study of histograms of parameters of the daily variation in low, medium and high C_p groups.	115
4.321	r_1 histogram.	115
4.322	r_2 histogram.	117
4.323	ϕ_1 histogram.	117
4.324	ϕ_2 histogram.	119
4.33	Analysis of significant positive and negative bihourly deviations associated with days of low, medium and high C_p.	120

Page

4.34 Sequential changes in daily variation related to geomagnetic disturbances. 122

4.341 Association of C_p maxima with cosmic ray daily variation. 123

4.342 Association of recurrent and nonrecurrent C_p maxima with daily variation. 125

4.343 Daily variation and the duration of solar activity related to geomagnetic disturbances. 128

4.344 C_p three analysis of A, B, C and D groups. 132

4.345 Association of C_p minima with cosmic ray daily variation. 134

4.35 Large daily variation and geomagnetic activity. 136

V. DISCUSSION. 139

5.1 Comparative study of cosmic ray intensity at Trivandrum, Kodaikanal and Ahmedabad. 139

5.2 Long term changes in the 12 month mean daily variation of low energy component of cosmic rays. 146

5.3 Source of daily variation. 146

5.4 Daily variation and electromagnetic state of interplanetary space. 153

5.5 Conclusion. 155

REFERENCES.

REPRINTS OF PAPERS PUBLISHED.

CHAPTER I

INTRODUCTION

The history of the study of time variations of cosmic rays can be divided into three periods. In the first period, fluctuations of several percent were recorded. Attempts were made to connect them with various geophysical and astrophysical phenomena and a search was made for the source of cosmic rays. The results of such measurements often contradicted one another as they rarely were beyond the limits of statistical errors.

In the second period the contributions of meteorological factors effecting cosmic rays were studied and it was realised that cosmic ray variations of atmospheric origin are often of the same order of magnitude as the variations observed. Thus for a long time it was believed that the primary intensity was constant and isotropic to a fraction of a percent.

In the third period recording techniques were developed in order to reduce statistical errors and to measure the secondary nucleonic component besides the

meson component. Variations due to atmospheric factors were rigorously examined, theoretically and experimentally. The significant variations which remained even after applying corrections for the atmospheric contribution were shown to be of extraterrestrial origin. In fact in certain cases the elimination of the atmospheric contribution increased the residual variations. In this period appropriate coupling coefficients were determined which correlate the measured secondary intensity with the primary cosmic rays. Moreover, a thorough study was made of the deflection of primary particles in the geomagnetic field.

The time variations of cosmic rays now provide us with a valuable tool for studying the electromagnetic state of interplanetary and interstellar space and for following high energy processes in the solar atmosphere. A great deal of work has therefore been done in this field in recent years. Elliot[1] has reviewed the status of knowledge upto 1951. More recent reviews of progress in this subject have been prepared by Sarabhai and Nerurkar[2] and by Singer[3]. Dorman[4] has treated this subject in great detail in his book "Time Variation of Cosmic Rays" and individual authors such as Simpson[5], Forbush[6] and Sarabhai et al[7] have reviewed particular aspects of the field, principally in the light of work of their own groups.

This thesis and the investigation conducted by the

author deals particularly with the daily variation at low latitudes and in this introduction reference is made specially to the experimental results and the interpretation of the solar daily variation and only generally to other types of variations of cosmic ray intensity.

In studying the time variation of cosmic rays it is necessary to make a distinction between changes in the level of the cosmic ray intensity which can be studied on a day to day basis and the solar daily variation of intensity related to an anisotropy of the primary radiation. The day to day changes in intensity could be ideally measured by placing an omnidirectional detector at a point in space unhindered by the shadow of the earth. The daily variation of intensity on the other hand would be observed even though all characteristics of primary radiation are constant, by a detector scanning a region of space in which cosmic ray intensity is anisotropic. In practice we are far removed from the ideal situation since our measurements are made on the surface of the earth with a changeable atmosphere above it. The variations which we study can be due to the anisotropy, meteorological factors and those referred to as primary variations which could be due to all other causes. Nevertheless it is possible, as we describe later to gain some information about the anisotropy of cosmic rays.

1.1 Methods for relating the observed secondary fluctuations to primary fluctuations

1.11 Geomagnetic effects.

For locating the source of anisotropy and for other studies it is necessary to know the deflections suffered by particles of various energies in the geomagnetic field. The results of investigations by Stormer[8] and Lemaitre and Vallarta[9,10,11] in this field have been summarised and presented in a convenient form by Alpher[12]. This work deals with isotropic radiation only. To interpret effects such as the solar flare effect where isotropy is not observed it becomes necessary to know in detail the trajectories of the particles. The work of computing individual orbits of protons has been done by Schlutter[13], Firor[14], Jory[15], Vallarta et al[16], Lust et al[17] and Lust[18]. Brunberg and Dattner[19] on the other hand have approached the problem by model experiments. They have determined 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. The results have been presented in convenient graphical form. These results as we will see in the next section form a most valuable basis for the interpretation of effects caused by anisotropic radiation.

1.12 Polar diagram of cosmic ray telescope

Brunberg[20] has recently worked out the intensities

which will be measured by ionisation chamber and counter telescopes of various semivertical angles of opening in the east-west plane for different positions of the source of anisotropy.

Let $I = I(p)$ particles/cm^2.sec.ster.momentum interval represent the differential momentum spectrum. Since the momentum of a particle does not change in the magnetic field the number of particles recorded by a telescope which subtends a solid angle dw around $\vec{p}$ (denoting the direction of arrival of particles with momentum p) and an area da perpendicular to $\vec{p}$ is

$$d^2\gamma = I(p)\, dp\, da \cos u\, M\, d\Lambda \qquad (1)$$

where $M = dw/dw_\infty$ is defined as the magnification of the beam. dw_∞ is the projection of dw on the sphere of asymptotic directions. This magnification is caused by the geomagnetic bending of particles. $d\Lambda$ is the solid angle of the source within the solid angle of telescope dw. u is the angle between the parallel beam of the particles and the axis of the telescope. Integrating the above expression for all the surface elements of the telescope we get

$$d\gamma = I(p)\, dp\, a \cos u\, G(u) M\, \Delta\Lambda \qquad (2)$$

where $G(u)$ is a function determined by the geometry of the telescope and takes into account the fact that only a part of the surface records particles arriving from the direction defined by the angle u. With the help of equation (2) the counting rate of a telescope can be calculated for

different angular positions of the source element represented by the solid angle $\Delta\Omega$ on the sphere of asymptotic directions and assuming a certain momentum spectrum. Each portion of the element gives a certain counting rate in the telescope for a given momentum interval. Let us mark out at each position of $\Delta\Omega$ a distance in the radial direction proportional to the counting rate of the telescope with $\Delta\Omega$ in this position. This will give a curved surface over the sphere, the height of which varies continuously. This "mountain" is defined as the 3-dimensional polar diagram of the telescope in the given momentum interval. The total counting rate for a certain angular position of the source element is given by

$$\gamma = a\,\Delta\Omega \int_{p_{min}}^{p_{max.}} K \cos u\, C(u)\, I(p)\, dp$$

So far we have not considered the effect of the atmosphere. Various processes in the atmosphere have a tendency to spread the beam so that a parallel beam of primary particles is gradually converted into more or less divergent beam of secondaries which are finally recorded by the telescope. The counting rate dn_μ after considering the role of the atmosphere becomes

$$dn_\mu = \int_{\alpha=0}^{2\pi} \int_{\beta=0}^{u_{max.}} a \cos\beta \sin\beta\, d\alpha\, d\beta\, I(p)\, dp\, K \Delta\Omega \int_0^\infty k\, dz$$

where $I(p)\, dp\, K \Delta\Omega \int_0^\infty k\, dz$ represents the number of μ mesons arriving at the telescope from the direction α, β (Azimuthal and Zenith angles of telescope respectively) produced by primary particles which came from the direction α', β'. The factor $K = k.J.D$, where k represents the

production rate of μ mesons (from π or primary particles) while D represents the decrease in meson intensity due to decay and J gives the absorption rate.

Taking a source of anisotropy whose intensity varies sinusoidally in the equatorial plane, Brunberg has shown that the amplitudes of the extraterrestrial intensity distribution are reduced in the first, second and third harmonic components of daily variation by factors of 0.72, 0.32 and 0.05 respectively when measured with an ionisation chamber at Huancayo. The corresponding reduction factors for cylindrical counter telescopes at Huancayo are as follows.

Semivertical angle in the east-west plane	Reduction factors for the harmonic components	
	1st Harmonic	2nd Harmonic
45°	0.86	0.53
25°	0.89	0.60
15°	0.92	0.66

Thus a narrow angle telescope would observe higher amplitudes compared to wide angle telescopes and ionisation chamber at low latitudes.

1.13 Methods of relating the primary cosmic ray intensity changes to the secondary intensity changes.

The spectrum of the observed secondary particles is related to the primary spectrum through a "multiplicity

function" or a "generating function". For geomagnetic field sensitive primaries this relation can be easily worked out without going into the details of the intervening multiplication processes. If for an observing station situated at latitude λ and longitude f and level with pressure h_0, intensity of ith component (muons, stars, bursts, soft component etc.) produced by the primary energy spectrum $D(E)$ is $N^i_{\lambda,f}(h_0)$, then following Dorman[21]

$$N^i_{\lambda,f}(h_0) = \int_{E^{min.}_{\lambda,f}}^{\infty} D(E)\, m^i(E,h_0)\, dE \qquad (1)$$

where $m^i(E,h_0)$ called "multiplicity" represents the number of type i particles formed by a single primary particle of total energy E at the pressure level h_0 in the atmosphere. To find the time variation of the observed intensity of the cosmic rays, we vary equation (1) with respect to all the parameters available in the equation to get

$$\frac{\delta N^i_{\lambda,f}(h_0)}{N^i_{\lambda,f}(h_0)} = -\delta E^{min}_{\lambda,f}\; W^i_{\lambda,f}(E^{min}_{\lambda,f}, h_0) + \int_{E^{min.}_{\lambda,f}}^{\infty} \frac{\delta D(E)}{D(E)}\, W^i_{\lambda,f}(E,h_0)\, dE$$
$$+ \int_{E^{min.}_{\lambda,f}}^{\infty} \frac{\delta m^i(E,h_0)}{m^i(E,h_0)}\, W^i_{\lambda,f}(E,h_0)\, dE \qquad (2)$$

where $W^i_{\lambda,f}(E,h_0) = \dfrac{D(E)\, m^i(E,h_0)}{N^i_{\lambda,f}(h_0)}$

is the coupling coefficient showing how large the secondary variation will be due to the variation of primary spectrum. In equation (2) the first term arises

due to variation in geomagnetic effective threshold $R^{min}_{1,f}$ of the primary particle. This variation can be due to combined influence of various geomagnetic disturbances.

The second term represents the variation of differential energy spectrum of the primaries. It reflects the variation of the primary flux of cosmic rays which are of extraterrestrial origin.

The third term represents the variation due to the variation of the multiplicity for a fixed primary flux. The variation of $n^i(E,h_o)$ can be due to a variation in the experimental conditions (e.g. change in the thickness of the shield) or to the variation in atmospheric conditions. To determine the coupling coefficient we differentiate equation (1) with respect to $R^{min}_{1,f}$

$$\frac{\delta N^i_{1,f}(h_o)}{\delta R^{min}_{1,f}} = -D(R^{min}_{1,f})\, n^i(R^{min}_{1,f}, h_o)$$

substituting this in equation (3) we get

$$W^i_{1,f}(R^{min}_{1,f}, h_o) = -\frac{1}{N^i_{1,f}(h_o)} \cdot \frac{\partial N^i_{1,f}(h_o)}{\partial R^{min}_{1,f}}$$

Thus if the latitude effect for a given ith component of cosmic rays is known then the right hand side of above equation can be determined and hence the coupling coefficient may be calculated for field sensitive primaries The coefficient for the region of higher energies can be

obtained by extrapolation although with a low degree of reliability.

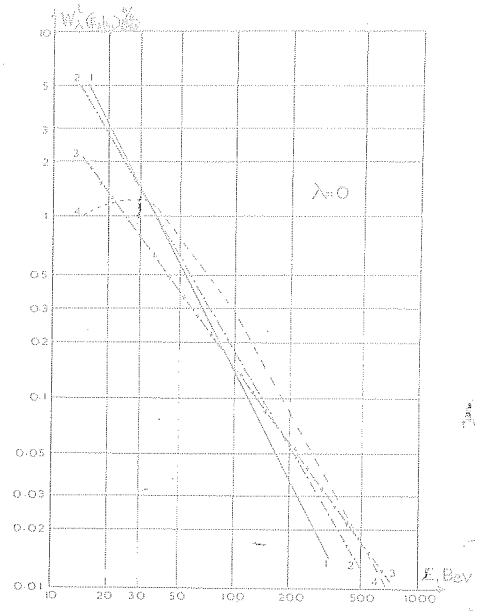

Fig. 1 - Coupling coefficients. (1) For total intensity (ionising component) at high altitude. (2) For sea level neutron intensity. (3) For 4300 meters altitude total intensity. (4) For sea level hard component.

Trieman[22], Fonger[23], Nagashima[24] and Dorman[21] have worked out the coupling coefficients for various components. Fig. 1 from Dorman indicates for $\lambda = 0$ the value of the coupling coefficients for total ionising intensity, hard component intensity and neutron intensity at sea level and total intensity at 4300 meters altitude, for primary energies upto 1000 Bev. Knowing the coupling coefficient and the geomagnetic and atmospheric correction, one can determine the source of primary variation (direction)

of anisotropy in space) for a particular type of variation observed under different conditions.

1.14 Practical methods of eliminating intensity changes due to atmospheric variations.

The role of atmosphere in causing changes in cosmic ray intensity has been greatly clarified in recent times. The early work in this field has been done by Duperier who presented a regression equation connecting the cosmic ray variations with barometric pressure, change in height of 100 mb level and with change of mean temperature between the 100 mb and 200 mb levels. The physical meanings to be attached to the coefficients of Duperier's equation have been given by Trefall[25,26,27], Barrot et al[28]. Modifications of Duperier's original equation have been suggested by Neda and Kudo[29] and other workers.

Dilbert[30], Maeda and Wada[31] and Hayakawa[32] have done theoretical work to deduce the contributions of various atmospheric parameters in cosmic ray variations. Maeda and Wada[31] have concentrated on the controversial problem of the contribution of temperature changes to the cosmic ray intensity. They have calculated the temperature coefficient as a function of energy and altitudes by using the energy spectrum of cosmic ray mesons. Fig. 2 shows their results in a convenient form. The atmospheric temperature effect has been separated into two terms, the first represents ordinary negative temperature effect due

to decay of μ mesons and the second gives the positive temperature effect due to the variation of μ meson production

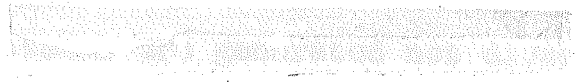

Fig. 2 - The coefficient of partial temperature effect at different depths in the atmosphere.

rates. The partial temperature coefficient which occurs in their equation expresses the contributions from the temperature change in each layer of the atmosphere instead of the average temperature change. Hayakawa et al[32] have extended the work of Maeda and Wada by considering nucleonic effects on the production of μ mesons.

Feinberg[33] has independently developed a theory of atmospheric effects in cosmic rays. Dorman[34,35], has extended Feinberg's work by taking into account the part

played by π mesons. His work is based on the following assumptions.

(1) μ mesons are generated not directly in the course of nuclear collisions but due to π meson decay. The π mesons are generated by the primary component of cosmic rays.

(2) The mesons are generated not at a definite isobaric level, but throughout the atmosphere according to the specific law corresponding to the law of absorption of the meson generating component.

The theory takes into account the ionisation losses of μ mesons traversing the atmosphere. Also no assumption regarding the equilibrium of the atmosphere is made. The complex expression deduced from this theory contains several variables, the chief among them being the ground pressure and the density of different isobaric levels from the top of the atmosphere down to the level of cosmic recorders. The results obtained by him are similar to those derived by Maeda and Nadu[31] and are summarised by the following equation.

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

where δN_μ is the variation in meson intensity at the level with barometric pressure h_0. $\delta T(h)$ is the change of temperature at the level h. The function $W(h)$ called "temperature coefficient density" has been presented by

him in the form of convenient graphs.

Dorman and Feinberg[36] have suggested a practical method of applying temperature correction to cosmic ray data. The above equation has been approximated to the following summation.

$$\frac{\delta N_m}{N_m} = - \sum_{i=1}^{11} K_i \delta T_i + \int$$

where K_i is the partial temperature coefficient for the ith layer obtained by integrating W(h) over the corresponding layer. They have pointed out that the summation over 11 standard atmospheric layers from 1000 mb to 50 mb is sufficiently accurate. The main difficulty with this method is that it cannot be used to correct the diurnal variation of cosmic rays on individual days. This is due to the fact that δT_i has to be determined by a radiosonde observations which have some inherent errors particularly when the diurnal variation of temperature is to be determined. Dorman and Feinberg have pointed out that an error equal to about 1°C performed systematically on all atmospheric levels results in an error in $\delta N_m/N_m$ of about 0.3% and hence they have suggested that an average of radiosonde observations of about 30 days should be taken.

Glokova[37], Kuzmin[38] and other Russian workers have shown that if the diurnal variation of cosmic rays is corrected by following Dorman's scheme the correction has an

amplitude of about 0.1% with a maximum near noon. Thus if the diurnal variation of cosmic rays has its maximum near noon the amplitude increases by applying temperature correction. For many Russian stations they found that the diurnal amplitude is almost doubled after temperature correction. On the other hand Maeda[39] has shown that the temperature variations in the atmosphere may give rise to a small diurnal variation of amplitude 0.05% with a maximum at 14 hours.

Miyazaki[40] has recently suggested a method for applying temperature correction to a comparatively low energy portion of cosmic rays. The method consists of comparing the cosmic ray intensity measured by identical instruments at two stations having almost the same latitude and longitude but different altitudes. The meson intensity at the two stations is given by

$$M_m = \int_{E_c}^{\infty} D(E)\, m_m(E)\, dE \qquad \text{At mountain station}$$

$$M_s = \int_{E_c}^{\infty} D(E)\, m_s(E)\, dE \qquad \text{At sea level station}$$

$m_m(E)$ and $m_s(E)$ are the multiplicity functions at the two stations and $D(E)$ is the primary spectrum with a cut off at E_c. He has shown that the fractional variations of the soft component consisting of particles which arrive at the mountain station but fail to reach the sea level station is given by

$$\eta = \frac{1}{\varepsilon - 1}\left(\varepsilon \frac{\Delta M_m^*}{M_m} - \frac{\Delta M_s^*}{M_s}\right)$$

where $\varepsilon = M_m/M_s$ and $\Delta M_m^*/M_m$ and $\Delta M_s^*/M_s$

represent the intensity variation when all atmospheric corrections have been applied. Taking the temperature correction at sea level to be of the form

$$\frac{\Delta I}{I_0} \frac{M_s}{M_0} = \int_0^{x_s} \gamma_s(x)\, \Delta T(x)\, dx$$

where x is the atmospheric depth in gm/cm^2, $\gamma_s(x)$ is the coefficient of the partial temperature effect for sea level μ mesons, $\Delta T(x)$ being the deviations from the average temperature at x. He has shown that

$$\eta_1 = \frac{1}{\varepsilon - 1} \left(\frac{\Delta M_\Delta}{M_0} - \alpha \Delta T_2 \right)$$

where $\frac{\Delta M_\Delta}{M_0} = \varepsilon \frac{\Delta M_m}{M_m} - \frac{\Delta M_0}{M_0}$

ΔT_2 = mean temperature changes of atmosphere between the sea level and mountain stations. The estimated value of α is = - 0.13% per °C.

Thus the difference in intensity has to be corrected for the temperature changes between the two stations only. Instead of depending on radiosonde observations for the mean temperature between the two stations, he has suggested the use of a Laplacian formula from meteorological physics. Studying the daily variation of cosmic rays he has found that there is a very high correlation between the corrected difference in meson intensity and the pressure corrected daily variation of

neutron intensity which is not subject to a temperature effect.

The low energy spectrum of primary cosmic rays can be studied with the help of neutron intensity measured with neutron piles developed by Simpson and his group. The study of the effects of meteorological factors on the nucleonic component is easier as there are no decay effects to complicate the problem. For neutrons Simpson et al[41] have estimated the barometric coefficient to be -0.9% per mm. change of Hg. This value agrees with the value calculated by Adams and Braddick[42], Meerdan and Thambyahpillai[43] and Rose and Katzman[44]. The pressure coefficient is constant over the geomagnetic latitude range $\lambda = 0^{\circ}$ to 54° and for atmospheric depths greater than 600 gm. Simpson et al[41] and Norman[4] have shown that the effect of atmospheric temperature variations on the neutron intensity is negligible. The values of temperature coefficient given by Simpson are as follows.

Temperature coefficient $= -0.02\%$ per $^{\circ}$C at $\lambda = 0^{\circ}$

$= -0.005\%$ per $^{\circ}$C at $\lambda = 50^{\circ}$

1.2 Anisotropy of primary radiation

1.21 The relationship of observed daily variation to anisotropy and the determination of the spectrum of the daily variation

Sarabhai and Nerurkar[2] have given a comprehensive

review of work done in this field upto 1956. The existence of an anisotropy of the primary radiation which causes the daily variation was established by Alfven and Malmfors[45] with directional telescopes. Elliot and Dolbear[46] with their extensive experiments with directional telescopes at Manchester have also confirmed the findings of Alfven and Malmfors. Recently Elliot and Hodwell[47] and Parsons[48] have cast doubt on the above result as it did not agree with their experiments with telescopes inclined in the east-west directions. Their conflicting results are probably due to the fact that they have considered a mean energy of particles responsible for daily variation and using this energy they have deduced the asymptotic directions of particles of this energy arriving from east and west directions at their instrument. Since the asymptotic longitude and latitude of particles are different, for particles arriving in two different directions at a point on the surface of the earth, considerations of only mean energy can be misleading.

Ahmert and Sittkus[49] showed a difference in the amplitude of daily variation measured by an ion chamber of omnidirectional sensitivity and by a vertical counter telescope of limited directional sensitivity. Sekido et al[50] pointed out that the amplitude of the daily variation increased from 0.19% to 0.24% when semiangle of the measuring telescope in the east-west plane was reduced from 40° to 12°. Sarabhai et al[7] showed that at low latitudes

the 12 month mean daily variation of meson intensity measured with telescope with semiangles 22^{0} in the east-west plane had, at different periods of time, a diurnal amplitude ranging from 0.3% to 0.8%. The latter amplitude being considerably larger than what can be expected from corresponding meteorological changes led the investigators to conclude that a large part of the observed daily variation can in fact be attributed to an anisotropy of primary radiation.

Firor et al[51] have reported from a study of the nucleonic components measured with neutron monitors at different latitudes that averaged over a large number of days the daily variation shows a peak to peak amplitude of about 1.0% which is comparable to the amplitude observed at low latitudes in meson telescopes of moderate semiangle.

Regarding the solar anisotropy of high energy primary particles evidence is available from measurements made at great depths underground and from extensive airshower experiments. The intensity of the measured radiation being low, the statistical significance of the determinations is poor in most cases.

1.211 Source of daily variation and its spectrum.

If the daily variation is caused by the anisotropy of cosmic ray intensity it is important to find the location of the source and its spectrum. We have seen in

an earlier section that the fractional variation of cosmic ray incensity N^{d}_{f} can be written as

$$\frac{\delta N^{d}_{\lambda,f}}{N^{d}_{\lambda,f}} = \int_{E^{min}}^{\infty} \frac{\delta D(E)}{D(E)} \; W^{d}_{\lambda,f} \; dE$$

Thus knowing $W^{d}_{\lambda,f}$ one can estimate the source spectrum $\delta D(E)/D(E)$ which gives the best fit with the experimental results $\delta N^{d}_{\lambda,f}/N^{d}_{\lambda,f}$. Dorman and Feinberg[36] have considered the daily variation data of different components of cosmic rays taken by instruments at different latitudes and longitudes. They have found that the best fit for all types of components is given by the following spectrum

$$\frac{\delta D(E)}{D(E)} = aE^{-1} \quad \text{if } E > E_1$$

$$= 0 \quad \text{if } E < E_1$$

where $a = 0.1$ and $E_1 = 6.6$ Bev

This shows that particles below 6.6 Bev do not produce any diurnal variation. They have defined "a" as the power of the source. To locate the position of the source they have defined the mean or effective angles of deflection in the geomagnetic field. They have found that the source of daily variation is almost at right angles ($82^{0} \pm 6^{0}$) to the earth-sun line and is to the left side of it. Further they have shown that the angle λ between earth-sun line and the position of the source decreases with increase of geomagnetic planetary index K_p. In this analysis however

they have considered the results of the average diurnal variation over an extended period of time, rather than the variation of the highly changeable character that is seen to occur on groups of days.

1.3 Long term changes in daily variation and their world wide characteristics.

Sarabhai and Kane[52] have discovered large world wide changes of 12 month mean daily variation of meson intensity. They have analysed the data of Christchurch, Cheltenham and Huancayo from 1936 to 1946 and have drawn attention to the correlated changes of amplitude and time of maximum of the diurnal component of daily variation. Pointing out the relationship of these changes with relative sun spot numbers and magnetic character figure they have suggested that the changes probably follow the 11 year cycle of solar activity.

Recently Parsons[53] and Sastry[54] have drawn attention to the fact that the 12 month mean amplitude of the daily variation has considerably reduced from sunspot minimum year 1954 to sun spot maximum year 1957. The time of maximum of daily variation has become later from 1954 to 1956 (Sastry). Sastry has also studied the characteristics of daily variation on individual days of the years, 1954, 1955 and 1956. His experimental data relates to counter telescopes of $22^0 \times 37^0$ semi-vertical angle in the east-west and north-south planes, operated at the mountain station of Kodaikanal near the geomagnetic

equator. He concludes that (1) the amplitudes on individual days have progressively reduced from 1954 to 1956 and (2) the scatter in the time of maximum of daily variation has increased from 1954 to 1956.

Thus the reduction in the amplitudes in the 12 month mean daily variation is caused by reduction of amplitude on individual days from 1954 to 1956 as also by the scatter of time of maximum. We have dealt with this problem in later chapters with the help of data from the sea level station at Trivandrum.

1.31 Relationship of long term changes with solar and terrestrial phenomena.

Thanbyahpillai and Elliot[55] have confined their attention to the time of maximum of the diurnal component of the daily variation. They find that the maximum for the hard component at Manchester and Stockholm shifted from 1400-1500 hours in 1948 to 1100-1200 hours in 1952. Combining data from various stations they conclude that the time of maximum has graddally shifted to later time of the day from 1933 to 1942 while from 1942 to 1952 the variation took place in the opposite direction. This led them to believe that the change in the solar anisotropy probably follows a 22 year cycle of solar activity.

Evidence for a 22 year cycle of solar activity has been recently presented by Steinmourer and Gheri[56] who have

compared in groups the data of past 23 years. They find that during sunspot minimum year of 1933, the time of maximum of the diurnal component was about 0700 hour comparable with the time of maximum about 20 years later in 1953-54. However the time of maximum in 1944 (11 years after the first minima) was earlier than 0700 hour. This again suggests that the complete cycle of solar activity has a period of 22 years. During some months in 1954 they observed the time of maxima of the diurnal variation to occur as early as 0300 hours. Similar changes in the phase of the diurnal variation have been reported by Possener and Heordan[57]. They have measured the ionizing component at sea level by means of unshielded counter telescopes pointing in the north and south directions at a zenith angle of 45° during the years 1948 and 1951 to 1954. They find that for several months during 1953 and 1954 the cosmic ray variation showed an anamolous change in phase, the time of maximum intensity occurring during the night. During these months the amplitude of daily variation of the nucleonic component of cosmic rays was found to decrease to a value not significantly different from zero. Conforto and Simpson[58] have demonstrated a progressive shift of the time of maximum of the diurnal variation to earlier hours during 1954. This anamolous change of phase occurred in the daily variation measured by nucleonic component and charged particles detectors.

Sarabhai et al[7] have demonstrated that in addition

to long term changes in the diurnal component in the daily variation significant changes also take place in the semidiurnal component. Venkatesan and Dattner[59] have shown that the changes in the semidiurnal component of dailyvariation are not world wide. Sastry has pointed out the apparent fallacy in Venkatesan and Dattner's method of comparing the semidiurnal components observed by different instruments and at different stations. Comparing the changes in semidiurnal component at the two equatorial mountain stations Huancayo and Kodaikanal he has shown the striking similarity of this component at the two stations.

Taking the daily variation as a whole instead of in terms of its harmonic components, Sarabhai et al[7] have shown a very interesting sequence of changes at Huancayo. Fig. 3 shows the 12 month mean daily variation at Huancayo. The daily variation which exhibits one maxima near noon from 1937 to 1943 changes over by 1952 to a variation exhibiting one maxima early in the morning. In the intervening period there is clear evidence of the progressive increase in the early morning maxima followed by a decrease of the noon maxima. During the period 1945 to 1950 the daily variation therefore exhibits two maxima instead of one. Only half the cycle of change appears to be completed in 11 years indicating a 22 year cycle of change of the anisotropy. They have thus concluded that the most appropriate manner of studing the changes is by examination of daily variation unresolved into its

harmonic components.

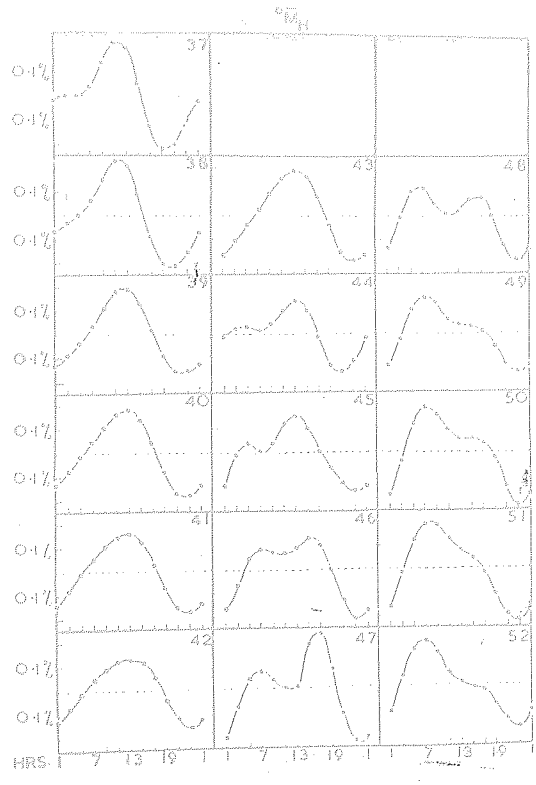

Fig. 3 - The 12 month mean daily variation of meson intensity at Huancayo during different years.

Venkatesan and Battner[59] have studied the data from a number of stations and they find that the changes in the diurnal amplitude follow more closely the changes in geomagnetic activity than they follow solar activity. They have suggested that the connection of cosmic ray with solar activity is only indirect and that the interplanetary electromagnetic state is the more important link.

Sarabhai et al[7] in their studies with narrow angle telescopes at low latitudes discovered that the daily

variation consists of two distinct types of variations, one having a maximum near noon and the other having a maximum at about 0900 hours. The relative change of these contributions are world wide in character. Further they have shown that the activity of these contributions are closely related to the solar cycle of activity and the pattern of addition and attenuation of these contributions appear to be reversed after 11 years. They have suggested that the daily variation can be studied in term of these two components.

1.4 Day to day changes of anisotropy.

The daily variation of meson intensity alters significantly from day to day showing thereby that the anisotropy of primary radiation changes from day to day.

Firor et al[51] have pointed out that the daily variation of the nucleonic component as revealed by neutron monitors is highly variable in character. Henry and Sittkus[60] and Firor et al[51] have studied the variation on groups of days. They find that there are some days on which the daily variation had a maximum during the day time, some days it had maximum in the night time while on other days there was no appreciable daily variation.

Sittkus[61] studied the amplitude of the daily variation measured by an ion chamber on individual days and noticed the tendency for large noon time maximum to occur on groups of days. These groups of days showed a

27 day recurrence tendency, but they were not associated with significantly different magnetic character figure than the rest of the days. Sarabhai and Nerurkar[62] have made similar studies with narrow angle telescope at Ahmedabad. They find a marked tendency for the diurnal maximum during 1954 to occur either at 1200 hours or in the early morning at about 0300 hours local time. They have found a 27 day recurrency tendency for days with large noon time maximum that usually occur in groups as observed by Bitchum.

The recurrence tendency of the solar anisotropy has been shown by Yoshida and Kondo[63] in ion chamber data of Huancayo. They find a very strong recurrence tendency upto two solar rotations. This recurrence tendency was found to be more prominent than in general cosmic ray intensity or magnetic character figure. Kane[64] has shown that the recurrence tendency in the daily variation, unlike the tendency in general intensity remains unchanged during the three years 1951, 1952 and 1953 studied by him. Olekova et al[65] from the data of 1953 and 1954 of U.S.S.R. stations have shown that there is no 27 day recurrence in the amplitude of diurnal variation near minimum of solar activity.

Sarabhai and Bhavsar[66] have studied the correlated day to day changes of anisotropy and mean cosmic ray intensity. They find that maxima at day time are associated with increase of intensity while maxima at night are

associated with decrease of intensity. For other days the mean intensity is normal.

The change of daily variation on magnetically disturbed days has been extensively studied by many workers. Sekido and Yoshida[67] have analysed the observations taken at Nagoya and Tokyo in relation to magnetic storms. They found that the amplitude of the diurnal variation increases on storm days and then gradually reduces, side by side they found that the time of maximum of the diurnal variation became earlier on storm days. They have also reported that the amplitude of the second harmonic component of daily variation reduces on magnetically disturbed days and the narrow angle telescopes show this reduction to greater extent than the instrument with wider semiangles. Sekido and Kodama[68] have analysed the Japanese data from 1949 to 1951 and Kumasayo data from 1937 to 1945. In both cases they find that with the increase of magnetic characteristics figures (D_s, F_s & C_p) the amplitude of the diurnal variation increases and the phase becomes earlier. They have also shown that the annual change of daily variation exists for vertical cosmic rays on magnetically quiet days.

Rumy and Sinthus[60] find from data of years 1953 and 1954 that the hour of maximum of diurnal variation becomes earlier with increase of K_p. Sandstrom[69] has studied the daily variation with telescopes pointing

towards north, south and vertical. He finds similar relation between diurnal variation and K_p as found by Japanese workers. Sandstrom[70] has resolved the daily variation into two components. The first of these has its maximum at 16 hours and corresponds to the particle wind predicted in the theory of Alfven. The second component has its maximum at 12 hours, and according to Sandstrom, it represents the sum of the various kinds of radial flow particles. He finds that the 12 hour component is correlated with geomagnetic activity. It is nonexistent or of reverse sign when geomagnetic activity is low. The amplitude of this component increases with increasing geomagnetic activity. The 16 hour component shows a correlation with geomagnetic activity of the order of $K_p \approx 5$.

Sekido et al[71] have studied the behaviour of the mean storm type vector representing the difference in the diurnal components of the disturbed period daily variation and the quiet period daily variation during each year. They have shown that the disturbance vector representing a storm type anisotropy points on the 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 quiet days anisotropy was however found to undergo a different type of secular variation. They suggest that the long term variation of diurnal component observed by Elliot et al[55] and others which does not follow 11 year periodicity

might be due to this secular variation of quiet day anisotropy.

Yoshida[72] has made a thorough analysis of the anisotropy of cosmic rays during cosmic ray storms. She explains the magnetic storm type changes as due to anisotropic flow of cosmic rays during the cosmic ray storm. This anisotropy is produced by the acceleration of cosmic rays in the solar stream.

Satya Prakash[73] in his study of association of G_p and daily variation has divided the neutron data taken at Kodaikanal in 1956-1957 into three groups. The first group represents low G_p days when $G_p \leq 0.5$, the second group has medium G_p values from 0.6 to 0.9 and the third G_p group has values equal to or greater than 1.0 . He finds sharp maxima and minima in the daily variation in high G_p group. For low G_p group the variation is gradual. The time of maximum of the diurnal component for the two groups remain almost unchanged while the amplitude of the diurnal component is smaller for days in high G_p group compared to low G_p group. This is contrary to the observations of Sandstrom[69] as described above. On the other hand Sastry[54] at Kodaikanal with a meson telescope observed during 1956, a behaviour exactly similar to that reported by Satya Prakash for the daily variation of local neutrons at the same station. This interesting problem has been further investigated in this thesis.

Sarabhai et al[74] have shown the world wide characteristics of day to day changes in daily variation. They have studied the daily variation on days on which Freiburg had a large amplitude. They find that Amsterdam ($\lambda = 54^0$N) and Ahmedabad ($\lambda = 13^0$N) also show high amplitudes on the abnormal days of Freiburg. However Kodaikanal on the magnetic equator does not exhibit any marked difference on days of abnormal amplitudes of Freiburg. They have suggested and explained the day to day changes in anisotropy in terms of the modulation of cosmic rays by streams of matter emitted by the sun.

1.5 Galactic anisotropy.

The study of sidereal time variation of cosmic ray intensity is related to the search for a galactic anisotropy in the primary radiation. In case cosmic rays come from great distances it will be of interest to study the sidereal time variations of high energy particles which travel almost with the velocity of light. Some of the recent results in this field are described below.

Daudin and Daudin[75] detected sidereal variations of amplitude 0.3% with hour of maximum at 2200 hours in the frequency of extensive air showers at latitude 43^0N at Pic du Midi. Farley and Storey[76] got an amplitude of 1.06% with maximum at 1930 hours L.A.T. at Auckland ($\lambda = 37^0$S) in the southern hemisphere. Recently Farley and Storey[77] have results of further experiments with more

counter sets to increase the counting rates. The results now show no evidence for the earlier sidereal variation, which suggests either that the earlier effect was, in some undetected way, spurious, or that the effect was genuine, but variable with time. Crawshaw and Galbraith[78] with their measurements of the frequency of extensive air showers likewise show the absence of a variation in sidereal time for primaries of energy 10^{16} eV, with an accuracy of $\pm$ 0.6% and for particles of energies $(2-5)10^{16}$ eV with an accuracy of $\pm$ 1%. They have however given evidence for a solar variation for these showers. This solar variation has both diurnal and semidiurnal components.

Balloon borne experiments have yielded conflicting evidence for the anisotropy of heavy primary particles (McClure and Pomerantz[79], Ingve[80], Stix[81] and Koshiba and Shino[82]). This is due to the fact that these experiments are difficult to perform and due to great variability of anisotropy from day to day observations with balloon flights cannot be compared amongst themselves and with the average data of ground stations.

Sakido et al[83] have reported remarkable results in their search for point sources with narrow angle altiazimuth telescopes inclined to the vertical at 80^{0}-85^{0}. They have given the first evidence of a point source in the region of declination 0^{0} and right ascension 5 hours 30 minutes with an intensity which is 20% of background intensity in the same direction.

This point source has not been confirmed by later workers. Nagai[84] and his group could not establish the existence of Galactic anisotropy of very high energy primaries.

1.6 Time variation of primary radiation.

1.61 Variation of Intensity with solar cycle.

The general intensity of cosmic ray changes with change of solar activity as reflected by the Zurich sunspot numbers. The studies of Forbush[85], Glokova[86], Lockwood[87], Fenton[88], Fenton and Rose[89] reveal a change of about 4 to 5% in the meson intensity at sea level and about 22% in the nucleonic intensity from maximum to minimum solar activity. This change has the same magnitude from Huancayo ($\lambda = 0.6^{\circ}S$) to Godhavn ($\lambda = 79.9^{\circ}N$) and is negatively correlated with sunspot numbers. The variation is similar for annual means, means of magnetically quiet and disturbed days which shows that this secular change in intensity is not produced by a series of cosmic ray storms accompanying some magnetic storms.

Neher[90,91,92], Meyer and Simpson[93] have presented similar evidence at high altitudes. Neher has shown that at the latitude of 65°-$80^{\circ}N$, there was a change in total ionisation of about 50% (altitude 70,000 ft.) from sunspot maximum year of 1937 to sunspot minimum year of 1954. Neher[94] has recently reported that the flux of the cosmic ray particles near the top of the atmosphere at Thule,

Greenland decreased by a factor of four between August 1954 and August 1957. The Fig. 4 from Neher shows the ionization at high altitudes during different periods.

Fig. 4

Fenton et al have pointed out that the changes in intensity are of two kinds both of which are simultaneously present and both of which are independently under solar control. They are (1) long term variation of about 11 years and (2) transient decreases of the order of a few days at the most.

1.62 Change of "knee" of latitude effect.

The most remarkable feature of the latitude effect is that beyond a latitude of about 53^{0} - 55^{0}, there is in general no further change in the total cosmic ray intensity

("knee") even at the highest altitude that can be reached with balloons. The experimental data of latitude effect upto 1950 has been summarised by Neher[95]. To avoid the errors due to appreciable day to day changes in cosmic ray intensity Neher et al[96] have made simultaneous flights of balloon borne instruments at different latitudes. Fig. 5 from Neher shows the "knee" of the intensity verses latitude curves for an atmospheric depth of 15 gm./cm^2 during 1937, 1951 and 1954.

Fig. 5 - Long term change of latitude effect at 15 gm. per cm^2 atmospheric depth.

The Fig. 5 shows clearly the shift of the "knee" to higher latitudes from 1937 to 1951. The low energy cut off for protons at 0.8 Bev during 1951 is accent

during 1954 when soft particles down to energies of 140 Mev (protons) is measured and there is no evidence of a "knee".

Recently, Meyer and Simpson[97] have taken additional observation to see if the "knee" is related to the general level of solar activity. They took observations during August 1956 when the level of solar activity had greatly increased. They have reported that the low energy cut off has reappeared in 1956 and that it was accompanied by further changes in the power law spectrum and total cosmic ray intensity.

1.03 Magnetic storm type changes.

Decrease in cosmic ray intensity associated with certain magnetic storms were reported as early as 1933 by Messerschmidt[98], Steinmaurer and Granigadel[99]. They found a decrease of about 1% in the hard component at sea level. A typical feature of magnetic storm is a rather sharp decrease in cosmic ray intensity after the onset of the main phase of the magnetic storm followed by a relatively slow return of the intensity to the normal level. This type of variation is often termed as a "Forbush event" and has been called "cosmic ray storm" by Japanese workers. The worldwide character of the storm effect was shown in 1937 by Forbush[100,101] and others. The decreases in some magnetic storms are as large as 10% but there are many examples where decreases occur without

magnetic storms and conversely magnetic storms occur without cosmic ray decreases. This suggests that the relationship between magnetic storms and cosmic ray decreases is not direct but both may be due to a common cause. Again when effective storms take place, the ratio of change of magnetic field strength to the change of cosmic ray intensity is not constant from event to event. In the large storm of March 1, 1942 no latitude effect was observed. On the other hand in some storms the low energy component of the primary radiation is disturbed more than the high energy component. Meher and Forbush[102] have compared a storm type decrease observed at 70,000 ft. over Texas with the decrease in the ion chamber at Mt. Wilson and have shown that the effect was four times more pronounced in the former case. In certain cases these events have occurred about 24 hours after a sudden increase associated with the solar flare. The magnetic storms generally start about a day later than the solar flare. Chapman[103] has shown recently that the decreases of intensity occurred on two occasions an appreciable time before measurable geomagnetic disturbances. Trefall[104] has concluded that magnetic storms with a dominant positive peak and a negative peak which is small or absent produce no change in intensity. Kitamura[105] has shown that large decreases are accompanied by magnetic storms with sudden commencement.

Sekido et al[106] have studied the solar relationship

of cosmic ray effective and noneffective magnetic storms which they have designated as S and N type respectively. They find that there is a good correlation between frequency of S type storms and 11 year activity of the sun, the N type storms have no such correlation and they have associated them with the supposed N regions on the sun. There is a correlation between the occurrence of S type storms and the central meridian passage of large sunspot groups, while this feature is absent for N type storms. The 27 day recurrence tendency shows sharp peaks for N type but sinusoidal changes for S type storms. The authors have concluded that S type are caused by wide corpuscular clouds ejected from sunspot groups but the N type storms are caused by narrow corpuscular beams from N regions.

Venkatesan (107) has analysed the data of Canadian stations from October 1956 to December 1957 to study the transient decreases in cosmic ray intensity. From world wide changes in cosmic ray intensity he has concluded that the changes are connected with the primary radiation. The main points of his analysis can be summarised as follows.

(1) Recurrences are clearly observed in small as well as in large decreases of cosmic ray intensity although the amplitudes of the recurrent decreases are not the same as the initial ones. There is therefore no real basis for distinguishing between the so called 27 day variation and Forbush decreases.

(2) The central meridian passages of specific active solar regions are seen to be associated with the decreases in cosmic ray intensity and with geomagnetic disturbances. No increase has been observed during the entire period of activity which could be associated with the central meridian passage of active solar regions.

(3) Although the connection between the central meridian passage and the terrestrial effects is clear, it is not possible to show an undisputed connection with specific features of the active solar regions like occurrence of flares and central meridian passage of sunspot groups.

1.64. 27-day recurrent changes of intensity.

A most remarkable type of day to day change of cosmic ray intensity has a 27-day recurrence. This was first discovered by Hess and Graziadei[108] with data from Hafelekar. Kolhoerster[109] and Haffler[110] also noticed the 27-day recurrence tendency in the hard component. Later this effect was firmly established with data from stations of the Carnegie Institute. Simpson et al[111] showed large and significant changes of intensity of a few percent in amplitude in neutron intensity. Simpson et al[112] have shown the association of increases with central meridian passage of active solar regions and regions of green coronal emission on the sun. These increases were often followed within two or three days by increased geomagnetic activity. Simpson et al have also shown the close relation

of the CMP of UR regions with cosmic ray increases during 1953. These regions as well as the increase of intensity persisted for several solar rotations.

The worldwide nature of the day to day variations have been demonstrated by a number of investigators. Forger[29] has demonstrated the similarity of day to day changes in intensity at Climax and Freiberg. He found an amplitude of the nucleonic component four or five times that of the meson component. Neher and Forbush[102] have found that the changes in intensity in the ion chambers at Huancayo and Cheltenham, in the neutron monitor at Climax and in the total ionization at 70,000 feet over Bismarck are correlated with each other.

The properties of the 27-day variation fluctuate greatly with solar activity. Meyer and Simpson[113] have shown that the recurrence tendency is more pronounced during the years of maximum solar activity when incidently the general intensity is low and is weak at sunspot minima when the general intensity is maximum. The close relation between the sunspot number and the cosmic ray intensity has been demonstrated by many workers (Kohlhörster[109], Hoka[114]). Sekido and Wada[115] have shown that S storms (storms affecting cosmic ray intensity) have a well defined 27-day recurrence tendency very similar to the recurrence of cosmic ray intensity, while N storms (not affecting cosmic ray intensity) have no 27-day recurrence tendency. Glokova[116] has shown that the amplitude of 27-day

variation decreases to almost half if the solar rotations during which effective magnetic storms take place are excluded from the averaged material. This again confirms the existence of a connection between the 27-day variation and the geomagnetic activity. Mavrdin and Thambyahpillai[117] find that the curves of intensity and magnetic activity (K_p) are somewhat shifted with respect to each other, the minima of intensity of cosmic rays occur about five days earlier than the maxima of geomagnetic activity. Simpson[118] and Kane[119] also concluded that the minimum of intensity in 27-day variations precedes the maximum of K_p index by several days.

Venkatesan[120] has recently studied the ionisation records at Huancayo from 1937 to 1955. He finds that the amplitude of 27-day variation is in general agreement with the changes in solar activity as revealed by sunspot number only for the years 1937-1946 and 1952-1955. The correlation is quite poor for the period 1946-1952, which he explains in terms of possible change in the electromagnetic conditions in the inter-planetary space during the solar cycle.

1.65 Solar flare increases.

The sudden increase (or bursts) in cosmic rays associated with observed solar flare, though quite rare provide direct evidence that 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 magnetic field in inter-planetary space and the influence of the earth's magnetic field on cosmic rays. The following are the main conclusions of the four solar flare events which were observed upto 1955.

(a) These rare cosmic ray increases which are associated with exceptionally intense solar flares reach their maxima about an hour after the beginning of the flare.

(b) The primary particles responsible for the increases were charged and had energies ≤ 15 Bev since an appreciable increase was not observed at Huancayo ($\lambda = 0^{\circ}$).

(c) The increase during the flare depends largely upon the longitude of the observation point.

(d) The magnitude of the effect of ionising component rapidly increases with height above sea level.

(e) The increase in neutron component is several tens of times as great as that of the ionising component.

(f) There are some peculiarities in the variations of intensity at the middle and high latitude stations.

Makido and Murakami [12] have analysed the amplitude and the duration of the solar flare increases in these four flares. They distinguished the effect occuring within the impact zone from the polar type of effect which has a longer duration and a less steep rise of intensity than the former. This suggests that the particles for the polar type increase have a different mode than those which arrive directly in the impact zone. They deduced a spectrum as R^{-5}

for flare radiation.

Treiman[122] has calculated that the solar magnetic moment should not exceed 5×10^{32} gauss.cm^3, if the calculations of the impact zone by Piror are to be retained. Similarly Kraushaar[123] has found the upper limit of galactic magnetic field as 3×10^{-6} gauss. Kraushaar has suggested that the particles emitted from the sun over a wide range of angles and deflected in a galactic magnetic field of this magnitude can explain the polar type increases.

1.691 Solar flare of 23rd February 1956.

This recent solar outburst was the most energetic cosmic ray event observed so far. It took place on the limb of the solar disc. The intensity of the flare had the maximum possible index 3. The intensity of the Hα line exceeded the background by 30% and the width of the Hα line at the maximum of the flare was 10Å. As many as 40 stations located from 83°N latitude to 73°S latitude recorded the cosmic ray increase. Complete isotropy was established within a very short time after the rise of the intensity to the peak value. Largest increases were recorded at middle and high latitude stations while the equatorial stations of Huancayo (Forbush), Kodaikanal (Sastry) and Trivandrum (author) recorded for the first time significant increases in intensity.

The results of the Indian stations have been analysed by Sarabhai, Sastry, Nandan and the author and a

reprint of the publication forms a chapter of this thesis. Sarabhai et al[124] have shown that if the observed increases at the equatorial stations are caused by solar protons travelling more or less along direct paths than the energy spectrum of flare radiation must extend upto approximately 67 Bev. They have estimated the flux of flare particles to be about 1.5 times the normal flux of background cosmic rays in the energy range 40 to 60 Bev. Thus the upper limit of energy of particles responsible for flare type increase is much higher than was hitherto believed.

A neutron monitor at Leeds which was in the early morning impact zone registered an increase of about 4500% (Marsden et al[125]). The neutron monitor at Climax recorded 2000% increase (Meyer and Simpson[126]) even though it was far away from a favoured impact zone. However an extensive air shower experiment at high latitude station at Schauinsland registered no additional events of energy $E > 10^{12}$ eV during the eruption (Hittkus et al[127]).

Kuzmin et al[128] at Yakutsk ($\lambda = 51^0$) and Brunberg and Lokhart[129] at Stockholm $\lambda = 58^0$ have noticed that the north pointing telescope recorded more particles than the south pointing telescope. The later authors are of the opinion that the flare particles did not travel in straight line orbits from the sun to the earth and that they have suffered a deflection in a mean magnetic field of the order of 6×10^{-6} gauss before reaching the north pointing

telescope at their latitudes.

Meyer et al[130] have studied this flare using the data from six neutron monitors distributed over a wide range of geomagnetic latitudes. Their results indicate that the flare radiation incident on earth an hour or more after the flare had a steep momentum spectrum (power law with exponent $n \approx -7$) and that the radiation fell off with time roughly as $t^{-3/2}$. They proposed a model for interplanetary conditions similar to that suggested by Davis[131] earlier. According to their model the earth was located in a relatively field free ($B < 10^{-6}$ gauss) cavity centred (1A.U. = 1.5×10^{13} cm) on the sun with radius somewhat greater than one astronomical unit and surrounded by a shell of finite thickness in which disordered magnetic fields ($B \approx 10^{-5}$ gauss) existed.

Elmore[132] has studied the delays in onset and the decay pattern of cosmic ray increases in this flare at various stations spread all over the world. He finds that the main features of cosmic ray effects especially the midnight effect and high latitude impact can be satisfactorily explained in terms of deflection of flare particle trajectories in an interplanetary field of the order of 3×10^{-6} gauss.

An interesting feature of this flare was that it occurred during a broad Forbush type intensity decrease. This Forbush decrease cannot be fully accounted by two

small magnetic storms observed on February 19 and 21, 1956. Recently Brown [133] has proposed a model which can explain the flare superimposed on Forbush decreases.

Lockhart [134] in his analysis has paid special attention to those studies which observed the earliest onset times. He has reported that Hobart which had an early onset time did not lie inside one of Firor's impact zones at the beginning of the solar flare. From Brunberg and Dattner diagrams he has shown that cosmic ray particles of momenta upto around 40 Gev/c did not arrive at Hobart from the direction of the sun which shows the existence of deflecting magnetic fields between the sun and the earth. He has suggested that the cosmic ray particles which caused the earliest onset times had come from directions towards a solar beam which produced the magnetic storm observed two days after the flare.

Lust and Simpson [135] have discussed the worldwide distribution of onset times. They have found time difference of $\leq$ 9 minutes between the commencement of intensity increases in different parts of the world. Using the flare particle spectrum they have calculated the cosmic ray intensity at the top of the atmosphere. It has been shown that for this flare 2000 hour impact zone is as important as the 0900 and 0300 hour impact zones. They have concluded that the low energy particles came later than the high energy particles and that back scattering

from disordered magnetic fields beyond the orbit of the earth cannot account for the time delays. It has been suggested that a diffusing envelope of magnetic field around the sun can explain the apparent source of flare, size and the dispersion effect (energy dependent spread of first arriving particles). This diffusion is produced by a small irregularity in the general solar dipole field. The impact zones are dominant in the first nine minutes after which isotropy sets in, this can be due to subsequent storage mechanism.

1.652 Effects of small solar flares

Firor[136] has studied the cosmic ray intensity variation during small flares of magnitude 1 . He finds that even during small flares additional particles of cosmic ray energies approach the earth from the direction of the sun.

McCracken[137] has reported a 2% increase in neutron counting rate about half an hour after the observation of an intense solar flare at 1225 U.T. on August 31, 1956. The event was observed approximately simultaneously at the widely separated longitudes of Australia and the U.S.A. The time delay between the first visual sighting of the flare and the earliest arrival of cosmic rays at the earth was about 20 minutes. It is shown that the quantity of cosmic rays which arrive at the earth was two or three orders of magnitude less than the quantity which arrived

during earlier flare effects. The effect was not observed by high counting rate neson telescopes. This and the temporal dependence of the small flare effects leads the author to conclude that only a small number of cosmic rays are produced in the solar flare.

Corrigan et al[138] (with Singer and Swetnick) have observed two very short lived increases of low energy cosmic rays on 9th August 1957 with a specially designed detector of very large sensitive area and short resolving time operated from an aircraft at 25000 feet in geomagnetic latitude 55°N. The first event which lasted for three minutes appeared to be associated with a solar flare of importance 1+ that occurred on the west limb 20 minutes before the event. The second event lasted for 2 minutes and the increase in both the events was 30%.

1.7 Interpretation of variations.

There is now enough evidence to suggest the strong influence of the sun on cosmic rays. From a clear understanding of atmospheric and geomagnetic effects, Simpson[139] and other workers have shown that the mechanism responsible for the changes of the cosmic ray intensity is of extraterrestrial origin and its association with solar phenomena is independent of the earth's system. The major points which suggest an association of cosmic rays with solar activity are summarised below.

(1) In some nonperiodic variations like solar flares,

the sun emits cosmic ray particles which can sometime attain energies in excess of 50 Bev.

(2) The sun also produces short duration changes of intensity many of which are related to CMP of active solar regions such as sunspot groups, unipolar regions and regions of intense coronal 5303Å emission.

(3) It is now known that certain active regions on the sun persist for several solar rotations and give rise to characteristic 27-day recurrences in cosmic radiation.

(4) The sun produces day to day fluctuations of anisotropy some of which are related to CMP of active regions on the sun.

(5) The general solar activity has a period of 11 years. The cosmic ray intensity as well as the low energy cut off has a period of 11 years.

(6) Certain phenomena on the surface of the sun have a periodicity of 22 years. Some of them are as follows.

(a) The state of magnetic polarity of bipolar sunspot.

(b) The alternating character of successive spot cycles.

(c) The frequency of prominences.

(d) The probable variation of solar diameter.

(e) The diverging motion of forming spot groups.

(f) The proper motion of spots in latitude.

It has been mentioned earlier that the 12 month

mean solar anisotropy undergoes a change coincident with a cycle of 22 years.

(7) Some of the cosmic ray variations are closely related to geomagnetic activity and this relationship is probably due to some common source of solar activity.

1.71 Geocentric and Heliocentric models.

Early workers tried to explain the variations as due to modulation of cosmic ray intensity by geomagnetic field perturbations. However later it was found that various types of cosmic ray variations cannot be explained by the observed variations in geomagnetic field.

Davis[131] has discussed a model in which the ion streams from the sun are able to transport the galactic field ($\simeq 10^{-5}$ gauss) outward until the magnetic pressure $H^2/8\pi$ begins to exceed the material pressure. Thus a field free cavity of a radius of about 200 A.U. is formed around the sun. This cavity would trap cosmic ray particles of energy less than 100 Bev for periods long compared to sunspot cycle. He has tried to show that a 1% change of the mean radius of such a cavity with the 11 year solar cycle could explain the 4% change of the mean intensity as observed by Forbush. This theory cannot explain the rapid fluctuations in cosmic rays because the travel time from the sun to the walls of this cavity is one year for the corpuscles and one day for cosmic rays. It also fails to explain the absence of cut off in 1954 as reported by

Meher and Stern.

Bêlcor[140] has recently modified the model first suggested by Davis. He has pointed out that since the electrical conductivity of interplanetary space is not infinite and the solar emissions are quite irregular, a small remnent magnetic field can be left in the cavity. He has suggested that the cavity should be replaced by a diamagnetic spheroid with semiaxes of roughly 5×10^{15} and 5×10^{14} cm with a magnetic field (inside) of about 10^{-9} gauss. He has explained the cut off in the primary rigidity spectrum by considering the different particle trajectories that are possible through this diamagnetic spheroid and the trapping of certain particles. The theoretical integral spectra for protons, α particles and heavy nuclei agrees well with the experimental observations. In this model the 4% cosmic ray fluctuations can be easily accounted by 1.6% fluctuations in the total corpuscular output of the sun over a sunspot cycle. He has been able to account for change in low rigidity cut off and its absence in 1954.

The main criticism against the models of Davis and Belcor is that instabilities of various kinds will disrupt the cavity walls thereby providing trajectories that would permit the escape of trapped particles.

Nagashima[141] has proposed a model involving a geo-electric field to explain the worldwide nature of

cosmic ray intensity variations. His theory explains fairly well the altitude and latitude dependence of variations observed by various workers. However it cannot explain large variations occurring during magnetically quiet periods when presumably no perturbing geoelectric fields can be present. Simpson's experimental observations between the range $\lambda = 45^{0}$N to 60^{0}N of latitude dependence of fractional changes in neutron intensity do not agree with the theoretical estimates calculated by assuming axially symmetric geoelectric fields at different distances from the earth. After a critical examination, Simpson[142] comes to the conclusion that the variation mechanism must be of extraterrestrial origin and its association with solar phenomena is independent of the earth's system. Moreover the existence of a geocentric electric field is doubtful because of the high electric conductivity of the ionosphere and of interplanetary space.

Morrison[143] has suggested a heliocentric mechanism in which large ionised gas clouds carrying tangled magnetic fields may move outward from the sun and engulf the earth, thereby shielding it from the incident galactic cosmic ray particles. The outward motion of these clouds sweeps back the low rigidity particles (convective removal). If the clouds have a speed of 2000 km/sec. the orbit of the earth will be swept out once every day, thus explaining the "knee" of latitude curve.

The difficulties with Morrison mechanism have been

summarised by Parker[144] as follows.

(1) The required number of outward clouds seem to imply a solar mass loss of the order of 10^{14} gm/sec. which is very much in excess of the estimates of 5×10^{10} gm/sec. obtained from the dynamics of comet tails.

(2) In order for outward rushing magnetic clouds of solar origin to screen the earth in all directions from galactic particles, it is necessary that clouds be ejected in all directions from the sun. Both visual and magnetic observations show that the violent aspects of solar activity (sunspots, flares etc.) with which we can associate the emission of clouds do not occur near the poles. This suggests that above both poles of the sun there would be large gaps in the outward moving cloud barrier. These leaks are serious because a relativistic particle can make the trip in 8 minutes, while the clouds will take one day to sweep the orbit. Hence it is difficult to explain any decrease of intensity.

(3) Since the outward rushing cloud mechanism has a characteristic time of one day it is not clear why the cosmic ray spectrum does not vary markedly with the appearance of active solar regions which are responsible for such phenomena as magnetic storms.

(4) The fact that from solar flares we observe cosmic ray intensity increase with sharp fronts and confined to geomagnetic impact zones (at least in the earlier phase) shows the orbit is comparatively free from

magnetic field, hence the assumption by Morrison of enough magnetic clouds (to produce Forbush decreases or the observed low energy "knee" - cut off) does not hold.

(5) The abrupt Forbush decreases (of the order of four hours) require either high velocity interplanetary clouds (so that the removal rate is increased) or more and magnetically denser clouds so that the barrier they form is less permeable. It can be shown that a decrease of say about five hours requires cloud velocities of 10^4 km/sec. or tangled interplanetary cloud fields as high as 0.5×10^{-2} gauss. These examples of Forbush decreases which take weeks or months to recover required that the cloud velocity or density (magnetic) occur uniformly throughout much of the solar system and be maintained for several hours.

Parker[144] has proposed a mechanism which operates within a few earth radii. Interplanetary magnetic gas clouds are captured by the terrestrial gravitational field forming a nebulous geocentric barrier which modulates the galactic cosmic ray particles. He has shown that the disordered magnetic field contained in a geocentric cloud built up from bits and scraps of captured interplanetary magnetic matter will be sufficiently long lived to give a fairly uniform effect on the cosmic ray intensity even though the solar outbursts which supply the cloud material may occur at irregular intervals. The geomagnetic field

has been shown to be sufficiently dense to support the weight of the nebula. Some of the characteristics of this geocentric model are given below.

(1) Low energy cut off :- Parker has shown that the disordered magnetic fields in the captured interplanetary material form transmitting scattering centres, the scattering by these centres produce a low energy cut off.

(2) Forbush decrease :- Whenever the terrestrial gravitational field is able to capture magnetic gas from a passing interplanetary cloud, we would expect the cosmic ray intensity to decrease at the surface of the earth. The fraction by which the intensity decreases will be approximately equal to the fraction by which the geocentric magnetic cloud is augmented. The length of time over which the decrease occurs will not be less than the time required for gravitational capture of magnetic clouds and of course the time may be much longer if for several days, passing magnetic gas is captured intermittently. Forbush decreases generally take a time of the order of 3 to 4 hours, this will correspond to free fall from about five times the earth's radius. Following the capture of magnetic gas the cosmic ray intensity should remain depressed until the newly captured fields decay. Calculation shows that decay may take a time of the order of several months.

(3) Solar flares :- A comparision of Pfrot's

calculation of orbits of particles from sun to earth with the experimental observations during solar flare shows that between sun and earth there are some deflecting mechanism which deviate the particles from their straight line orbits. Parker has shown that the geocentric disordered barrier will produce a random deflection of the order of one radian which is of the correct order of magnitude.

(4) Geomagnetic effects :- Here there are at least two processes,

(a) The weight of the magnetic clouds forming the geocentric barrier presses down on the geomagnetic field, compressing the field beneath the bottom of the clouds. Thus we expect that the effect is to increase the geomagnetic field at the surface of the earth.

(b) It can be shown that the presence of nonmagnetic gas clouds, i.e. gas which does not carry an internal magnetic field, will have just the opposite effect.

Ideally suitable combinations of these two effects, while the earth is capturing new interplanetary material, can produce both a cosmic ray decrease and a magnetic storm that is an initial increase and a more prolonged decrease of the horizontal component of the geomagnetic field. The proportions of magnetic and nonmagnetic gas composing the captured material determine to what extent the cosmic rays decrease will be accompanied by a magnetic storm and vice versa.

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This theory has many attractive features but at present, there is no evidence to show the presence of a geocentric barrier. The detection of a narrow absorbtion line of the barrier clouds in the solar spectrum taken by rocket borne spectrographs can establish the existence of geocentric barrier.

Recently Parker[145] has shown that the 11 year cycle of cosmic ray intensity can be explained by the hydrodynamic outflow of gas from the sun. The outward flow of hydrodynamic gas is inferred by Biermann from observations of comet tails and should stretch out the magnetic lines of force of the solar magnetic field, leading to an essentially radial magnetic field in the inner solar system. A heliocentric shell of disordered field of $\approx 10^{-5}$ gauss is formed when turbulence sets in at a distance from the sun. Such a shell was inferred from the observations of last solar outburst. The reduction in cosmic ray intensity in years of high solar activity can be explained on this model. There is a close agreement of computed cosmic ray energy spectrum with the spectrum observed at earth. Parker has suggested that Forbush type decreases are local geocentric phenomena produced by the interaction of the out flowing gas from the sun with the earth. Parker's analysis makes no attempt to interpret features of the solar daily variation and changes occurring in them which are related to solar activity.

1.72 Modulation in interplanetary space.

Alfven[146] has suggested that the solar beams or jets of ionised gas which are responsible for geomagnetic storms and aurora can also explain variations in cosmic ray intensity. In his theory the frozen in magnetic field carried by moving ionised beams in interplanetary space will give rise to an electric field for an observer in a fixed frame of reference. The acceleration and deceleration of cosmic rays traversing the field may be expected to cause increases or decreases. Brunberg and Dattner[147] have considered this model in great details, they find that to explain the decreases in cosmic rays associated with magnetic storms, there should be a magnetic field of the order of 10^{-5} gauss in the vicinity of the earth.

Brunberg and Dattner[148] have pointed out that seen from a fixed coordinate system the rotating sun would be strongly polarised so that there will be voltage difference between the poles and the solar equator of the order of 10^{9} volts. The combined action of the electric field produced by the polarisation and the solar magnetic field will make charged particles partake in a general rotation with the sun so that the earth will receive an excess of radiation from the 18 hourly direction. Thus a tangential anisotropy is produced. Sandstrom[149] has shown that on Alfven's model the diurnal variation should consist of two components; first is the 18 hour component

due to particle wind and the second is a 12 hour component due to radial flow of particles inside the corpuscular beams associated with active sunspots and solar flares. Alfven[150] has shown the possibility of an outward radial flow of energy depending on the accelerating processes within the solar system. This will impart a radial anisotropy to cosmic rays which will change with the 11 year cycle of solar activity. These explanations require a general solar magnetic field of the order of 10^{-5} gauss at the earth's orbit to account for a diurnal variation of amplitude approximately 0.2%.

Nagashima[151] has quantitatively examined the trajectories of cosmic ray particles passing through the beam under the combined influence of the electric field inside the beam and a frozen magnetic field within the beam derived from the solar dipole field. A feature of this theory is that associated with every beam there is a minimum energy below which no anisotropy would be produced. For higher energies, the percent anisotropy would progressively decrease with increasing energy. His finding that the maximum anisotropy would be produced in the direction pointing towards the sun agrees with the experimental determination of the storm type vector by Nakada et al[152]. This theory can also explain the 11 year cycle of variation of storm type anisotropy as being due to a change in the density of the solar streams and the strength of the trapped magnetic fields during the solar

cycle of activity.

Nagashima has not tried to explain the night time maximum as observed in the daily variation on groups of days. Recently Sarurkar[153] has shown that by admitting random orientation for the frozen in magnetic fields, occurrence of a night maximum at low latitudes can be explained by an extension of Nagashima's theories.

Dorman[4] has tried to interpret the various diverse features of cosmic ray variations. His theory is based on the modulation of an isotropic primary intensity by changes in the electromagnetic state of interplanetary space. He has worked out the expected cosmic ray effects due to different orientation of the frozen magnetic field and position of the beam with respect to the earth. He has also explained the implications of tubulence in the beam.

Dorman's theory in its present form is not able to explain the secular or day to day change of daily variation or the rather remarkable form of the daily variation at low latitudes during some years. Dorman has examined many possible cases of solar beams but none appears to explain the very significant changes observed in 1954. He therefore concludes that further investigations are required in this field.

However the existing theories are still inadequate

to explain the experimentally observed features of the diurnal variation. Any theory advanced to interprot the solar anisotropy and it-s changes with time should be able to explain the semidiurnal type of variation observed on certain days at low latitudes as also the following features.

(a) The 12 month mean daily variation has exhibited for several years two significant maxima. This indicates that the daily variation cannot at all times be satisfactorily described in terms of the diurnal component alone.

(b) The principal maximum of daily variation has shifted by as much as 10 to 12 hours over a period of years. This shows that during some years the daily variation exhibits a principal maximum during the day while in others the maximum is shifted to the night.

(c) The existence of a permanent anisotropy has not been proved beyond any doubt. Even if such an anisotropy is present it is masked by large variable anisotorpies.

(d) The amplitude of the daily variation is a function of the directional sensitivity of the recording instrument. The change of amplitude of the daily variation with change of semiangle of the telescope is very much larger than can be normally expected. Large amplitude of the order of 1.2% have been observed with narrow angle telescopes at low latitudes.

None of the above mentioned models have been able to explain all the observed variations of cosmic rays. Further progress depends not only in comparing the various models with more experimental facts, but on various types of experiments with different components of cosmic rays conducted at different periods of the solar activity.

1.6 Statement of the problem.

The anisotropy of primary cosmic ray intensity is found to vary from day to day. Side by side large world wide changes in the form of anisotropy also take place from year to year. In this dissertation the changes in the average parameters of 12 month mean daily variation from 1955 to 1957 are studied. The relationship of changes in the average parameters with the characteristics of daily variation on individual days are investigated.

The world wide character of changes of daily variation is studied. The impact of this study on the nature of cosmic ray daily variation source and its spectrum is investigated. Further it is of interest to know whether the experimental results point to a unique cosmic rays daily variation source or if there are more than one sources. With data extending to three years an attempt has also been made to find the solar control over the daily variation source as the solar activity of sun spots increasing from 1954 was maximum in 1957. A

comparison of the results of this investigation is made with the various theories to see if it is sufficient to consider the average characteristics of daily variation or it is necessary to compare the day to day changes.

Analysis is done to examine the relationship between cosmic ray daily variation and the geomagnetic planetary index C_p. C_p disturbances are divided into recurrent and nonrecurrent groups and the association of each of these groups with average characteristics of daily variation are studied. Further an attempt has been made to understand the conflicting results of various authors in the relation between geomagnetic disturbances and the changes in cosmic ray daily variation.

The three years data taken at Trivandrum, Ahmedabad and Kodaikanal with identical cosmic ray telescopes is compared to investigate whether the changes in the daily variation at these three stations are consistent with a form of anisotropy outside or if a geocentric model at a closer distance is in operation. An attempt has been made in this connection to understand the particular model or models which were operating in these three years to produce changes in daily variation.

The solar flare data of the three stations mentioned above have been used to find if there are occasions on which solar flare effect produces high energy particles whose influence can be observed on the earth.

CHAPTER II

EXPERIMENTAL TECHNIQUE

The following considerations apply to the design of apparatus for the measurement of the daily variation of cosmic ray intensity.

(1) Appropriate geometry.

The characteristics of the daily variation depend upon the direction of measurement and the cone of acceptance of the measuring apparatus. It is therefore advantageous to study the nature of the daily variation with counter telescopes having a restricted cone of acceptance, for such telescopes reveal a daily variation of more prominent amplitude than an omnidirectional device such as an ionisation chamber. It has been mentioned in the last chapter that many workers have reported higher daily variation amplitudes in narrow angle counter telescopes compared to wide angle telescopes. Barabhai et al[62] have shown that the optimum limit of semi-vertical angle in the east-west plane is about 5^{0}, below this the amplitude of the daily variation does not increase. As the cone of acceptance of the telescope reduces, the counting rate decreases with a corresponding increase of the standard error of the results. Hence a compromise is to be made between the cone of acceptance and the counting

rate of the telescope. For our experiment we have used telescopes having a semi-vertical angle of 22° in the east-west plane and 37° in the north-south plane. The hourly triple coincidence counting rate of one telescope of the above mentioned geometry is about 4000 at sea level. It has been mentioned in the first chapter that the 12 month mean daily variation amplitude of this telescope has varied from 0.6% to 0.3% in different periods.

(2) Provision for normalisation in the event of partial failure of equipment.

The useful life of self-quenched counters is quite limited, hence to get uninterrupted data there should be as many duplicate counter telescopes as possible. In case of any break down due to counter failure in one telescope the other identical telescope enables the continuity of the data to be maintained.

The simultaneous running of a number of identical telescopes increase the reliability of the study because genuine variation in the cosmic ray intensity would be equally reflected in all the telescopes. Further when the data of all the telescopes are combined the statistical error goes down. In the present experiment, four similar telescopes were in operation.

(3) Stability.

For long term studies of time variation of cosmic rays it is necessary that the apparatus chosen should be

stable and retains its characteristics. The mains A.C. voltage should be stabilised with the help of a constant voltage transformer. All D.C. voltages should also be stabilised. Suitable quenching units should be used with the counters to improve their plateau characteristics, stability as also their useful life. Synchronuous clocks for automatic camera unit should be avoided because of possible fluctuations in the frequency of A.C. mains voltage.

(4) Freedom from interferences

To avoid electrical interfeeding of pulses between the units only earthed shielded cables should be used to feed the pulses from one unit to another. The lengths of cables should be as small as practicable to avoid spurious electrical pick up and attenuation and distortion of signals. All the output terminals of power supplies must be decoupled with suitable condensers to avoid undesirable interfeeding through the power supplies.

With the precautions mentioned above, two complete and independent units were built at Trivandrum. First one has four telescopes each having semivertical angle of 22° in the east-west plane and of 37° in the north-south plane. The other unit has eight telescopes having semivertical angles of 5°, 10°, 20° and 45° in the east-west plane. In this dissertation the data of the former unit are discussed, hence the construction details of only former unit are given below.

2.1 The apparatus

The schematic diagram of the experimental set up of (22^{0}- 37^{0}) telescopes is shown in Fig. 6. It consists essentially of four vertical triple coincidence telescopes. Two identical sets of four counter trays A,B,C and D and A',B',C' and D' are mounted side by side with vertical separation of 20 cm. between individual trays of each set. Each tray consists of four Geiger counters connected in parallel. Tray A,B,C; B,C,D; A',B',C'; and B',C',D' are connected in triple coincidence. The length of each counter is 30 cm and diameter 4 cm and thus each tray has a sensitive area of 480 cm^{2}. The whole apparatus is

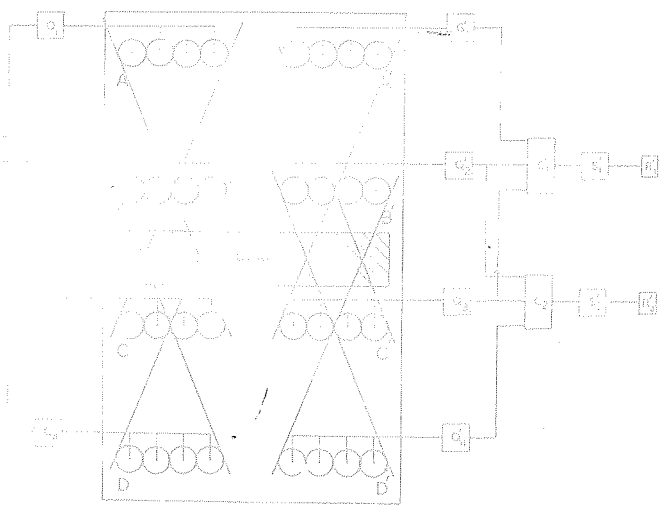

Fig. 6 - Experimental arrangement of counter telescopes.

aligned so that the axes of the counters lie along the north-south plane, the telescopes then subtend a semivertical

angle of 22^0 in the east-west plane and 37^0 in the north-south plane. To eliminate the soft component 8 cm of lead absorber is introduced between the trays B-B' and C-C'.

The output pulses of the four trays A,B,C and D are fed to separate electronic quenching units Q_1,Q_2,Q_3 and Q_4 and the outputs Q_1,Q_2,Q_3 and Q_2,Q_3,Q_4 are in turn fed to coincidence units C_1 and C_2 respectively. The output pulses from coincidence units C_1 and C_2 are scaled down by scalers S_1 and S_2 and finally recorded by mechanical registers R_1 and R_2. Exactly similar arrangement is made to record coincidences from telescopes A',B',C' and B',C',D' by recorders R_1' and R_2'. The dials of the mechanical recorders R_1, R_2 and R_1', R_2' are photographed at hourly intervals by an automatic photographic arrangement.

For cosmic ray directional study a triple coincidence telescope is better than a double coincidence telescope because it reduces the contribution of side showers and of chance coincidences. The significance of a scaler unit is two fold. Due to the random distribution of the coincidence rate, there is a definite probability for occurrence of events within a small time interval, if this interval is shorter than the resolving time of the mechanical recorder there would be a loss of counts. With a suitable scaler in between it is possible to obtain a uniform distribution of counts. Again the scaler reduces

the wear and tear of the mechanical recorders. All the telescopes in the above apparatus have scale-of- four units.

2.2 Geiger Muller counter.

The Geiger Muller counter which works on the production of an electrical discharge is essentially a diode filled with some gas like argon or hydrogen and operates in the region of the unstable corona discharge. It is so sensitive that the liberation of a single pair of ions any where within the tube is sufficient to initiate the discharge. Wilkinson[154], Korff[155] Montgomery and Montgomery[156] and Stever[157] have discussed the process of development of the pulse in a counter and its quenching in a self-quenched counter.

When an ionising particle passes through a counter it produces a few ion pairs in the sensitive volume of the counter. The free electrons trigger an avalanch and a discharge which spreads rapidly throughout the length of the counter. The discharge lasts only for a few micro-seconds. Soon the field conditions inside the counter are altered due to the positive space charge found in the high field sensitivity region near the central wire and the discharge is quickly extinguished. 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 important property of a Geiger Muller counter is that the magnitude, duration and

general character of discharge in the tube is independent of the specific ionising power of the initial particle. It is necessary that Geiger counters should have (1) low operating potential (2) long operating range (3) high efficiency (4) stability with use and time (5) large pulse size and short recovery time and (6) small temperature coefficient. All the features cannot simultaneously be attained to a maximum degree and hence a workable compromise is necessary.

All the self-quenched Geiger Muller counters used during the present investigation were prepared by the author at Trivandrum. The total pressure of the mixture of the gases was kept at 10 cm. Argon and Ethyl Acetate were filled in the ratio of 9:1. The starting potential lies round 1250 volts with the plateau extending for about 250 volts with a slope less than 1% in 100 volts and an efficiency of about 90%. The useful life of the counters varied from 3 months to 12 months. In the early stages of the working of the apparatus described above it was found that the useful life of some counters in the lower most trays was consistently less than those in the other trays. This was caused by increased counts due to background radio activity of thorium. The monazite present in the beach sands of the south-west coast of India starting from Quilon to Cape Comorin are rich in thorium. Hence the lower most tray was shielded from background activity by keeping about 2 cm of lead below this tray (D and D'). As

a precautionary measure all the trays were protected from sides with about 2 cm of lead.

2.21 Preparation of Geiger counter

Metal counters were preferred because of their ruggedness and because there is no need to protect them from light, the glass counters have to be protected to prevent the photoelectric effect on the cathode. Fig. 7 shows a typical metal counter prepared at Trivandrum.

Fig. 7 - Geiger Muller counter.

The cathode is made out of thin walled brass tubing of 4 cm diameter. Thin tungsten wire is used for the anode. The selected tubes are fitted with end pieces which are cut from a brass rod of 4.5 cm diameter so that they fit tightly inside the brass tube. Holes are drilled at the centre of these discs to fit the glass seals that hold the anode wire in its place and at the same time provide for evacuation and filling of the counter. The holes drilled are made a bit conical by using a reamer so that the tapering ends of the glass seals fit tightly in them.

First of all the inside surfaces of brass tube and its disc are polished with steel wool, next they are cleaned carefully with commercial ethyl acetate and then rinsed with pure ethyl acetate to remove metallic powder, dirt, greases etc. The parts of the counter are then assembled as shown in figure 7. A suitable length of 4 mil. diameter tungsten wire is threaded through the capillary of the glass seals. The ends of the glass seals introduced on either side extend at least 3 cm into the counter thereby forming protective sleeves over the ends of the anode wire. Metal to metal joints and metal to glass joints which fit closely are cleaned and warmed to about 300°F and Araldite type 1 is applied to make the joints leak proof. The technique of applying araldite is very similar to that of soft-soldering. All joints are kept warm until araldite sets, a process which can be observed by a change in colour. The thin tungsten wire forming the anode is spot welded at both the ends to thicker tungsten wire which protrude outside the glass seals. The protruding pieces are provided with metal beads of nickel and silver so that copper wire for external electrical contact can be joined to them. The counters thus ready for filling are connected to a vacuum system and evacuated it. While evacuating, the counters are warmed slightly to drive out moisture and the central wire is glowed to incandescence by passing a current through it. This is necessary to burn out dust and sharp points on the wire. About 24 hours after evacuating, the

counters are tested for any small leakage. Leak proof counters are filled with 1 cm of ethyl acetate and 9 cm of argon. The filling gases are then allowed to mix for about two hours and the characteristics of the counters are then checked individually for their plateau characteristics.

The testing of the counter is done with resistance quenching using a megohm resistance. The pulses are also observed on the oscilloscope to see whether any multiple pulses are developed. The high voltage is raised in steps of 25 volts above the threshold, and the counts taken for five minutes with the help of a stopwatch. With the normal cosmic ray intensity, if there is a plateau of about 200 volts the counters are sealed off with the help of a hand torch. The counters are kept overnight with the voltage at the middle of the plateau region and retested the next morning. Counters which were good after aging were used for the experiment.

2.3 Electronic units.

2.31 Quenching unit.

The quenching unit used in the present investigation consists of a single shot multivibrator and cathode follower. Fig. 8 shows the circuit of the quenching unit. The twin triodes of 6SN7 tube are used for univibrator action. In the stable state the left half of the 6SN7 tube is non-conducting and the right half is conducting. The grid of

the conducting tube has been returned to a positive voltage instead of connection to usual negative supply. This increases the steepness of the slope of its grid voltage when it is returning towards its initial voltage from cut off value. This is necessary for stability.

Fig. 8 - Quenching unit.

Another advantage is the stable quiescent grid voltage at nearly zero volts, as otherwise a precision voltage divider is required to establish accurately the quiescent grid bias.

The negative pulse from the counter triggers the univibrator as a result of which a rectangular negative pulse of about 350 volts and of duration 1000 micro-seconds develops at the anode of the counter. This brings down the voltage across the counter far below the threshold and keeps it low until the discharge in the counter is quenched. The pulse fed to the coincidence unit has to be

sharp, for proper resolution of two separate events. Hence the output pulse of the univibrator is passed through a differential RC net work having a short time constant of the order of 0.5 microseconds. This network differentiates the square pulse into a positive and a negative pulse, both of very short width. The diode 6H6 allows only negative pulses to be passed to the grid of 6J5 tube, which is used in the circuit as a cathode follower. As the pulse has got a big amplitude the loss of gain in the cathode follower stage is not important, however we get a source of low output impedence and this minimises the loss of signal in multichannel connecting cables. This circuit can furnish negative pulses of about 20 volts and 3 microseconds duration at an output impedence of about 600 ohms.

2.32 Coincidence unit.

The coincidence circuit used is shown in Fig. 9. It is of well known Rossi type. The important property of the circuit is that an output pulse is obtained only when the input pulses from various channel arrive within a very short interval of time of the order of a few microseconds. To secure high resolution and good discrimination between partial and total coincidences, sharp cut off pentodes with low internal resistances are used. The plates of the coincidence tube are tied together and connected through a common resistance to the plate voltage supply. The suppressor grids of all the tubes are

connected to the cathodes so that the tubes are conducting. When the negative pulses arriving simultaneously make all the tubes nonconducting, the change in potential of the plate circuit becomes considerable and a large output pulse is produced. The resolving time of the circuit used

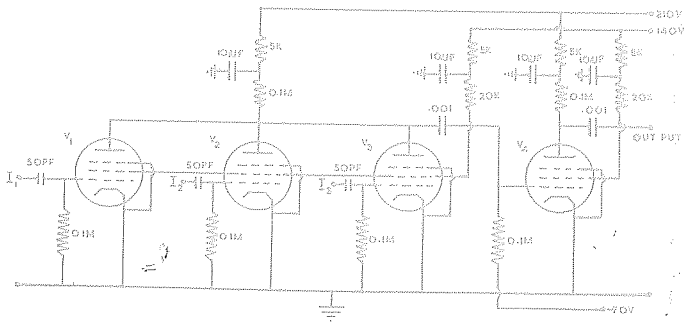

Fig. 9 - Coincidence unit.

is of the order of 4 microseconds. To avoid the small pulses of partial coincidence that might be developed due to the finite internal impedence of the tubes a level discriminator is used at the output which selects the large pulses of three-fold coincidences only, to be passed to the next unit. In addition to the discriminator the last tube acts as phase inverter and amplifier. Thus finally the coincidence unit gives amplified negative pulses.

2.33 Scaling unit.

A bistable multivibrator is used to scale down the

pulses. Fig. 10 shows a scale of two unit. For 22° telescope two such stages were used to get a scaling factor of four. The scale of two circuit has two stable states, in one the first tube is conducting and the other nonconducting and in the second stable state, the position is just the reverse. The plate of each tube is connected

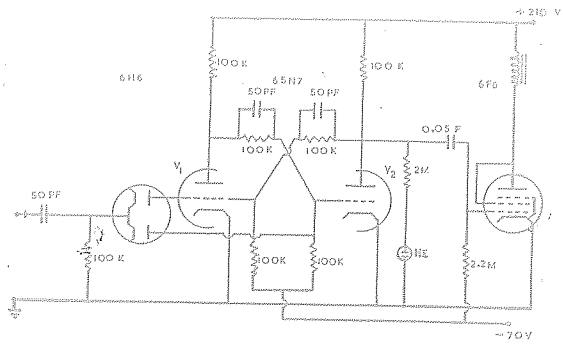

Fig. 10 - Scaling unit.

to the grid of the other by R.C. coupling. A negative pulse applied to the conducting tube triggers the circuit so that this tube becomes nonconducting and the other tube becomes conducting, that is the circuit goes to the other equilibrium state and it remains there till another pulse arrives. Thus the two tubes alternately conduct and do not conduct. A stage following this unit will receive alternate positive and negative pulses as the tubes fluctuate between the two states. By selecting pulses of one type a scaling factor of two is obtained. The resolving time of this scaler is about 15 microseconds.

The cascade of scaling units is followed by a recorder driving a power circuit consisting of a 6P6 tube. This power pentode is normally biased below cut off and the electromechanical recorder forms its plate load. Pulses from the last scaler stage are fed to the grid of the power tube. The arrival of a positive pulse makes the tube to conduct and it is registered in the electromechanical recorder. Neons are used as indicators, and are very useful for checking the function of different scaling stages during operation.

2.34 Power supplies.

The mains voltage, 230 volts, 50 cycles A.C. available at Trivandrum laboratory is stabilised with the help of a constant voltage transformer. The output of this transformer is 220 volts when the input voltage varies from 180 volts to 240 volts. The power for various D.C. power supplies and filaments of vacuum tubes are derived from this constant voltage transformer. The most desirable features of a regulated D.C. power source are high stabilising power, low internal resistance and low ripple output. Hunt and Hickman[158] have discussed in detail various types of voltage stabilising circuits and have shown that the simple degenerative type are in general most satisfactory. The D.C. voltages supplied to the counters and their associated units are stabilised by degenerative type of stabilising circuits.

2.3.4 High voltage power supply

Fig. 11 shows the circuit diagram of the high voltage supply used for providing voltage for G.M.counters. The tube 807 is used as a regulator tube while tube 6SJ7 is used as a feed back amplifier. Two points are of importance in this circuit. Firstly, 6SJ7 is used as a

Fig. 11 - High voltage regulated power supply.

starvation amplifier and therefore the gain is very large, which improves the percent regulation. These starvation circuits (Volkers[152]) can have very large gain upto 2500 using a pentode with extremely low screen voltage and very high plate load resistance. Secondly, the current to the reference tube is fed from the regulated (output) side, which also ensures more stability and better regulation. By varying the potentiometer P, it is possible to vary the output voltage over a large range, from 800 to 1700 volts.

The power supply is adjusted to an output of 1200 volts and the various voltage tapping for counters are obtained from the bleeder circuit. Each tapping of the bleeder is bleased with a condenser to avoid interfeeding of counter pulses which may result in spurious counts.

2.342 Low voltage power supply

D.C. voltages of 420V, 210V are stabilised with the help of a circuit shown in Fig. 12. This circuit uses a difference amplifier and its principal has been discussed in details by Elmore and Sands[160]. VR75 tubes

CIRCUIT DIAGRAM OF V POWER SUPPLY.

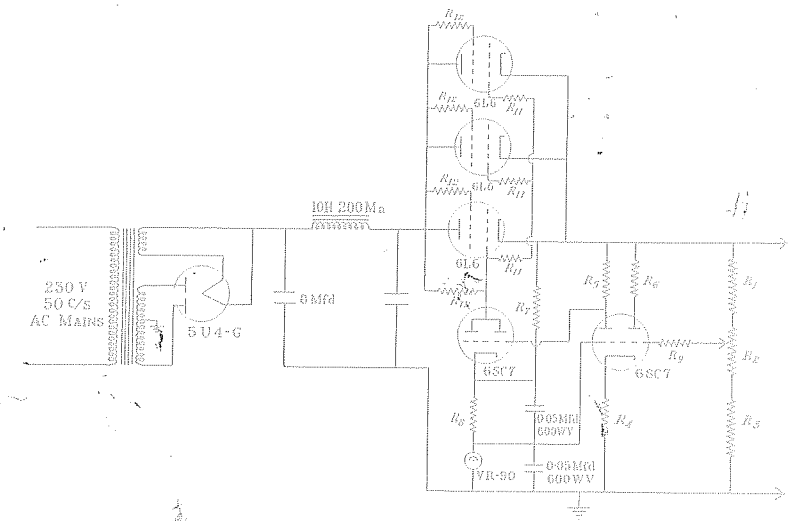

Fig. 12 - Circuit diagram of a low voltage stabilised power supply.

have been used to stabilised -75 volts and 150 volt power supplies.

2.35 Automatic photographic device.

All cosmic ray records are obtained by photographing the mechanical counters every hour. The device consists of a camera unit and an automatic relay control unit. The camera unit is shown in Fig. 13. The

Fig. 13 - Camera unit.

electromechanical recorders registering the counts, a clock and a calendar 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. The camera has a short focus lens and a sprocket to move the 35 mm film. The shaft of the sprocket protrudes outside the camera and is coupled to a low speed motor which rolls the film through one frame after each exposure. With the help of a relay arrangement triggered by an electrical contact of a few seconds

duration made hourly by a clock, the following sequence of operation is achieved at hourly intervals.

(a) Momentary lighting of the bulbs which exposes the film.

(b) Moving the film through one frame, thus leaving the camera ready for the fresh exposure.

Fig. 14 - Automatic sequence control circuit.

Fig. 14 shows the relay control circuit used for this purpose. 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 bulb momentarily. At the same t plate circuit of this tube is made open and so it st

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 second tube for a time in which the film is rotated by one frame. After these operations the circuit comes back to its initial state.

At a time the camera can hold about 30 feet of film. Every day in the morning the exposed film of the previous is removed and developed. The readings of the mechanical recorders are noted down from the negatives.

CHAPTER III

METHODS OF ANALYSIS

3.1 Cosmic ray data

From the hourly photographs, readings for odd hours namely 2300, 0100, 0300.....2100 I.S.T. only are noted down in the daily record sheets. Differences between the successive bihourly records give the rates of secondary meson intensity centred at 0000, 0200,.... 2200 hours for each day. From these readings the mean of each day m, centred at 1100 hours I.S.T. is computed. The 12 dihourly values for the ith telescope are then expressed as deviations, Δm_0^i, Δm_2^i.....Δm_{11}^i from the daily mean $\bar{m}^i$ on each day.

On each day the 12 bihourly deviations from the daily mean obtained in this way from different telescopes of identical geometry are tabulated side by side. Each bihourly is then examined to see if within the limits of the experimental error the deviations from mean of diffe telescopes are similar. Besides this daily routine che observations of the rates of groups of counters in tri as well as voltages, pulses etc. are examined. One variety of checks so applied, it is easy to pick out

faulty telescopes and locate the fault too./ data for such telescopes are rejected on that particular day and if necessary for some consecutive days earlier to it depending upon the nature of the fault. Daily mean values $\bar{m}$ of each telescope are also plotted to check whether telescopes of similar geometry show similar day to day variations beyond 2σ level of significance.

After this selection procedure, the values for the same hourly interval as well as the mean values on each day for properly functioning similar telescopes are added together. The resultant data of each day thus comprises of twelve values $\Sigma\Delta m_0^i, \Sigma\Delta m_2^i, \ldots\ldots\ldots\ldots \Sigma\Delta m_{22}^i$, centred at 0000, 0200,.....2200 hour I.S.T. The summation extends from $i = 1$ to $i = 4$ as there are four telescopes of similar geometry in the present investigation. These twelve deviations from the mean are then expressed as twelve percent deviations $\Delta M_0, \ldots\ldots \Delta M_2, \ldots \Delta M_{22}$; where

$$\Delta M_h = \frac{\sum_{i=1}^{4} \Delta m_h^i}{\sum_{i=1}^{4} \Delta \bar{m}^i} \times 100$$

The barometric pressure and ground temperature readings for the hours 0000, 0200.....2200 were obtained from the daily weather charts of Trivandrum meteorological Observatory. India Meteorological Department collects data of upper atmosphere at Trivandrum with the help two radiosonde flights every day. The temperature

standard isobaric levels are noted every day from their observations. The ground temperature and pressure data are expressed as twelve deviations from daily mean to facilitate application of meteorological corrections. For applying pressure correction a barometric coefficient of -2.2% per cm.Hg. is used on grounds discussed by Sarabhai et al[7].

3.31 Fourier analysis.

For cosmic ray studies it is important to know the nature of periodicities involved in the daily variation and the relationships of these periodicities with the known geophysical and astrophysical periodicities. Thus we must resolve the daily variation into its harmonic components. Various authors, such as Thompson[161], Whittaker and Robinson[162], Nonney[163] and Kane[164] have described labour saving computational methods for evaluating the harmonic coefficients. The method suggested by Kane is followed as it is quick and accurate and it gives the first and the second harmonics with minimum labour.

Any time dependent function F(t) can be expressed in terms of a Fourier series of the type

$$F(t) = a_0 + (a_1 \cos t + b_1 \sin t) + (a_2 \cos 2t + b_2 \sin 2t) \ldots$$

$$= a_0 + \sum_{n=1}^{\infty} (a_n \cos nt + b_n \sin nt)$$

where a_0, a_1, b_1, b_2, a_2.....are independent of t, and are called "Fourier coefficients". If the experimental curve is defined by 12 equally spaced ordinates U_0, U_1, U_2, ...U_{11} corresponding to the times t_0, t_1, t_2, ...t_{11} respectively, then harmonic analysis consists in determining the coefficients a_0, a_n and b_n such that $(U_1 - F(t_1))$ is as small as possible. If the twelve values are expressed as deviations from the mean, the coefficient a_0 becomes zero. The coefficient a_n and b_n corresponding to a 12 ordinate scheme are given by

$$a_n = \frac{\left(\sum_1^{12} U_1 \cos nt_1\right)}{6} \quad \text{and} \quad b_n = \frac{\left(\sum_1^{12} U_1 \sin nt_1\right)}{6}$$

where values of n = 1, 2, ...etc. correspond to first, second,.....etc. harmonics respectively. F(t) can also be written as

$$F(t) = \sum_1^{\infty} r_n \sin (nt + \Psi_n) \qquad (A)$$

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 nth harmonic respectively and

$$r_n^2 = a_n^2 + b_n^2 \quad \text{while} \quad \Psi_n = \tan^{-1} a_n/b_n$$

To study the solar daily variation we spread the twelve ordinates over an interval of solar day. We consider only the first two harmonics, having periods of 24 hours and

12 hours, the higher harmonics being very small.

3.32 The harmonic dial.

The sine wave of function F(t) as described by equation (1) can be represented vectorially as shown in Fig. 15. The figure shows only the first harmonic, one can represent the second and higher harmonics in a similar way and this way of representation is called a harmonic dial. It is clear that the Fourier coefficients are simply the components of the vector in the two

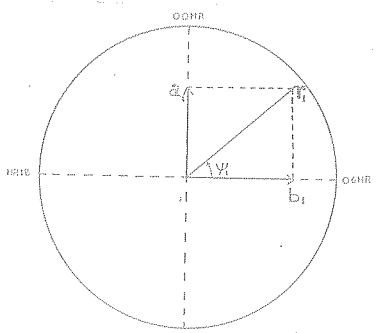

Fig. 15 - The harmonic dial.

directions at right angles.

The maximum of the sine wave $r_1 \sin(t + \psi_1)$ occurs when $t + \psi_1 = 90^0$ that is to say

$$t_{max} = 90 - \psi_1 = \phi_1$$

If we insert a time scale on the harmonic dial such that

it starts from the 'a' axis and measures in a clockwise direction then the vector will indicate directly the time of maximum ϕ_1. For the first harmonic 360° of harmonic dial corresponds to 12 hours. This type of representation is very useful for comparing the variations recorded by different instruments, or for studying the relation between different periodic phenomena.

3.3) Standard error of the Fourier coefficients

If the standard errors in the data $U_0, U_1, U_2, U_3, \ldots\ldots$ and U_{11} are known it is possible to determine the standard errors of the values of the Fourier coefficients a_0, a_1, $b_1 \ldots\ldots$ etc. Let ε be a linear function of $U_0, U_1 \ldots\ldots U_{11}$, say $k_0U_0 + k_1U_1 + \ldots\ldots\ldots k_{11}U_{11}$ and let the standard error of each of the quantities $U_0, U_1 \ldots\ldots U_{11}$ be q. Then the standard error of ε is

$$(k_0^2 + k_1^2 + k_2^2 + \ldots\ldots\ldots k_n^2)^{\frac{1}{2}} \cdot q \qquad //$$

Thus in the 12 ordinate scheme, since $12a_0 = (U_0 + U_1 + \ldots\ldots U_{11})$ the standard error of a_0 is $q/\sqrt{12}$. Similarly the standard error of a_1, b_1, a_2, b_2 etc. can be found out. They are all found to be $q/\sqrt{6}$. The standard error of r and Ψ can be determined knowing β the standard error of both a and b. We have

$$\delta r = \frac{a\delta a + b\delta b}{\sqrt{a^2 + b^2}}$$

which gives the standard error in r as β.

Moreover since,

$$\delta\Psi = \frac{b\,\delta a - a\,\delta b}{\sqrt{a^2 + b^2}}$$

the standard error in Ψ is given by $\beta/\sqrt{a^2+b^2}$.

Apart from the convenient way of representation the harmonic analysis has two distince advantages. Firstly in the measurement of randomly distributed events like cosmic rays the estimate of a bihourly percent deviation is associated with a standard deviation of $\pm 100/\sqrt{N}\% = \sigma$ where N is the bihourly counting rate of the day. A deviation more than 2σ in a bihourly corresponds to a probability of 95.4% that it is due to non-random causes. If for a particular experiment $\sigma = \pm 0.8\%$ then a bihourly deviation will not be considered statistically significant unless it exceeds 1.6%. We have seen however that for a 12 ordinate curve, the standard erro reduces by a factor of $\sqrt{6} = 2.4$. Thus at the same level of significance an amplitude of the diurnal variation of 0.7% can be considered significant.

The second advantage lies in the fact that for many geophysical phenomena, only first two harmonics are important. Thus for such phenomena, instead of 12 bihourly deviations only four parameters namely a_1, b_1, a_2, b_2 are necessary to define the daily variation. Moreover since these coefficients are scalers they can be added up to derive the coefficients of the harmonic components for groups of days.

3.4 Correlation analysis

Correlation analysis enables one to determine the relationship between two or more variables. The correlation coefficient "r" gives a measure of the degree of this relationship, thus r = 0 corresponds to the absence of any correlation. It is clear that correlation coefficient can be positive or negative.

If ΔM and ΔP represent the deviations from mean for cosmic ray intensity and ground pressure respectively over a common interval of time, the correlation coefficients between the two is given by

$$r_{MP} = \frac{\Sigma (\Delta M \cdot \Delta P)}{\sqrt{\Sigma (\Delta M)^2 \cdot \Sigma (\Delta P)^2}}$$

the summation being carried out for all the pairs of ΔM and ΔP values for that period. The regression equation between the two variates is then $\Delta M = b_{MP} \cdot \Delta P$ where

$$b_{MP} = r_{MP} \left[\frac{\Sigma (\Delta M)^2}{\Sigma (\Delta P)^2} \right]^{1/2}$$

When there are more than two variables we use the method of partial correlation to find a measure of the relation-ship between any two variables, the rest of them remaining constant. Let ΔM, ΔP, ΔT be the deviations from mean of meson intensity, pressure and temperature respectively over a common interval of time. Then the

partial correlation coefficient between M and P when T does not vary is given by

$$r_{MP.T} = \frac{r_{MP} - r_{MT} \cdot r_{PT}}{\left[(1 - r_{MT}^2)(1 - r_{PT}^2)\right]^{\frac{1}{2}}}$$

where r_{PT} is the correlation coefficient between pressure and temperature. r_{MT} is the correlation coefficient between oceans and temperature. r_{MP} is the correlation coefficient between ocean and pressure.

The following regression equation expresses the relation between the three variables. $\Delta M = \alpha_p \Delta P + \alpha_T \Delta T$

where $$\alpha_p = \frac{r_{MP} - r_{MT} \cdot r_{PT}}{1 - r_{PT}^2} \cdot \frac{\Sigma(\Delta M)^2}{\Sigma(\Delta P)^2}$$

and a similar relation for α_T. Partial correlation can also be extended to cases where there are more than three variables. The standard error associated with the correlation coefficient is given by

$$\sigma_r = \pm 0.67 \frac{1 - r^2}{\sqrt{N}}$$

where r is the correlation coefficient and N is the number of pairs from which r is calculated. The larger the value of N the lesser would be the value of the standard error and hence greater would be the significance of r.

3.5 Chree analysis

The recurrence tendency of phenomena and the association between two events can be detected by the aid of a special averaging method, originally devised by Chree for the analysis of geomagnetic character figures. This analysis reveals any recurrence tendency among the observations and also gives the average period of the recurrence tendency. This method is free from any preconceived ideas about the length and significance of the recurrence tendency.

Let us assume that we have observed n phenomena and the effect of these on cosmic ray intensity is under investigation. The values of cosmic ray intensity corresponding to the times of onset of these phenomena are entered in a vertical column numbered zero. The values of the intensity for times following this zero are entered in a sequence of columns arranged to the right of column zero and numbered +1, +2, +3 etc. The data for times preceeding the time zero are entered in the table to the left in columns numbered -1, -2, -3 etc. Thus we get a table of n rows.

The mean value of the intensity for each column is then found and plotted on a graph against the corresponding column number. This curve immediately shows the effect on cosmic rays if any by the observed phenomena. A similar procedure is employed to find the

recurrence tendency of cosmic ray variations.

3.6 Punch card system of tabulation of data.

For cosmic ray problem the data has to be sorted for different criteria and each group of days so obtained has to be represented by average parameters. In this type of analysis it is convenient to use the punch card system of tabulation of data. Much labour is saved by using electric puncher, sorter and tabulator for analysis of this type.

Each card gives full information of one day, namely hlhourly percent deviations of cosmic ray intensity, diurnal and semidiurnal components of solar daily variation the mean intensity of the day and the harmonic components of pressure. In the present investigation Hollerith cards of eighty colum - ten row type were used for tabulating the primary data. The following is the scheme of the punched card.

Punch card tabulation of data

Column	Description
1, 2	Type of telescope.
3, 4	Year
5, 6, 7	Day of the year
8, 9	Lunar phase/a
10, 11	C_p index for the day
12, 13	Solar declination
14 to 37	The 12 pressure corrected cosmic ray percentage bihourly deviations for 0000, 0200,.....2200 hours which are described in chapter III.
38, 39	The variance χ^2 for the day.
40	Reliability indicating number of bihourly deviations extrapolated if any.
41	Number of telescope working on the day.
42	Range of in which r_1 or r_2 whichever is larger lies.
43 to 46	Total mean bihourly rate from which percent deviations of bihourly values of cosmic ray intensity are calculated.
47 to 49	Normalized total mean bihourly rate corrected for pressure variations.
51 to 58	a_1, b_1, a_2 and b_2 the Fourier coefficients of meson daily variation.
59 to 66	r_1, r_2, ϕ_1 and ϕ_2 calculated from a_1, b_1, a_2, b_2 respectively.
67, 68	Ratio r_1/r_2.
69 to 76	Fourier coefficients of daily variation of barometric pressure P_{a_1}, P_{b_1}, P_{a_2} and P_{b_2}.
77 to 79	Mean barometric pressure for the day.
80	Blank.

CHAPTER IV

EXPERIMENTAL RESULTS

A cosmic ray recording unit consisting of four triple coincidence counter telescopes with semiangles $22^{0} \times 37^{0}$ pointing to the vertical was started at Trivandrum in the year 1954. The author took charge of this unit in October 1954 and operated it till the end of September 1957. Table 1 shows the working of the telescopes during the three years 1955, 1956 and 1957. The number of days for which data are available are lower in 1955 and 1956 compared to 1957. The large number of interruptions in the year 1955 were due to frequent power failures, the apparatus was therefore shifted to a new premises in August 1956.

4.1 Corrections for meteorological factors.

We have discussed earlier in chapter I, the meteorological corrections which should be applied to cosmic ray data. For the vertical telescopes at Trivandrum a pressure coefficient of -2.2% per cm change of Hg. has been used to correct the cosmic ray hourly intensity. For calculation of temperature correction two valid methods are available at present. These methods have been given by (1) Maeda and Wada[31] and by (2) Dorman and Feinberg[36].

Table 1

Number of days in each month of the years 1955, 1956 and 1957 for which daily variation data of Trivandrum are available and percent days in each year on which all four, three, two and one only of the telescopes were functioning.

No.of tels. working	J	F	M	A	M	J	J	A	S	O	N	D	Total days	%
1955														
4	13	6	12	5	8	2	4	12	8	11	17	5	103	38
3	0	12	6	13	11	9	10	3	4	8	0	10	86	32
2	2	5	5	4	8	2	7	8	5	4	6	8	64	24
1	1	2	0	1	0	3	2	2	1	1	0	2	15	6
Total working days	16	25	23	23	27	16	23	25	18	24	23	25	268	
1956														
4	16	10	11	3	7	11	7	7	21	20	21	23	157	52
3	11	11	6	8	6	6	8	6	3	7	5	2	79	26
2	2	4	3	12	6	8	7	9	1	1	0	1	54	18
1	0	1	2	2	5	0	0	0	0	0	0	2	12	4
Total working days	29	25	22	25	24	25	22	22	25	28	26	28	302	
1957														
4	22	19	10	11	20	14	18	10	23	18	27	21	213	63
3	7	3	12	10	5	5	4	11	2	7	3	8	77	23
2	2	4	8	7	3	2	5	7	0	2	0	2	42	12
1	0	0	0	1	1	2	1	2	0	0	0	0	7	2
Total working days	31	26	30	29	29	23	28	30	25	27	30	31	339	

Both these methods lead to similar expressions for temperature correction. A knowledge of temperature changes at different layers in the atmosphere is essential for temperature correction by these methods. For daily variation studies we would require the daily variation of temperature at various levels of the atmosphere. The radiosonde instrument used at present for temperature observations of the upper atmosphere has many inherent errors. The most important of these is the error caused by direct heating of the thermal element by sunlight. Realising this many workers have attempted to estimate the magnitude of the diurnal variation of temperature in the upper atmosphere.

Kay[165] has summarised the results of nearly 14000 ascents made in the course of four years at four stations in England. He finds a diurnal variation of temperature of about 2^{0}-3^{0}K which changes with the seasons. It has been suggested by Kay that this and other results of the flights can be explained as due to inherent errors in radiosonde measurements. These errors can be casual or systematic. The casual errors are due to inevitable random sampling of non-uniform conditions in the upper atmosphere and also due to lack of strict intercomparability between instruments. The important systematic errors in radiosonde elements are (1) errors in pressure measurement and (2) errors in temperature measurement mostly caused by the direct irradiation by sunlight.

A study of regular daily variation of temperature in the upper atmosphere was undertaken by Desai and Venkateswaran[166] at Ahmedabad. They did not observe diurnal variation in temperature with amplitude larger than 1°C above 2 km.

Glokova et al[37] have applied the temperature correction to their data using radiosonde data at a number of stations separated in longitude and they find that the amplitude of the diurnal variation of temperature was about 0.1% with a maximum near noon. Berman and Felsberg[167] have pointed out that a systematic error of 1°C in all the layers can change the temperature correction by about 0.3%.

Sarabhai et al[7] have discussed the significance of the various causes which can produce a daily variation of temperature in the upper atmosphere. They conclude that the daily variation of temperature gets attenuated rapidly from ground level to about 2 km where it becomes negligible. It becomes important again in the ozone ultraviolet absorption region. This ozone ultraviolet region is well above the levels where meson production in the atmosphere is important. We are therefore justified in assuming that the daily variation of temperature above 2 km may be neglected in applying temperature correction to the data of Trivandrum station by using Berman's method. Instead of depending on the radiosonde observations of temperature of 900 mb level required in this method we

have estimated the phase and amplitude of diurnal variation from Beer's[168] relation. According to Beer's experimental results, the mean temperature between ground and 2 km would have an amplitude of about 0.32 times the amplitude of the temperature variation at ground. The average yearly daily variation curve of Trivandrum has been corrected by this method.

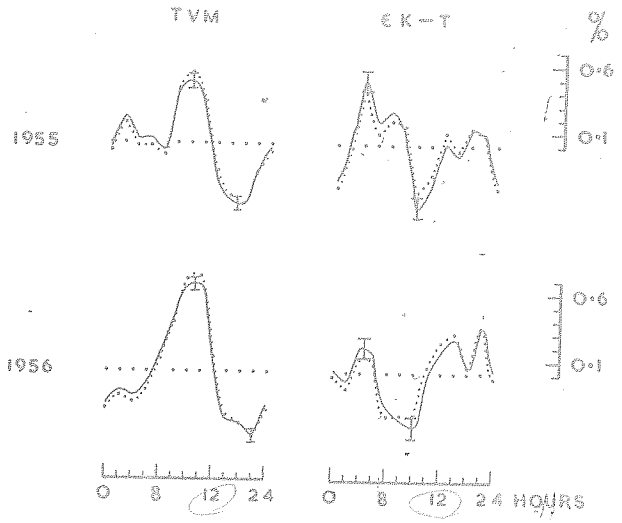

Fig. 16 - 12 month mean daily variation curves for Trivandrum and the difference in daily variation at Trivandrum and Kodaikanal (€ K - T) with and without temperature correction.

Fig. 16 shows the yearly curve of 1955 and 1956 with and without temperature correction. The temperature correction has an amplitude of about 0.06% with time of maximum at 1500 hours. In both the years the temperature increases slightly, the amplitude of the daily variation without significantly altering its phase. The figure shows

that the temperature correction is negligible.

In chapter I Miyazaki's[40] method of applying temperature correction to the secondary meson intensity related to the comparatively low energy primary cosmic rays has been discussed. The main conclusion of Miyazaki's results is that the difference in pressure corrected intensities of two stations situated at the same latitude and longitude but at different altitudes needs to be corrected only for the temperature variations of the atmosphere between the two stations. Trivandrum and Kodaikanal stations satisfy Miyazaki's conditions. Moreover, identical cosmic ray telescopes are in operation at these stations for some time past. We have applied temperature correction to the difference in daily variation of these stations by using the temperature coefficient of Miyazaki. Figure 10 shows the ε K - T curves of daily variation with and without temperature correction. Here K and T represent the pressure corrected percent daily variation at Kodaikanal and Trivandrum respectively. ε is the ratio of absolute cosmic ray intensity at Kodaikanal to that at Trivandrum. The mean daily variation of temperature between Trivandrum and Kodaikanal is estimated from the daily variation of temperature at Trivandrum, using Beer's relation as before. The amplitude and time of maximum of the temperature correction are 0.09% and 1500 hours respectively.

It will be observed that when the amplitude of

the daily variation is large as it is in 1955, 1956 and 1957 this correction is negligible. In the further analysis of this chapter which deals with studies of daily variation of cosmic rays only, temperature correction has not been applied. All the data however have been corrected for pressure changes.

4.2 Long term changes.

4.21 Examination of 12 month mean daily variation.

The following notation has been used throughout this chapter.

r_1 - The amplitude of the diurnal variations.

ϕ_1 - The time of maximum of the diurnal variations.

r_2 - The amplitude of the semidiurnal variations.

ϕ_2 - The time of maximum of the semidiurnal variations.

To remove the effect of seasonal variations, only 12 month mean curves have been considered. The mean yearly curve has been computed by taking an average of the hourly deviations of each day. Fig. 17 shows the 12 month mean moving average curves of daily variation centered at the three month epochs, June 1955, September 1955, December 1955 and so on.

In Table 2 the first and second harmonic coefficients of the 12 month mean curves have been given. The 12 month mean values of relative sunspot number and C_p, the daily planetary index of geomagnetic disturbances have also been

indicated in the same table. The time series presented in this diagram is quite interesting as the solar activity

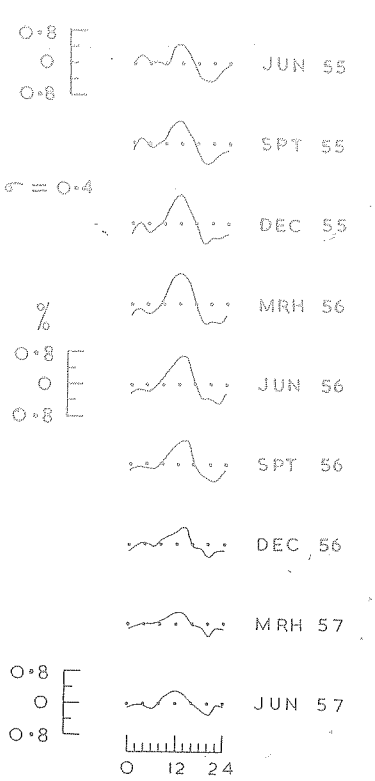

Fig. 17 - 12 month mean daily variation curves centered at the three month epochs from 1955 ~~to 1956~~ to 1957.

increasing from 1954 became maximum in 1957. All the curves in this diagram have been derived from pressure corrected cosmic ray intensity, the temperature correction has already been shown to be negligible for daily variation studies. In any case for comparison of the 12 month mean curve at the same station the meteorological corrections are not important since the average variations of barometric pressure and of atmospheric temperature for a period of a year remain fairly constant from year to year. The main points of the 12 month mean daily variation at Trivandrum can be summarised as follows.

Table 2

Table showing the values of r_1, r_2, ϕ_1 ϕ_2 describing the diurnal and the semidiurnal components of the 12 month mean daily variation at Trivandrum centered at successive three month epochs for the period January 1955 to December 1957. Values of 12 month mean C_p and relative sunspot number for all epochs are also indicated.

Epochs	r_1	r_2	ϕ_1	ϕ_2	C_p	R
	γ	γ				
1955	$\sigma = \pm 0.02$					
Jun.	0.29	0.26	130°	18°	0.5	31.4
Sept.	0.37 (1)	0.25	143°	11°	0.6	48.9
Dec.	0.44	0.26	160°	10°	0.7	69.1
1956						
Mar.	0.53	0.28	167°	16°	0.7	90.3
Jun.	0.46	0.23	169°	26°	0.8	106.1
Sept.	0.37	0.22	170°	37°	0.8	112.7
Dec.	0.24	0.14	161°	45°	0.7	117.7
1957						
Mar.	0.20	0.10	160°	34°	0.8	123.4
Jun.	0.18	0.14	168°	22°	0.8	143.8

(1) The diurnal deviation at 0200 hours in the average daily variation which is significantly positive in 1955 has slowly disappeared and in 1957 it has assumed a negative value.

(2) The 1200 hour maximum increases in amplitude

in 1956 and then decreases in 1957 to a value less than the amplitude in 1955.

(3) The 1800-2000 hour minimum has decreased from 1955 to 1957.

(4) The first harmonic amplitude $\bar{r}_1$ is maximum in 1956 and its value is lower in 1957 compared to that in 1955.

(5) The time of maximum $\bar{\phi}_1$ of the first harmonic component is later in 1957 compared to 1955. The change in $\bar{\phi}_1$ takes place from June 1955 to December 1955 and there after it has not changed upto December 1957.

(6) The amplitude $\bar{r}_2$ of the second harmonic has decreased from 1955 to 1957.

(7) The time of maximum $\bar{\phi}_2$ of the second harmonic does not show any systematic change.

(8) The 12 month mean daily variation is not directly correlated with either 12 month mean $\bar{C}_p$ or 12 month mean relative sunspot number $(\bar{R})$.

4.22 Examination of distribution in different years of characteristics of the daily variation.

The daily variation has been found to vary from day to day, it is therefore important to study the variability of the daily variation from day to day before we attach any physical meaning to the 12 month mean data.

The parameters describing the daily variation namely r_1, ϕ_1, r_2 and ϕ_2 have large standard errors on any individual day. This study has therefore been made by analysing the frequency distribution of the above mentioned parameters. These distributions are then compared with the characteristics of 12 month mean daily variation. Fig. 18 shows r_1, r_2, ϕ_1 and ϕ_2 distributions in the three years.

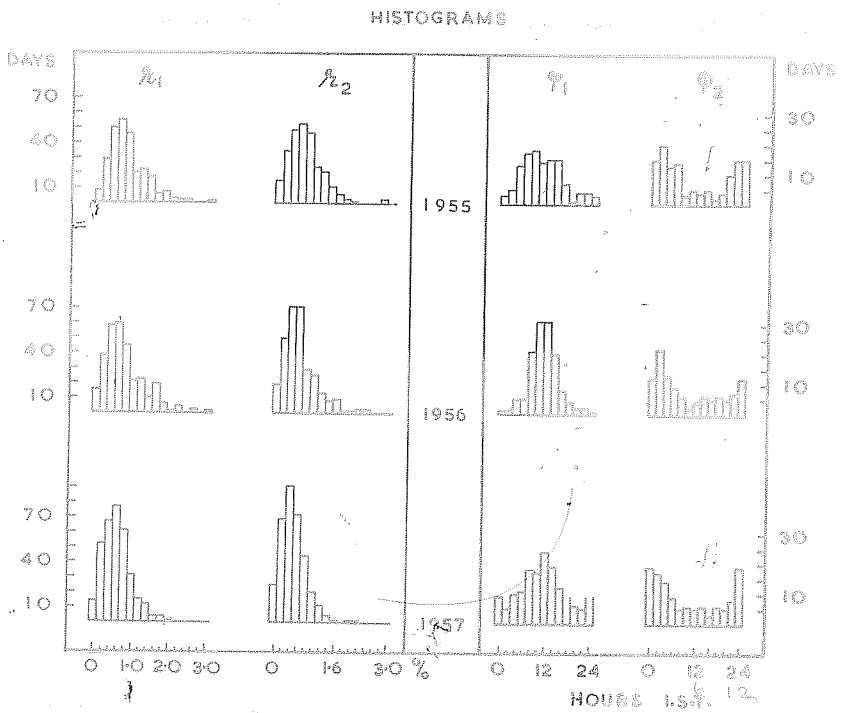

Fig. 18 - The histograms for the years 1955, 1956 and 1957 showing the distribution of values of the parameters of the harmonic components of the daily variation on individual days. (a) r_1 histogram (b) r_2 histogram (c) ϕ_1 histogram (d) ϕ_2 histogram.

4.221 r_1 histogram

The r_1 histogram shows that the occurrence of large daily amplitudes on individual days decreases from

1955 to 1957. Days having r_1 greater than 1.0 constitute 26.5% of days in 1955, 25.6% in 1956 and only 14.5% in 1957. Moreover, days with low amplitude ($r_1 \leq 0.5$) are maximum in 1957 compared to days in 1955 and 1956.

It has been pointed out that the mean amplitude of 12 month curve is $r_1 = 0.39\% \pm 0.02$ in 1955 compared to $0.46 \pm 0.02\%$ and $0.22 \pm 0.02\%$ in 1956 and 1957 respectively. Table 3 shows that the amplitudes in 1955 and 1956 on individual days were comparable. Thus while

Table 3

Table showing the percent amplitudes for different r_1 groups in the three years.

Year	$r_1 < 0.5$	$0.5 < r_1 < 1.0$	$r_1 > 1.0$	$r_2 < 0.5$	$0.5 < r_2 < 1.0$	$r_2 > 1.0$
1955	22.8%	50.7%	26.5%	26.5%	53.0%	20.5%
1956	24.9%	49.5%	25.6%	35.2%	48.5%	16.3%
1957	30.4%	55.2%	14.5%	41.6%	50.7%	7.7%

the smaller amplitude of the mean daily variation curve in 1957 can be due to small amplitudes on individual days, the larger amplitudes of the average daily variation in 1956 compared to 1955 must be due to a greater scatter of time of maximum in 1955 compared to 1956.

4.222 r_2 histogram

The percent days having r_2 greater than 1.0% in

this histogram are 20.5%, 16.3%, 7.7% for 1955, 1956, and 1957 respectively. This shows that the occurrence of large semidiurnal amplitudes on individual days decreases from 1955 to 1957. Days having amplitudes less than 0.5% are maximum in 1957 compared to 1955 and 1956. The 12 month mean curve also shows a smaller amplitude in 1957 compared to 1955 and 1956.

4.223 ϕ_1 histogram

On days on which r_1 is smaller than the 2σ level of significance, ϕ_1 is expected to have a large error, hence in Fig. 18, ϕ_1 and ϕ_2 histograms of the three years are shown only for those days which have $r_1 > 2\sigma$ and $r_2 > 2\sigma$ respectively. The histogram of ϕ_1 shows a shift of time of diurnal maximum to later hours from 1955 to 1957. Further as we had concluded earlier in 4.221, there is more scatter in the distribution of 1955 compared to 1956 and 1957. The scatter is minimum in 1956 which is responsible for higher amplitudes in the average daily variation of 1956.

The harmonic dial in Fig. 19 shows the percent days (having significant amplitudes) in the years 1955 to 1957, which have their time of maximum centered at 0000 hour, 0600 hour, 1200 hour or 1800 hour. The diagram includes those days which have r_1 or $r_2 \geq 2\sigma$. The time of maximum is grouped as follows

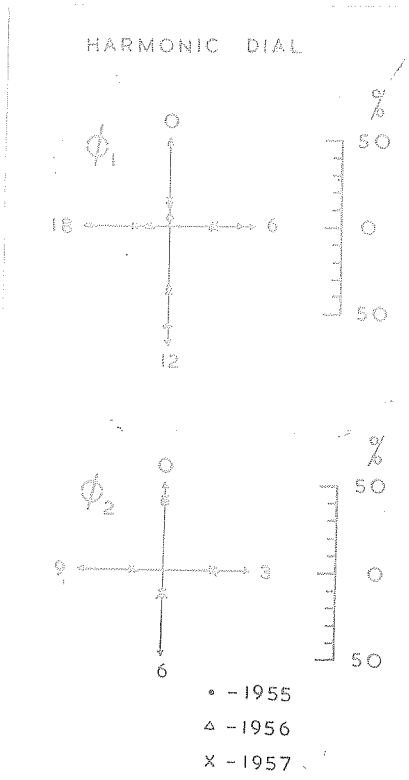

Fig. 19 - Harmonic dials showing the frequencies of times of maxima (ϕ_1 and ϕ_2) at hours corresponding to 0°, 90°, 180° and 270°.

Time of maximum from	Classified as
2100 to 0300 hour	0000 hour
0300 to 0900 hour	0600 hour
0900 to 1500 hour	1200 hour
1500 to 2100 hour	1800 hour

It is clear from the harmonic dial in the figure that the time of maximum of days with significant amplitudes has become later in 1957 compared to 1955 and 1956. The maximum frequency of occurrence is at 0600 hour in 1955, at 1200 hour in 1956 and at 1800 and 0000 hours in 1957.

4.224 ϕ_2 histogram

This histogram does not appear to change from 1955

to 1957. Figure 19 shows the frequency distribution of ϕ_2 in different years for days with significant amplitudes. It is striking to note that there is no change in the frequency of occurrence of time of maximum from year to year.

4.23 Analysis of significant positive and negative bihourly deviations of the 12 month daily variation.

In the earlier sections the changes in the parameters $\bar{r}_1$, $\bar{r}_2$, $\bar{\phi}_1$ and $\bar{\phi}_2$ of the 12 month mean daily variation were studied. It has been pointed out by Kemp and Littkus[60] and by Tarabani and Satya Prakash[169] that for a thorough study of the daily variation, the deviations from mean of the bihourly values should also be considered as rapid changes are not adequately represented by the first two harmonic components of the daily variation.

Fig. 20 shows the frequency distribution of significant bihourly deviations of the daily variation in 1955, 1956 and 1957. Bihourly deviations which showed a deviation greater than 2 σ from the mean of any day have been considered. The frequencies of positive and negative bihourly deviations have been shown separately.

The features common to all the three years are :

(1) The maximum frequency of positive bihourly deviations occur from 1200 to 1400 hours.

(2) The maximum frequency of negative bihourly deviations occur from 1600 to 2200 hours.

The frequency of positive deviation from 1200 to 1400 hour is significantly less in 1957 compared to 1955 and 1956. Similarly the frequency of negative deviation from 1600 to 2200 hours is less in 1957 compared to 1955 and 1956.

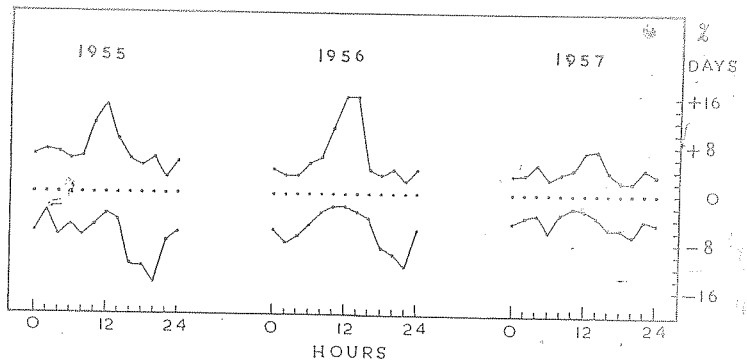

Fig. 20 - Frequency distributions of significant positive and negative bihourly deviations of the 12 month daily variation at Trivandrum for 1955, 1956 and 1957.

This analysis gives similar features of daily variation as the 12 month mean curves. It shows that the frequency of occurrence of significant bihourly deviations at most prominent hours (1200 to 1400 hours and 1600 to 2200 hours) is smaller in 1957 compared to 1955 and 1956.

4.3 Daily variation and geomagnetic activity

4.31 Mean daily variation on groups of days having low, medium and high values of C_p

To understand the relation between daily variation and geomagnetic activity the association between C_p, the daily planetary character figure for geomagnetic disturbances and various parameters of the daily variation have been studied. In the first instance all the days in the three year period 1955 to 1957 have been divided into three groups as shown in Table 4. The average daily variation in each of these groups is calculated and plotted in Fig. 21(a). The amplitudes and times of maxima of the first two harmonic components for each group are given in Table 4.

Table 4

Table showing the characteristics of the mean daily variation (1955 + 1956 + 1957) for low, medium and high C_p groups.

Group	C_p	No. of days.	r_1	ϕ_1	r_2	ϕ_2
C_p^L	0.0 to 0.5	333	0.33±0.02	157°	0.20±0.02	30°
C_p^M	0.6 to 1.0	270	0.29±0.02	169°	0.21±0.02	21°
C_p^H	1.1 to 2.0	174	0.34±0.03	149°	0.22±0.03	12°

It is clear from the figure and the above table that there is no significant difference in the mean daily variation of the three groups. To study the relationship of C_p with daily variation during each year separately the data have been divided into three yearly groups. Analysis

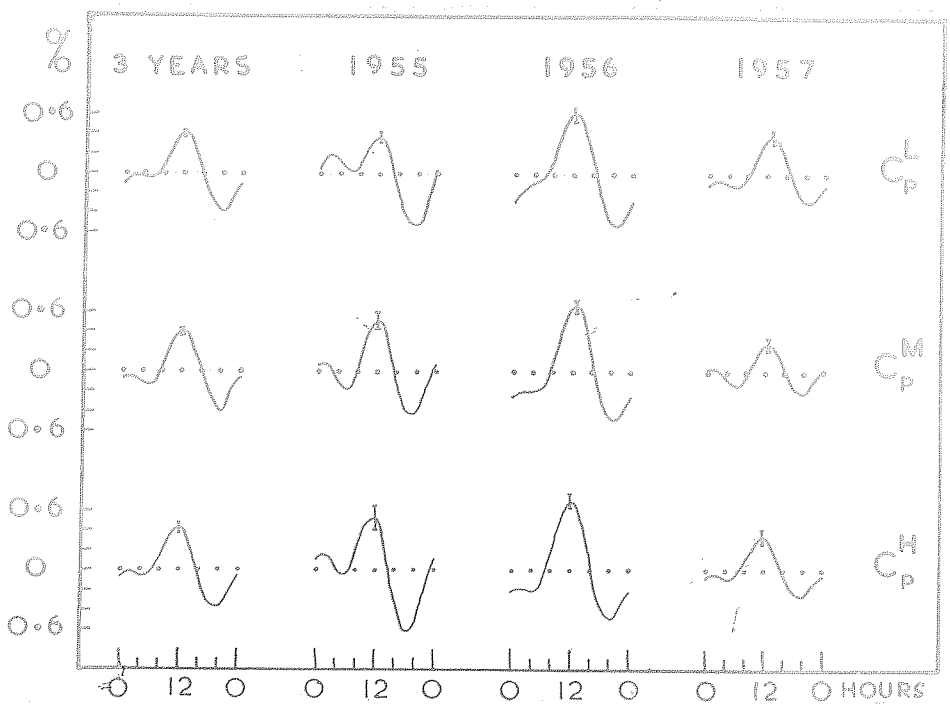

Fig. 21 - Mean daily variation in the low, medium and high C_p groups (1) for the combined data of 1955, 1956 and 1957 (2, during individual years.

similar to that mentioned above is done separately for the three years 1955, 1956 and 1957. Fig. 21(b) shows the daily variation in the three C_p groups of each year. In Table 5, the first and the second harmonic components of the daily variation in each of the groups are indicated.

In the year 1955 r_1 is larger in high C_p group (C_p^H) compared to medium C_p group (C_p^M). The difference in amplitudes is however only a little larger than the statistical error associated with the daily variation in each group.

Table 5

Table showing the characteristics of the mean daily variation for low, medium and high C_p groups during 1955, 1956 and 1957.

Group	Year	r_1	ϕ_1	r_2	ϕ_2
C_p^L	1955	0.29 ± 0.03	124°	0.24 ± 0.03	27°
C_p^M		0.25 ± 0.04	154°	0.30 ± 0.04	11°
C_p^H		0.36 ± 0.06	130°	0.32 ± 0.06	10°
C_p^L	1956	0.46 ± 0.03	165°	0.19 ± 0.03	34°
C_p^M		0.45 ± 0.03	175°	0.23 ± 0.03	28°
C_p^H		0.46 ± 0.04	170°	0.25 ± 0.04	10°
C_p^L	1957	0.23 ± 0.03	178°	0.15 ± 0.03	37°
C_p^M		0.12 ± 0.03	171°	0.16 ± 0.03	21°
C_p^H		0.22 ± 0.03	160°	0.13 ± 0.03	0°

During 1956 there is no significant difference in the mean daily variation of the three groups. In 1957 the diurnal amplitude r_1 is smaller in medium C_p group than in the low and high C_p groups. There is no significant change in the times of maxima from group to group in any year.

Thus in 1955 and 1957 while the diurnal amplitude appears to increase from medium to high C_p groups, low and high C_p groups have similar amplitudes. This feature

could not be established beyond statistics when the data of all the three years were studied together.

4.32 Study of histograms of parameters of the daily variation in low, medium and high C_p groups.

In section 4.31 we have examined the characteristics of the average daily variation for three C_p groups during each of the three years. In the present section the association with C_p is studied in relation to the histograms of the parameters of the daily variation on individual days.

4.321 r_1 histogram.

Fig. 22(a) shows r_1 histograms in the three C_p groups in the years 1955, 1956 and 1957. All the histograms are skew to the right i.e. towards high amplitudes. The total frequency in the high C_p group of 1955 is only 19 and hence this group has not been studied in this section. Statistical analysis shows that the Gamma distribution given by

$$f(x) = \frac{\theta^{\alpha}}{\Gamma(\alpha)} x^{\alpha-1} e^{-\theta x} \qquad \theta > 0, \quad \alpha > 0$$

fits all the histograms of each year in different C_p groups. The parameters θ and α are different for different groups. However the analysis of variance of parameters θ and α indicates that the difference in the

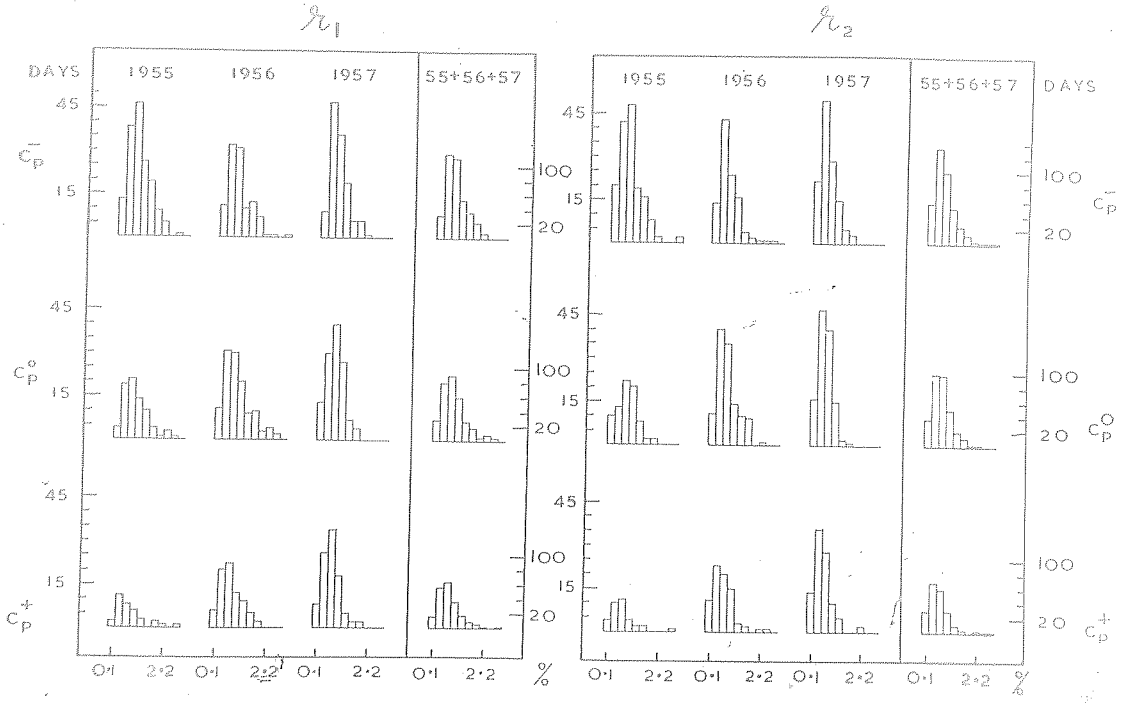

Fig. 22 - Histograms of diurnal and semidiurnal amplitudes in low, medium and high C_p groups. (a) r_1 histogram (b) r_2 histogram.

values of δ and α from low C_p group to high C_p group are not significant in the two years studied (1956 and 1957). The analysis further reveals that the values of parameters δ and α do not change significantly in any group from 1956 to 1957.

On the other hand we observed in the earlier section that the amplitude of the average diurnal variation is less for the medium C_p group than for the high C_p group in 1957. As we shall see later the decrease of amplitude of average curve is brought about by a high scatter of times of maxima in medium C_p group during 1957 compared

to high C_p group.

4.322 r_2 histogram

Figure 22(b) shows r_2 histograms in the low, medium and high C_p groups of each year. The χ^2 test is performed to find the goodness of fit of Gamma distribution to the various histograms. It is found that the Gamma distribution fits the histograms of the three groups in 1956 and 1957. In 1955 this distribution fits the histograms of low and high C_p groups, however in the medium C_p group the frequencies expected from Gamma distribution are significantly different from those observed in this group. The analysis of variance of the parameters also reveals a significant difference between σ and α of medium group of 1955 and those of other groups.

4.323 ϕ_1 histogram

Fig. 23(a) shows the histograms of ϕ_1 for days with significant amplitude (r_1 or $r_2 > 2\sigma$). In the year 1955 the ϕ_1 histogram on low C_p days shows a broad peak around 0900 hours. In medium C_p group there is an indication of two C_p peaks one at about 0600 to 0700 hours and the other at 1400 hours. The high C_p group has too few days to draw any conclusion.

In 1956 the low C_p group has a sharp peak around 1200 hours. In the medium C_p group the peak shifts to later hours and becomes symmetrical. In the high C_p group

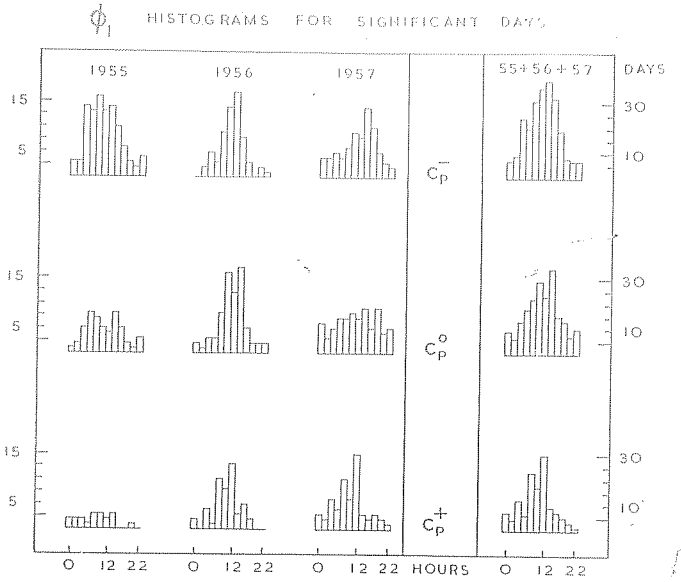

Fig. 23(a) Histograms of diurnal time of maximum (ϕ_1) for days with significant amplitudes in low, medium and high C_p groups.

it shows a distribution similar to low C_p group. In the year 1957, the low C_p group shows a peak at about 1400 hours. The medium C_p group shows a high scatter of time of maximum while the high C_p group shows a peak around 1200 hours.

The year-to-year changes in ϕ_1 histograms of different groups can be summarised as follows.

The year to year change can be followed in all the three years in low C_p group where the time of maximum becomes later by about 4 hours from 1955 to 1957. In

medium C_p group the scatter is large in 1955 and 1957 compared to 1956. In high C_p group there is almost no change from 1956 to 1957.

The relatively little change of histograms with C_p in 1956 is responsible for larger amplitude of the 12 month mean daily variation.

4.324 ϕ_2 histogram.

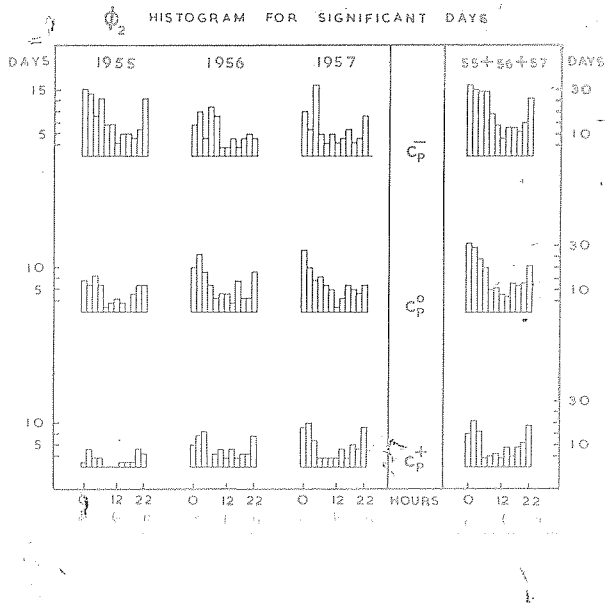

Fig. 23(b)-Histograms of semidiurnal time of maximum (ϕ_2) for days with significant amplitudes in low, medium and high C_p groups.

Fig. 23(b) shows that there is no significant change with C_p of ϕ_2 histograms in any of the three years.

4.33 Analysis of significant positive and negative hourly deviations associated with days of low, medium and high C_p

It is interesting to examine the association of changes in significant positive and negative hourly deviations of daily variation in different C_p groups. In Fig. 24 the frequency distribution of significant hourly deviations of the daily variation data from 1955 to 1957 have been plotted. The frequencies of positive and negative hourly deviations have been shown separately. Hourly deviations which showed a deviation greater than 2σ from the mean of any day have been considered.

In all the C_p groups the most frequent positive hourly deviations are between 1000 to 1400 hours and negative deviations between 1600 to 2200 hours. The frequency of positive hourly deviations at 1000 to 1400 hours is maximum in high C_p groups and minimum in low C_p groups. The frequency in medium C_p group is in between the low and high C_p groups. There is no significant change in the negative deviation from 1600 to 2200 hours from low C_p group to high C_p group.

In figure 24 the hourly deviations for the individual years also have been shown. It is clear from this figure that in all the three years the frequency of 1000 to 1400 hour hourly deviations is more in medium

and high C_p groups compared to the low C_p group.

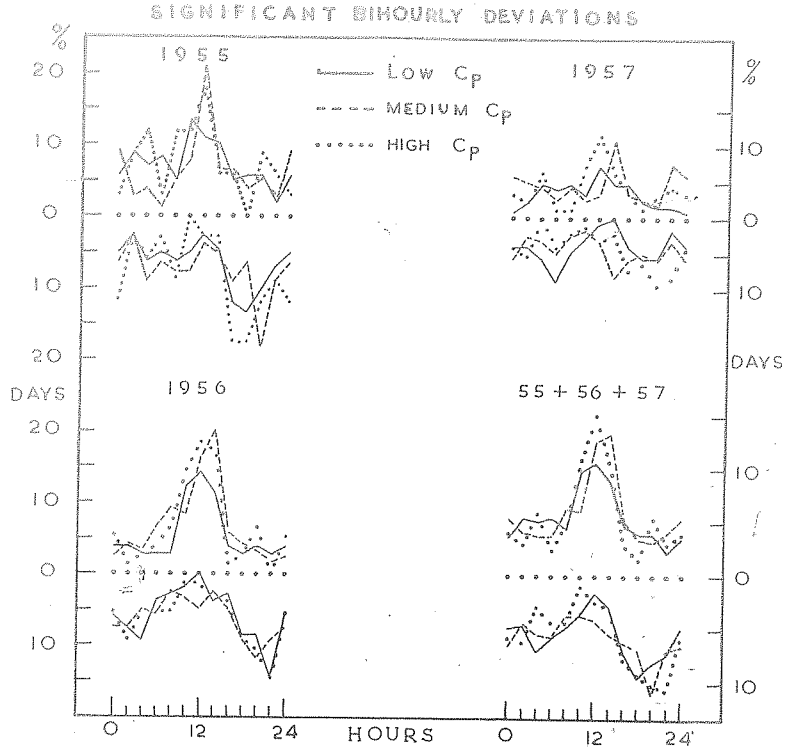

Fig. 24 - Frequencies of significant positive and negative bihourly deviations in low, medium and high C_p groups.

In the year 1955 the medium C_p group differs significantly from low and high C_p groups in the frequency of positive bihourly deviation at 0400 hours. We have seen in section 4.322 that medium C_p group of 1955 was significantly different from low and high C_p groups in the same year. Here the figure shows that 0400 hour deviations has higher frequency in low and high C_p groups compared to medium C_p group.

We have seen earlier from the analysis of sections 4.321 and 4.322 that the characteristics of the average

daily variation of medium C_p group differs significantly from the characteristics from the average daily variation from low and high C_p groups and that there was no significant difference between low and high C_p groups. The analysis of significant positive and negative hourly deviations reveal a significant difference between the frequency distribution of positive hourly deviations near noon, this difference was not seen in the analysis of earlier sections.

4.24 Sequential changes in daily variation related to geomagnetic disturbances

Fig. 25 (a) shows a plot of mean C_p values on epoch days and also on five days before and after the epochs of each C_p group. The analysis has been seperately done for the ~~three~~ years 1956 & 1957. The figure shows that in each year high C_p values have a tendency to remain high for about two days on either side of epoch.

Low Cp values also remain low for $\pm$ 2 days. In the medium-C_p group the mean value of C_p on epoch day is about 0.8. There is no significant change in C_p from -5 to +5 days in medium groups of the ~~three~~ years 1956 & 1957.

This analysis indicates that instead of a classification merely on C_p values, individual C_p maxima and minima which include one or more days on either side of high and low values of C_p respectively should be

considered. Further the changes in cosmic ray daily variation should be studied not only on epoch day but also a few days before and after epoch day. Analysis of this type has been discussed in this section.

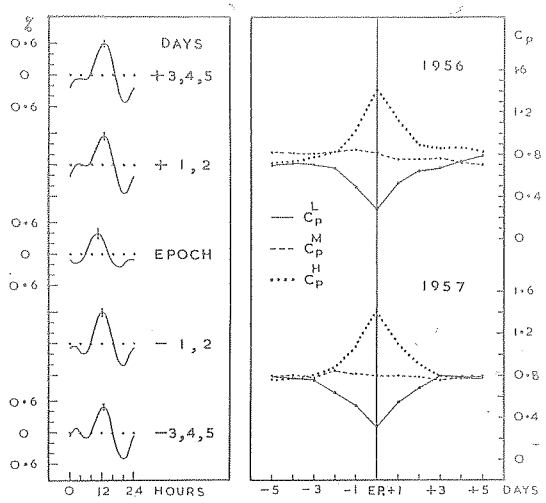

Fig. 25 - (a) Diagram showing the mean values of C_p on the epochs of low, medium and high C_p days and also on 5 days before and 5 days after the epochs.

(b) Mean daily variation on epochs (also on 5 days before and after epochs) of C_p maxima days.

4.3.4 Association of C_p maxima with cosmic ray daily variation.

A C_p maximum is defined by the following points.

(1) It should have a value ≥ 1.0.

(2) If this happens on more than one consecutive day, the day with the maximum value of C_p is chosen as epoch. If there are two or more days having C_p values

which are equal but larger than the rest of the consecutive days with values $C_p \geq 1.0$, the first day is taken as epoch.

Maxima selected this way are considered epochs in this analysis. The average daily variation has been calculated for all epoch days and also on five days preceeding and following the epochs. Fig. 25(b) shows a plot of the daily variation.

The amplitude and times of maxima of the diurnal and semidiurnal components are given in Table 6 below.

Table 6

Table showing the characteristics of the mean daily variation on epoch days of C_p maxima and on five days before and five days after epoch.

Days	r_1	r_2	ϕ_1	ϕ_2	r_1/r_2
+3, +4, +5	0.42±0.03	0.24±0.03	170°	40°	1.8
+1, +2	0.40±0.03	0.23±0.03	160°	50°	1.7
epoch	0.25±0.04	0.14±0.04	150°	20°	1.8
-1, -2	0.33±0.03	0.26±0.03	170°	20°	1.3
-3, -4, -5	0.29±0.03	0.26±0.03	160°	40°	1.1

The above table indicates that the amplitudes r_1 and r_2 of the first and second harmonic components decrease on epoch day. The times of maxima of the two harmonics are earlier on epoch days, though this change is not established with significance in our study. The

amplitude of the first harmonic increases after epoch day and in consequence the importance of the second harmonic component related to the first is less during and after the epoch than before it.

4.342 Association of recurrent and nonrecurrent C_p maxima with daily variation.

The daily planetary index C_p is generally regarded as good index of solar particle radiation in the vicinity of the earth. When activity of a particular region of the sun persists for a period longer than the period of rotation of the sun, the ocean from this region can again reach the earth. This leads to recurrence tendency of C_p and geomagnetic storms. The recurrence period varies from 25 to 28 days (27 ± 1 days) depending upon the heliolatitude of the region responsible for corpuscular beams. Recurrent and nonrecurrent C_p maxima are generally associated with different type of disturbances on sun. Central meridian passage of weak coronal emission is found to be associated with enhanced 27 day recurrent activity and with C_p maxima of the recurrent type. Nonrecurrent C_p maxima have been found to be associated with c.m.p. of sunspot groups which exhibit high activity in solar radio noise emission in the one meter wave length. They have also been associated with sunspot groups which have a magnetic field which is of complex type

We have therefore divided the C_p maxima defined in the earlier section into two classes.

(1) C_p maxima which show a recurrence tendency of 27 $\pm$ 1 days before or after epoch.

(2) C_p maxima which do not show a recurrence tendency of 27 $\pm$ 1 days.

The daily variation on epochs of these two classes and also on $\pm$3 days of epochs has been shown in Fig. 26.

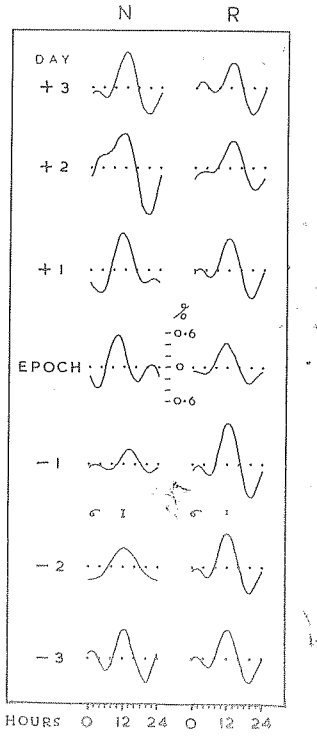

Fig. 26 - Mean daily variation on epochs and on $\pm$ 3 days of epochs of recurrent C_p maxima days (R) and nonrecurrent C_p maxima days (N).

Table 7 gives the amplitudes and times of maxima of diurnal and semidiurnal components of the daily variation from -3 to +3 days. The table shows that in the group

of recurrent C_p maxima the first harmonic amplitude is maximum on -1 day. There is no significant change of time of maxima on any day in this group. In the nonrecurrent group on -1 day the amplitude of the first harmonic becomes small and the time of maximum becomes later. After epoch the amplitude of both components are in general higher than during the three days immediately preceeding epoch. The other significant change in the nonrecurrent group occurs on epoch day when the time of maximum of the second harmonic becomes earlier.

Table 7

Table showing the characteristics of the mean daily variation on epoch days (and on three days before and after epochs) of recurrent and nonrecurrent groups of C_p maxima .

Group R = Recurrent. Group N = Nonrecurrent. ($2\sigma = 0.11$)

Day	r_1 R	r_1 N	ϕ_1 R	ϕ_1 N	r_2 R	r_2 N	ϕ_2 R	ϕ_2 N	r_1/r_2 R	r_1/r_2 N
+3	0.26	0.38	153°	160°	0.26	0.26	40°	10°	1.0	1.4
+2	0.32	0.60	175°	130°	0.18	0.26	45°	30°	1.7	2.3
+1	0.34	0.41	157°	160°	0.28	0.24	25°	320°	1.2	1.7
0	0.26	0.26	156°	168°	0.16	0.30	357°	280°	1.6	0.9
-1	0.43	0.12	160°	200°	0.34	0.11	25°	60°	1.3	1.1
-2	0.34	0.28	165°	190°	0.27	0.04	17°	10°	1.3	7.0
-3	0.28	0.21	161°	110°	0.26	0.31	22°	30°	1.1	0.7

It is very interesting to find that the major change in the daily variation of the recurrent and non-recurrent group occurs on -1 day. In recurrent group the

amplitude of the first harmonic increases while in non-recurrent group the amplitude of the first harmonic decreases on -1 day.

4.343 Daily variation and the duration of solar activity related to geomagnetic disturbances.

The recurrence tendency discussed in the last section can occur either on both sides of epochs ($\pm 27 \pm 1$ days) or on the rotation following epoch ($+27 \pm 1$ days) or during the rotation preceeding the epoch (-27 ± 1 days). It is interesting to study the variation associated with the duration of geomagnetic disturbances. When recurrence of C_p is only on $+27 \pm 1$ days we can interpret the occurrence as either connected with new activity on the sun or with the particle radiation coming for the first time in the vicinity of the earth. When recurrence is only on -27 ± 1 days, we have decaying activity, or the radiation leaving the vicinity of the earth. The terminology which is used to designate the various types of events is indicated in Table 6. The total number of events of each type during the three year period are indicated in the table.

Table 6

Type	Recurrence of C_p maximum	No. of events from 1955 to 1957
A	on $+27 \pm 1$ and -27 ± 1 days	26
B	on $+27 \pm 1$ days	26
C	on -27 ± 1 days	26
D	non-recurrent $\pm 27 \pm 1$ days	22

Fig. 27 gives the daily variation on epoch days of each of the above four groups as also on three days following and three days preceeding epochs. Table 9 gives the amplitudes and times of maxima of the diurnal and semidiurnal components of the daily variation on these days.

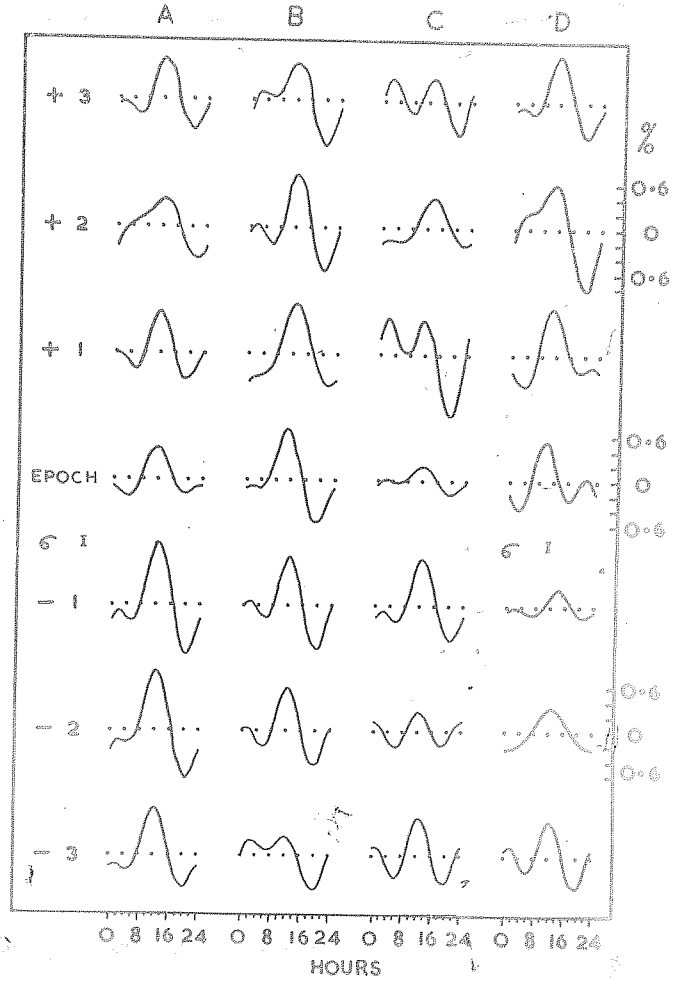

Fig. 27 - Mean daily variation on epoch days (and also on 3 days before and three days after the epochs) of groups A, B, C and D.

It is very interesting to find that the amplitude r_1 on epoch day is significantly higher in group B (representing fresh disturbances) compared to other groups. The table shows that the major change in r_1 does not occur

Table 9

Table showing the characteristics of mean daily variation on epochs (and also on three days before and three days after epochs) of groups A, B, C, and D.

Days	r_1%				θ_1 in degrees				r_2%				θ_2 in degrees				r_1/r_2			
	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
+ 3	0.31	0.39	0.13	0.38	170	140	120	160	0.25	0.25	0.30	0.26	20	40	60	10	1.2	1.5	0.4	1.4
+ 2	0.35	0.39	0.28	0.60	160	170	210	130	0.12	0.37	0.11	0.26	70	30	60	330	2.7	1.0	2.5	2.3
+ 1	0.29	0.51	0.44	0.41	170	190	110	160	0.28	0.17	0.42	0.24	10	40	30	320	1.0	3.0	1.0	1.7
0	0.26	0.47	0.13	0.46	180	140	160	160	0.17	0.27	0.08	0.30	340	350	30	280	1.6	1.7	1.6	0.9
-1	0.53	0.37	0.39	0.12	170	150	180	200	0.36	0.35	0.28	0.11	30	20	30	60	1.5	1.1	1.4	1.1
-2	0.50	0.30	0.07	0.28	160	160	190	190	0.30	0.32	0.20	0.04	30	10	00	10	1.9	0.9	0.4	7.0
-3	0.40	0.26	0.20	0.21	170	120	180	110	0.25	0.19	0.33	0.31	10	50	20	30	1.6	1.4	0.6	0.7

σ (of r_1 and r_2) = 0.07%.

on epoch days in all the groups. In group A, r_1 increases on -1, -2 days, in group B it increases on epoch day and +1 day, in group C r_1 increases on +1 day, while in group D it increases on +2 day. Group D differs significantly from all recurrent groups as here the amplitudes after the epoch are larger than before the epoch.

A significant change in r_2 occurs only in group C where on +1 day r_2 (like r_1) increases. There is no significant change in ϕ_1 in any one of the groups. The time of maximum of the second harmonic ϕ_2 becomes earlier on epoch day of nonrecurrent group D.

Thus we find that the changes in group A (recurrence on both sides) which satisfies most stringent conditions of recurrence are opposite to those in group D which satisfies stringent condition of nonrecurrence. The changes in group B and C are in between those of A and D. In Fig. 28 a comparison of daily variation in groups A and D is shown. Here the days from +1 to +3 and from -1 to -3 have been combined so that the former gives the picture of daily variation after the epoch while the latter gives the daily variation before the epoch.

Table 10 shows the first and second harmonic components of the daily variation on epochs and also before and after epochs of recurrent (A) and nonrecurrent (D) groups.

The table shows that before the epoch the recurrent group has larger amplitude of both the harmonics of daily

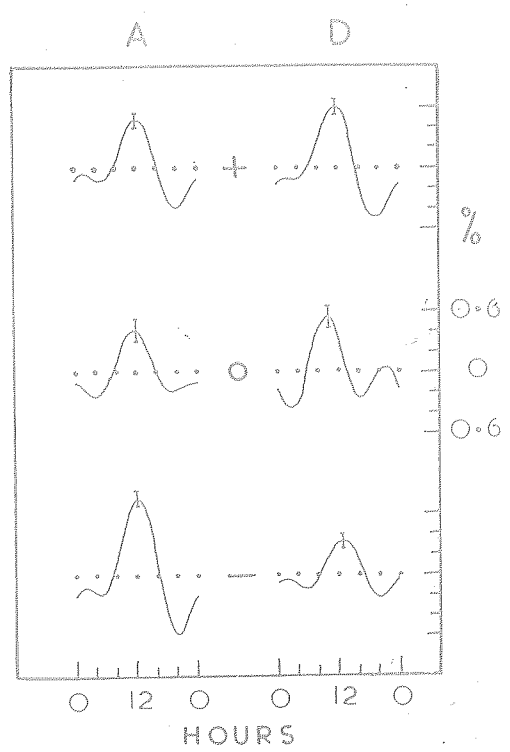

Fig. 28 - Mean daily variation on epochs, before epochs (-) and after epochs (+) of recurrent (A) and nonrecurrent (D) groups of C_p maxima days.

variation than that in the nonrecurrent group. On the epoch day the difference in groups A and D appears to occur in the second harmonic only though it is not statistically significant. After the epoch the amplitude r_1 of daily variation of group A is less than the amplitude in group D.

Large amplitude of daily variation in recurrent group before epoch compared to that in nonrecurrent group was concluded from the analysis of section 4.342. The analysis of the present section shows in addition to this

Table 10

Table showing the characteristics of the mean daily variation on epochs, before and after epochs of groups A and D.

	r_1		r_2		ϕ_1		ϕ_2	
after epoch	A	D	A	D	A	D	A	D
+1, +2, +3	0.31±0.04	0.43±0.04	0.21±0.04	0.22±0.04	170°	150°	22°	0°
epoch	0.20±0.07	0.26±0.07	0.17±0.07	0.30±0.07	180°	160°	340°	280°
before epoch -1, -2, -3	0.49±0.04	0.20±0.04	0.30±0.04	0.14±0.04	170°	180°	20°	30°

feature smaller amplitude (r_1) after the epoch in recurrent group compared to nonrecurrent group. This is mainly due to the fact that in this section most stringent condition (recurrence on both sides of epochs) has been applied to choose C_p maxima of recurrent type.

4.344 C_p chree analysis of A, B, C and D groups.

Fig. 29 shows a chree analysis of C_p of A, B, C and D groups for 30 days before and after epochs for the combined data of three years.

The mean C_p for all the groups is 0.71. The widths of epochs of groups A, B, C and D are 7 days, 2.8 days, 7 days and 2.5 days respectively. Thus the 'fresh' type of geomagnetic disturbances and the nonrecurrent disturbances last for a shorter time compared to those in the other

groups. Another note worthy feature is that from -6 to -22 days and for +6 to +22 days the variability of C_p in the time series of nonrecurrent group D is much greater than the variability for any of the other time series. The root mean square deviation is 0.13 for D group compared to about 0.07 for A, B or C groups. Moreover, in the D time series we have indication of a periodic rise and fall of C_p on both sides of epoch. The high values occur at an average spacing of about 7.5 days while the low values have an average spacing of 6.3 days.

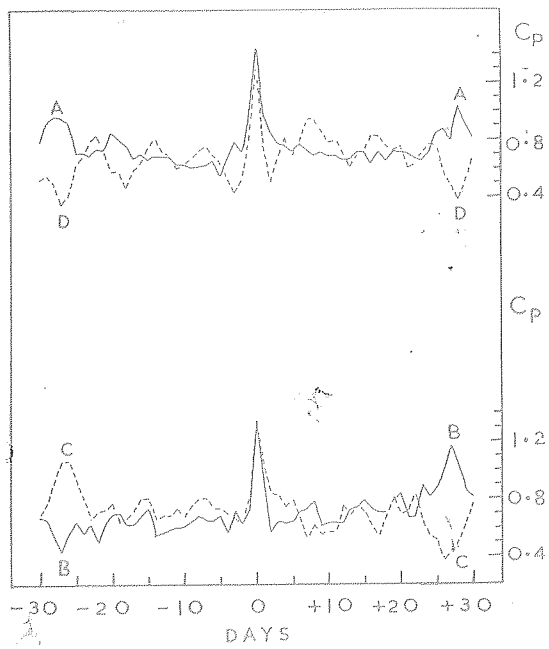

Fig. 29 - Three analysis of C_p for epochs of groups A, B, C and D upto ±30 days.

A - Recurrent on +27±1 and -27±1 days.
B - Recurrent on +27±1 days.
C - Recurrent on -27±1 days.
D - Nonrecurrent ±27±1 days.

4.345 Association of C_p minima with cosmic ray daily variation.

Bell and Glazer[170] have shown that on the sun, central meridian passage of strong coronal emission in the 5303 line is found to significantly inhibit geomagnetic disturbances and is thus associated with C_p minima. It is therefore important to examine the recurrence tendency of C_p minima and to investigate if a relation exists between C_p minima and daily variation. The yearly average C_p values are

Year	1955	1956	1957
Average C_p	0.5	0.8	0.8

In this study we have therefore considered only those days which have C_p less than 0.5. Out of those low C_p days the C_p minima epochs are selected in the following way.

(1) There should not be more than three consecutive days having values less than 0.5.

(2) If two or three consecutive days occur with values of C_p less than 0.5, the day having minimum value of C_p is considered as epoch.

(3) If two or three consecutive days have equal value of C_p (less than 0.5), the first day is considered as epoch.

The selected minima are divided into two groups as follows.

Group	Type	Conditions to be fulfilled
L	Recurrent	It should have similar minima on either before or after or both before and after epochs on 27 ± 1 days.
M	Nonrecurrent	It should not have values less than 0.5 on ±27 ±1 days.

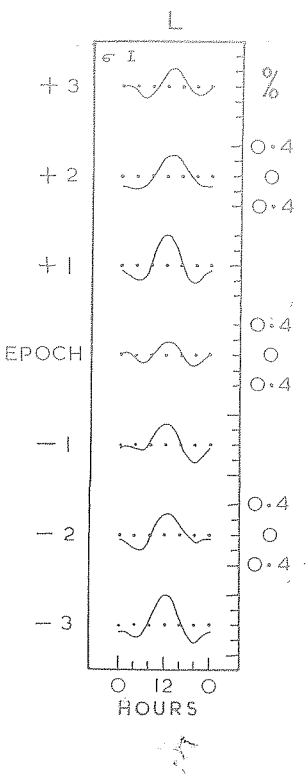

Fig. 30 - Mean daily variation on epochs (and also 3 days before and three days after epochs) of C_p minima days (L - recurrent type.

As very few epochs of group M are available from 1955 to 1957 this group has not been studied. Group L has 33 events in the three year period. The daily variation on epochs of recurrent group and also on ±3 days of epochs is shown in Fig. 30. The first and second harmonic components of the daily variation from +3 to -3 days are

Group	Type	Conditions to be fulfilled
L	Recurrent	It should have similar minima on either before or after or both before and after epochs on 27 ± 1 days.
N	Nonrecurrent	It should not have values less than 0.5 on ± 27 ± 1 days.

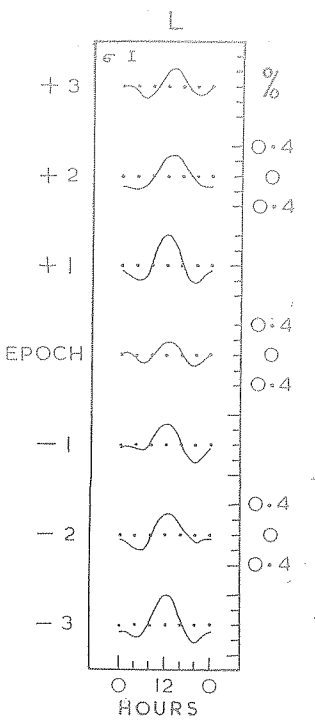

Fig. 30 - Mean daily variation on epochs (and also 3 days before and three days after epochs) of C_p minima days (L - recurrent type.

As very few epochs of group N are available from 1955 to 1957 this group has not been studied. Group L has 33 events in the three year period. The daily variation on epochs of recurrent group and also on ±3 days of epochs is shown in Fig. 30. The first and second harmonic components of the daily variation from +3 to -3 days are

given in Table 11.

Table 11

Table showing the characteristics of the mean daily variation for recurrent group of C_p minima events.

Day	r_1%	r_2%	ϕ_1	ϕ_2
+3	0.23 ± 0.07	0.25 ± 0.07	200°	30°
+2	0.42 ± 0.07	0.16 ± 0.07	190°	20°
+1	0.48 ± 0.07	0.33 ± 0.07	180°	350°
Epoch	0.17 ± 0.07	0.22 ± 0.07	166°	29°
-1	0.38 ± 0.07	0.25 ± 0.07	150°	20°
-2	0.34 ± 0.07	0.25 ± 0.07	200°	20°
-3	0.46 ± 0.07	0.29 ± 0.07	180°	10°

It is clear from the table that the first harmonic amplitude (mean) $\bar{r}_1$ is smaller on epoch day compared to days on either side of epoch. There is no significant change in $\bar{r}_2$, $\bar{\phi}_1$ and $\bar{\phi}_2$.

4.35 Large daily variation and Geomagnetic activity.

Various workers have reported large amplitudes of daily variation which occur on groups of days. In this section we have studied the association of days having large amplitudes of daily variation with C_p. Days having large daily variation amplitudes have been considered as

epochs and the values of C_p on these epochs and on either side of epochs have been considered. To make the criterion of selection strict, only those epochs have been considered which show a large daily variation simultaneously at Trivandrum and also at Ahmedabad. Both these stations are situated at sea level at about the same geomagnetic longitude. The geomagnetic latitude of Ahmedabad is 13°N. Cosmic ray data from 1955 to 1957 taken with identical instruments are used in the present study. The epochs represent the days on which both stations have either diurnal or semidiurnal component significant at the 3 σ level i.e. amplitude greater than 0.90%. C_p chree analysis for ± 5 days is shown in Fig. 31 separately for the three years.

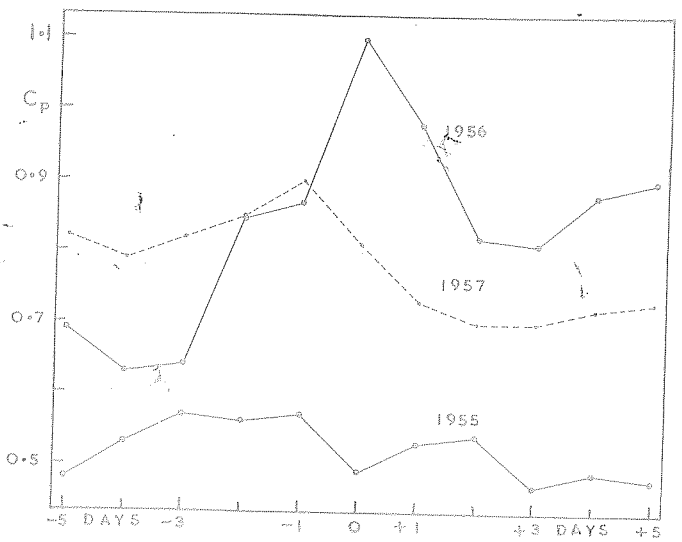

Fig. 31 - C_p chree analysis of days having large amplitudes simultaneously at Ahmedabad and Trivandrum during 1955, 1956 and 1957.

In the years 1955 and 1957 the selected days with high amplitudes do not show any marked relationship with C_p. During 1956 large amplitude days are definitely associated with high C_p. There is a sharp peak on epoch day showing a value of C_p equal to 1.1 compared to the value $C_p = 0.6$, -3 or -4 days earlier. The decrease in C_p value is less on the positive side of the epoch compared to the negative side.

Thus of the three years studied it is only in 1956 that high amplitudes of daily variation of the two sea level stations, Trivandrum and Ahmedabad are associated with significantly high values of C_p.

CHAPTER V

DISCUSSION

5.1 Comparative study of cosmic ray intensity at Trivandrum, Kodaikanal and Ahmedabad.

To study the energy dependence of cosmic ray daily variation data for 1955, 1956 and 1957 collected at Trivandrum, Kodaikanal and Ahmedabad with vertical counter telescopes of identical geometry have been analysed. The telescopes at all the three stations have 10 cm of lead as absorber. The hourly deviations at all these stations have been corrected for barometric pressure changes. As has been discussed earlier the temperature correction to the daily variation is expected to be negligible when the amplitude of the variation is greater than about 0.2%. Further since the maximum latitude separation between the three stations is about 14° and since they are situated at the same geomagnetic longitude, the daily variations of the temperature in the upper atmosphere (above 2 km) are expected to be

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* The author is grateful to Dr.T.S.G.Sastry and Mr.N.A. Razdan for supplying the data for Kodaikanal and Ahmedabad.

similar over the three stations. Thus if at all there is a temperature correction due to changes in the upper atmosphere it will have similar amplitude and time of maximum at all the three stations and it will not affect significantly the comparative study of this chapter. Hence no correction has been applied for upper air temperature changes. The situation of the three stations is given below.

	Trivandrum	Ahmedabad	Kodaikanal
(1) Height above sea level	Sea level	Sea level	2.3 km above sea level
(2) Geomagnetic latitude	$1^{0}S$	$13^{0}N$	$1^{0}N$
(3) Geographic latitude	$8^{0}N$	$23^{0}N$	$10^{0}N$
(4) Geographic longitude	$77^{0}E$	$77^{0}E$	$73^{0}E$
(5) Geomagnetic cut off of primary particles from the vertical direction	17 Bev	14 Bev	17 Bev

The geomagnetic cut off of primary particles at these stations have been estimated by considering the higher order terms of the geomagnetic dipole (Quenby and Webber[171]).

In an earlier section the secondary cosmic ray intensity of ith component at any station (λ, f) was represented as

$$N^{i}_{\lambda,f}(h_0) = \int_{E_{min}}^{\infty} D(E) m^{i}(E, h_0) dE$$

Thus Trivandrum and Ahmedabad stations differ in the

cut off h_{min}; while Trivandrum and Kodaikanal stations differ in the multiplicity function $m^d(L,h_0)$. Fig.32 shows the experimentally obtained 12 month mean daily variation at Trivandrum, Ahmedabad and Kodaikanal for the years 1955, 1956 and 1957. The points represent the daily variation unresolved into its harmonic components while the smooth curves represent the variation built up from the diurnal and semidiurnal components only.

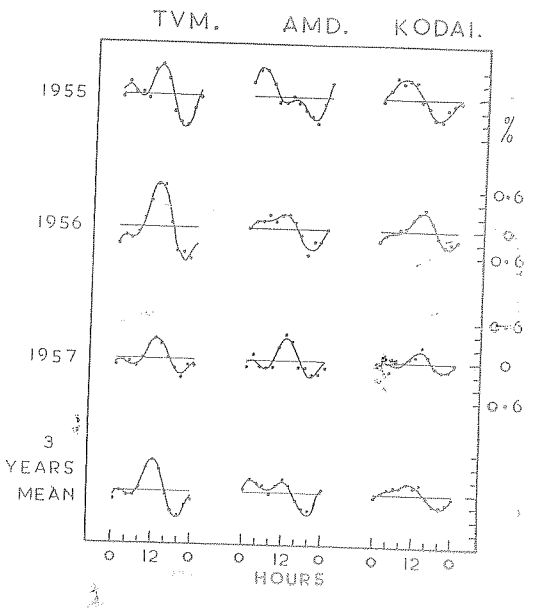

Fig. 32 - 12 month mean daily variation curves of Trivandrum, Ahmedabad and Kodaikanal for the years 1955, 1956 and 1957. The smooth curves represent the 12 month mean daily variation built up from the diurnal and semidiurnal components while the points represent the mean percent variation (unresolved into its harmonic components) at 1hourly intervals.

Table 12 given the amplitudes and times of maxima of the 12 month mean daily variation at these stations. From this table we find that

(1) in the year 1955, Trivandrum and Ahmedabad have the same amplitude of the diurnal component while

Table 12

Table showing the diurnal and semidiurnal components of the 12 month mean daily variation at Trivandrum, Ahmedabad and Kodaikanal in 1955, 1956 and 1957.

Station	r_1	r_2	β_1	β_2
		1955		
Trivandrum	0.29 ± 0.02	0.26 ± 0.02	130°	16°
Ahmedabad	0.29 ± 0.02	0.19 ± 0.02	63°	64°
Kodaikanal	0.30 ± 0.02	0.04 ± 0.02	91°	261°
		1956		
Trivandrum	0.46 ± 0.02	0.23 ± 0.02	169°	20°
Ahmedabad	0.23 ± 0.02	0.10 ± 0.02	110°	23°
Kodaikanal	0.21 ± 0.02	0.10 ± 0.02	172°	61°
		1957		
Trivandrum	0.22 ± 0.02	0.17 ± 0.02	178°	22°
Ahmedabad	0.18 ± 0.02	0.17 ± 0.02	171°	23°
Kodaikanal	0.10 ± 0.02	0.08 ± 0.02	178°	50°

the amplitude of the semidiurnal component is slightly larger at Trivandrum. The time of maximum of diurnal

component is later at Trivandrum compared to Ahmedabad. The time of maximum of semidiurnal component is earlier at Trivandrum compred to Ahmedabad.

For the same year Kodaikanal has the same amplitude of diurnal component as at the sea level stations, but it has a negligible amplitude of semidiurnal component compared to the other stations. The time of maximum of the diurnal component at Kodaikanal is later than that at Ahmedabad but earlier than that at Trivandrum.

(2) In the year 1956, the 12 month mean amplitudes of the diurnal and semidiurnal components at Trivandrum are large compared to the other two stations. The amplitude of the semidiurnal component at Kodaikanal has increased in this year compared to 1955, and has become equal in magnitude to the amplitude at Ahmedabad. The time of maximum of diurnal component is earlier at Ahmedabad compared to the other two stations (at the same lattitude).

(3) In the year 1957, the diurnal and semidiurnal amplitudes are similar at Trivandrum and Ahmedabad while Kodaikanal has smaller amplitudes compared to the other two stations.

There is a good agreement in the times of maxima of the diurnal and semidiurnal components in this year at the three stations.

A comparison of the daily variation (Fig. 32) curves as such reveals the following features.

(1) In 1955 and 1956, the morning maximum (0000 - 0600 hours) is more pronounced at Ahmedabad than at Trivandrum while the noon maximum is more pronounced at Trivandrum compared to that at Ahmedabad. At Kodaikanal during any particular year the seperation between morning and noon maxima is not so clear as at the sea level stations, but the intensity in the morning hours is always higher than at corresponding hours in Trivandrum. The evening minimum from 1800 to 2000 hours has the same amplitude at the sea level stations in each of the three years.

5.2 Long term changes in the 12 month mean daily variation of low energy component of cosmic rays.

It has been mentioned in the first chapter that the difference in daily variation at Trivandrum and Kodaikanal refers to the daily variation of secondary meson intensity related to the comparatively low energy primary cosmic rays.

Thus if T, A and K represent the percent change in daily variation observed at Trivandrum, Ahmedabad and Kodaikanal, then as mentioned in chapter I, the percent daily variation of secondary component which refers to the difference in intensity (of Kodaikanal and Trivandrum)

is

$$\frac{1}{\varepsilon - 1}(\varepsilon K - T) \quad \text{where} \quad \varepsilon = \frac{B_{\lambda,t}\text{ Kodaikanal}}{B_{\lambda,t}\text{ Trivandrum}}$$

Similarly percent variation of the component responsible for difference in daily variation at Trivandrum and Ahmedabad is

$$\frac{1}{\varepsilon' - 1}(\varepsilon' A - T) \quad \text{where} \quad \varepsilon' = \frac{B_{\lambda,t}\text{ Ahmedabad}}{B_{\lambda,t}\text{ Trivandrum}}$$

Fig. 33 shows the experimentally observed percent change

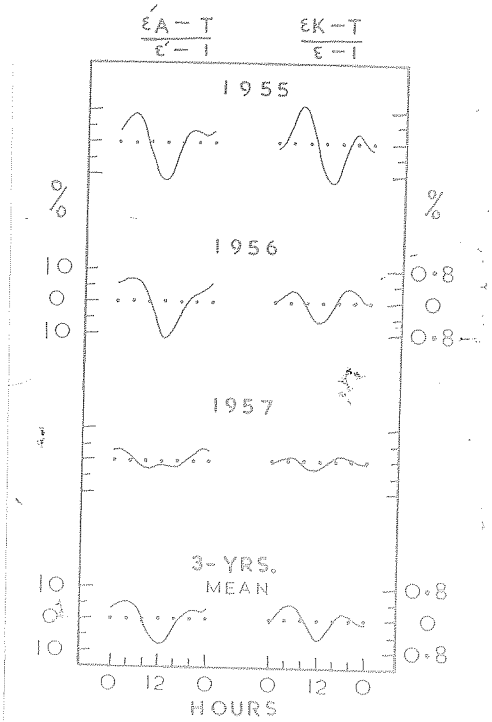

Fig. 33 - 12 month mean daily variation curves of low energy component $\frac{\varepsilon K - T}{\varepsilon - 1}$ & $\frac{\varepsilon' A - T}{\varepsilon' - 1}$ in the years 1955, 1956, 1957 and the mean daily variation during the three years.

in the difference in intensity at Trivandrum - Kodaikanal and at Trivandrum - Ahmedabad. It is clear from this figure that the percent amplitude of low energy component decreases from 1955 to 1957 (assuming that ε and ε' which are dependent on the exponent of spectrum of primary particles, have not changed significantly from 1955 to 1957).

5.3 Source of daily variation.

Since with the spinning of the earth the asymptotic directions of trajectories of cosmic rays measured by the meson telescopes at the three stations scan essentially the same region of the celestial sphere, it should be possible to explain all differences in the daily variation observed at the three stations through differences in the primary cut off (for Trivandrum and Ahmedabad) and differences in the multiplicity function (for Trivandrum and Kodaikanal); provided the daily variation is caused by solar anisotropy outside the influence of geomagnetic field. Thus, assuming a single source of anisotropy we have estimated the daily variation expected at Kodaikanal and Trivandrum utilising the following equation (already mentioned in chapter I).

$$\frac{\delta N_{\lambda,\varepsilon}}{N_{\lambda,\varepsilon}} = \int_{E_{min.}}^{\infty} \frac{\delta D(E)}{D(E)} \cdot W^{d}_{\lambda,\varepsilon}(E,h_0)\,dE$$

This equation, however, does not consider the geomagnetic

bending of the particles. Various workers have used the above equation and have shifted the vector representing the above variation by a mean angle of deflection. Considering the importance of the vastly different bending (particularly near the geomagnetic cut off) of the particles in causing variations, we have adopted the method of numerical integration of the above equation.

Table 13 gives an outline of the method adopted.

Table 13

Table showing the method of numerical integration for estimating the daily variation at a particular station due to a source of anisotropy.

Energy in Bev	γ	Groups according to deflection (hours).	$W^{\lambda}_{\lambda,r}(\theta,h_0)$ coupling coefficient.	Amplitude expected with spectrum αE^{-n}	$W^{\lambda}_{\lambda,r}\frac{\delta D(E)}{D(E)}$
E_1	A_1^0	ϕ_1	W_1	K_1	W_1K_1
E_2	A_2^0				
E_3	A_3^0				
E_4	A_4^0	ϕ_2	W_2	K_2	W_2K_2
E_5	A_5^0				
⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮
E_{n-4}	A_{n-4}^0				
E_{n-3}	A_{n-3}^0	ϕ_{n-1}	W_{n-1}	K_{n-1}	$W_{n-1}K_{n-1}$
E_{n-2}	A_{n-2}^0				
E_{n-1}	A_{n-1}^0				
E_n	A_n^0	ϕ_n	W_n	K_n	W_nK_n

In column I of this table the primary spectrum has been divided into small energy bands from geomagnetic cut off energy to ∞. Near the geomagnetic cut off energy the geomagnetic deflections are large and hence the band width chosen is narrower. In column II of the table we have given the geomagnetic deflection (Ψ_λ) of particles of various energies as read out from Brunberg and Lautner's curves. The deflection for particles near the geomagnetic cut off energy has been obtained by extrapolation. In column III the energy bands are grouped together such that the particles in each group have deflections within about $\pm 15^0$ of the mean of the group. Column IV gives the coupling coefficient $W^i_{\lambda,r}$ of each group multiplied by the energy band-width of the group. In column V the amplitudes of various energy bands which result from a source spectrum $\delta D(E)/D(E)$ are given. Column VI gives the product of columns IV and V.

To find the daily variation at a particular station caused by a source spectrum ($\delta D(E)/D(E)$), we have to find the vector summation of column VI by taking into account the differential bending of particles of different groups of energy. This has been done by first building up individual vectors (with the amplitudes given in column VI and assuming an arbitrary direction of the source of anisotropy). These vectors are then shifted by angles as given in the column III. The shifted vectors are added to find the resultant vector of daily variation.

Using the above method of numerical integration and assuming a source spectrum $\delta D(E)/D(E)$ of the form aE^{-n}, one can evaluate a resultant vector for any station for which geomagnetic cut off E_{min} is known. The variables here are the value of the constant "a" and the original direction of anisotropy. These two are fixed separately for a diurnal and a semidiurnal vector in such a way that the two vectors agree in both phase and amplitude with the experimentally observed diurnal and semidiurnal components of Trivandrum daily variation curve. Once these two variables are thus fixed the expected daily variation curve at Kodaikanal or Ahmedabad can be evaluated by using a different coupling coefficient $W^{i}_{\lambda,E}$ (for Kodaikanal) and a different geomagnetic cut off E_{min} (for Ahmedabad). On obtaining the percent daily variation at Kodaikanal and Ahmedabad in this way, the variation $\varepsilon K-T/\varepsilon-1$ and $\varepsilon' A-T/\varepsilon'-1$ can be evaluated and compared with experimentally observed values.

Fig. 34 shows a comparision of the experimentally observed curves and the estimated percent daily variation of $\varepsilon K-T/\varepsilon-1$ for two types of source spectrum viz.

$$\frac{\delta D(E)}{D(E)} = aE^{-1} \quad \text{and} \quad \frac{\delta D(E)}{D(E)} = aE^{-4}$$

in the years 1955, 1956 and 1957 as also on low, medium and high C_p days of 1955 and 1956. As in chapter IV the days with C_p values less than 0.5 represent low C_p group (C^{L}_{p}), days with values between 0.6 and 1.0 belong to

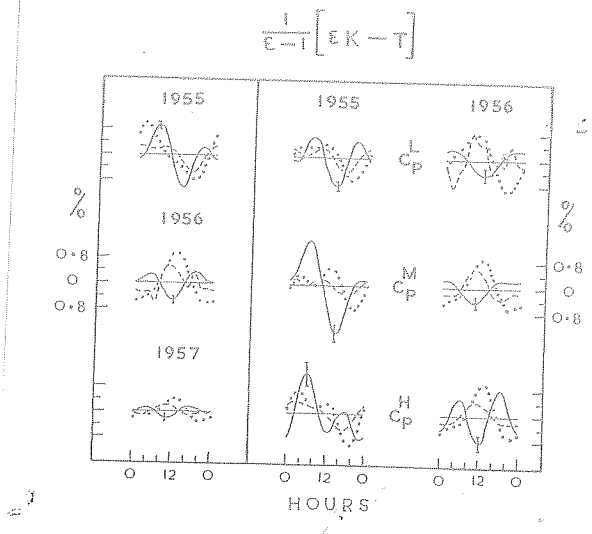

Fig. 34 - Figure showing a comparison of experimentally observed percent daily variation of low energy component ($\varepsilon K-T/\varepsilon-1$) with the variation estimated by assuming a single source of anisotropy. The comparison refers to the 12 month mean daily variation in the years 1955, 1956 and 1957 as also on low, medium and high C_p days of 1955 and 1956.

Solid curves (————) represent the experimentally observed curves.

Dotted curves (- - - - -) represent the daily variation estimated from a source of anisotropy with spectrum $\delta D(a)/D(a') = a'^{-1}$.

Point curves (.....) represent the daily variation estimated from a source of anisotropy with spectrum $\delta D(a)/D(a) = a'^{-4}$.

medium C_p group (C_p^M) while days with values of C_p greater than 1.0 represent the high C_p group (C_p^H).

It is clear from the figure that the form of the estimated mean daily variation (with a source of spectrum $a\epsilon^{-1}$ or $a\epsilon^{-4}$) is not similar to the form of the 12 month mean daily variation in any year. Further the significant difference between the estimated and experimentally observed daily variation is present on geomagnetic quiet days as well as on geomagnetic disturbed days.

Daily variation at the two stations (Trivandrum and Kodaikanal) have also been estimated by considering a source (with spectrum $a\epsilon^{-n}$) which does not produce any daily variation below a certain energy (cut off) ϵ_0. Calculations show that the cut off loses its importance when the spectrum of the daily variation becomes steep ($n > 2$). For a spectrum $a\epsilon^{-1}$, a cut off at $\epsilon_0 = 1.22$ Bev leads to a daily variation amplitude at Trivandrum which is larger than the amplitude at Kodaikanal by a factor of 1.1. This model of the source also cannot explain the large difference in amplitudes at Kodaikanal and Trivandrum observed in 1956 and 1957. This leads to the conclusion that the experimentally observed 12 month mean daily variation in low energy and in high energy are not caused by a single unique source of anisotropy.

Following the same method and assuming the same source of anisotropy, we have estimated the daily variation

for Ahmedabad station. Calculations show that if there is only one source of anisotropy (with spectrum $a\ell^{-1}$ or $a\ell^{-4}$) outside the geomagnetic field, the two stations should have similar form of daily variation. Experimentally we find that it is only in the year 1957 that these two stations have daily variation of the same form. The differences in the daily variation at these stations in 1955 and 1956 cannot be explained by a single source of anisotropy.

A comparison of these three stations thus shows that one single source of daily variation fixed in space cannot explain the 12 month mean daily variation observed at these stations. It is significant to note in this connection that according to Brunberg (as mentioned in chapter I) the attenuation due to geomagnetic bending and atmospheric scattering and geometry of the telescopes, the diurnal and semidiurnal components of any source of anisotropy are not alike. Thus the semidiurnal component is attenuated much more than the diurnal one. One expects therefore, that the ratio of the diurnal to the semidiurnal amplitudes should be larger and larger as one descends down in the atmosphere. Thus the daily variation at Trivandrum and Ahmedabad should have a smaller proportion of semidiurnal component as compared to the daily variation at Kodaikanal. We see from table (12) that this is not true. The fact that the semidiurnal component has a large amplitude at the sea level stations compared to mountain

station suggests that probably more than one sources are operating either simultaneously or individually on different days.

5.4 Daily variation and electromagnetic state of interplanetary space.

Various models (Alfven, Nagashima, Dorman - mentioned in chapter I) of daily variation are linked with the electromagnetic state of the interplanetary space in the neighbourhood of earth. The change in the electromagnetic state according to these models is brought about by streams of ionised matter emitted from the sun. Geomagnetic disturbances are often related to the interaction of the solar beams with the geomagnetic field. The time series of C_p can indicate the relative position of the beam with respect to earth. Thus a study of association of C_p and daily variation can throw some light on the electromagnetic state of interplanetary space.

The great association between C_p and daily variation which has been looked in the last chapter indicates that their relation changes from year to year. This is particularly clear from the analysis of section 4.35, where we find that only in 1956 the days having high amplitudes simultaneously at Ahmedabad and Trivandrum are linked with high values of C_p.

In 1955 and 1957 we find that the medium C_p group has a smaller amplitude of the diurnal variation compared to

low and high C_p groups. Satya Prakash[73] in his analysis of data (1957) of nucleonic component taken at Kodaikanal also finds that in 1957 the medium C_p group has a smaller amplitude compared to the other groups.

We have seen in the last chapter that recurrent and non recurrent C_p maxima epochs show different features of daily variation indicating thereby that C_p does not represent the same state outside. We have seen that recurrent C_p maxima show a change in daily variation before the epoch. This is because the recurrent C_p maxima relate to streams of longer duration (section 4.3&4) and hence their approach to earth is from back side due to spinning of the sun. In the other case (nonrecurrent) we get little effect before the epoch but a much larger effect after the epoch. The nonrecurrent C_p maxima have a small duration and have been found to be associated with Forbush decreases. Nonrecurrent C_p maxima according to this model have to be associated with the ejection of a solar cloud for a short duration. This interacts with the geomagnetic field and in addition to its own transient effect which precede its interaction with the earth's magnetic field by only a few hours, it leaves a geocentric cloud which has its effects on the mean intensity and the anisotropy of cosmic rays following the geomagnetic disturbances. Thus the experimental observations are in confirmity with the broad outlines of the two different types of phenomena associated with streams of different kinds.

5.5 Conclusion

Going from the year of minimum activity of sunspots to the year with maximum activity the following changes are known to occur as reported by various other workers.

(1) The mean intensity of the cosmic rays decreases.

(2) The energy spectrum of the primary cosmic rays changes (Simpson[172]).

(3) Low energy cut off ("knee") comes into existence

Our results now show that the amplitude of daily variation on individual days decreased and the percent change of daily variation of low energy also got reduced as the solar activity increased from 1955 to 1957. Thus the model of anisotropy should explain not only the three features mentioned above but also the behaviour of daily variation described in the present work as also the 22 year cycle of change of the two maxima observed at the equatorial stations.

An attempt to explain the differences in the 12 month mean daily variation at the three stations of Ahmedabad, Kodaikanal and Trivandrum reveals that a single source of anisotropy outside the influence of the geomagnetic field does not explain the characteristics of the daily variation at all the three stations. In this connection it is important to compare on a day to day basis, the daily variation measured simultaneously at different latitudes and altitudes with identical meson telescopes and neutron

monitors. This comparison during different periods of solar activity can lead to an understanding of the source of anisotropy.

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PAPER 39

THE ANISOTROPY OF PRIMARY COSMIC RADIATION AND THE ELECTROMAGNETIC STATE IN INTERPLANETARY SPACE

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ABSTRACT

Study of the anisotropy of cosmic rays from the measurement of the daily variation of meson intensity has demonstrated that there are significant day-to-day changes in the anisotropy of the radiation. New experimental data pertaining to these changes and their solar and terrestrial relationships are discussed.

An interpretation of these changes of anisotropy in terms of the modulation of cosmic rays by streams of matter emitted by the sun is given. In particular, an explanation for the existence of the recently discovered types of daily variations exhibiting day and night maxima respectively, can be found by an extension of some ideas of Alfvén, Nagashima, and Davies. An integrated attempt is made to interpret the known features of the variation of cosmic ray intensity in conformity with ideas developed above.

The study of the daily variation of cosmic ray intensity provides a unique tool for the evaluation of the anisotropy of the primary cosmic radiation, and changes occurring in it. Since the anisotropy is related to theories of the origin of cosmic radiation and to the electromagnetic state in interplanetary space, it is of importance to summarize the current status of our knowledge derived from measurements of the daily variation of cosmic ray intensity.

1. The daily variation of cosmic rays and the anisotropy of the primary radiation is of a highly variable character. This is seen in large long-term changes of the 12-monthly mean daily variation of meson intensity (Sarabhai and Kane[1], Sarabhai, Desai and Venkatesan[2], Thambyahpillai and Elliott[3], Steinmaurer and Gheri[4]), the day-to-day changes correlated with magnetic character figure and the occurrence of large amplitudes of the daily variation of meson intensity on groups of days

(Sittkus[5], Remy and Sittkus[6]). It is seen from Fig. 1 that on these same days the daily variation at Amsterdam (H. F. Jongen, private communication) at $\lambda = 54°$ N, at Ahmedabad (U. D. Desai) $\lambda = 13°$ N show similar features. However, Kodaikanal (D. Venkatesan) on the magnetic equator

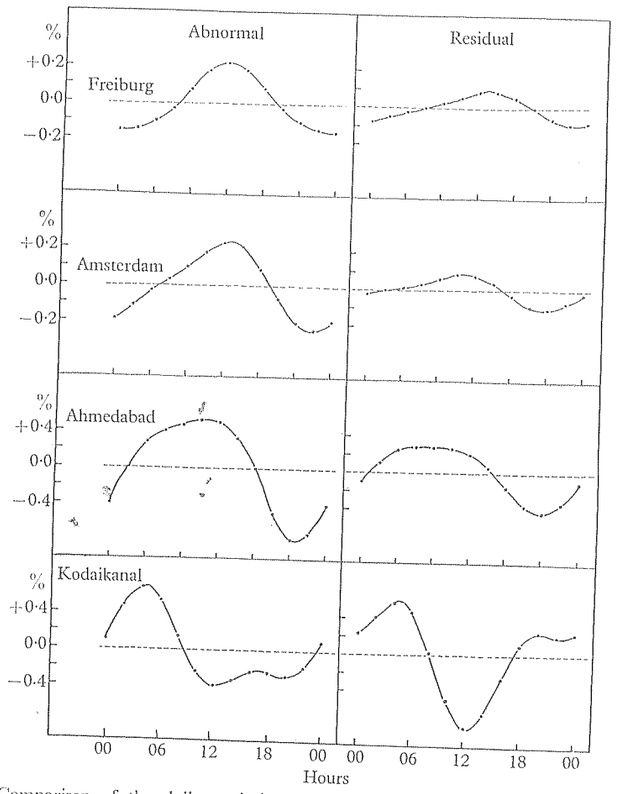

Fig. 1. Comparison of the daily variation at Freiburg (Sittkus), Amsterdam (Jongen), Ahmedabad (Desai) and Kodaikanal (Ventakesan) on days of abnormal amplitudes at Freiburg with the daily variation on residual days.

does not exhibit any marked difference on days on which Sittkus gets abnormal amplitudes.

2. During several years the daily variation, particularly at low latitudes, exhibits two maxima instead of one. This is seen not only in data from Huancayo during 1937–52 (Sarabhai, Desai and Venkatesan[2]) but also

in data at Ahmedabad, Kodaikanal (Venkatesan and Sastry) and Trivandrum (Duggal) during 1950–5 as shown in Fig. 2. The changes of the daily variation indicate that they are primarily due to two types of anisotropies

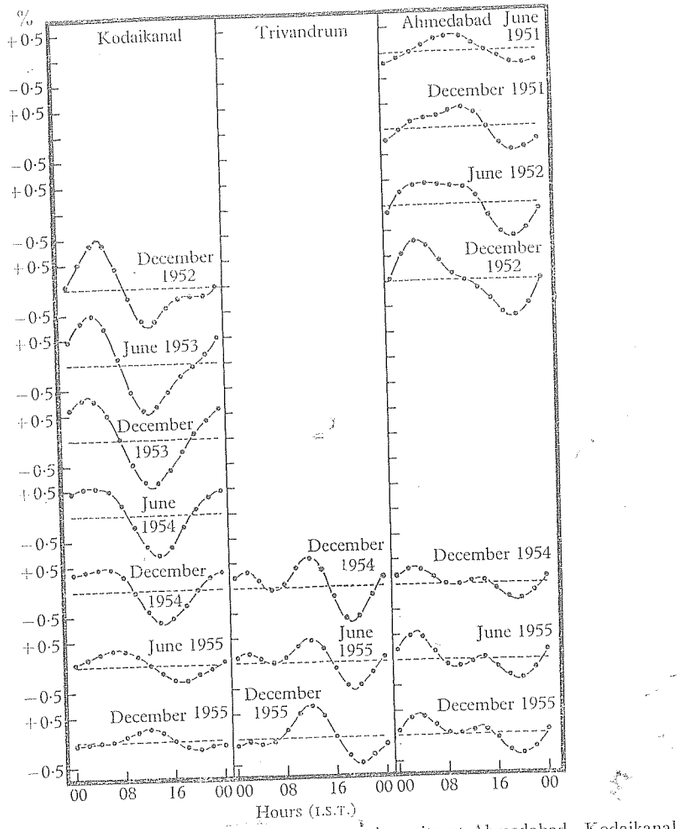

Fig. 2. Twelve-monthly mean daily variation of meson intensity at Ahmedabad, Kodaikanal and Trivandrum centred at six-monthly intervals 1950–5.

which correspond to maxima at 03.00 and 11.00 hours local time respectively (Sarabhai, Desai and Venkatesan[2]).

3. The daily variation of radiation incident in directions very close to the vertical is characterized by large amplitudes and undergoes large changes (Ehmert[7], Sarabhai and Nerurkar[8]). For stations in low

latitudes it exhibits maxima centred at 11.00 hours or 03.00 hours on a majority of days. On some days, which appear to be associated with low values of K_p, the daily variation has two maxima instead of one. The cone within which the radiation with large amplitude appears to be incident is restricted to a semi-angle of about 5° around the vertical. The semi-angle of the cone is however variable, so that during different periods the ratio of the amplitude in narrow angle and in wide angle telescopes varies, as shown in Table 1 (Ehmert[7], Sarabhai and Nerurkar[8]).

Table 1. *The ratio of the diurnal amplitudes measured with telescopes of different semi-angles on identical days during different periods*

	1954					1955								
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Total	Reference
$\frac{CT(\pm 5°)}{CT(\pm 15°)}$	1·52	1·79	1·72	1·74	2·17	2·40	1·83	1·65	1·68	0·79	1·18	1·04	1·60	10
$\frac{CT(\pm 45°)}{IC}$	—	—	—	—	—	—	—	—	—	—	—	—	1·5:1 to 2·4:1	7

The recorders are designated by IC for ionization chamber and CT ($\pm x°$) for counter telescope of semi-angle $x°$ in the east–west plane.

4. The comparison of the daily variations with telescopes pointing to the vertical, the east and the west directions indicates that the spread of times of maxima in the three directions is much less than is expected. This is seen in the curves of the daily variation and the harmonic components shown on harmonic dials in Fig. 3 (*a*) and (*b*). These relate to a study made by Nerurkar at Ahmedabad with telescopes pointing to directions inclined at 45° to the vertical.

5. The long-term changes appear to follow the 22-year cycle of solar activity (Thambyahpillai and Elliot[3], Steinmaurer and Gheri[4], Sarabhai, Desai and Venkatesan[2]). The occurrence of the anisotropy which gives a maximum near noon and the anisotropy which gives a maximum at night-time is on groups of days which have a 27-day recurrence tendency.

If we consider the above facts, the most important conclusion is that at the present moment our knowledge of the characteristics of a permanent anisotropy, if indeed such exists, is very meagre. Initially, it is appropriate to consider for interpretation only the variable anisotropy about which we have now a number of well-established experimental facts and solar and terrestrial relationships. Theories which have been advanced in the past

to explain only the average characteristics of the diurnal component of the daily variation, and those which do not take into consideration the existence of the two types of anisotropies which produce daily variations with maxima separated by approximately 8–10 hr are clearly inadequate. A theory which explains the variable anisotropy by a modulation of the primary intensity seems most promising in this context.

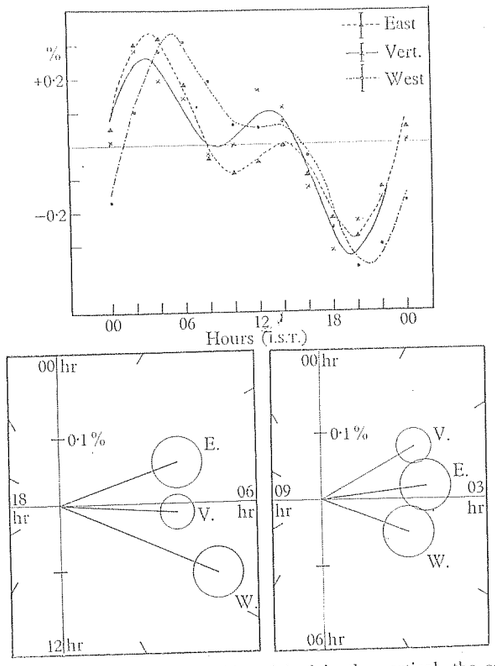

Fig. 3 (*a*, upper). The daily variation at Ahmedabad in the vertical, the east and the west pointing telescopes. (*b*, lower), harmonic dials showing the diurnal and the semi-diurnal components of the daily variation in the three telescopes at Ahmedabad.

Nagashima[9] has proposed a theory to explain the magnetic-storm type anisotropy which is directed towards the 12-hr direction. His theory postulates neutral beams of ionized particles ejected from the sun. These carry with them a trapped magnetic field derived from the solar dipole field. The charge separation which occurs in the beams as viewed from the earth, creates an electric field across the beams so that cosmic rays which traverse the beams and come to the earth suffer an acceleration or a

deceleration depending on the orientation of the beam and the earth. Nerurkar[10] has studied the implications of an extension of Nagashima's ideas. If the magnetic field trapped within a beam is derived from the high local magnetic field in the neighbourhood of the active region from which the beam is ejected, it would be possible to expect a magnetic field frozen within the beam but having no preferred orientation in relation to the solar dipole field. For the purpose of the theory, the author has assumed that the solar beam would have an outward radial velocity of from 500 to 2000 km/sec, a width of about 5×10^{12} cm and a magnetic field of from 10^{-5} to 5×10^{-6} gauss at the distance of the earth from the sun. These values are consistent with theories of geomagnetic disturbances involving neutral but ionized streams of matter ejected from the sun.

With the daily variation of cosmic ray intensity which arises as an observational effect due to the spinning of the earth, it is only possible to study the anisotropy in the east–west plane. We have therefore to consider the electric field produced in the beam in the east–west plane due to the component of the magnetic field in the direction perpendicular to this plane. We have also to consider the situation that arises because the beam has an angular velocity derived from the spinning of the sun and it approaches the earth, envelops it and then recedes from it. These three cases are illustrated in Fig. 4 (*a*), (*b*) and (*c*) respectively. The top and the bottom series of diagrams of the figure relate to the reversal in direction of the component of the magnetic field perpendicular to the ecliptic. The diagrams illustrate the directions in space, as viewed from the earth, along which cosmic rays suffer acceleration or deceleration after traversing the beam. They also show in a schematic manner the increase or decrease according to local time of mean intensity of a definite primary region due to the spinning of the earth. Some of the consequences of the theory are as follows:

(1) While in the case of particles being accelerated we get an increase of intensity, there is a decrease when particles are decelerated. However, the time of occurrence of the increase and the decrease is separated by 12 hr. Therefore, the maximum of the daily variation occurs at approximately the same time irrespective of the relative position of the beam with respect to the earth.

(2) Depending on the negative or positive sign of the component of the trapped magnetic field, an anisotropy is produced which would give a maximum in the daily variation either at about 08.00 or at about 16.00 hours before deflexion in the geomagnetic field. The measured time of maximum depends on the correction to be applied for bending of the trajectories in the geomagnetic field.

(3) The magnitude of the anisotropy would vary in relation to the magnitude of the component of the trapped magnetic field in the direction perpendicular to the east–west plane. For different orientation of the trapped field of varying magnitude, we can expect the average anisotropy to correspond to a daily variation at low latitude having a most probable time of maximum 03.00 hours or 11.00 hours respectively, even though the

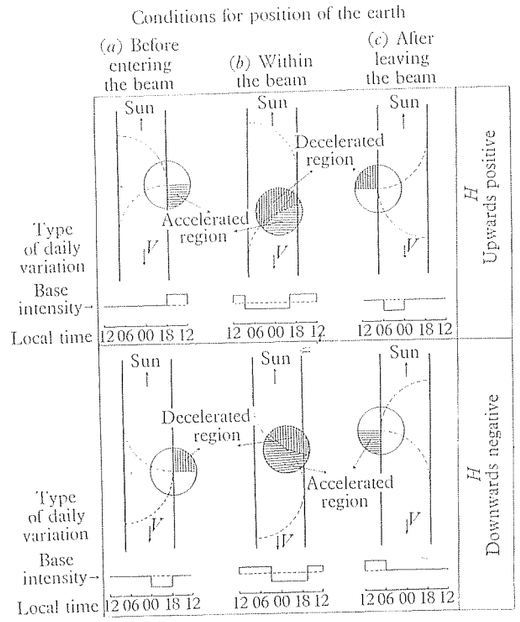

Fig. 4. Accelerated and decelerated regions and the type of daily variation for positive primaries of energy $= 2E_{min}$ when the earth is (*a*) on the right side, (*b*) within, and (*c*) on the left side of the beam. The component of the trapped magnetic field perpendicular to the plane of the paper is positive and towards the reader in upper figures and negative and away from the reader in lower figures.

time of maximum as well as the amplitude on each particular occasion would be different. Table 2 indicates the expected amplitude and time of maximum of the diurnal component of the daily variation at low latitudes.

(4) The anisotropy is only produced for primary cosmic rays of energy above a certain minimum value E_{min}. E_{min} depends on the width of the beam, the magnitude of the trapped magnetic field and its orientation in

Table 2. *The percent amplitude and the time of maximum of the diurnal component of the daily variation of meson intensity in equatorial latitudes.*

Width of the beam $= 5 \times 10^{12}$ cm				When H is positive		When H is negative	
H (gauss)	Velocity (cm/sec)	Change in energy (eV)	E_{min} (Bev)	Amplitude (%)	Time of maximum (hr)	Amplitude (%)	Time of maximum (hr)
10^{-5}	2×10^{8}	$1{\cdot}3 \times 10^{8}$	10	0·65	1030	0·65	0300
10^{-5}	10^{8}	$0{\cdot}65 \times 10^{8}$	10	0·33	1030	0·33	0300
10^{-5}	5×10^{7}	$0{\cdot}33 \times 10^{8}$	10	0·16	1030	0·16	0300
5×10^{-6}	2×10^{8}	$0{\cdot}65 \times 10^{8}$	5	0·44	1130	0·39	0130
5×10^{-6}	10^{8}	$0{\cdot}33 \times 10^{8}$	5	0·22	1130	0·20	0130
5×10^{-6}	5×10^{7}	$0{\cdot}17 \times 10^{8}$	5	0·11	1130	0·10	0130

respect to the east–west plane. No appreciable anisotropy is produced for cosmic ray particles of energy less than E_{min}, while for increasing energy above E_{min}, the per cent anisotropy goes on diminishing. This explains why averaged over long periods the amplitude of the daily variation measured with a neutron monitor is about the same at Huancayo as it is at Climax, even though the mean energy of primary radiation is 19 Bev and 7 Bev respectively (Firor, Fonger and Simpson [11]). Similarly there is almost no latitude effect observable in the amplitude of the daily variation measured with ionization chambers at Huancayo, Cheltenham and Christchurch. Comparison between a neutron monitor and a meson detector cannot be made directly on account of the differences in the response functions of the instruments with respect to directions of arrival of particles. The energy dependence of the anisotropy also reconciles with theory the experimentally observed small change in time of maximum of the daily variation measured in the east and the west directions.

The special properties of the daily variation of intensity measured with narrow angle telescopes pointing towards vertical require much further consideration for experimental study and interpretation.

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