The variation of atmospheric temperature with height during daytime and night-time (Fig. 6) shows that temperature gradient at night is comparatively low. So the Eqn. (2) is applicable in the ionospheric region at night.

\[ \Delta N_{\text{ox}} \text{(Bernoulli's principle)} \]

![Graph showing atmospheric temperature variation](image)

**Fig. 6.**

55

DAY TO DAY CHANGES IN THE DAILY MEAN INTENSITY OF COSMIC RAYS

R. P. KANE, S. R. KANE AND B. A. HOLLA

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**ABSTRACT.** Data obtained at Kodaikanal (geomag. lat. 1°N, altitude 2300 meter) for cosmic ray meson and the muonic component are analysed for the first 12 months of the I.G.Y. (July 1957–June 1958). Day to day changes of the mean intensity and their relationship with geomagnetic phenomena are studied. Comparison is made with neutron monitor data at Haunanyo, Ottawa and Resolute. A variation spectrum of the type \( d\Phi/dE \propto E^{-2} \) is obtained.

1. **INTRODUCTION**

During the I.G.Y. period, several workers in the world have operated cosmic ray meson telescopes and neutron monitors on a continuous basis. The Physical Research Laboratory, Ahmedabad, India, also participated in this effort and contributed data for neutron monitors and cubical meson telescopes for the stations at Ahmedabad and Kodaiikanal. Besides these instruments, a narrow angle telescope of semi-angles 10° in the E–W plane and 20° in the N–S plane was also operated at Kodaiikanal during the I.G.Y. period. Since meson telescopes and neutron monitors at different latitudes and altitudes have different energy responses to the primary cosmic ray intensity, a comparison of data from these gives an idea about the energy dependence of cosmic ray variations.

In this communication we have described the results of an analysis of results obtained with five different cosmic ray measuring instruments. Details of these are given in Table I.

**Table I**

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Situation</th>
<th>Alt. (met.)</th>
<th>Geomagnetic</th>
<th>Cut off energies (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meson telescope</td>
<td>Kodaiikanal</td>
<td>2343</td>
<td>1°</td>
<td>147°</td>
</tr>
<tr>
<td>(30° x 20°)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neutron pito</td>
<td>Kodaiikanal</td>
<td>2343</td>
<td>1°</td>
<td>147°</td>
</tr>
<tr>
<td>&quot;</td>
<td>Haunanyo</td>
<td>5400</td>
<td>-1°</td>
<td>354°</td>
</tr>
<tr>
<td>&quot;</td>
<td>Ottawa</td>
<td>101</td>
<td>57°</td>
<td>311°</td>
</tr>
<tr>
<td>&quot;</td>
<td>Resolute</td>
<td>17</td>
<td>83°</td>
<td>289°</td>
</tr>
</tbody>
</table>

493
II. ENERGY RESPONSE OF THE VARIOUS INSTRUMENTS

Before proceeding with an examination of the results of analysis of the data from the various instruments, it is advisable to get an idea of their energy responses. This was attempted by following Dorman's (1967) method, which is outlined below:

The number \( N(\lambda) \) of secondary cosmic ray particles at a latitude \( \lambda \) and at an atmospheric depth \( h \) is given by

\[
N(\lambda) = \int_{E_0^c}^{E_c^c} D(E) N(E, h) dE
\]  \hspace{1cm} (1)

where \( D(E) \) represents the primary energy spectrum at the top of the atmosphere and \( N(E, h) \) is the "multiplicity function" which gives the number of secondary particles produced by a primary particle of energy \( E \). The lower limit of integration \( E_0^c \) is the minimum (critical) energy for arrival of primary cosmic rays in the vertical direction at latitude \( \lambda \).

Dividing Eq. (1) by \( N(\lambda) \) and multiplying by 100, we get

\[
100\% = \frac{\int_{E_0^c}^{E_c^c} D(E) N(E, h) dE}{\int_{E_0^c}^{E_c^c} N(E, h) dE} = \int_{E_0^c}^{E_c^c} \frac{W(E, h) dE}{E_c^c}
\]  \hspace{1cm} (2)

where \( W(E, h) \) represents the percentage contribution to the secondary component at depth \( h \), due to primaries of energy \( E \). \( W(E, h) \) is known as the "coupling constant". A knowledge of its functional relationship with \( E \) is necessary to get an idea of the energy response of any particular instrument. \( W \) involves the product of the primary energy spectrum \( D(E) \) and the multiplicity function \( M(E, h) \). The primary energy spectrum of cosmic ray intensity is now fairly well established. But the multiplicity function \( M(E, h) \) is difficult to calculate theoretically because of many complex processes involved in the interactions of primary cosmic ray particles with air nuclei. Dorman (1967) has pointed out that the coupling constants \( W \) can also be evaluated from a knowledge of the latitude dependence of cosmic ray intensity, as follows:

Differentiating (1) partially with respect to \( E_0^c \), we get

\[
\frac{\partial N(\lambda)}{N(\lambda)} = -\frac{\partial \frac{E_0^c}{E_0^c} \cdot \frac{D(E) M(E, h)}{N(\lambda)} = -\frac{\partial E_0^c}{E_0^c} \cdot \frac{W(E, h)}{E_0^c}
\]  \hspace{1cm} (3)

It is clear, therefore, that \( W(E, h) \) is directly related to the latitude effect of the secondary component observed at a depth \( h \). Since the latitude effect of the various secondary components have been precisely obtained experimentally, the coupling constants \( W(E, h) \) can be easily calculated for energies between 0 and 15 BeV which is the maximum vertical cut-off energy (at \( \lambda = 0^\circ \)). For higher energies, Dorman suggests extrapolation methods which are based partly on experimental results and partly on theoretical considerations.

The coupling constants \( W(E, h) \) are different for different secondary components and for different altitudes and latitudes and have been calculated by Dorman from experimental latitude effect data. Fig. 1 gives the coupling constants as percentage per BeV for the various secondary components mentioned in Table I. Since the latitude dependence of the muon component at the altitude of Kodak-kanal is not known, the coupling constants for the same are obtained by averaging the coupling constants for ion-chamber measurements at 10 Km altitude and hard component measurements at sea-level.

**Fig. 1. Coupling constant W (percentage per BeV) for various secondary components.**

A: Rossatte neutrons, B: Ostermy neutrons, C: Ions, D: Kcohoden neutrons, E: Kodak-kanal muons. All plots are normalized to give \( \int W(E) dE = 100 \).

Knowing the value of \( W \) for all energies between \( E \) and \( \infty \), it should be possible to calculate the mean energies to which the various instruments respond. A statistical method of obtaining the same would be to calculate mean energy \( \bar{E} \) by the formula

\[
\bar{E} = \frac{\int E W(E) \cdot dE}{\int W(E) \cdot dE}
\]  \hspace{1cm} (4)

However, this method does not succeed for any of the curves given in Fig. 1 because of the following reason. For high energies, the plots in Fig. 1 can be...
II. ENERGY RESPONSE OF THE VARIOUS INSTRUMENTS

Before proceeding with an examination of the results of analysis of the data from the various instruments, it is advisable to get an idea of the differences in their energy responses. This was attempted by following Dorman's (1957) method, which is outlined below:

The number $N_\lambda(h)$ of secondary cosmic ray particles at a latitude $\lambda$ and at an atmospheric depth $h$ is given by

$$
N_\lambda(h) = \frac{\int D(E) \cdot M(E, h) dE}{E_\lambda^*} \quad \ldots (1)
$$

where $D(E)$ represents the primary energy spectrum at the top of the atmosphere and $M(E, h)$ is the "multiplicity function" which gives the number of secondary particles produced by a primary particle of energy $E$. The lower limit of integration $E_\lambda^*$ is the minimum (critical) energy for arrival of primary cosmic rays in the vertical direction at latitude $\lambda$.

Dividing Eq. (1) by $N_\lambda(h)$ and multiplying by 100, we get

$$
100\% = 100 \frac{\int D(E) \cdot M(E, h) dE}{N_\lambda(h)} \cdot \frac{W(E, h) dE}{E_\lambda^*} \quad \ldots (2)
$$

where $W(E, h)$ represents the percentage contribution to the secondary component at depth $h$, due to primaries of energy $E$. $W(E, h)$ is known as the "coupling constant". A knowledge of its functional relationship with $E$ is necessary to get an idea of the energy response of any particular instrument. $W$ involves the product of the primary energy spectrum $D(E)$ and the multiplicity function $M(E, h)$. The primary energy spectrum of cosmic ray intensity is now fairly well established. But the multiplicity function $M(E, h)$ is difficult to calculate theoretically because of many complex processes involved in the interactions of primary cosmic rays with air nuclei. Dorman (1957) has pointed out that the coupling constants $W$ can also be evaluated from a knowledge of the altitude dependence of cosmic ray intensity, as follows:

Differentiating (1) partially with respect to $E_\lambda^*$, we get

$$
\frac{\partial N_\lambda(h)}{\partial E_\lambda^*} = \frac{\partial E_\lambda^*}{\partial E_\lambda^*} \frac{D(E) \cdot M(E, h)}{N_\lambda(h)} - \frac{E_\lambda^*}{\partial E_\lambda^*} \cdot \frac{W(E, h) dE}{E_\lambda^*} \quad \ldots (3)
$$

It is clear, therefore, that $W(E, h)$ is directly related to the latitude effect of the secondary component observed at a depth $h$. Since the latitude effects of the various secondary components have been precisely obtained experimentally, the coupling constants $W(E, h)$ can be easily calculated for energies between 0 and 15 BeV which is the maximum vertical cut-off energy (at $\lambda = 0$). For higher energies, Dorman suggests extrapolation methods which are based partly on experimental results and partly on theoretical considerations.

The coupling constants $W(E, h)$ are different for different secondary components and for different altitudes and latitudes and have been calculated by Dorman from experimental latitude effect data. Fig. 1 gives the coupling constants as percentage per BeV for the various secondary components mentioned in Table I. Since the latitude dependence of the meson component at the altitude of Kodaikanal is not known, the coupling constants for the same are obtained by averaging the coupling constants for Ion-chamber measurements at 10 Km altitude and had component measurements at sea-level.

![Fig. 1. Coupling constant W (percentage per BeV) for various secondary components. A: Atmospheric mesons, B: Ottawa neutrons, C: Hanayama neutrons, D: Kodaikanal neutrons, E: Kodaikanal mesons. All plots are normalized to give \( \int W \cdot dE = 100 \).](image)

Knowing the value of $W$ for all energies between $E^*$ and $\infty$, it should be possible to calculate the mean energies to which the various instruments respond. A statistical method of obtaining the same would be to calculate mean energy $\bar{E}$ by the formula

$$
\bar{E} = \frac{\int W(E) \cdot E \cdot dE}{\int W(E) \cdot dE} \quad \ldots (4)
$$

However, this method does not succeed for any of the curves given in Fig. 1 because of the following reason. For high energies, the plots in Fig. 1 can be
approximated to a relation of the type \( W = kE^{-\nu} \). However, the values of \( \nu \) are all less than 2 whereas the integral in the numerator of Eq. (4) is convergent only if \( \nu > 2 \). Hence, Eq. (4) does not yield finite values for the mean energy \( E \).

Fanger et al. (1953) have avoided this difficulty by assuming an arbitrary definition of mean energy \( \bar{E} \),

\[
\frac{1}{1+\bar{E}} = \frac{1}{E} \int \frac{W(E) dE}{1+\bar{E}}
\]

Using this formula, the mean energies for the various secondary components referred to in Table I would be as follows:

- Kodaiskanal meson: 34 BeV
- Kodaiskanal neutron: 34 "
- Huanacayo ": 34 "
- Ottawa ": 12 "
- Resolute ": 11.5 "

One may also view the energy response qualitatively by calculating the percentage of particles contributed by primaries confined to an energy range 0 to \( E \) for various values of \( E \). Fig. 2 gives the percentages for the various secondary components.

![Fig. 2. Percentage of secondary particles contributed by primaries of energies below \( E \). Symbols A, B, C, D & E have the same meaning as in Fig. 1.](image)

It can be seen from Fig. 2 that for the neutron monitors at Ottawa and Resolute, almost 50% of the secondaries are due to primary energies between 0 to 15 BeV while for the nucleonic component at Huanacayo and Kodaiskanal the corresponding energy range is 15 to 35 BeV. For Kodaiskanal meson intensity, the range is still higher viz. 15 to 75 BeV.

### III. DAILY MEAN INTENSITY OF COSMIC RAYS

The daily mean intensities of the nucleonic component and meson component of cosmic ray intensity at the various places corrected for barometric effect only are plotted in Fig. 3 for the period July 1957 to June 1958. The daily means of \( H \), the horizontal component of earth's magnetic field at Kodaiskanal, are also plotted.

![Fig. 3. Plot of daily mean intensities. Symbols A, B, C, D & E are as in Fig. 1. \( H \) represents the horizontal component of earth's magnetic field at Kodaiskanal.](image)

It can be seen from Fig. 3 that the daily mean intensity shows large fluctuations during the period under consideration. Variations as high as 5% at the equatorial stations and 10% or more at high latitude stations are observed frequently. Many of the sharp minima indicate Forbush type decreases.

To find out the extent to which these variations are simultaneous at the various stations, correlation coefficients are calculated for the various pairs. They are given in Table II.

It can be seen from Table II that:

(a) Kodaiskanal neutrons and Huanacayo neutrons are very highly correlated with each other but not so much with either Kodaiskanal mesons or Ottawa and Resolute neutrons.
approximated to a relation of the type $W = kE^{\nu}$. However, the values of $\nu$ are all less than 2 whereas the integral in the numerator of Eq. (4) is convergent only if $\nu > 2$. Hence, Eq. (4) does not yield finite values for the mean energy $E$.

Fonger et al. (1953) have avoided this difficulty by assuming an arbitrary definition of mean energy $E$ as,

$$\frac{1}{1+E} \int_{E_0}^{\infty} \frac{W(E) dE}{E^\nu}$$

Using this formula, the mean energies for the various secondary components referred to in Table I would be as follows:

- Kodakanal meson: 54 BeV
- Kodakanal neutron: 34 BeV
- Huancayo: 34 BeV
- Ottawa: 12 BeV
- Resolute: 11.5 BeV

One may also view the energy response qualitatively by calculating the percentage of particles contributed by primaries confined to an energy range 0 to $E$ for various values of $E$. Fig. 2 gives the percentages for the various secondary components.

---

**Fig. 2.** Percentage of secondary particles contributed by primaries of energies below $E$. Symbols A, B, C, D, & E have the same meaning as in Fig. 1.

It can be seen from Fig. 2 that for the neutron monitors at Ottawa and Resolute, almost 50% of the secondaries are due to primary energies between 0 to 15 BeV.

---

**Day to Day Changes in the Daily Mean Intensity, etc.**

The daily mean intensities of the nucleonic component and meson component of cosmic ray intensity at the various places corrected for barometric effect only are plotted in Fig. 3 for the period July 1967 to June 1968. The daily means of $H$, the horizontal component of earth's magnetic field at Kodakanal, are also plotted.

---

**Fig. 3.** Plot of daily mean intensities. Symbols A, B, C, D, E are as in Fig. 1. $H$ represents the horizontal component of earth's magnetic field at Kodakanal.

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To find out the extent to which these variations are simultaneous at the various stations, correlation coefficients are calculated for the various pairs. They are given in Table II.

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It can be seen from Table II that

- Kodakanal neutrons and Huancayo neutrons are very highly correlated with each other but not so much with either Kodakanal mesons or Ottawa and Resolute neutrons.
TABLE II

<table>
<thead>
<tr>
<th></th>
<th>Kodakanal neutron</th>
<th>Kodakanal neutron</th>
<th>Humasono neutron</th>
<th>Ottawa neutron</th>
<th>Resolute neutron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kodakanal mean</td>
<td>1.00</td>
<td>0.68</td>
<td>0.50</td>
<td>0.70</td>
<td>0.89</td>
</tr>
<tr>
<td>Kodakanal neutron</td>
<td>0.68</td>
<td>1.00</td>
<td>0.91</td>
<td>0.72</td>
<td>0.85</td>
</tr>
<tr>
<td>Humasono neutron</td>
<td>0.70</td>
<td>0.91</td>
<td>1.00</td>
<td>0.86</td>
<td>0.71</td>
</tr>
<tr>
<td>Ottawa neutron</td>
<td>0.70</td>
<td>0.73</td>
<td>0.86</td>
<td>1.00</td>
<td>0.97</td>
</tr>
<tr>
<td>Resolute neutron</td>
<td>0.70</td>
<td>0.66</td>
<td>0.71</td>
<td>0.97</td>
<td>1.00</td>
</tr>
</tbody>
</table>

(b) Ottawa and Resolute neutrons are very highly correlated with each other.

It seems, therefore, that the mean intensity variations are broadly parallel at all the stations indicating a world wide nature of the variations, but there are differences also between stations at different latitudes as also between means and nucleonic component. It is also observed that the average ranges of the variations for Kodakanal neutron and Humasono neutron are about the same, while the ranges of neutron intensity at Ottawa and Resolute are more than twice the base at Kodakanal or Humasono. Kodakanal mean intensity has a range somewhat lesser than Kodakanal neutron intensity. This indicates a strong energy dependence where lower energies have larger variations.

It must be noted, however, that the mean intensity is not corrected for upper air temperature effect and is not, therefore, directly comparable to the neutron intensities. The lower correlation between neutron and mean intensities could be due to this fact. Unfortunately, upper air radio-sonde data for Kodakanal are not available and hence it is not possible to estimate and correct for the upper air temperature effect at Kodakanal.

IV. RECURRENCE TENDENCIES IN THE DAILY MEAN INTENSITY VARIATIONS

To study the recurrence tendencies in the daily mean intensity, the days on which Ottawa neutron intensity showed maxima and minima were chosen as epoch days and three diagrams were drawn for the various intensities for $n = -60$ to $+60$ about the epoch day $n = 0$. These are shown in Fig. 4.

Fig. 4(a) and 4(b) refer to Ottawa neutron intensity maxima and minima respectively as epochs. It will be seen that there is a 27-day recurrence tendency for both the maxima and minima. Three diagrams for $H$, the horizontal component of earth's magnetic field at Kodakanal is also plotted in Fig. 4. It will be seen from Fig. 4(b) that $H$ has a minimum at $n = 0$ which means that on cosmic ray minima days, value of $H$ is also minimum. However, the magnitude of the minimum in $H$ is rather small ($\sim 70$ gamma). This is discussed further in Sect. V.

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Day to Day Changes in the Daily Mean Intensity, etc. 499

Fig. 4. Three diagrams of daily mean intensities of cosmic rays and earth's magnetic field for Ottawa neutron intensity (a) Maxima and (b) Minima as epoch days.
A-Ottawa neutron, B-Resolute neutron, C-Humasono neutron, D-Kodakanal neutron, $E =$ Kodakanal mean, $F =$ Horizontal component of earth's magnetic field.

V. RELATIONSHIP WITH GEOMAGNETIC DISTURBANCES

As a measure of the geomagnetic disturbance of any particular day, a character figure $C_p$ is evolved, which takes into account deviations from averages of the

Fig. 5. Three diagrams of daily mean intensities of cosmic rays and earth's magnetic field for $C_p$ maxima as epoch days.
A-High latitude neutrons, B-Equator neutrons, C-Equator means, D-Horizontal component of earth's magnetic field, $E-C_p$ values.
TABLE II

Correlation coefficients between the various components

<table>
<thead>
<tr>
<th></th>
<th>Kodakanal mean</th>
<th>Kodakanal neutron</th>
<th>Huancayo neutron</th>
<th>Ottawa neutron</th>
<th>Resolute neutron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kodakanal mean</td>
<td>1.00</td>
<td>0.68</td>
<td>0.70</td>
<td>0.70</td>
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</tr>
<tr>
<td>Kodakanal neutron</td>
<td>0.68</td>
<td>1.00</td>
<td>0.91</td>
<td>0.97</td>
<td>0.96</td>
</tr>
<tr>
<td>Huancayo neutron</td>
<td>0.70</td>
<td>0.91</td>
<td>1.00</td>
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<td>0.70</td>
<td>0.73</td>
<td>0.86</td>
<td>1.00</td>
<td>0.97</td>
</tr>
<tr>
<td>Resolute neutron</td>
<td>0.50</td>
<td>0.65</td>
<td>0.71</td>
<td>0.97</td>
<td>1.00</td>
</tr>
</tbody>
</table>

(b) Ottawa and Resolute neutrons are very highly correlated with each other.

It seems, therefore, that the mean intensity variations are broadly parallel at all the stations indicating a world wide nature of the variations, but there are differences also between stations at different latitudes as also between mean and neutron component. It is also observed that the average ranges of the variations for Kodakanal neutron and Huancayo neutron are about the same, while the ranges of neutron intensity at Ottawa and Resolute are more than twice those at Kodakanal or Huancayo. Kodakanal mean intensity has a range somewhat lesser than Kodakanal neutron intensity. This indicates a strong energy dependence where lower energies have larger variations.

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Day to Day Changes in the Daily Mean Intensity, etc. 499

Fig. 4. Three diagrams of daily mean intensities of cosmic rays and earth's magnetic field for Ottawa neutron intensity (a) Maxima and (b) Minima as epoch days.

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V. RELATIONSHIP WITH GEOMAGNETIC DISTURBANCES

As a measure of the geomagnetic disturbance of any particular day, a character figure Gp is evolved, which takes into account deviations from averages of the

Fig. 5. Three diagrams of daily mean intensities of cosmic rays and earth's magnetic field for Gp maxima as epoch days. A - High latitude neutron, B - Equator neutron, C - Equator neutron, D - Horizontal component of earth's magnetic field, E - Gp values.
variations in the various magnetic elements at several locations all round the world. Values of $C_p$ range from 0 to about 2.0. To study the relationship between $C_p$ and cosmic ray variations, days of maxima of $C_p$ values were chosen as epoch days and Chree diagrams were drawn for the daily mean intensity of cosmic rays. These are shown in Fig. 5.

It seems that $C_p$ maxima are followed within a day or two by cosmic ray minima. This is in agreement with earlier observations of similar nature by workers elsewhere (e.g., Simpson 1954).

However, it is found that the changes in the mean cosmic ray intensity associated with $C_p$ maxima are not very large. Thus, the changes at equator are of the order of 1% only whereas it is seen from Fig. 1, that the mean intensity variations are sometimes as large as 5% for equatorial stations. It is obvious, therefore, that there is no one-to-one relationship between $C_p$ maxima and cosmic ray minima. Apart from the possibility that some of the cosmic ray changes have apparently no connection with $C_p$ maxima at all, it is also possible that all $C_p$ maxima are not on the same footing so far as their effects on cosmic ray intensity are concerned. It is worthwhile, therefore, to see whether a criterion could be decided, upon which one could separate out those $C_p$ maxima which are better related to cosmic ray changes than the others. In the past, attempts have been made (Sekido et al., 1950) to study separately cosmic ray storms which are, and are not, associated with geomagnetic disturbances. However, the selection criterion there is the effect on cosmic ray intensity itself. We have adopted a criterion which was first introduced by Allen (1944). The $C_p$ maxima are divided into 4 groups according to whether they are preceded and/or succeeded by significant maxima at 27 day interval. Thus, the four groups are:

**Group A:** $C_p$ maxima preceded and succeeded by $C_p$ maxima at $\pm 27$ days.

**Group B:** $C_p$ maxima succeeded by $C_p$ maxima at $\pm 27$ days but not preceded at $\pm 27$ days.

**Group C:** $C_p$ maxima preceded by $C_p$ maxima at $\pm 27$ days but not succeeded at $\pm 27$ days.

**Group D:** $C_p$ maxima having no preceding or succeeding maxima at $\pm 27$ days.

Taking $C_p$ maxima in each group separately as epoch days, Chree diagrams were drawn for the various cosmic ray intensities as also for the horizontal component of earth's magnetic field. In Table III, we have summarized the main features of the Chree diagrams. For comparison, the main features are revealed by Fig. 5 for all $C_p$ maxima as epochs are also included in Table III.

It is clearly seen from Table III that though all types of $C_p$ maxima produce cosmic ray minima at about $n = 0$ to $+2$, the magnitude of the drop is cosmic...
variations in the various magnetic elements at several locations all round the world. Values of \( C_p \) range from 0 to about 2.0. To study the relationship between \( C_p \) and cosmic ray variations, days of maxima of \( C_p \) values were chosen as epoch days and three diagrams were drawn for the daily mean intensity of cosmic rays. Those are shown in Fig. 5.

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However, it is found that the changes in the mean cosmic ray intensity associated with \( C_p \) maxima are not very large. Thus, the changes at equator are of the order of 1% only whereas it is seen from Fig. 1, that the mean intensity variations are sometimes as large as 5% for equatorial stations. It is obvious, therefore, that there is no one-to-one relationship between \( C_p \) maxima and cosmic ray minima.

Apart from the possibility that some of the cosmic ray changes have apparently no connection with \( C_p \) maxima at all, it is also possible that all \( C_p \) maxima are not on the same footing as far as their effects on cosmic ray intensity are concerned. It is worthwhile, therefore, to see whether a criterion could be devised, upon which one could separate out those \( C_p \) maxima which are better related to cosmic ray changes than the others. In the past, attempts have been made (Sekido et al., 1950) to study separately cosmic ray storms which are, and are not, associated with geomagnetic disturbances. However, the selection criterion there is the effect on cosmic ray intensity itself. We have adopted a criterion which was first introduced by Allen (1944). The \( C_p \) maxima are divided into 4 groups according to whether they are preceded and/or succeeded by significant maxima at 27 day intervals. Thus, the four groups are:

- Group A: \( C_p \) maxima preceded and succeeded by \( C_p \) maxima at \( \pm 27 \) days.
- Group B: \( C_p \) maxima succeeded by \( C_p \) maxima at \( +27 \) days but not preceded by \( C_p \) maxima at \( -27 \) days.
- Group C: \( C_p \) maxima preceded by \( C_p \) maxima at \( -27 \) days but not succeeded by \( C_p \) maxima at \( +27 \) days.
- Group D: \( C_p \) maxima having no preceding or succeeding maxima at \( \pm 27 \) days.

Taking \( C_p \) maxima in each group separately as epoch days, three diagrams were drawn for the various cosmic ray intensities as also for the horizontal component of earth's magnetic field. In Table III, we have summarised the main features of the three diagrams. For comparison, the main features as revealed by Fig. 5 for all \( C_p \) maxima as epochs are also included in Table III.

It is clearly seen from Table III that though all types of \( C_p \) maxima produce cosmic ray minima at about \( n = 0 \) to \( +27 \), the magnitude of the drop in cosmic
ray intensity is not the same for all. Thus, $C_p^b$ and $C_p^o$ maxima which are
cxcaractcrized by either a fading or an absent recurring tendency have the largest
effect on cosmic rays. The effect is about 1.5% at equator and 4% at high lati-
tude for neutrons. The ratio of these two is, however, about the same for all
types of $C_p$ maxima.

It seems, therefore, that $C_p$ maxima which do not have recurring tendencies
produce the greatest reduction in cosmic ray intensity. From the last two columns
of Table III, it is seen that the association of all $C_p$ maxima with characteristics
of $B$ variation is not the same. Thus the $C_p$ maxima of the $C_p^b$ or $C_p^o$ type
show a larger range in the value of $B$ as compared to the range due to other $C_p$
maxima.

It is now well-known that geomagnetic disturbances of the recurring type are
associated with coronal activity and C.M.P. of weak coronal emission. On the
other hand, the non-recurring type disturbances are associated with S.C. type of
magnetic storms and also with sunspot groups of complex magnetic field, and
with C.M.P. of sunspot groups having high activity in solar radio noise. It seems,
therefore, that cosmic ray events have a better association with phenomena of the
latter type.

There are, however, two major apparent discrepancies in these observations.
They are as follows:

(a) Through $C_p$ maxima having little or no 27 day recurrence tendencies are better
associated with cosmic ray minima, the Chree diagrams for cosmic ray intensity minima as epochs show prominent recurrence
tendencies as shown in Fig. 4(b).

(b) Though the non-recurring type $C_p$ maxima are also associated with
S.C. type magnetic storms, there is no one-to-one relationship between
cosmic ray storms (viz. sharp minima of cosmic ray intensity) and the
S.C. type storm decreases of the horizontal component of earth's magnetic
field.

These discrepancies can, however, be understood if the following assumptions
are made:

(i) The recurring type geomagnetic disturbances do have some effect on
cosmic ray intensity though the effects are not as prominent as in the
case of effects of non-recurring type storms. This is borne out by results given in Table III.

(ii) The non-recurring type disturbance need not be assumed to be directly
responsible for cosmic ray minima but both may have a common
source of origin. The effects of the common source may persist longer
in cosmic ray intensity than in geomagnetic disturbances.

Day to Day Changes in the Daily Mean Intensity, etc. 563.

(iii) As stated earlier, all cosmic ray intensity minima are not associated
with minima of horizontal component of earth's magnetic field. How-
ever, when a Chree diagram is drawn for intensity minima of the hori-
zontal component of magnetic field at Kodaikanal as epoch days, it
is found that the cosmic ray intensity shows a prominent minimum on or about the epoch days and the magnitude of this minima is quite
large, about half of the general range of variation in cosmic ray intensity
(Fig. 6). Thus, all cosmic ray storms are not associated with magnetic
storms of the S.C. type. But many of the S.C. type magnetic storms are
associated with cosmic ray storms. This is not incompatible with
(a) and (b) above.

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Fig. 6. Chree diagrams of daily mean intensities of cosmic rays for minima of horizontal
component of earth's magnetic field as epoch days. A-High latitude neutron.,
B-Equator neutrons, C-Equator muons, D-Horizontal component of earth's magne-
tic field.

VI. ENERGY DEPENDENCE OF THE VARIATIONS IN PRIMARY INTENSITY

As has been shown so far, fluctuations as high as 5% at equator and 10-15% at
high latitudes are observed in cosmic ray intensity. It is obvious, therefore,
that the variations of cosmic ray intensity have energy spectra significantly
different from the primary energy spectrum. Referring to Eq. (1), we obtain
by differentiating partially with respect to $D(E)$,

$$100 \frac{\Delta J(E)}{J(E)} = \frac{\Delta D(E)}{D(E)} - \int \frac{\Delta J(E)}{D(E)} \delta E$$

... (6)
ray intensity is not the same for all. Thus, C,p and C,q maxima which are characterised by either a fading or an abrupt recurring tendency have the largest effect on cosmic rays. The effect is about 1.5% at equator and 4% at high latitude for neutrons. The ratio of these two is, however, the same for all types of C,p maxima.

It seems, therefore, that C,p maxima which do not have recurring tendencies produce the greatest reduction in cosmic ray intensity. From the last two columns of Table III, it is seen that the association of all C,p maxima with characterisation of H variation is not the same. Thus the C,p maxima of the C,p,q type show a larger range in the value of H as compared to the range due to other C,p maxima.

It is now well-known that geomagnetic disturbances of the recurring type are associated with coronal activity and C.M.P. of weak coronal emission. On the other hand, the non-recurring type disturbances are associated with S. C. type of magnetic storms and also with sunspot groups of complex magnetic field, and with C.M.P. of sunspot groups having high activity in solar radio noise. It seems, therefore, that cosmic ray events have a better association with phenomena of the latter type.

There are, however, two major apparent discrepancies in these observations. They are as follows:

(a) Through C,p maxima having little or no 27 day recurrence tendencies are better associated with cosmic ray minima, the Chree diagram for cosmic ray intensity minima as epochs show prominent recurrence tendencies as shown in Fig. 4(b).

(b) Though the non-recurring type C,p maxima are also associated with S. C. type magnetic storms, there is no one-to-one relationship between cosmic ray storms (viz. sharp minima of cosmic ray intensity) and the S.C. type storm decreases of the horizontal component of earth's magnetic field.

These discrepancies can, however, be understood if the following assumptions are made:

(i) The recurring type geomagnetic disturbances do have some effect on cosmic ray intensity though the effects are not so prominent as in the case of effects of non-recurring type storms. This is borne out by results given in Table III.

(ii) The non-recurring type disturbance need not be assumed to be directly responsible for cosmic ray minima but both may have a common source of origin. The effects of the common source may persist longer in cosmic ray intensity than in geomagnetic disturbances.

\[
\frac{dN(E)}{dE} = \frac{\delta N(E)}{dE} W(E, kE) \quad (6)
\]

Day to Day Changes in the Daily Mean Intensity, etc. 503

(iii) As stated earlier, all cosmic ray intensity minima are not associated with minima of horizontal component of earth's magnetic field. However, when a Chree diagram is drawn for intensity minima of the horizontal component of magnetic field at Kodaikanal as epoch days, it is found that the cosmic ray intensity shows a prominent minimum on or about the epoch days and the magnitude of this minima is quite large, about half of the general range of variation in cosmic ray intensity (Fig. 6). Thus, all cosmic ray storms are not associated with magnetic storms of the S.C. type. But many of the S.C. type magnetic storms are associated with cosmic ray storms. This is not incompatible with (a) and (b) above.

Fig. 6. Chree diagrams of daily mean intensity of cosmic rays for minima of horizontal component of earth's magnetic field as epoch days. A: High latitude neutrons, B: Equator neutrons, C: Equator muons, D: Horizontal component of earth's magnetic field.

VI. ENERGY DEPENDENCE OF THE VARIATIONS IN PRIMARY INTENSITY

As has been shown so far, fluctuations as high as 5% at equator and 10-15% at high latitudes are observed in cosmic ray intensity. It is obvious, therefore, that the variations of cosmic ray intensity have energy spectra significantly different from the primary energy spectrum. Referring to Eq. (1), we obtain by differentiating partially with respect to $D(E)$,

\[
100 \frac{\delta N(E)}{N(E)} = \frac{\delta D(E)}{D(E)} W(E, kE) \quad (6)
\]
VII. CONCLUSION

The broad conclusions of the above analysis may be summarised as follows:

1. The daily mean intensities of cosmic rays as observed by meson telescope and neutron monitors at the stations of Kodakkanal, Hunsanyo, Ottawa and Resolute show large fluctuations during the period July 1957 to June 1958. The range of fluctuations is about 3–5% and 5% for mesons and neutrons respectively at equatorial stations and 10–15% for neutrons at high latitudes.

2. The maxima and minima of the daily mean intensity of cosmic rays exhibit strong 27-day recurrence tendencies.

3. An analysis with $Q_p$ maxima as epochs indicates that $Q_p$ maxima are followed by cosmic ray minima with a probable lag of 1 or 2 days. Amongst the $Q_p$ maxima, the non-recurrent types seem to be better associated with cosmic ray minima.

4. Cosmic ray storms are not invariably associated with magnetic storms but magnetic storms of the S.C. type are many times associated with cosmic ray minima.

5. Large cosmic ray intensity decreases are world-wide in nature but their magnitude seems to be more than double at high latitudes as compared to that at equator.

6. The day to day variations of cosmic ray intensity are energy dependent. The variation spectrum $\delta N(E)/N(E)$ is of the type $E^{-1}$ where $N(E)$ is the primary energy spectrum.

ACKNOWLEDGMENTS

The authors are grateful to Professor V. A. Sarabhai for valuable guidance during the course of this investigation. Thanks are due to various research groups who have contributed neutron monitor data during the I.G.Y. The co-operation of the staff of the Solar Physics Observatory Kodakkanal, is greatly appreciated.

APPENDIX

Epoch dates for the various Chern diagrams

<table>
<thead>
<tr>
<th>Month</th>
<th>Ottawa maxima</th>
<th>Ottawa minima</th>
<th>$Q_p$ max.</th>
<th>$Q_p$ min.</th>
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For the L.H.S., the experimental values are about 3—4% for Kodaikanal, about 5% for Kodaikanal and Huancayo neutrons and about 10-15% for Ottawa and Resolute neutrons.

It is found that a variation spectrum of the type $\delta (E)/(E)$ for $E < 1$ fits the experimental values reasonably well. It should be noted, however, that such a spectrum fits only to the gross effects mentioned above. In individual events and for smaller time intervals, far too large effects (100% or more) have been observed at high latitudes. The energy spectrum involved there should be far more steep. Values as high as $E^{-2}$ have been suggested (Sekido and Murakami, 1955).

VII. CONCLUSION

The broad conclusions of the above analysis may be summarised as follows:

1. The daily mean intensities of cosmic rays as observed by meson telescope and neutron monitors at the stations of Kodaikanal, Huancayo, Ottawa and Resolute show large fluctuations during the period July 1957 to June 1958. The range of fluctuations is about 5—6% and 5% for mesons and neutrons respectively at equatorial stations and 20—15% for neutrons at high latitudes.

2. The maxima and minima of the daily mean intensity of cosmic rays exhibit strong 27-day recurrence tendencies.

3. An analysis with $C_{P}$ maxima as epochs indicates that $C_{P}$ maxima are followed by cosmic ray minima with a probable lag of 1 or 2 days. Amongst the $C_{P}$ maxima, the non-recurrent types seem to be better associated with cosmic ray minima.

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6. The day-to-day variations of cosmic ray intensity are energy dependent. The variation spectrum $\delta (E)/E$ is of the type $E^{-2}$ where $E$ is the primary energy spectrum.

ACKNOWLEDGMENTS

The authors are grateful to Professor V. A. Babu for valuable guidance during the course of this investigation. Thanks are due to various research groups who have contributed neutron monitor data during the I.G.Y. The cooperation of the staff of the Solar Physics Observatory Kodaikanal, is greatly appreciated.

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Day to Day Changes in the Daily Mean Intensity, etc. 505

Thanks are due to S. R. Thakore and others for computational help and to the Atomic Energy Commission of India for financial assistance.

REFERENCES


APPENDIX

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<table>
<thead>
<tr>
<th>Month</th>
<th>Ottawa maxima</th>
<th>Ottawa minima</th>
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