CHAPTER VII.

STUDY OF THE CHARACTER OF COSMIC RAY INTENSITY VARIATIONS DURING SOLAR AND MAGNETIC DISTURBANCES

A number of investigations have been reported in literature on the character of cosmic ray intensity variations during the large solar flares and the intense magnetic storms, but very little information is available for variations during the smaller solar flares, and associated magnetic storms.

In this chapter we have discussed the effect of 86 small solar flares (reported by Kodaikanal and Nizamiah Observatory, India, during July, 1957 to August 1958)\(^2\) of importance 1 and 2 and the associated magnetic storms on cosmic ray meson intensity, recorded at Ottawa (\(\lambda=57^\circ\)N), Churchill (\(\lambda=70^\circ\)N) and Resolute (\(\lambda=83^\circ\)N) during 1957-58, by the superimposed epoch method of Chree (1913)\(^3\). High latitude stations were chosen for analysis because in this case the effect is more pronounced.

\(^1\) A part of this investigation is published in the Nat. Acad. Sci (India), 34, Sec. A (1964), 17A, 105 (1958).
We have also tried to study the profiles of intensity variations, due to such magnetic storms to examine the properties of corpuscular streams and the nature of their interaction with the earth.

The following points were particularly kept in view:

1. The effect of those small solar flares, on cosmic-ray intensity which are followed by magnetic storms and also of those which are not followed by magnetic storms.

2. The effect of small solar flares and their associated magnetic storms at different latitudes and on days of different sunspot activity.

3. The effect of solar flares of different importance on cosmic ray intensity.

4. Association between the solar phenomena and subsequent geomagnetic effects, which are studied by considering the values of the geomagnetic indices $C_p$.

The data of geomagnetic storms and $C_p$ values used here are taken from J. Geophys. Res. 1957 and 1958. For 1958, the values of $C_p$ are taken
from the data supplied by Dr. J. Bartles, Zurich Observatory, Switzerland.

7.1 **METHOD OF ANALYSIS**

The daily average cosmic-ray meson intensity was calculated for each of the seven days before the flare and seven days after it. The average of the 14 days taken together was then compared with the daily average and percentage deviations calculated.

7.2 **ASSOCIATION BETWEEN THE DAILY MEAN MESON INTENSITY AND SOLAR FLARES FOLLOWED AND NOT FOLLOWED BY MAGNETIC STORMS**

The meson intensity at Ottawa is examined from the point of view as discussed below:

Eighty-six flares observed during 1957-58 are divided into two groups A and B. Group A contains those flares which are followed by Magnetic storms.

If the interval, \( \Delta t \), between the occurrence of solar flares and the geomagnetic storms is less than 5 days, then the flare is considered to be followed by a magnetic storm, and is put in group A. If the delay is greater than 5 days, the flare is considered
to be not followed by a magnetic storm and is put in group B. In this way 76 flares fall in group A and 10 fall in group B.

The results obtained are shown in Fig. 36. The curve for the flares followed by magnetic storms shows the peculiar feature that the average meson intensity increases even before the flare day. The maximum increase is about $0.17 \pm 0.036\%$ and it occurs about two days before the flare. After the flare, the intensity falls below its average value. It continues to fall until the minimum is reached two to three days after the flare. The minimum is about $-0.24 \pm 0.036\%$.

In the case of the flares which are not followed by magnetic storms, the meson intensity shows a trend that is so to say, in phase opposition to the earlier case. Average intensity reaches a minimum of about $-0.81 \pm 0.042\%$ nearly two days before the flare. It returns to its normal value and increases to about $+0.37 \pm 0.042\%$ two to three days after the flare.

Our results are in general agreement with those of Hogg (1949) who based his observations.

FIG. 36
AVERAGE SUPERPOSED VALUES OF $I_n$ FOR 7 DAYS BEFORE AND AFTER FLARES WHICH ARE FOLLOWED AND NOT FOLLOWED BY M-STORMS FOR THE PERIOD 1957-58.
on large solar flares.

7.3 **VARIATION OF COSMIC RAY MESON INTENSITY WITH SOLAR FLARES (FOLLOWED BY MAGNETIC STORM) AT DIFFERENT LATITUDES.**

On the basis of 41 flares, Fig. 37 and Table 32 has been constructed.

From Fig. 37, it is noted that meson intensity does not show any significant increase on the flare day during the period examined here at any latitude. It means that during the period Jan. to Aug. 1958 (which is the period of maximum sunspot activity) meson intensity does not show any increase associated with small solar flares of importance 1 and 2, at any latitude.

Kaminer (1960), Towle and Lockwood (1959) and Ghielmette et al. (1960) also arrived at the same result.

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Fig. 17. Overall super-imposed values of J0 for 5 days before and after the final day.
Fig. 37 also shows that after the flare day, meson intensity decreases below the normal level, reaches the minimum and then slowly recovers its normal level. This is noticed at all the three latitudes examined here. The magnitude of the dip (maximum decrease) and its time of occurrence at different latitudes are given in Table 32. From the results given in Table 32, it is evident that the magnitude of the dip is almost constant on all the three latitudes from $57^\circ$ to $83^\circ N$. But the time of occurrence of the dip increases as the latitude increases. The dip becomes more and more shallow as we move towards the pole. This indicates that the profile of the dip and its time of occurrence are rigidity dependent. Webber (1962) also discussed cosmic-ray decreases associated with large magnetic storms and showed a very pronounced rigidity dependence extending at least over the range 1-30 Gev.

Another significant point from these curves is that there is an increase in meson intensity before the flare day on all the latitudes examined here. This increase occurs on the first day before the flare day.

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8. W.R. Webber, Progress in Elementary Particle and Cosmic Ray Physics, $\&$, 77 (1962)
<table>
<thead>
<tr>
<th>Station</th>
<th>Ottawa</th>
<th>Churchill</th>
<th>Resolute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geomagnetic Latitude.</td>
<td>57°N</td>
<td>70°N</td>
<td>83°N</td>
</tr>
<tr>
<td>Increase at the flare day.</td>
<td>+0.00%</td>
<td>+0.05±0.044%</td>
<td>+0.33±0.044%</td>
</tr>
<tr>
<td>Decrease at the dip.</td>
<td>-0.27±0.046%</td>
<td>-0.24±0.044%</td>
<td>-0.27±0.044%</td>
</tr>
<tr>
<td>Dip day after the flare day.</td>
<td>2nd day.</td>
<td>3rd - 4th day.</td>
<td>5th day.</td>
</tr>
</tbody>
</table>
on Resolute (83°N) and Churchill (73°N), while at Ottawa (57°N) it occurs on 2nd day before the flare day.

7.4 ASSOCIATION BETWEEN VARIATIONS OF MESON INTENSITY AND THE IMPORTANCE OF THE SOLAR FLARES.

76 flares which were followed by magnetic storms in two groups were studied to see the association between the importance of the flares and the character of the cosmic ray intensity variations. The first group has 12 flares of importance 2, and the second group contains 64 flares of importance 1, observed during the year 1957-58. The results are shown in Fig. 38 and Table 33. It is seen that there is no increase of meson intensity on the flare day or any day just after the flare day.

The results, which are based on a slightly different study, are in agreement with those discussed in the chapter VI, and also with the other investigators.

The significant points in the character of meson intensity variations shown in Fig. 38 are as follows :-
<table>
<thead>
<tr>
<th>Period</th>
<th>Group I</th>
<th>Group II</th>
</tr>
</thead>
<tbody>
<tr>
<td>1957-58</td>
<td>Importance of the flare.</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Percentage: decrease from mean at dip.</td>
<td>-1.51±0.085%</td>
</tr>
<tr>
<td></td>
<td>Occurrence of the dip after the flare day.</td>
<td>Second day</td>
</tr>
</tbody>
</table>
(1) Both in the case of the flares of importance 2 and 1, meson intensity shows a significant decrease on 2nd day after the flare day. The magnitude of the decrease (dip) for flares of importance 2 is $-1.5 \pm 0.085\%$ and it occurs on the second day following the flare. For flares of importance 1, the magnitude of the decrease is $-0.32 \pm 0.037\%$ and it occurs on the second day after the flare.

(2) Both in the case of the flares of importance 2 and 1, meson intensity shows a significant increase on the 2nd day prior to the flare and we call this increase "Pre-flare increase". The magnitude of these pre-flare increases for the flares of importance 2 and 1 are $+1.35 \pm 0.085\%$ and $+0.75 \pm 0.037\%$ respectively.

(3) During the period July 1957 to August 1958, which is the period of maximum solar activity, it is found that the magnitude of the decrease of meson intensity after the flare day as well as the pre-flare increase is larger in the case of the flares of importance 2 than in the case of the flares of importance 1. But the time of occurrence of the maximum decreases (dip) and maximum pre-flare increase is the same for the flares of importance 2 as of importance 1.
7.5 RELATIONSHIP BETWEEN THE VARIATIONS OF MESON INTENSITY AND THE SUNSPOT ACTIVITY.

To observe the effect of solar flares (considered only those followed by magnetic storms) of lesser importance on meson intensity during the time of different sunspot activity, the period 1957-58 has been divided into three groups. On the basis of the sun-spot numbers.

(i) The first group extends from July to December 1957.
(ii) The second group (which is the sum of the first and second) extends from July 1957 to August, 1958 and
(iii) The third group from January to August, 1958.

Daily mean meson intensity of Ottawa has been analysed for these three groups and the results obtained are given in Table 34, and plotted in Fig. 39.

The significant points in the character of meson intensity variations shown in Fig. 39 are as follows :-

(i) Form the table 34 and Fig. 39, it is clear that for all the three groups discussed above, there
Fig. 79: Superimposed values of $\sin \theta$ for 7 days before and after the flare.
<table>
<thead>
<tr>
<th>Periods</th>
<th>1957</th>
<th>1957-58</th>
<th>1958</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunspot numbers</td>
<td>212.3</td>
<td>199.5</td>
<td>186.6</td>
</tr>
<tr>
<td>Percentage decrease from mean at dip</td>
<td>-1.04±0.044%</td>
<td>-0.57±0.034%</td>
<td>-0.27±0.046%</td>
</tr>
<tr>
<td>Dip day after the flare day (n=0)</td>
<td>2nd to 3rd day</td>
<td>2nd to 3rd day</td>
<td>2nd day</td>
</tr>
</tbody>
</table>
is a dip which occurs between two or three days after the flare day. The magnitudes of this dip for the first, second and third group are, $-1.04 \pm 0.044\%$, $-0.57 \pm 0.034\%$ and $-0.27 \pm 0.046\%$ respectively. This shows that the magnitude of the decrease (dip) of meson intensity increases as the sunspot activity increases, but its time of occurrence is almost constant during the period of different sunspot activities.

(ii) For all the three groups, meson intensity shows a significant increase (pre-flare increase) on the 2nd day prior to the flare day. The magnitudes of this increase for the three groups are $1.42 \pm 0.004\%$, $1.19 \pm 0.034\%$, and $0.49 \pm 0.046\%$ respectively. From these results one may say that the magnitude of the pre-flare increase also increases as the sunspot activity increases.

7.6 RELATIONSHIP BETWEEN SMALL SOLAR FLARES AND GEOMAGNETIC DISTURBANCES.

The relation between small solar flares and the geomagnetic effects is studied by the three method, considering the geomagnetic indices $C_p$ for the days before and after the flare events. The relation between $C_p$ and flares of importance 2 (nine cases) and of importance 1 (37 cases) are examined
separately for the period Jan. to Aug., 1958 and the results are shown in Fig. 40.

In the case of the flares of importance 2, the average superimposed values (in %) of $C_p$ show a large increase starting from the first day after the flare and reaching the peak value on the 2nd day after the flare. In the case of the flares of importance 1, the average superimposed value of $C_p$ (in %) starts increasing on the flare day and shows a peak value on the first day after the flare.

The magnitude of increase for the peak value of $C_p$ is quite large in the case of the flares of importance 2. The delay is also larger in the former case than in the latter. Since the former is based only on 9 cases, these conclusions are only of a tentative nature. However, it is certain that there is an increase in $C_p$ after solar flares.

Similar relation was also observed by Dodson and Hedeman (1958)\(^9\) considering the solar flares of all importances during the period Jan. 1949 to April, 1956 (115 cases), and by Denisse (1952)\(^10\) and Simon (1954)\(^11\).

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FIG. 40 RELATION BETWEEN THE SOLAR FLARE AND GEOMAGNETIC DISTURBANCES

CURVES A, B REPRESENT THE RELATION BETWEEN SUPERPOSED VALUES OF $C_2$ AND SOLAR FLARE OF IMPORTANCE 1 AND 2 RESPECTIVELY.
7.7 The delay between the occurrence of a solar flare, and the start of the associated geomagnetic storms.

Statistical data to study the effect is given in Table 35. The average delay in our case is one day and 3 hours. The frequency distribution is shown in Fig. 41. In Table 35, the delay \((4\Delta t)\) is calculated in units of a whole day (difference on calendar dates) rather than in the exact time interval in hours between the start of flares and storms.

7.8 Discussion and interpretation of experimental result:

The decrease of meson intensity following flares with magnetic storms shows association between magnetic storms and cosmic ray decrease. This indicates that both have a common cause. In the past years many models have been proposed to explain the cause of these Forbush type cosmic-ray decreases.

Chapman (1937)\(^{12}\) suggested that these may be explained on the basis of a ring-current of the kind

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Figure 4:
Frequency distribution between ∆t & solar flares.
∆t represents the time interval between the solar flare & start of geomagnetic storm.
### TABLE --35--

<table>
<thead>
<tr>
<th>Period</th>
<th>Δt (in days)</th>
<th>Number of cases of solar flares(f)</th>
<th>Percentage of the number of cases.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1957-58</td>
<td>0</td>
<td>35</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>20</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10</td>
<td>13%</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>7</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>3</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>Average Delay</td>
<td>1 day 3 hours.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total number of flares: 78</td>
<td></td>
</tr>
</tbody>
</table>
postulated by Chapman and Ferraro in their theory of magnetic storms. Nagashima (1951), (1953)\(^1\) modified this ring current hypothesis. But this ring current hypothesis or any change in the earth's dipole field cannot explain cosmic-ray decreases observed at polar latitudes, Churchill (70°N) and Resolute (83°N) during the period 1957-58 (period of maximum solar activity) and also cosmic-ray decreases observed at Thule (89.5°N) in 1951. Thus the ring current hypothesis for cosmic ray decreases is untenable.

Morrison (1956)\(^4\) explained the cosmic-ray decreases on the basis of the diffusion model. Morrison's model has been extended by Parker (1956)\(^5\) and also by Singer (1957)\(^6\). But one difficulty with this model is that it requires large magnetic fields to affect cosmic-rays of relevant energies, (about 30 Gev.). Another difficulty is that it leads to large latitude dependence of the cosmic-ray decreases. On the contrary, the observed latitude effect is very small and the variations observed in neutron counters are not very much greater than those of ion chambers or meson telescopes at sea level. This diffusion

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13. K. Nagashima, J. Geomag and Geoelect.\(2,100\) (1951); J. Geomag. and Geoelect.\(2,141\) (1953).
model also does not account for the increase in intensity observed by us before the flares.

Alfven (1946, 1949)\textsuperscript{17} and Nagashima (1951,1953)\textsuperscript{18} proposed the electric field model based on the solar stream. Alfven suggested that the decrease in cosmic-ray intensity is due to the electric field which arises as a result of the motion of the solar corpuscular stream through the solar magnetic field. According to this model, the energy lost by a particle crossing the solar stream is \((V/x)b\), where \(V\) is the stream velocity, \(x\) is the 'Frozen-in' magnetic field carried by the stream, and \(b\) is the breadth of the stream. This model has been extended by Burnberg and Dattner (1954)\textsuperscript{19}.

This model also explains the increases in meson intensity found by us to occur before the flare day. Blokh, Glokova and Dorman (1959)\textsuperscript{20} also observed small increases in the case of the individual magnetic storms. Dorman (1960)\textsuperscript{21} and others\textsuperscript{22} expressed the opinion that this increase

\begin{itemize}
  \item 18. K. Nagashima, J. Geomg. Geoelect., 2, 100(1950); 2, 141 (1953).
  \item 19. E.A. Burnberg and A. Dattner., Tellus, 6, 73; 254(1954).
\end{itemize}
is due to a shock wave from the abruptly approaching face of the corpuscular beam carrying a frozen-in magnetic field. The possibility of the formation of a shock wave by means of the front face (or the approaching face) of the beam (or stream) was discussed by Singer (1957) who also investigated the geomagnetic effects of this shock wave on its arrival at the earth. Recently, the acceleration of charged particles during the passage of the front of a shock wave in magnetic plasma has been considered in detail by Dorman and Freidman (1959), and Dorman (1960) and Snabansky (1961). It is shown that in the front part of a solar stream carrying a frozen-in magnetic field, the plasma and the magnetic field are apparently compressed. Hence this enhanced magnetic field will reflect the charged particles incident on it, and among all the particles falling on the surface of the earth there will be a definite fraction of those

particles that are reflected from the stream. In such reflection there is a head-on collision in which particle energy increases somewhat, and this should lead to an increase in the intensity of cosmic-rays on the surface of the earth.

(ii) Nature of the profiles and the solar stream.

The results discussed in this chapter have shown that in the case of the flares followed by magnetic storms there is an increase in cosmic-ray meson intensity before the flare on the 2nd day. This increase is also noticed in the case of flares of importance 2 and 1 and at different latitudes. From theoretical consideration developed by Dorman and other investigators, it is clear that this increase could occur only in the case of magnetic storms which give rise to types I and II falling profiles (Fig. 42) and the increase should not occur with storms of type III profiles (Dorman 1960).

Thus, on a purely qualitative basis we can broadly say that the decrease profile which we observed in Fig. 36, for the flares followed by magnetic storms is either of type I or type II, Fig. 42. From Fig. 36 it seems that the decrease profile is of the type II. From the curves in Fig. 37, which
Fig 42 Different possible types of profiles of cosmic-ray intensity variations during magnetic storms (Dorman 1976)
give the decrease profile of meson intensity at three different latitudes, it seems that in this case also the decrease profiles on different latitudes are of type II. Figs. 38 and 39 show that for flares of importance 2 and 1 and also for flares during the period of different sunspot activity, the decrease profile is of the type II. Thus on the basis of these profiles, one may say that these meson intensity decreases are caused when the earth is enveloped by the leading face of the stream.

(iii) DECREASE AT HIGHER LATITUDES

Fig. 37, shows that the polar decreases seems to be both larger and wider than those at other latitudes. The reason for this (as discussed by Singer, 1958) may be the presence of trajectory dispersion which exists at all other latitudes. But at the polar latitudes even a non-monochromate detector will received all primary particles from the same direction. Singer held that the motion of the particles beyond about 40-earth-radii becomes controlled by the interplanetary magnetic field. In any case, whatever the cause of the Forbush decreases it clearly affects all the particles entering the polar detector, but only
a portion of the particles at other latitudes. This fact indicates that the polar telescope has the important ability to look out further into space than telescopes at other latitudes.