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Meso-scale study of Rainfall over Poona and neighbourhood*

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ABSTRACT. A meso-meteorological network of autographic raingauges and microbarographs was established in every mile square of 36 square miles centred round the Poona Observatory. Spells of thunderstorms occurred only in association with large scale disturbances observable on synoptic charts. Rainfall from a single thunderstorm cloud was found to be about 7×10^6 metric tons. Monsoon rainfall showed significant variations both in time and space and was not made up of steady and continuous rain as is often believed. A strengthening of the monsoon rainfall is associated with a larger number and higher intensity of rainspells and not with any increase in the duration of rainspells.

1. Introduction

Poona (India) with latitude 18° 32′ and longitude 73° 51′ is situated at an elevation of 560 m above mean sea level to the east of the Western Ghats. The hottest period is premonsoon season March, April and May; of this during the seven weeks from third week of April to the first week of June, Poona's weather is characterised by intense convective activity. Cumulonimbus develops on some of these days on the afternoons and thunderstorms with squalls, heavy precipitation and sometimes hail, occur. The frequency of such thunderstorms increases often as the season advances from April to June. The thundershowers merge into the non-thunderstorm rain of the southwest monsoon season by about 10 June on an average. During the monsoon season (June to September) the station remains highly cloudy with frequent light rainfall. The annual rainfall of Poona of 67 cm stands in contrast to the 650 cm on the crest of the nearby Sahyadri escarpment or the 180 cm on the coastal strip to the west. The amount of precipitation given by the pre-monsoon thunderstorms varies widely and conspicuously even over the small areas of the Poona city (approximately 50 square miles)—parts of the city experience a heavy downpour when other parts remain dry. With a view to understand the premonsoon thundershower activity and its eventual transformation into the monsoon rainfall a meso-scale study of this typically tropical phenomenon was undertaken. The facilities that could be harnessed as also the time available for organization were rather limited. Results of this study are described in the following sections.

2. Observational network

A square of side 6 miles centred on the Poona Observatory was divided into 36 mile squares. A syphon type self-recording raingauge was installed in each of these squares. Sixteen barographs were also placed along with the raingauges at selected stations. Satisfactory exposure for the raingauges was ensured by choosing well exposed terraces of buildings in the area for locating them; barographs were installed inside suitable rooms within the buildings.

Continuous records of rainfall and atmospheric pressure were obtained from this network for the period 15 May to 17 June 1963. The network was also made to function during 5 to 12 July 1963 when an active spell of monsoon occurred. The locations of the various observing stations are shown in Fig. 1.

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It was observed early in the study that most thunderstorm cells covered areas considerably larger than 36 square miles and it was considered useful to examine all the available rainfall data in a larger area around Poona. Over 30 raingauge stations belonging to the State Government record daily rainfall in the area of 30 miles round Poona and a much larger number during the monsoon season. Fig. 2 gives a contour map of this area as also the distributions of these raingauge stations. All the rainfall data as far as they became available from the stations shown in Fig. 2 were collected for the periods, 1 May to 17 June 1963 and 5 to 12 July 1963 for the purpose of this analysis. These data enabled a study of the variation of the rainfall from the mountainous area of the Western Ghats to the plateau to the east under differing strength of the monsoon.

Fujita (1962) refers to a threefold classifications of meso-meteorological network according to the density of spacing of observatories.

Category	Specification	Average spacing between neighbouring stations in miles
α	Coarse	30
β	Medium	5
γ	Fine	1

The network used in the present study accordingly falls under γ classification in Fig. 1 network and α to β classification in Fig. 2 network.

3. Premonsoon thundershowers

(a) Cases of thundershowers observed

Since the beginning of May 1963 premonsoon thunderstorms occurred mainly in 4 spells—(*i*) from 1 to 4 May, (*ii*) 13 to 18 May, (*iii*) 22 and 23 May and (*iv*) 1 to 7 June. Arrangements for observations in every square mile were made only by 15 May and hence details of the spells prior to this date are incomplete. The mean rainfall which occurred over an area 30 miles round Poona ending at 0830 IST of each day are indicated in the lower part of Fig. 3. The pibal winds taken at 00 and 12 Z over Poona for various levels are also given. The interesting features of two of the well recorded spells are given below.

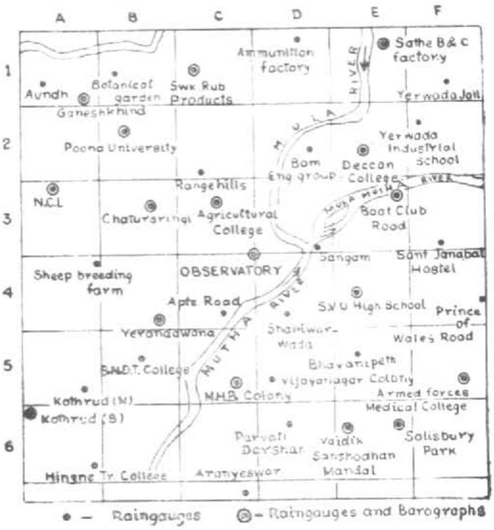

Fig. 1. Meso-scale study of thunderstorms over Poona
One sq. mile grid used in the study covering 36 miles round the observatory

Thundershower spell (22 and 23 May)— Fig. 3 shows that this spell resulted from disturbed flow in the lower atmospheric levels over Poona and neighbourhood. 22 May was an active thunderstorm day with three separate spurts of activity. One spurt which gave 2 to 3 mm of rain occurred in squares A6 and B6 between 1545 and 1610 IST and a third spurt in C5, D5 and F5 between 1910 and 1945 IST. The other spurt was the heaviest. It started at 1530 hrs in the square E2 over a small area. The isohyets and isochrones of rainfall in the experimental grid is shown in Fig. 4. The western edge of the rain area progressed westwards with a speed less than 5 mph. The rainfall amounts also decreased as one proceeded west; towards the western edge there was little or no rain. The main thunderstorm cell moved from northeast to southwest very slowly and at the same time gradually died out before reaching the western edge of the area under study.

Thundershower spell (1 to 7 June)— Thunderstorm activity of variable magnitudes occurred within the area of 30 miles round

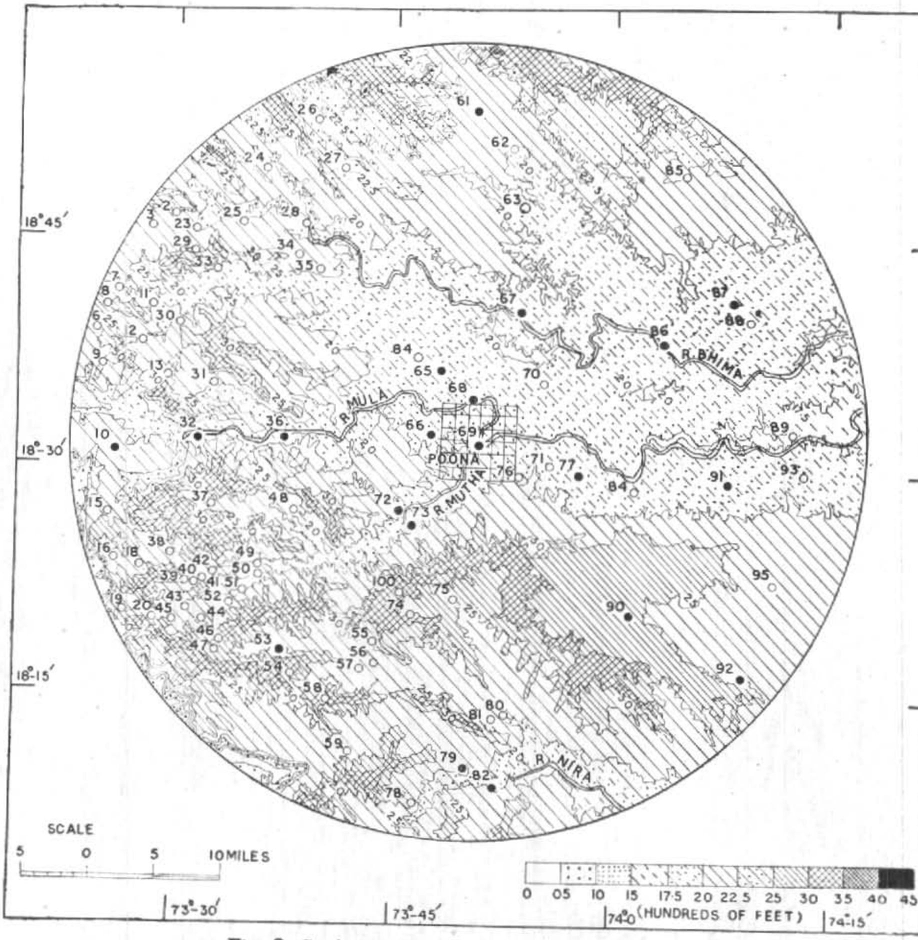

Fig. 2. Contour map of Poona and 30 miles around

o indicates raingauges operating during the monsoon season

● indicates raingauges operating throughout the year

The figures by the side of the station circles are serial numbers of the stations

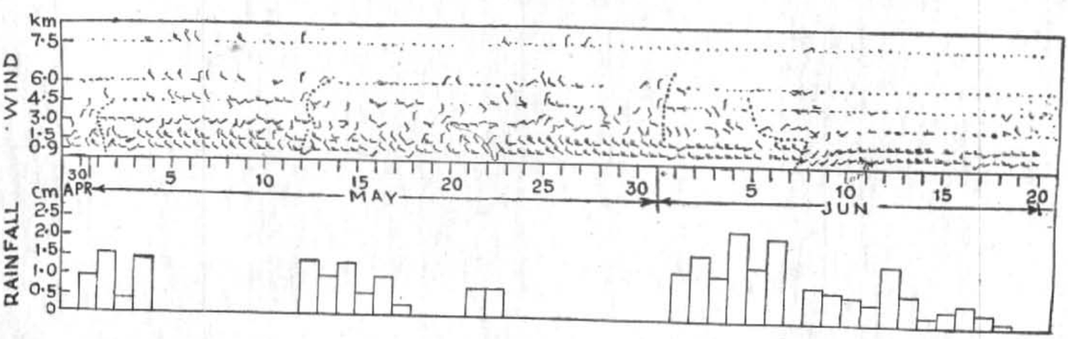

Fig. 3. Winds over Poona and mean daily rainfall over 30 miles around Poona, May-June 1963

(Dotted lines represent upper air trough lines)

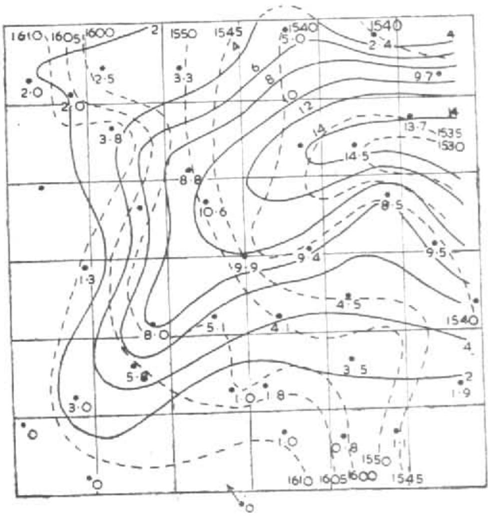

Fig. 4. Isohyets (mm) of one thunderstorm rainfall (continuous lines) and isochrones of commencement of precipitation (broken lines) on 22 May 1963

Poona on different days. The disturbed flow conditions which caused this spell can be seen in Fig. 3. The activity on 1, 2, 3 and 6 June was well marked and affected the experimental area.

2 June was the most active thunderstorm day of this spell. Showers occurred all over the grid (Fig. 5). The precipitation commenced fairly simultaneously at about 1545 IST at the various recording points in the grid without any clear cut pattern of movement of the thunderstorm cell. A maximum rainfall of 7 cm was recorded in C1 square near the northern boundary. The heaviest fall of 8 cm from this cell occurred at the Military Engineering College $1\frac{1}{2}$ miles to the north of northern boundary of the grid. The precipitation rates shown in Fig. 6 are well marked by the wide variation in their structures and timings at the various grid points. The heaviest recorded intensity 8·4 cm per hour occurred in B1 and C1 squares. The duration of rain spell decreased from 50 minutes in the north to 30 minutes in the south.

(*b*) *Role of large scale disturbance in inducing convection*

Study of synoptic charts for the period showed that all spells of thunderstorm activity occurred in association with large scale disturbances observable on a synoptic scale. In all, four spells of easterly to southeasterly winds appeared over Poona within the first two kilometres in association with the development of troughs over the Indian Peninsula and the resulting influx of moisture from the Arabian Sea or Bay of Bengal. On the other hand the dry periods occurring between the thunderstorm spells were mainly associated with westerly or northwesterly winds extending much above 2 km. A synoptic scale disturbance thus appears to be crucial for tropical convection and to control the meteorologically significant results of small scale phenomena. This aspect has also been stressed by Malkus (1963).

(*c*) *Intensities of precipitation*

An examination of the intensity of precipitation in the different grid squares associated with the different thunderstorm spells shows that as a rule the intensity of a shower rises to its highest value and then falls, the rise and fall being almost equally rapid. The intensity maximum is reached at about the middle of the duration of rainfall. Analysis of the rainfall presented in the Report of the Thunderstorm Project (1949) by Byers and Braham, on the other hand, indicates that the intensity of thunderstorm shower generally reaches its maximum very soon after the shower starts but falls off at a much slower rate. The major part of the precipitation in the latter case occurs in the early part of the shower. The significant difference in this precipitation feature between the 1949 U.S. Project and the present study is a matter worth studying further in detail.

It will be of some interest to compare the intensity of rainfall of 2 June thunderstorm precipitation with similar precipitation elsewhere. Information on short period rainfall rates in India or in any other tropical areas is not available. A comparative idea may, however, be gained from the rates of rainfall observed on this occasion with the classification of British rainfall. Bilham (1935) categorises 54 mm in 50 minutes as a very rare fall. The highest rate of rainfall recorded on the present occasion is 60 mm in B1 square

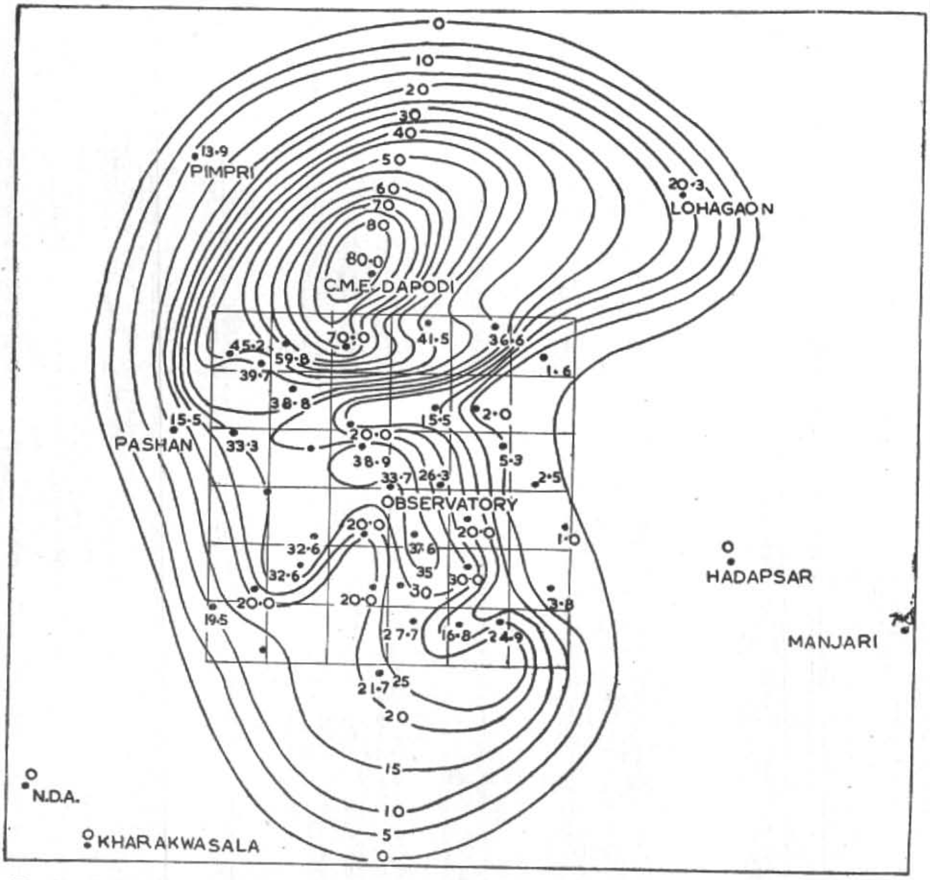

Fig. 5. Isohyet (mm) of rainfall in and around the experimental area on 2 June 1963. The outermost curve is the line of zero rainfall which fell from one thunderstorm

and 70 mm in C1 square during an interval of 50 minutes. The heaviest rainfall rate in an average thunderstorm shower, experienced by these two squares would be called 'very rare' by British rainfall standards. Poona is 560 m. a.s.l. so that at the coastal and plain stations in India much higher rates of precipitation can be expected.

The rate of rainfall measured over a 5-minute interval over a few locations on this occasion was as high as 10 cm/hr. (4 in/hr). This compares well with the maximum intensity of rainfall observed in some of the meso-meteorological studies, *vide* Fig. 36 of Fujita (1962) and Fig. 25 of Donaldson and Atlas (1963).

(*d*) *Amount of precipitation falling from a single thunderstorm*

From the *nil* values of 24-hour rainfall reports received from stations within a few miles of the boundary of the grid it has been possible at least in one case to isolate the area covered by precipitation from a single thunderstorm cell (Fig. 5). From the space and time continuity within the grid the rainfall that occurred from a single thunderstorm cloud on 2 June could be extended in respect of rainfall in the immediate neighbourhood also. Although the reports from outside the grid are not numerous, the isohyet of zero rainfall could be drawn with sufficient justification so as to isolate the lower limit

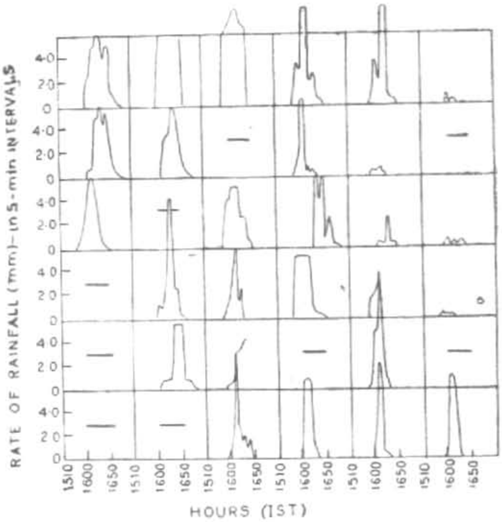

Fig. 6. Rate of rainfall — precipitation in 5-min intervals that fell on 2 June 1963

— indicates incomplete records

TABLE 1

Duration and intensities of heavy rain spells

Duration in minutes	Peak intensities in mm per 15 minutes															
	2·1 to 3·0	3·1 to 4·0	>4·0	Total	2·1 to 3·0	3·1 to 4·0	>4·0	Total	2·1 to 3·0	3·1 to 4·0	>4·0	Total	2·1 to 3·0	3·1 to 4·0	>4·0	Total
	5 July 1963				6 July 1963				7 July 1963				8 July 1963			
30	1	1	..	2	..	..	..	..	7	3	1	11	3	..	..	3
45	9	..	2	11	9	..	..	9	14	10	..	24	4	..	..	4
60	4	..	1	5	4	..	..	4	4	7	4	15	2	..	..	2
75	2	..	..	2	2	..	..	2	11	2	1	14	2	1	..	3
90	2	2	..	4	1	1	..	2	4	7	..	11	..	..	..	..
105 and above	11	..	..	11	1	1	..	2	6	14	7	27	..	..	..	..
Total	29	3	3	35	17	2	..	19	46	43	13	102	11	1	..	12
Average duration of a spell	75 minutes				62 minutes				70 minutes				51 minutes			
Average No. of spells per square	1·1				0·7				3·3				0·4			

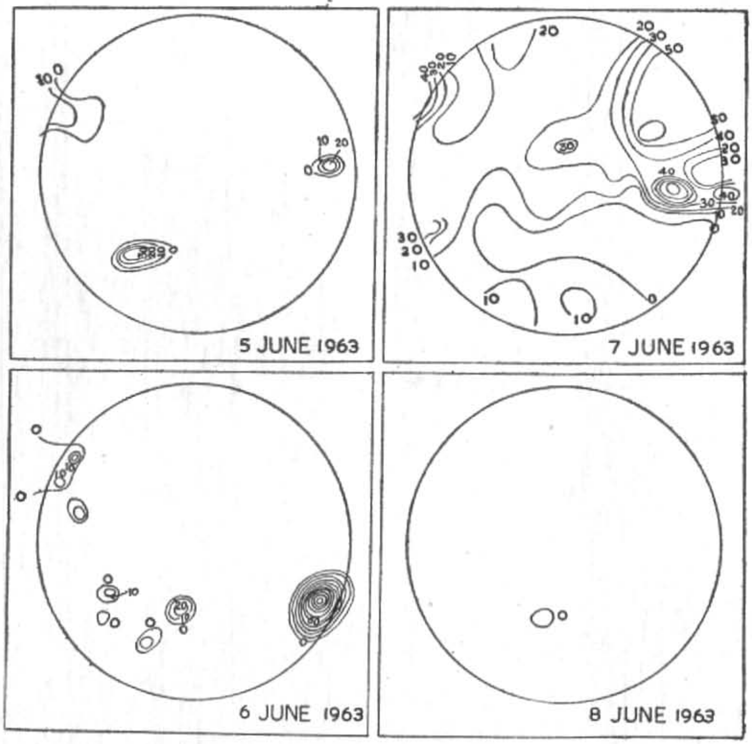

Fig. 7. Isohyets of rainfall (cm)
(Note the isolated nature of showers)

of the area covered by this thunderstorm. The areas enclosed by the isohyets of different values were planimetered. A total rainfall of 7×10^6 metric tons was found to have fallen over an area of 264 square kilometres, corresponding to an average rainfall of 2·6 cm over this area. The water yield of this thunderstorm is equivalent to 4—6 air-mass thunderstorms of the midwest United States (Fujita 1962).

(*e*) *Pressure variations accompanying thunderstorms*

The network of 16 barographs used in the experiment gave reasonably good records on the two most active thunderstorm days, namely, 22 May and 2 June but lack of synchronisation of the clocks has handicaped an exact appraisal of the time variation of pressure changes and their association with the activity of the thunder cell. The following observations seem, however, important.

On 22 May, at most of the stations small initial pressure fluctuations were followed by a fall in pressure. Thereafter the commencement of the shower roughly coincided with a rise in pressure. The pressure rise continued for about half an hour and then the pressure fell and merged with the diurnal curve. The isochrones of pressure maximum practically coincided with the isochrones of maximum intensity of rain. The same characteristics were observed in respect of the thunderstorm spell on 2 June except that the initial fall of pressure was less marked. The magnitude of the pressure rise, however, does not appear to be proportional to either the precipitation intensity or the total precipitation that fell from the thunderstorm. An intensity of 4 mm of rain/5 min and a total precipitation of 14·5 mm on

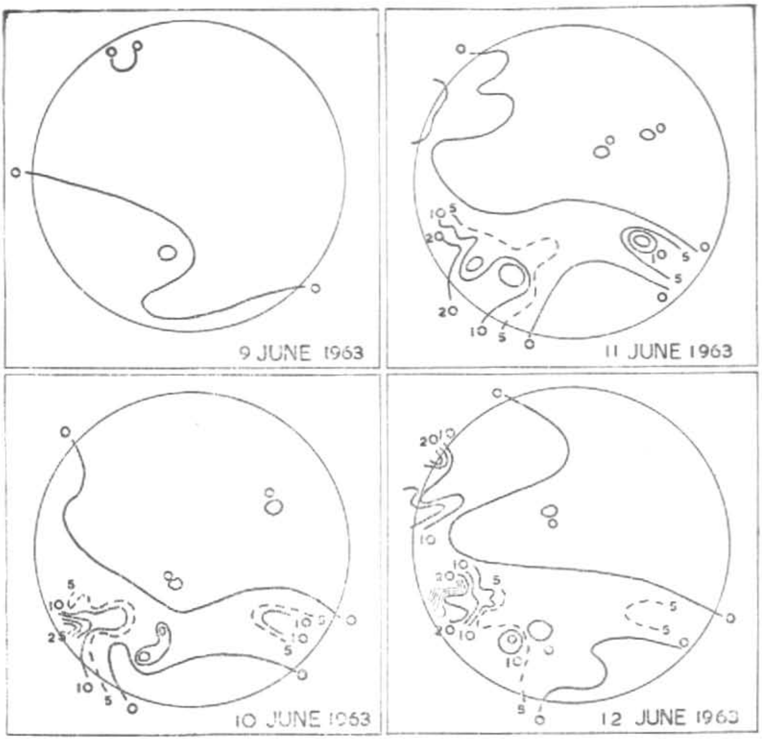

Fig. 8. Isohyets of rainfall (cm)

(Note the heavy rainfall over the Ghats)

22 May gave a pressure rise of 1·6 mb while an intensity of 7 mm/5 min with a total of 70 mm of rain on 2 June gave practically the same pressure rise, *i.e.*, 1·4 mb.

4. Monsoon rainfall

It is well known that in the Indian Peninsula the rainfall is generally unaccompanied by thunderstorms once the monsoon is established. Such rainfall commenced in the study area—30 miles round Poona, on 9 June. Steady and strong westerlies set in over Poona in the lower troposphere simultaneously (Fig. 3). The daily rainfall reported from 5 to 12 June seen in Figs. 7 and 8 shows clearly the features of the transition from premonsoon thunderstorm season to the monsoon season. Cellular convective precipitation which was more over the plateau to the east of the Ghats gave place to a system of fairly heavy and steady precipitation over the Ghats from 9th onwards. The monsoon precipitation from 9 to 17 June was very low over the plateau; cloudy weather with occasional light drizzle characterised the weather over Poona and neighbourhood. Some mile-squares in the experimental grid did not record any rain between 9 and 17 June but moderate or heavy precipitation occurred over the Ghats 20 to 30 miles to the west of Poona. Occurrence of daily precipitation over the Ghats with or without rains

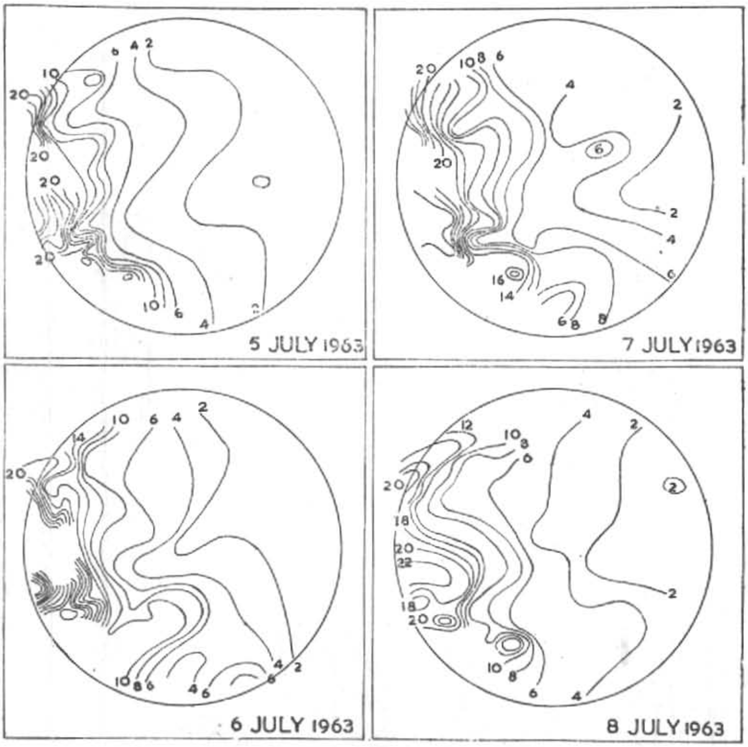

Fig. 9. Isohyets of rainfall (cm) during a strong monsoon spell

in the plateau to the east is a characteristic of the monsoon season over this area.

The monsoon spell from 5 to 8 July was particularly heavy, 7 July being the most active day for the plateau to the east (Fig. 9). Very heavy rain of the order of 20 to 30 cm was reported on some of these days from over the Ghats to the west. Steady westerlies prevailed over the area in the lower troposphere during this period. The rainfall over the grid on 7 July decreased from west to east (Fig. 10). It varied over the grid from 43 to 74 mm on a strong monsoon day (7 July) and 8 to 27 mm on a relatively weaker day (8 July).

Heavy rain spells during strong monsoon

Fig. 11 shows the hourly intensity curve of each observing station in the grid for 7 July. The highest intensity was 15·8 mm in one hour. The variations in intensity at any particular observing site indicate that moving cells of convective clouds are embedded in the monsoon clouds and give passing heavy rain-spells. The formation and movement of these convective cells in the monsoon clouds are aspects which merit detailed study. With the data available a statistical study was carried out. The 15-minute intensities of rainfall were worked out from the autographic charts for all the squares in the grid for each day in respect of 5, 6, 7 and 8 July. Duration of spells whose maximum intensity was more than 2·0 mm in 15 minutes (*i.e.*, 8 mm per hour) were counted. This value of the lower limit of intensity ensured that only the significant spells were included. The peaks were counted

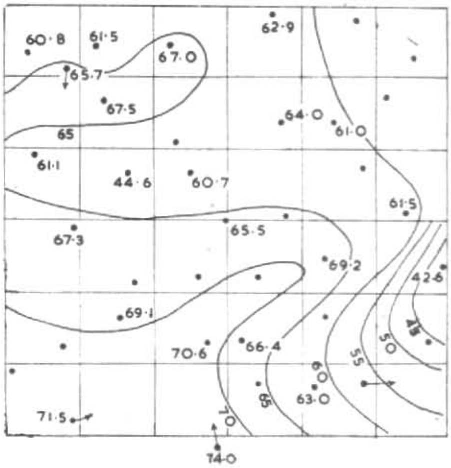

Fig. 10. Isohyets (mm) of 24-hr rainfall in monsoon rain on 7 July 1963

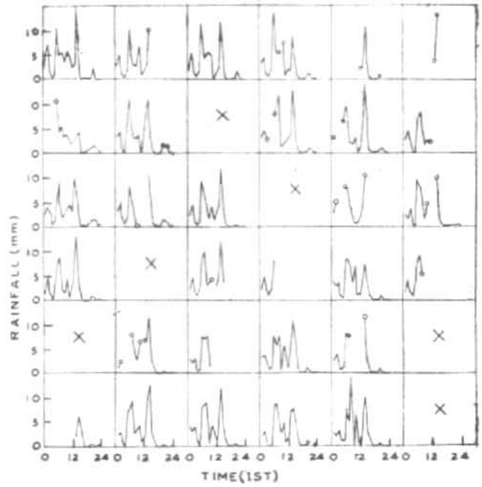

Fig. 11. Hourly variation of rainfall—7 July 1963
× indicates records incomplete

separately only if the dips separating two peaks were more than half the magnitude of the earlier peak. Table 1 shows the frequency of such spells of various intensities of rain lasting for 30, 45, 60, 75 etc minutes. It may be seen that on a heavy monsoon day such as 7 July about 3 heavy rain spells of average duration of 70 minutes occurred over any individual square. The heavy monsoon rainfall on 7th is due to rain spells of much larger number and intensity as compared with days of weaker monsoon such as 5 and 6 July and not to longer durations of rain spells. This affords an interesting insight into the nature of monsoon rainfall at least over Poona and neighbourhood.

Diurnal variation of monsoon rainfall

Hourly rainfall averaged over all the 36 squares was plotted and examined for each of the days 5 to 8 July but no noticeable diurnal variation in intensity could be detected.

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