SOME SALIENT FEATURES OF THE SPACE-TIME VARIATIONS OF RAINFALL OVER INDIA AND NEIGHBOURHOOD

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SINCE Blanford (1888) published his classical monograph on the "Rainfall of India", the systematic collection, processing and publication of rainfall data by the India Meteorological Department have provided a large volume of additional material which have stimulated several studies on various facets of this subject. A recent study by Lettau and White (1964) on the "Fourier Analysis of Indian Rainfall" may be mentioned in this connection. In the present communication, attention is sought to be focused on certain aspects of the space and time variations of rainfall that have emerged from a study of the monthly and pentad rainfalls of observatory stations based on long-period normals (fifty years or more).

2. It is well known that the mean monthly rainfall of several Indian stations show two maxima and two minima. Over North India, the primary rainfall maximum occurs during the south-west monsoon season and the secondary maximum during the winter period. Over peninsular India, the situation is different. Figure 1 gives a diagrammatic representation of the space-time variation of the wettest month over India and neighbourhood. The isolines approximately demarcate the areas corresponding to the epochs of rainfall maxima. Over large areas of central and north India, July is the rainiest month. However, over a belt extending from upper Burma to the extreme north of India through the Indo-Gangetic plain, August is the month of maximum rainfall. In the interior of peninsular India, the maximum rainfall month shifts over fairly abruptly from July to September south of latitude 20° N., and to October or November at lower latitudes. The south-western coastal areas as well as lower Assam and East Pakistan experience the highest rainfall in June. Along the east coast of India, the maximum rainfall month shifts from July to October near latitude 20° N.; south of 15° N., the rainfall maximum occurs in November.

3. Figure 2 shows the space-time variations of the secondary rainfall maximum. Over most of north and central India, the secondary maximum is associated with the winter rains in January-February caused by western disturbances. To the west and north of this area, the feeble penetration of the south-west monsoon current gives rise to the secondary maximum in July-August. In the interior of peninsular India south of 20° N., the secondary maximum occurs in May, June, July or September over the different areas; along the Kerala coast, October is the month of secondary maximum.

4. The spatial variation of the lowest minimum rainfall month (driest month) is shown in Fig. 3. A regular time sequence from September in the extreme west and north to February in the extreme south-eastern parts of the peninsula can be noticed. The north-eastern parts of the tip of peninsular India as well as of Ceylon are driest in the south-west monsoon months June to August. Over the western parts of central India, March-April are the driest months.

5. The manner in which the epoch of secondary minimum rainfall is geographically distributed can be seen from Fig. 4. The significant features are the temporal progression of the minimum north-westwards across north India and west Pakistan from March to June, the June-July-August minimum over the interior of peninsular India, and the September minimum over the Kerala coast. Also noteworthy is the July minimum over lower Assam, east Pakistan and upper Burma.

6. A deeper insight into the space-time variations of rainfall is provided by the pentad normal rainfall curves of individual stations. A few typical curves are presented in Figs. 5 to 8. Similar curves have been prepared for over 100 stations. Some of the significant facts brought out from the study of these curves are listed below.

(i) In the first pentad of June (pentad 31) a sudden increase in the slope of the rainfall curves is noticed at several stations in the interior of the country as far north as Jodhpur, Bikaner, Delhi and Jammu.

(ii) As the rainfall on the west coast is steadily increasing from the beginning of June, there is a steady decrease at the interior stations over the south peninsula (Madurai, Tiruchirapalli, Kodaikanal, Bangalore, etc.). The minimum rainfall at the interior stations is reached towards the end of June (pentad 35/36), which practically corresponds to the epoch of maximum at the coastal stations.
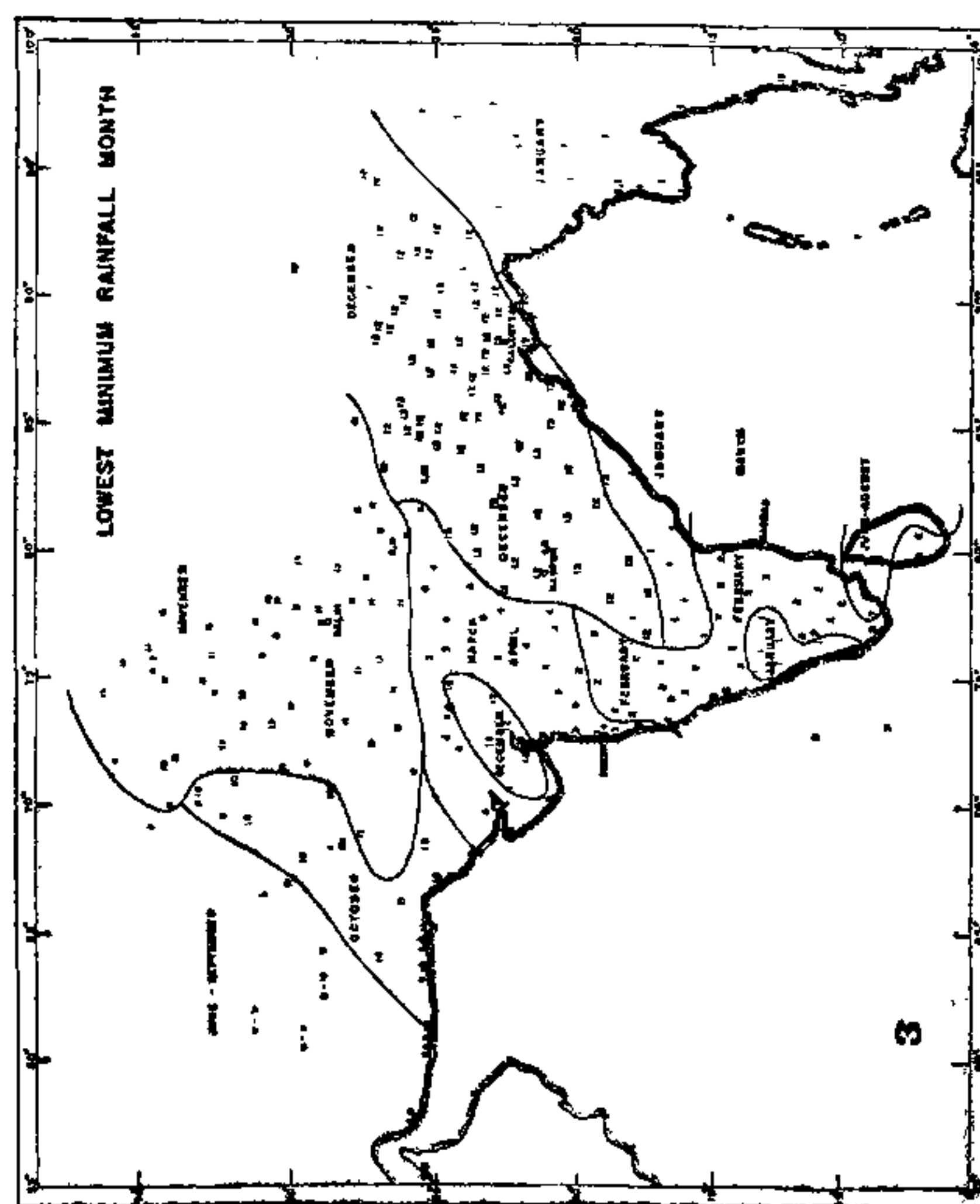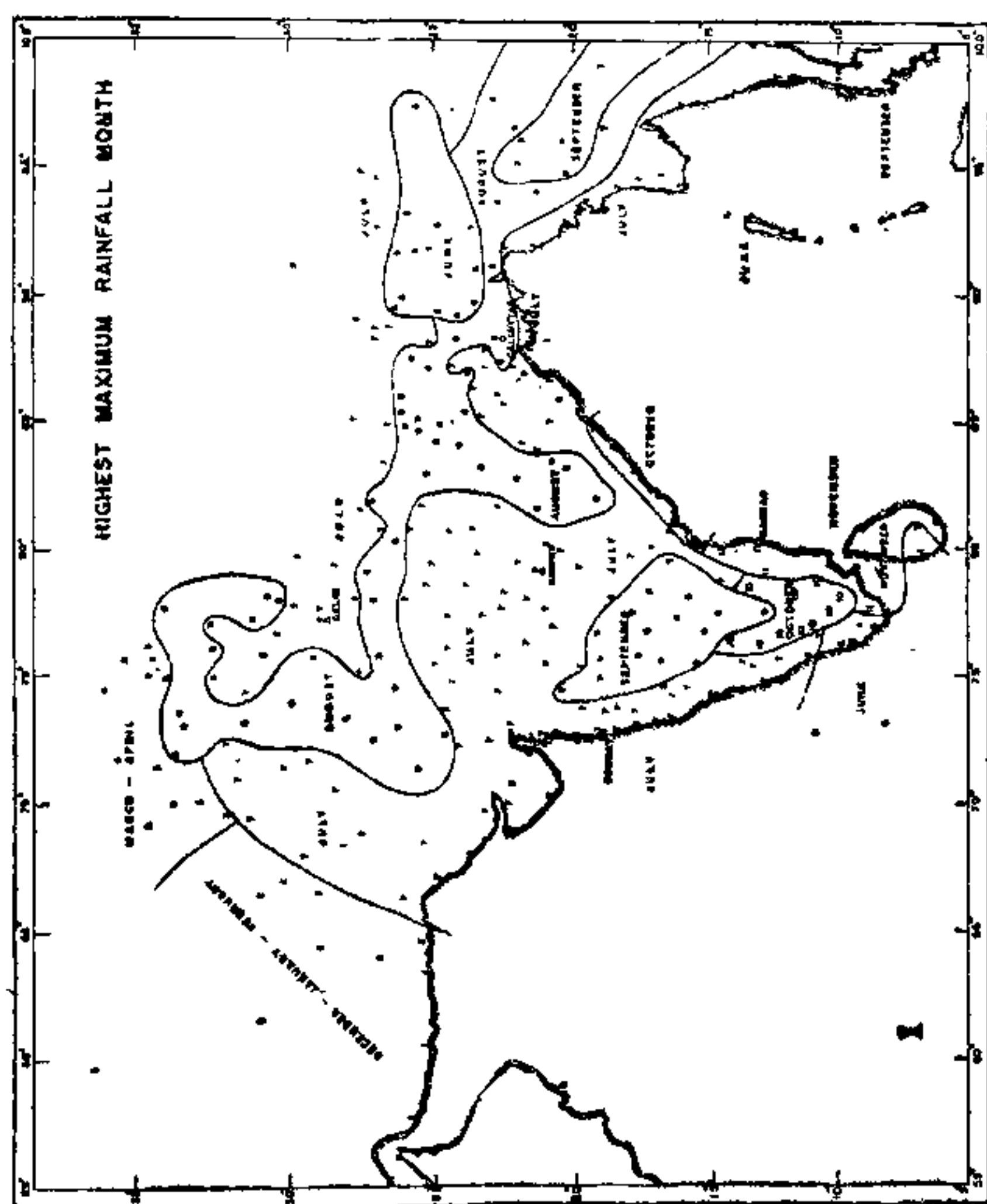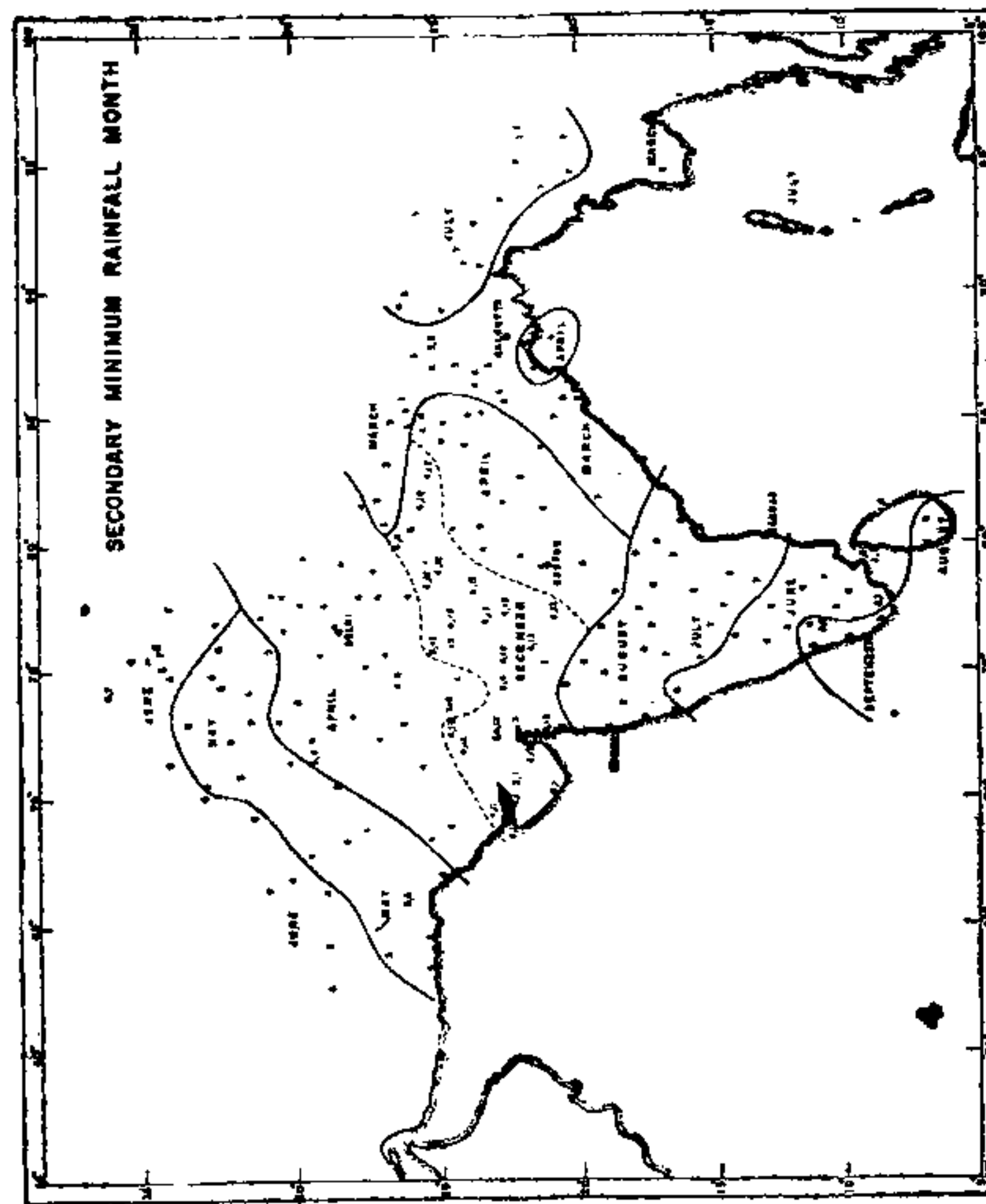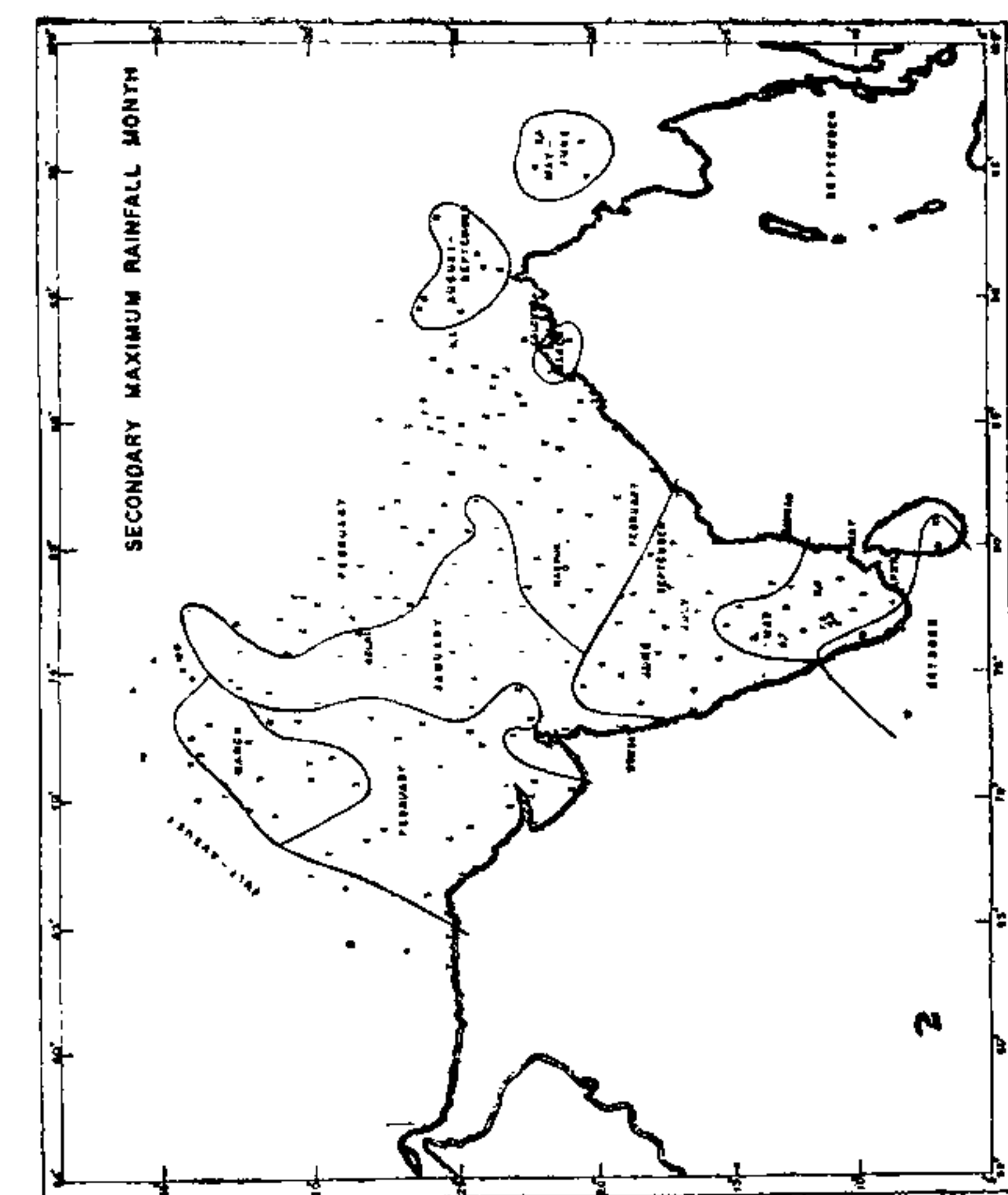
FIGS. 1–4. Fig. 1. Highest maximum rainfall month. Fig. 2. Secondary maximum rainfall month. Fig. 3. Lowest minimum rainfall month. Fig. 4. Secondary minimum rainfall month.

(*iii*) At stations such as Pamban, Cuddalore, Nagapattinam, Madras and Nellore on the east coast of the south peninsula, a steep increase in the slope of the rainfall curve sets in at or near pentad 56 (about 10 October); the peak value is attained at or about pentad 61 (first week of November).

(*iv*) After attaining peak value in July or early in August, the rainfall curves of a large number of stations over north, central and peninsular India register a decline reaching a minimum value at or near pentad 46 which is centred round 16 August. In Figs. 5 to 8, this feature can be noticed for stations such as Ratnagiri, Bombay and Surat on the west coast, at Ahmednagar, Poona, Aurangabad, Malegaon,
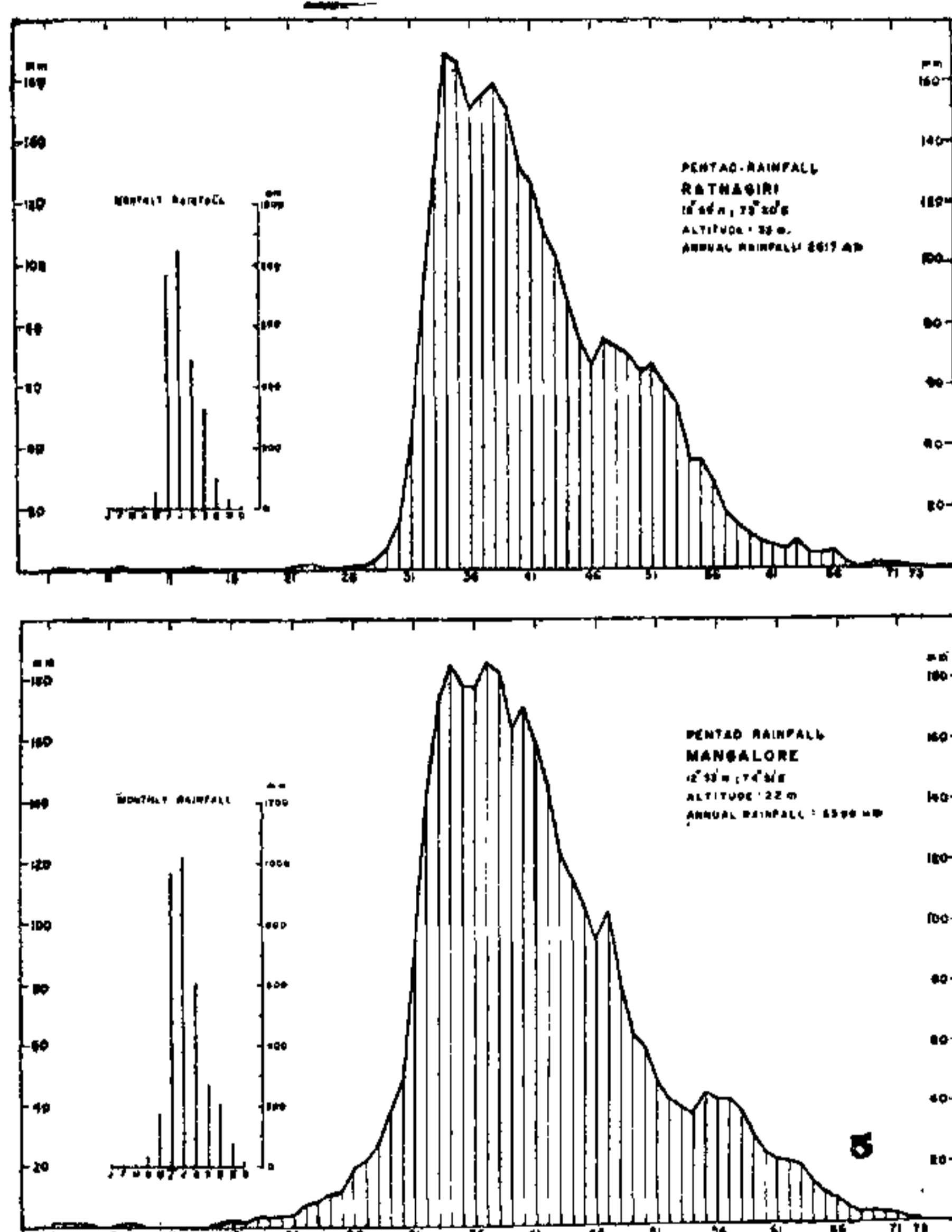

FIG. 5. Pentad rainfall: Ratnagiri, Mangalore.

etc., in the interior, and at Jodhpur, Bikaner and Delhi over north-west India. S e v e r a l other stations such as Allahabad, Varanasi, Lucknow, Nagpur, Jabalpur, Ahmedabad, Veraval, Bhuj, etc., also show this feature. After reaching a minimum during pentad 46, the rainfall curve again registers an increase before the final decrease sets in by the middle or end of September depending upon the location of the station. The second maximum is very conspicuous at some stations and less so at others.

7. This rainfall minimum which occurs near 16 August at a large number of stations over

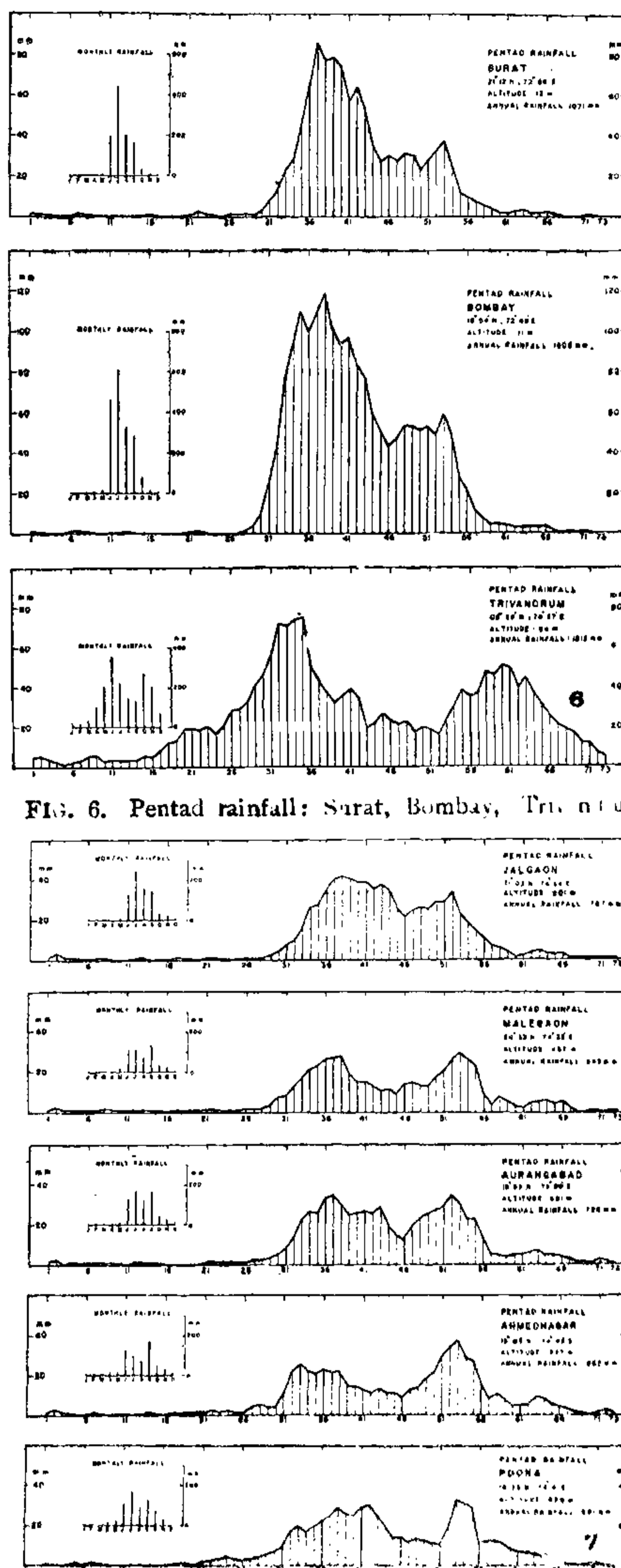India is an important new feature brought out by the pentad rainfall curves. The fact that

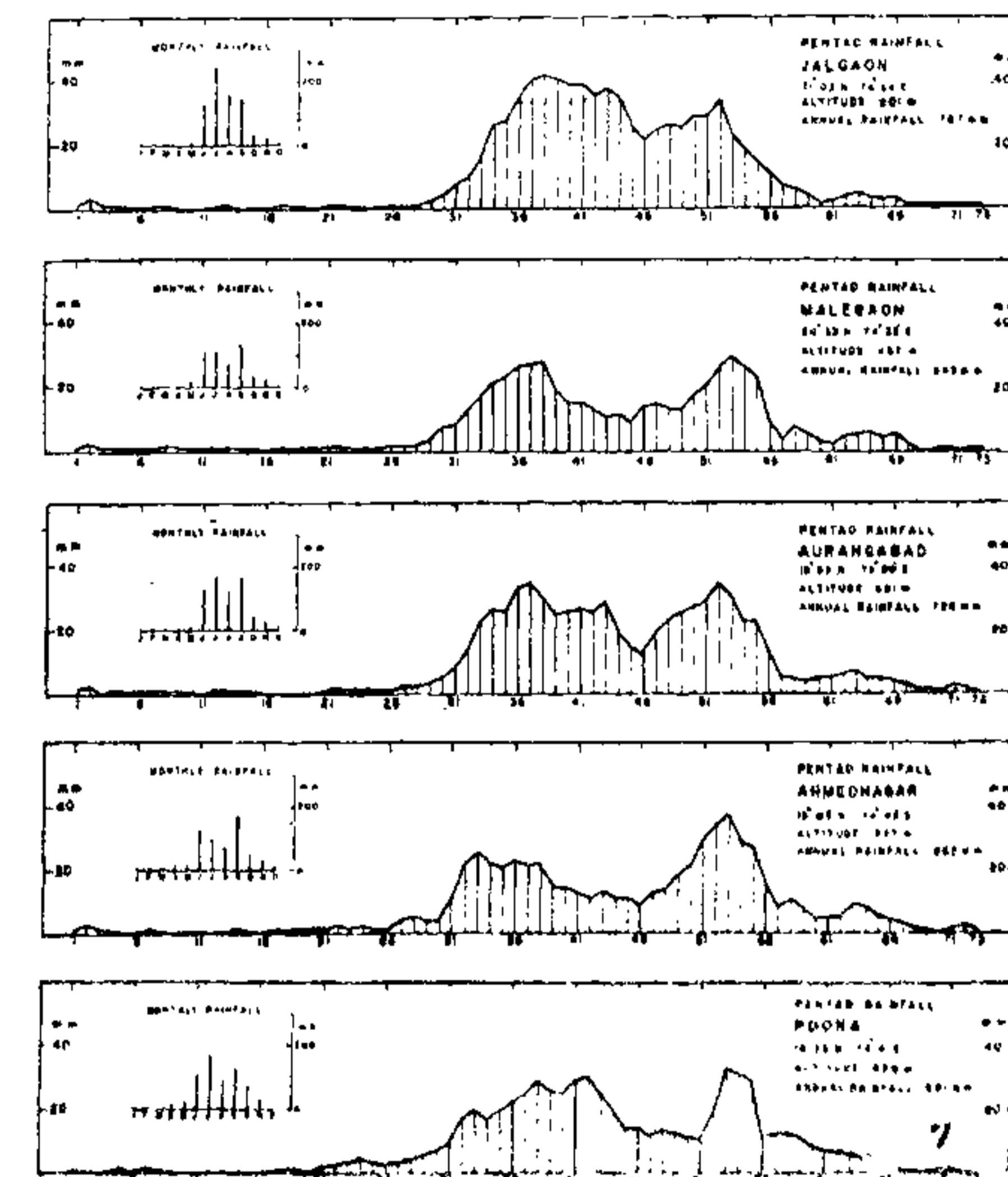FIG. 6. Pentad rainfall: Surat, Bombay, Trivandrum.

FIG. 7. Pentad rainfall: Jalgaon, Malegaon, Aurangabad, Ahmednagar, Poona.

such a minimum is shown by rainfall curves of widely separated stations based on the mean data for the fifty-year period 1901 to 1950 suggests that we are concerned here with a feature

of the monsoon circulation which is more or less repetitive from year to year. Hence, on the basis of the space and time variation of rainfall, the monsoon season can be divided into two periods, one from the beginning of June till the middle of August and the other from the middle of August till the end of September.
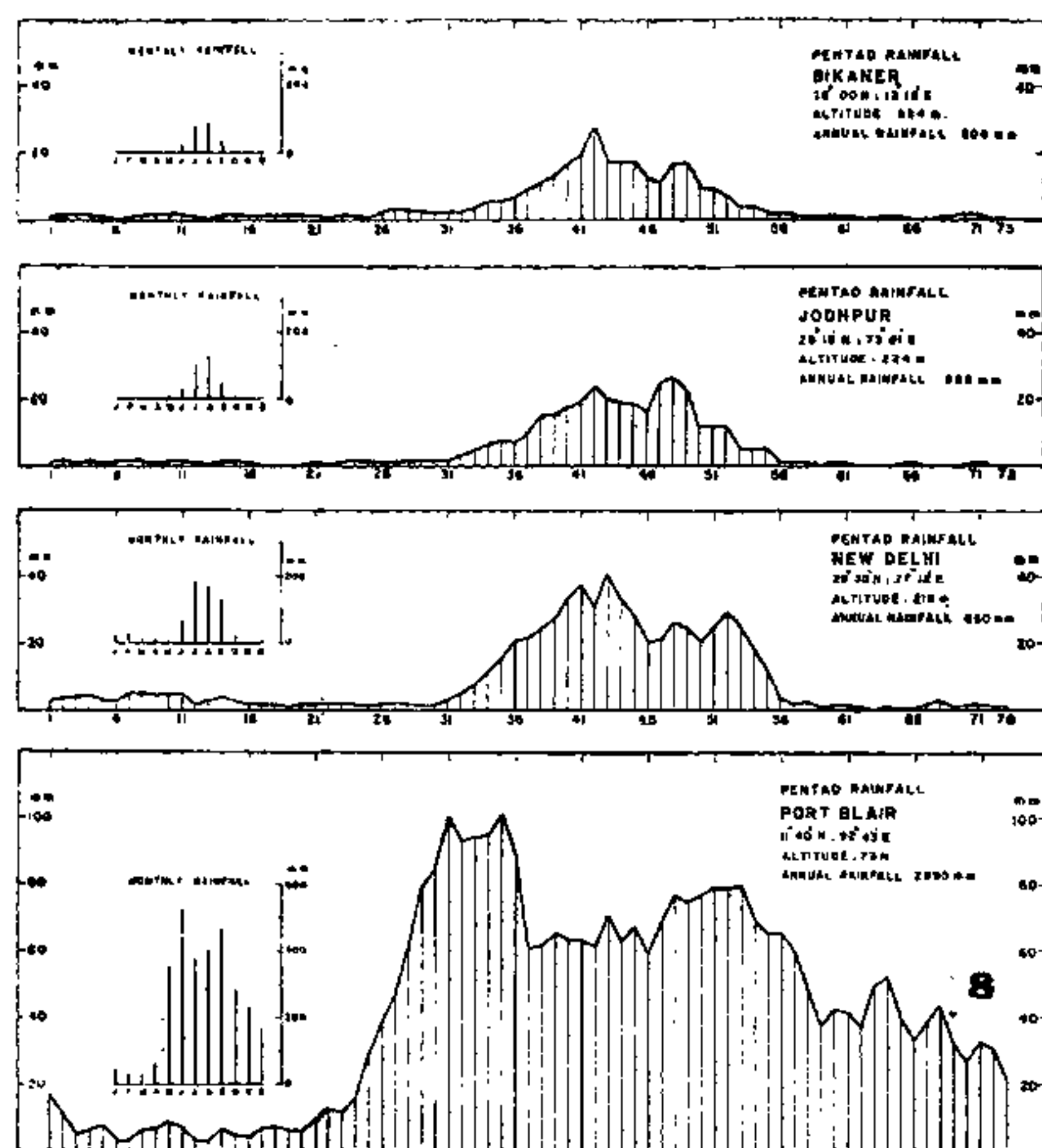

FIG. 8. Pentad rainfall : Bikaner, Jodhpur, New Delhi, Port Blair.

8. It is of interest in this connection to inquire whether there is independent evidence for any abnormality in the monsoon circulation about the middle of August. A recent study by K. Ramamurthi (1969) on 'breaks' in the south-west monsoon during July and August based on records for the eighty-year period 1888-1967 shows that the ten-day period 10-20 August is characterised by the maximum frequency of occurrence of 'breaks'; there is a rapid decline in the frequency for the succeeding ten-day period. 'Breaks' are characterised by a considerable decrease of rainfall over large areas of the country. On such occasions, the monsoon trough moves close to the foot of the Himalayas and cannot be clearly traced on the surface synoptic charts and low level wind charts. The 'break' is followed by the 'revival' of the monsoon before its gradual southward retreat sets in beginning from September.

9. On the basis of the present study it follows that the middle of August is a significant epoch in the south-west monsoon season. Climatologically this epoch appears to denote

the maximum northward extension of the monsoon trough at the lower levels before its southward retreat commences.

10. The dependence of the space-time variations of tropical rainfall on the north-south seasonal migrations of the equatorial trough has been pointed out by Riehl (1954). At stations that lie in between the extreme limits reached by the trough in February and August the rainfall variations can be expected to show two maxima corresponding to the northward and southward passage of the trough. From an examination of the monthly rainfall patterns of a number of tropical stations round the globe, Riehl has concluded that a simple scheme of trough movement is not sufficient to explain all the observed patterns, although in some cases (*e.g.*, Colombo), the double rainfall peaks are quite conspicuous. It is well known that the equatorial trough has its maximum north-south amplitude of seasonal oscillation exceeding 30° of latitude over the Asian monsoon area as compared with about 5° over the western hemisphere. Hence, it is interesting to examine the space-time variations of rainfall over Indian stations in relation to trough movement. From this point of view, the rainfall minimum observed around 16 August is of particular interest. Although in addition to seasonal trough movement, rainfall is controlled by several synoptic features that vary from year to year, the effect of the trough stands out in the long period rainfall average. Preliminary study shows that the two rainfall maxima on either side of the minimum near 16 August occur during pentads 42-44 (last week of July-first week of August) and pentads 48-52 (last week of August-middle of September) at several stations in north and central India.

11. In this context, mention may be made of a study by Pachecko (1959) relating to weather at the important cities of India on Independence Day (15 August). He found that the chance of rainfall from dawn to dusk was less than 50% at several places. The present study shows that the Indian Independence Day is also a day of special meteorological significance as it coincides with the epoch of the extreme northward swing of the mean monsoon circulation and the associated minimum rainfall over large parts of the country.

12. It is generally assumed that the meteorological conditions over the Indian monsoon area are nearly identical in July and August and the meteorological parameters for these two months are often combined in several stu-

dies. Judged by the rainfall variations, these two months have different characteristics. A critical study based on five-day means of surface and upper air parameters as well as synoptic-climatological studies are needed for understanding the major features of the space-time variations of the mean monsoon rainfall.

1. Blanford, H. F., "The rainfall of India," *Ind. Met. Mem.*, 1888, 3.
2. Lettau, K. and White, F., "Fourier analysis of Indian rainfall," *Ind. J. Met. and Geophys.*, 1964, 15, 27.
3. Pachecko, J. A., "Weather on independence day at important cities of India," *Ibid.*, 1959, 10, 155
4. Ramamurti K., "Some aspects of the 'Break' in the Indian south-west monsoon in July and August," *IMD FMU Rep. No IV*, 1969, 18, 3.
5. Riehl, H., *Tropical Meteorology*, 1954, p. 79.

OCCURRENCE OF SODIUM, POTASSIUM, RUBIDIUM, CALCIUM AND STRONTIUM IN SOME INDIAN RIVERS *

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A KNOWLEDGE of the chemical composition of river-water and the stream supply of elements into the oceans is essential in understanding the geochemical cycle. Moreover it has significance in the study of the suitability of waters for human consumption, irrigation and industry. Though the mineral content of drinking water supplies (mainly lake and well-waters) has been studied extensively,[1,2] there is little data available on the chemical composition of major Indian rivers and the supply of elements into the sea by these rivers.[3] The present paper reports the sodium, potassium, rubidium, magnesium, calcium and strontium content of waters from some major Indian rivers and an estimate of the input of these elements into the oceans through these rivers.

Water samples were collected from the midstream regions of the rivers (for locations of samples *see* Table I). All samples were filtered through Millipore filters prior to analysis.

Atomic absorption spectrophotometry was employed for the estimation of all elements. Potassium and calcium were estimated directly while twenty-fold dilution was necessary for the determination of sodium and magnesium. For the estimation of rubidium and strontium 200 ml. of water were evaporated to near dryness with 5 ml. of concentrated nitric acid. The residue was taken up in distilled water, any undissolved matter remaining was further treated with a 1 : 1 mixture of hydrofluoric and perchloric acids, evaporated to dryness and boiled with a few ml. of 1 : 100 nitric acid. The solutions were combined, filtered and made upto 25 ml. Rubidium and strontium were estimated in this solution. The results of these analyses and the locations and dates of collection of the samples are given in Table I.

The sodium, potassium, magnesium and calcium values reported here are similar to those observed by Deb and Chadha for major Indian rivers as reported by Soman *et al.*[2] When compared to the world mean, sodium and magnesium values are significantly higher, calcium content is nearly the same while potassium values are lower. Both rubidium and strontium content is higher than those reported for major rivers from other parts of

TABLE I
Analysis of water from some Indian rivers

River	Location of sampling	Date of sampling	Na ppm	K ppm	Rb ppb	Mg ppm	Ca ppm	Sr ppb
Ganges	.. Allahabad	Nov. 1968	17·0	1·9	4	14·4	26·7	180
,,	.. ,, (Bamroh)	Jan. 1968	20·0	2·0	7	13·0	24·7	220
,,	.. Patna	,,	29·0	1·7	8	14·6	26·0	460
,,	.. Calcutta (Nabdeep)	,,	16·6	1·6	3	13·8	20·0	140
Cauvery	.. Trichy	Dec. 1967	13·0	1·0	2	8·2	11·5	180
,,	.. ,,	Oct. 1967	21·4	2·1	2	11·0	17·2	140
Krishna	.. Vijayawada	,,	21·0	0·8	4	4·8	11·7	90
Godavari	.. Rajamundri	,,	17·4	0·8	4	7·2	11·5	90
Sabarmati	.. Ahmedabad	Dec. 1968	65·0	1·7	8	18·2	9·5	150
Mutha	.. Khadakwasla	Dec. 1967	10·0	0·3	3	2·4	4·0	80
Mean	..		23·0	1·4	4	10·7	16·2	173
World Mean	..		6·3†	2·3†	1·5‡	4·1†	15·0†	60‡

Values taken from Livingstone.[5]   ‡ Median values for North American rivers, taken from Durum and Hafty.[4]