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RESEARCH ARTICLE

A climatological singularity around mid-August in the summer monsoon rainfall of India

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Pentad, or five-day-interval, rainfall analysis of the normal summer monsoon rainfall of India shows a climatological singularity around mid-August. The decreasing rainfall trend from the end of July is arrested at this epoch, followed by an increase till the end of August, after which the decreasing trend again continues. We suggest that this feature is causally linked with the north–south movements of the Inter-Tropical Convergence Zone (ITCZ) across the country during the summer monsoon months.

THE four months June to September constitute the summer (south-west) monsoon season of India when the country *as a whole* receives nearly 80% of its annual rainfall. Except the southeastern and the extreme northern parts, the rest of the country receives 70 to 90% of the annual rainfall from the summer monsoon. Figure 1 is a well-known diagram from the records of the India Meteorological Department (IMD)[1], which shows the manner in which the monsoon rains advance and recede across the country. This is a climatological picture based on the average for several years. The monsoon rains set in over Kerala and the northeastern parts of the country by the beginning of June and cover the entire country by the second week of July. The withdrawal of the monsoon rains from north west India starts from the beginning of September and proceeds in a direction roughly opposite to that of the onset. As Figure 1 shows, there are substantial differences between the onset and withdrawal phases of the

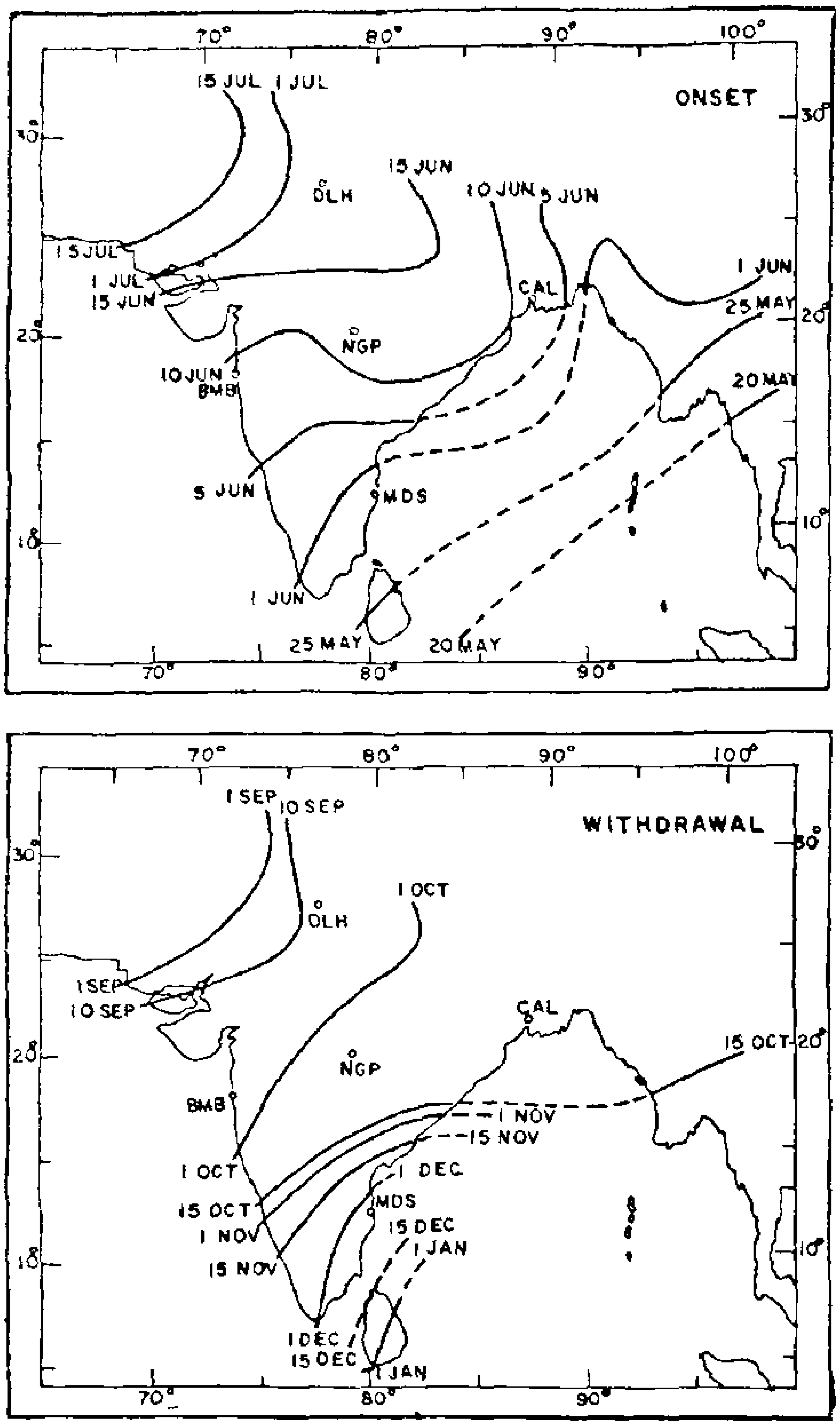

Figure 1. Progression of the normal dates of onset and withdrawal of the summer monsoon over India

monsoon. This is largely due to the differences in the surface and atmospheric conditions preceding the onset and withdrawal phases. A dry land with parched vegetation due to the heat of April–May and heavily dust-laden atmosphere over north India precede monsoon onset. A wet land with lush green vegetation nourished by the monsoon rains and a largely dust-free atmosphere over north India obtain when withdrawal of the monsoon sets in: at this time cloudy skies and rains still prevail over large parts of the country. The primary rainfall season for Tamil Nadu (and the secondary rainfall season for Kerala) is during October–December, associated with the retreating phase of the summer monsoon. Traditionally this is known as 'north-east monsoon' because of the low-level wind circulation.

Monthly and pentad rainfall

In what follows the term 'normal rainfall' is used to denote the rainfall averaged over the period 1901–1950. The annual normal rainfall is the sum of 12 monthly normal values. The choice of a smaller time interval provides a finer resolution of the rainfall pattern for a station or an area. A five-day period (pentad) is a convenient unit for this purpose. In such a case the annual normal rainfall will be the sum of 73 normal pentad values. Examination of the rainfall pattern over smaller time intervals is similar to the examination of a spectrum under high dispersion which often reveals new features.

Two rainfall climatological publications[2,3] with data base 1901–1950 have provided the material for the present study. From these publications, monthly and pentad normal rainfall data were obtained for 230 stations, as shown in Figure 2. Examination of the data revealed the existence of a climatological rainfall minimum around pentad 46 (14–18 August) for several stations during the summer monsoon season[4–7]. This feature, which is obscured if we examine the data on a monthly basis (low dispersion), is illustrated in Figure 3, in which the normal monthly and pentad rainfall patterns of some stations are shown for the entire year.

The summer monsoon months June to September contribute respectively 19, 32, 29 and 20% of the seasonal rainfall. July and August, which together account for 61% of the rainfall of the season and nearly 50% of the annual rainfall of the country, are generally

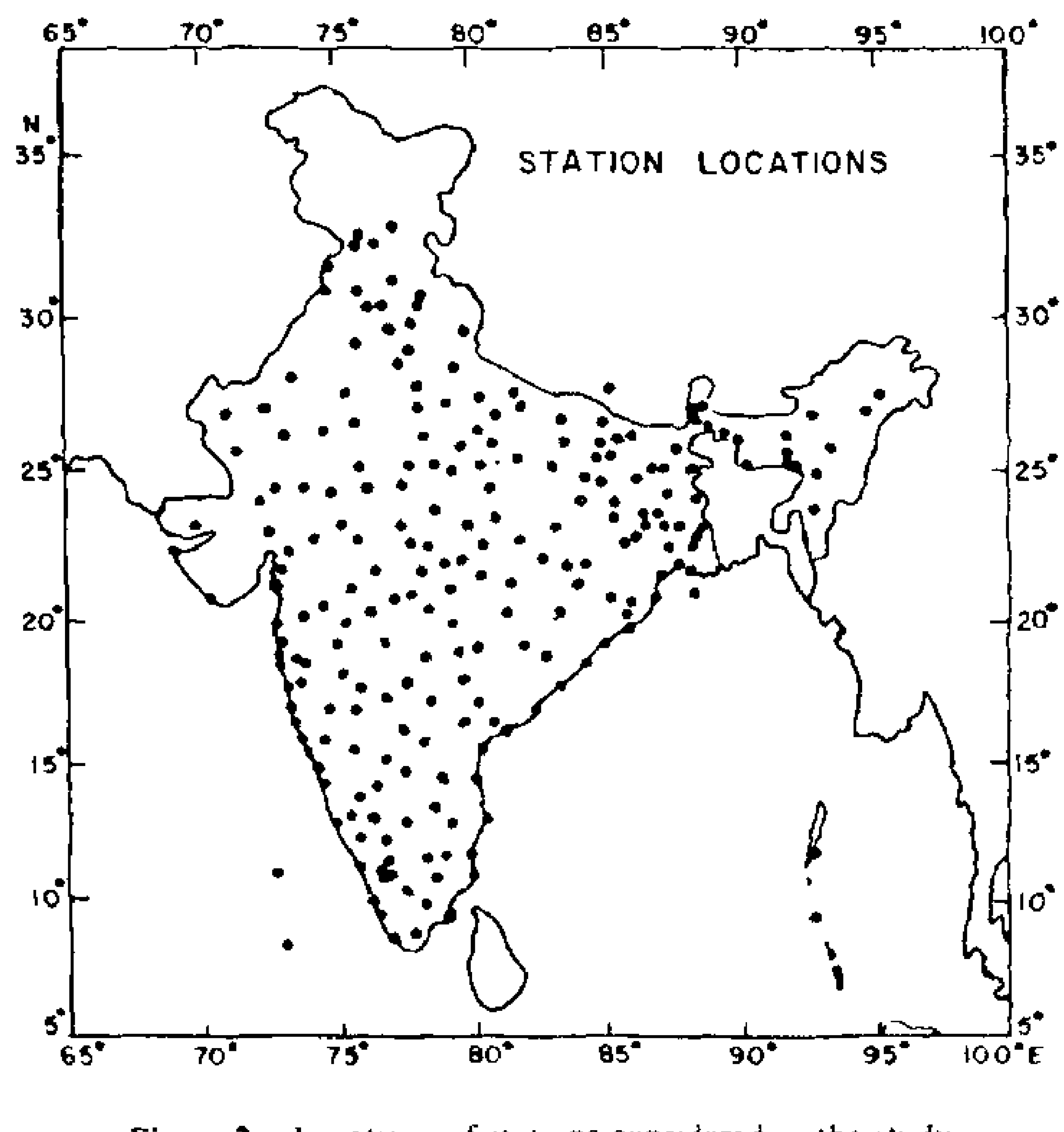

Figure 2. Locations of stations considered in the study

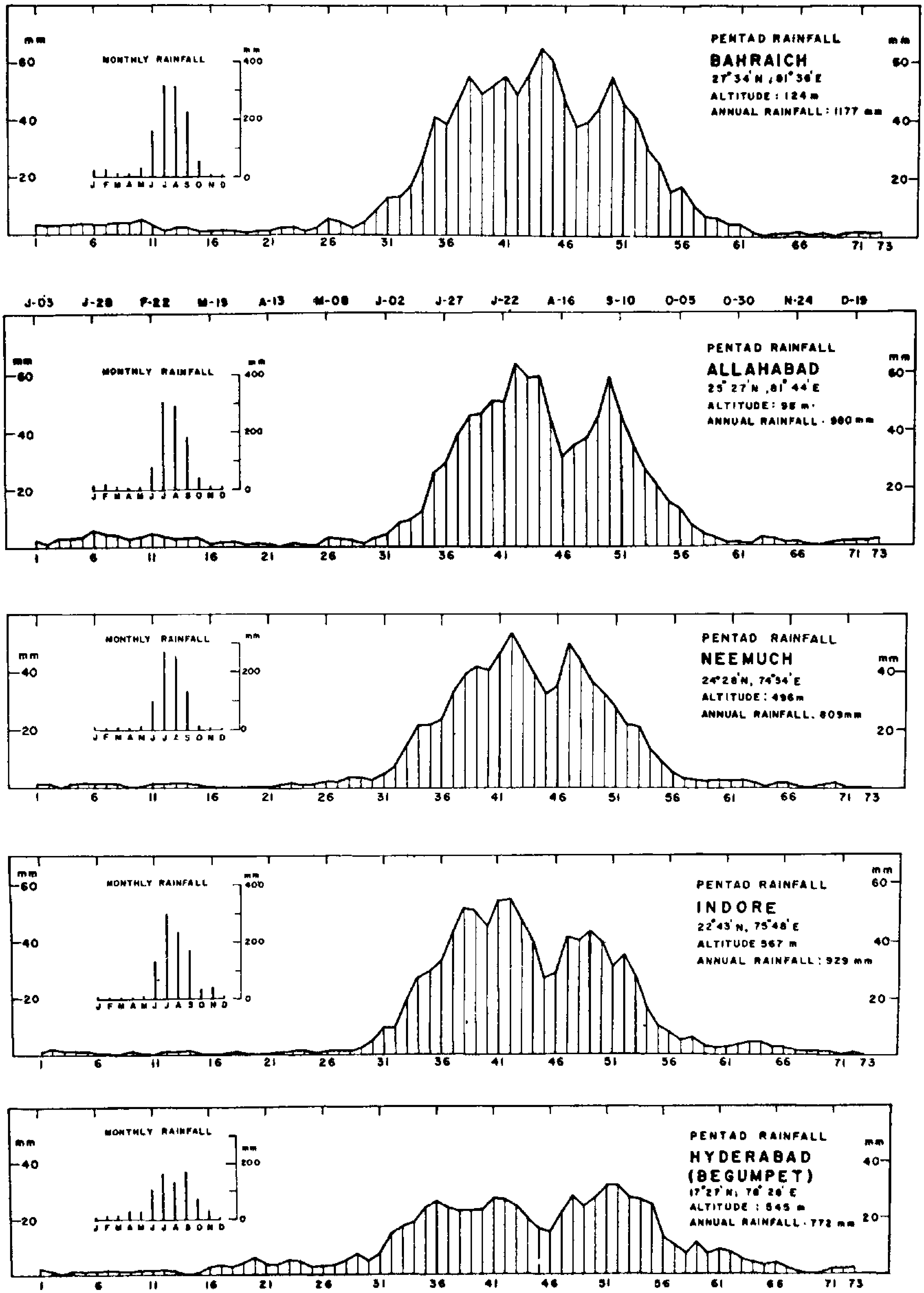

Figure 3. Monthly and pentad rainfall patterns of some stations showing minimum around mid-August

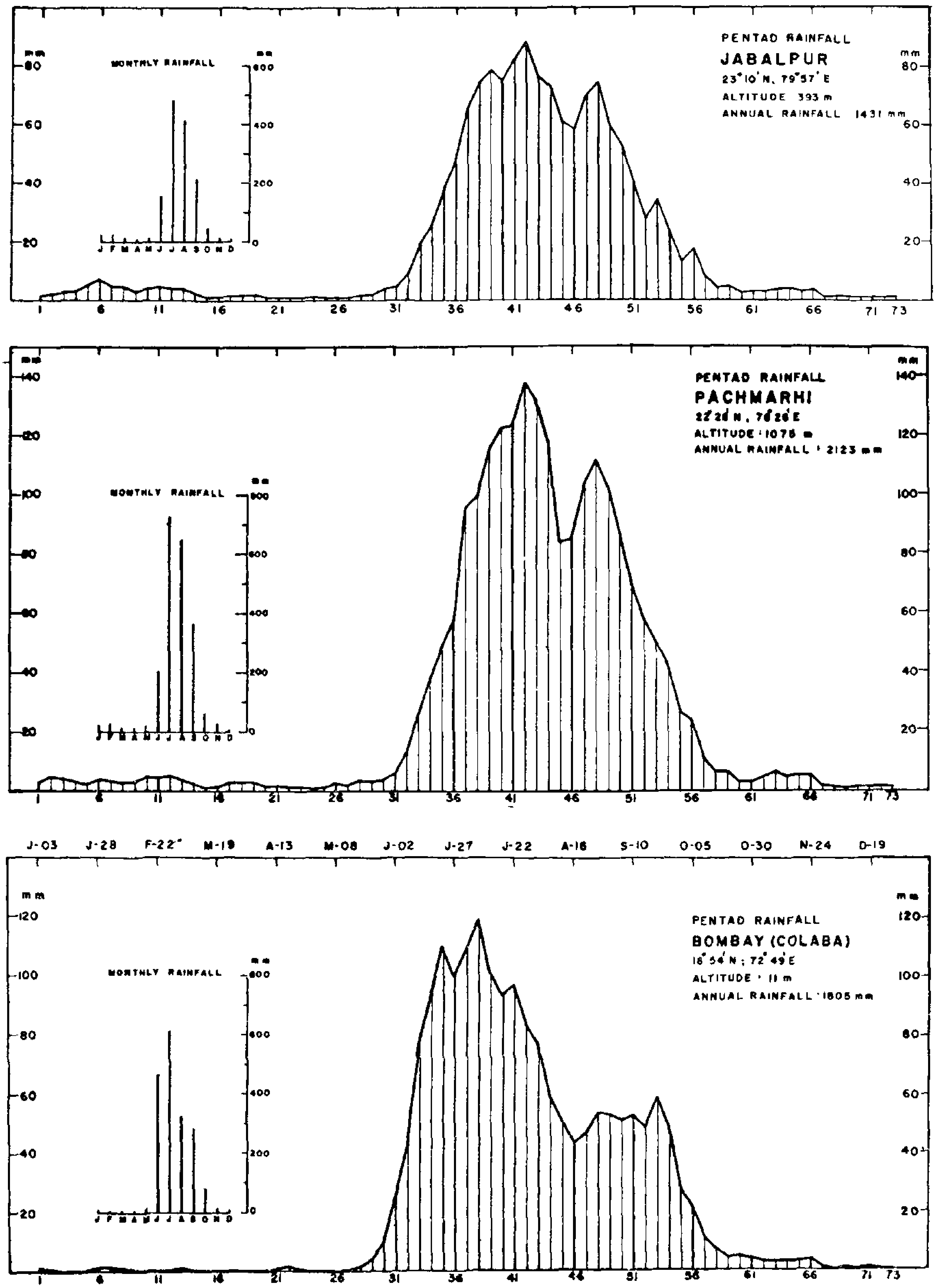

Figure 3. Monthly and pentad rainfall patterns of some stations showing minimum around mid-August.

regarded as constituting the established phase of the summer monsoon. On the 5-day scale this season extends from pentad 31 (31 May–4 June) to pentad 55 (28 September–2 October).

All-India summer monsoon rainfall

A picture of the time variation of the all-India summer monsoon rainfall is obtained by combining the pentad rainfall data of all the stations. Because of the large variations in the rainfall at individual stations, it is expedient, in the present context, to work with the rainfall for individual pentads normalized with respect to the rainfall for pentad 46 (mid-August). The ratios p_n/p_{46} ($n = 31, 32, \ldots, 55$), where p_n and p_{46} denote the rain amounts for pentads n and 46 respectively, were worked out for all the stations. Examination of the time series of the ratios showed the existence of a minimum around pentad 46 for 65% of the stations shown in Figure 2, the majority of which lie to the north of 15°N. The remaining stations did not conform to this pattern; some of them showed minimum two or three pentads earlier. Figure 4,*a* shows time variation of the ratio p_n/p_{46} averaged for all the stations in the first category. Leaving out one pentad at either end, this diagram depicts the time variation of the summer monsoon rainfall from pentad 32 to pentad 54. Figure 4*b* shows a similar presentation for all the stations combined.

The significant feature that is noticed is the difference between the ascending and descending phases of the rainfall. The onset of the monsoon in early June is followed by a progressive increase in rainfall over the entire country, which attains maximum in pentad 42 (25–29 July). Note that the rainfall fluctuates close to the maximum from pentad 39 (10–14 July). The ascending phase covers the months June–July and the descending phase the months August–September. After reaching the peak towards the end of July, there is a steep decline in the rainfall till pentad 46 (mid-August). The fall is arrested at this epoch followed by an increase up to pentad 49 (29 August–2 September) and a steady decline thereafter. The second maximum is conspicuous in Figure 4,*a*, but is marginal in Figure 4,*b* which combines the data for all the stations. In both cases the period from the middle till the end of August stands out as a climatological singularity in the Indian summer monsoon rainfall.

Discussion

The pentad scale which divides the summer monsoon season into 25 equal intervals provides deeper insight into the time variation of the seasonal rainfall than four monthly values. We draw attention in Figure 4 to the part of the rainfall curves above the horizontal broken line, which represents $p_n/p_{46} = 1.0$, and note that the decreasing rainfall trend from the maximum and the increasing trend up to the maximum are similar. Why does the decreasing rainfall trend get arrested

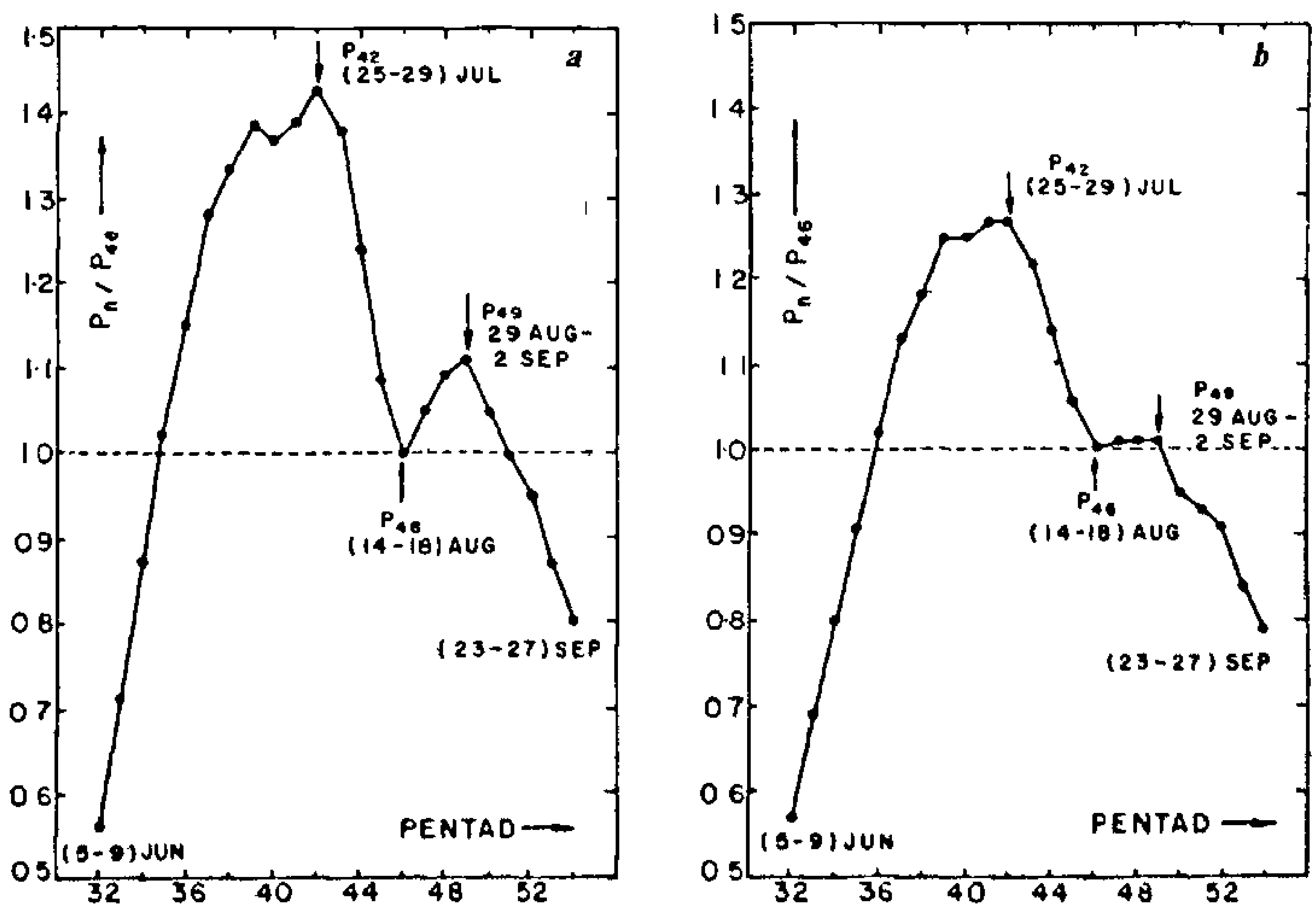

Figure 4. Temporal variation of all-India summer monsoon rainfall showing climatological singularity around mid-August (*a*) for stations that show rainfall minimum around pentad 46, and (*b*) for all stations.

from the middle till the end of August with a second maximum at several stations, particularly over north and central India'?

In seeking an answer, we should bear in mind that we are dealing with a climatological feature in the normal rainfall. It is well known that there are large interannual variations in the summer monsoon rainfall on different spatial and temporal scales. Such variations are smoothed out when data for a long period are averaged. Hence any singularity that stands out in the long-term normal rainfall should arise from a cause that is repetitive from year to year about the same epoch.

The monsoon phenomenon is basically linked with north–south oscillations of the Sun and the associated migrations of the Inter-Tropical Convergence Zone (ITCZ) across the country. Figure 5, adapted from Riehl[8], shows that the ITCZ has its largest annual amplitude of oscillation over India and the oceanic areas to the south. As stated by Riehl, the extreme northern and southern locations of the ITCZ and the associated summer and winter circulations have a lag of about two months from the summer and winter solstices. Accordingly, these extremes would be reached around mid-August and mid-February respectively. The ITCZ is a zone of intense convective activity and rainfall. According to Riehl[8], stations that are traversed twice by the ITCZ in the course of its annual migration would experience two rainfall maxima corresponding to the two transits. Most of north and central India is traversed twice by the ITCZ during the onset/withdrawal phases of the monsoon. The rainfall minimum between the two maxima may be expected when the ITCZ and the associated circulation features attain the extreme northward displacement around mid-August. This appears to be the explanation for the mid-August climatological minimum in the Indian summer monsoon rainfall separated by maxima on either side.

In this context reference should be made to the phenomenon known as 'break monsoon' associated with the south–west-monsoon season. In such situations, the axis of the monsoon trough, which is identified with the ITCZ, shifts from its normal position over north India to the foot of the Himalayas. This leads to heavy rains along the slopes and foothills of the Himalayas, with large decrease of rainfall over the central parts of the country and the plains of north India. At the same time it is noticed that feeble low-pressure systems develop in the southern Bay of Bengal and move westwards, giving rains to the southeastern parts of the peninsula (Tamil Nadu) and the northern parts of Sri Lanka. We have thus two regions of rainfall, one to the extreme north and the other to the south of the country, while large parts of north and central India are characterized by positive pressure anomalies and descending air motion leading to suppression of rainfall. According to a study by Ramamurthy[9] based on data for 80 years, break-monsoon situations have maximum frequency of occurrence during the period 11–20 August.

The present study leads to the conclusion that the climatological minimum around mid-August in the summer monsoon rainfall is causally linked with the extreme northward displacement of the ITCZ, with a lag of about two months from the summer solstice. The two rainfall maxima on either side of the minimum correspond to the two transits of the ITCZ during the advancing and retreating phases of the monsoon over north and central India. It should be emphasized that we are dealing with a large-scale climatological feature of the summer monsoon rainfall. Various types of synoptic systems influence the spatial and temporal

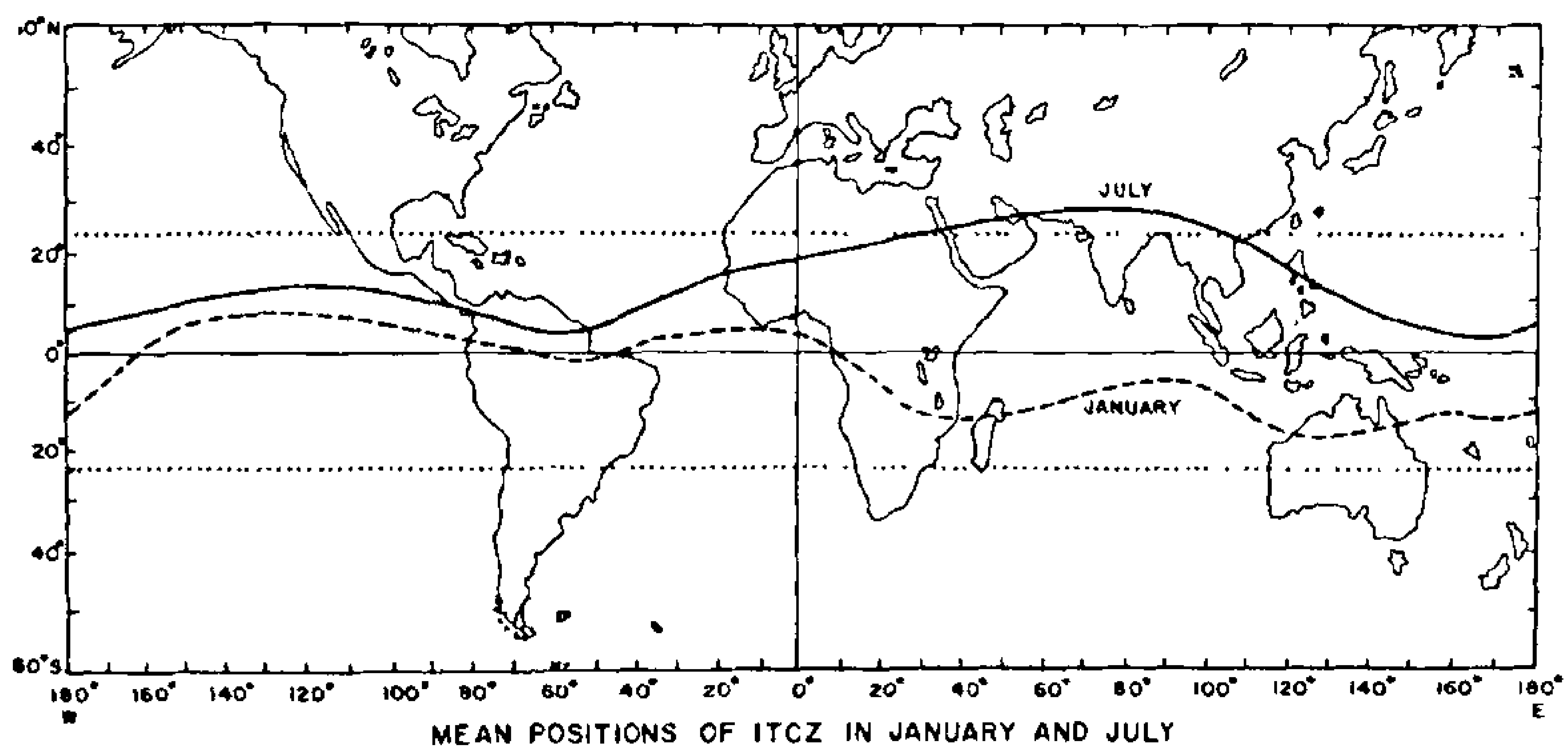

Figure 5. Mean positions of the Inter-Tropical Convergence Zone (ITCZ) round the globe in January and July.

rainfall distribution in individual years. As such the mid-August minimum noticed in the normal summer monsoon rainfall has a climatological significance similar to that of the normal date of monsoon onset over Kerala around the beginning of June.

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RESEARCH COMMUNICATIONS

Comparable role of copper in haemocyanins and oxide superconductors

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In this communication I draw attention to the comparable behaviour of Cu with respect to the reversible oxygen uptake in natural oxygen carriers, such as haemocyanins, and typical defect perovskites $YBa_2Cu_3O_{7-x}$. There are other similarities as well between the Cu sites in both groups of compounds.

THE active sites in Cu proteins and multi-copper oxidases perform a variety of biological functions, including oxygen transport, electron transfer and superoxide dismutation[1,2]. One such group of proteins, viz. haemocyanins, have binuclear Cu sites responsible for reversible oxygen uptake. Correspondingly, in multi-Cu oxidases such as laccases, the binuclear Cu sites are designated type 3. This form of Cu in haemocyanins and laccases is EPR-silent and is diamagnetic even to the very sensitive SQUID magnetometer. The Cu–Cu distances are less than 4 Å in both types and are antiferromagnetically coupled[3,4].

An important property of defect perovskite, $YBa_2Cu_3O_{7-x}$, is the reversible uptake of oxygen during thermal cycling between 350°C and 850°C; these compounds are, in fact, synthetic oxygen carriers. For values of x in the range 0.0 to 0.2, high-T_c (95 K) superconductivity is observed, but without dependence on the value of x. In the range of x between 0.2 and 0.6, composition-dependent low T_c (70 to 50 K) is noticed, while with $x > 0.6$ (or > 0.65), the samples are nonsuperconducting[5].

Goodenough[6] has argued that the redox reaction associated with oxygen intercalation/disintercalation in $YBa_2Cu_3O_{7-x}$ is related to the nature of Cu sites. The process is confined to the intercalating layer, with peroxide formation occurring between copper-bridging oxygens in contact with one another, if the oxidation exceeds $O_{6.5}$. Sarma *et al.*[7,8] did indicate the possible presence of peroxide-like species under certain conditions. Similar behaviour has been noted in the case of haemocyanins too. It has been shown earlier[2,9,10] that uptake of oxygen by deoxyhaemocyanin results in a peroxide bridge between the two Cu ions of a binuclear site. This oxygen uptake is also reversible, responsible for oxygen transport in molluscs and arthropods. It represents a well-studied example of a natural oxygen carrier.

The binuclear Cu sites in deoxyhaemocyanin are Cu^+, while in oxyhaemocyanin they are Cu^{2+} with a peroxide bridge. These sites are antiferromagnetically coupled[9,10], and function as cooperative two-electron donors/acceptors with a high redox potential[4]. The sites in haemocyanins and other Cu-bearing proteins, such as tyrosinase, are susceptible to bonding by CO as well. However, the type-3 binuclear Cu sites in laccases do not take up CO and may or may not have a bridging ligand.

From the vast amount of information available on 1,2,3 and other closely related systems, it appears that the Cu sites lying along the b axis, with linear coordination in $YBa_2Cu_3O_6$, and which on oxygen uptake finally transform to a coplanar configuration in $YBa_2Cu_3O_7$, can be regarded as synthetic analogues of the binuclear Cu sites of haemocyanins (antiferromagnetically coupled and with a bridging ligand). The dioxygen that is taken up would progressively be transformed to a peroxide ion, probably through an intermediate superoxide. Thus, as oxygen stoichiometry increases from $O_{6.4}$ to O_7, oxygen will intercalate along the b axis and will take part in the redox process.

Iwazumi *et al.*[11], through X-ray absorption near edge structure (XANES) measurements of Cu K-absorption