THE ONSET PHASE OF THE SOUTHWEST MONSOON

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ABSTRACT

The fluctuations in the dates of onset of the southwest monsoon over south Kerala for the years 1901–1982 are illustrated. The seasonal variations in the meteorological parameters over India at the surface and in the upper air leading to the onset of the southwest monsoon towards the end of May are briefly discussed. The results of superposed epoch analysis are presented to illustrate the sharp increase in pressure gradient that occurs over the west coast with the onset of the monsoon.

INTRODUCTION

THE southwest monsoon which gives most of the annual rainfall of India durig the four months, June to September, is the most outstanding feature of Indian meteorology. The average annual rainfall over the plains of India is about 110 cm of which nearly 80% is contributed by the southwest monsoon. Food production, power generation and drinking water supply are all dependent on the monsoon rainfall which has a crucial control on the national economy. The total amount of water which falls as rain over India during the southwest monsoon is about 3×10^{12} tons. If this water is distributed uniformly, the entire country would be submerged under 3 feet of water. The actual distribution is far from uniform resulting in floods and droughts which often co-exist over different areas.

DATE OF ONSET OF THE MONSOON

The normal date of onset of southwest monsoon over south Kerala is 1 June. (The outbreak of the SW monsoon rains is traditionally known as "Edavapaathi" in Kerala. It means the middle of the month of "Edavam" according to the Malayalam Calender and practically coincides with 1 June). In about a week to ten days the monsoon rains generally reach Bombay. However, it takes some six weeks for the rains to be fully established over the entire country. The extreme northwestern parts of India are the last to receive the monsoon rains by about mid-July and the first from which the rains start retreating by the beginning of September.

There are substantial year-to-year variations in the date of onset of the monsoon over south Kerala. During the period 1901 to 1982 the earliest date of onset was 11 May (in 1918 and 1955) and the most delayed onset date was 18 June (in 1972). The manner in which the dates of onset have fluctuated between these two extremes can be seen from figure 1 which is a histogram presentation of the frequency of the dates of onset in 5-day intervals from 11 May to 20 June for the 82-year period. The maximum frequency of 20 falls in the period 31 May to 4 June. In 39 years the onset occurred before 31 May and in 23 years after 4 June. The mean onset date evaluated

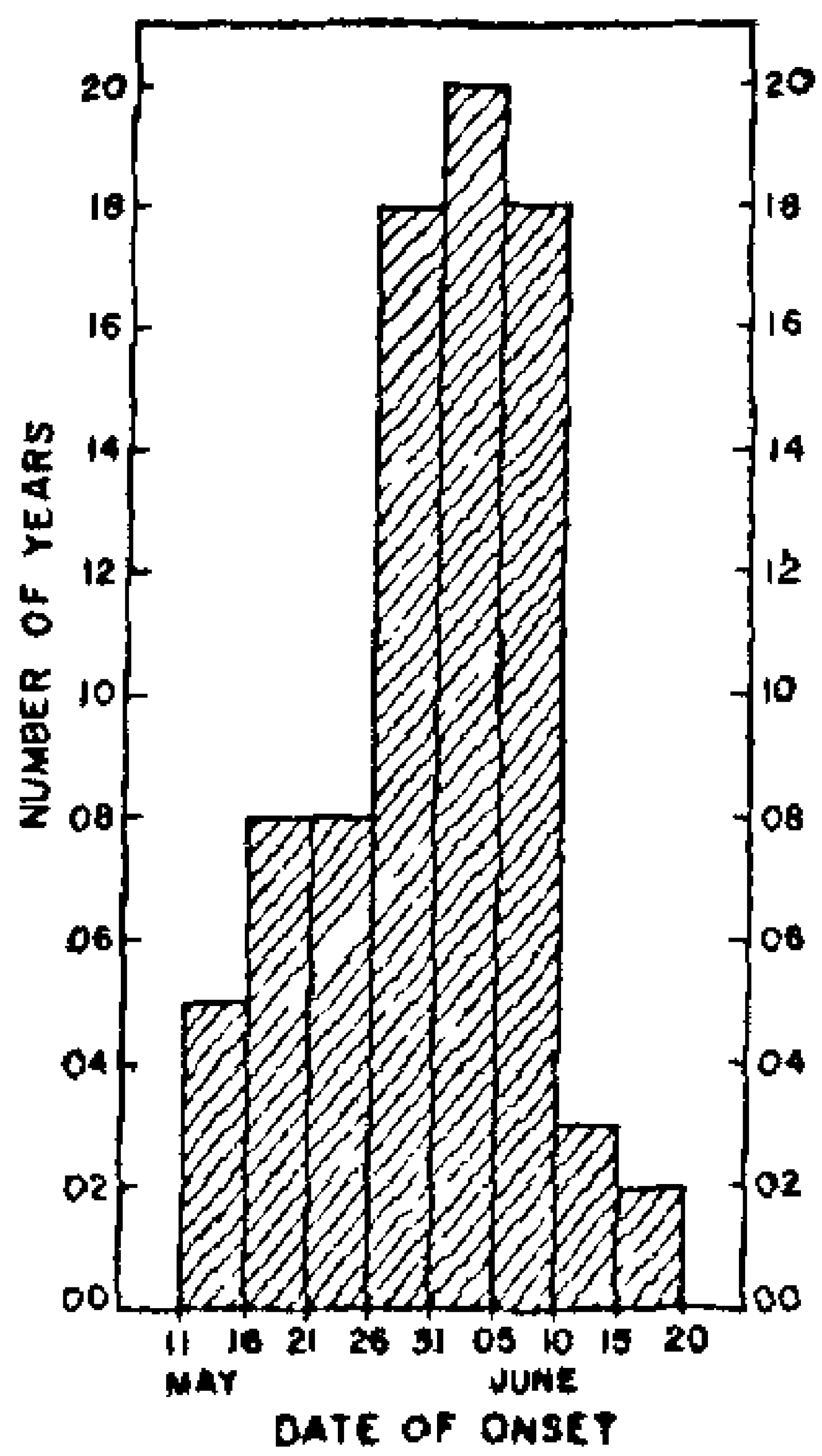

Figure 1. Dates of onset of the southwest monsoon over south Kerala (1901-82)

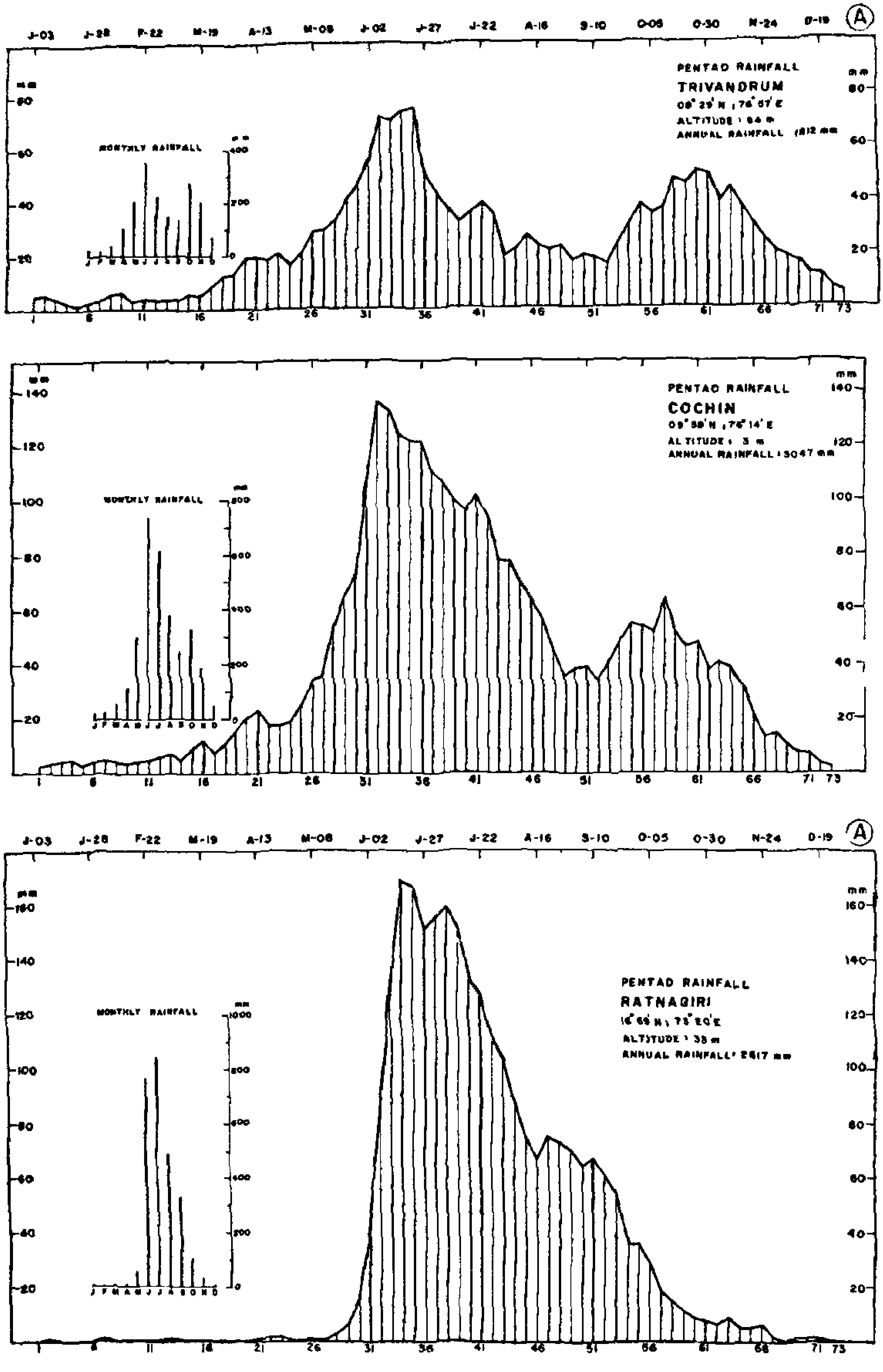

Figure 2. Normal pentad and monthly rainfall of Trivandrum, Cochin and Ratnagiri.

from the observed frequency distribution is 30 May with a standard deviation of 8.2 days. The median and mode of the frequency distribution fall on 1 June.

THE BURST OF THE MONSOON

The onset of the southwest monsoon which is accompanied by a steep increase of rainfall along the west coast is often referred to as "the burst of the monsoon". At stations along the south Kerala coast where the pre-monsoon thunderstorm activity is pronounced, the increase in rainfall accompanying the onset of the monsoon is not as spectacular as at stations further north. This feature can be appreciated from figure 2 which shows the monthly and pentad rainfall diagrams of the three stations Trivandrum, Cochin, and Ratnagiri. The steep increase in rainfall around pentad 31 whose middle date is 2 June may be noted at the northern station.

CLIMATOLOGICAL FEATURES LEADING TO THE ONSET

The onset of the summer monsoon marks the change over from the winter to the summer circulation. These are the two main circulations with contrasting features that prevail over south Asia. The transition to the summer circulation is associated with changes in several meteorological parameters at the surface and in the upper air which build up progressively with the advance of the season and reach a critical stage by the end of May leading to the burst of the monsoon. Some of these changes are briefly outlined below[1,2].

(i) *Surface pressure gradients*: In figure 3 is shown the monthly march of mean sea level (MSL) pressure at five stations across India from Trivandrum in the south to New Delhi in the north. The reversal of surface pressure gradient across the country which occurs by about mid-March and mid-October may be noted. The north south MSL pressure gradients attain maxima in January and July with opposite signs. The pressure gradient associated with the southwest monsoon is steepest in mid-July which is the

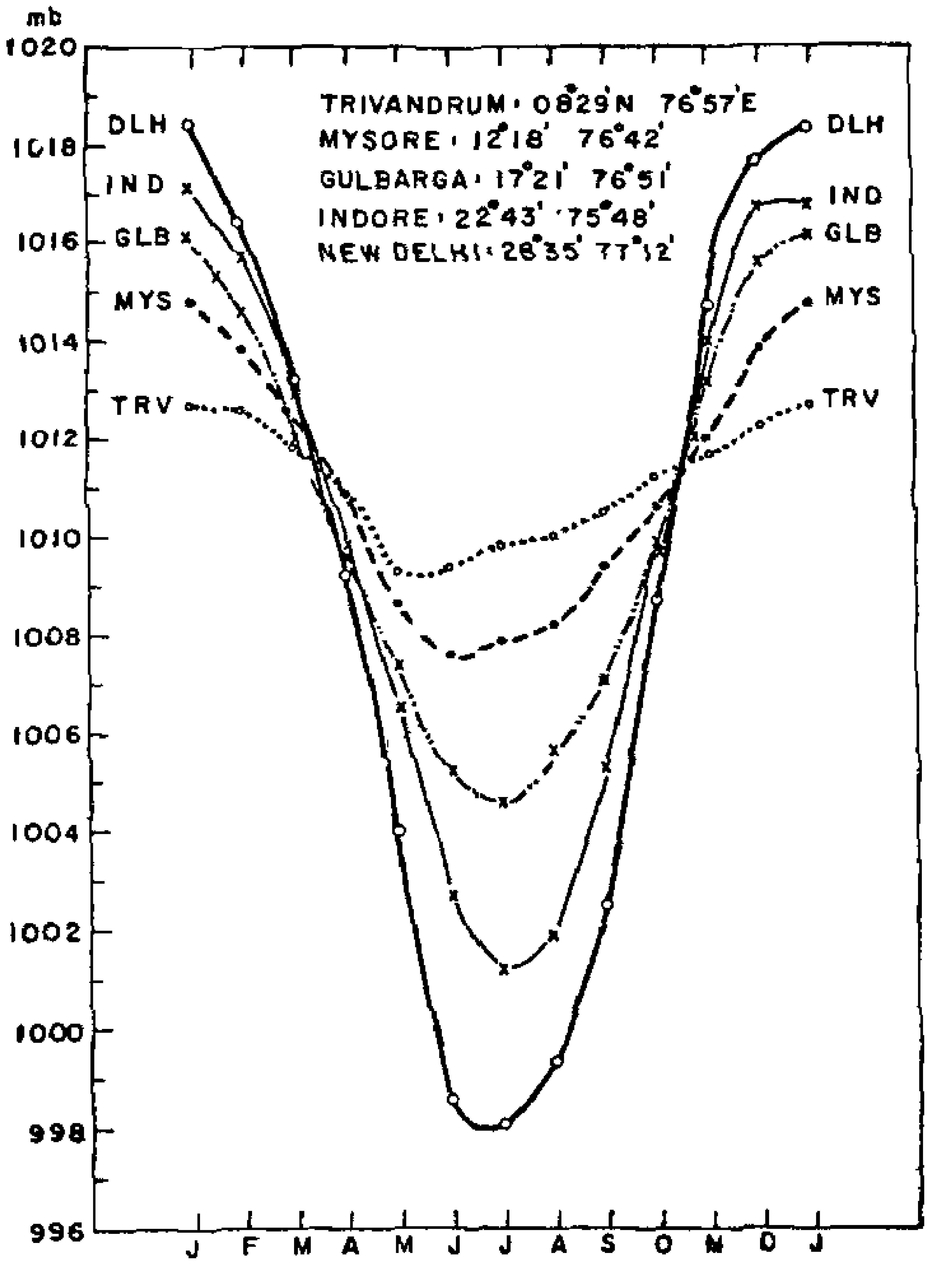

Figure 3. Seasonal variation of mean sea level pressure across India.

epoch by which the rains are established over the entire country. It may be noted that at the surface, the summer-type pressure gradient (pressure decreasing towards the north) prevails for about 7 months and the winter-type pressure gradient (pressure increasing towards the north) for 5 months.

(ii) *Pressure gradients in the upper air*: The seasonal march of pressure gradients across the country at seven standard isobaric levels is shown in figure 4. The mean monthly aerological data of Trivandrum, Nagpur and New Delhi (stations representative of south, central and north India) have been utilised for this diagram. The mean monthly upper winds for the three stations at the respective levels are also shown. The reversal of the pressure (contour) gradients and winds across the country at the various levels from winter to summer stand out conspicuously. Note that at 500 mb (mid-troposphere) there is little variation of pressure across the

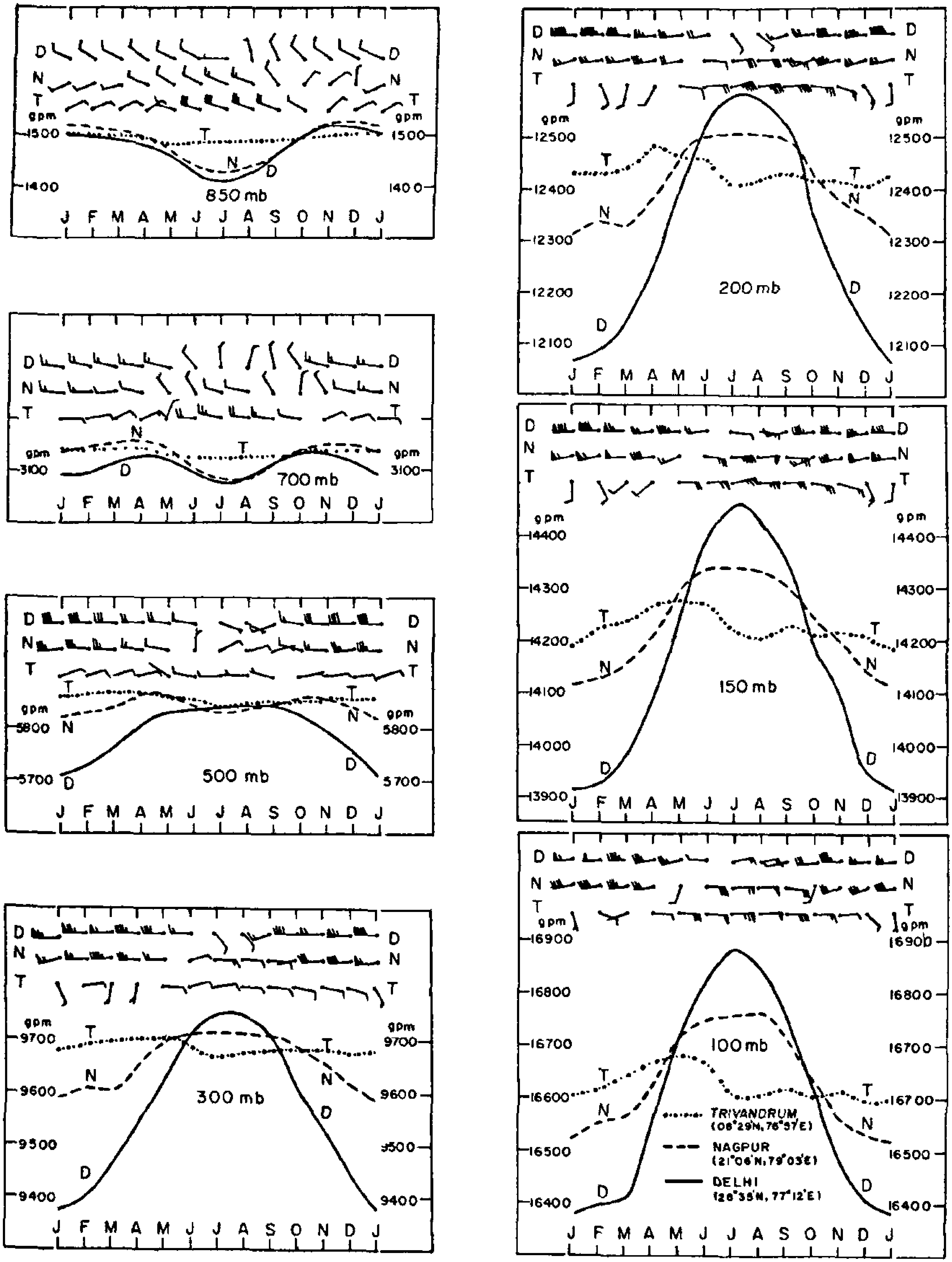

Figure 4. Seasonal variation of contour heights and winds at standard isobaric levels across India.

country during the summer monsoon months. Below this level pressure decreases from south to north while aloft there is increase of pressure from south to north on account of this, the monsoon westerly winds in the lower troposphere over peninsular India change over to easterlies at the upper tropospheric levels. The easterlies attain maximum strength (known as the tropical easterly jet stream near the tropopause level over peninsular India.

(iii) *Temperature gradients*: Closely coupled with the pressure changes are the monthly march of temperatures at the surface and in the upper air. These are illustrated in figure 5 with the data of the same three stations. At the surface and in the troposphere below 200 mb temperature

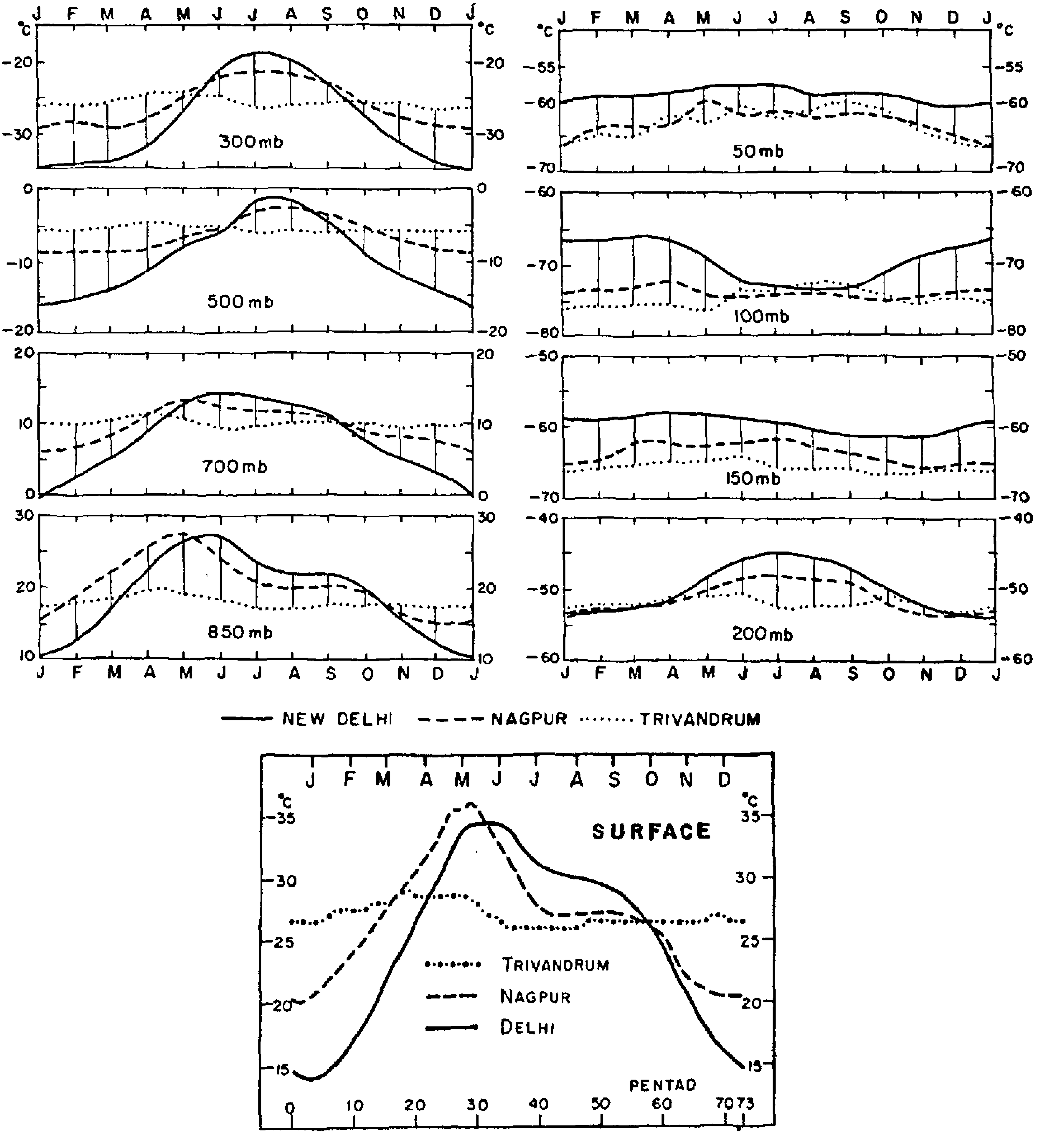

Figure 5. Seasonal variation of surface and upper air temperatures across India.

decreases towards the north in winter. During the summer monsoon months the thermal gradient across the country is in the reverse direction.

(iv) *The wind field*: The seasonal variation of winds across the country is illustrated in figure 6 which shows the mean monthly upper winds from the surface to 25 km level at Trivandrum, Madras, Nagpur and New Delhi. The reversal of the wind from winter to summer is the most salient feature. At Trivandrum and Madras the lower tropospheric easterlies are replaced by westerlies with the onset of the monsoon. The strong easterlies in the upper troposphere at these stations during the southwest monsoon season may be noted. At Delhi strong westerlies

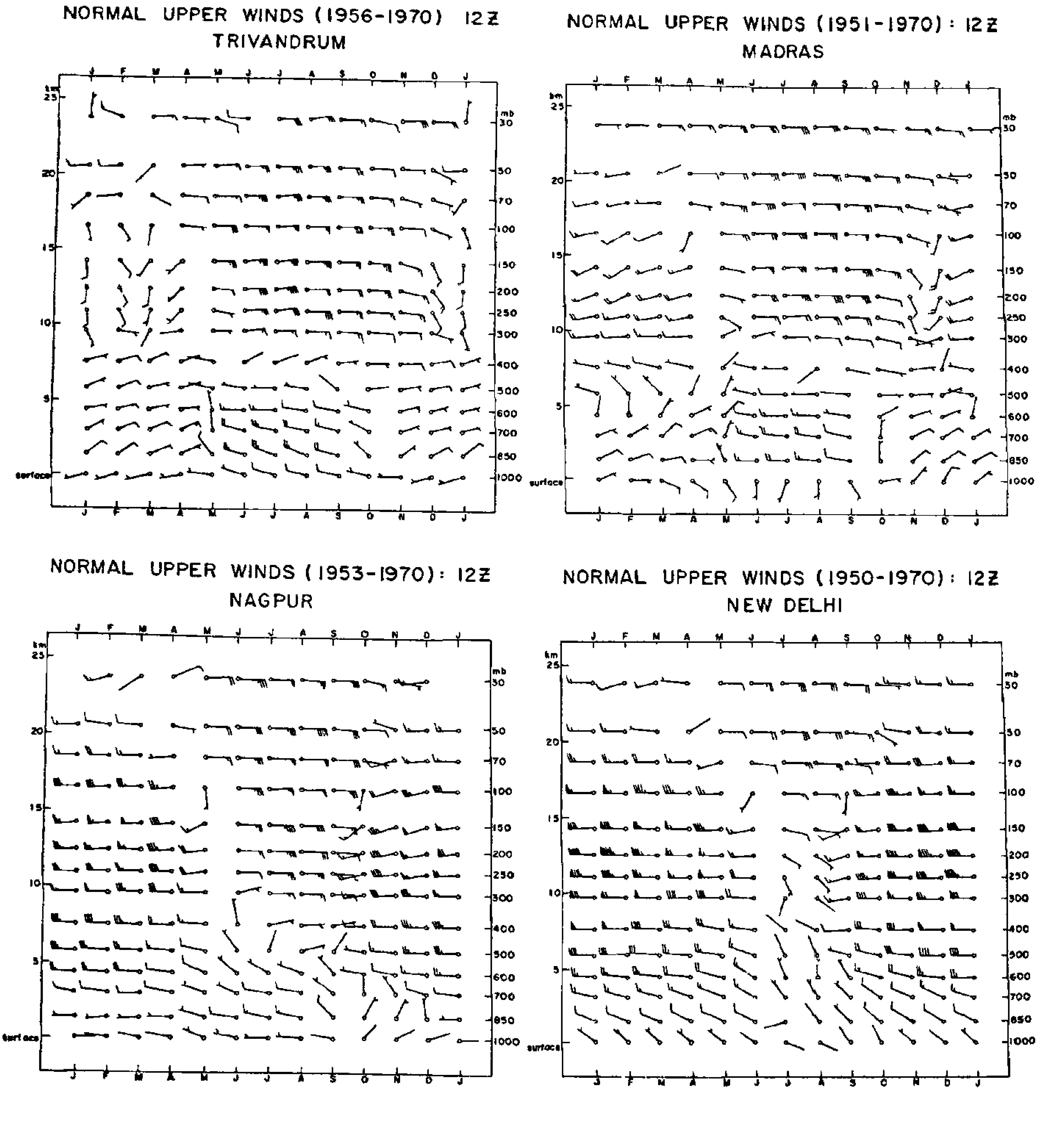

Figure 6. Seasonal variation of winds across India.

prevail in the upper troposphere in the winter months while weak easterlies are noticed in July and August. The easterlies strengthen with elevation in the lower stratosphere. The winds over Nagpur and New Delhi show that the duration of the summer monsoon circulation in the upper troposphere over north India is only about half the duration of the winter circulation.

It should be noted that the pressure, temperature and wind fields are inter-related. The seasonal reversal of the fields at the different levels occurs with spatial and temporal phase lags. It is found that the reversal of the pressure gradient sets in first at the surface and at levels close to the tropopause and progress upwards/downwards towards the mid-troposphere.

(v) *Tephigrams*: The variations of pressure, temperature and humidity in the vertical at Trivandrum, Nagpur and New Delhi in the two typical months of January and July, representative of the winter and summer monsoon conditions, are shown in figures 7(a) and (b). The contrasting features may be noted. In January, temperatures decrease from Trivandrum to Delhi below 200 mb (~ 12 km) while the reverse situation obtains aloft. On account of this, the winter westerlies over north India attain maximum strength at about 200 mb level (the subtropical westerly jet stream) and decrease in speed aloft. In July, Delhi is warmer than Nagpur and Trivandrum at all tropospheric levels. In the lower stratosphere temperatures are nearly the same at all the three stations. The thermal wind being easterly, the monsoon westerlies over the peninsula weaken with elevation above the first 2 km and become strong easterlies in the upper troposphere (the tropical easterly jet stream). The dew point curves show the low moisture content of the atmosphere in winter and the high humidity of the air during the southwest monsoon season.

SYNOPTIC FEATURES ASSOCIATED WITH THE ONSET PHASE

The synoptic features associated with the onset phase of the summer monsoon have been studied by several workers[3-24]. A comprehensive review has been presented by Ananthakrishnan *et al*[25].

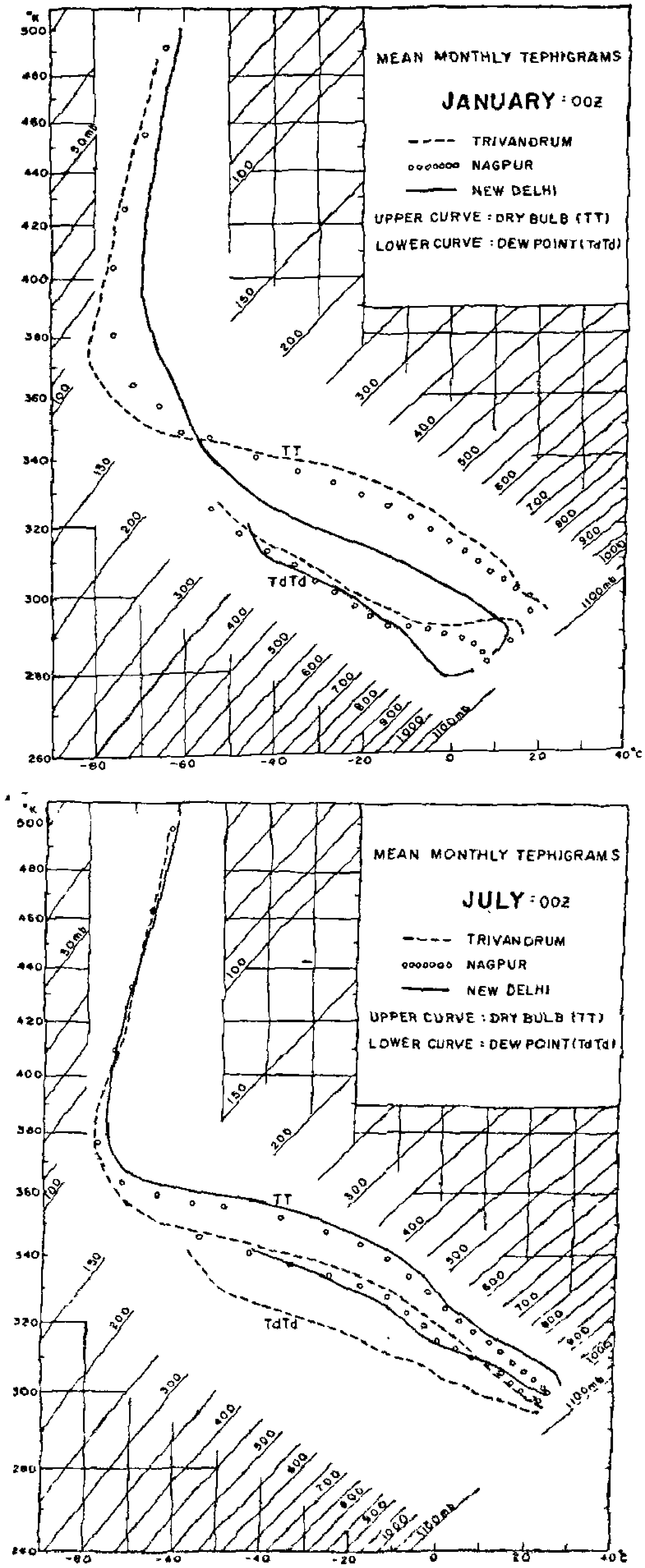

Figure 7. Mean monthly tephigrams of Trivandrum, Nagpur and New Delhi (*a*) January; (*b*) July

With the northward march of the sun and associated increase in the isolation from March to May, the temperature and pressure gradients of the winter season undergo progressive weakening. Increasing convective activity in the form of thunderstorms is experienced in April and May, particularly over the southern parts of the peninsula and also over the northeastern parts of the country. By the end of May, the sequence of changes in the surface and in the upper air becomes favourable for the advance of the summer monsoon. The synoptic situation that leads to the onset of the monsoon on the west coast in several years is a low pressure system-trough of low pressure, depression or cyclonic storm— that forms in the southeast Arabian sea and moves in a northerly direction towards the Gujarat coast. Such a system that formed in June during the MONEX year of 1979 and ushered in the monsoon rains along the west coast was investigated by Krishnamurti *et al*[26]. They designated the system as "the onset vortex of the southwest monsoon". Their study showed that the strong horizontal wind shear in the low level westerlies over the Arabian sea provides energy for the maintenance of the vortex which is initiated through the barotropic instability mechanism.

PRESSURE GRADIENT ALONG THE WEST COAST DURING THE ONSET PHASE

An interesting aspcet of the onset phase is the manner in which the pressure gradient along the westcoast changes. To examine this aspect we consider two stations along the west coast: Trivandrum in the south and Bombay in the north. The MSL pressure difference ΔP= Trivandrum *minus* Bombay, can be taken as a measure of the pressure gradient. The progressive march of ΔP from 1 May to 30 June based on the pentad pressure normals published by the India Meteorological Department (IMD) is shown in figure 8(d). We see that the pressure gradient is extremely feeble at the beginning of May but increases progressively reaching a value of about 3 mb by the time of monsoon onset on the Kerala coast (1 June) and nearly 6 mb by the end of June. Examination of the normal pressure values for the two stations shows that there is a slight fall of pressure at Trivandrum from 1 to 20 May after which the pressure rises gradually. At Bombay there is a continuous fall of pressure from 1 May till the end of June. It is seen that the fall of pressure at Bombay contributes more to the enhancement of the pressure gradient than the rise of pressure at Trivandrum.

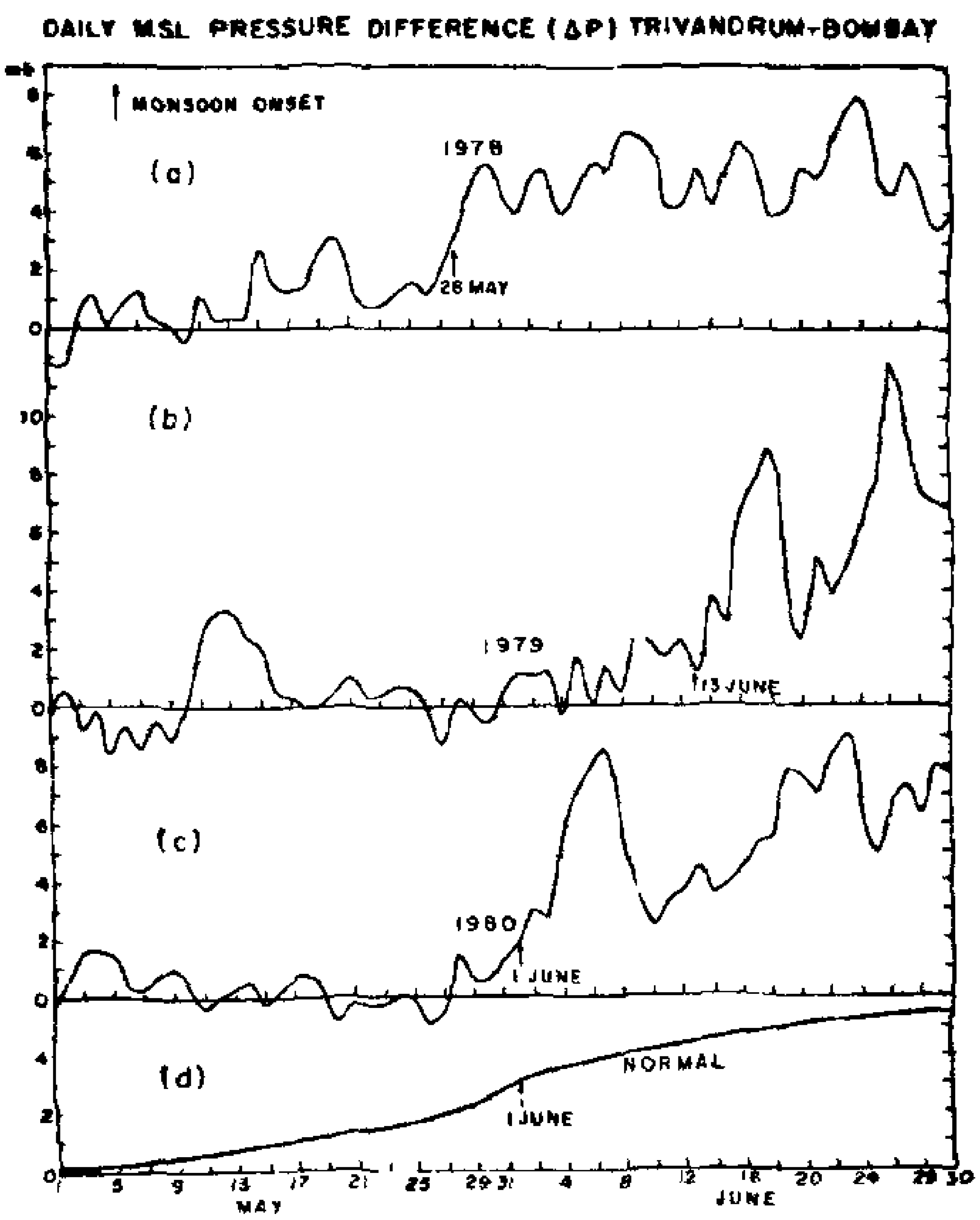

Figure 8. Variation of pressure gradient over the west coast during the onset phase of the southwest monsoon.

Examination of the daily pressure data of Trivandrum and Bombay for individual years shows that an important aspect of the pressure gradient along the west coast associated with the monsoon onset is not brought out by normal ΔP curve in figure 8 (d). The time series of ΔP for individual years shows that a rapid increase in the pressure gradient occurs at the time of onset of the monsoon over south Kerala instead of the gradual increase shown by the normal curve. This is illustrated by figures 8 (a), (b) and (c) which show ΔP curves for the years 1978, 1979 and 1980. The actual date of onset of the monsoon over south Kerala is indicated on each of the curves. The increase in ΔP close to the date of onset may be noted. There are appreciable year-to-year variations in the nature of the ΔP curves. In particular, large fluctuations occur in June after the monsoon onset. In 1979 a sharp increase in the pressure gradient set in starting from 10 May which reached a maximum on 13 May and declined thereafter. This was in association with a severe cyclonic storm that crossed the Andhra coast north of Nellore on 12 May, moved northwestwards and weakened. This was followed by increase of pressure over large parts of the country. Pressures rose at Trivandrum and Bombay by almost the same amount so that the value of ΔP remained small till about 10 June. The onset of the monsoon was delayed by about a fortnight in 1979. Apart from this, the behaviour of the monsoon rains was erratic with prolonged "break monsoon" conditions. This resulted in drought and famine over large parts of north and central India.

SUPERPOSED EPOCH ANALYSIS

Because of the fluctuations in the date of onset of the monsoon from one year to another, the increase in the pressure gradient associated with the onset of the mosoon is smoothed out when the daily MSL pressure values are averaged for several years, resulting in a gradual increase of the pressure gradient along the west coast as in figure 8 (d) instead of the fairly abrupt increase seen for the individual years in figures 8 (a), (b) and (c). To bring out this feature in the data averaged for several years, the technique of superposed epoch analysis was adopted. The daily MSL pressure data of Trivandrum and Bombay for May and June were assembled for the 20 years, 1961 to 1980. From this, the time series of ΔP were prepared for the period 1 May to 30 June for all the 20 years. The ΔP time series were superposed with the date of monsoon onset over south Kerala taken as zero date for the individual years. The mean values of ΔP were worked out for the zero date and also for 15 days on either side. The results of the analysis are shown in figure 9. Notice that prior to the onset, the ΔP values are small and fluctuate around 0.5 mb.

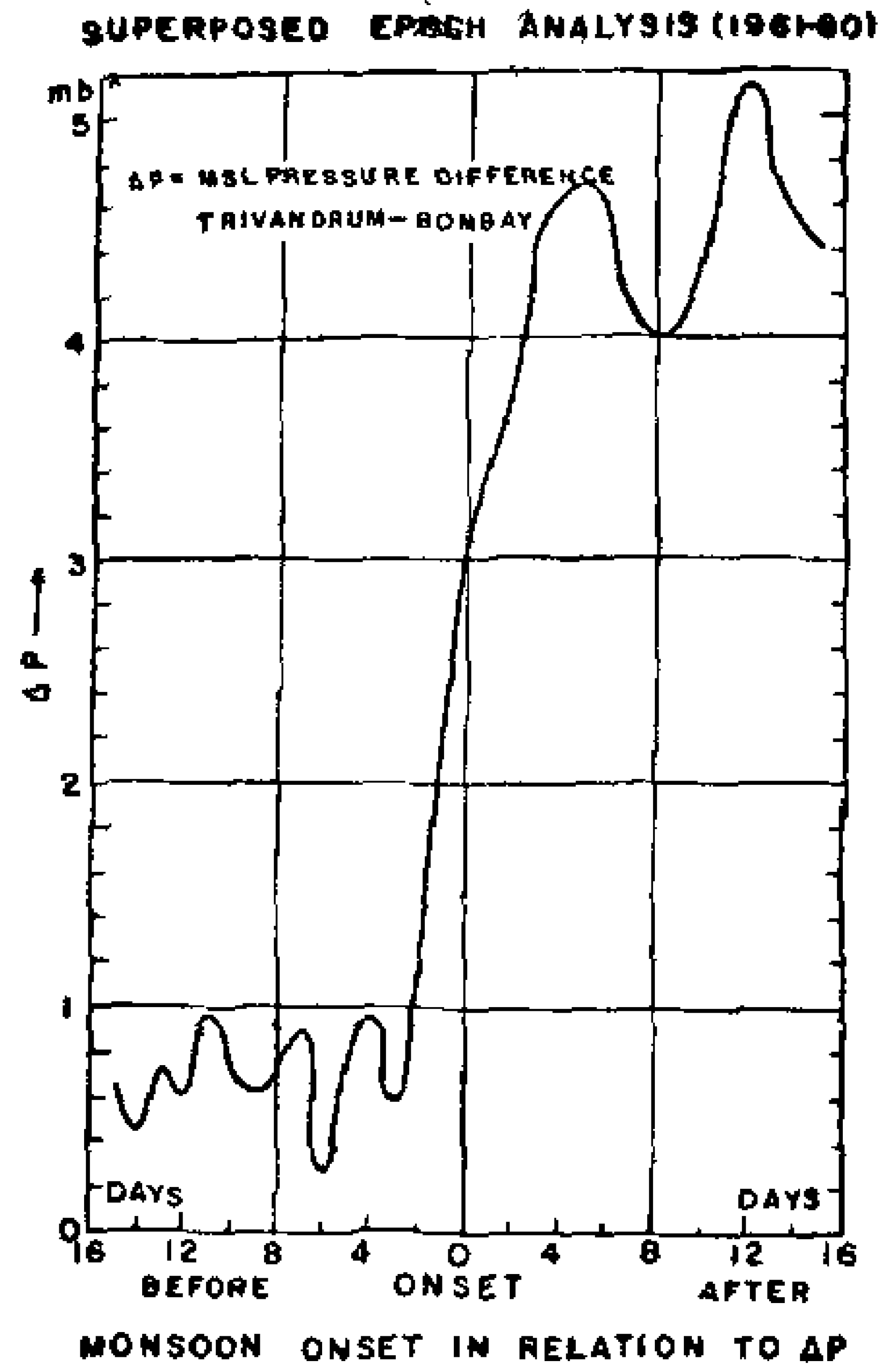

Figure 9. Superposed epoch analysis showing sharp rise in pressure gradient over the west coast during the onset phase of the monsoon

Almost simultaneous with the onset there is an increase of ΔP by about 4 mb. This increase begins to manifest about 2 days before the onset and the maximum value of the gradient is reached 2 to 3 days after the onset date. Thereafter the further increase in ΔP is somewhat irregular.

Figure 9 shows that the pressure difference of about 4 mb between Bombay and Trivandrum is established in about 4 to 5 days centred on the onset date of the monsoon over south Kerala. The actual pressure data for individual years show that the fall of pressure at Bombay contributes more towards the enhancement of the pressure gradient than the rise of pressure at Trivandrum. This increase of pressure gradient along the west coast associated with the onset of the monsoon appears to be linked with the low pressure system (onset vortex) which forms in the southeast Arabian sea and moves northwards as stated in earlier.

THE PREDICTION PROBLEM

Prediction of the date of onset of the monsoon in individual years is a matter of practical importance and scientific interest. Because of the complexity of atmospheric processes there is at present no way of attempting the prediction theoretically employing mathematical-dynamical models of the atmosphere. Empirical statistical methods are currently in use for this purpose. Utilising past data, correlation coefficients are worked out between the onset dates (reckoned as number of days from 1 April or 1 May) and *antecedent* meteorological parameters (predictors) likely to be associated with the initiation of the monsoon circulation. Since the monsoon circulation is extensive in space and in time, the parameters chosen as predictors need not be confined to India. After study of the correlation coefficients, a choice of the most promising parameters is made and a multiple regression formula is established linking the date of onset and the selected parameters. This forms the prediction equation. The prediction equation currently in use in the IMD employs as predictors upper tropospheric winds during the winter months of the following Indian and Australian stations: New Delhi (300 mb, January); Calcutta (200 mb, December); Trivandrum and Madras (200 mb, February); Darwin, Australia (200 mb, January).

Recently Kung and Sharif[27] have published a multi-regression forecast scheme for prediction of the onset date of the southwest monsoon. The predictors employed are: 100, 200 and 700 mb upper air parameters over India and Australia; and the sea surface temperature over the Indian sea area. According to these authors the predicted and observed dates of onset are found to be in good agreement.

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