

## Importance of Upper Tropospheric Thermal Anomalies for Long-Range Forecasting of Indian Summer Monsoon Activity

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### ABSTRACT

Upper tropospheric monthly mean values of geopotential height at selected Indian stations during the pre-monsoon months of April and May, and the monsoon months of June, July and August, have been used to study the interannual variation in the upper tropospheric thermal field for the years 1968–77. The 300–100 mb thickness anomalies averaged over these stations reveal that 1) the anomalies observed during the pre-monsoon period of April–May generally persist through the subsequent monsoon months of June, July and August; and 2) a warm (cold) anomaly over northern India during the pre-monsoon months is followed by above-normal (below-normal) monsoon rainfall activity. The study may be useful in long-range forecasting of Indian summer monsoon rainfall activity.

### 1. Introduction

The summer monsoon of Southeast Asia is the largest anomaly of the general circulation. Although the recurrence of the summer monsoon over India is

markedly regular, its activity often varies from year to year. One extremity may result in severe drought, a single sufficient factor to disrupt the economy of the country. Therefore, it is vital to study the dynamics of the monsoon that are responsible for

TABLE 1. The 300–100 mb thickness anomaly (gpm) averaged for New Delhi, Bombay and Calcutta.

Month	Year									
	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
April	-60	-36	+9	-0	-45	+31	-15	+33	+13	+32
May	-112	-55	+33	-6	-34	+28	+7	+79	+66	+21
June	-106	-84	+26	-11	-18	+36	+34	+96	+33	+6
July	-90	-84	+47	-1	+43	+45	-5	+85	-29	-2
August	-65	-104	+38	-6	+36	+27	+44	+75	-42	-1

these variations, and that occur before the monsoon season, to improve the long-range prediction of monsoon activity.

Murakami (1974, 1975, 1978), Krishnamurti *et al.*, (1975) and Kanamitsu and Krishnamurti (1978) have shown that variations in the behavior of the monsoon are simultaneously evident in the upper tropospheric thermal and circulation anomalies. If these anomalies can be found to occur before the monsoon is established, their existence not only would help us to better understand the monsoon genesis, but would aid in the long-range forecasting of monsoon activity as well. The present study is an attempt toward this aim through examination of the interannual variation in the upper tropospheric thermal field.

The author earlier computed height anomalies at about 60 Indian and neighboring radiosonde stations, at all standard levels in the troposphere. On examining the vertical variation of height anomalies over individual stations, great similarity was observed over most of the northern Indian stations and the magnitudes of the anomalies were generally found to increase from 500 to 100 mb level. Three important stations have been selected that are more or less representative of the central and northern Indian region, north of 18°N.

## 2. Data and analysis procedure

Monthly mean values of geopotential height at New Delhi (28°35'N, 77°12'E), Bombay (19°07'N, 72°51'E) and Calcutta (22°39'N, 88°27'E) at the 300 and 100 mb levels, for the months of April, May, June, July and August during the period from 1968 to 1977, have been taken from *Monthly Climatic Data for the World*. Anomalies of 300–100 mb thickness were calculated from this data set. Indian radiosonde stations switched over to the audiomodulated-type instruments after 1967. The earlier instruments registered temperatures that were 2–3°C higher in the upper troposphere than the later type. Since it is necessary to use a set of homogeneous data for computing a mean, data prior to 1968 have not been used. Rainfall departure values for the southwest monsoon season (June–September) of India were obtained from an earlier study by Parthasarathy

and Mooley (1978). In this study, rainfall departures were calculated according to subdivisions and area-weighted data. Normals were obtained from a long series of data extending from 1841 to 1977.

## 3. 300–100 mb thickness anomaly

From the values of height anomalies at 300 and 100 mb levels, thickness anomalies of 300–100 mb layer were calculated at New Delhi, Bombay and Calcutta for the months of April–August for 10 years from 1968 to 1977. The averaged values for these stations are shown in Table 1.

Positive (negative) sign of the anomaly would indicate a warmer (cooler) layer and the magnitude would indicate the degree of warming (cooling). In the present case, where the thickness of the layer is taken between 300 and 100 mb levels, the thermal characteristics would pertain to the upper troposphere, representative at the mean level of 200 mb. The anomalies during 1968, 1969, 1970, 1971, 1973 and 1975 showed persistency of sign and, except for 1971, large magnitude throughout the 5-month period. The years 1972, 1976 and 1977 showed persistency for the first three months. In the case of 1974, the only year not showing persistency in the upper troposphere, further examination, showed persistently negative anomaly in the middle troposphere (500–200 and 850–500 mb thickness) from May through September. The indication is that a cooler/warmer than normal upper troposphere over central and northern India, as observed during the pre-monsoon period, generally persists through the early monsoon months, and can be termed a "characteristic feature" of that year because of its relevance to the rainfall activity of the ensuing summer monsoon season, as discussed in the next section.

## 4. Thickness anomaly and summer monsoon rainfall departure

Fig. 1 shows the interannual variation of 300–100 mb thickness anomaly, averaged for New Delhi, Bombay and Calcutta for the month of April, and of summer monsoon season (June–September) rainfall departure (%) of India from 1968 to 1977. The

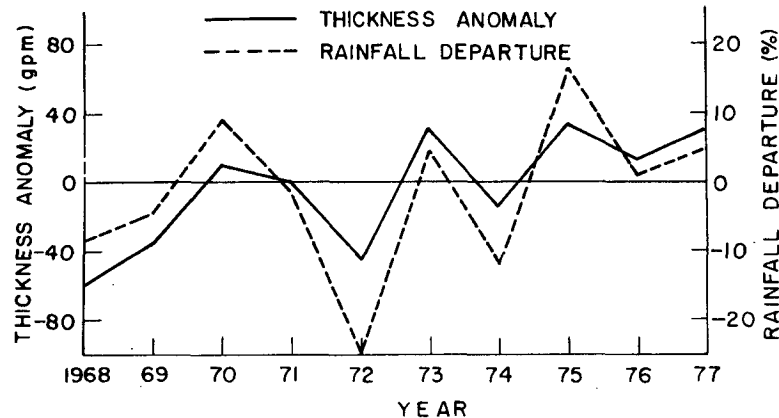


FIG. 1. Interannual variation of 300–100 mb thickness anomaly (gpm) averaged for New Delhi, Bombay and Calcutta for the month of April (continuous line); and of summer monsoon rainfall departure (%) for India (dashed line).

former is shown by a continuous line and the latter by a dashed line. There seems to be a one-to-one correspondence between the signs of thickness anomaly and rainfall departure—the negative thickness anomaly during 1968, 1969, 1971, 1972 and 1974 showing correspondence with negative rainfall departure during summer monsoon season of these years, and positive thickness anomaly during 1970, 1973, 1975, 1976 and 1977 showing correspondence with positive rainfall departure. The correlation coefficient between the two series is 0.8022, significant at the 1% level. The correlation is less significant with the thickness anomaly for May ( $r = 0.6510$ , significant at 5% level). Warmer upper tropospheres over north India during the pre-monsoon period thus seem to have a link with the good rainfall activity of the coming summer monsoon season and, conversely, a cooler upper troposphere over north India during the pre-monsoon period seems to have a link with the below-normal rainfall activity of the coming summer monsoon season. This very significant correlation may find useful application in long-range forecasting of the Indian summer monsoon rainfall activity.

### 5. Verification

In order to examine how far this method would be useful for operational purpose, it was felt that a verification could be made for a year not included in the statistics. The summer monsoon of 1979 was therefore chosen to test the method. Unfortunately, thermal anomalies over north India could not be computed for April 1979 because of paucity of observations at most of the north Indian radiosonde stations. Computations made with the available data for the month of May 1979 indicated that the upper troposphere over central and north India was 3–4°C cooler than the normal and the 300–100 mb thickness anomaly, averaged for New Delhi, Bombay and

Calcutta was –116 gpm. Based on these computations, a below-normal rainfall activity for Monsoon–1979 was predicted in the first week of June 1979—before the onset of monsoon. The actual rainfall for India for the monsoon season of 1979 was found to be 16% below normal, with major parts of the country experiencing one of the severest droughts in the past 100 years. Persistency and severity of cooling was also observed, as the data for the subsequent months of June, July and August continued to show the same order of thermal anomaly.

The positive response of the test suggests that the method worked out in the study may be used operationally, for the forecast of the summer monsoon activity, at least one month ahead.

### 6. Conclusions

The study reveals the following features:

- 1) Warming/cooling of the upper troposphere over central and northern India, as observed during the pre-monsoon period, generally persists through the early monsoon months.

- 2) A warmer (cooler) upper troposphere over northern India during the pre-monsoon period is linked with above-normal (below-normal) rainfall activity during the ensuing summer monsoon season over India.

Because the correlation between the pre-monsoon-period anomalies and the monsoon rainfall departure is highly significant, it may be useful in giving long-range forecasts of the seasonal rainfall activity of the coming summer monsoon.

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