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Relationship between tropospheric thickness anomalies and Indian summer monsoon rainfall

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सार — उत्तरी भारतीय केन्द्रों की चुनी हुई वायु परतों की अप्रैल से जुलाई तक 28 वर्षों (1968-1995) की अवधि की, क्षोभमंडलीय औसत मासिक स्थूलता (थिकनेस) की विसंगतियों का विश्लेषण किया गया है। अप्रैल और मई की स्थूलता विसंगतियां उल्लेखनीय रूप से जुलाई में भी जारी रही। मई-जुलाई में विभिन्न वायु परतों की स्थूलता की विसंगतियों का परवर्ती अखिल भारतीय मौसमी मानसून वर्षा के साथ सामान्यतः सार्थक (5% से 0.1% स्तर तक) रैखिक परस्पर संबंध पाया गया। विभिन्न वायु परतों की स्थूलता के सभी महीनों के विश्लेषण से पता चला है कि मई की 850 से 300 और 850 से 100 हेक्टो पास्कल वायु परतों की स्थूलता विसंगतियों का संबंध अधिकतम (0.1% स्तर तक सार्थक) है। रैखिक और बहुप्रतिगमन परिणामों से पता चलता है कि 850 से 300 हेक्टोपास्कल की स्थूलता की विसंगतियां भारतीय मानसून वर्षा के दीर्घावधि पूर्वानुमान के लिए उपयोगी पूर्वसूचक हैं।

ABSTRACT. The tropospheric mean monthly thickness anomalies of northern Indian stations of selected layers for the months April to July for a 28 years (1968-95) period have been analysed. The thickness anomalies of April and May exhibit significant persistence through July. Also, the thickness anomalies of different layers for the months May-July are found to have generally significant (5% to 0.1% level) linear correlations with the succeeding all India seasonal monsoon rainfall. Out of different layers and all the months analysed, the thickness anomalies of 850-300 and 850-100 hPa layers for May are found to have maximum correlations (significant at 0.1% level). From linear and multiple regression results, 850-300 hPa thickness anomaly is seen to be a useful predictor for long range prediction of Indian monsoon rainfall.

Key words — Thickness anomalies, Correlation coefficients, Linear regression, Multiple regression.

1. Introduction

The interannual variability of Indian summer monsoon rainfall is well known. Since Walker's times several studies have been made to correlate this variability with variations in the surface and upper air mean monthly or mean seasonal meteorological parameters for months/seasons preceding the monsoon and from places within and even beyond the monsoon regime. With the advance of pre-monsoon season, gradual warming of the troposphere takes place and consequently the heights of isobaric levels increase. In certain years this increase may be rapid and in others it may be slower than normal. The height of isobaric levels or thickness of different layers in the troposphere during the pre-monsoon months can be an index of the transformation of the circulation from winter to monsoon type. Thickness for the month immediately preceding the onset of monsoon may give better results compared to those of other pre-monsoon months.

Studies made by Krishnamurti *et al.* (1975), Kanamitsu and Krishnamurti (1978) and Verma (1980, 1982) have shown that future performance of the monsoon is reflected by the upper tropospheric thermal and circulation anomalies over the Indian sub-continent for pre-monsoon months. Based on the upper tropospheric thermal field for the short period 1968-77, Verma (1980) has inferred that a warm (cold) anomaly over northern India during the pre-monsoon months is followed by above (below) normal monsoon rainfall activity over India. However, he had examined only one layer 300-100 hPa in the upper troposphere. In connection with long range prediction of monsoon, Shukla (1987) recommended a detailed examination of long term records of circulation features like tropospheric thickness anomalies,

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TABLE 1

Correlation coefficients (CC) between monsoon rainfall (R) and anomalies of five thickness layers for four months based on data for the period 1968-95

Month	Thickness Layer (hPa)				
	TH1 (850-500)	TH2 (850-300)	TH3 (500-300)	TH4 (300-100)	TH5 (850-100)
April	0.37	0.32	0.16	0.25	0.30
May	0.43@	0.63*	0.56+	0.58+	0.62*
June	0.41@	0.49@	0.37	0.57+	0.56+
July	0.38	0.51+	0.39@	0.49@	0.52+

@ Significant at 5% level + Significant at 1% level * Significant at 0.1% level

500 hPa April ridge etc. In this paper, we have considered the long term records of tropospheric thickness anomalies of selected Indian stations for their predictive value for the Indian summer monsoon rainfall. To make the study more comprehensive we have analysed the entire troposphere by stratifying the atmosphere into five layers to identify the best layer. We have adopted statistical method to quantify the results and their significance.

2. Data

The Indian radiosonde stations changed over to audio-modulated type of instruments after 1967 and the upper air temperatures recorded prior to 1968 are reported (Verma 1980) to be 2 to 3°C higher than those of later period. The data utilised in this study are from 1968 onwards. Data prior to 1968 is not used to eliminate bias in data due to change of instrument. Monthly mean values of geopotential heights of standard isobaric levels upto 100 hPa for a number of Indian stations for the months April to July and the period from 1968 to 1995 were collected from Monthly Climatic Data for the World. Averages were computed using these data and anomalies of 850-500 (TH1), 850-300 (TH2), 500-300 (TH3), 300-100 (TH4) and 850-100 (TH5) hPa thicknesses were calculated for the stations New Delhi, Bombay and Calcutta. Anomaly values were averaged for the three stations to give a representative value for the northern part of India. Similar method was followed by Verma (1980).

Area-weighted rainfall (R) data for the country as a whole for the Indian monsoon seasons (June-September) for the corresponding period were collected from the ADGM(R)'s office of India Meteorological Department at Pune.

3. Thickness anomalies and Indian monsoon performance

The relationship between different thickness anomalies and all India monsoon rainfall has been studied by correlation analysis for pre-monsoon months April and May and monsoon months June and July. It is found that thickness anomalies of layers under study for the month of May have statistically significant correlations with succeeding monsoon seasonal rainfall. The linear correlation coefficients (CC) between monsoon seasonal rainfall (R) and thickness anomalies of different layers for four months based on the period 1968-95 are given in Table 1. Among thickness anomalies for different layers of May, the thickness anomaly (TH2) for the layer 850-300 hPa is found to have best correlation which is significant even at 0.1% level of significance. The second best correlation is for the layer 850-100 hPa. On examining the values in Table 1, it is interesting to note that the CC's for all layers are generally maximum for the month of May. Singh *et al.* (1995) have also found similar results for the mean sea level pressure.

The CCs of various thickness anomalies of April with corresponding thickness anomalies of those of May, June and July and CCs of thickness anomalies of May with those of June and July are shown in Tables 2(a) and 2(b) respectively. These correlations point out significant persistance of April and May thickness anomalies during the subsequent two-month period. Clearly, the CCs of thickness anomalies of May with those of June

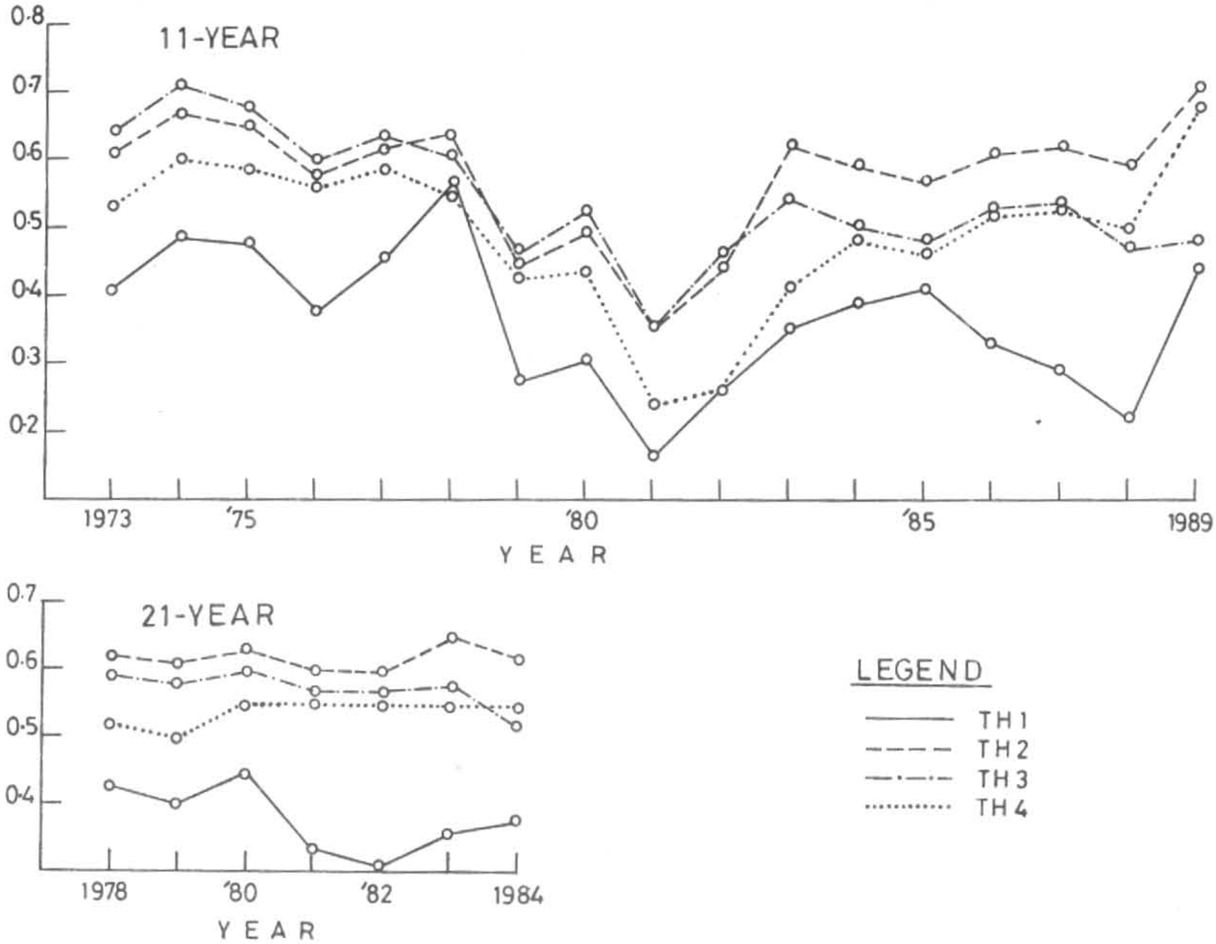

Fig. 1. Variation of CCs of different thickness anomalies and all India monsoon rainfall for 11 and 21-year sliding windows

TABLE 2 (a)

CCs of thickness anomalies of April with thickness anomalies of succeeding months

Layer (hPa)	May	June	July
850-500	0.47	0.47	0.35
500-300	0.64	0.64	0.28
300-100	0.61	0.41	0.40
850-300	0.57	0.63	0.30
850-100	0.65	0.54	0.42

TABLE 2 (b)

CCs of thickness anomalies of May with thickness anomalies of June and July

Layer (hPa)	June	July
850-500	0.65	0.53
500-300	0.78	0.46
300-100	0.86	0.74
850-300	0.78	0.57
850-100	0.88	0.72

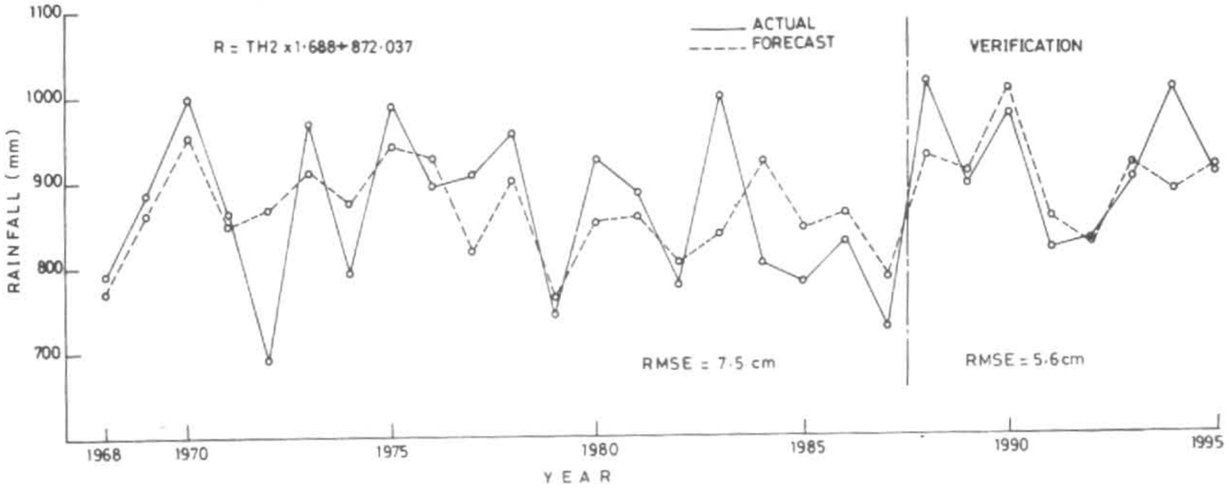

Fig. 2. Performance of linear regression equation between TH2 of May and R for 1968-87 with verification for 1988-95

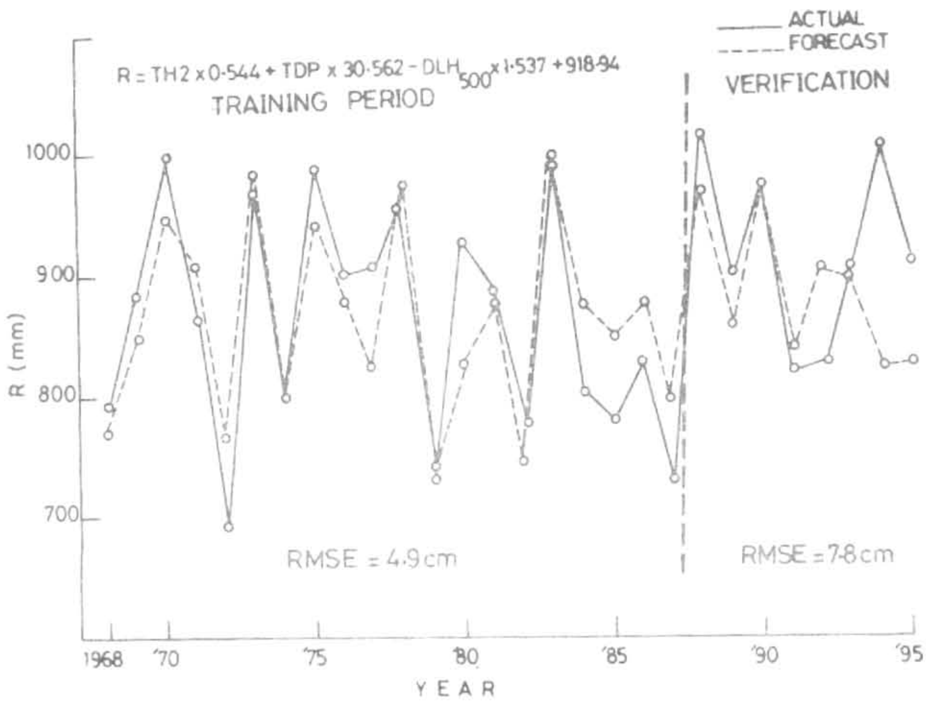

Fig. 3. Performance of multiple regression equation for the 1968-87 with verification for 1988-95

TABLE 3

Statistical properties of the CCs for 11-year sliding window

Value	TH1	TH2	TH3	TH4	TH5
Mean	0.39	0.58	0.55	0.49	0.55
Standard Deviation	0.10	0.09	0.09	0.11	0.10
Coefficient of Variability	26.12	15.26	15.82	21.96	17.99

and July are more significant. These results, based on longer period data, re-affirm the observation of Verma.

With a view to examine the suitability of these thickness anomalies in regression equations, the CCs have been evaluated for sliding windows of 11 and 21 years. These results for the month of May for the four layers are presented in Fig. 1. The CC values are plotted against the middle year, *i.e.,* 1973 for the window period of 1968-78. The variation of CCs for different layers show a similar pattern of decreasing or increasing trend for common periods which is a testimony to the coherence of data. The mean, standard deviation and coefficient of variability for the CCs for 11-year window are shown in Table 3. It is evident from this table that the correlation of thickness anomaly of 850-300 (TH2) exhibits more stability during the period of study.

An examination of the monthly mean heights of different stations in the northern part of India reveals that the heights for the lower troposphere decrease with the advance of season from April onwards and the heights in the middle troposphere (500 hPa) remain nearly constant while the heights increase in the upper troposphere. In studying the thickness anomalies, it is more appropriate to take into account the changes in the lower troposphere as well as those in the upper troposphere. In view of this and the stability aspect discussed in previous paragraph, the layer within the lower and upper troposphere (850-300 hPa), appears to be marginally better suited for use in regression equation.

Using the 850-300 hPa thickness anomalies (TH2) of May and R, we have developed a single parameter linear regression equation between them, based on data for the 20-year period, 1968-87; and verified the equation with the monsoon rainfall data for an independent period 1988-95. The results are shown graphically in Fig. 2. The fit of data and performance of the equation during independent data period, by and large, appear to be good. The root mean square error (RMSE) for the eight year verification period is 5.6 cm which is comparable to RMSE of other single parameter regression equations.

On seeing the potential of thickness anomalies as a parameter, we have developed a multiple regression equation using the new parameter TH2 in combination with other well known circulation parameters. The regression equation comprises 850-300 hPa thickness anomaly (TH2), seasonal mean sea level pressure difference of Tahiti and Darwin (Mar-Apr-May minus Dec-Jan-Feb) (TDP) and meridional wind component of 500 hPa over Delhi (DLH_{500}). The multiple regression equation and its performance with training period (1968-87) and verification period (1988-95) are shown in Fig. 3. The multiple correlation coefficient (MCC) of the equation is 0.84. The root mean square error (RMSE) between actual and forecast rainfall for the independent period is 7.8 cm, which is higher than the regression equation with the single parameter TH2. We also note that the multiple regression model forecast departed more from the actual for the recent two years 1994 and 1995, the departure being more than the RMSE in case of the year 1994.

4. Conclusions

Analysis of 28-year data of tropospheric thickness anomalies suggests :

(*i*) Correlation coefficients of April and May thickness anomalies with those of succeeding monsoon months upto July confirm persistence of thickness anomalies. The May anomalies are showing more significant persistence.

(*ii*) Significant linear correlation observed between various thickness anomalies for May and the succeeding all India seasonal monsoon rainfall.

(*iii*) The thickness anomalies, especially for the layer 850-300 hPa, are seen to be a useful parameter in regression-based long range prediction models for Indian summer monsoon rainfall.

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