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Long-range prediction of monsoon activity : A synoptic-diagnostic study*

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सार — मानसून के पूर्व महीने – अप्रैल और मई तथा मानसून माह–जून, जुलाई और अगस्त की अवधि में भारत के 60 स्टेशनों और आस पड़ौस के स्टेशनों की भूविभव ऊंचाई, तापमान एवं पवन के उपरितन उष्णकटिबंधीय मासिक माध्य मानों का उपयोग 1967 से 1976 तक के उपरितन उष्णकटिबंधीय क्षेत्रों में उपरितन अन्तर वार्षिक विचरण के अध्ययन के लिये किया गया है। चुने हुए भारतीय स्टेशनों पर मोटाई के अपवाद (1) उपरितन क्षोभमंडल के गर्म (पुनस्तापन)/शीतलन एक उत्तर और उत्तर-पश्चिम भारतीय क्षेत्र पर वृहत परिमाण परिघटना होने (2) अप्रल और मई (मई में अति सुस्पष्ट) के महीनों में, सामान्यतः परवर्ती मानसून महीनों में दीर्घस्थाई रूप में प्रेक्षित अपवाद होने की सलाह देते हैं। उत्तर और उत्तर-पश्चिम भारतीय क्षेत्रों में गर्म (ठंडा) उपरितन क्षोभमंडल के वर्ष जोकि मानसून महीनों के पूर्व के मई माह (और शायद अप्रैल से) से प्रारंभ होते और परवर्ती मानसून महीनों के दौरान सामान्यतः दीर्घस्थाई होने वाले वे वर्ष हैं जब भारत में ग्रीष्म मानसून वर्षा अच्छी (कम) होती है।

विरोधाभासी मानसून में मई के महीने में भारतीय उपमहाद्वीप पर उपरितन क्षोभ मंडलीय परिसंचलन उत्तर-पश्चिम भारतीय क्षेत्र की उप-उष्णकटिबंधीय पछुआ हवाओं की तरंग संरचना में काफी अन्तर दर्शाते हैं।

अध्ययनों से पता चला है कि पछुआ हवाओं में उपरितन क्षोभमंडलीय स्थाईवत तरंगें उत्तर और उत्तर पश्चिम भारतीय क्षेत्र पर मानसून पूर्व के महीनों के दौरान ताप क्षेत्र को काफी प्रभावित करती हैं जिसकी वजह से भारत में मई परवर्ती ग्रीष्म मानसून की सक्रियता को प्रभावित करती है। इसकी मानसून की सक्रियता के दीर्घ परिसीमा पूर्वानुमान में महत्व हैं।

ABSTRACT. Upper tropospheric monthly mean values of geopotential height, temperature and wind at about sixty Indian and neighbouring stations during the pre-monsoon months of April and May, and monsoon months of June, July and August, have been used to study the inter-annual variation in the upper tropospheric fields for the years 1967 to 1976. Thickness anomalies at selected Indian stations suggest, (1) that warming/cooling of upper troposphere is a large-scale phenomenon over north and northwest Indian region and (2) that the anomalies as observed in the months of April and May (more predominantly in May), generally persist during the subsequent monsoon months. It is found that the years of warmer (cooler) upper troposphere over north and northwest Indian region, beginning from the pre-monsoon month of May (and perhaps from April) and generally persisting during the subsequent monsoon months, are the years when the summer monsoon rainfall over India was good (poor).

The upper tropospheric circulation over Indian sub-continent during the month of May in the contrasting monsoons show marked difference in the wave structure of sub-tropical westerlies over northwest of Indian region.

The study suggests that the upper tropospheric quasi-permanent wave in the westerlies can significantly effect the thermal field over north and northwest Indian region during the pre-monsoon months, which in turn, may influence the activity of the subsequent summer monsoon over India. This may have value in long-range prediction of monsoon activity.

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1. Introduction

The summer monsoon of southeast Asia is the largest anomaly of the general circulation. Although the recurrence of summer monsoon over India is very regular, its activity often varies from year to year and sometimes the variation is very much marked. One extremity may result in severe drought — a single sufficient factor to disrupt the economy of the country. It is, therefore, vital to study the dynamics of the monsoon which are responsible for these variations or anomalies, to help long-range prediction of monsoon activity.

The drought year of 1972 was characterised by anomalous circulation on a global scale. A number of studies (Murakami 1975; Krishnamurti *et al.* 1975) have examined different aspects of the flow pattern anomalies during 1972. Kanamitsu and Krishnamurti (1978) showed that the global tropical motion field during 1972 in the upper troposphere was quite anomalous on planetary scale. Murakami (1978) observed that 200 mb zonal mean flow in summer 1972 near India was exceptionally stable. These studies reveal that the anomaly in the behaviour of the monsoon is evident in the upper tropospheric anomalies, particularly in the thermal and circulation anomalies. A numerical experiment by Murakami (1974) suggests a possible existence of one direction atmospheric tele-connection between equatorial central Pacific and the monsoon region in the sense that the heating anomalies prescribed over the monsoon region excite strong response in zonal winds over the equatorial central Pacific, while equatorial forcing (anomaly) does not cause any significant change in the monsoon circulation. Therefore, it would be quite reasonable to examine the upper tropospheric dynamics over India and neighbouring north and northwest region to understand the monsoon activity. Again, if the aim is to have some idea of the forthcoming monsoon activity, the anomalies must be observed during the pre-monsoon months and must persist for a sufficiently long period of time. The present synoptic-diagnostic study is an attempt towards this aim, through examining the inter-annual variation in the upper tropospheric fields.

2. Data and analysis procedure

Monthly mean values of geopotential height temperature and wind at about 60 Indian and neighbouring radiosonde stations between equator to 45° N and 25° E to 145° E at 500, 300, 200 and 100 mb levels, for the months of April, May, June, July and August during the years from 1967 to 1976 have been taken from the *Monthly Climatic Data for the World.* The values of height and temperature anomalies have been calculated by subtracting these 10-year means from individual values. Corrections have been applied in computing the anomlies to take into account the fact that Indian stations switched over to audiomodulated radiosondes during this period.

3. Vertical variation of height anomaly ($-\partial\phi'/\partial p$)

Height anomalies are computed at standard levels from 850 mb to 50 mb levels at individual stations. 50 mb observations are very few. The magnitudes of height anomalies (ϕ') are very small below 500 mb level and so these are not shown in the figures.

On examining the vertical variation of height anomalies over individual stations, great similarity is observed over most of the northern Indian stations. This is shown at selected stations of New Delhi, Jodhpur, Calcutta, Gauhati, Nagpur and Bombay for the months of April, May, June, July and August between 500 mb and 100 mb levels in Figs. 1 to 5. The significant points of this aspect are as follows :

(*i*) Magnitudes of ϕ' generally increase from 500 mb level to 100 mb level. Examination of ϕ' at 50 mb level, which is available at few stations only, indicates that the magnitudes of ϕ' generally decrease from 100 mb to 50 mb level, *i. e.,* ϕ' are probably largest in magnitude at about 100 mb level.

(*ii*) Broadly, vertical variation of height anomaly ($-\partial\phi'/\partial p$) fall under the following two categories :

(*a*) $-\partial\phi'/\partial p > 0$, *i. e.,* ϕ' increasing with decreasing pressure. This type of variation would indicate that the layer of atmosphere between 500 and 100 mb levels is warmer than average and the warming decreases from 100 mb to 500 mb level (and most probably is maximum around 100 mb level).

(*b*) $-\partial\phi'/\partial p<0$, *i.e.,* ϕ' decreasing with decreasing pressure. This type of variation would indicate that the layer of atmosphere between 500 and 100 mb levels is cooler than average and the cooling decreases from 100 mb to 500 mb level (and most probably is maximum around 100 mb level).

(*iii*) The stations selected here are more or less representative of central and northern Indian region north of 18° N. In any one of these months during a particular year (and more in the month of May), the stations show almost identical behaviour of height anomaly in the upper troposphere. This suggests that in any month out of these, the upper tropospheric thermal behaviour is a large-scale phenomenon, covering at least the central and northern Indian region.

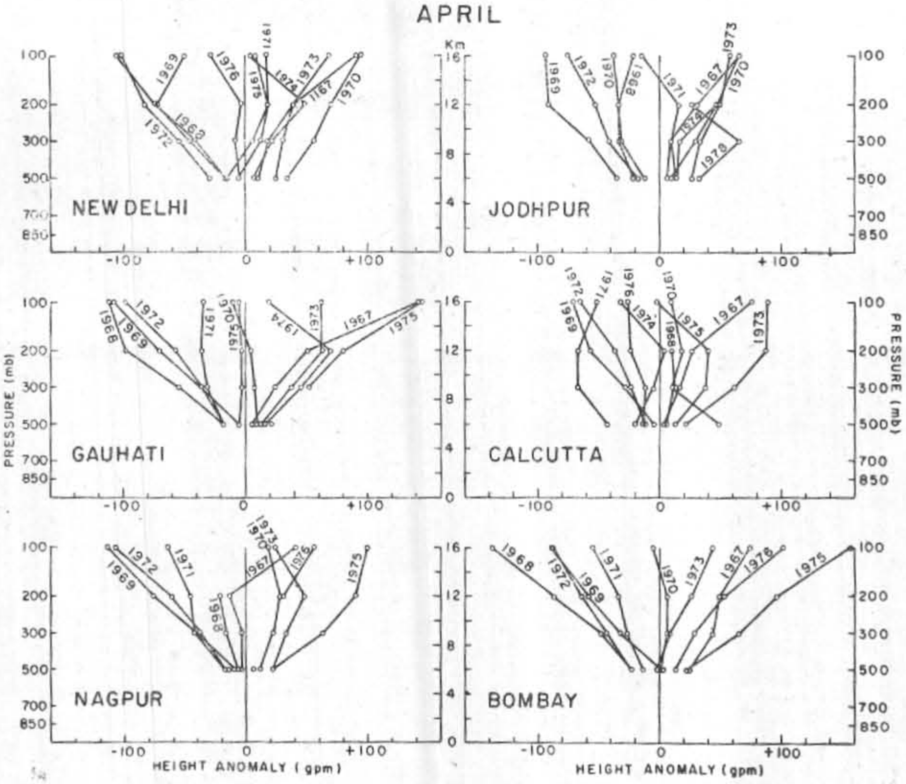

Fig. 1. Vertical variation of height anomaly (gpm) at New Delhi, Jodhpur, Gauhati, Calcutta, Nagpur and Bombay and its inter-annual variation during April

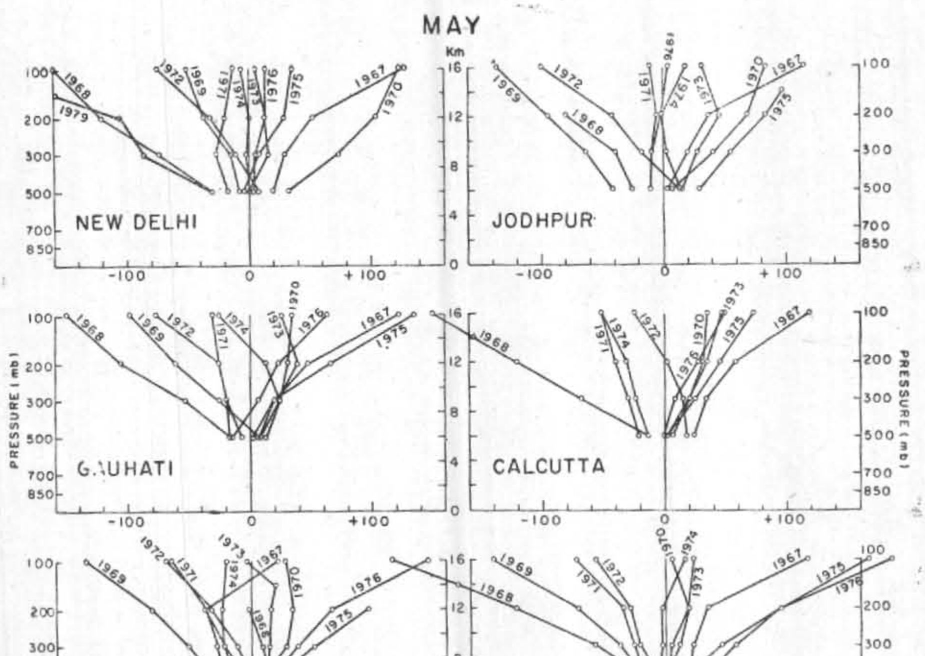

Fig. 2. As in Fig. 1 except for the month of May

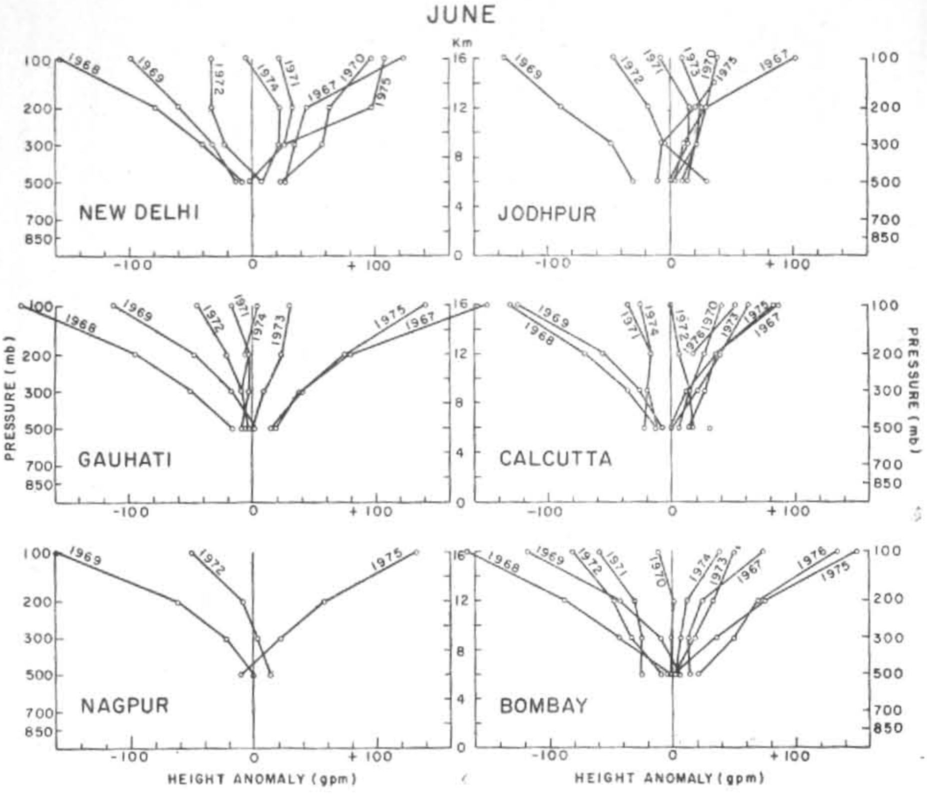

Fig. 3. As in Fig. 1 except for the month of June

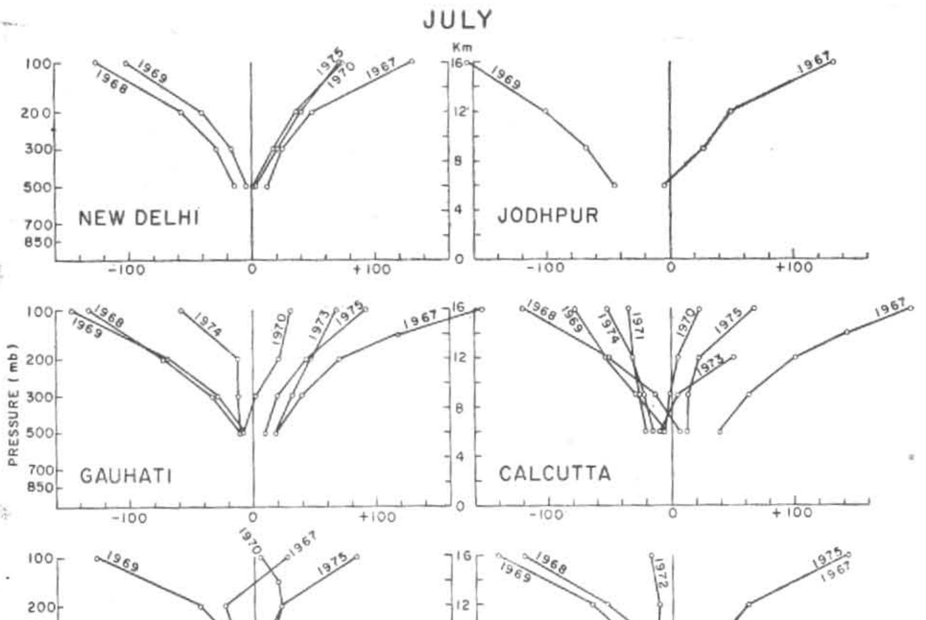

Fig. 4. As in Fig. 1 except for the month of July

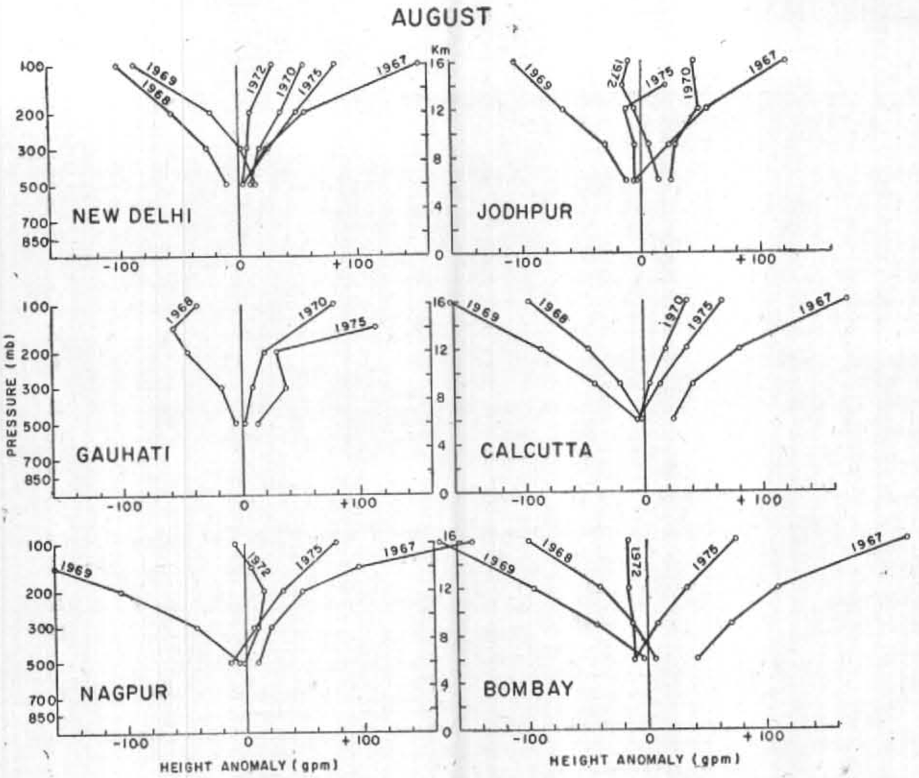

Fig. 5. As in Fig. 1 except for the month of August

(iv) Again, the stations show almost identical behaviour of height anomaly in the upper troposphere during all the months from April through August in a particular year. This suggests that the upper tropospheric thermal behaviour over central and northern Indian region has a long persistency of few months from April through August.

4. Rate of change of thickness anomaly in the vertical between 300 and 100 mb levels

From the values of ϕ' at 300 mb and 100 mb levels, rate of change of thickness anomaly or $-\partial\phi'/\partial p$ is calculated at New Delhi, Bombay and Calcutta for the months of April through August for all the ten years. These are shown in Table 1. The unit is 10^{-2} gpm mb^{-1} . Months having less than 20-days of data are excluded.

The sign of $-\partial\phi'/\partial p$ would indicate nature of thermal anomaly. Considering only the two broadly observed cases, as mentioned in the previous section, positive sign would indicate warmer than average or the source of thermal energy, and negative sign would indicate cooler then average or the sink of thermal energy. The magnitude would indicate a measure of surplus or deficit of thermal energy depending on its sign. In this present case, where the thickness of the layer is taken between 300 and 100 mb levels, the thermal energy behaviour would pertain to the upper troposphere, representative at the mean level of 200 mb, an important upper tropospheric level so far as the circulations are concerned.

The five-month period of April through August has been divided into two identifiable sub-periods. The pre-monsoon period of April and May, and the active monsoon period of June, July and August. An estimate of the thermal behaviour of the layer, on the basis of the average, is shown as warmer (W), normal to warmer (NW), normal to cooler (NC) and cooler (C) for the two sub-periods separately. The following significant points are noted:

(*i*) During the years 1967 and 1975, the upper troposphere, as indicated over New Delhi, Bombay and Calcutta, was much warmer than average during the pre-monsoon months of April-May and more or less remained so during the subsequent monsoon months of June, July and August.

(*ii*) During the years 1968 and 1969, the upper troposphere, as indicated over New Delhi, Bombay and Calcutta, was much cooler than average during the pre-monsoon months of April-may and more or less remained so during the subsequent monsoon months of June, July and August. The only odd value appears at Calcutta during April 1968. During

TABLE 1

Rate of change of thickness anomaly in the vertical ($-\partial\phi'/\partial p$) between 300 and 100 mb levels at New Delhi, Bombay and Calcutta in April–August from 1967 to 1976 [(Unit : 10^{-2} gpm mb^{-1}). Months having less than 20 days of data are left blank]

Month	Station	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
Apr	New Delhi	+36	—32	—3	+20	+6	—24	+19	— 9	—	—10
Apr	Bombay	+16	—45	—29	— 6	—14	—23	+18	— 0	+46	+37
Apr	Calcutta	+30	+32	—22	— 1	+8	—21	+9	—14	—	— 7
May	New Delhi	+49	—44	—17	+25	+7	—32	+0	— 2	+14	— 1
May	Bombay	+47	—83	—53	— 3	—24	—18	+9	+7	+61	+59
May	Calcutta	+43	—61	—	+8	—11	—20	+14	—14	+24	+21
Thermal behaviour of layer		W	C	C	NW	NC	C	NW	NC	W	NW
Jun	New Delhi	+45	—58	—33	+20	— 2	— 5	—13	+28	+40	—23
Jun	Bombay	+26	—62	—54	— 5	—17	—24	+16	+16	+57	+42
Jun	Calcutta	+31	—49	—50	+14	— 8	— 8	+21	— 4	+36	+20
Jul	New Delhi	+53	—49	—43	+29	— 0	+20	+9	+3	+26	—51
Jul	Bombay	+52	—52	—54	—	—15	— 2	+16	—17	+54	+20
Jul	Calcutta	+66	—54	—49	+11	— 4	+26	+23	—14	+27	—32
Aug	New Delhi	+65	—38	—43	+19	— 5	+12	— 4	+22	+29	—56
Aug	Bombay	+75	—44	—76	+1	—24	— 2	—	+14	+34	+14
Aug	Calcutta	+66	—39	—61	+13	— 4	+20	+18	+7	+26	—45
Thermal behaviour of layer		W	C	C	NW	NC	NW	NW	NW	W	NC

W — Warmer, NW — Normal to Warmer, NC — Normal to Cooler, C — Cooler

the year 1972, the pre-monsoon period indicates a cooler upper troposphere. During the later part of the monsoon, however, this became normal to warmer.

(*iii*) During the years 1970, 1973 and 1976, the upper troposphere over these stations was normal to warmer during the pre-monsoon months of April-May and more or less remained so during the subsequent months of June, July and August except in 1976, when it changed to cooler.

(*iv*) During the years 1971 and 1974, the upper troposphere over these stations was normal to cooler during the pre-monsoon months of April-May. In 1971 it remained so during the subsequent monsoon months of June, July and August, in 1974 it changed to normal to warmer. Here it may be noted that during 1974, the monsoon activity was unusual. The onset, the advance and the withdrawal — all were delayed by about a month. Pre-monsoon and monsoon season of 1974, for all practical purposes, be treated as if shifted ahead by about one month.

(*v*) From the stability point of view, in the case of large ($\geqslant 20\times10^{-2}$ gpm mb^{-1}) and positive values, the layer may be treated as being warmer and unstable, and in the case of large and negative values, the layer may be treated as being cooler and stable.

5. Height anomaly and rainfall departure

From the discussions in the previous section it is now evident that upper tropospheric anomalies can be best represented by the anomalies at 200 mb level and in time the anomalies can be averaged for (*i*) April-May and (*ii*) June-August. This is shown in Fig. 6 for New Delhi and Bombay. For this purpose, a longer 20-year period from 1958 to 1977 is taken, which is split into two periods for 10-year each to eliminate the error due to change over to A.M. Radiosonde, while calculating the anomalies. At both the stations, the change was made from 1968. Rainfall departure for SW monsoon season (June-September) of India is shown by the bottom graph. Rainfall departure values are calculated from the normal value of 87.61 cm (taken from Parthasarathy & Mooley 1978). The following significant points are brought out by these graphs;

(*i*) The close resemblance of anomalies from year to year between New Delhi and Bombay indicates that the upper tropospheric thermal anomaly is a large-scale phenomenon.

(*ii*) The close resemblance of anomalies from year to year during the two periods of April-May and of June-August indicates that in the time-scale, upper tropospheric height (or thermal) anomalies have a tendency to persist from pre-monsoon months through the subsequent monsoon months.

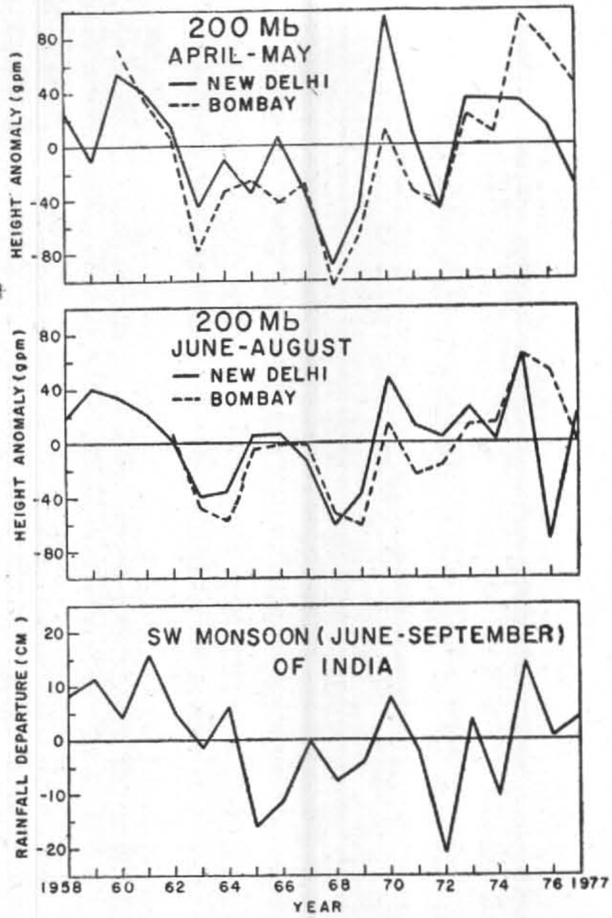

Fig. 6. Yearly variation 200 mb height anomaly during April-May and during June-August at New Delhi and Bombay and of monsoon season (June-September) rainfall departure of India

(*iii*) In general, the anomalies are larger during the pre-monsoon period than during the subsequent monsoon period, perhaps masked by the monsoon activity in the later period.

(*iv*) The rainfall departure of SW monsoon (June-September) season of India (bottom graph) and the 200 mb height anomalies during the pre-monsoon period (top graph) show a good association indicating that the nautre of the anomalous thermal field in the upper troposphere during the pre-monsoon months, may be an indicator of the activity of the subsequent monsoon.

6. Upper tropospheric anomalies during contrasting monsoon years of 1972 and 1975

The summer monsoon activity over India is defined mainly in terms of rainfall and its distribution. 1972 was the year of large deficient monsoon rainfall (— 21 cm departure from the normal of 87.6 cm) and 1975 was the year of large excess monsoon rainfall (+14 cm). The nature of the rainfall anomaly was more or less uniformly distributed throughout the country in these two monsoon seasons. These two years are the two very contrasting monsoon years in the recent past. This can be seen in the rainfall departure graph in Fig. 6. The large deficient rainfall over India in summer 1972 may be due to the so markedly observed global anomalies. The anomalies which caused the excess rainfall over India in summer 1975 may not be global in nature, but they were certainly of large-scale and prevailed predominantly over north and northwest of India. These anomalies in the 200 mb thermal and flow fields are depicted in Fig. 7 in respect of May 1972 and May 1975 over Afro-Asian region. Area of positive height anomaly is shown hatched. W indicates area of maximum positive temperature anomaly and C indicates area of maximum negative temperature anomaly. Streamlines are shown by arrows

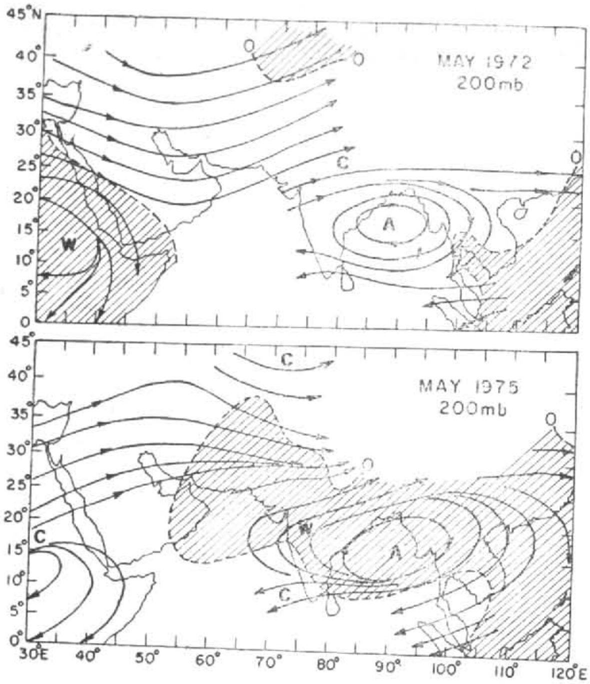

Fig. 7. May month streamlines at 200 mb level during the years 1972 and 1975. Hatching indicates area of positive height anomaly. W indicates region of maximum positive temperature anomaly and C indicates region of maximum negative temperature anomaly

and A shows the position of the anticyclone. Although, only 200 mb level analysis is presented, the analyses at 300 and 100 mb levels are almost identical to this.

The following two significant contrasts are observed : (*i*) In May 1972, almost whole of southeast Asia was cooler than normal in the upper troposphere. The maximum negative temperature anomaly being over north central India. Northeast Africa was warmer than normal.

In May 1975, almost whole of southeast Asia, east of about 55 deg. E longitude, was warmer than normal in the upper troposphere. The maximum positive temperature anomaly being over central India. Northeast Africa was cooler than normal, (*ii*) In May 1972, a well marked trough in the sub-tropical westerlies along about 55 deg. E longitude was observed in the upper troposhere.

In May 1975, a well marked ridge at about the same location was observed instead.

7. The possible role of upper tropospheric quasi-permanent trough/ridge in the sub-tropical westerly waves over northwest of India during the pre-monsoon period

Analysis of upper tropospheric monthly mean winds in May reveal that:

(*i*) a more or less pronounced trough was observed over northwest of India along about 50 deg. E during the years of 1968, 1969, 1971, 1972 and 1974. Trough observed during May 1972 was very much pronounced. It is noteworthy that these were the years when the upper troposphere over north and northwest India was either cooler or normal to cooler in the pre-monsoon and the early monsoon period as discussed in section 4 and the seasonal rainfall departure of India was negative (Fig. 6 bottom graph).

(*ii*) a more or less pronounced ridge was observed over northwest of India along about 55 deg. E during the years of 1967, 1970, 1973, 1975 and 1976.

Ridges observed during May 1967 and May 1975 were quite pronounced. It may be noted that these were the years when the upper troposphere over north and northwest India was either warmer or normal to warmer in the pre-monsoon and the early monsoon period as discussed in section 4 and the seasonal rainfall departure of India was positive (Fig. 6 bottom graph).

Position of such a 200 mb level trough during May 1972 and the ridge during May 1975 - the two very contrasting monsoon years; may be seen in the streamline analysis shown in the Fig. 7.

On the basis of the above mentioned observations in the flow field anomaly and the thermal field anomaly during the pre-monsoon period, and the rainfall activity of the monsoon over India, the following possible role of the upper tropospheric quasi-permanent trough/ridge in these processes is suggested.

The larger upper troposheric westerly momentum transport from the sub-tropical region of northwest India, associated with the quasi-permanent trough there, may result in upper tropospheric cooling during the pre-monsoon and early monsoon period over north India. This weaker thermal driving force in the upper troposphere, which plays an important role in maintaining the monsoon circulation, seems to affect the subsequent monsoon rainfall activity adversely. Conversely, lesser upper tropospheric westerly momentum transport from the sub-tropical region of northwest India, associated with the quasi-permanent ridge there, may result in upper tropospheric warming over north India during the pre-monsoon and early monsoon period. The stronger thermal driving force in the upper troposphere seems to affect the subsequent monsoon rainfall activity favourably.

8. Concluding remarks

The main results of the study are summarized as follows:

(*a*) Thickness and temperature anomalies in the monthly means at individual stations suggest that (*i*) warming/cooling of the upper troposphere is a large-scale phenomenon over north and northwest Indian region; (*ii*) this warming/cooling of the upper troposphere has a long persistency of about 4-6 months, beginning from the pre-monsoon months of April-May. It is most marked in the month of May.

(*b*) The Inter-annual variations during the period of 1967 to 1976 (and even a longer period of 20-years) suggest that :

(*i*) the warmer upper troposphere over north and northwest Indian region during the pre-monsoon months of April and May has generally good correspondence with the normal to above normal rainfall activity of the coming monsoon season over India and

(*ii*) the cooler upper troposphere over north and northwest Indian region during the pre-monsoon months of April and May has generally good correspondence with the normal to below normal rainfall activity of the coming monsoon over India.

(c) The contrasting monsoons also show some significant contrasts in the synoptic patterns during the pre-monsoon month of May. The poor monsoons are preceded by the upper tropospheric quasi-permanent trough in the sub-tropical westerlies over northwest of Indian region. The good monsoons are preceded by the ridge instead. It is suggested that this upper tropospheric quasi-permanent synoptic feature of pre-monsoon period possibly plays an important role in affecting the subsequent summer monsoon rainfall activity over India.

The later two results show association of the summer monsoon activity with the upper tropospheric anomalies observed in the thermal and wind fields during the pre-monsoon period. These results, therefore, may find useful application in long-range prediction of monsoon activity.

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References

Kanamitsu, M. and Krishnamurti, T. N., 1978, Northern summer tropical circulations during drought and normal rainfall months, *Mon. Weath. Rev.*, **106**, pp. 331-347.

Krishnamurti, T. N., Astling, E. and Kanamitsu, M., 1975, 200 mb wind field in June, July and August 1972, Dep. of Met., Florida State Univ., 115 p.

Murkami, T., 1974, Atmospheric response to heat sources during July. UHMET 74-04. Dep. Met., Univ. of Hawaii.

Murakami, T., 1975, Inter annual cloudiness changes, *Mon. Weath. Rev.*, **103**., pp. 996-1006.

Murakami, T., 1978, Regional energetics of the 200 mb summer circulations, *Mon. Weath. Rev.*, **106**, pp. 614-628.

Parthasarathy, B. and Mooley, D. A., 1978, Some features of a long homogeneous series of Indian summer monsoon rainfall, *Mon. Weath. Rev.*, **106**, pp. 771-781.