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Phases of the summer monsoon and oscillations of the equatorial trough

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ABSTRACT. In continuation of earlier studies by Pant (1978), the oscillations of the equatorial trough and the associated phases of the summer monsoon over the Indian subcontinent were studied. For this purpose, the data relating to MONEX-79 were also considered. A "weak" or "break" monsoon phase is associated with the insitu appearance of the planetary oceanic equatorial trough in the lower troposphere around 10° N. The revival of the monsoon activity is associated with the northward progress of the southern trough and its re-establishment around 20° N.

Study of mid-tropospheric temperature changes over Tibet and Sinkiang have brought out clearly that the setting in of "weak" or "break" monsoon condition is concurrent with the occurrence of very low temperatures in the middle troposphere, particularly over Sinkiang. The physical picture that emerges from this study is that under low zonal index conditions advection of cold air behind large amplitude middle latitude troughs results in cooling of the Tibetan Plateau and the neighbourhood in the middle levels. This results in the destruction of the reverse Hadley cell and re-establishment of the direct cell with its upward limb near 10-15 ° N. This is a physically consistent picture and explains many of the observed characteristics of the weak and active phases of the monsoon described by several authors.

The results of the study hold out possibilities of prediction of the phases of the monsoon over periods of a week to ten days based on the temperature changes over the Asian continent to the north of India.

1. Introduction

One of the important scientific objectives of MONEX-1979 (summer component) is to study the onset of monsoon. In this connection, the following important questions are raised:

(*i*) Does the ITCZ merely lose its identity in its equatorial position under the influence of the continentality (viz., continental monsoon trough)?

(*ii*) What are the dynamical mechanisms that describe the replacement of an oceanic ITCZ by a continental monsoon trough? Furthermore, what is their relation to the onset of monsoon?

In order to study the oscillations of the planetary equatorial trough, it is better to consider these at 700 mb, where the purely local effects don't penetrate. Further, synoptic experience has shown that features of circulation at 700 mb have greater significance for monsoon rainfall over the Indian sub-continent and surrounding areas.

Two of the well known phases of the summer monsoon are: (*i*) the "active" phase when large parts of India, including the central parts, get normal or above normal rainfall and (*ii*) the "break" in the monsoon when rains practically cease over most of the country including the central parts except the hill areas in the extreme north and the north-east and the southern Peninsula. In the active phase, the monsoon trough at 700 mb runs east-west at about 20° N over the Indian sub-continent. In the "break" monsoon phase, while the trough around 20° N disappears on many occasions, there is a trough around 10-15°N within which cyclonic vortices form, move in a westerly direction and cause an east-west band of rain in the southern Peninsula.

2. Weak monsoon

Pant (1978) reported the simultaneous existence of two troughs in the monsoon field, one in the northern Indo-Gangetic plains and another in the 10—15°N latitudinal belt across the southern Peninsula, during the summer monsoon

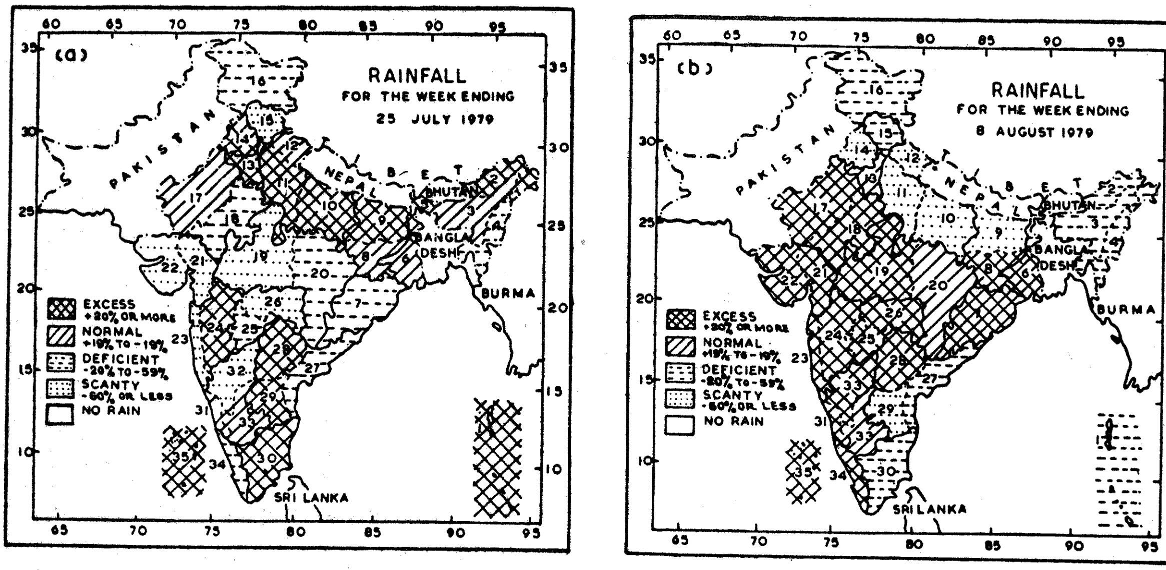


Fig. 1 (a—b). Percentage departure of rainfall from normal for the week ending (a) 25 July 1979 and (b) 8 August 1979

of 1977. Each one of these was associated with an east-west belt of precipitation with weak monsoon conditions over central parts of the country. This is different from the well known "break" monsoon conditions in that plains of north India also get good rainfall in this case. Rainfall in the southern Peninsula is common to both and is caused by the low pressure systems (Koteswaram 1950) which originate in the second low latitude trough and move east to west. Thus, regions which are normally in the rainshadow region of Western Ghats get rain during "breaks" and during the type of "weak" monsoon conditions reported by Pant. The position in which the second low latitude trough forms is also the normal position of the planetary equatorial trough over the Far East and the Pacific for this part of the year.

When "weak" or "break" monsoon conditions set in, there is an in-situ formation of the second trough in the south, and during the revival of the monsoon, there is a gradual northward shift of the southern trough until it comes to a position of about 20° N, normal for strong monsoon conditions. This northward shift of the equatorial trough is comparable to the one that occurs at the time of onset of monsoon but takes place much faster, *i.e.,* in about a week's time.

In any study of this nature, there is always a question as to how common or representative is the observed phenomenon. In order to find an answer to this question a few years synoptic charts were examined. It was found that the occurrence of two troughs simultaneously, one in the north and another in the south, was noticed in the last week of July 1973. From 2nd August 1973, the southern trough progressively moved northwards upto 15-20° N and resulted in the revival of the monsoon activity. The percentage departures of rainfall for the week ending 1 August 1973 shows two distinct belts of rainfall, one over northern plains and the other over extreme south Peninsula and Lakshadweep. Similar map for the week ending 8 August 1973 shows the strengthening of monsoon activity.

1979 monsoon has failed in several meteorological sub-divisions and weak monsoon conditions existed for over three weeks—a record. In this year also, the evolution from weak to strong monsoon conditions was similar to the one observed in 1973 and 1977. The maps showing the rainfall departures for the weeks ending 25 July 1979 and 8 August 1979 (Figs. 1a-1b) illustrate the "weak" and strong monsoon conditions respectively.

The evolution of the 700 mb circulation pattern between 23 July 1979 and 5 August 1979 (Figs. 2a-2c) is similar to the one observed in 1973 and 1977 and confirms its importance for monsoon rains over the Indian sub-continent.

Alexander et al. (1978) prepared the composite pentad anomaly charts and found that the anomaly trough slowly shifts northwards with the strengthening of the monsoon. This observation based on data for the period 1965-1973 confirms the hypothesis put forward above for the evolution of the monsoon circulation from a "weak" or "break" phase of the monsoon to an active phase.

3. Lull in the onset phase

After monsoon sets in over Kerala it does not always proceed regularly northward. Sometimes,

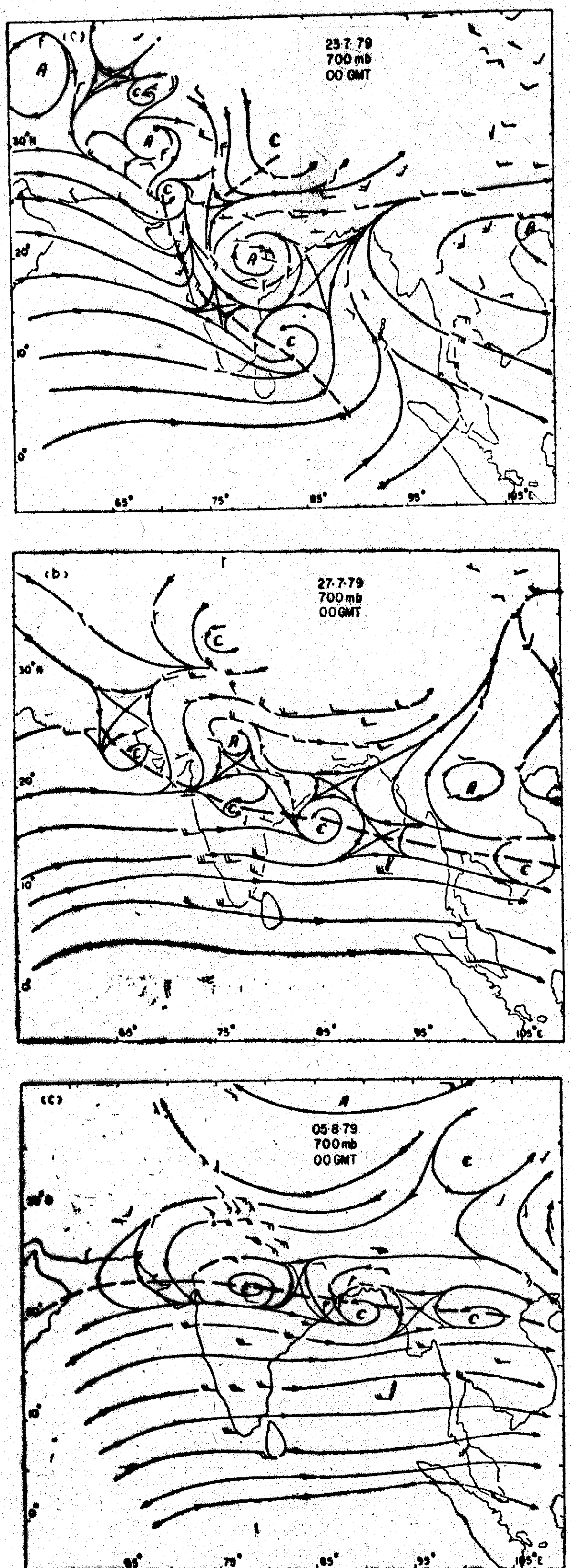


Fig. 2 (a—c). Evolution of the monsoon circulation between 23 July 1979 and 5 August 1979

it reaches a particular latitude and does not progress further for several days. It is interesting to see what happens to the planetary equatorial trough under these circumstances.

In 1976, there was a lull in the advance of monsoon from 9 June to 24 June and there was good progress from 25th onwards. It was seen that the monsoon trough which was far to the south during the "lull" also shifted northwards with the progress of the monsoon (Figs. 3a-3c).

In 1978, the advance of the monsoon was smooth and gradual without a lull of the type described above and the monsoon trough also progressed gradually northwards.

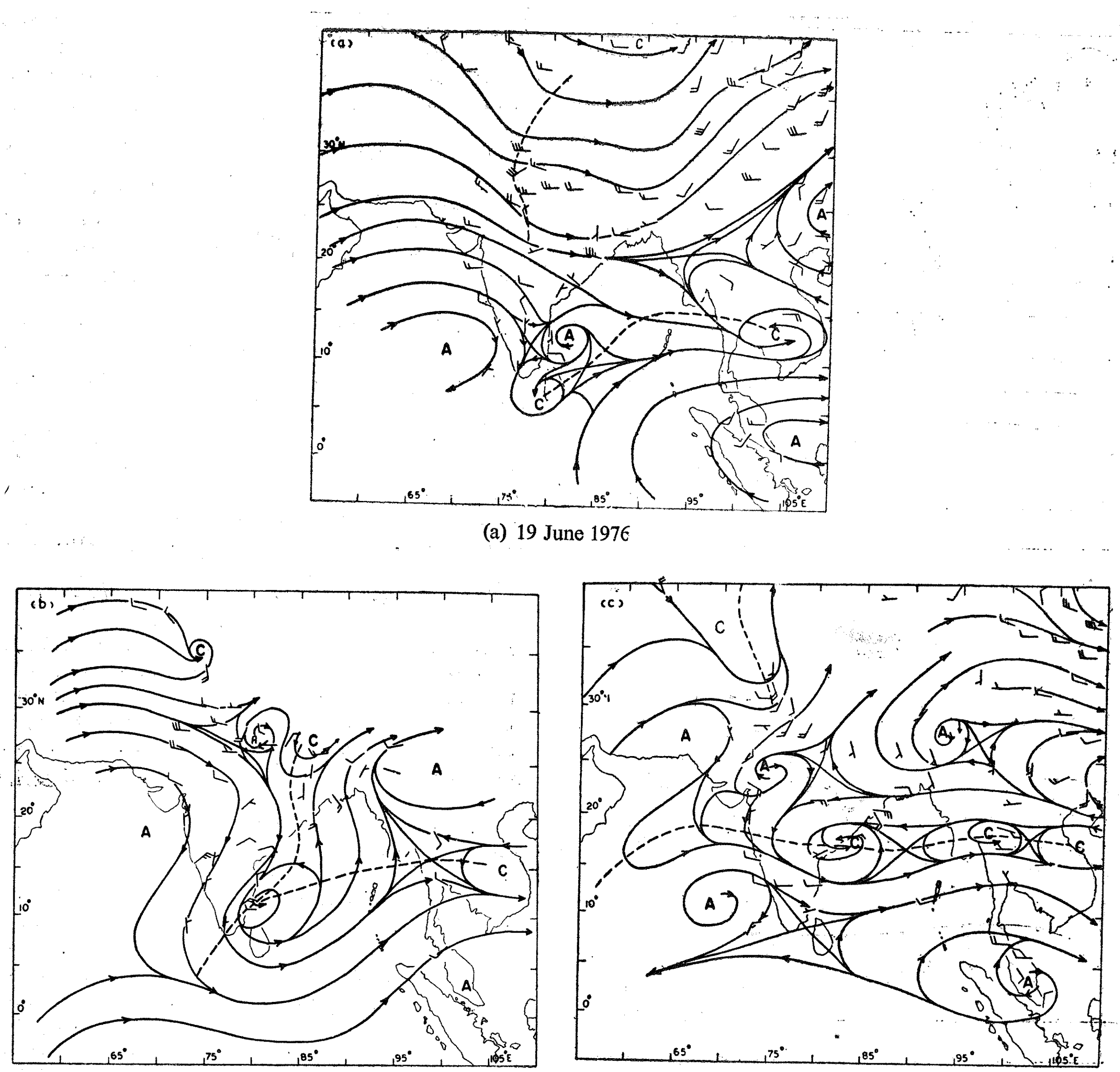
Thus it appears that during the onset and establishment phase of the monsoon also, the trough lies at low latitude whenever the progress of monsoon is arrested. As the monsoon's progress is revived, the trough also shifts northwards.

This behaviour of the monsoon trough raises many questions. Are there two monsoon troughs? If so, what is their origin? How can the sudden appearance of the trough in the south in a position preferred by the planetary equatorial trough, be explained? What is the forcing that shifts the southern trough to its normal active monsoon position?

On the planetary scale, in response to solar heating, the oceanic equatorial trough in the northern summer will be around 10°N at 700 mb. It is only over the Indian sub-continent that the planetary through extends upto 20°N apparently due to some additional forcing over the land mass of Asia. When this particular forcing is either weak or does not exist temporarily, then the latent planetary trough in the south appears. When the forcing gradually re-establishes, then the southern planetary trough is pulled, as it were, northward until it reaches its equilibrium position for an active monsoon condition. As far as the trough in the north is concerned, under "break" monsoon conditions, it disappears resulting in westerlies all over the subcontinent. The simultaneous existence of the two troughs is a special case in between the two extreme cases of 'active' and 'break' monsoon conditions discussed above.

4. Fluctuations in monsoon activity and 500mb temperature over Sinkiang and Tibet

Flohn (1960) and Koteswaram (1960) postulated that heating over the Tibetan plateau plays an important role in maintaining the monsoon trough in the Indo-Gangetic plains. The evidence that we have to look for initially is, therefore, a thermal forcing over the Asian land mass for maintaining the monsoon trough. An examination of the upper air temperature data of a



(a) 19 June 1976

(b) 21 June 1976

(c) 24 June 1976

Fig. 3. Evolution of the monsoon at 500 mb circulation between 19 June 1976 and 24 June 1976

few stations to the west of Tibetan Plateau and over the plateau have brought out some interesting facts. 500 mb level is chosen for this purpose as it is the standard level which can represent the conditions over Tibetan Plateau well.

500 mb temperature data of five upper air stations, three of which are in Sinkiang, bordering the Tibetan Plateau in the north (51709, 51828 and 51777) and two located in the southeastern Tibet (55591 and 55299) were examined. Of these, data for 51709 (Kashi-39° 28′ N 75° 59′ E) and 55299 (Nagqu-31° 29′ N 92° 03′ E) were more regularly available on the charts of Regional Meteorological Centre, (WWW) New Delhi. It was noticed that 500 mb temperature changes during the summer monsoon were much larger at Kashi (51709) in Sinkiang compared to those at Nagqu (55299) in Southern Tibet. Further, temperatures over Nagqu in Tibet were about 5°C higher than over Kashi in Sinkiang. But the general direction of change (increase/decrease) was similar at both the stations on all important occasions. The changes observed at Kashi will be discussed below:

Taking up the 'weak' monsoon case first, on 23 July 1979, the 500 mb temperature was as low as —12°C and begain rising from 25th reaching high values of —2°C to —1°C between 1 to 3 August 1979 (Fig. 4a). Northward shift of the monsoon trough and revival of monsoon occurred during the above period of gradual rise in temperature. The rise is about 10°C and occurred over a period of 10 days. The description of the evolution of weather systems given

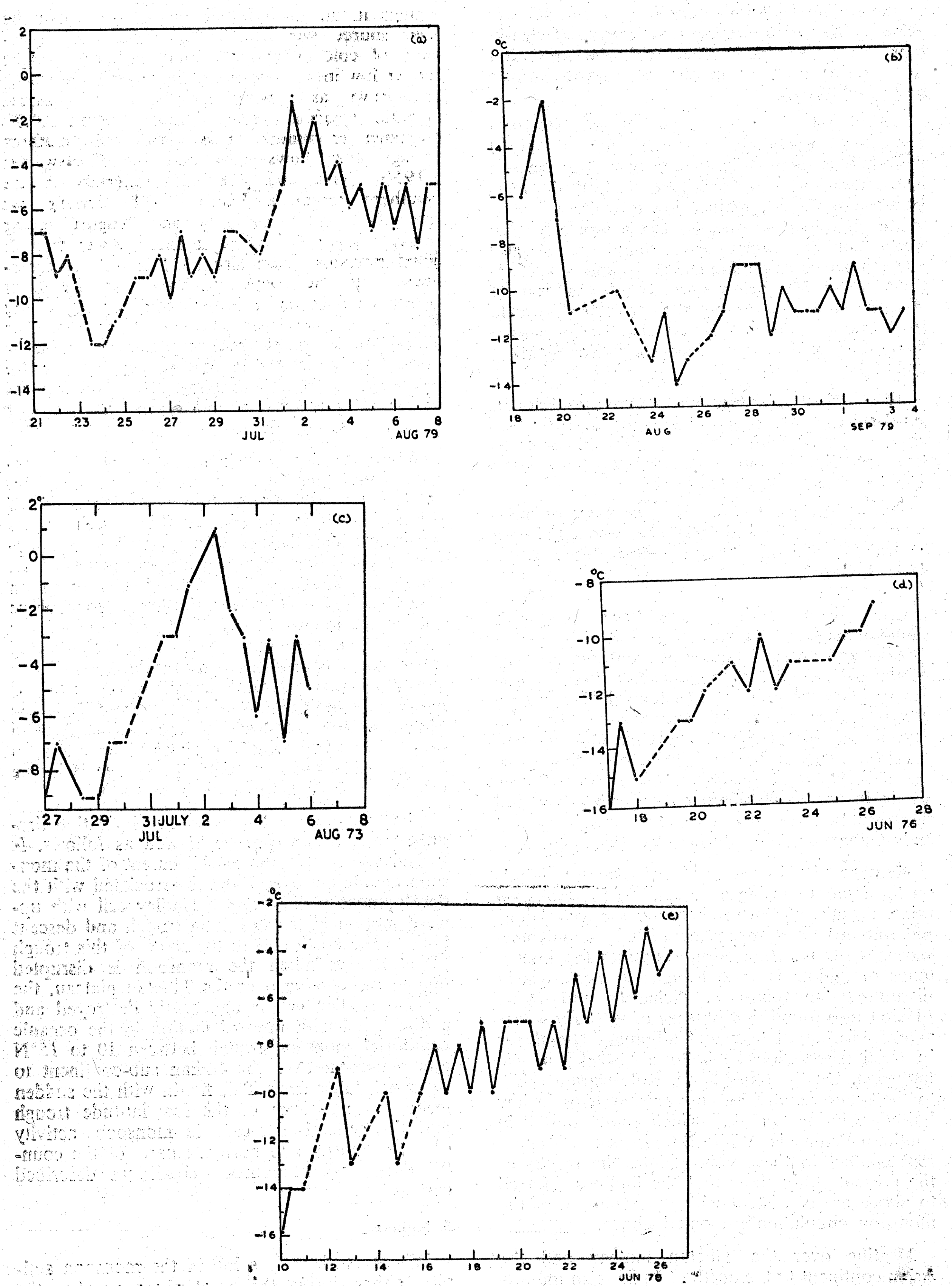


Fig. 4 (a-e).—500 mb temperature at Kashi (Lat.39° 28′ N, Long. 75° 59′ E) in the *Indian Daily Weather Report* and *Weekly Weather Report* for this period brings out clearly how the revival took place with the formation of a series of lows in the northward shifting monsoon trough.

The break that set in on 19 August 1979 continued practically unabated for a record period. It is interesting to note that after the rise in temperature in early August, the 500 mb temperature at Kashi remained low near about —8°C in the first half of August. There was a further steep fall in temperature around 20 August and temperatures remainde low around —11°C to —12° (6 to 7°C below normal) till the end of August (Fig. 4b). Thus the prolonged 'break' in monsoon in 1979 was associated with a relatively long spell of low temperature over Sinkiang and Tibet.

The revival of monsoon activity and northward shift of the trough at 700 mb in 1973 was also associated with a rise in 500 mb temperature at Kashi from —9°C on 29 July 1973 to about 0°C on 2 August (Fig. 4e).

During the onset phase also, progress of monsoon both in 1976 and 1978 was associated with a gradual rise in 500mb temperatures [Figs. 4(d) & 4(e)].

Comparison with temperatures occurring simultaneously at Delhi brings out that during "weak" and "break" phases of monsoon, a strong northward gradient of temperature builds up in the middle troposphere. The revival of monsoon activity takes place with the decrease or even reversal of this gradient. These changes in temperature gradient are physically consistent with the observed fact of predominance of westerly winds in the troposphere over north India and disappearance of the monsoon trough in the Indo-Gangetic plains during "breaks".

Ramage (1971) reviewed different view points on the factors causing a "break" in the monsoon rains. Prominent among them are the suggestions put forward by Ramaswamy (1962) and Koteswaram (1950). Ramaswamy stresses the importance of middle latitude troughs in westerlies in disrupting the monsoon. Pisharoty and Desai (1956) also found that passage of westerly waves across Tibetan Plateau and adjoining Himalayas in quick succession leads to a "break" in the monsoon. On the other hand, Koteswaram refers to the occurrence of low pressure systems in low latitudes during "breaks" which cause rainfall in southern Peninsula. While Ramage sees an apparent conflict in these view points, the results of the present study show that the findings referred to above are consistent with the evolution of the monsoon circulation presented above.

Heating over the Tibetan Plateau and the Asian continent to the north of India is an important "forcing" for maintaining the monsoon trough in the north Indian plains. But when the heat source over Tibet is "quenched", by intrusion of cold polar air behind westerly troughs under low index conditions, monsoon temporarily withdraws, as it were, and the latent seasonal oceanic trough in the low latitude (around 10° N) becomes prominent. It is within this southern trough that 'lows' described by Koteswaram (1950) form and give rain generally in the southern Peninsula, Pant's (1978) finding that the zonal index for July and August during drought years like 1972 is much lower than in good monsoon years like 1975 is also in agreement with the above hypothesis. In the years when zonal index is lower than normal during July and August, intrusions of polar air over Tibet will be more frequent resulting in below normal temperatures in that region. As per the results presented in this paper, low temperatures in the Tibetan region will result in 'weak' or 'break' monsoon condition.

When the 'forcing' (heating) over Asia is re-established, there is a fresh onset of monsoon, as it were, with the gradual northward shift of the low latitude trough. As the trough moves northward, the place of formation of 'lows'/'depressions' also shifts northward upto the head Bay. Thus the South-North shift of the monsoon trough is very well seen in the lower troposphere and is an important mode of oscillatin of the monsoon circulation. Just as Tamil Nadu and other parts of southern peninsula east of the Western Ghats get rain during 'break' or 'weak' monsoon conditions, it is learnt from Burmese Meteorologists that areas to the east of Arakan ranges get rain during the phase when monsoon is weak over India or when the trough is in the process of shifting from south to north.

The evolution of the monsoon circulation described above can also be viewed as follows. It is well known that the establishment of the monsoon circulation over India is associated with the development of the reverse Hadley cell with upward motion in the monsoon trough and descent both to the north and to the south of this trough (Pant 1978). When the monsoon is disrupted due to the cooling over the Tibetan plateau, the reverse Hadley cell is apparently destroyed and a direct cell with upward motion in the oceanic equatorial monsoon trough between 10 to 15°N and a descent over the Indian sub-continent to the north takes over. This fits in with the sudden insitu re-appearance of the low latitude trough and the general decrease in monsoon activity over the central and northern parts of the country during weak monsoon conditions described earlier.

5. Summary

Whenever there is a lull in the monsoon activity, either during the onset phase or after the establishment of monsoon, a trough in the lower

troposphere appears at about 10°N, the preferred position for the planetary oceanic equatorial trough during northern summer. The revival of the progress of monsoon or a revival of the monsoon activity from a 'break' or 'weak' monsoon condition is associated with a gradual northward shift of the trough as during the onset phase. 'Weak' monsoon conditions and a 'lull' in the progress of the monsoon appear to be associated with a cooling over Sinkiang and Tibet. The revival of monsoon activity and progress in monsoon are associated with mid-tropospheric heating. Thus heating over Sinkiang and Tibet as a whole is an important forcing responsible for maintaining the summer monsoon trough in the plains of north India. Advection of low temperature associated with large amplitude middle latitude troughs seems to play an important role in cooling the Tibetan plateau. While the fall in temperature takes place rapidly (over one or two days) the recovery takes much longer, a week to ten days.

The present study throws some new light on the evolution of the circulation during different phases of the monsoon and its relation to the forcing over Asian landmass. Apart from this, the slow evolving changes in circulation and the associated rainfall pattern identified in this study are useful for indicating areas of monsoon activity in the 3-7 days range. Such weather outlooks during monsoon season will be beneficial to the farmers.

Further work defining the limits of cooling (heating) required over Tibetan Plateau and surroundings in order to disrupt (activate) the monsoon over the country is in progress. Methods of predicting different phases of the monsoon on the basis of results described here will be presented in a forthcoming paper.

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