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Thickness advection at the 500-mb surface in relation to very heavy rainfall

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ABSTRACT. Thickness and contour analyses of 700, 500 and 300-mb pressure surfaces were made for some spells of very heavy rainfall along the West Coast of India during the monsoon season, 1958. It is shown that areas of warm advection indicated by the contour-thickness grids at the 500-mb surface represented regions of very heavy rainfall more readily than those at other pressure surfaces.

1. Introduction

The southwest monsoon over India during 1958 (June—September) was characterised by spells of heavy to very heavy rainfall along the west coast, under synoptic situations uninfluenced by depressions. Some stations in the Konkan and over the Deccan Ghats notably Bombay, Dahanu, Khandala, Lonavala and Mahabaleshwar set up new records for heaviest daily or seasonal rainfalls. Although influx of moisture and the orography of the Western Ghats would have obviously influenced such heavy downpours, occasions of very little rainfall on the windward sides of the mountains when apparently similar monsoon current strikes them are not rare. As pointed out by Sawyer (1952), orography augments the rainfall only when favourable dynamical factors producing upward motion are available. Sutcliffe's theory of thickness patterns enables one to locate areas of increasing convergence at sea level by computing the thermal divergence upto the level of non-divergence (assumed to be 500-mb level) (Sutcliffe and Forsdyke 1950). In spite of the non-validity of the geostrophic assumption in the tropics, fairly good qualitative results were obtained by the use of this theory over Indian areas north of Lat. 10°N in earlier studies (George 1953; Mull, Gangopadhyaya and George 1955), wherein it was shown that the sea level convergence, measured by the thermal divergence upto the 500-mb level was maximum over regions of steepest ascent of the diffluent portions of the 1000-500 mb thickness over the contours. These were regions of maximum warm advection within the 1000-500 mb layer. Active 'weather' was noticed over these areas in the situations studied as well as in the field of depressions (Koteswaram and George—*see reference*). Sea level divergence and absence of weather occurred over regions of cold advection at the 500-mb level.

In the present study, some selected spells of very heavy rainfall along the west coast during the monsoon mentioned above have been analysed and their relation to the warm advection indicated by the contour-thickness grids at the 500-mb surface is pointed out.

2. Importance of 1000-500 mb thickness patterns during the monsoon season

The wind circulation over India during the southwest monsoon season suggests in general a single level of non-divergence near about the 500-mb level, in so far as cyclonic circulations extending upto about this level produce appreciable 'weather' in those sectors where the zones of convergence associated with them are superposed by the diverging portions of easterly waves or jet streams which exist above this level. This observed behaviour enables one to infer a two-layered structure for the atmosphere during the monsoon. In such an atmosphere, the convergence at sea level in accordance with Sutcliffe's theory can be truly represented only by the thermal divergence upto the level of non-divergence, *i.e.*, within the 1000-500 mb layer. As pointed out earlier, this divergence can be assessed by the extent of warm advection indicated by the contour-thickness grids at the 500-mb surface.

During the monsoon, the atmosphere is in neutral equilibrium for moist air as the lapse rate approaches the saturation adiabatic. Hence, as pointed out by Venkataraman (1955), thermal stability sufficient to inhibit vertical ascent caused by dynamical factors over areas of warm advection is absent in active monsoon area. For routine forecasting purposes, therefore, zones of warm advection at the 500-mb surface can be identified as areas of heavy rainfall, provided other factors such as orography, availability of moisture, pre-existence of a zone of convergence at sea level etc are given due consideration.

On a constant pressure surface, isotherms correspond to isentropes. Assuming uniform lapse rate upto the pressure surface, the thickness configuration indicates the slope of an isentropic surface, having the 'valley' over the warmest region (highest thickness) and the 'hill' over the coldest area (lowest thickness). Thus warm (positive thickness) advection implies isentropic ascent and cold (negative thickness) advection indicates isentropic descent of air. Although isentropic movement of air may not be valid under widespread convective activity, it appears to lead to the formation of thick layer clouds such as, altostratus and nimbostratus during active monsoon when the atmosphere is generally in neutral equilibrium as stated earlier. As these clouds extend well above the 500-mb level (Venkateswara Rao 1955) and since the zero isotherm is near about this level, warm advection at the 500-mb surface, rather than that at the 700-mb surface can be expected to be intimately related to the very heavy rainfall resulting from such clouds.

3. Analyses of some spells of very heavy rainfall

Among the various spells of heavy to very heavy rainfall that occurred at a number of places over contiguous areas along the west coast, those recorded at 0300 GMT of 26 June, 11 July, 19 July and 24 August 1958 were analysed and discussed here as illustrations. 700-mb and 500-mb contour charts are prepared by the differential method in the usual manner by gridding 1000-mb contours and the appropriate thicknesses. As the radiosonde height values at higher levels were not quite reliable, streamlines instead of contours are drawn on the 300-mb charts, on which the relevant thermal winds and their flow lines are also shown. The grids between these two flow lines would indicate qualitatively the nature and extent of advection, if any, at this level, just as the contour-thickness grids at the lower pressure surfaces. The charts so prepared for 1200 GMT on days prior to the occurrence of the very heavy falls mentioned above are given in Figs. 1-4 (a–c). Thermal troughs and ridges are located on these charts from sequences observed a few days prior to and after these dates. Areas of very heavy rainfall exceeding 8·5 cm are shown by hatching on the appropriate 500-mb charts, given in Figs. 1b–4b. These charts are described briefly below.

3.1. *Vigorous monsoon over the Konkan on 26 June 1958*—Vigorous monsoon conditions prevailed over the Konkan on the 25th-26th and heavy to very heavy rainfall occurred at a number of places during the

24 hours ending 0300 GMT of 26 June. The chief amounts were—Bombay (Santacruz) 23·2 cm, Colaba 16·0 cm and Mahabaleshwar 11·2 cm.

Figs. 1a—1c represent the 700-mb and 500-mb contours and 300-mb streamline charts at 1200 GMT of 25 June 1958. It could be seen that, over the area of very heavy rainfall, thickness advection was maximum at the 500-mb surface, appreciable at the 700-mb surface and negligible at the 300-mb level. Upto the 500-mb level (Figs. 1a—1b) this advection occurred over the forward sector of an advancing thermal trough and the associated thermal divergence would have increased cyclonic vorticity over and near the sea level trough which was pre-existing over the area where maximum rainfall also occurred.

3.2. *Spell of very heavy rain on 11 July 1958*—Under the influence of the first monsoon depression which formed over the north Bay of Bengal on 9 July and moved west-northwestwards into northwest Madhya Pradesh and weakened there by the morning of 11th, monsoon became vigorous in Saurashtra and north Konkan and strong in south Konkan and Maharashtra. Very heavy falls of rain were reported from a number of stations in these areas by 0300 GMT of 11 July, chief amounts being Mahabaleshwar 29·8 cm, Khandala 26·6 cm, Bombay (Santacruz) 24·1 cm, Dwarka 23·5 cm, Porbandar 23·2 cm, Dahanu 16·1 cm and Bombay (Colaba) 10·6 cm.

The upper air charts given in Figs. 2a—2c show that warm advection over the area of very heavy rain was greatest at the 500-mb level, small at the 700-mb and 300-mb levels. As in the earlier case described in Sec. 3.1, the thermal divergence at the 500-mb level would have increased sea level convergence over the area of heaviest falls, which occurred in the forward sector of the thermal trough at the 500-mb level.

3.3. *Highest 24-hour rainfalls on 19 July 1958*—An upper level trough developed over the north Konkan, north Maharashtra and west Madhya Pradesh and the monsoon became vigorous in the north Konkan on the 19th. Exceptionally heavy falls occurred in and near the Deccan Ghats. Khandala recorded 51·6 cm, Lonavala 43 cm and Mahabaleshwar 38 cm of rain by 0300 GMT of this day. These amounts were greatest falls on record for a single day for these stations. Very heavy falls were also reported from many other stations in north Konkan on this day.

It is interesting to see from the charts in Figs 3a—3c that, over the area of maximum rainfall, there was warm advection at the 500 and 300-mb levels, while the advection was cold at the 700-mb level. The warm advection and associated thermal divergence at the 700-mb was over Saurashtra and northeast Arabian Sea far removed from the region where very heavy rainfall actually occurred.

3·4. *Strong to vigorous monsoon in the Konkan on 24 August 1958*—During the week ending 27 August 1958, the axis of the seasonal trough lay close to the foot of the Himalayas between 23rd and 26th; but a feeble upper air trough extending from Saurashtra to Orissa persisted between 2 and 4 km till 26th. Under its influence, locally heavy to very heavy rain occurred in Konkan on most days of the week. Bombay (Santacruz) had 21·8 cm, Colaba 17·9 cm, Harnai 17·1 cm, Ratnagiri 13·3 cm, Mahabaleshwar 11·7 cm and Vengurla 10·1 cm of rain by 0300 GMT of 24th.

It can be seen from Figs. 4a—4c, that over the area of heavy rain indicated in Fig. 4b, warm advection at the 500-mb surface was as unmistakable as the cold advection at the 700 and 300-mb levels (Figs. 4a and 4c) on this occasion.

4. Conclusion

It would be clear from the foregoing that the heavy rainfall along the west coast under study occurred over regions of warm advection within the 1000–500 mb layer as revealed by the contour-thickness grids at the 500-mb surface.

5. Acknowledgement

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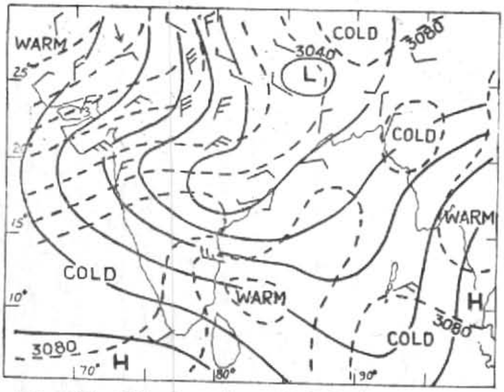

Fig. 1(a). 700-mb contours (full lines) and thicknesses upto the pressure surface (dotted lines) drawn at intervals of 20 gdm

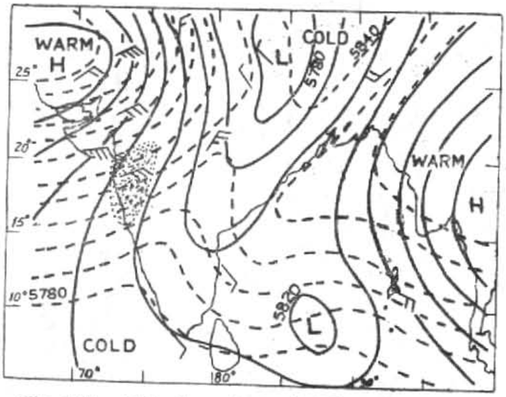

Fig. 1(b). 500-mb contours (full lines) and thicknesses upto the pressure surface (dotted lines) drawn at intervals of 20 gdm

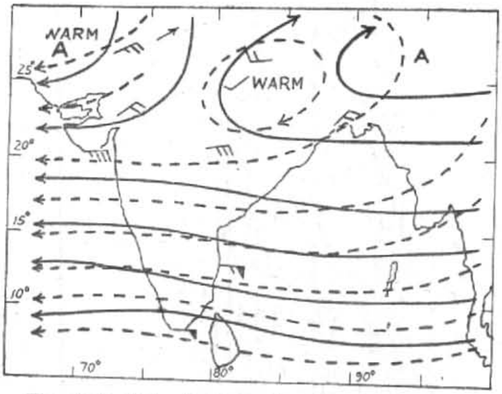

Fig. 1(c). 300-mb streamlines (full lines) and flow lines corresponding to the thermal winds (dotted lines) upto the pressure surface

Figs. 1(a) to 1(c). 25 June 1958 (1200 GMT)

Only the thermal winds from 1000 mb (0·6 km), 700 mb (3·0 km), 500 mb (6·0 km) and 300 mb (10·5 or 9·0 km, whichever level available) have been plotted on charts (a), (b) and (c). Pennant is shown by a filled triangle; the lowest contours and lowest thicknesses in Figs. 1(a) and 1(b) alone have been labelled with their actual height values in gdm. The area of heavy to very heavy rainfall along the West Coast has been shaded in Fig. 1(b).

H—Contour high L—Contour low A—Anticyclonic circulation

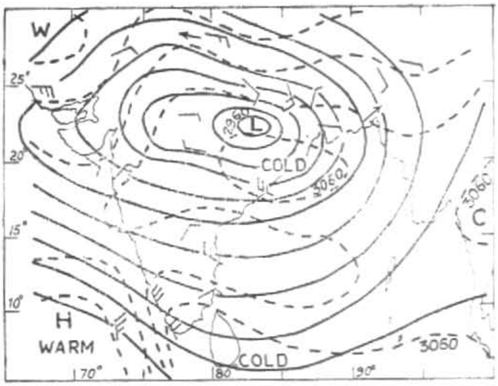

Fig. 2(a). 700-mb contours (full lines) and thicknesses upto the pressure surface (dotted lines) drawn at intervals of 20 gdm

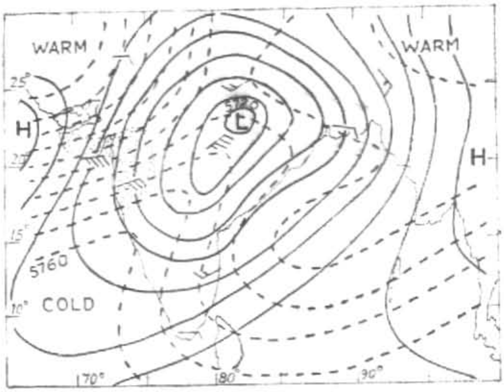

Fig. 2(b). 500-mb contours (full lines) and thicknesses upto the pressure surface (dotted lines) drawn at intervals of 20 gdm

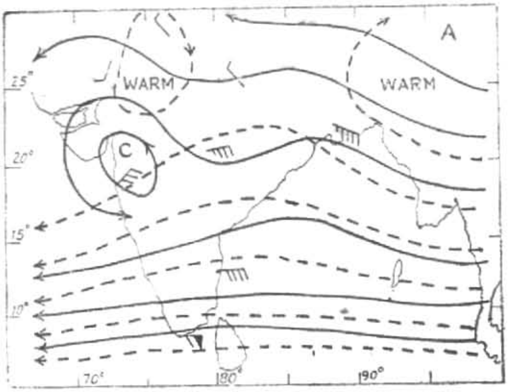

Fig. 2(c). 300-mb streamlines (full lines) and flow lines corresponding to the thermal winds (dotted lines) upto the pressure surface

Figs. 2(a) to 2(c). 10 July 1958 (1200 GMT)

Only the thermal winds from 1000 mb (0·6 km), 700 mb (3·0 km), 500 mb (6·0 km) and 300 mb (10·5 or 9·0 km, whichever level available) have been plotted on charts (a), (b) and (c). Pennant is shown by a filled triangle; the lowest contours and lowest thicknesses in Figs. 2(a) and 2(b) alone have been labelled with their actual height values in gdm. The area of heavy to very heavy rainfall along the West Coast has been shaded in Fig. 2(b).

H—Contour high L—Contour low A—Anticyclonic circulation C—Cyclonic circulation

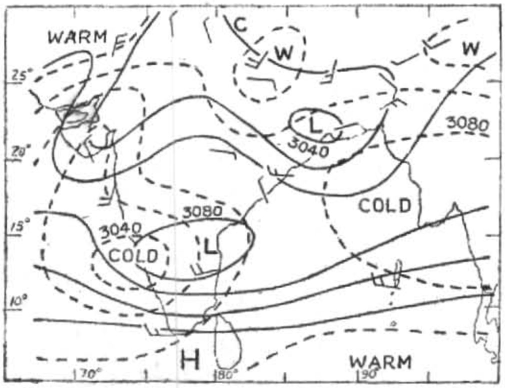

Fig. 3(a). 700-mb contours (full lines) and thicknesses upto the pressure surface (dotted lines) drawn at intervals of 20 gdm

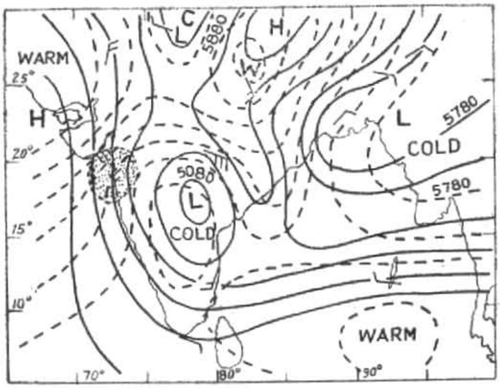

Fig. 3(b). 500-mb contours (full lines) and thicknesses upto the pressure surface (dotted lines) drawn at intervals of 20 gdm

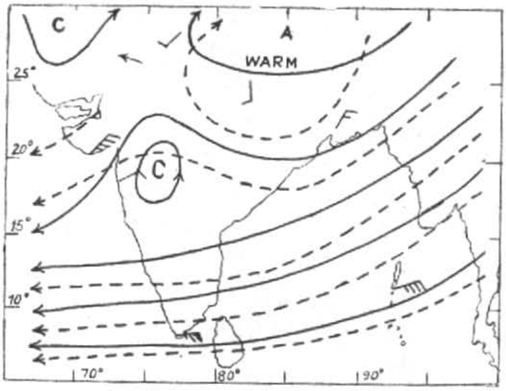

Fig. 3(c). 300-mb streamlines (full lines) and flow lines corresponding to the thermal winds (dotted lines) upto the pressure surface

Figs. 3(a) to 3(c). 18 July 1958 (1200 GMT)

Only the thermal winds from 1000 mb (0·6 km), 700 mb (3·0 km), 500 mb (6·0 km) and 300 mb (10·5 or 9·0 km, whichever level available) have been plotted on charts (a), (b) and (c). Pennant is shown by a filled triangle; the lowest contours and lowest thicknesses in Figs. 3(a) and 3(b) alone have been labelled with their actual height values in gdm. The area of heavy to very heavy rainfall along the West Coast has been shaded in Fig. 3(b).

H—Contour high L—Contour low A—Anticyclonic circulation C—Cyclonic circulation

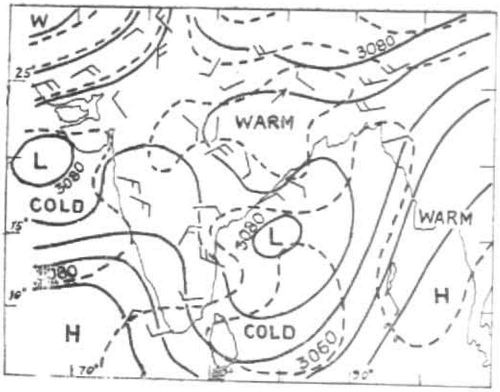

Fig. 4(a). 700-mb contours (full lines) and thicknesses upto the pressure surface (dotted lines) drawn at intervals of 20 gdm

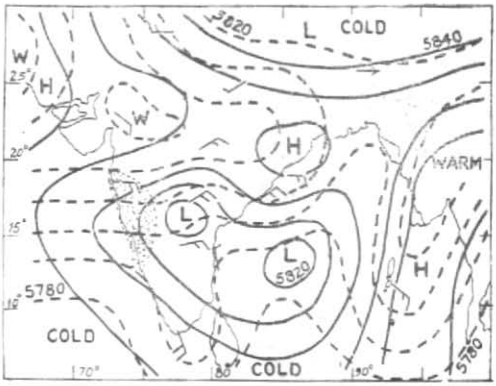

Fig. 4(b). 500-mb contours (full lines) and thicknesses upto the pressure surface (dotted lines) drawn at intervals of 20 gdm

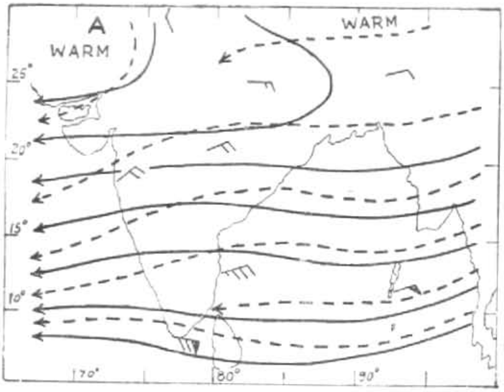

Fig. 4(c). 300-mb streamlines (full lines) and flow lines corresponding to the thermal winds (dotted lines) upto the pressure surface

Figs. 4(a) to 4(c). 23 August 1958 (1200 GMT)

Only the thermal winds from 1000 mb (0·6 km), 700 mb (3·0 km), 500 mb (6·0 km) and 300 mb (10·5 or 9·0 km, whichever level available) have been plotted on charts (a), (b) and (c). Pennant is shown by a filled triangle; the lowest contours and lowest thicknesses in Figs. 4(a) and 4(b) alone have been labelled with their actual height values in gdm. The area of heavy to very heavy rainfall along the West Coast has been shaded in Fig. 4(b).

H—Contour high L—Contour low A—Anticyclonic circulation