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Trough of low pressure over the Gangetic Valley during the southwest monsoon season and its implications — A suggested new approach

B. N. DESAI

173, Swami Vivekananda Road, Vile Parle (West), Bombay

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ABSTRACT. Current ideas about the trough of low pressure over the Gangetic Valley, facts of weather and climatology during the southwest monsoon season and the role of the topographical features of the Indo-Pakistan subcontinent in the formation of the trough, have been stated briefly. A new approach about the establishment of the trough is suggested and implications of the same are discussed.

1. Introduction

As the activity of the southwest monsoon in terms of rainfall over the Indian subcontinent is closely associated with the seasonal trough of low pressure, considerable attention has been given to the study of its development, maintenance and intensification. The movement of the troughs in the westerlies has been considered since long to affect the activity of the trough and this aspect has been intensively studied since more upper air data became available. It is proposed to review briefly in this communication the various factors associated with the trough with a view to understand their significance.

2. Current ideas about the trough

The physical causes of the monsoon winds are to be found in the thermally controlled seasonal migration of the planetary pressure and wind belts in the continental sections of the globe and seasonally changing differential heating of land and sea. This results in the low pressure area over the West Pakistan and the associated trough extending southeastwards to southwest Bengal. It is believed that the burst of the monsoon over India–Burma area occurs only when the semi-permanent upper air trough in the westerlies near 90°E disappears and two troughs appear, one along 65° to 68°E to the west of the Tibetan plateau and the other to its east along 100° to 105°E, the westerly jet at the same time shifting from its position to the south of the plateau to its north (Flohn 1965). Simultaneously a warm anticyclone gets established over Tibet.

The points mentioned above would make one incline to the view that the burst of monsoon over the India–Burma area occurs only when the western disturbances or the troughs in the westerlies cease to travel along the southern periphery of the Himalayas. If the troughs in the westerlies take a more southerly course, the activity of the seasonal trough of low pressure is considered to get affected adversely. The movement of the trough to the foot of the Himalayas or its total disappearance in spite of the "heat low" continuing over West Pakistan, is believed to result from the persistent movement of the troughs in the westerlies along the southern periphery of the Himalayas; such movements also coincide with the movement southwards of the westerly jet and weakening, distortion or disappearance of the Tibetan "high". In 1954 the mean monthly upper air contours for July showed a "low" to the north of the eastern Himalayan range instead of the "high" in the normal monthly charts (Pisharoty and Desai 1956); this resulted in heavy rain and unprecedented floods in Assam, north Bengal and Bihar. A review of the work, however, shows that there are many occasions when the monsoon trough gets established over the subcontinent even before the westerly jet shifts to the north of Tibet; the Arabian Sea branch of the monsoon has actually extended at times into the Punjab *via* Gujarat and east Rajasthan before the Bay current had extended even to Uttar Pradesh.

It is also considered by some that the establishment of the easterly jet is associated with the advance of the monsoon.

Ramamurthi and Jambunathan (1965) have observed that weakening of the westerlies or the northward shift of the upper tropospheric westwind maximum over north India or the appearance of strong upper level easterlies over the south Peninsular India, are *not* pre-requisite conditions for ushering in the monsoon rains. This would also mean that the establishment of the seasonal trough of low pressure need not necessarily take place *only after* the northward shift of the westerly jet or the establishment of the easterly jet.

In view of what has been stated above, one might incline to the view that the causes of the establishment of the seasonal trough might be even

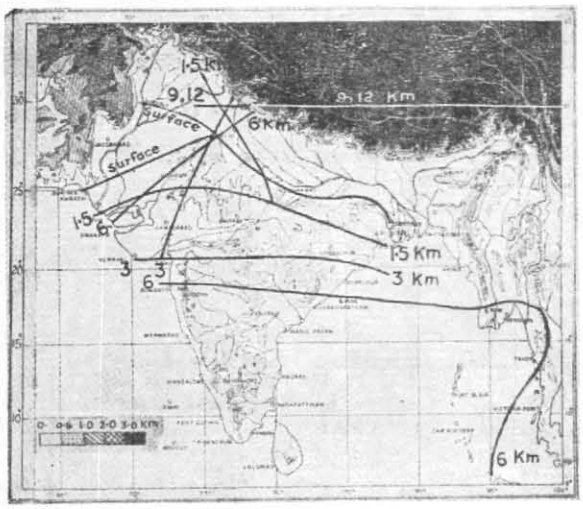

Fig. 1

independent of the movement of the westerly jet to the north of Tibet or of the troughs in the westerlies across more northerly latitudes than in April and May, although they might affect its activity from the point of rainfall and make the depressions from the Bay moving west to northwest, take a more northerly course to north or northeast.

3. Summary of facts of weather, climatology and topography

According to known facts of weather and climatology of the Indian subcontinent during the southwest monsoon season, there is (1) a heat low (shallow in vertical extent) over West Pakistan, but with little rain, (2) a trough of low pressure over the Gangetic Valley, its axis extending from near Delhi to Calcutta and slopping equatorwards with height — position at 6·0 km being near Lat. 19°N over the Peninsula (Fig. 1), with well-distributed rain to the south of its position at the surface between 75° and 85°E upto a distance of about 200 miles even in the absence of depressions from the north Bay and (3) absence of the trough during breaks in the monsoon, rain being confined to the Himalayas and the submontane districts. It is also known that the topographical features of the subcontinent (Fig. 1) play an important role in (1) the distribution and intensity of rainfall (Simpson 1921), (2) the location of the heat low and giving rise to the trough of low pressure over the Gangetic Valley (Banerji 1930, 1931), (3) making the southwest monsoon a large-scale self-sustaining cyclonic circulation in the lower levels of the atmosphere (Petterssen 1953), (4) deflecting the southwesterly to westerly moist current over the Bay of Bengal northwestwards to the east Punjab through Bengal, Bihar and Uttar Pradesh, the tropical easterlies being present only above about 4·0 km (Simpson 1921, Desai 1951a) and (5) changing the characteristic airmass stratification (lower moist air — deflected trades about 1·5 km deep — and upper relatively drier unstable westerly air from northeast Africa and Arabia with an inversion or isothermal layer between the two) over the Arabian Sea west of about 68°E into a more or less homogeneous air mass about 6·0 km deep over the Peninsula (Desai 1966a, 1966b, 1966c, 1967).

At the western end of the axis of the Gangetic Valley trough there is a wedge of drier continental air associated with the West Pakistan heat low (Fig. 1) to the south of the wedge there is southwesterly to westerly moist air and to its north the easterly to southeasterly deflected moist air except above about 4·0 km where there is tropical easterly air (Desai 1966c). To the west of the partition running northwestwards at 1·5 km and northeastwards at 3·0 and 6·0 km there is drier continental air.

The partition between the middle latitude westerlies and the tropical easterlies at 9·0 and 12·0 runs along about 30°N across Tibet (Fig. 1) during the normal as well as active and weak monsoon conditions (Desai 1966c); the position of the partition between the westerly and easterly air at 6·0 km given in Fig. 1 of the 1966 paper has been slightly modified – Fig. 1 of this paper (*also* Desai 1967) in view of the observations after 1956 over the area.

Further, over the region of the trough where rain falls temperatures are actually low and where rain is prevented they are high; during break in the rains, temperatures rise and the trough is absent. Thus the trough of low pressure over the Gangetic Valley would not appear to be essentially a consequence of heat but of the topographical features of the country (Banerji 1930, 1931), although the low over West Pakistan is due wholly to high temperatures; the westerly jet which is to the north of the monsoon low is not a part of it (Petterssen 1953).

4. Suggested new approach about establishment of the trough over the Gangetic Valley

The change of wind direction from southeast (trades) to southwest to west (deflected trades) takes place at 2—3°S during the northern summer; a trough comes into existence to the south of the equator between about 60° and 110°E (Desai 1966c). In April and May under the influence of the heat low over and near the central parts of the country, there is already influx of moist southwesterly to southerly winds into Burma, Assam and Bengal and as such, the southern hemisphere air which is flowing near the equatorial latitudes

as a result of the trough to the south of the equator, gets into the circulation over the Bay causing early occurrence of monsoon there; the air associated with the equatorial trough and in which there is generally no inversion upto about 6·0 km, might even be called equatorial monsoon air, distinct from the air that crosses the equator to the west of 60°E and in which there is an inversion between about 900 and 800 mb (Desai 1966a, 1966b, 1966c, 1967). At this time over the east Arabian Sea, there is still air of land origin — northwesterly winds — extending upto the southern tip of the Peninsula. As the monsoon air extends northwards into the Bay due to deflection of the same by the Burma coast mountains and northwestwards to the Punjab due to further deflection by the Assam mountains and the Himalayas as mentioned earlier, the trough of low pressure over the Gangetic Valley gradually develops and the northwesterly winds over the east Arabian Sea back to west to southwest and the deflected trades get into circulation over the Arabian Sea and are drawn towards the west coast of India at the beginning of June; as a result the trough over the Gangetic Valley still becomes better oriented and defined and the monsoon current extends over other parts of the country. With the establishment of this trough, there is easterly flow (southwesterly to westerly moist air which has travelled over the Peninsula and the Bay or the monsoon air which has entered the Bay directly and got deflected by the Burma coast and Assam mountains and the Himalayas and with which subsided air from the mountains has got mixed) to the north of its axis upto about 4·0 km; higher up there are tropical easterlies to the north of the trough axis. The high pressure area gets established over Tibet and troughs in the westerly current come into existence along about 65—68°E and 105—110°E, their southern end extending to about 30°N (Flohn 1965). Thus the semi-permanent trough in the westerlies which is along about 90°E during May disappears, and the westerly jet shifts to the north of Tibet and the troughs in the westerlies moving eastwards take a more northerly course than in May. The movement of low pressure waves from the east would also stimulate the monsoon air flow and intensify the trough over the Gangetic Valley.

5. Implications of the new approach about the trough

If the above mechanism is plausible, the troughs in the westerlies moving eastwards, will take a more southerly course whenever the trough over the Gangetic Valley gets weakened, or when it disappears due to absence of the monsoon air over the Arabian Sea, the Peninsula and the Bay; the troughs in the westerlies can, under such circumstances, move in succession eastwards across northern India (their influence extending to even as far south as 20°N at times), weakening or distorting the Tibetan high or even replacing it by a low (Pisharoty and Desai 1956) at the same time; the westerly jet may also move southwards. As soon as the Gangetic Valley trough re-forms, the troughs in the westerlies will take a more northerly course and the westerly jet shift northwards.

If the 'highs' over the south Indian Ocean south of about 20°S and over Africa in the winter hemisphere are weak and not properly oriented and so also the heat low extending from Somalia to West Pakistan, the flow of air across the equator west of 60°E towards the Indian subcontinent will be adversely affected. Similarly, if troughs in the middle latitude of the southern hemisphere move too far south, the 'highs' in the south Indian Ocean will be located in more southerly latitudes than usual and their orientation might change and intensity decrease; consequently the strength of the southeast trades as well as their direction might so change that the flow of air crossing the equator from the southern hemisphere might be affected adversely; the changes in the reverse direction will strengthen the flow of air across the equator into the Indian subcontinent and increase rainfall there (Desai 1951b). The surges of (*i*) falling pressure over Asia, and (*ii*) rising pressure near the equator and developments over Africa which can inject cyclonic vorticity with the westerly shear, will considerably affect the flow of air across the equator (Petterssen 1948); these factors have been discussed in detail in a separate paper.

When the trough of low pressure over the Gangetic Valley is absent and the zone of the westerlies extends to as far south as 25°N, pressure departures from the average become positive over the belt extending from northwest India to south Bengal; on such occasions easterly to southeasterly winds appear over the Bay and the Peninsula, particularly south of 18°N and the flow of monsoon air is confind to the south of about 10°N. If the flow of air across the equator can be stimulated by factors mentioned earlier or due to low pressure waves from the east moving westwards across the south Bay and then northwestwards or northwards into the west Bay or the Peninsula or across it into the east Arabian Sea off the west coast, the trough of low pressure over the Gangetic Valley will get re-established and the troughs in the westerlies move to the north of 30°N or of Tibet.

As mentioned earlier, there is at the surface a trough to the south of the equator between 60° and 110°E; this trough extends at least upto 500 mb during the monsoon season (Desai 1966c). Waves in the easterlies south of equator moving westwards from east of about 110°E, can accentuate

the trough as well as the flow of the southeast trades across the equator west of 60°E while moving westwards along the trough, making the monsoon current pulsatory (Malurkar 1950, Desai 1951). If this view of the equatorial trough is correct, one should expect weaker and shallower equatorial westerlies during the breaks in the monsoon over India.

In view of the mechanism of the trough of low pressure over the Gangetic Valley discussed above, it will be apparent that there will not be any ITCZ in the conventional sense (*i.e.*, meeting of the trades of the two hemispheres) over the Indian subcontinent during the southwest monsoon season (Desai 1966c).

6. Concluding remarks

It is realised that the new approach about the trough of low pressure over the Gangetic Valley suggested above, is not quite in line with the hitherto prevailing ideas of the Indian meteorologists. But the same has been suggested solely with a view to see if the forecasting of the vagaries of the monsoon current and the associated rainfall over the subcontinent can be improved by such an approach. A critical study of synoptic charts extending over the Indian Ocean can show how far the new approach is helpful from the point of short and medium range forecasting during the southwest monsoon season.

Existing ideas of the Indian meteorologists regarding the formation and movement of the monsoon depressions and the associated rainfall are not affected by the suggested new approach about the trough.

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