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Troughs on either side of the equator and vortices embedded in them and relation between transport of moisture across the equator and the rainfall on the West Coast of India

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ABSTRACT. A critical examination has been made of Raman's paper (1965) on the subject and it is shown that his streamlines and interpretations of the IIOE data discussed by him, are not acceptable.

1. Introduction

In his paper on 'Cyclonic vortices on either side of the equator and their implications', Raman (1965) has drawn the following conclusions —

(1) There are distinct troughs over the Indian Ocean on either side of the equator with separate zones of convergences associated with each; each trough system migrates with the sun's movement in its own hemisphere, the migration of one being apparently independent of the displacement of its counterpart in the other hemisphere.

(2) The equatorial region is dry in the northern summer and the transport of moisture across the equator from the winter to the summer hemisphere is considerably less; the strength of the outflow from the southern hemisphere anticyclone is not correlated with precipitation along the west coast of India, it being perhaps predominantly serving to intensify the southern hemisphere trough.

(3) The concept of a single convergence zone between the trades of the two hemispheres, *viz.*, the Intertropical Convergence Zone (ITCZ) seasonally migrating from one hemisphere to the other and carrying the weather along with it, needs radical revision.

The above conclusions have been examined to see how far they are justified.

2. Discussion

In support of the first conclusion, charts of Raman and Dixit (1964) have been quoted and the positions of troughs in each hemisphere at the surface during January, April, July and October have been given in Fig. 1 of his paper (1965); in Figs. 2 and 3 are given the mean streamline analysis charts for 700 mb during January and July respectively.

The trough at the surface farthest from the equator in each hemisphere is, as is well-known, brought about by the thermally controlled migration of the planetary pressure and wind belts and seasonally changing differential heating of land and sea (Desai 1966 c). In this trough one airmass is from the winter hemisphere and the furthermost limit of it is the axis of the trough. The other trough which is nearest to the equator has the same airmass in it and is possibly associated with the turning of the trades either to the north or the south of the equator in the northern and southern winter respectively. Thus the trough for July in the southern hemisphere is in the same airmass, while that in the northern hemisphere represents the northernmost limit of the air of the other hemisphere. The trough in July over the Indian subcontinent consists of two distinct portions (Desai 1966 c, 1967); at the western end there is 'heat low' of West Pakistan and it has to the south of the trough axis air from the winter hemisphere; the rest of the trough which lies over the Gangetic valley has both to the south and north of its axis air from the southern hemisphere, the latter air, *i.e.*, to the north of the trough axis, being the same as that to its south which has been deflected by the mountains on the Burma coast and of Assam and the Himalayas and whose properties have got somewhat modified. This gives rise to a wedge of drier hotter continental air at the western end of the trough over the Gangetic valley, there being a partition between the easterly moist air and the westerly drier air joining at its southern end with the main trough axis; we thus get a 'triple point' on the trough axis, which is very significant from the point of forecasting heavy to very heavy rainfall during the southwest

monsoon season, particularly when depressions from the north Bay of Bengal move west to northwestwards across the country (Desai 1946). This 'triple point' is displaced southeastwards with height upto about 1·0 km as a result of differences in the lapse rates in the three airmasses, and above that height southwestwards, 'triple point' being near the Gulf of Cambay at about 3·0 km (Desai 1966 c, 1967).

The position of the July trough between 30°N, 70°E and 25°N, 63°E given by Raman (1965) in Fig. 1 of his paper is, therefore, not acceptable and so also its position from Calcutta to Chittagong (Desai 1966 c, 1967).

Similarly the January trough in the southern hemisphere represents the southernmost limit of the air from the other hemisphere, there being southeast trades to the south and deflected northeast trades to the north of the trough axis; the trough for the same month in the northern hemisphere is possibly largely due to the turning of the northeast trades while approaching the equator.

It has been shown by Desai (1967) that the trough over the Gangetic valley in the monsoon months is not due to high temperatures, but due to dynamical causes as contemplated by Banerji (1930, 1931) and Petterssen (1953), the topographical features of the subcontinent contributing significantly to the generation of the same.

It is difficult to accept Raman's view that each trough system migrates in its own hemisphere with the movement of the sun, the migration of one being independent of the displacement of its counter part in the other hemisphere. It is established beyond doubt by the IIOE results (Desai 1966 a, 1966 b, 1966 c, 1967) that the trades of one hemisphere moving towards the equator across into the other hemisphere under suitable conditions in the Indian Ocean with the movement of the sun at least upto about 1·5 km in the Arabian Sea; the depth of the moist current entering the Bay directly from the winter hemisphere, is about 6·0 km. One is, therefore, not justified in assuming that the movement of the sun-controlled trough, which is away from the equator will stop just at the equator when the migration of the sun continues to the more southerly or northerly latitudes according to the southern or northern summer season. The presence of the trough nearest to the equator only over parts of the globe where monsoons prevail, is itself an evidence against Raman's hypothesis of its being associated with certain temperature values over the surface of the sea. One may also find that the trough nearest the equator is weak or even absent when crossing of the trades of one hemisphere into the other is on a restricted scale or absent. The circumstances under which the equatorial trough during the monsoon can get accentuated are discussed by Desai (*see* Ref.).

In support of the cyclonic vortices being embedded in the troughs in the upper air Raman has given 700 mb mean streamlines charts for January and July (Figs. 2 and 3 respectively). The following remarks are relevant for these figures with reference to the Indian subcontinent.

Raman and Dixit (1964) with practically the same data for January over land, have shown 'A' over the West Coast near 18°N, 73°E, while Raman (1965) has shown it near 16°N, 79°E (Fig. 2). Similarly for July, Raman and Dixit have shown only one 'C' to the southeast of Allahabad, while Raman (Fig. 3 of 1965) has shown the same vortex further southeast and a second over north Saurashtra and neighbouring area. Further, in the former publication (Raman and Dixit 1964) air over the Peninsula at 700 mb in July is shown to have originated in the southern hemisphere, while in the later paper (Raman 1965) it has been shown as originating in the northern hemisphere itself. A question, therefore, arises how one is to rely on conclusions where streamlines and vortices over the Indian subcontinent are drawn differently with practically the same data by the same author in two successive years; one will be inclined to think that Raman's bias in favour of his own ideas is responsible for such differences. Further, as far as July or the monsoon months are concerned, it is well-known that the axis of the trough slopes equatorwards with height, its position over the Indian subcontinent being near 21°N at 3·0 km and near 19°N at 6·0 km (Desai 1966 c). The position of the trough at 6·0 km has been modified in the 1967 paper (Desai 1967) in view of observations after 1956. As a result of the presence of the three air masses at the western end of the trough, one will get an impression of a cyclonic vortex over Saurashtra and south Gujarat and the Konkan in the lower and middle troposphere; in fact the 'triple point' is associated with heavy to very heavy rain under certain circumstances over the area (Desai 1946,1967) as mentioned earlier. The exact position of the trough at different levels on different occasions will depend upon the prevailing weather situations.

Raman has stated that the vortices are active in the middle troposphere say at 700 and 500 mb and possess warm or cold cored characteristics. In this connection a reference is invited to papers of Desai (1967, *see* Ref.) wherein it is shown that if one considers the nature of air masses involved in these systems, the temperature differences at different levels become clear.

The second conclusion of Raman may now be examined. From the charts of Royal Netherlands Meteorological Institute (1952) for 'Percentage Duration of Precipitation' for July, it is seen that it is more to the south of the equator upto 10°S and east of 65°E due to convergence on account of the equatorial trough; to the west upto 5°S and north of the equator to the west of 70°E it is small, being large in the east Arabian Sea west of the West Coast and in the Bay east of 90°E and north of 15°N. Less duration over other areas over the west and north Arabian Sea is due to absence of sufficiently strong convergence to break up the inversion and over the southwest Bay due to the presence of only weak convergence although there is ordinarily no inversion and there is more or less homogeneous airmass. Higher duration values off the West Coast and in the east Bay are due to the effect of orography; in the latter case there is also increase in the cyclonic convergence due to influence of the seasonal trough of low pressure over the Gangetic valley. Over the northwest Bay the nearness of the eastern end of the trough axis from the surface upto about 3·0 km also causes more convergence and hence larger duration percentage of precipitation.

The IIOE results have definitely shown that the deflected trades extend only to 1·0 to 1·5 km over the Arabian Sea west of about 68°E, although within about 500 km of the West Coast, the depth of the moist current increases and becomes about 6·0 km on the coast (Desai 1966, 1967). It has also been shown that little moisture can be added due to evaporation during travel of warm continental air over cold sea as an inversion develops right from the surface; if there is a partition sloping eastwards with height due to the continental air flowing above the deflected trades and there is an inversion between the two airmasses, there would also not be appreciable transport of moisture upwards into the continental air (Desai, *see* Ref.). Raman has not been able to appreciate influence of the Western Ghats and difficulty of appreciable transport of moisture upwards by evaporation from the sea surface due to presence of inversion either right from the surface or between the two airmasses. As such, presumptions have been made which are not warranted if one remembers the facts of weather, climatology and topography.

In view of the discussion in the above paragraph, it is not necessary that the outflow from the southern hemisphere anticyclone should have any correlation with the precipitation on the West Coast, although it has to be recognised that if the flow is stimulated across the equator west of about 60°E more deflected trade airmass will flow towards the Western Ghats and cause more precipitation along and near the coast; if the outflow occurs to the east of 60° E, it will also stimulate the activity of the trough south of the equator (Desai, *see* Ref.); the movement of the low pressure waves westwards to the south of the equator from the east of 110°E, will also stimulate activity of the equatorial trough (Malurkar 1950).

In view of the discussions on the two conclusions, it can be stated that Raman's remarks regarding ITCZ cannot be accepted; of course, the trough over the Gangetic valley has no northern hemisphere air to its north due to the influence of topography as shown by Desai (1966 c, 1967). It is well-known to the Indian meteorologists that storms and depressions during the non-monsoon months form over the region of the trough (ITCZ) where airmasses from the two hemispheres are present, their place of formation moving southwards from October to January and northwards from March to May.

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