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Hypothesis about droughts and zonal cell over north India during summer monsoon

B. N. DESAI

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

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ABSTRACT. The zonal cell over north India during normal summer monsoon and its shift eastwards during droughts proposed by Pisharoty on the analogy of the zonal cell in the equatorial Pacific-Walker's cell discussed by Bjerknes has been critically examined. It is shown that, considering facts of the nature of the normal monsoon trough circulation and the associated rainfall distribution, temperatures at the surface, normal pressure distribution and the areas over which positive pressure anomalies occur, one cannot accept Pisharoty's hypothesis. It is also shown that there is no possibility of a zonal cell over the equatorial Indian Ocean envisaged by Bjerknes. In the end, remarks about the lower monsoon trough and the upper easterly circulation have been made.

1. Introduction

As even over drought areas in India there is no significant decrease of the total precipitable water below that of a normal monsoon year, one is tempted to infer that droughts are caused by a change in the dynamical conditions over the area, a change from a general rising motion to a sinking motion over the area of drought during the major portion of the period June to September.

On the basis of existence of a zonal cell over equatorial Pacific, and assuming that the zonal cell envisaged by Bjerknes (1969) over the Pacific is apparently along the thermal equator (the geographical and thermal equators being in about the same location over the central Pacific), Pisharoty (1972) has suggested existence of such a zonal cell over north India during normal monsoon years over longitudinal belt 95° to 65°E between latitudes 20° and 28°N with the rising air limb over the eastern half and the sinking air limb over the western half of the cell; the eastern half rising air limb is roughly over northeast India and the western half sinking air limb over west Rajasthan, northwest Gujarat and Sind, *i.e.*, over and around the desert area in the northwest of the subcontinent. Das (1962) has also stated that during the normal monsoon, one has to infer indirectly, a zonal cell roughly between Bengal and Rajasthan, with its rising limb over northeast India (Assam-Bengal) and the sinking limb over northwest India (Rajasthan-Sind).

Pisharoty (1972) has also stated that during the drought years over India, the zonal cell mentioned above might be considered to have been displaced eastwards by about 20 to 30 degrees of longitude, so that the sinking air limb is over India and the rising air limb over Burma and Indo-China. In support of the latter argument he has stated that droughts over north India were generally associated with excess rainfall over Indo-China, and above normal pressures over north India. It is assumed by Pisharoty that the sinking air limb of the zonal vertical circulation cell is associated with an above normal pressure. On the basis of this hypothesis, droughts could be predicted, according to Pisharoty, about three weeks before if a lower value of the sea-temperature by a couple of degrees below the normal value is noticed over the north Bay of Bengal in May-June. Considering that such an eastward shift of the monsoon cell might be associated with a simultaneous and similar eastward displacement of the equatorial Pacific zonal cell, one might notice above average sea-temperatures in the equatorial belt of the Pacific between longitudes 160°E and 160°W. The approximate positions of the monsoon cell and the Pacific cell along the thermal equator are shown by Pisharoty in the figure given in his paper (1972).

According to Bjerknes (1969), the Pacific equatorial zonal cell given in Fig. 8 of his paper (also called 'Walker circulation' cell) is the result of thermal circulation which can be assumed to be caused by gradient of sea-temperature along the equator. The sinking air belt in the Walker circulation occupies about 120° of longitude and the rising air one some 20 to 30° of longitude. The shift of the sinking air limb east or westward is associated with marked changes in Canton Island (2°48′S, 171°43′W) rainfall. Bjerknes (1969) has also considered possibility of a zonal cell over the Indian Ocean where there is a weak thermally-driven air circulation along the equator with sinking air off Africa and rising air over Indonesia. The Walker circulation is distinguished from other tropical east-west exchanges of air by its having a large tapping of potential energy by combining the large-scale rise of warm moist air and descent of colder dry air.

It is proposed to consider in this paper Pisharoty's hypothesis about Indian droughts and the zonal cell in the light of some facts of the equatorial zonal cell in the Pacific given by Bjerknes and other facts about possibility of a zonal cell over the Indian Ocean with the rising air limb over Indonesia and the sinking air limb off Africa indicated by Bjerknes.

2. Discussion

(a) *Precipitable water over drought areas*

From an examination of TT-T_dT_d curves, it is seen that during short or long scarcity periods, although the general nature of the TT curves remains the same as during active monsoon period, there is a decrease in lapse rate in layer between about 900 and 800 mb with a decrease in the T_dT_d values, *i.e.*, the relative humidity is less above about 900 mb. It is also noticed that during dry periods, isothermal conditions or inversions appear over Bombay and also over Goa on some occasions; the height of the base of inversion or isothermal layer on such occasions is highest over Goa and decreases north or northwestwards, it being lowest over Karachi and at intermediate height over Veraval-Ahmedabad. Even in normal monsoon years the low-level inversion base is lower over Karachi than over Veraval, as the nose of drier continental airmass protrudes southeastwards into the maritime airmass (Sawyer 1947). During dry periods the thickness and strength of the lower deflected trades decreases and in the upper levels there is spreading in direction between S and E of drier continental air from direction between W and N. As a result of lower relative humidity during droughts, air would have to rise much higher for the formation of clouds and occurrence of showers than during normal monsoon when humidity is high and a rise by even 100 or 200 m can cause showers. This ascent can be caused either by insolation or presence of dynamical conditions which lead to convergence and ascent of moist air to give rain. It would thus appear that during scarcity periods, insolation is not able to give showers due to lower relative humidity in spite of presence of adequate amount of precipitable water as over arid areas in the northwest of the subcontinent (Desai 1966, 1968) where the lower moist current is about 1-1.5 km thick, but there are ordinarily no dynamical conditions present to cause adequate ascent of the moist air to give rain. It would, therefore, be not correct to presume as done by Pisharoty (1972) that there is sinking motion over the scarcity areas, the inversion or isothermal layer being due to spreading of drier warmer air over moist cooler air and *not* due to subsidence.

(b) *Other features associated with droughts*

Desai (1970) and Rao and Desai (1973 a, b) have enumerated features generally associated with short or long breaks in rains. The following remarks might be made about the five points mentioned by Pisharoty (1972).

(1) Points (*i*), (*iv*) and (*v*) should not be considered separately as the latter two points are connected with point (*i*). When the monsoon trough is not well-developed or is weak, the easterly winds in Assam and the northern parts of the Indo-Gangetic Valley are weak, and when the trough is absent, they are replaced by westerly winds. When the trough is near the hills, the easterly winds are confined to surface layers and there are westerly winds above about 1.0 km. When the trough is normal, its axis slopes southwards with height, while when it is near the hills, the northern boundary of the westerly winds above about 1.0 km, slopes northwards with height (Rao and Desai 1971).

(2) Point (*ii*) of Pisharoty — During 1899 drought, no depression moved W to NW-wards from the north Bay in June, yet the rainfall during that month was normal; during July, August and September, 1, 2 and 2 depressions respectively moved from the north Bay inland, but not one of them moved west of about 78°E (Rao and Desai 1973 b). The depressions cause heavy to very heavy rain in their southwest quadrant, while activity of the trough without depressions gives well-distributed warm front type rain to the south of the axis at the surface; the width of the rain belt to the south of the axis decreases as its slope increases, moderate

to heavy rain occurring if the slope of the trough axis is steep (Rao and Desai 1971).

It is seen from paper of Ramamurthy (1968) that, while in some years as the number of depressions decrease there is increase in breaks, in other years no such relation is noticed.

(3) Second part of point (*iv*) of Pisharoty— The upper troposphere easterlies are weak during droughts and the location of the maximum speed zone might also get shifted. It has, however, to be recognised that there is *no* 'cause-effect' relation between strength of the lower monsoon circulation and of the upper easterlies. There are actually occasions when, with active or strong monsoon conditions over the Peninsula, the maximum in the easterlies is less pronounced than during weak monsoon (Desai 1970; Rao and Desai 1973 a; Ramamurthi 1972).

(4) Point (*iii*) of Pisharoty — Weakening of the south-north pressure gradient during droughts is reflected in the appearance of positive pressure anomalies over different parts of the country (Desai 1970; Rao and Desai 1973 a, b; Ramamurthy 1968). During 1899 drought surface winds over the country were stronger than normal, while over the Arabian Sea they were weaker than normal (Ramage 1969). As stated by Desai (1970), winds over central and north Arabian Sea are sometimes strong during breaks in rains as a result of steep pressure gradient between south Pakistan and north and central Arabian Sea and plenty of dust moves eastwards from Arabia side, as it also happened during early part of the monsoon in 1973.

It may be stated here that from the time the India Meteorological Department started forecasting, positive pressure anomalies over western India and surrounding areas to the north, east and south have been taken as criteria for forecasting scanty rainfall over different areas, even though we are not quite clear about factors which give rise to positive pressure anomalies.

(c) *Can the zonal cell over equatorial Pacific be considered as being caused by nearness of thermal equator?*

As stated by Bjerknes (1969), the zonal cell is a thermally-driven one, there being gradient of sea-temperatures along equator, the rising air limb being over warmer sea-temperatures area and the sinking air limb over relative cooler sea-temperatures area. As such, it cannot be assumed, as done by Pisharoty, that the zonal cell over equatorial Pacific is due to nearness of the thermal equator over the area, there being actually movement of cold waters along the equator either east or westward, depending on actual conditions over the area.

(d) *Extent of rising and sinking air limbs in the equatorial Pacific and the Indian monsoon cells*

As stated by Bjerknes (1969), the sinking air limb in the Pacific cell occupies about 120° longitudinal belt and the rising air limb 20 to 30° longitudinal belt. In the monsoon cell over India given by Pisharoty in the figure in his paper (1972), the rising air limb spreads over a larger longitudinal belt than the sinking air limb. While there might be warmer sea-temperatures between 160°E and 160°W for the Pacific cell, there are actually no warmer surface temperatures in the lower levels over the rising limb area of the monsoon cell between about 110° and 85°E. It is well-known that over India during normal monsoon year, surface-temperatures are higher over the area of sinking air than over the area of rising air in the zonal cell of Pisharoty (Rao and Desai 1973 b). Similarly during the drought years over north India, surface-temperatures are higher over the area of drought, *i.e.*, sinking air area than further east, *i.e.*, rising air area where there is rain. This means that rain is not caused by rising of moist air because it is warm, a contrast to conditions in the zonal cell over equatorial Pacific, but due to other causes like air masses convergence zones, rising of warm moist air over cold air or over high ground and forced ascent by orographic barrier.

It has to be recognised that the monsoon activity over India is associated with the monsoon trough circulation extending upto about 500 mb, the axis of the trough extending from near Delhi to Calcutta over the Gangetic Valley at the surface and it being along about 18°N at 500 mb (Rao and Desai 1973 a). There is no rising of air only over one area of northeast India, but along the entire length of the trough; the easterly moist air being warmer than the westerly air, rises over the latter along its entire length giving rise to warm front type rain to the south of the axis of the trough at the surface even in the absence of depressions (Desai 1970; Rao and Desai 1971, 1973 a). It would thus appear that the monsoon trough circulation over India occurring over the longitudinal belt 70° to 95°E in which air is rising along the entire trough axis, has a structure entirely different from that of the equatorial Pacific cell which is thermally driven and in which air rises in one limb and sinks in another limb.

(e) Relation between excess rain over Indo-China and droughts over north India

The causes of rain during June-September need not necessarily be the same over Indo-China and north India. Over India there is monsoon trough circulation upto about 500 mb, while over Indo-China there is no such circulation. Thus excess rainfall over Indo-China and droughts over north India cannot be due to the shift of the monsoon cell eastwards. Coincidences in some years in the two are to be considered as accidental and *not* due to cause-effect relationship between the two.

Further, during droughts over north India outside most of northeast India where rainfall might be normal or in excess as in 1899, there is scanty rain also over western and northern parts of the Peninsula.

(f) Above normal pressure over the sinking air limb and over drought areas

It is shown in Fig. 8 of Bjerknes (1969) and the figure of Pisharoty (1972) that the warm moist air ascending in the rising limb ultimately descends in the sinking limb. One should expect the rising air to get warmed by the latent heat released during condensation and thus when it descends in the sinking limb, might not be colder than the air it replaces. The rise in pressure can occur by descent of cold dry air just as fall in pressure occurs with rise of warm moist air. The pressure may actually fall over the area of sinking limb if air which had formerly risen in rain systems and got warmed by latent heat released, descends as stated by Ramage (1966). The winds over the desert area in the northwest of the subcontinent in the layers upto about 3 km veer with height and would not support subsidence of air there from middle and upper troposphere. The rise in pressure cannot, therefore, presumably be due to descent in the sinking limb of air which has ascended in the rising limb area. During 1972 monsoon season, the drought conditions prevailed not only over the country north of 20°N but even over large portion of the Peninsula south of that latitude. The positive pressure anomalies belt during 1972 monsoon was over western India and extending eastward upto West Bengal or to western half of the Peninsula or to the Arabian Sea as far south as 10°N at different times during drought, the areas of maximum positive anomalies and drought conditions sometimes coinciding.

In the great drought year of 1899, precipitation during July to September was more than 40 per cent deficient over the west coast north of 10°N and over the Peninsula between about 15° and 20°N in the belt between west coast and about 80°E, besides over the rest of the country outside most of northeast India where precipitation was normal or in excess. In that year the positive pressure anomalies during the period of drought, July to September, were maximum (2.0 mb or more) over the central Arabian Sea near 15°N, 60°E; the pressure anomalies were negative to the east of the line running from about 30°N, 70°E to 20°N, 83°E and over north of Tamil Nadu (Ramage 1969).

In view of what has been stated above, the cause of rise in pressure both over the sinking area of the cell in the Pacific and over north India where there are drought conditions, have to be sought elsewhere. As far as the Indian area is concerned, the above normal pressures over drought areas are probably due to lower than usual temperatures in the middle and upper troposphere (Rao and Desai 1973 b), the temperatures being so low that they offset even fall in pressures caused by higher than usual temperatures in layers from surface to about 850 mb. The causes responsible for lower than usual temperatures in the middle and upper troposphere for short or long periods over India, have to be investigated.

(g) Inversion or isothermal conditions over scanty rainfall areas of the Indian subcontinent

It is well known that even during normal monsoon years, there is an inversion or isothermal layer over the area in the northwest of the subcontinent. As shown by Desai (1966, 1968), this inversion is an airmass one, there being cold moist air in the surface layers and warm drier air above; it is not due to subsidence as contemplated by Ramage (1966). During droughts the inversion base lowers and the inversion extends east and south or southeastwards (Rao and Desai 1973 b). If this inversion is due to subsidence of air which has originally risen and got warmed by latent heat released during condensation, the specific humidity of air as it descends should remain constant, but it actually increases; the temperature of the descending air at the top of the inversion should be much higher than what is actually observed. Subsidence as being the cause of inversion, is thus ruled out. Warm drier air from areas generally between west and north spreads over a shallow layer of cool moist air and gives rise to an airmass inversion.

(h) *Is there a zonal cell over equatorial belt of the Indian Ocean with rising limb over Indonesia and sinking limb off Africa?*

From moisture data over Gan just to the south of equator near 73°E and Seychelles near about 5°S and 55°E (Saha 1970), it is seen that there is adequate moisture at least upto 600 mb from the surface, the amount increasing from 600 mb downwards; this would mean absence of sinking air below 600 mb level over the western Indian Ocean off East Africa.

It is also known from Findlater's papers (1969 a, b; 1971) that there is a moderate to strong meridional flow in the equatorial western Indian Ocean and neighbouring coastal area between about 37° and 45°E, the maximum being in the belt 38°-42°E. This flow has at times has speed of 50 to 100 kt between layers 600 and 2400 m; such conditions also prevail to the north of the equator and extend over the Indian Peninsula. The low-level jet which is embedded in the monsoon current is initiated by the cold fronts moving eastwards in the middle latitudes of the southern hemisphere, the speed being enhanced by the canalising effect over the Mozambique channel as a result of the topographical features to the west of the east coast of Africa and those running SSW to NNE across Madagascar (Desai 1972). The moderate to strong westerly winds upto about 600 mb over the Peninsula in the monsoon months are thus maintained by the meridional flow across equator in the western Indian Ocean upto about 600 mb and *not* by the subsiding meridional flow in the upper troposphere directed equatorwards from near 30°N over the Tibetan area (Rao and Desai 1973 a).

3. Concluding remarks

It can be stated on the basis of the above discussion that one cannot accept the hypothesis about droughts and zonal cell put forward by Pisharoty (1972) for forecasting droughts in the Indian subcontinent. The causes of droughts and the way in which they can probably be predicted are discussed by Rao and Desai (1973 a, b). The delays in the onset of monsoon are caused by the same factors which are responsible for breaks in rains or droughts. Das (1962) and Pisharoty (1972) have proposed the zonal cell with air rising over northeast India and sinking over Rajasthan-Sind because of their not being able to appreciate the mechanism of the development and structure of the monsoon trough and the rainfall associated with it when it is active or strong in the absence of a depression; the facts of observations are against their zonal cells as shown in this paper.

The monsoon circulation would not appear to be a closed cell in the sense of the Hadley cell. It is difficult to define its limits in the manner contemplated by Pisharoty (1972). The extent of the Asiatic summer low is large. The monsoon circulation cannot, therefore, be postulated as if air is rising in one part and sinking in another part to an equal extent (Rao and Desai 1973 a). Reversal of flow in zonal and meridional directions from lower to upper troposphere has led some workers to suggest closed circulations which will be difficult to justify for mass continuity.

The Indian monsoon trough circulation upto about 500 mb which is self-sustaining and is topographically directed (influence of Western Ghats, Burma coast mountains, Himalayas, mountains on the northwest of the subcontinent and Baluchistan plateau and the Aravallis across Rajasthan—Desai 1967), although the moist air entering it to the south of the trough axis which slopes southwards with height, has its origin in the southern hemisphere; the SE trades are directed first NNE-ward across equator upto about 5°N and than NE-ward upto about 12°N by the plateau to the west of the east coast of Africa and hills and mountains on the eastern side of the plateau (Desai 1972), and also by the hills and mountains over southeast Arabia, and then further NE to E-wards under the influence of the heat-low extending from Somalia to Pakistan across southeast Arabia and which extends only upto about 800 mb level. Above the southeast trades, there is less moist air with saturation adiabatic lapse upto above 500 mb, having its origin also in the southern hemisphere.

South of 25°N zonal winds are westerly in lower troposphere and easterly in upper troposphere. The origin of the upper tropospheric flow need not necessarily wholly be from the flow in the lower troposphere in the monsoon area, made possible through vertical motion.

The view that air flowing out southwards from the Tibetan anticyclone in upper troposphere and sinking in the equatorial region and constituting the return flow of surface westerlies which pick up copious moisture during its northward travel over warmer sea surface (Koteswaram 1958) or that the mean meridional circulation (which is direct) mainly contributes to the maintenance of the mean zonal motion (Keshavamurty 1968), would not also appear correct

According to Krishnamurti (1971), there is evidence of mass 'spill-over' from the region of south west monsoon in horizontal and meridional directions, suggesting that the southwest monsoon is an intense energy source for the tropical latitudes.

The inflow into and outflow from the monsoon area may be linked with the general circulation in other areas. The role of the monsoon would be to distribute the excess heat gained in the continental areas to other regions of the northern hemisphere and also of the southern hemisphere.

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