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Causes responsible for the onset and maintenance of the summer monsoon over India*

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ABSTRACT. Ideas put forward by Walker (1972) about the onset and maintenance of monsoon rains on the west coast of India considering validity of the hypothesis of Ramage (1966), have been discussed from the point of climatological, hydrodynamical and observational facts given in published papers, and it is shown that they are untenable. The Indian summer monsoon can be understood in the light of considerations advanced in the papers of Rao and Desai (1973 a,b).

1. Introduction

In a recent paper in the *Vayu Mandal* Bulletin, Walker (1972) discussed the question of the convective processes associated with the onset and maintenance of the monsoon rains over the west coast of India with particular reference to the baroclinic circulation and the small-scale convection. It is stated that the onset of the monsoon is always accompanied by reversal of the upper flow to easterly. He has accepted the hypothesis put forward by Ramage (1966), the heat-low over northwest of the Indian subcontinent being maintained and intensified through the summer by subsidence of air originally lifted and warmed by the release of the latent heat in monsoon rain systems to the east and south; further, according to Ramage, the precipitation agency over the coast of western India is nearly always a quasi-stationary mid-tropospheric cyclone which develops, intensifies and dissipates over a period of one to three weeks in the vicinity of Bombay. When a deep layer of moist air (presumably from the Bay) is present over the eastern part of the northern Arabian Sea, subtropical cyclogenesis occurs, producing a burst of west Indian rains; this in turn increases subsidence over the heat-low, intensifying the heat-low and the associated low-level monsoon circulation. When the supply of moist air is cut off, the subtropical cyclone fills, the heat-low weakens and a break takes place in the monsoon rains. With renewal of moisture supply, the sequence is repeated.

From the references given by Walker, it would appear that he has probably not seen papers of Desai, which show that Ramage's hypothesis is untenable, as well as some papers of other workers on the subject.

It is proposed to give in this note view about the onset and maintenance of the summer monsoon on the basis of climatological facts, hydrodynamical considerations and facts of observations brought forward by Desai and other workers in the various published papers.

2. Discussion

(1) *Climatological facts*

As stated by Desai (1970 d) in April, shallow heat-low develops over the Peninsula which gradually moves northward with the progress of summer. In association with this, air which has travelled over sea is drawn into the circulation and convective thunderstorms with showers at times accompanied with hail, occur over the Peninsula, extending even into the central parts of the country. Under the influence of the heat-low there is also influx of moist air from the Bay

*This paper deals with an article by J. M. Walker published in *Vayu Mandal*, Bulletin of the Indian Meteorological Society in its July-September 1972 issue, Vol. 2, No. 2, pp. 169-173. In order to bring the various aspects of this subject, which is of very great interest to professional meteorologists and serious students of the subject, it has been considered desirable to seek the medium of this journal for publication of these comments on the article of J. M. Walker — *Editor.*

into West Bengal and Bangla Desh in the lower levels above the surface, the depth of the current increasing eastward towards Bangla Desh to about 2.0 km; above the moist air, there is dry westerly to northwesterly air with nearly dry adiabatic lapse. Thuderstorms known locally as Nor'westers occur over the area. Dust and thunderstorms accompanied with showers also occur over northwest India and from Uttar Pradesh to Assam in association wi[illegible] eastward passage of the troughs in the westerlies (Desai 1970 d).

During May southern hemisphere air is flowing near the equatorial latitudes as a result of the equatorial trough and this cool air gets into the circulation over the Bay where there are already southerly to southwesterly winds, causing advance of the monsoon there. At this time over the Arabian Sea, there is ordinarily warm air of land origin (westerly to northwesterly winds) extending upto the southern tip of the Peninsula. The cool air from the southern hemisphere extends northward into the Andaman Islands and Tennasserim by about 20th May, Central Burma by 25th May and Bangla Desh by 1st June. Due to establishment of the heat-low over Pakistan by this time and the deflection of the southern hemisphere moist air by the Burma coast and Assam mountains and the Himalayas, the trough of low pressure gradually develops over the Gangetic Valley. At the same time the winds over the Arabian Sea back to west to southwest and the deflected trades get into circulation over the area and are drawn towards the west coast of India, the monsoon setting in over south Kerala at the beginning of June. With this, the trough over the Gangetic Valley becomes better defined and the monsoon current extends over the other parts of the country (Desai 1970 d; Rao and Desai 1973 a). The meeting of the moist westerly and easterly (deflected southwesterly) winds takes place over the Gangetic Valley.

(2) *Hydrodynamical considerations*

Banerji (1930, 1931), has considered hydrodynamical factors and shown that, if the western Himalayas and mountains on the northwest frontier of the subcontinent were absent, the heat-low would not be over Pakistan but further west. He has also shown that the airflow from the southern hemisphere which gets into the circulation of the heat-low, is affected by the presence of (*i*) the Western Ghats (cyclonic curvature due to the northern portions and anticyclonic curvature due to the southern portions), and (*ii*) the Burma coast mountains and the eastern Himalayas, there being cyclonic circulation and circular shape of the airflow or bulging of the isobars in the Bay and northwest deflection of the monsoon current to the Punjab through northeast India and Uttar Pradesh. The moist southwesterly to westerly air current from the Arabian Sea and the moist easterly current (the deflected southwesterly current) from the Bay side referred to earlier, meet along the Gangetic Valley, giving rise to trough over there. The Gangetic Valley trough is connected at its western end with the heat-low over Pakistan. The topographical features of the subcontinent thus play an important role in the location of the heat-low and the development of the Gangetic Valley trough.

The influence of topographical features will also extend in the upper levels atleast upto their height. The heat-low extends upto about 850 mb, while the trough extends upto about 500 mb, its axis sloping southward with height (Rao and Desai 1973 a).

Petterssen (1953) has also stated that the topographical features contribute significantly in making the monsoon circulation self-sustaining in the lower levels of the atmosphere. The topographical features make the Indian monsoon circulation up to about 500 mb peculiar from monsoons in the other parts of the world. The westerly jet is not a part of the monsoon circulation.

(3) *The facts of observations on the basis of published papers*

(*a*) Under the influence of the heat-low, the cool southern hemisphere air extends northeast and eastward across equator over the Arabian Sea underneath the hot continental air, giving rise to an airmass inversion over the West and North Arabian Sea and over South Pakistan and neighbourhood. The low-level airmass inversion over West and North Arabian Sea was to be expected in view of the data presented in earlier work done in India (Ramanathan and Banerji 1931; Hariharan 1932; Mal, Basu, and Desai 1932; Desai and Mal 1933; Sawyer 1947), its presence was confirmed by the 1963-64 IIOE data (Desai 1967 a; 1968 a; 1969, 1970 a, c; 1971). The presence of low-level airmass inversion over the West and North Arabian Sea can also be inferred from the papers of Findlater (1969 a; 1971).

(*b*) There is no inverse relation between the depth of the heat-low and intensity of rains over Western India (Desai 1967 b).

It has also been shown by Ramamurthi (1972) that there is no consistent relationship between intensity of the heat-low and the monsoon rains along the west coast of India.

The causes of rainfall in Western India have been mentioned by Desai (1967 b; 1970 d).

(*c*) The low-level inversion over the heat-low is not due to subsidence (Desai 1966; 1967 b; 1968 b, c). The mean sounding over Karachi during August 1963 given by Ramage (1966) can be easily understood in the light of normal conditions which show that the low level inversion is an air-mass one, the hot air from Baluchistan plateau and northwest frontier side flowing over the cool moist monsoon air.

The conditions over the West and North Arabian Sea and over the Indian subcontinent due to the continental air being hottest at the surface are such that whenever it is present side by side with the cool maritime air at the surface, there will be a low-level inversion with a 'nose' of continental air protruding into the maritime air (Ramanathan and Banerji 1931; Mal, Basu and Desai 1932; Desai and Mal 1933; Sawyer 1947).

The nature of temperature and humidity curves to be expected if a flight is made across the 'nose' of the continental air protruding into the monsoon air, is given in Fig. 5(b) of Mal, Basu and Desai (1932).

The presence of the hot continental air in the lower levels in cyclonic systems make the circulation weak in those levels over the Arabian Sea ordinarily, the same becoming stronger above the reversal level where the continental air is colder than the maritime air (Desai 1970 a).

(*d*) As shown by Desai (1968 b; 1970 b), the data used by Ramage for showing rain situations being warmer in the middle and upper troposphere than the lull situations are *not* correct. Hence Ramage's presumption that there is subsidence over the heat-low of air originally lifted and warmed by release of latent heat in the rain system to its east and south is *not* justified.

(*e*) It has been shown by Desai (1970 a) that the cyclone over the northeast Arabian Sea during the beginning of July 1963, formed due to a strengthening of the Arabian Sea monsoon current and that no moist air from the east, *i.e.*, the Bay side, reached it prior to 5th July, the cyclone actually weakening after 4th evening. The cyclone in question was not of subtropical type. It had weak circulation in the lower levels due to presence of continental air in it along with the maritime air which gave rise to a low-level inversion and 'nose' of continental air protruding into the maritime airmass as mentioned in (*c*) above. When, however, the continental air is replaced by the easterly moist air from the Bay, the cyclone can have strong circulation even from the surface as in the north Bay (Desai 1972 a).

(*f*) The onset of the monsoon over the west coast and its performance depend upon the flow of air across equator from the western Indian Ocean and adjoining coast of East Africa, pressure gradient between western India and equator being such that the air from the southern hemisphere can extend to the west coast of India (Desai 1970 d; 1972 b). If there is positive pressure anomaly over western India and neighbourhood, the air from the southern hemisphere will be diverted eastward to the Bay south of about Lat. 10°N instead of the west coast leading to break in rains over the west coast (Rao and Desai 1973 b). The positive pressure anomaly is considered to be due to lower than usual temperatures in the middle and upper troposphere rather than due to subsidence.

Ramamurthi (1972) has shown that there is inverse relation between pressure anomaly at Surat on the coast near Lat. 21°N and rainfall on the west coast, the larger the positive or negative pressure anomaly at Surat, the smaller or larger the rainfall over the west coast.

(*g*) The self-sustaining monsoon trough circulation over India upto about 600 mb would not develop unless the air from the southern hemisphere extends to the country across the west coast of India and Sri Lanka and its south under the influence of the heat-low over Pakistan. The heat-low is present throughout the year, bu tthe monsoon current waxes and warms under the influence of the troughs in the westerlies of th e middle latitudes of the (*i*) southern hemisphere—these can give rise to even jet-speed flow across equator in the western Indian Ocean and neighbouring coastal area (Desai 1972 b), or (*ii*) northern heimsphere—these can both intensify or weaken the heat-low as well as the monsoon trough. The relatively colder air in the middle and upper troposphere brought from the north under the influence of (*ii*) can persist even for a period of more than a week, preventing exclusion of southern hemisphere air to the west coast and producing breaks in rains there.

During breaks in rains over western India and west coast, it is frequently seen that the hot continental air from direction between west and north extends over western India and the west coast even upto about Lat. 15°N; as seen from soundings, the base of inversion on such occasions is higher over Ahmedabad than over Karachi, or higher over Bombay than over Ahmedabad and which in turn is higher over Goa than over Bombay, there being below only shallow layers of monsoon air with relative humidity lower than usual over the area. In spite of presence of sufficient quantity of moisture on such occasions, rain is little on the coast as conditions are not favourable for the ascent of air to levels where clouds and rain can form, the airmass inversion preventing the same. If the monsoon current from across the equator is absent as in May, rain does not occur over the west coast.

While existence of subsidence is possible at times, and which may give rise to inversion above the moist air layer, it is considered on the basis of facts of observations that breaks are due to causes mentioned earlier and *not* due to subsidence as believed by Ramage (1966). There is westerly flow in lower levels as in May during breaks and the monsoon trough is absent, the easterly flow (deflected southwesterly current) being not there.

During persistent long breaks with little or no rain, high temperatures and low vapour pressures prevail, the area being swept by air from warmer regions and there being also little evaporation from the dry soil.

(*h*) As shown by Desai (1970 d) and Rao and Desai (1973 a), there is no cause-effect relation between the onset of the monsoon and disappearance of the westerly jet to the south of the Himalayas or its shift to the north of Tibet or establishment of the easterly jet over the Peninsula.

From the data presented by Ananthakrishnan (1970), the 500-mb level would appear a transition level for circulations building up in the lower (from the surface upwards) and upper (from 100 mb level downwards) troposphere during the transition from winter to the summer monsoon circulation. Thus the development of upper easterly maximum would not appear to have any particular significance from the point of onset of monsoon. The development of the lower monsoon circulation upto about 600-mb level and of the upper easterly circulation would appear to be independent of each other and there would not appear any cause-effect relation between the two (Rao and Desai 1973 a), although changes in the circulation patterns in the upper levels may considerably affect rainfall associated with the lower level circulation patterns.

Ramamurthi (1972) has concluded that the strength of the upper troposphere east wind maximum over south Peninsula is less during strong monsoon than in weak monsoon. The cause of east wind maximum, is therefore not the latent heat released through heavy rain which occurs during strong monsoon over central India.

(*i*) According to observations, although the humidity is very high on the coast over Sind (Pakistan) and Kutch (India) during the summer monsoon, the same decreases as the monsoon air moves inland under the influence of the heat-low due to higher temperatures there. The convective clouds which might grow, dissipate as soon as they reach the inversion layer (Simpson 1921), there being above the monsoon air warmer drier air from Baluchistan side (airmass inversion) and *not* due to subsidence suppressing convection. The convection processes set up by insolation are not sufficiently strong to penetrate the strong airmass inversion at about 1.0 km or destroy it and reach the upper drier unstable airmass level where the convective cloud can grow rapidly.

(*j*) The fact that the surface temperatures are lower over the area of the Gangetic Valley trough where rain occurs due to its activity and are high when the trough is weak or absent at the surface as during pronounced breaks, would suggest that the trough is due to dynamical and *not* thermal causes as the low over Pakistan, although the former is connected with the latter at its northwestern end near Delhi. This would show that the development of cyclones over the northeast Arabian Sea is due to strong monsoon conditions either in the Arabian Sea or even both in the Arabian Sea and the Bay of Bengal, the cyclones *not* developing if the monsoon is not strong over the northeast Arabian Sea in the vicinity of Bombay; the moist current from the Bay does not ordinarily reach the northeast Arabian Sea and adjoining areas to its east on such occasions.

(*k*) The monsoon activity once started, does not persist for one to three weeks as presumed by Ramage (1966). The monsoon current is of a pulsatory nature, each pulse or surge lasting 2-6 days, depending upon the strong flow across equator from the western Indian Ocean and coastal areas of East Africa and pattern of pressure distribution over the Indian area (Desai 1972 b; Rao and Desai 1973 a).

During the period studied by Miller and Keshavamurthy (1967) there were three surges, and *not* one; the first starting after 18 June 1963 and ending on morning of the 26 June, the second starting immediately after 26th morning and ending on morning of 30 June and the third again commencing immediately after 30th morning and beginning to weaken after 7 July morning, as seen from day-to-day rainfall distribution on the west coast. The fact of the fresh surges of the monsoon current following one after the other in quick succession depends upon conditions in the middle latitudes of both the southern and northern hemispheres, they being very favourable at times for a period over 4-6 days and extending even to three to four or more weeks and very unfavourable at other times in either or both the hemispheres that there is unusual delay even in the onset of monsoon on the west coast or there result prolonged breaks.

3. Concluding remarks

From the foregoing considerations, it would appear that one cannot accept ideas put forward by Walker (1972) about the onset and maintenance of the monsoon rains over the west coast of India on the basis of hypotheses of Ramage (1966). The ideas held prior to 1963 still hold good as they explain majority of observed facts, including the data collected during the IIOE period and also those given by Findlater (1969 a, b; 1971). The ideas which hold good for Pacific or Atlantic cannot be applied to the Indian Summer Monsoon due to the fact that the continental air which takes part in the monsoon circulation practically throughout the season over the northeast Arabian Sea and at the beginning of the season or during prolonged breaks over the Bay of Bengal, is hottest at the surface and becomes colder than the maritime air only above a certain level–reversal level, the peculiarity of the 'nose' of continental airmass protruding into the maritime airmass affecting both the nature and extent of precipitation in and near the area of the 'nose'. The topographical features of the Indian subcontinent also produce a dynamical monsoon trough circulation upto-about 600 mb besides the shallow heat-low circulation over Pakistan, there being only heat-troughs over other regions, *e.g.*, over the African summer monsoon area.

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