Indian J. Met. Geophys. (1973), **24**, 2, 131-136

551·553·21 : 551·577·38 (545)

Conditions for normal summer monsoon rainfall and causes of droughts over western India

Y. P. RAO

Meteorological Office, New Delhi

and

B. N. DESAI

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

(Received 14 October 1970)

ABSTRACT. Model for the Arabian Sea summer monsoon proposed by Ramage (1969) and his conclusions about drought of 1899 in western India have been discussed. The heat-low over Pakistan and the air from across the equator drawn north and northeastwards which helps development of the trough over the Gangetic valley under the influence of the topographical features of the subcontinent, are considered the primary causes responsible for the setting up of monsoon circulation upto about 600 mb and the latent heat of condensation would *not* appear to play any significant role in the same.

Conditions for normal summer monsoon rainfall and causes of droughts over western India have been indicated in the light of facts of weather, climatology and topography. Even if the heat-low is present over Pakistan, weak flow of air from across the equator or its absence is the primary cause of droughts as the same leads to weak trough or its absence over the Gangetic valley.

The monsoon circulation over India might be considered as consisting of two layers surface to 600 mb and 500 to 200 mb, the layer 600-500 mb being transitional one; changes in each layer can take place independently and there is no cause-effect relation between the two.

1. Introduction

In a recent paper Ramage (1969) has proposed a model for the Arabian Sea summer monsoon and drawn conclusions about the great drought of 1899 from anomaly charts and stated that the drought can be understood on the basis of his model. As this question is important for Indian meteorologists, it is proposed to consider Ramage's model and his conclusions about the drought of 1899 in the light of facts of weather, climatology and topography of the subcontinent and published papers.

2. Discussion

I. *Comments on six points of Ramage's model*

Although Ramage has referred to his 1966 paper in the *Journal of Atmospheric Sciences*, he has not referred to paper of Desai (1967 a) published in the same journal. As the question of the droughts is very important, the various points mentioned by Ramage (1966 and 1969) may be considered in detail to see how far they are valid.

(*i*) The depth of the moist layer over the desert area is *not* limited due to subsidence. The depth of the moist layer over the Arabian Sea north of about 10°N and west of about 68°E is not more than 1·5 km. East of 68°E and south of 20°N the depth of the moist layer, when there is dry air above, increases and the inversion base is raised and over the west coast the depth becomes about 6·0 km and there is absence of inversion because of the barrier of the Western Ghats across the path of the moist air; no such barrier across the path of the moist air exists over the west coast between 20° and 25°N and hence the depth of the moist current over the desert or heat-low area is small as over the Arabian Sea west of about 68°E (Desai 1966 a, 1968 b, c and 1969 a ; Rao and Desai 1970 a).

Over the west and north Arabian Sea, Pakistan and western India, the airmass stratification (Fig. 4 of Desai 1970 c and Fig. 1 of Rao and Desai 1971) is such that an inversion develops due to spreading of hot continental air over the cool moist air of oceanic origin.

(*ii*) Subsidence is based on the evidence of Karachi 00 GMT upper air temperature and humidity data (Ramage 1966—Fig. 4) which showed inversion between 890 and 825 mb with high humidity below 900 mb and at 500 mb with 41 per cent at 825 and 700 mb; Ramage considered that the inversion was due to subsidence over the heat-low area of air originally lifted in the rain systems to the east and south and which had been warmed due to latent heat released. Desai (1967 a) has shown that this is not correct. The low-level inversion over the heat-low area is due to spreading of warm dry air from Baluchistan and northwest frontier side over the cool moist air from the Arabian Sea (Desai 1966 a, 1968 b, c). The increase in humidity above 700 mb was due to presence of warm moist air from the east. Higher temperature above 700 mb can also be due to the presence of air from north in which subsidence had taken place (Desai 1967 a).

Subsidence of air originally lifted in the rain systems and warmed by the latent heat released, has been presumed by Ramage on the basis of Fig. 16 of Dixit and Jones (1964). It has been shown by Desai (1968 a, 1970 b) on the basis of data available in the India Meteorological Department that the temperature differences given by Dixit and Jones for 500, 300 and 200-mb levels between active monsoon and weak monsoon conditions over western India are *not* correct, and Ramage's inferences drawn from the same cannot, therefore, be accepted.

Further, temperatures at 500, 300 and 200 mb between about 25° and 35°N are ordinarily higher than those to the south of 25°N (Rao and Ramamurthi 1968; Rao and Desai 1970 b) and these high temperatures are not due to release of latent heat but due to presence of the Tibetan plateau.

(*iii*) There are no subtropical cyclones over the northeast Arabian Sea (Desai 1967 a, 1970 a). One gets this impression because there are dry and moist airmasses present over the area and the former although hottest at the surface becomes colder than the latter due to differences in lapse rates above a certain level—'reversal level' whose height may vary between 700 and 500 mb depending upon the actual conditions. The warm dry air spreads over the cool moist air below the reversal level—dry warm front conditions and the warm moist air spreads over the cold dry air above it—usual warm front type conditions. As a result of these peculiar conditions, the disturbance will be strongest in about the middle troposphere.

(*iv*) Cyclones can develop in the northeast Arabian Sea even without the presence of moist air from the east from the Bay of Bengal (Desai 1970 a); the moist easterly current in such cases is the W-SW'ly moist air which has been deflected by the Western Ghats under the prevailing pattern of pressure distribution over the area. The cyclone dissipates when the moist air does not enter its field or is withdrawn and the drier air takes its place.

(*v*) The moist current over the heat-low area becomes deep when the upper drier air is replaced by the moist air brought over the area in connection with the disturbances moving towards or across the area (Desai 1967 a).

(*vi*) The Gangetic valley trough is not due to thermal causes as the low over Pakistan; it develops due to dynamical causes (Desai 1967 a, b; Rao and Desai 1970 c).

(*vii*) There is no close inverse relation between pressure anomaly over Jacobabad (heat-low area) and rainfall anomaly over area to its east and south as shown by Desai (1967 a).

(*viii*) The heat-low over Pakistan has lower pressure than heat-lows elsewhere because of the role of topography in its location (Desai 1967 b, 1968 d) and the presence of (*a*) warm dry air from west and northwest between about 1·5 and 3·0 km, (*b*) subsided warm air from northwest between about 3·0 and 6·0 km and (*c*) warm easterly air over the area above about 3·0 km (Desai 1967 a).

(*ix*) Rain over western India is due to the influence of the Western Ghats, the strengthening of the Arabian Sea monsoon current as such or under the influence of a depression in the north Bay for the area between 18° and 21°N, the movement of depressions from the Bay and the Arabian Sea across or near the area and the presence of airmass partitions giving rise to triple point and perpendicular action conditions over western India with or without the presence of a depression (Desai 1967 a, 1970 c).

Desai (1969 a) has discussed the causes of high percentage duration of rain over the central west coast of the Peninsula and the adjoining east Arabian Sea (Fig. 3 of Ramage 1969).

(*x*) Causes of more depressions in the Bay of Bengal than over the northeast Arabian Sea (Fig. 4 of Ramage's paper 1969) have been discussed by Desai (1968 d, 1970 c; Rao and Desai 1970 c).

In view of what has been stated above Ramage's conclusion that during normal summer monsoon feed-back among heat-low surface depression over central and northeast India and sub-tropical cyclones maintain both the rhythmic monsoon rains of western India and steady wind circulation over the Arabian Sea, would not appear tenable and his model cannot also be accepted.

II. *Comments on 'Anomaly charts' of Ramage for 1899 drought*

(*a*) There was more than normal rainfall over northeast India (Fig. 6 of Ramage's paper 1969) because depressions — one in July, two in August and two in September affected the area as seen from Fig. 11 of his paper. No depressions affected west of 78°E.

(*b*) Surface temperatures were abnormally high (Fig. 7 of Ramage's paper 1969) as there was less rain. It is well known that temperatures are low over the area of the monsoon trough and high when the trough is absent or weak and there is no associated rain over the area (Desai 1967 b).

Locations of positive pressures and high temperatures anomalies did *not* more or less coincide; actually the highest pressure anomalies were over the Arabian Sea to the west of the west coast near 15°N, 60°E (Fig. 8 of Ramage's paper 1969). There was no relation between temperature and pressure anomalies because probably there was present colder air than usual in upper levels over the area. The fact that the depressions turned north to northeast (Fig. 11 of Ramage's paper 1969) would show influence of westerly troughs extending to even south of 25°N, colder air from northern latitudes being brought in their rear probably due to absence of well-developed Tibetan warm anticyclone as in July 1954 (Pisharoty and Desai 1956).

(*c*) Vapour pressure was in defect over the area of high positive temperature anomaly not because of subsidence of dry air from above, but due to horizontal movement of dry air from west and north. If the flow of air from across the equator is weak or absent over the Arabian Sea and there is present air from Arabia side, it will not pick up any moisture from the sea surface as an inversion develops from the sea surface due to travel of warm air over the cooler sea surface (Desai 1966 b, 1968 b); under such circumstances conditions as in May prevail when there is no rain on the west coast of the Peninsula.

(*d*) There are years when even with weak monsoon conditions, there are strong winds over the central and north Arabian Sea (Desai 1970 c). Strong dust raising winds occur over northwest India also in May when the monsoon conditions have not set in over the area.

(*e*) Ramage (1969) has stated that during June 1899 monsoon rainfall over western India was normal. No depression from the Bay of Bengal moved to the area. This would show that causes other than depressions from the Bay moving westnorthwestwards across the country can even give normal rainfall. Such instances are many. Thus although in some years there might be relation between rainfall and depressions from the Bay, there is no cause-effect relation between the two.

Five depressions formed in the Bay in July, August and September as a result presumably of passage of low pressure waves from the east across upper Burma, but they did not move west of about 78°E as the Arabian Sea monsoon was weak as judged from rainfall on the west coast; weak Arabian Sea monsoon conditions also presumably did not lead to disturbed weather developments over the north of the Peninsula or western India due to travel of low pressure waves in the upper air from the east or in connection with the travel of westerly troughs in more southerly latitudes than usual over the area west of about 75°E. The Bay depressions in July, August and September in 1899 were apparently fed by moist air which had directly entered the south Bay from equatorial area between about 60° and 80°E or from the south Arabian Sea south of 10°N and which had crossed equator between 38° and 60°E, the high pressure anomaly over the central Arabian Sea near 15°N (Fig. 8 of Ramage 1969) apparently preventing flow of moist air north to northeastwards towards the west coast of India and producing high rainfall anomaly (Fig. 6 of Ramage 1969).

It is thus not possible to accept Ramage's conclusions about drought of 1899.

III. *Conclusions of Simpson about 1899 drought and good rains in 1894.*

Simpson (1921) has discussed the drought of 1899 but his findings have not been taken note of by Ramage (1969). Desai (1970 c) has given a summary of Simpson's conclusions in the section on 'breaks' in monsoon rains. The main points which Simpson noted on comparing 1894 year of good rains with 1899 year of drought are :

(*i*) Pressures were higher over India and the Arabian Sea and isobars ran more north-south over the west coast of the Peninsula as in May in 1899 than in 1894 (*see* Fig. 8 of Ramage 1969).

(*ii*) Pressures were about normal in the south Indian Ocean. Isobars just south of equator ran east-west in 1894 while they ran SE-NW in 1899 showing that the equatorial trough was probably not properly developed in the latter year. The south Indian Ocean 'high' had not properly developed in 1899.

(*iii*) Winds over the Arabian Sea had more northerly component in 1899 as in May than in 1894 (*see* Fig. 1 of Ramage 1969 for resultant wind direction).

(*iv*) Temperatures were higher over the region of the Gangetic valley trough in 1899 than in 1894 (*see* Fig. 7 of Ramage 1969).

Conditions (*i*) and (*ii*) would mean that the pressure gradient between the Indian area and south Indian Ocean was weak and there could not be any appreciable crossing of air across equator to give strong monsoon conditions over the Arabian Sea. On comparing conditions in 1894 with those of 1899 it can be stated that the flow of air across the equator on the Arabian Sea side is very important from the point of good monsoon conditions over western India. Even if there is sufficient flow of moist air across the equator in the western Indian Ocean, there will be little rain over the west coast of the Peninsula and western India if the pressure anomaly is high as in 1899 presenting flow of air to the west coast north of about 10°N and diverting the same to the south Bay of Bengal causing normal or excess rainfall in northeast India.

IV. *Conditions for normal summer monsoon rainfall and causes of droughts in western India*

From the foregoing discussion it would be clear that for normal summer monsoon rains in western India, the following amongst others are the more important requirements (*see* Desai 1970 c; Rao and Desai 1970 c).

(*i*) Pressure must not be higher than normal over western India and neighbourhood. The lower they are the better for good monsoon rains. The reverse will cause deficient rainfall.

(*ii*) Pressures should not be lower than normal over the south Indian Ocean; in fact higher pressures there than normal would be favourable. This condition along with condition (*i*) will give normal flow of air across the equator for good monsoon conditions over the Arabian Sea. If the pressure gradient between the Indian area and south Indian Ocean is weak, the flow of air across the equator and hence the monsoon would be weak.

(*iii*) Low pressure waves from the east across Burma north of 15°N should not be less than normal and they should be associated with good monsoon conditions over the Arabian Sea so that monsoon depressions if formed, can move to west of 78°E or upper low pressure circulations moving east to west without formation of surface depressions in the Bay, would intensify and even be felt at surface west of about 78°E; without good Arabian Sea monsoon conditions, the disturbances from the east may not move west of 78°E.

If the low pressure waves from the east move westwards south of 15°N, the monsoon will be weak in western India.

(*iv*) If the troughs in the westerlies affect tracks of disturbances from the Bay east of 78°E, the movement of Bay depressions to western India would be inhibited. Their affecting tracks west of 75°E would not adversely affect rains in western India.

(*v*) The warm anticyclone over Tibet should develop so that troughs in the westerlies do not travel in more southerly latitudes than usual. Under such circumstances the westerly troughs movements across extreme north might also intensify the heat-low over Pakistan due to accentuation of the upper trough near 70°E to the west of the plateau, and stimulate monsoon circulation increasing rainfall (Desai 1970 c; Rao and Desai 1970 c). If the Tibetan warm anticyclone is absent the upper trough near 70°E would not develop and the westerly troughs may travel in more southerly latitudes than usual and bring cold air from north over northwest and central India and cause excess pressure and weak monsoon circulation and less rains than usual there, resulting in positive temperature anomalies at the surface.

(*vi*) Developments in Africa north of equator which introduce cyclonic shear in monsoon winds over the Arabian Sea would stimulate monsoon activity over the west coast and western India (Desai 1970 c).

(*vii*) Weak monsoon conditions over the Arabian Sea due to weak flow of air from across the equator would mean conditions as in May and scanty rainfall over the west coast and western India. It would thus appear that for usual monsoon rains in western India, one should know conditions not only over India but also over the neighbouring areas to the north, east, west and south including over the south Indian Ocean, as the monsoon rainfall over India is due to the integrated effect of these factors on the monsoon circulation over India upto about 600 mb (Desai 1969 b).

Ramage's (1969) statement that the latent heat released from the great pre-monsoon thunderstorms of the Indian sub-continent may play an important role in the future monsoon rains and the previous *local* rather than far-off events are important, cannot be accepted. It is doubtful if the pre-monsoon thunderstorms can help setting up normal monsoon circulation over India which is primarily dependent upon the flow of air from across the equator and its north to northeastward movement under the influence of the heat-low over Pakistan and its being further influenced by the Western Ghats and the Burma coast mountains and the Himalayas giving bulging isobars over the Bay and deflection of the monsoon air northwestwards to the Punjab across the Uttar Pradesh and Bihar and bringing into existence the trough of low pressure over the Gangetic valley where the W-SW'ly and SE-El'y currents meet at the surface (Desai 1967b, 1968 d; Rao and Desai 1970 c).

V. *Forecasting floods and droughts*

To forecast floods and droughts over western India 4 to 8 days ahead one must be able to predict how the monsoon circulation over India is going to be affected by the various far off factors mentioned in Section IV and their integrated effect on the same (Desai 1969 b). Any models which might be suggested for predicting monsoon rains have to consider effect of topographical featuers of the sub-continent on the air motion as the same makes the monsoon circulation self-sustaining upto about 600-mb level (Rao and Desai 1970 c).

3. Concluding Remarks

One cannot accept the statement of Ramage (1969) that droughts over western India might well be, to a large degree self-perpetuating, a massive but local atmospheric distortion not necessarily associated with appreciable anomalies elsewhere. The droughts are associated with external conditions even over far off areas as will be seen from the above discussion. Local atmospheric conditions are certainly important but they are considerably modified by the external conditions.

Ramage's statement (1970) that there is compensating divergence in mid-troposphere over the desert lows is not correct as far as the heat-low over Pakistan is concerned as seen from papers of Desai (1967 a, 1968 a, 1970 b). His statement in the paper that there is a meeting of dry desert air and relatively moist air of maritime origin along the axis of the trough in which heat-lows lie, is also not correct as there is no I.T.C.Z. over the area of the trough as shown by Desai (1967 b, c). The low over Pakistan is due to heat while the trough over the Gangetic valley is due to dynamical causes (Desai 1967 b; Rao and Desai 1970 c).

Ramage (1970) stating that the upper trough near 68°-70°E to the west of the Tibetan high be considered as accountable for summer time heat-low over Pakistan, cannot be accepted as the low can come into existence before setting up of the upper trough or persist even after its disappearance (Desai 1969 b). The statement of Washington and Kasahara (1970) that the monsoon circulation is driven primarily by release of latent heat rather than surface heating cannot be accepted in view of what has been stated above about Ramage's views. Without the air from the southern hemisphere getting into the circulation of the heat-low over the northwest of the Indian sub-continent and the influence of topography on the moist air motion as mentioned earlier, the monsoon circulation would not be set up. One should consider the monsoon circulation over India to consist of two layers — surface to 600 mb and 500 to 200 mb, the layer 600-500 mb being transitional one; developments in each layer can take place independently, there being no cause-effect relation between the two as shown in the earlier discussions.

REFERENCES

Desai, B. N.

1966 a *Indian J. Met. Geophys.*, **17**, pp. 399-400.
b *Ibid.*, **17**, pp. 559-562.

1967 a *J. Atmos. Sci.*, **24**, pp. 216-220.
b *Indian J. Met. Geophys.*, **18**, pp. 473-476.
c *Ibid.*, **18**, pp. 573-580.

1968 a *Proc. Indian Acad. Sci.*, **68A** pp. 103-107.
b *Indian J. Met. Geophys.*, **19**, pp. 159-166.
c *Curr. Sci.*, **37**, pp. 694-695.
d *Geogr. Rev. India*, **30**, 4, Special Issue, pp. 33-44.

1969 a *Proc. Indian Acad. Sci.*, **69A**, pp. 1-6.
b *Curr. Sci.*, **38**, p. 313.

1970 a *Indian J. Met. Geophys.*, **21**, pp. 71-78.
b *Ibid.*, **21**, pp. 421-432.
c Synoptic Climatology of the Indian Subcontinent. *India met. Dep. M.G.R.* No. 2.

Dixit, C. M. and Jones, D. R. 1964 'Kinematic and dynamical study of active and weak monsoon conditions during June and July 1964', Rep. IMC, Bombay.

REFERENCES (contd)

Petterssen, S. 1956 *Weather Analysis and Forecasting*, 2nd, Ed. Vol. 1, 'Motion and Motion Systems', McGraw Hill, Co., New York.

Pisharoty, P. R. and Desai, B. N. 1956 *Indian J. Met. Geophys.*, **7**, pp. 1-6.

Ramage, C. S. 1966 *J. atmos. Sci.*, **23**, pp. 144-150.

1969 *Summer droughts over western India*. Year book of the Assoc. of Pacific Geographers, Oregon State Univ. Press, Vol. 30, pp. 41-54. Contribution No. 199 from Hawaii Inst. of Geophys. Pap. read at 5th Tech. Congress on 'Hurricanes and Tropical Meteorology', Caracas, Venezuela, 20-28 Nov. 1967.

1970 Proc. Symp. 'Tropical Meteorology', 2-11 June 1970, Honolulu, Hawaii, I-VII 1-3; Abstract in *Bull. Amer. Met. Soc.*, **51**, 3, p. 296.

Rao, Y. P. and Desai, B. N. 1970 a *Indian J. Met. Geophys.*, **21**, p. 126.

b *Tellus*, **22**, pp. 465-469.

c Proc. Symp. 'Tropical Meteorology', 2-11 June 1970, Honolulu, Hawaii, J VI-6; Abstract in *Bull. Amer. Met. Soc.*, **51**, 3, p. 297.

1971 *Vayu Mandal* (Bull. Indian Met. Soc.), **1**, pp. 34-36.

Rao, Y. P. and Ramamurthi, K. M. 1968 *Forecasting Manual*—Part I, Climatology of India and neighbourhood, 2. Climatology of India, pp. 1-17 and charts, India Met. Dep.

Simpson, G. C. 1921 *Quart. J. R. met. Soc.*, **47**, pp. 151-172.

Washington, W. M. and Kasahara, A. 1970 Proc. Symp. 'Tropical Meteorology', 2-11 June 1970, Honolulu, Hawaii, Abstract in *Bull. Amer. Met. Soc.*, **51**, 3, p. 297.