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AIRMASS STRATIFICATIONS OVER THE ARABIAN SEA DURING THE SUMMER MONSOON AND THEIR MODIFICATIONS

In a recent paper Ramamurthi (1972) has discussed activity of the Arbian Sea monsoon and mean temperature and humidity soundings at Bombay during strong and weak monsoon and some soundings over the Arabian Sea on 7, 8 and 9 July 1963 during the IIOE period. It is proposed to consider in this note the data presented by Ramamurty in the light of the work done so far by the present author and others.

1. The circulation in the lower levels in the 'Gujarat low' is weak not because of the presence of the heat-low over Pakistan, but due to the presence of the warm continental airmass in those levels and which spreads over the cool moist airmass, giving rise to a dry warm front (Ramanathan and Banerji 1931; Mal *et al.* 1932; Desai and Mal 1933; Desai 1970 a,b) it is only above the reversal level, *i.e.*, in about the middle troposphere that the circulation is well developed due to continental air becoming colder than the moist air. This gives rise to a low-level inversion and a 'nose' of continental airmass protruding into the moist maritime airmass.

Desai (1972 a) has also shown that when the warm continental airmass in the lower level circulation in the northeast Arabian Sea is replaced by the moist easterly airmass from the Bay side, the low over the Arabian Sea has strong wind circulation even in the lower levels.

2. There are two types of airmass stratifications over the Arabian Sea (Desai 1968, 1969 a) and not only of one type as presumed by Ramamurthi (1972). In both the stratifications there is presence of moist unstable airmass in the surface layers; above, however, in one case there is dry unstable airmass with an inversion between the two (Fig. 1 of Desai 1970 a), while in the other case there is less moist airmass with nearly saturation adiabatic lapse with or without an inversion between the two airmasses (Figs. 1 and 2 of Desai 1968). In view of the upper air climatological charts (India met. Dep. 1968), one would expect possibility of presence of tropical easterly airmass above about 600 mb in both the cases. The temperature differences between the tropical easterly and the continental airmasses might not, however, be significant due to there being subsidence in the latter although there might be significant humidity differences (Sawyer 1947); the easterly moist airmass might be actually warmer than the westerly moist airmass in the second case, the boundary between the westerly and easterly airmasses sloping southward with height (Desai 1967; Rao and Desai 1971 a).

The continental airmass above the cool moist airmass can extend even to near the west coast of India between about Lats. 18 and 10°N when the monsoon is weak as it happened on 8 and 9 July 1963 (Desai 1970 c) or spread south and eastwards over the Arabian Sea in association with a disturbance over the northeast Arabian Sea (Desai 1970 a).

3. The strength of the monsoon current is intimately connected with the flow of air across equator from the western Indian Ocean and the adjoining coastal area of East Africa and its reaching the west coast of India. The pulsatory nature of the monsoon current is probably due to the pulsatory nature of the jet-speed southerly flow across equator as discussed by Desai (1972 b). The 'Gujarat low' and the 'eastern low' mentioned by Ramamurthi (1972) are probably the result of the strong monsoon (India met. Dep. 1970 a,b).

4. When the Arabian Sea monsoon is weak the flow of air across equator from the southern hemisphere is not able to reach in sufficient strength the west coast of India, there being positive pressure anomalies over western India and the adjoining north Arabian Sea or over the central Arabian Sea, the pressure gradient between western India and equator weakening (Desai and Rao 1972). The positive pressure anomalies are probably due to colder temperatures than usual above about 850 mb over the area.

Ramamurthi (1972) has also shown that there is inverse relation between pressure anomaly over Surat and the rainfall over the west coast of the Peninsula. According to him there is no consistent relationship between the intensity of the heat-low and the monsoon rain along the west coast of India, a conclusion against Ramage's hypothesis (1966) and which supports view of Desai (1967).

5. As stated by Rao and Desai (1971 b), on 7 July 1963 there was the same type of airmass stratification both at Lat. 23°N, Long. 68°E and Lat. 20°N, Long. 70°E, but at the latter location the airmass stratification was changed due to nearness of convergence zones above the surface; as a result Veraval nearby got 4 cm rain between 7 and 8 July mornings. As the monsoon had begun to weaken after 7 July morning, rainfall on the west coast decreased; observatories on the west coast between Trivandrum and Surat both inclusive, had 122, 66, 38 and 19 mm rainfall between mornings of 6 and 7, 7 and 8, 8 and 9, 9 and 10 July respectively. There was no Gujarat low'; the monsoon weakened after the

cyclone in the northwest Arabian Sea moved northwards and weakened after 4 July 1963 (Desai 1970 a; and Rao and Desai 1970 b). The soundings at Lat. 16°N, Long. 72° E and Lat. 12°N, Long. 73°E for 7 July given by Ramamurthi (1972) would show less moist air with nearly moist adiabatic lapse upto about 725 mb.

The Ghats influence helps in destroying the low-level inversion and in modifying the surface layer unstable airmass in such a manner that there results nearly saturation adiabatic lapse as seen from July mean sounding of Bombay (Fig. 1 a of Desai 1969 a); they also probably increase humidity in the upper less moist airmass (Desai 1969 a — also *see* Fig. 10 of Ramamurthi 1972). The two ascents on 7 July at Lat. 16°N, Long. 72°E and Lat. 12°N, Long. 73°E would show that if there were soundings in the east Arabian Sea south of Lat. 18°N on 2 and 4 July, they might have also shown the second type of airmass stratification mentioned by Desai (1968, 1969 a) instead of only the first type of airmass stratification to the north of that latitude mentioned by Desai (1970 a) on those days.

The Western Ghats are also responsible for raising the base of the low-level inversion and changing airmass stratification in the first type mentioned earlier as shown by Desai (1968, 1969 a, 1970 a, c). Rao and Desai (1971 b) have stated as mentioned earlier that nearness of the convergence zones also helps in modifying significantly the airmass stratification.

For getting an idea about influence of the Ghats on the airmass stratification, one should consider as far as possible soundings on the *same day along about the same latitude* and *not* at latitudes much further north or south and on different days as stated by Desai (1970 c). There were no marked synoptic influences below about 550 mb on 8 July 1963. The soundings along 18°N at Longs. 66° and 71°E on that day show how airmass stratification was changed as the Ghats were approached (Desai 1970 c); the sounding at 18°N, 71°E shows greater influence of the Ghats than the one at 17°N, 70°E (Fig. 12 of Ramamurthi 1972) as it was nearer them than the latter. There was 1 to 2 cm orographic rain between Ratnagiri and Dahanu between 8 and 9 July mornings.

Monsoon had further weakened between 9 and 10 July, there being little or no rain on the coast from Mangalore to Goa; there were also no marked synoptic influences over the area. As shown by Desai (1970 c) the soundings at Lat. 13°N, Long. 72°E showed influence of the Ghats on the stratification when compared with the sounding at Lat. 12°N, Long. 67°E on 9 July 1963. The soundings at Lat. 15°N, Long. 70°E (Fig. 12 of Ramamurthi 1972) also shows some influence of the Ghats as at Lat. 13°N, Long. 72°E.

6. The mean soundings (Figs. 10 and 11) and potential pseudo wet bulb temperatures for Bombay (Table 1) during strong and weak monsoon given by Ramamurthi (1972), are interesting. Bombay had moist westerly air upto about 600 mb at least with high humidity and nearly saturation adiabatic lapse throughout during strong monsoon, the influence of the Ghats modifying the surface layer unstable airmass, destroying the low-level inversion and increasing humidity in the upper less moist airmass (Desai 1969 a).

During weak monsoon warm dry air from direction between west and north replaces the moist air above the surface layers, there is less than 5°C lapse in the mean sounding between 800 and 700 mb and lower humidity above 800 mb. It is well-known that during breaks or weak monsoon conditions over Bombay area, there is sometimes even a low-level inversion over Bombay, the base of the inversion being lower at Ahmedabad than at Bombay and lower at Bombay than at Goa if the continental air from north and northwest extends to Goa latitude.

Ramamurthi (1972) has given potential pseudo wet bulb temperature values at different levels in Table 2 for one location on 7 July and three locations on 8 July. There is on 8 July a fall in temperature at 850 mb at Long. 66°E and at 750 mb at Long. 70°E, while at Long. 71°E the temperature is as high as 295°C upto 700 mb; thus, the Ghats influence was more at 71°E than at 70°E and more at the latter location than at 66°E. Temperatures at different levels upto 550 mb at Long. 70°E on 7 July were between 298 and 295°C as the airmass stratification was modified due to convergence zones nearby as mentioned earlier (Rao and Desai 1971 c).

7. The extension of clouds westwards over the Arabian Sea from the west coast of the Peninsula when the monsoon is strong, is mainly due to the effect of the Ghats as discussed by Desai (1969 b, 1970 b), the forced ascent of the moist air giving rise to *Cu* and *Cb* clouds above nimbostratus which spread westwards as soon as they reach the level of the upper easterlies.

The Ghats produce a trough off the coast in the moist airmass when the monsoon is strengthening or is strong; in the trough there will be ascending currents which explain increase of cloudiness and appearance of *Cu* and *Cb* clouds and rain

east of about Long. 68°E (Desai 1968). Such a trough also appears off the Arakan coast in the Bay due to the effect of the mountains on the coast there when the monsoon is strong or strengthening (Desai 1970 d).

8. Regarding the influence of orography on rainfall, a reference is invited to papers of Desai (1969 b; 1970 d). The amount of rain depends on the normal component of moist winds to the Ghats; the value of this component increases considerably when a depression is forming in the northwest Bay of Bengal and heavy to very heavy rain occurs on the Konkan coast even without a depression in the northwest Arabian Sea. Further, when there are convergence zones over and near the west coast—marked synoptic influences at different levels, very heavy rain also occurs but orography has only small role on such occasions; 31 and 32 cm rain recorded at Dahanu on 5 and 6 July 1963 mornings, 13, 14, 19 and 17 cm at Alibag, Colaba, Santacruz and Dahanu respectively on 7 July 1973 morning was due to such effects.

Concluding remarks

In the end it may be stated that the IIOE data can be understood on the basis of ideas about the summer monsoon held prior to 1963 if one recognises that the low-level inversion over the west and north Arabian Sea shown by those data, was to be expected in view of the earlier work done (Ramanathan and Banerji 1931; Mal *et al.* 1932; Desai and Mal 1933; Sawyer 1947) and the upper winds data; the inversion is an airmass one and *not* due to subsidence. Further, this peculiar airmass stratification is also responsible for weak circulation in 'lows' in the lower levels over the northeast Arabian Sea generally and over the Bay of Bengal when the continental air is present over it in the beginning of the season or during prolonged breaks. Even over the northeast Arabian Sea when the continental air is absent, the low circulation is strong even in the lower levels (Desai 1972). In the east and south Arabian Sea south of the line about 8°N, 50°E—20°N, 73°E, the airmass stratification when the monsoon is active or strong, is such that there is less moist air with nearly saturation adiabatic lapse above the surface layer of moist unstable airmass instead of the dry unstable airmass to the north of that line as on 2 and 4 July 1963 (Desai 1970 a). The finding of Ramamurthi (1972) that (*i*) the strength of the upper easterlies over the Peninsula is not related to the strength of the lower westerly monsoon current, supports the view of Rao and Desai (1971 c) that the lower and upper circulations develop independently although perturbations in the upper troposphere affect the weather realised, (*ii*) there is no consistent relationship between the intensity of the heat-low over Pakistan and the monsoon rains on the west coast and this supports the view of Desai (1967) and (*iii*) there is inverse relation between pressure anomalies over western India and rainfall on the west coast of the Peninsula supports the hitherto prevailing idea used in forecasting.

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