

*Airmasses upto 500 mb level over the Indian summer monsoon trough area*

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**ABSTRACT.** Rao and Desai (1973) have indicated the nature of airmasses present over India and neighbourhood during July—typical monsoon month—on the basis of India Met. Dep. Forecast. Manual Part I—2. "Climatology of India and neighbourhood—Climate of India (1968)". In the publication "Upper Air Atlas of India and Neighbourhood" (India Met. Dep. 1972), are given (i) Normal upper air temperature and contours and (ii) Normal upper winds from which one can draw inferences about airmasses over the area. Ramage and Raman (1972) have given 850, 700 and 500 mb charts for July in Vol. 2, Upper Air Meteorological Atlas of the International Indian Ocean Expedition (IIOE) from which also inferences can be drawn about airmasses over the area in question. It is seen from India Meteorological Department (1972) upper winds charts and charts of Ramage and Raman (1972) that the axis of the monsoon trough, which extends from near Delhi to Calcutta at the surface and slope southwards with height, has on both sides the air of continental origin while according to Rao and Desai and India Meteorological Department (1972) normal upper air temperature and contour charts, the axis of the monsoon trough at 850 and 700-mb levels has moist air of oceanic origin on both sides.

The chart showing distribution of rainfall over India during July would not appear to support the inferences about airmasses drawn from charts of Ramage and Raman and India Meteorological Department upper wind charts.

### 1. Introduction

On the basis of temperature and wind data published by the India Meteorological Department (1968), Rao and Desai (1973) have given boundaries between different airmasses over India and neighbourhood in July which can be taken to represent a typical monsoon month. Since then India Meteorological Department (1972) have brought out the Upper Air Atlas of India and neighbourhood in two parts, the first part contains normal upper air temperatures and contours

with winds at standard levels and the second containing upper wind data with streamlines and isobars at 0.9, 1.5, 3.0, 6.0 km etc. levels. Ramage and Raman (1972) have given circulation patterns and streamlines for different standard levels. It is proposed to discuss in this note the position of the boundaries between different airmasses at different levels on the basis of the data in the above publications and to see how far they agree with the normal climat. temp. data 1951-1970 published by India Meteorological Department (1972) and similar data given by Ramage and Raman in their

publication. An attempt has also been made to discuss the normal rainfall for July with reference to the airmass boundaries mentioned above.

## 2. Discussion

2.1. Rao and Desai (1973) have given boundaries between different airmasses over India and neighbourhood during July at different levels in their Fig. 8, which is reproduced in this paper as Fig. 1. The details of different airmasses at different levels are as under.

### 2.1.1. Surface

The continental air is to the north and west of the boundary and the deflected trades—monsoon airmass—to its south and the east. The Gangetic valley trough axis extending from near Delhi to near Calcutta through Allahabad and Gaya has moist southeasterly to westerly warmer air to its north and southwesterly to westerly cooler air to its south. The E'ly to SE'ly airmass to the north of the monsoon trough axis is actually the SW'ly to W'ly monsoon airmass which has been deflected by the Burma coast and Assam mountains and the Himalayas and it is warmer than the latter airmass due to travel over land where there is little rain but some moisture might be added due to evaporation.

### 2.1.2. 850 mb (1.5 km)

There is warmer continental air to the north and west of the boundary line and cool deflected trades—monsoon airmass—to its south and the east. The monsoon trough axis is of the same type as at the surface and extends from near Jabalpure to near Balasore, there being moist air on both the sides of this trough.

### 2.1.3. 700 mb (3.0 km)

To the north of the boundary line there is continental air and the monsoon airmass to its south and the east. At this level the monsoon airmass does not consist of the deflected trades but less moist airmass with nearly saturation adiabatic lapse, its origin being in the south Atlantic (Ramage and Raman 1972)—the westerly winds having backed to SW to S'ly near Madagascar area under the prevailing pressure pattern and crossing the equator move to the west coast of the Indian Peninsula. On both the sides of the monsoon trough axis extending from near Surat to near Puri, there is moist airmass as at 850 mb.

### 2.1.4. 500 mb (6.0 km)

The southwesterly to westerly monsoon airmass, its origin being the same as at 700 mb is to the south and the west and the southeasterly to easterly tropical airmass to the north and east of the boundary line which passes through near Bombay to Puri. The boundary between dry continental airmass and the easterly tropical airmass is indicated by the line passing through near Delhi.

From the position of the boundaries between different airmasses given in Fig. 1, it would appear that the hot continental air spreads over the cool monsoon air southeastward over the Arabian Sea from the surface upto about 700 mb, but it is again near about surface position at 500 mb level. Over land the triple point, where the warmer continental, cool moist westerly and less cold and moist easterly airmasses meet, is displaced southeastward from the surface to 850 mb level and southwestwards from 850 to 700 mb levels. At 500 mb there is no triple point and the boundary between the dry and moist airmasses is near about its position as at the surface. Thus as a result of the continental air being warmest and the monsoon air the coldest at the surface and a difference in the lapse rates in the two airmasses, the continental airmass becomes colder than the moist monsoon airmass above a certain level—reversal level. Thus over the Arabian Sea the dry continental air spreads over the moist air upto the reversal level near about 600 mb, above which level the latter flows over the former. Over land the SE'ly to E'ly air being warmer than the W'ly air at the surface, the boundary between the two moist airmasses slopes southwards with height up to about 500 mb. Over the subcontinent north of latitude about 19°N, the moist SE'ly to E'ly air spreads over the W'ly to NW'ly dry continental air above about 900-mb level, the latter rising over the former upto that level.

Miller and Keshavamurthy (1967) have mentioned that at times intense mid-tropospheric cyclones develop between 700 and 500-mb levels in the trough over northeast Arabian Sea and that these cyclones are of the subtropical type. Referring to this Rao and Desai (1974) have stated that with the passage of low pressure waves from the east, at times cyclonic circulation develops in the middle troposphere over northeast Arabian Sea which may strengthen the Arabian Sea monsoon at the surface and in lower levels and it is generally the strengthening of the Arabian Sea monsoon which leads to development of cyclonic circula-

tions higher up as the western end of the trough axis between about 700 and 600-mb levels is nearby, where triple point conditions normally exist. Any fluctuation in the quasi-stationary position of the triple point in the horizontal or in the vertical under the prevailing weather conditions may lead to locally heavy to very heavy rainfall depending on the area of its location both with and without the presence of a depression. Some of the heavy to very heavy rainfall recorded over Gujarat area are due to such triple point conditions (Desai 1946, 1967, 1970a).

The temperature contrasts between different airmasses at the boundary are maximum at the surface and decrease with height and disappear at the reversal level; above which they are only slight or even sometimes not noticeable, but the humidity in continental air is much less than in moist monsoon air which makes the latter rise over the former airmass.

The rise of the continental air above the moist air gives rise to a low level airmass inversion both over the Arabian Sea and also over the subcontinent north of latitude 20°N and west of about longitude 70°E (Desai 1970-b and c). During breaks when the continental air extends further south and eastward, the inversion is found even over Bombay and Goa; the base being higher at Goa than at Bombay and higher at Bombay than at Ahmedabad and Veraval and higher at the latter two places than over Karachi, north Arabian Sea and west Arabian sea. The IIOE period soundings as well as the sounding data over the subcontinent support the above inferences.

2.2. The boundaries between different airmasses at different levels on the basis of the temperature and contour charts published by the India Meteorological Department (1972) are given in Fig. 2. It would appear that they generally agree with the boundaries given in Fig. 1 except for the fact that boundary between the moist monsoon airmass and the dry continental air at 850-mb level is displaced northwards and passes through Karachi and Bikaner and in view of this the triple point seen near Jabalpur in Fig. 1 at this level is shifted northwestwards to near Pilani.

In Table 1 are given the normal temperature and humidity data at 850, 700 and 500-mb levels for the stations Bombay, Ahmedabad, Nagpur, Calcutta, Lucknow, Delhi and Jodhpur taken from the normal climatic temperature data for the period 1951-1970 published by India Meteorological Department (1972). The humidity values in Table 1

generally support the boundaries between different airmasses given in Figs. 1 and 2 although the boundary between cold monsoon and dry continental airmasses at 850-mb level in Fig. 1 would require slight northward displacement.

2.3. In Fig. 3 are given the boundaries between different airmasses at 0.9, 1.5, 3.0 and 6.0 km a.s.l. based on the upper wind charts published by the India Meteorological Department (1972). In drawing the boundary, the convergence of streamlines is taken into account as defining the boundary between different airmasses. Some of the significant features noticed in Fig. 3 are mentioned below :

(i) The boundary between the monsoon air and the continental airmass is further south at 0.9 km than at 1.5 km. This cannot be accepted as the depth of the monsoon airmass decreases with height from north to south.

(ii) The monsoon trough axes at 0.9, 1.5 and 3.0 km levels are in the continental airmass. This will not be supported when one considers the humidity values at 1.5 and 3.0 km levels given in Table 1. It is also observed that more rain generally occurs to the south of the axis which will not be possible unless the air to the north of the monsoon trough is also moist and rises above the air to its south, the former being warmer than the latter.

(iii) At 6.0 km the airmass between Mangalore and Ahmedabad would appear as the same prevailing to the south of Mangalore, the latter having backed to SE'ly to E'ly under the circulation pattern indicated in their analysis. It is however considered that the boundary between different airmasses at 6.0 km given in Fig. 3 cannot be accepted in view of the data given in Table 1.

2.4. The boundaries between different airmasses at different levels on the basis of the charts of Ramage and Raman (1972) are given in Fig. 4, the same being drawn considering the confluence of streamlines as done for Fig. 3. Given below are some of the significant points in respect of Fig. 4.

(i) The monsoon trough axes at 850 and 700-mb levels lie in the continental airmass. This will not be supported by the temperature and moisture data given in their own charts as well as those given in Table 1.

(ii) The flow patterns in the north Arabian Sea are based on aircraft data presumably collected during IIOE period and particularly in 1963 when



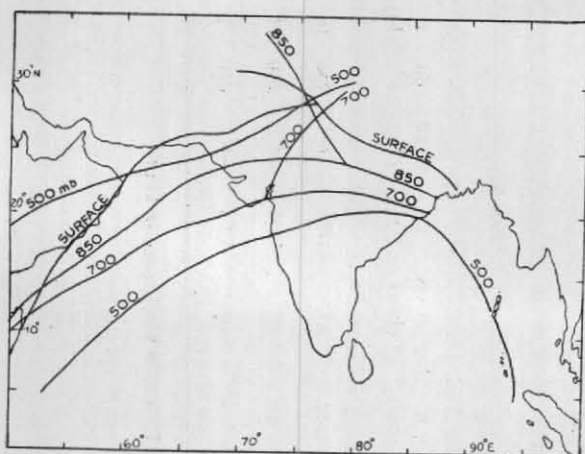


Fig. 1

(Reproduced Fig. 8 of Rao and Desai 1973)

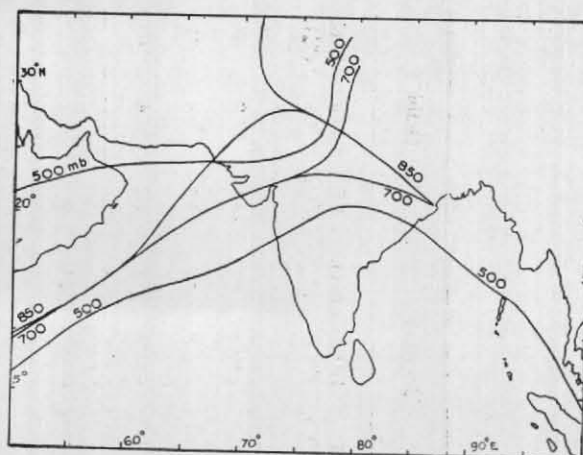


Fig. 2

(Based on normal upper air temperature and contour charts, India met. Dep. 1972)

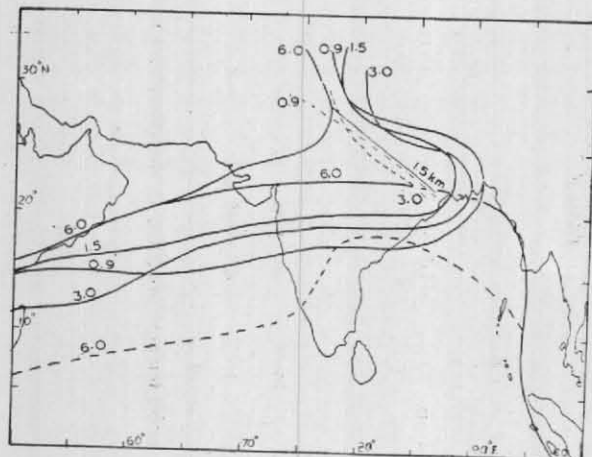


Fig. 3

(Based on normal upper winds charts, India met. Dep. 1972)

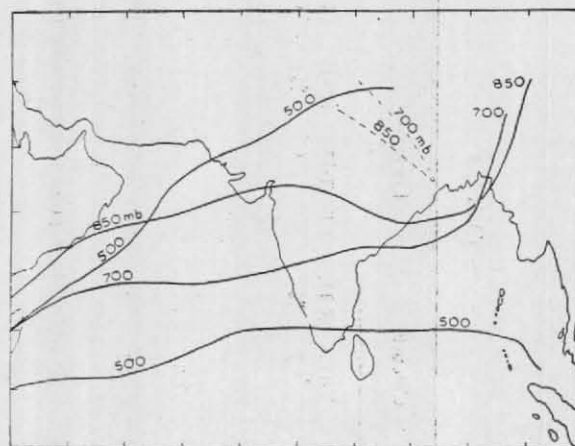


Fig. 4

(Based on upper air charts of Ramage and Raman 1972)

Figs. 1-4. Approximate position of partitions between different airmasses at different levels over the Indian subcontinent and neighbourhood during July

there were definite synoptic patterns over northeast Arabian Sea and neighbourhood as discussed by Desai (1970b) and Rao and Desai (1974). This is also apparent from the data given in Table 2 taken from the charts of Ramage and Raman for those levels. It may be seen from this table that the aircraft data are only a few in number when compared with the data over Karachi, Veraval and Bombay which extend over a number of years. It is felt that combining such data in a single chart is completely misleading and no experienced Indian

Meteorologist can accept the flow pattern of Ramage and Raman at those levels as depicting the normal conditions during July.

(iii) The boundary of the westerly monsoon airmass at 500-mb passes near Socotra, Cochin and Car Nicobar, the airmass to the north of this boundary being the easterly tropical airmass, the winds having backed to westerly to the south of Bombay latitude as per their flow pattern. The 500-mb level chart of Ramage and Raman cannot thus

TABLE 1

Level (mb)	Bombay		Nagpur		Calcutta		Lucknow		Ahmedabad		Jodhpur		Delhi								
	TT (°C)	R.H. (%)	TT (°C)	R.H. (%)	TT (°C)	R.H. (%)	TT (°C)	R.H. (%)	TT (°C)	R.H. (%)	TT (°C)	R.H. (%)	TT (°C)	R.H. (%)							
850	18.7	16.3	20.7	17.2	77	20.5	17.6	88	22.9	18.6	78	20.9	16.9	77	23.6	16.9	64	23.9	17.9	68	
700	11.2	6.1	71	11.5	8.3	76	12.4	8.7	82	13.6	9.2	71	12.9	6.2	62	14.1	6.2	58	13.3	8.4	71
500	-2.6	-9.8	58	-2.6	-6.8	75	-1.6	-6.0	74	-0.1	-5.9	63	-1.9	-7.6	63	-1.5	-7.9	59	-1.2	-7.4	63

TT=Dry bulb temperature (°C), TdTd=Dew point temperature (°C), R.H.=Relative humidity (%).

TABLE 2

Level (mb)	Aircraft				Karachi				Veraval				Bombay							
	Lat. (°N)	Long. (°E)	No. of obsns.	dd (°)	ff (kt)	TT (°C)	TdTd (°C)	No. of yrs of obsns.	dd (°)	ff (kt)	TT (°C)	TdTd (°C)	No. of yrs of obsns.	dd (°)	ff (kt)	TT (°C)	TdTd (°C)	No. of yrs of obsns.	dd (°)	ff (kt)
850	23	66	5	022	8	10	22.8	18.5	326	5	4	192	16.6	257	18	10	18.8	16.4	256	16
700	21	68	6	228	11	10	15.9	5.4	038	12	4	12.5	5.0	257	10	10	11.3	6.2	250	11
500	22	67	10	060	10	10	-1.4	-6.4	064	11	4	-2.3	-	103	03	10	-2.3	-8.2	010	1

TT=Air temperature (°C), TdTd=Dew point temperature (°C), dd=Resultant wind direction, ff=Resultant wind speed in knots

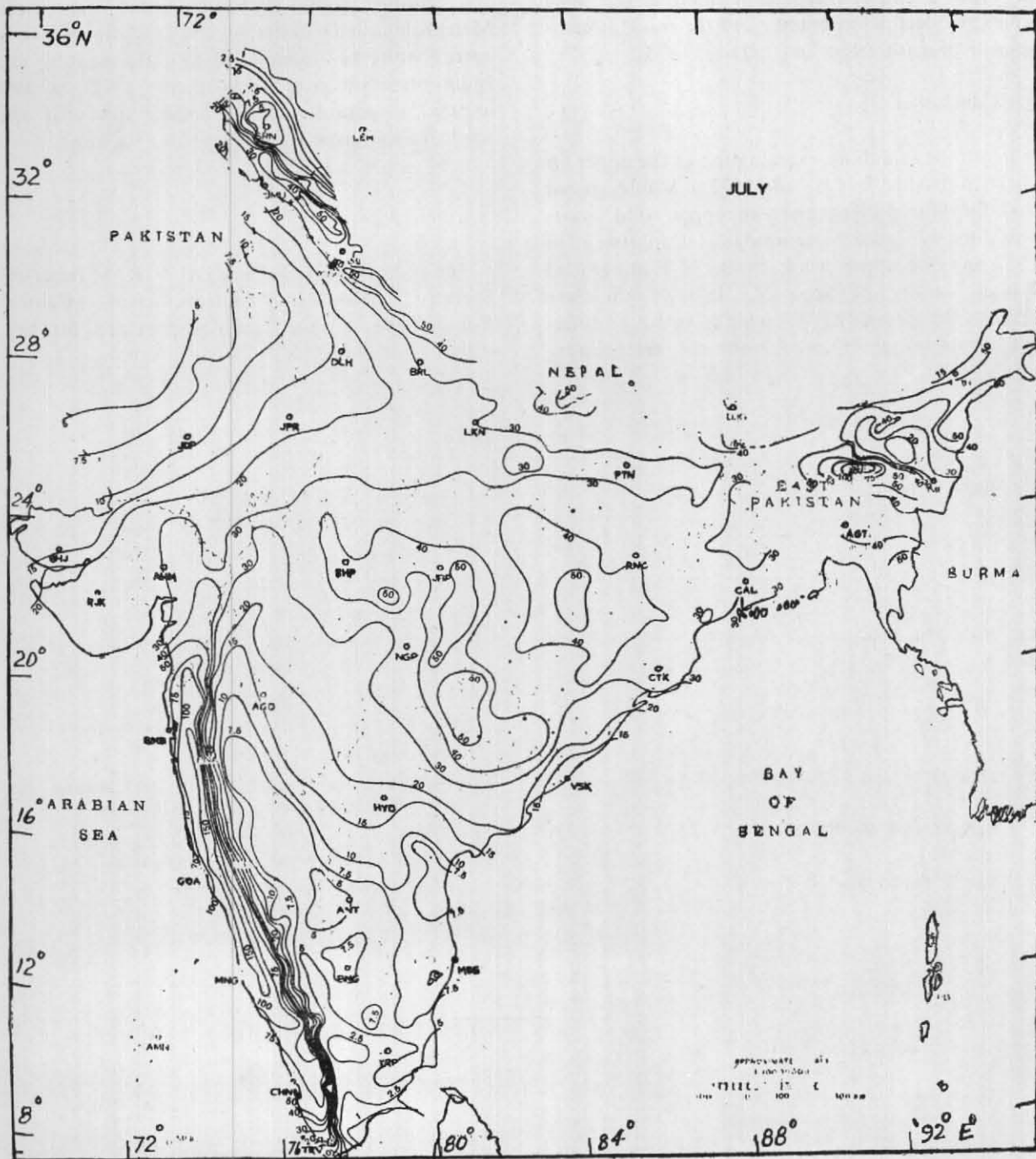


Fig. 5. Normal rainfall for July (India met. Dep. 1971)

be taken to represent normal conditions during July.

2.5. Fig. 5 represents the normal rainfall during July with isohyetal analysis as published by India Meteorological Department (1971). If one considers the July rainfall over different parts

of the country with reference [to the monsoon trough axis given in Figs. 3 and 4, one cannot explain the same if the monsoon trough axis is considered to be in the continental airmass. The July rainfall distribution can be understood with reference to the airmass boundaries given

in Figs. 1 and 2, keeping in mind at the same time the effect of orography and the track of monsoon depression (Rao and Desai 1973).

### 3. Conclusion

From the foregoing examination of the upper air charts published in 1968 and 1972, it would appear that the flow pattern given in upper wind charts published by India Meteorological Department of 1972 and the upper wind charts of Ramage and Raman cannot be accepted. In fact they are against the prevailing boundaries between different airmasses as inferred from the temperature

and contour charts, also published by the India Meteorological Department (1972) which generally agree with the humidity data published by the India Meteorological Department (1972) as well as the temperature and moisture data for the land stations given by Ramage and Raman.

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