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Bay of Bengal Monsoon

B. N. DESAI

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

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ABSTRACT. Synoptic charts for 00 and 12 GMT for 1 and 2 June 1963 have been examined and it is observed that there was no cyclone at Lat. 11°N, Long. 95°E at 00 GMT on 2 June as indicated by Ramage (1963, 1964) in his 500-mb stream lines chart. There could only be a short-lived vortex of small extent near the boundary of the fresh monsoon air; such a vortex was present both at 700 and 500 mb as shown by aircraft reports. It is shown that to use data of drop-soundings for the 1st when there was no cyclone, to determine structure of the so-called cyclone in existence on the 2nd at a distance of 500 to 900 km from its centre, is not justified. The causes responsible for absence of inversion generally at 850 mb over the Bay have been discussed. The conditions over the Arabian Sea 200-300 miles west of the Western Ghats and over the Bay during the monsoon season are such that models for one cannot be made applicable for the other, just as the subtropical cyclone model for the Pacific cannot be valid for the Bay where there is no inversion at 850-mb level.

1. Introduction

Rao and Desai (1965) have discussed in a general manner the inapplicability of the model for the Bay of Bengal monsoon (reproduced here as Fig. 1) suggested by Ramage (1963, 1964) with reference to rainfall distribution as well as levels from which the same occurs, specially when there are monsoon depressions and cyclones. Large amounts of rainfall associated with these systems cannot occur if the ascent of moist air takes place only above 600 mb as shown in his model because the moisture is much smaller at 600 mb and above when compared with the levels between surface and 600 mb. In the model ascent is shown from the surface below 600 mb only at a distance of about 400 km to the west of the centre, while widespread and heavy rain actually occurs in the southwest quadrant of the disturbance, heaviest rainfall being near the centre where the model shows ascent of air only above 600 mb; rainfall is considerably less to the west of the centre beyond 400 km from the centre where only ascent of moist air is shown in the model.

Ramage has given in his paper 500 mb streamline isotach analysis (reproduced as Fig. 2) of winds composited from land station observations for 00 GMT of 2nd and RFF measurements for both 1 and 2 June 1963. As there was no well-defined cyclonic circulation at the surface and at 200 mb where there was only general easterly flow above 500 mb cyclone centre, he has concluded that there was a circulation system which weakened downward and upward from the middle troposphere. This conclusion in conjunction with the data of the two soundings (reproduced as Fig.3), *i.e.*, rain sounding 1 to 3°C colder than the other below about 650 mb (cold-cored with respect to the environment) and about the same amount warmer above that level (warm-cored with respect to the environment), has been utilised by Ramage to consider that the system markedly resembled the sub-tropical cyclone of the Pacific (1962). The model in Fig. 1 has been proposed by him using the sub-tropical cyclone model, additional data obtained by the RFF over the Arabian Sea and the data of circulation at the surface (Fig. 1 of his paper—not reproduced), 500 mb (Fig. 2) and 200 mb and of the soundings given in Fig. 3.

It is proposed to discuss in this paper synoptic conditions of 1 and 2 June 1963 to find out the nature of the mid-tropospheric cyclone observed by aircraft on the latter date (Fig. 2) and to understand the data of soundings (Fig. 3) on the former date.

2. Discussion

According to the surface reports the monsoon had strengthened in the Bay Islands between Lat. 7° and 14°N and east of Long. 90°E between 03 GMT of 31 May and 1 June, rainfall being more south of Lat. 10°N than to its north; Nan Cowrie had 26 cm of rain, Nicobar 15 cm, Maya Bandar and Kondul 3 cm each, Long Island and Tavoy 2 cm each and Port Blair less than a quarter cm during the period. In southeast Arabian Sea the activity of the monsoon was confined to south of Lat. 11°N, Amini Devi having 7 cm of rain, Calicut 4 and Cochin 2 between 31 May and 1 June mornings. From the pressure changes, one could infer that a low pressure wave was moving towards the Andaman Sea from the east.

In Table 1 are given temperature data for 850, 700, 600 and 500 mb and wind data for Visakhapatnam and Port Blair for 00 and 12 GMT of the Ist and 2nd. Upper air charts for 500 mb for the same hours are also shown in Figs. 4 to 7. The

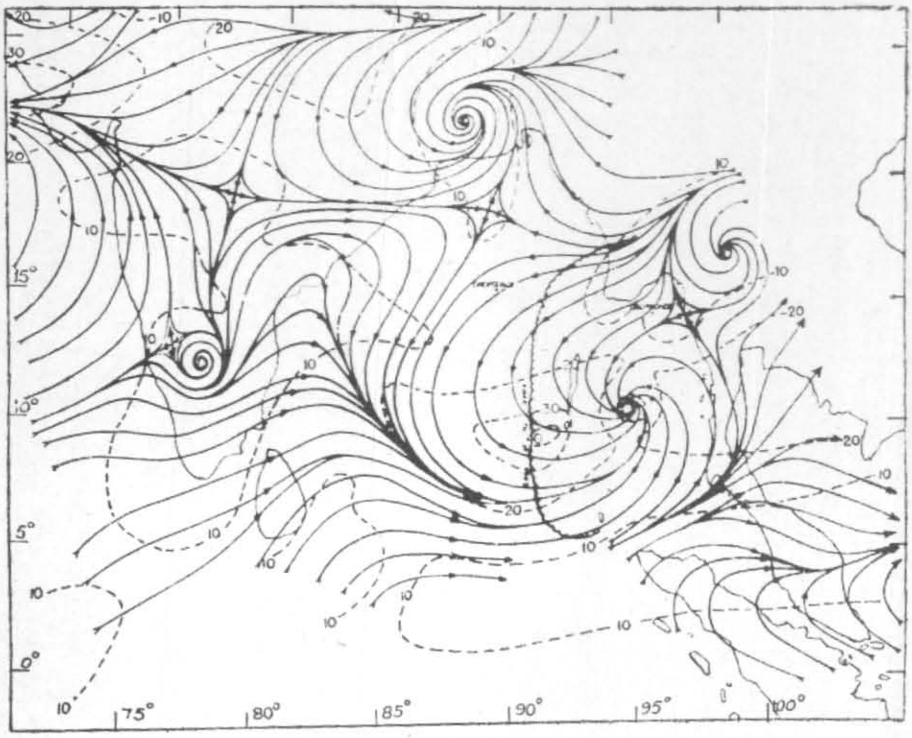

Fig. 2

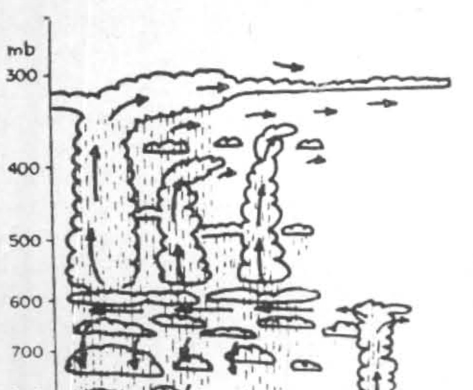

Fig. 1

data for extra-Indian stations and aircraft reports are taken from the charts of the I.M.C. while at Bombay. The approximate positions of air mass partitions are indicated by broken lines. It is seen from the upper wind at Port Blair that the monsoon was weak over the Andaman Islands, large amounts of rainfall having occurred only south of Lat. 10°N as mentioned above. The fresh monsoon air was apparently to the south of Port Blair. Visakhapatnam can be taken as a representative of continental air. Comparing Visakhapatnam temperatures with Port Blair ones at different levels (Table 1) it would appear that Port Blair was

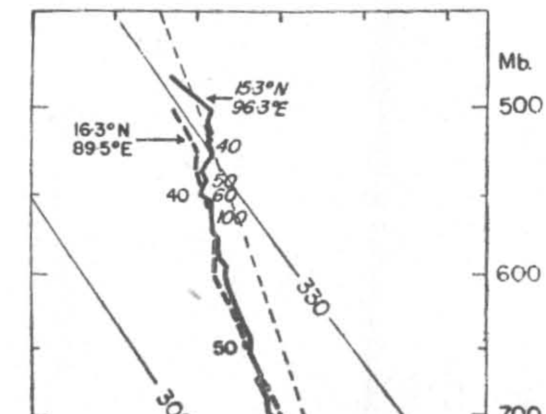

Fig. 3

TABLE 1

Level	1 June 1963						2 June 1963					
	00 GMT			12 GMT			00 GMT			12 GMT		
	Temp. (°C)	Dir. (°)	Speed (kt)	Temp. (°C)	Dir. (°)	Speed (kt)	Temp. (°C)	Dir. (°)	Speed (kt)	Temp. (°C)	Dir. (°)	Speed (kt)
VISAKHAPATNAM												
850 mb	26·0	260	11	25·0	310	10	24·1	280	15	28·0	290	14
700 ,,	13·5	200	04	12·0	300	10	10·5	300	15	12·2	320	21
600 ,,	3·6	330	08	2·5	330	10	2·3	310	13	4·5	280	15
500 ,,	—5·5	010	11	—7·0	280	08	—5·5	320	10	—4·5	300	21
PORT BLAIR												
850 mb	20·0	240	16	20·0	250	24	19·5	270	30	16·5	240	15
700 ,,	7·0	250	08	10·2	260	25	10·5	270	55	7·0	280	12
600 ,,	—1·7	250	10	5·5	260	33	4·5	260	37	1·0	320	17
500 ,,	—7·5	250	16	—2·2	270	15	—0·6	250	23	—6·5	330	17
6·0 km		260	18		320	04		250	22		310	24
7·2 km		240	12		010	10		240	12		310	16
9·0 km		210	17		100	08		250	17		—	—

colder than Visakhapatnam at all levels; if Port Blair had fresh monsoon air at all levels, temperatures there would become higher above (about 700 mb) than those at Visakhapatnam due to a difference in the lapse rates in the two air masses. It would appear that at 500 mb there were three air masses—the monsoon air, the easterly tropical air and the continental air.

The soundings in Fig. 3 for 1 June were apparently corresponding to a period (time of dropsounding is not given by Ramage in his paper) between 00 and 12 GMT of that day. Ramage's statement that the sounding at Lat. 15·3°N, Long. 96·3°E was in the rain area can be accepted (Fig. 4). 100 per cent humidity between about 750 and 550 mb was apparently due to the dropsounding passing through large *Cu* and *Cb* clouds and rain formed as a result of forced ascent of moist air due to the presence, at a distance of about 200 km, of hills about 1·0 km high on the Tennasserim coast. The isothermal region and low humidity (40—60 per cent) in this sounding between 550 and 500 mb and higher lapse rate above, might be due to presence of relatively drier air. The other sounding in Fig. 3 at Lat. 16·3°N, Long. 89·5°E to the west of the rain area was probably in relatively drier air throughout with no cloud formation. The isothermal region between 600 and 550 mb would show that the air there, below and above, was of different origin; between 550 and 500 mb this sounding shows lower lapse than the other sounding in the layers above 500 mb.

It would appear from Fig. 3 that the differences in temperatures in the two soundings between 675 and 550 mb were so small that they cannot be taken as stated by Rao and Desai (1965) to show warm-cored cyclone characteristic above about 650 mb as done by Ramage.

Between 00 and 12 GMT of the 1st the area of heavy rain had shifted northwards; Nicobar had 9 cm of rain, Port Blair and Tavoy 3 cm each, Nan Cowrie 2 cm and Kondul and Victoria Point 1 cm each.

It would appear that winds at Port Blair (Table 1) had considerably strengthened upto 600 mb since morning, indicating arrival of fresh monsoon air there and consequential increase in rainfall. On comparing temperatures at Port Blair at different levels at 00 and 12 GMT, it would appear that they were higher at the latter hour by 2° to 7°C above 850 mb than at the former. One would have expected a fall in temperature (Desai 1951, Desai and Koteswaram 1951). The causes of this rise are not quite clear; it is possible that the same was due to the release of heat during condensation.

On comparing Visakhapatnam temperatures with those at Port Blair, it would appear that although the former had higher temperature upto 700 mb than the latter, above that height there was a reversal, Port Blair becoming warmer than Visakhapatnam.

The changes in Rangoon winds at 700 mb since morning (from 120°/11 kt to 250°/6 kt) would show that the influence of low pressure wave from the east was felt at that level. From winds of Rangoon for 500 mb (80°/5 kt) chart (Fig. 5) it would appear that the easterly current though weak, was still over the area.

Between 1200 GMT of the 1st and 00 GMT of the 2nd, very little rain had fallen; Nicobar had 1 cm of rain and Nan Cowrie 2 cm.

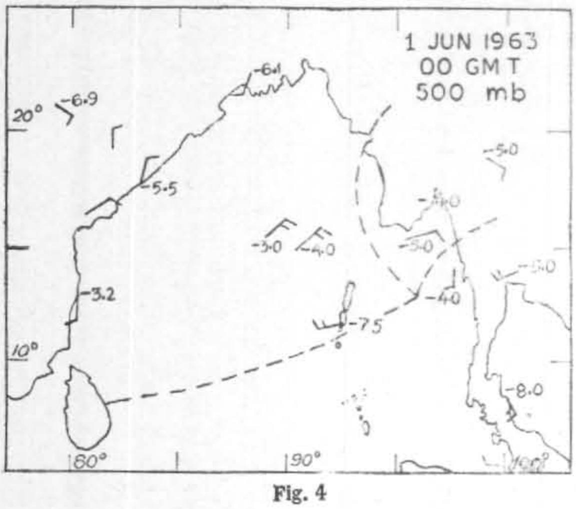

Fig. 4

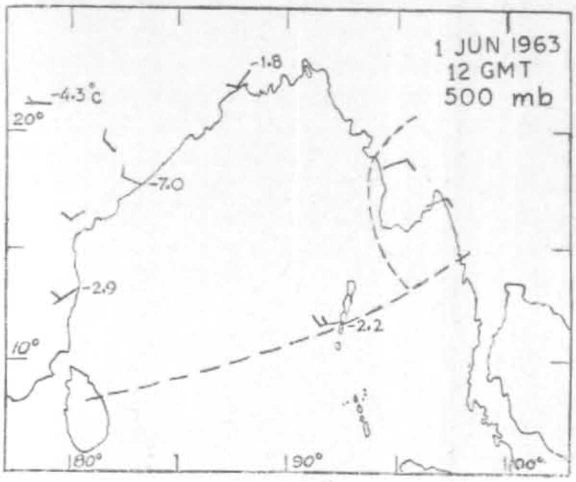

Fig. 5

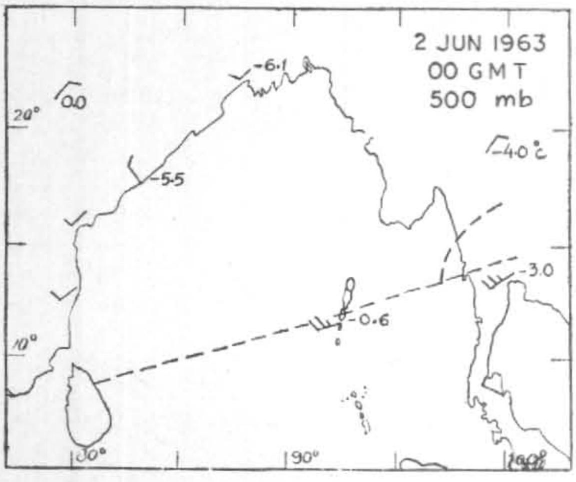

Fig. 6

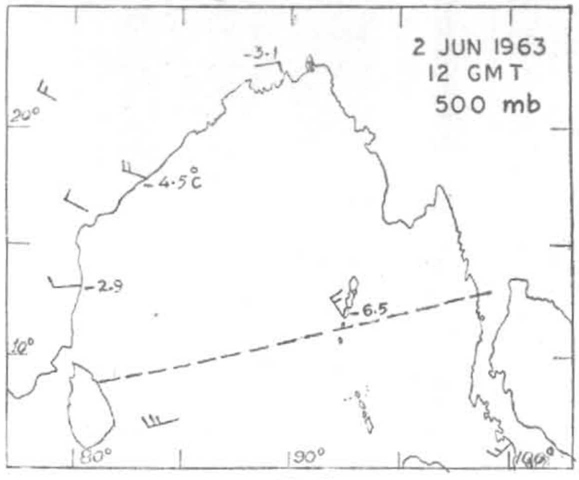

Fig. 7

The pressure changes showed that the low pressure area was moving towards Burma area from the east.

On comparing charts for 12 GMT of the 1st with those for 00 GMT of the 2nd, following inferences could be drawn—

(a) *850 mb* — There was little change over Burma and Andaman Sea area.

(b) *700 mb* — Burma winds showed that the winds were under the influence of low pressure area from the east moving towards the area.

(c) *600 mb* — The easterly flow over Rangoon–Sandoway area had apparently weakened.

(d) *500 mb* — From the wind data of station near Lat. 19°N, Long. 99°E and Bangkok (Fig. 6) it would appear that they were under the influence of low pressure area moving westwards.

From the winds over Port Blair (Table 1), it would appear that the fresh monsoon air had continued to be over the station and deepened although little rain had occurred since the previous evening as stated above. Temperature changes at different levels were between 0·3° and 1·6°C and irregular, again pointing to the same conclusion, *i.e.*, presence of the monsoon air mass. On comparing Visakhapatnam and Port Blair temperatures it would appear that the reversal level had lowered to 700 mb, being between 700 and 600 mb the previous evening.

Port Blair winds are against a cyclone near Lat. 11°N, Long. 95°E. The area was close to the fresh monsoon air partition practically at all levels including 500 mb level (Fig. 6). 500 mb chart for 00 GMT of 2 June reproduced by Ramage in his paper and given as Fig. 2 may now be discussed. The following remarks are relevant—

(*a*) It is not right to prepare a chart for 00 GMT of 2nd with all land stations data for that hour but compositing the same with RFF measurements of both 1st and 2nd; there is no doubt that the air currents will move between the 1st and 2nd. In this case a well-marked low pressure area was moving towards the region from the east; the fresh monsoon current had moved northwards between the 1st morning and evening, with significant changes at Port Blair.

(*b*) The stream lines show cyclonic vortices near Lat. 11°N, Long. 95°E, Lat. 16°N, Long. 100°E and near Lat. 22°N, Long. 89°E. The available wind data given in Fig. 6 would show no such vortices.

On looking to the data of RFF flight 30602A (IIOE copy), for 2 June available in the IMC at Bombay, it is seen that the aircraft at 11077 N 95221 E at 0625 GMT had wind 248°/39 kt—pressure 698·6 mb—height 10443 ft—temp. 7°C and at 11031 N 94990 E at 0631 GMT wind 253°/36 kt—pressure 699·0 mb—height 10431 ft — temp. 6°C; there is a pencil remark in the data sheet 'Passed just S of cyclone centre' against observations between these two times. From these remarks it would appear that a vortex was present not only at 500 mb (Fig. 2) but also at 700 mb.

On comparing the data for 12 GMT with those for 00 GMT of the 2nd (Table 1; also Figs. 6 and 7), the following conclusious could be drawn —

(*a*) Over Port Blair area the fresh monsoon current had moved southwards since the morning. The winds at 700 mb and above had come under the influence of the low pressure wave moving towards the area from the east.

(*b*) There was no cyclone near Lat. 11°N, Long. 95°E.

(*c*) Temperatures had fallen by 2·7° to 4·0°C from 850 to 600 mb at Port Blair. They were nearer temperatures there at 00 GMT of the 1st when Port Blair was colder than Visakhapatnam at all levels.

From (*c*) it would appear that there was no fresh monsoon air over the station at 00 GMT of the 1st and 12 GMT of the 2nd, the same having advanced northwards by 12 GMT of the 1st and withdrawn southwards after 00 GMT of the 2nd.

From the foregoing discussions, it will be seen that there was no cyclone at 500 mb at Lat. 11°N, Long. 95°E (Figs. 4 to 7). Fig. 2 of Ramage for 500 mb cannot be accepted—compare Fig. 7 for 500 mb. Yet one has to accept Ramage's statement that the aircraft located a cyclone at Lat. 11°N, Long. 95°E, diameter about 50 km at 500 mb; there was also a vortex at 700 mb as seen from remarks quoted above. The fresh monsoon partition was near Lat. 11°N, Long. 95°E area at 12 GMT of the 1st and 00 GMT of the 2nd. It is well known that cyclone vortices of *small extent* and *short-duration* giving plenty of precipitation, develop at this partition. What has been reported by aircraft on the 2nd morning at 700 and 500 mb was not the cyclone of the usual type, but only cyclonic vortex of small extent and short-duration near the partition. The circulation hardly extending beyond 50 km and being short-lived, Port Blair at a distance of about 300 km was naturally not affected.

Under the circumstances, one cannot accept interpretation of Ramage for the data in Fig. 3; they should be interpreted as done in this paper. As the locations of aircraft was 500 km northnortheast and 900 km northwest and of Port Blair 300 km westnorthwest of the centre at Lat. 11° N, Long. 95°E and there was no effect of cyclone at any of the three locations, there being only a cyclonic vortex of small extent (50-km diameter) and of short-duration, the question of drawing inferences of warm core and cold core as done by Ramage does not arise. Further, data in Fig. 3 are for the 1st while the short-duration small extent vortex was on the 2nd morning; as such, there is also no question of relating data of the 1st (Fig. 3) with structure of the small extent short-duration vortex on the 2nd. Ramage's model reproduced in Fig. 1 is proposed, as stated in the introduction utilising the subtropical cyclone model, additional data obtained by the RFF over the Arabian Sea, and the data presented in his 1963 and 1964 papers. According to the model, there is maximum horizontal convergence at 600 mb; compensating motion is upward above 600 mb and downwards below 600 mb. There is no question of descending air below 600 mb because as stated above, there was cyclonic vortex of small extent and short-duration even at 700 mb on the 2nd near Lat. 11°N, Long. 95°E, presumably below the one at 500 mb, both being part of the same. The vortex being of short duration and small extent, would not naturally be observed on 0·5 km chart (Fig. 1 of Ramage's paper, not reproduced here) for 00 GMT of the 2nd as at 500 mb—Fig. 6. There is thus no justification at all to consider that the model in Fig. 1 is valid even remotely for the Bay of Bengal monsoon; the facts about precipitation are also against subsidence below 600 mb as stated by Rao and Desai (1965).

Ramage has stated that his model of subtropical cyclone does not apply to the Bay of Bengal monsoon as far as the absence of subsidence inversion at 850 mb is concerned; to account for the same, he has, presumed that the descending air was reaching the surface. Regarding this it must be stated that there is generally no inversion over the Bay of Bengal during the monsoon season at about 850 mb in contrast to the Arabian Sea about 200-300 miles west of the Western Ghats; the air over the Bay consists of that which has—(*a*) crossed the Peninsula from the Arabian Sea side north of about Lat. 10°N, the Ghats having destroyed the inversion and also increased the depth of the moist current to about 6·0 km from 1·5 km and (*b*) entered Bay directly south of Lat. 8°N from the equatorial region east of Long. 60°E, the low level inversion having been destroyed and moisture considerably increased in all levels due to the presence of the equatorial trough (Desai 1966).

There is also no question of comparing the Arabian Sea monsoon with the Bay of Bengal monsoon, because the monsoon current over the Arabian Sea is only about 1·5 km deep west of about Long. 68°E, while over the Bay it is about 6·0-km deep over the whole area; the Western Ghats help destroying the inversion and increasing the depth of the current to about 6·0 km, besides causing heavy rainfall along and near them, while the Burma coast mountains in conjunction with the Assam mountains and the Himalayas cause deflection of the monsoon current north and northwestwards and give rise to the trough of low pressure over the Gangetic plains (Desai 1966), besides causing orographic rain along and near the coasts. Desai has shown that the Arabian Sea inversion at about 1·5 km is due to air masses and not due to subsidence and that Ramage's model (1966, 1967) for the Arabian Sea monsoon is also against the facts of Indian weather, climatology and topography as his Bay monsoon model.

Ramage has misquoted Desai (1951) regarding the 1947 case —"The circulation appeared to be most vigorous between 700 and 500 mb, while the air in the circulation was colder than the environment at least from the surface to above 700 mb" and "monsoon depression circulations are usually observed first between 2 and 4 km and only later at the surface". The depressions in the Bay form in three ways— (1) without a low pressure wave coming from the east and due to strengthening of the monsoon current itself (Desai 1951), (2) due to the arrival of a low pressure wave from the east, the monsoon current strengthening as a result of it and the circulation appearing later at the surface (Desai 1951) and (3) due to simultaneous effect of the arrival of a low pressure wave from the east and the strengthening of the monsoon current (Desai and Koteswaram 1951). The development of the depression at the surface and in the higher levels is generally rapid or simultaneous in the third case and slow in the first and second cases. In case one the vertical extent is generally less than in cases two and three. The air in the circulation is colder than the environment from the surface to about 700 mb because the monsoon air is colder than the continental air; higher up due to a difference in the lapse rates in the two air masses, the monsoon air becomes warmer than the continental air. The low pressure circulations from the east appear first in the higher levels because lower portions are held up by the mountain barriers running north-south across Burma and they are sloping westwards with height.

Regarding remark of Ramage during discussion of his 1963 seminar paper 'what surprises me about monsoon precipitation is not how squally it is, but considering how heavy the rain is, how unsqually it is'. It may be stated that squally weather as well as heavy rain is experienced by ships at sea, particularly near the monsoon partition, presumably due to *Cb* clouds above; the roots will be around 4·0 km, only with conditions as in the model for the subtropical cyclone where convergence is maximum at 600 mb with upward motion above that level. In the case of squally weather and heavy rain along and near the West Coast and the Burma coast, the base of the *Cb* might be even lower than 1·0 km just above the nimbostratus sheet which may be even at 300 m or less. Heavy rain in the interior is generally not or need not be accompanied with squally weather, its mechanism being as discussed by Desai (1951, 1967) and Desai and Koteswaram (1951). Heavy rainfall on the West Coast is to a large extent due to the barrier of the Western Ghats, although the presence of troughs or trough axis in the higher levels or perpendicular and triple point conditions, particularly to the north of Lat. 15°N, do increase rainfall there further (Desai 1967).

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