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On the formation, direction of movement and structure of the Arabian Sea Cyclone of 20-29 May 1963

B. N. DESAI

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

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ABSTRACT. Data presented in Mazumdar's paper (1965) have been examined to understand the formation, movement and structure of the Arabian Sea cyclone of May 1963. It is observed that the conclusions arrived at by Desai and Rao (1954) in their examination of some of the famous Indian cyclones are generally supported by this case study except for the unusual southwesterly movement during the later stages which was under the directive influence of an upper tropospheric anticyclone to its west. There is evidence of asymmetric distribution of wind and weather (Desai and Basu 1933, Basu and Desai 1934) and of at least two air masses—warmer drier continental air and colder moist monsoon air in the outer storm area. The Tiros reports of centres can perhaps be helpful in forecasting movement of the cyclones. The differences in air and water temperatures cannot justifiably be utilised to show that the sea surface contributes substantial part of the energy of the cyclone as the air temperature would have considerably decreased with replacement of warmer continental air by colder monsoon air, the water temperature, however, not changing appreciably over the area.

1. Introduction

Mazumdar (1965) has given data of RFF and RAF reconnaissance flights, Tiros VI satellite and surface and upper winds of the coastal stations over Arabia while discussing in a general way this cyclone for assessing the nature of precipitation associated with it from the point of view of accumulation of locusts over the Arabian Peninsula. The data presented by Mazumdar are extremely interesting from the point of view of the structure and unusual movement southwestwards of the cyclone after the 25th when it was about 300 km to the east of Salalah on the Arabian coast.

2. Discussion

(*a*) *Formation and movement of the cyclone*

Some low pressure waves moved from east to west between Lat. 3° and 10°N during the first fortnight of May. With the passage of one such low pressure wave from the east across the south Bay into the southeast Arabian Sea, a trough of low pressure developed over the area after the 15th. In association with this development, there was an extension of equatorial westerlies gradually northwards into the southeast Arabian Sea. One well-marked trough in the westerlies while moving eastwards, had extended into the southeast Arabian Sea as far south as Lat. 5°N on the 15th and it was followed by another trough which reached Lat. 15°N on the 18th (Ramamurthi and Keshavamurty 1964—Fig. 4 — 300-mb level). There was also the influence of an upper tropospheric anticyclone (near Lat. 11°N, Long. 70°E) which extended to about Lat. 9°N on the 19th over the area. As a result of the influence of the two troughs in the westerlies and the upper tropospheric anticyclone, the trough of low pressure over the southeast Arabian Sea developed into a depression by 1200 GMT of the 19th near Lat. 9°N, Long. 71°E; due to paucity of observations it is not possible to determine the centre with much accuracy. The depression intensified into a storm by 1200 GMT of the next day. The storm while moving northwestwards became severe by 0600 GMT of the 22nd. A RFF aircraft reported lowest surface pressure 984 mb at 0630 GMT on the 22nd at the centre near Lat. 11·3°N, Long. 66·1°E with maximum wind of 60 kt in the east quadrant; one and half hour later, the aircraft reported centre near Lat. 11·5°N, Long. 65·9°E, the maximum wind being 70 kt in the southern quadrant and the circular eye having diameter about 30 km.

While the cyclone was moving northwestwards, steep pressure gradient developed and with it the inner core of violent winds. A RFF aircraft reported at 0813 GMT of the 24th centre near Lat. 14·7°N, Long. 60·1°E with lowest surface pressure 947 mb and highest wind 104 kt on the east-west wall, the lowest wind in the centre being 37 kt.

S.S. *Jala Dhruv* and S.S. *Saudi* were near the inner core of violent winds on the 24th and S.S. *Jala Durga* and S.S. *Mohammedi* within the outer storm area on the 26th. Extracts from their logs are given in Table 1.

From the ships' data and RFF reports it would appear that the width of the inner core of violent winds with steep pressure gradient was probably about 60 km on the 24th, there being lighter winds in the eye with radius about 20 km; the

TABLE 1

Date	Hour (GMT)	Position Lat. (°N)	Position Long. (°E)	Wind Direction (deg.)	Wind Force (kt)	Pressure (mb)	Weather
			S. S. *Jala Dhruv*				
24 May 1963	00	15·7	58·0	280	09	1003·5	Cloudy
	03	15·9	58·7	60	19	1003·4	Drizzle
	06	16·0	59·5	30	60	999·4	Rainsqualls
	09	16·2	60·0	50	50	996·3	Heavy rainsqualls
	12	16·3	60·6	80	51	994·9	Heavy rainsqualls
	15	16·4	61·4	100	36	1000·3	Cloudy
	18	16·6	62·1	140	30	1004·8	Cloudy
Remarks—The ship crossed the path of the storm at about 1100 GMT and was about 100 miles from the core when closest to it at about 1200 GMT							
			S. S. *Saudi*				
24 May 1963	00	15·9	59·0	20	13	1002·8	Cloudy
	03	16·0	59·4	360	37	1001·9	Rain
	06	15·3	59·3	360	37	997·8	Rain
	09	14·9	59·1	320	68	989·7	Rain
	12	14·4	59·6	260	68	998·3	Rain
	15	14·3	59·8	250	52	1007·8	Drizzle
			S. S. *Jala Durga*				
24 May 1963	06	11·1	64·7	240	16	1005·9	Cloudy
	18	11·1	61·7	250	16	1005·1	Rain
25 May 1963	06	11·8	59·2	220	40	1002·8	Overcast
	09	12·0	58·6	220	47	1002·6	Rain
	18	12·6	57·0	200	47	—	Showers
26 May 1963	06	13·8	56·7	220	50	—	Showers
	12	13·5	56·0	230	50	998·8	Overcast
	18	13·6	55·3	230	50	996·3	Overcast
			S. S. *Mohammedi*				
26 May 1963	12	13·8	58·6	230	37	999·9	Cloudy
	18	13·7	57·6	230	44	1002·0	Cloudy
27 May 1963	00	13·6	56·4	200	52	999·0	Cloudy
	12	14·1	54·9	200	44	999·0	Drizzle

outer storm area extended to about 150 km beyond the inner core.

After 1200 GMT of the 25th the cyclone moved westwards and then southwestwards, skirting the Arabian coast. It passed to the east, south and southwest of Salalah, where maximum wind was only 40 kt and lowest pressure 991·7 mb at 1200 GMT of the 26th; these observations of Salalah would show that the width of the inner core of violent winds had probably decreased, only the outer storm area affecting the station. From the observations of S.S. *Jala Durga* and S.S. *Mohammedi* it would appear that on the 26th the outer storm area extended to about 600 km from the centre in the southwest quadrant.

A RAF aircraft reported the centre of the cyclone near Lat. 16·0°N, Long. 52·7°E at 1540 GMT of the 27th with lowest surface pressure 945 mb before the radio-altimeter became unserviceable. The observations of this aircraft would show that the cyclone was still severe, but that the width of the inner core of violent winds had possibly decreased.

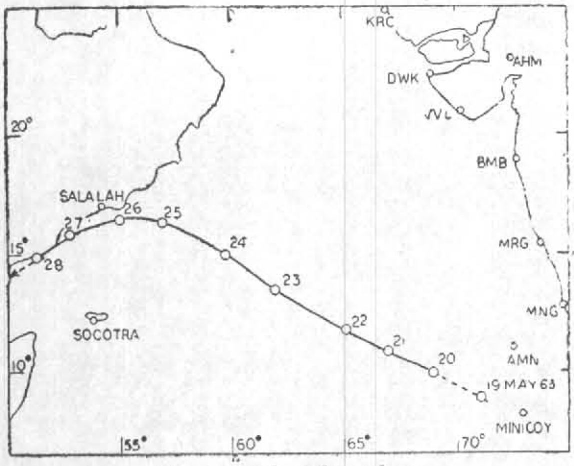

Fig. 1. Track of the cyclone
Position of the centre corresponds to 1200 GMT of the day

A ship reported 50 kt southerly wind at 1200 GMT of the 28th near Lat 15·1°N, Long. 52·1°E with pressure 999·3 mb. The cyclone weakened thereafter, presumably due to the supply of the monsoon air from across the equator being not maintained and the same being replaced by the southwesterly to westerly air from north Africa.

The track of the cyclone is given in Fig. 1, positions of centre corresponding to 1200 GMT of the day.

From the available observations it is not possible to say if there were any upper tropospheric patterns responsible for the intensification of the disturbance into a cyclone of severe intensity with steep pressure gradient and inner core of violent winds between the 22nd and 24th. It is possible that after the impetus for initial deepening from external systems, the cyclone deepened further by itself due to considerable energy released as a result of condensation of water vapour.

It would appear from the track given in Mazumdar's paper that there was a depression even at 00 GMT of the 18th. However, from the data available in the Bombay R.C. Charts it is not possible to locate a definite depression till about 12 GMT of the 19th. Further, Mazumdar has indicated that the depression intensified into a storm by 00 GMT of the 19th; according to the author's examination, it is not possible to say that there was a storm before 12 GMT of the 20th. There is a marked difference in the track of the author and of Mazumdar after 12 GMT of the 25th; these points are discussed later in this section.

The cyclone moved practically northwestwards till 12 GMT of the 25th skirting the upper tropospheric anticyclone at 300 mb to its north which remained practically steady between the 22nd and 29th (Ramamurthi and Keshavamurty 1964). After the 25th evening the cyclone took an unusual course moving westwards till the 26th and southwestwards off the Arabian coast (Fig. 1) thereafter. This unusual movement was apparently due to the directive influence of the anticyclone to its north becoming ineffective and that of the upper tropospheric anticyclone (at 300 mb) over Ethiopia which remained more or less at Lat. 13°N between the 23rd and 27th (Fig. 3—Ramamurthi and Keshavamurty 1964) becoming effective; this anticyclone became indistinct on the 28th due to the disturbance moving towards the Ethiopian area in the upper air (at 300 mb). It would thus appear that the cyclone curved to southwest under the influence of low latitude quasi-stationary anticyclones in the upper troposphere in directing the movement of cyclones both in the Arabian Sea and Bay of Bengal for curving south or southwestwards should be, it is considered, kept in mind as of those in the middle latitudes for curving north to northeast.

There might be also other causes responsible for this unusual movement southwestwards, but from the available data it is not possible to state anything regarding the same. This case supports Desai and Rao's (1954) conclusions regarding formation, intensification and movement of cyclones except for the unusual movment southwestwards.

Mazumdar (1965) has stated that the cyclone struck the Arabian coast near Salalah at about 0000 GMT of the 27th. This would not appear justified in view of the following facts —

(*i*) As mentioned earlier a special RAF reconnaissance aircraft recorded surface pressure as low as 945 mb at the centre near Lat. 16·0°N, Long. 52·7°E on the 27th; the earlier lowest pressure at the centre was 947 mb on the 24th. The track followed by the RAF aircraft is given by Mazumdar in Fig. 9 (a) of his paper.

(*ii*) From the surface data for Salalah given by Mazumdar in Figs. 11 and 14 of his paper, it is seen that the lowest pressure recorded there was only 991·7 mb at 1200 GMT of the 26th against the lowest pressure of about 945 mb at the centre. The wind shift from north to east occurred between 1800 and 2100 GMT of the 26th, the pressure continuously rising after 1200 GMT.

TABLE 2

Position of the surface centres of the cyclone

Date 1963	Tiros VI centre with time	RFF centre with time	Centre from track corresponding to Tiros centre time
19 May	12°N, 68°E (0643 GMT)	—	At the most a depression near 9°N, 71°E
22 May	12°N, 65°E (0534 GMT)	11·3°N, 66·1°E (0630 GMT)	Near 11·4°N, 65·7°E
24 May	14°N, 60·6°E (0513 GMT)	14·7°N, 60·1°E (0813 GMT)	Near 14·5°N, 60·4°E
26 May	16°N, 55°E (0448 GMT)	—	Near 16·7°N, 55·7°E

Thus cyclone passed to the east, south and southwest of Salalah and *not* over it (Fig. 1). Further, the station came under the influence of only the outer storm area with maximum speed of wind 40 kt against more than 100 kt in the inner storm area.

(*b*) *Structure of the cyclone*

(*i*) Centres at the surface as derived from Tiros VI and as reported by RFF reconnaissance aircraft

In Table 2 are given positions of surface centres derived from the above reports as well as the cyclone track given in Fig. 1.

It would appear that the Tiros centre was about 500 and 80 km ahead to the northwest of the track centre on the 19th and 22nd respectively and about 50 km and 80 km to south and southwest of the track centre on the 24th and 26th respectively. Tiros VI centres for the surface are based on clouds while those by the aircraft are determined from much lower height and in the track from only the surface observations. As such, if the axis of the eye is vertical then only the three centres would agree. The difference in the positions of the Tiros, aircraft and track centres will increase with a decrease in the slope of the axis of the eye at the surface and at the cloud top; the difference may also be great if the circulation at the surface is ill-defined, while it is well-defined in the upper levels and is moving forward as on the 19th. Hubert and Timchalk (1964) have discussed differences in centres determined from Tiros and aircraft data and shown that maximum difference between the two can be more than even 150 km. The direction of the slope of the axis of the eye at the surface and cloud top would appear to indicate the direction in which the high level vortex circulation is or would be moving. In the present case the inclination was northwestwards in the beginning and it changed to south and southwestwards later when the influence of the Ethiopian upper tropospheric anticyclone (at 300 mb) became effective as stated earlier. Thus the surface centre determined with the help of Tiros judged with reference to that determined with surface or low level aircraft observations, can perhaps help to indicate the direction of movement even in the absence of high level winds. Looking into Tiros reports from this viewpoint, if the same is also supported by future studies, might further increase utility of the Tiros data in day-to-day forecasting.

TABLE 3

Rainfall amounts recorded at Salalah

Date	Time (GMT)	Rainfall (mm)
26 May	0600	0·2
	1800	3·6
27 May	0600	134·0
	1800	40·0
28 May	0600	20·0
	1200	32·0

(*ii*) Asymmetric structure and presence of different air masses in the outer storm area.

In Fig. 2 are given approximate positions of boundaries between the drier continental and moist monsoon air masses for 12 GMT of the 26th as judged from available wind data and weather remarks taken from Fig. 14 of Mazumdar's paper.

From vertical time-section of Salalah given in Fig. 11 of Mazumdar's paper it is seen that the northerly winds in the outer storm area were stronger than the easterly to southeasterly winds. Low clouds and rain lasted longer in the easterly to southeasterly winds, duration—from about 2100 hrs of the 26th to about 1200 hrs of the 28th. In Table 3 are given rainfall amounts recorded at Salalah taken from Mazumdar's paper.

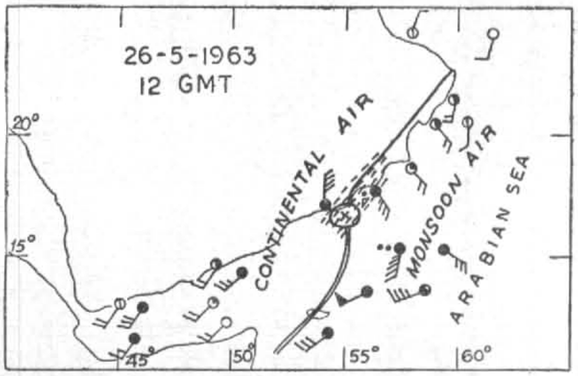

Fig. 2. Approximate positions of boundaries between the drier continental and moist monsoon air masses at 1200 GMT of 26 May 1963

At the partition marked by single line, the moist colder monsoon air will undercut drier warmer continental air upto the reversal level, above which the moist air becoming warmer due to differences in the lapse rates between the two air masses, will rise above the colder drier continental air. At the partition marked by double line, the drier warmer continental air will rise over the colder moist monsoon air in the lower levels and undercut it above the reversal level.

It would appear from Table 3 that maximum rain occurred between 18 hrs of the 26th and 06 hrs of the 27th, rainfall continuing upto 12 hrs of the 28th although with lesser intensity. As stated earlier, the wind shift from north to east occurred between 18 and 21 hrs of 26th. It would thus appear that rainfall was more during the easterly to southeasterly winds than during northerly winds period. The northerly continental air at the surface was relatively warmer and had lower humidity than the southeasterly to easterly air—westerly to southwesterly monsoon air turned under cyclonic circulation. Further, the presence of coastal hills near Salalah would also increase duration and intensity of rain in the easterly to southeasterly wind period as the cyclone moved southwestwards parallel to the coast. The observations of Salalah thus support the view that the structure was asymmetric in the outer storm area and that there are evidences of at least two air masses taking part in that area (Fig. 2) as observed by Desai and Basu (1933) and Basu and Desai (1934) in their study of some important Indian cyclones.

According to RFF data for the 22nd (Fig. 5 of Mazumdar's paper) there were surface winds of 70 kt in the southern, 60 kt in the eastern and 50 kt in the west and north quadrants, showing asymmetric distribution of wind speeds. The fact that the aircraft experienced rain while flying to the cyclone and no rain further north on return flight both tracks being in the area of southeastely winds, would show that there was "nose effect" (Desai and Mal 1933, Sawyer 1947) and that the slope of the partition between the continental and the monsoon air masses was steep above the reversal level BC′ instead of BC in Fig. 3. From Figs. 2(a) and 2(b), 3(a) and 3(b)and 4(a) and 4(b) of Mazumdar's paper of Tiros reports, it is seen that the clouds did not extend too far, skies being clear or there were only a few clouds at some distance from the centre; this would also support the view that the slope of the partition above the reversal level was steep — BC′ in Fig. 3.

From the RAF reconnaissance flight reports given by Mazumdar in his paper (Figs. 9 and 9a), it is seen that while the aircraft flying at a height of 1500 m was moving over the sea towards the cyclone, with the lowering of the cloud (*As*) base from about 5500 m to 4000 m, there was overcast sky with slight rain; temperature fell from 26°C to 15°C at the level of flight. From Fig. 9 where cloud information is given during flight, it is seen that rain did not presumably reach ground. This would mean that the rain passed through dry air and due to evaporation cooling, temperature of air fell from 26°C to 15°C. The cloud pattern in Fig. 9 would show that there might be "nose effect" as a result of the presence of the hot dry continental air with near dry adiabatic lapse and of the cold moist monsoon air with near saturation lapse. In Fig. 4 is given approximate vertical cross-section round about 1400 GMT of the 27th about 20—60 km from the coast and over the sea between points at Lat. 13·9°N, Long. 48·4°E (southwest of Riyan) and Lat. 16·7°N, Long. 53·6° E (southwest of Salalah); the aircraft flew at 1500 m south of the cyclone on flight to Salalah and at 2800 m through the southern edge of the eye on return flight to Aden, the latter flight being nearer the coast than the former. The aircraft entered cloud at 1353 GMT at 1500 m while flying to Salalah; it reported rain out of low cloud at about 1640 GMT while flying at 2800 m on the return flight. The rain noticed at about 1310 GMT was presumably due to ascent of moist air over the continental air above the reversal level (warm front). It would appear from Fig. 4 that the slope of the partition between the continental and moist air masses was very steep—almost vertical—upto about 3000 m.

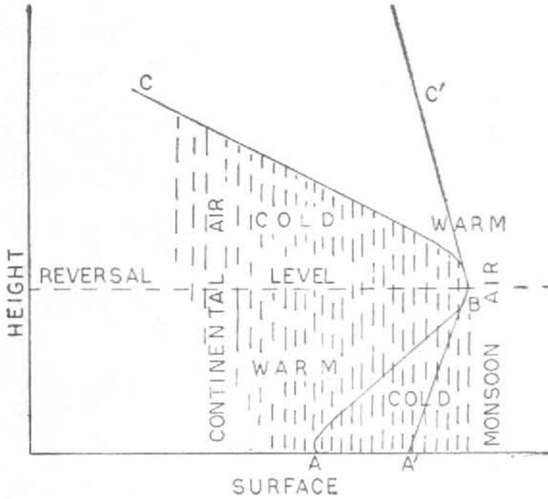

Fig. 3. Approximate vertical cross-section showing distribution of rainfall at the surface in the moist colder monsoon and drier warmer continental air masses

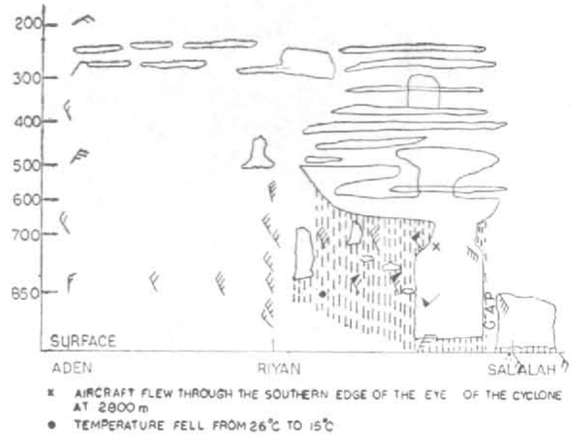

Fig. 4. Approximate vertical cross-section at about 1400 GMT of 27 May 1963 between Aden and Salalah utilising RAF aircraft flight data, upper winds at Aden and Riyan and Salalah surface data

Marked convergence in the inner storm area of the cyclone would give rise to towering *Cu* and *Cb* clouds and rainfall; there was presumably also considerable influence of the high ground and hills to the west of the coast. Higher up, the slope was less steep, the height of partition near Lat. 16°N, Long. 52·7°E being about 3000 m and near Lat. 14·2°N, Long. 49·5°E about 5500 m; the clouds also extended much further away, there being high clouds even as far as Aden.

If there are two air masses of the type mentioned above, rain will occur both in the continental air and monsoon air at the surface as shown by Desai and Mal (1933) from the study of a cyclone moving northwestwards across the south of the Peninsula from the southwest Bay in May 1930. The distribution of rain associated with such a discontinuity with reference to its position at the surface, would depend on its inclination with height below the reversal level, being more both in amount and duration in the cold moist monsoon air than in the warm dry continental air if the slope of the discontinuity from the surface to the reversal level is small (AB in Fig. 3) and above that level large (BC′ in Fig. 3); conditions of 22nd, 24th and 26th when the cyclone was moving northwestwards and later westwards, were apparently of this type, clouds not extending much further away from the centre as seen from the Tiros reports mentioned earlier. On the 27th when the cyclone was moving southwestwards conditions were of opposite type (A′B below reversal level and BC above it in Fig. 3) and rainfall and clouds extended to a much longer distance on the continental air mass side.

Thus the idea of air masses in the outer storm area would appear to be supported from the Salalah, RAF reconnaissance flight, coastal upper winds and ships observations.

It will not be out of place to mention here that Mazumdar (1965) has presumed presence of a secondary vortex near Lat. 14·5°N, Long. 58·5°E (Fig. 14 of his paper), to explain rainfall over the southern half of the Oman Peninsula, it having travelled to that area independently of the primary or main vortex. The presence of S'ly—45 kt wind near Lat. 15·3°N, Long. 57·3°E (Fig. 2) is against the secondary vortex. Tiros report in Fig. 4 of his paper does not also show any secondary vortex. The rainfall over the area can be explained on the basis of the movement of the cyclone itself. From Fig. 10 of Mazumdar's paper in which vertical time-section of Masirah winds is given, it is seen that they veered as the cyclone moved towards the coast and were mainly southerly at least upto 2·0 km between 00 GMT of the 26th and 18 GMT of the 27th; the rainfall which occurred over the southern half of the Oman Peninsula was probably mostly orographic rain, the moist winds striking the high ground, hills and mountains over the Peninsula, some of them being as high as 2·0 to 3·0 km.

(c) *Subsidence associated with the cyclone*

From the data of RFF reconnaissance flights on 22 and 24 May given in his paper, Mazumdar has drawn conclusion that there was subsidence over the storm-core itself. The following remarks are relevant in connection with the subsidence incidence from different sources for this cyclone—

(*i*) On 22 May RFF aircraft flying at 488 m experienced near centre (Lat. 11·5°N, Long. 65·9°E) at 08 GMT, a maximum temperature of 25°C in the eye, the temperature being 20°C near the ring of the hurricane winds. There were clouds in the eye and the aircraft also reported rain at the time with remarks about precipitation all round. In view of clouds and rain in and around the eye, one would not be justified in presuming that 5°C higher temperature in the eye was due to subsidence. It is possible that the temperature difference was due to evaporation cooling of the drier continental air in the area of strong winds where there was more rain than in the eye; this explanation is in line with that advanced for the aircraft data of 27th referred to earlier. The squall line and the line of cumulonimbus clouds reported at 300—500 km northeast of the storm by RFF aircraft on the 22nd was presumably due to the steepness of the partition, referred to earlier, extending northeastwards.

(*ii*) The dropsonde data of RFF flight on 24 May at 0852 GMT over the storm core when the aircraft was at 14·9°N, 59·9°E given in Fig. 8 of his paper, have also been utilised by Mazumdar to show subsidence over the core of the cyclone. This conclusion would not appear justified. The dropsonde was presumably released when the aircraft was at or above 5000 m. It might have undergone considerable drifts while descending to the sea as mentioned by Mazumdar himself. Presence of isothermal and inversion between 825 and 675 mb in Fig. 8 of Mazumdar's paper will, therefore, probably be at some distance away. As the percentage humidity was relatively lower between 825 and 675 mb, particularly between 775 and 675 mb, it is possible that there was presence of continental air in the layer which was humidified by rain as there was heavy rain both at 0800 and 0900 GMT and presumably also at 0852 GMT, the time of dropsonde; this layer of continental air might have moist monsoon air both below and above as would happen due to "nose effect" mentioned earlier.

(*iii*) The neph analysis of Tiros observations for 22, 24 and 26 May given in Figs. 2 b, 3b and 4b respectively of Mazumdar's paper, show clear skies or little cloud to the north and northwest of the centre. This was probably due to steepness of the partition above the reversal level as mentioned earlier and not, it is considered, due to subsidence in the forward portion of cyclone at some distance from the core on those days.

(*iv*) The RAF reconnaissance aircraft reported on 27 May long narrow clearance running parallel to the coast at about 70 km from Salalah and 25 km from the coast. This clearance to the northeast was presumably due to divergence over that area.

(*d*) *Supply of energy to the cyclone*

Mazumdar has stated that in the case of this cyclone, the distribution of water temperature followed a varied pattern. In the initial stages it appeared that air was generally warmer than the sea, but as the storm intensified and progressed there were a number of reports in which sea temperatures were 2°—4° C higher than the air temperature and that it was true even when the lower air temperature could not be attributed to rain-cooling within the storm field. From these observations he would appear to infer that the sea surface acted as "heat source" from which substantial part of the storm's energy was derived. Regarding this inference the following remarks are relevant:

The water temperatures would have presumably not changed during the earlier or later stages of the cyclone except those in association with advection of cooler water currents in the south central and southeast Arabian Sea from across the equator as during the monsoon season. There can, however, be changes in air temperatures due to changes in the air masses. In the beginning there was warm continental air which had higher temperature than the water temperature. Later the cold monsoon air advanced northeast to northwards and there would have been lower air temperature due to its replacing warmer continental air; the monsoon air temperature might even be lower than the water temperature over the area. Further, as there was drier, continental air in the storm field, if rain falls through it due to "nose effect" referred to earlier (Fig. 3) and reaches surface there can also be sufficient cooling due to rain to account for lower air temperature than water temperature. As such, if one takes the temperatures of the air masses and also rain-cooling of drier air mass into consideration where water temperatures are available, there is no valid reason to assume that the sea surface contributed substantial part of the storm's energy. These cyclones are not dry; they are accompanied with torrential rains which are caused due to ascensional movement of moist air and condensation of water vapour. It is the heat liberated during condensation of water vapour which probably contributes most of the energy for the formation, intensification and maintenance of the cyclone. Once this supply of heat is decreased or cut off due to moist current weakening or withdrawing, the cyclone weakens or fills up. In the present case the cyclone weakened after the 28th presumably due to both weakening and withdrawal of the moist currents.

3. Acknowledgement

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