

Some aspects of Bay of Bengal Cyclone of October 1963

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ABSTRACT. An attempt has been made to study the structure of the circulation through the entire troposphere around the cyclonic storm which formed in the Bay of Bengal and crossed Coromandal Coast near Cuddalore and lay near Vellore on 21 October 1963 (1200 GMT). Latent heat and sensible heat energy have been estimated around the lateral boundary of the storm circulation and heat and moisture fluxes computed. The circumstances under which the system recurved and the cause for the heavy precipitation far away from the storm centre have also been briefly discussed.

1. Introduction

Jordan (1952) made an observational study of the upper wind circulation around the tropical storms. Palmen and Riehl (1957) computed heat and energy budget in hurricanes from the mean distribution of temperature and moisture. Gangopadhyaya and Riehl (1959) examined the exchange of heat, moisture and momentum between hurricane ELLA (1958) and its environment. The present study interests itself in the structure of circulation around a cyclonic storm in the Indian region through the entire troposphere. The energy content around the lateral boundary of the storm was examined. Heat and moisture fluxes around the boundary were computed. A factor of interest was the recurvature of the storm and its subsequent movement, another being a second maximum in rainfall far away from the storm centre. These aspects have also been briefly discussed.

2. Synoptic situation

To describe the synoptic situation, surface and 300-mb charts have been presented on three days. Streamline analysis, a direct analysis of the wind field suggested by Bjerknes and Sandstrom (1910) has been used on the maps. The importance of this analysis was demonstrated by Palmer (1952), Riehl (1954) and Ramage (1955). The streamlines are defined by the tangent to the wind but the spacing as drawn is not a function of

the speed. However, as the importance of the isobaric analysis in understanding well developed tropical circulations cannot be underestimated, surface isobaric charts have also been presented. In all the surface streamline charts (1200Z), winds reported by ships at 0600Z and 1800Z have also been plotted. However, the winds plotted on the land are for 3000-ft level pertaining to the hour of the chart. Isotachs have not been drawn to avoid congestion on the maps.

The westward movement of a cyclonic circulation in the equatorial trough was followed from 14 October 1963 from South China Sea and was also evidenced by marked shower activity along the south Tenasserim Coast and subsequently over the Bay Islands. Fig. 1 shows the cyclonic circulation near Lat. 10°N and Long. 92°E on 18 October 1963 (1200 GMT) when it intensified into a depression. Fig. 2 shows the distribution of sea surface temperatures composited for 17-18 October 1963. The disturbance further intensified into a cyclonic storm by about 0600 Z of 20th when it lay in the southwestern periphery of the upper tropospheric anticyclone. The track of the storm is shown in Fig. 3. Also shown in the same figure are the successive positions of a westerly trough which moved eastward during this period. No distinction is made of variation in intensity at storm stage.

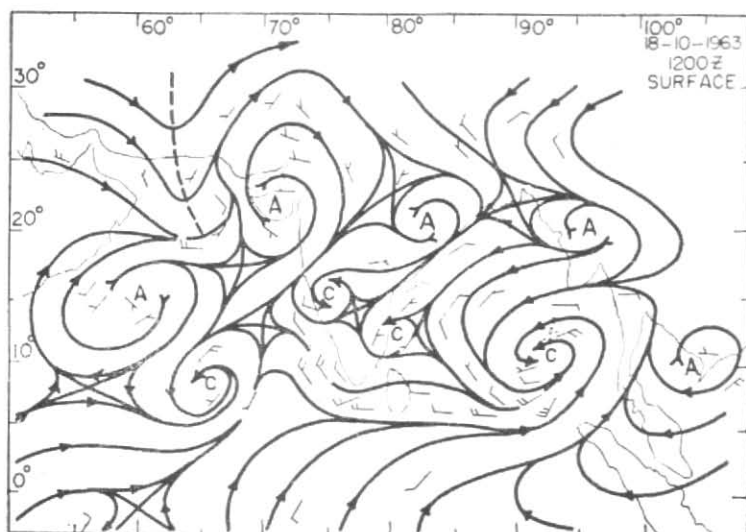


Fig. 1

Figs. 4(a) and 4(b) show the surface streamline and isobaric charts on 21 October 1963 (1200Z) when the storm lay near Vellore, and was already inland for about 6 hours. The 300-mb chart for the corresponding hours is shown in Fig. 4(c). The surface chart shows a well marked asymptote of convergence to the southeast of the storm. Winds of about 40 knots were reported in circulation within a distance of one to two degrees latitude away from the storm centre. Winds to the south of Ceylon were 30 knots strong far away from the centre in the region of marked confluence between southwesterlies and southeasterlies. The 300-mb chart shows the storm circulation of a very small extent with anticyclonic flow all around. A trough in westerlies lies over West Pakistan area. Winds plotted with broken arrows are the debriefing reports from aircraft more or less corresponding to the hour and the level of the chart.

Figs. 5(a) and 5(b) show the surface charts on 22nd (1200 Z). The disturbance weakened considerably and lay as a depression as can be seen from the pressure field, but its grip

on circulation around was still considerable. A trough extended from the circulation north-northeastwards being well marked over north coastal Andhra Pradesh and adjoining Orissa. Fig. 5(c) shows the 300-mb charts on 22nd (1200 Z). The cyclone no longer extended upto this level but was seen as a feeble trough. The trough in westerlies was from Ladakh to northeast Arabian Sea.

Figs. 6(a) and 6(b) show the surface features on 23rd (1200 Z). The depression further weakened and lay over north Mysore. The trough over north coastal Andhra Pradesh and Orissa was well marked and extended further north. Fig. 6(c) shows the TIROS nephanalysis showing the vortex on 23rd (obtained through the courtesy of Col. Sadler, U.S.A.F.). Broken to overcast cumulonimbus bands were reported to the south and the east of the disturbance and overcast cumulus and stratus bands to the west and the northwest. Over the region of the trough extending north and northeast from the storm overcast cumulus and stratus were reported. Fig. 8(d) shows the 300-mb chart on 23rd. The trough in westerlies moved rapidly eastward.

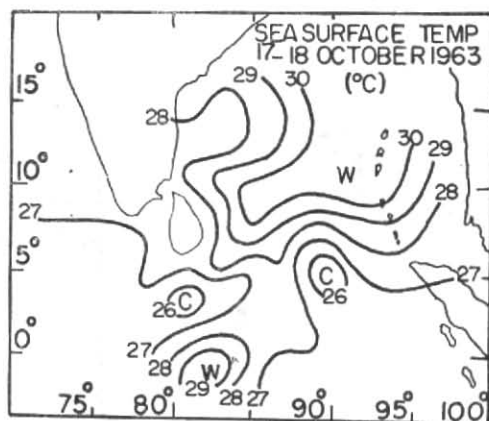


Fig. 2

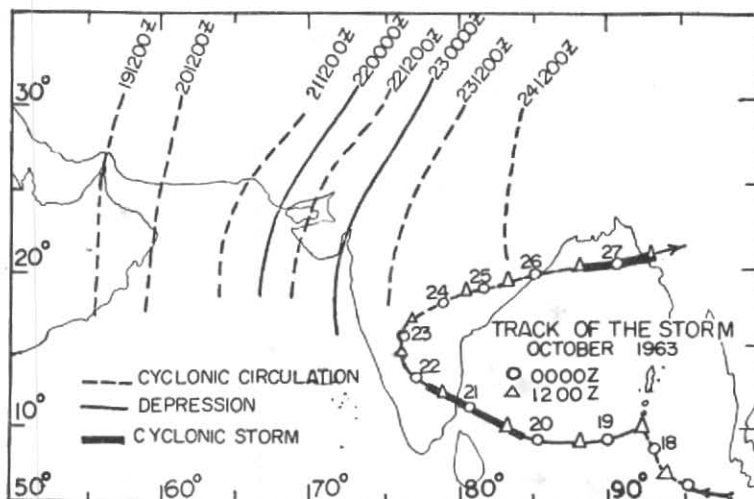


Fig. 3

3. Structure of the circulation around the storm

In this study an examination of the vertical profile of the tangential and radial components of motion was made. The mean energy content around the storm was also computed. All these computations were made when the storm lay inland near Vellore on 21 October 1963 (1200 Z). A circle of radius of about six degrees latitude, though large, was only suitable for the study of the circulation around the storm as restricted by the location of RS/RAWIN stations around it. Fig. 7 shows the circle with the stations around it.

As the gaps between Colombo and Visakhapatnam and between Bombay and Minicoy have been found to be large, points A (Lat. 11°N , Long. 84°E) and B (Lat. 13°N , Long. 73°E) were chosen to fill the gaps. Streamline isotach charts were analysed for all levels upto 100 mb and the winds at A and B at these levels obtained from the analysis. By 21 October (1200Z) the cyclone was already inland for about ten hours and was diminishing in intensity. However, winds in its circulation were about 40 knots in the lower troposphere and about 60 knots at 700 mb.

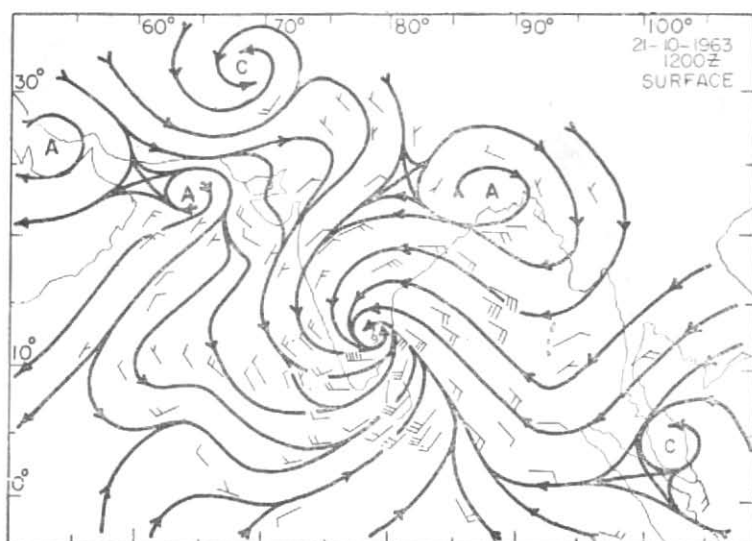


Fig. 4(a)

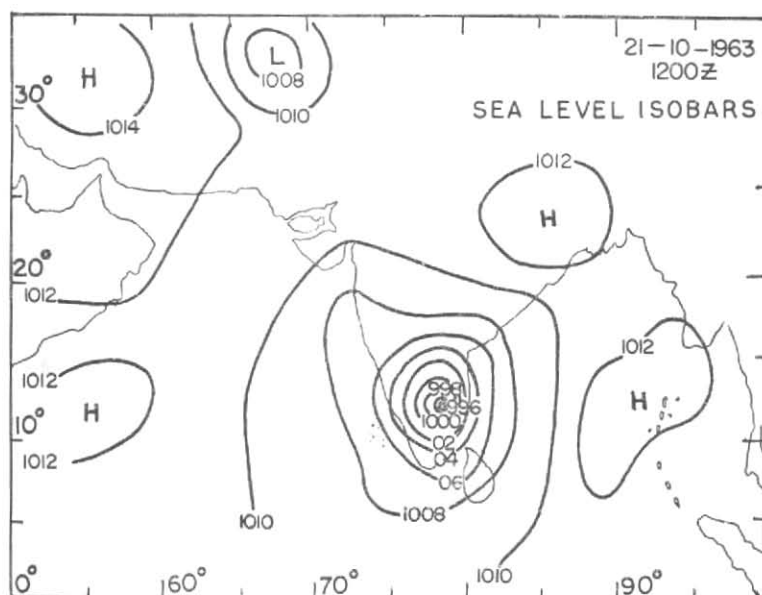


Fig. 4(b)

Figs. 8(a) and 8(b) show the vorticity and vergency fields at 850-mb level and Figs. 8(c) and 8(d) those at 200-mb level respectively. One interesting feature was a second

region of convergence over coastal Andhra Pradesh. Also noticeable was a zone of divergence to the northwest of the storm, the direction in which the storm subsequently

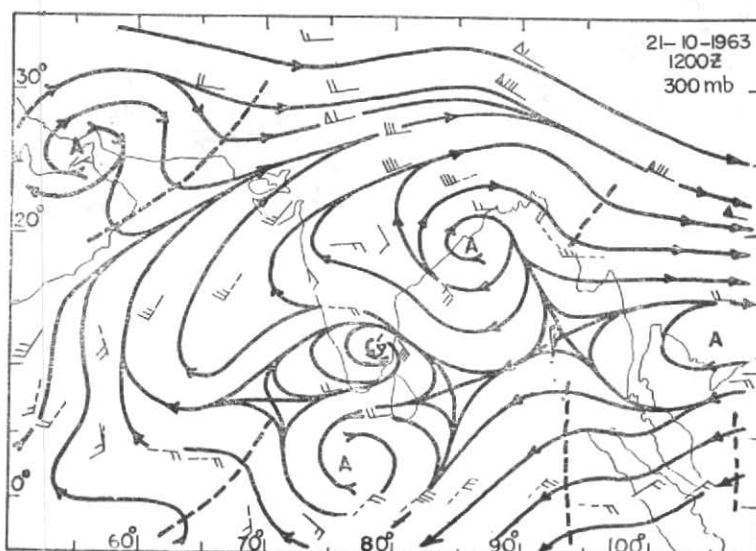


Fig. 4(c)

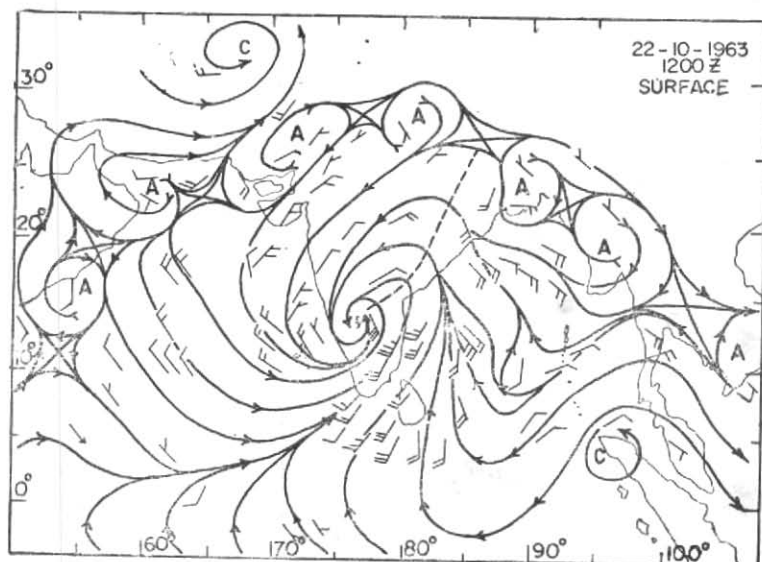


Fig. 5(a)

moved. At 200-mb level a region of anticyclonic vorticity lay over coastal Andhra Pradesh and Orissa with considerable divergence in the region where an anticyclone

lay till 24th. The computations that follow also suggest that most of the circulation features characteristic of hurricane structure were present in the storm. The following

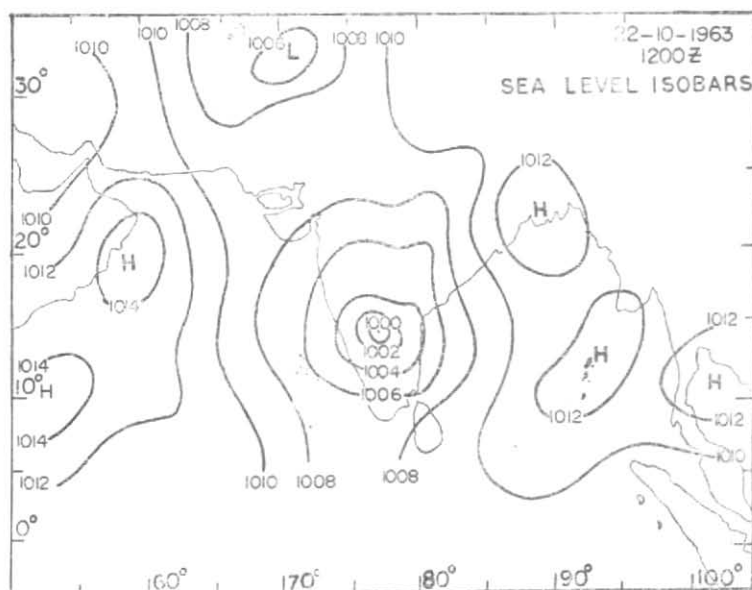


Fig. 5(b)

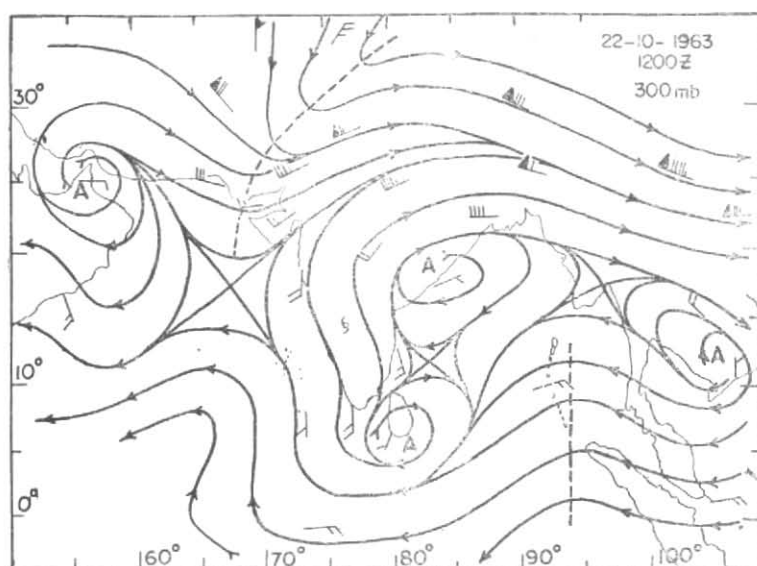


Fig. 5(c)

quantities were examined — tangential component of motion C_s , radial components of motion C_n , specific humidity q , enthalpy plus potential energy $C_p T + gZ$ and the total

energy content around the storm. For each station around the circle these quantities were plotted against pressure on a linear scale upto 200 mb for every 100 mb and for

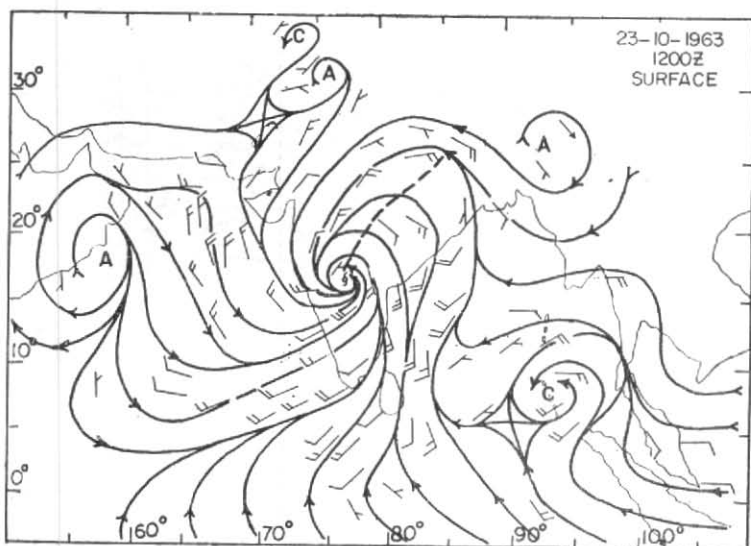


Fig. 6(a)

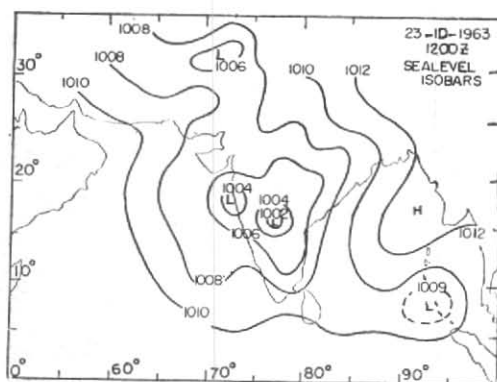


Fig. 6(b)

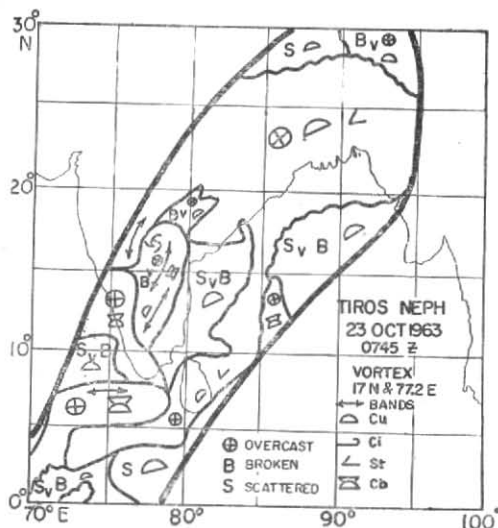


Fig. 6(c)

layers of 50-mb thickness from 200 to 100 mb. Vertical cross-sections were then prepared.

Fig. 9 shows the tangential component of motion in knots. The circulation was pre-

dominantly cyclonic in the lower and middle troposphere. It was also cyclonic even in the upper troposphere towards Visakhapatnam. This was due to the presence of an active anticyclonic circulation aloft over north coastal Andhra Pradesh and adjoining Orissa,

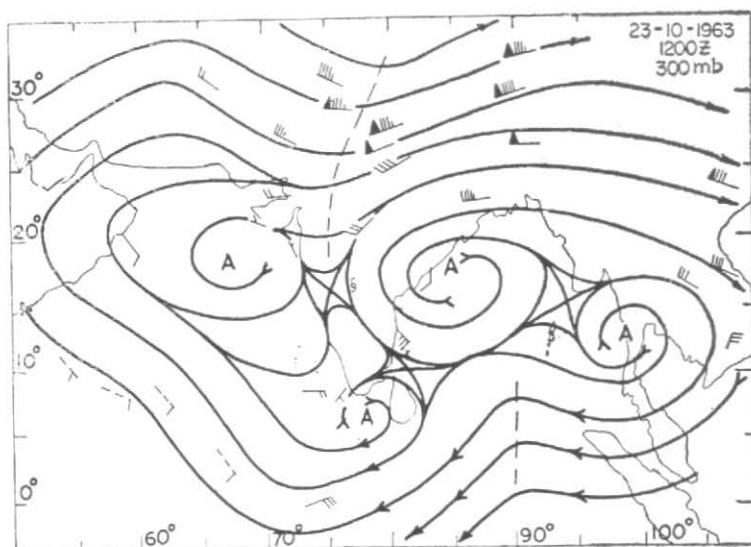


Fig. 6(d)

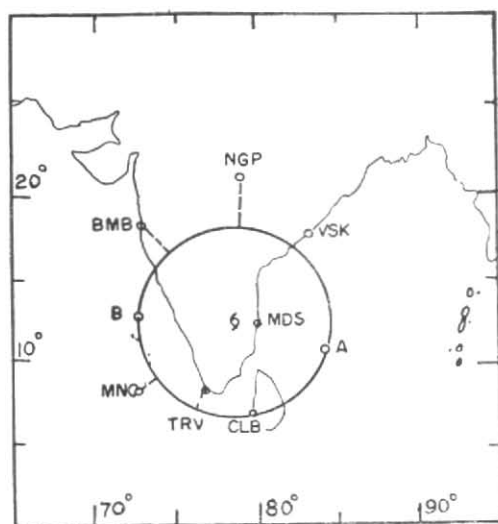


Fig. 7. Circle around the storm with RS/RW stations shown around

which with respect to the circle under consideration was cyclonic. In the upper troposphere the flow was clockwise towards north, northwest and south. However, a region of anticyclonic tangential components was

noticed in the mid-troposphere towards southwest.

The radial components of wind at different stations were worked out and the vertical cross-section of the same is shown in Fig. 10. The storm displacement was vectorially subtracted from the actual radial components, before preparing the cross-section to yield the component relative to the moving centre. The inflow is maximum at 90C mb and is from directions between the south and the east. There was also another region of inflow to the south and the southsouthwest in the mid-troposphere. Outflow was noticed only above 300 mb, being maximum above 200 mb towards northnorthwest and southeast. The region of inflow and cyclonic tangential components were noticed from the directions, between the south and the east, *i.e.*, to the rear of the storm. Most of the outflow took place to the southwest and northwest well-correlated with the anticyclonic flow in Fig. 9.

Fig. 11 shows the vertical profile of the mean tangential circulation and the mean radial circulation obtained by averaging the values for all stations around the circle. For

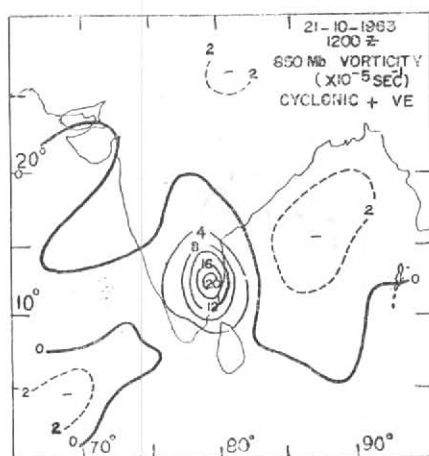


Fig. 8(a)

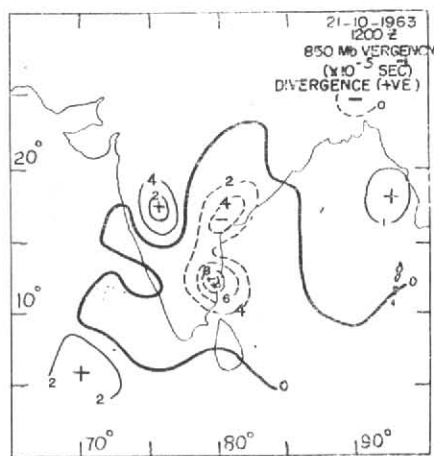


Fig. 8(b)

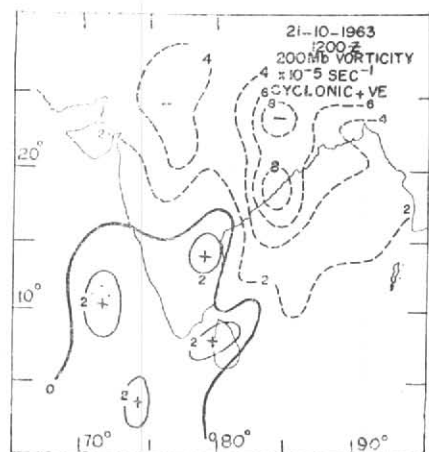


Fig. 8(c)

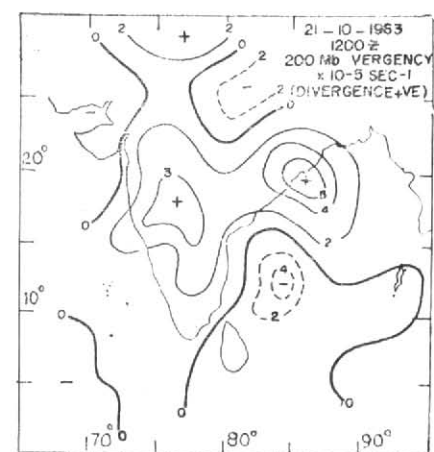


Fig. 8(d)

obtaining the mean radial component \bar{C}_n , the following procedure was adopted. The layer mean values of C_n were plotted on vertical cross-sections with pressure on linear scale as ordinate and peripheral distance around the boundary as abscissae. After the completion of the analysis ten equally spaced points around the circumference of the circle were selected and values of C_n for each layer of 100-mb thickness were read out from the

analysis at each point. This technique was adopted in order to weight all the stations around the boundary regardless of spacing of the stations. These ten values were averaged horizontally to obtain the mean value around the circle for each layer. Similar procedure was adopted in the case of other parameters also.

The tangential circulation was mostly cyclonic upto 200 mb and was anticyclonic

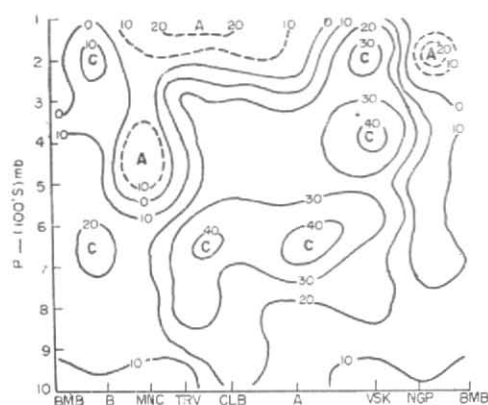


Fig. 9. Vertical profile of the tangential component of wind (C_s) around the lateral boundary of the storm — 21 October 1963 (1200 GMT)

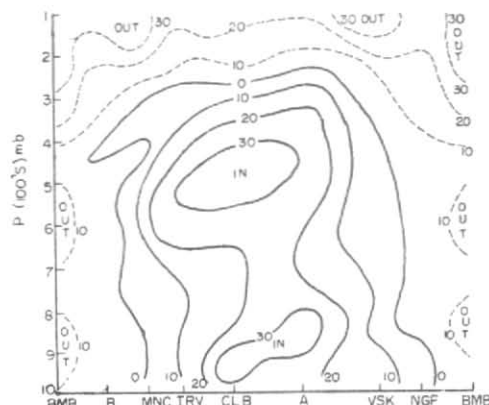


Fig. 10. Vertical profile of the radial component of wind (C_r) around the lateral boundary of the storm — 21 October 1963 (1200 GMT)

above it. The circulation was strongest (cyclonic) at about 700 mb. The radial components were inward upto about 400 mb and outward above it. The maximum radial components (inward) were noticed between 600 and 500 mb instead of at lower levels. This is probably due to the storm being inland and friction playing its active role effecting the lower troposphere. At 300 mb the tangential components were still cyclonic while the radial components were outward. In the 300-mb chart shown in Fig. 4(e), while there is a cyclonic circulation of a small areal extent more or less vertically above the storm below, it is surrounded by anticyclonic circulation immediately all around. The values of sensible heat energy ($C_p T + gZ$), specific humidity q and latent heat energy L_q and the total energy ($C_p T + gZ + L_q$) at different stations for each layer of 100-mb thickness are shown in Tables 1, 2 and 3 respectively.

The values of ($C_p T + gZ$) did not vary very much at different stations and hence the deviations of ($C_p T + gZ$) (in tenths of cal. gm^{-1}) from the mean value for the circle were worked out and the vertical profile is shown in Fig. 12. It can be seen that large positive values of deviations are noticed in the mid-troposphere towards south and the

east and negative values towards the rest of the directions.

The deviations of specific humidity (in tenths of gm. kg^{-1}) from the mean vertical distribution around the circle are shown in Fig. 13. High positive values were noticed towards the region of large inflow from the directions between the south and the east. Large negative values were noticed to the north and the west from where relatively dry air was being drawn into circulation in contrast to the large moisture inflow from the ocean surface from the directions between the south and the east.

It can be seen from Table 2 that the specific humidity decreases with height and tapers off to very low values. The latent heat values are neglected above 500-mb levels for want of humidity values.

The mean distribution of ($C_p T + gZ$) and ($C_p T + gZ + L_q$) around the lateral boundary of the storm on 21 October 1963 (1200 GMT) is shown in Fig. 14. While sensible energy increases with height, the total energy shows a maximum in the lower and the upper troposphere and a minimum in the layer of 600 to 500 mb. Such a variation of total energy in tropics is well known and in the

TABLE 1

Values of $(C_p T + gZ)$ in cal/gm at different stations on 21 October 1963 (1200 GMT)

	P(100's mb)									
	10-9	9-8	8-7	7-6	6-5	5-4	4-3	3-2	2-1.5	1.5-1
Trivandrum	74.5	74.9	75.7	77.3	78.6	79.3	80.6	81.2	82.0	84.7
Minicoy	74.7	75.2	75.1	75.9	76.8	78.2	80.7	80.9	81.8	..
Visakhapatnam	74.6	75.0	75.9	76.6	77.2	78.6	79.6	80.6	81.4	83.5
Nagpur	—	75.1	75.4	76.1	76.9	78.1	79.9	82.0	83.3	85.8
Bombay	75.6	75.4	75.9	75.9	77.2	78.7	79.6	80.9	82.3	83.4
Madras	74.5	74.7	75.6	76.7	78.3	79.5	80.8	82.2	83.5	84.0

TABLE 2

Values of specific humidity (gm/kg) and L_q (cal/gm) at different stations on 21 October 1963 (1200 GMT)

		P(100's mb)					
		10-9	9-8	8-7	7-6	6-5	5-4
Trivandrum	q	17.7	14.4	10.7	7.3	4.1	1.3
	L_q	10.3	8.5	6.3	4.3	2.4	0.9
Minicoy	q	17.1	12.5	8.0	3.0	1.2	—
	L_q	10.0	7.3	4.7	20.0	0.8	—
Visakhapatnam	q	17.7	13.5	10.5	7.4	2.0	0.4
	L_q	10.3	7.8	6.1	4.4	1.4	0.3
Nagpur	q	—	7.0	5.1	2.9	1.1	—
	L_q	—	4.1	2.9	1.7	0.7	—
Bombay	q	15.7	11.0	8.2	6.6	3.9	1.1
	L_q	9.3	6.5	3.9	2.2	1.4	0.4
Madras	q	18.0	14.4	11.2	7.8	4.1	1.4
	L_q	10.5	8.5	6.6	4.6	2.4	0.9

TABLE 3

Values of $(C_p T + gZ + L_q)$ (cal/gm) at different stations on 21 October 1963 (1200 GMT)

	P(100's mb)									
	10-9	9-8	8-7	7-6	6-5	5-4	4-3	3-2	2-1.5	1.5-1
Trivandrum	84.8	83.4	82.0	81.6	81.0	80.2	80.6	81.2	82.0	84.7
Minicoy	84.7	82.5	79.8	77.9	77.6	78.2	80.7	80.9	81.8	—
Visakhapatnam	84.9	82.8	82.0	81.0	78.6	78.9	79.6	80.6	81.4	83.5
Nagpur	—	79.2	78.3	77.8	77.6	78.1	79.9	82.0	83.3	85.8
Bombay	84.9	81.9	79.8	78.1	78.6	79.1	79.6	80.9	82.3	83.6
Madras	85.0	83.2	82.2	81.3	80.7	80.4	80.8	82.8	83.5	84.8

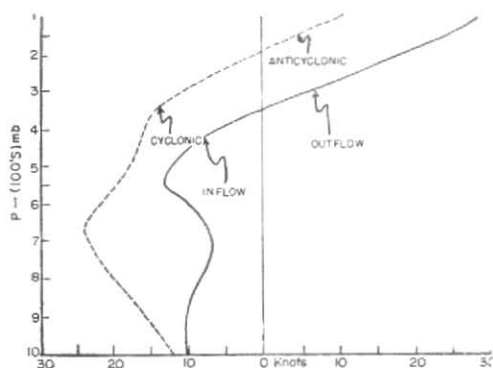


Fig. 11. Vertical profile of mean tangential (C_θ) and radial (C_n) components of motion around the lateral boundary — 21 October 1963 (1200 GMT)

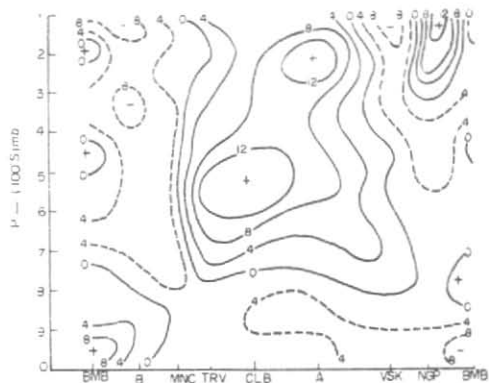


Fig. 12. Vertical profile of the deviations of ($C_p T + gZ$) from the mean (in tenths of cal/gm) around the boundary — 21 October 1963 (1200 GMT)



Fig. 13. Vertical profile of the deviations of specific humidity (q) from the mean (in tenths of gm/kg) around the boundary — 21 October 1963 (1200 GMT)

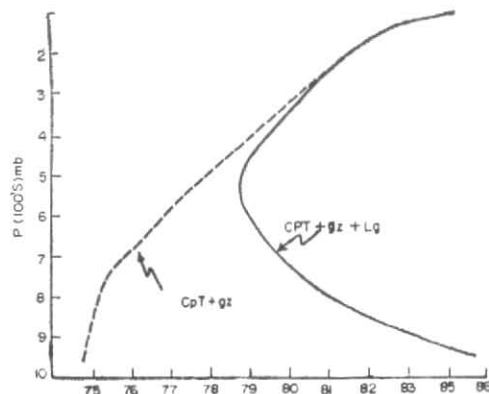


Fig. 14. Vertical profile of the mean distribution of ($C_p T + gZ$) and ($C_p T + gZ + Lq$) around the lateral boundary — 21 October 1963 (1200 GMT)

case of this storm the level of minimum energy more or less, coincides with the level of maximum inflow.

4. Heat and moisture fluxes

The circular arrangement of the stations around the storm centre suggested a cylindrical co-ordinate system for computing the energy transport across the boundary. The flux integrals involve the product of radial component of wind C_n and the energy parameters around the boundary. The transport of sensible heat relative to the travelling centre in the cylindrical co-ordinate system is given by—

$$H = \iint (C_p T + gZ) C_n ds (dp/g) \quad (1)$$

where ds is the horizontal distance along the lateral boundary and the moisture (latent heat) transport by—

$$L = \iint L_q C_n ds (dp/g) \quad (2)$$

These terms may be split up into contributions of mean and eddy motions. The eddy motions arise out of variations of wind and other parameters around the boundary.

These may be written as

$$H = \bar{H} + H^1 = \iint (\overline{C_p T + gZ}) C_n ds \frac{dp}{g} + \iint (\overline{C_p T + gZ})' C_n' ds \frac{dp}{g} \quad (3)$$

TABLE 4

Fluxes of sensible heat and latent heat (moisture) by mean and eddy transport across the lateral boundary (cal/sec)

Sensible heat	Latent heat
$\bar{H} = 1.4 \times 10^{15}$	$\bar{L} = 0.5 \times 10^{15}$
$H' = 0.1 \times 10^{15}$	$L' = 0.1 \times 10^{15}$
$H = \bar{H} + H' = 1.5 \times 10^{15}$	$\bar{L} = \bar{L} + L' = 0.6 \times 10^{15}$

$$L = \bar{L} + L' = \iint \bar{L}_q \bar{C}_n ds \frac{dp}{g} + \iint \bar{L}'_q \bar{C}'_n ds \frac{dp}{g} \quad (4)$$

Vertical integration in equations (3) and (4) was performed by averaging different parameters over layers of 100-mb thickness upto 200 mb and for 50-mb thickness from 200 to 100 mb. 100 mb is chosen to be the top limit as this level nearly coincides with the base of the tropopause.

The sensible heat and moisture heat fluxes around the lateral boundary were computed employing equations (3) and (4). The values of the fluxes for mean and eddy motions are shown in Table 4.

If no vertical flow takes place between the upper and the lower boundary and the pressure inside the volume is constant then the net mass flux around the closed surface integrated from the surface to the tropopause should be equal to zero. Mass balance was obtained with little adjustment. The computation of sensible heat and latent heat fluxes, have shown a net energy flux inward — mainly through mean motion.

5. Rainfall

One of the most interesting features of the storm period was the peculiar distribution of rainfall around the storm area. The rainfall amounts reported over north coastal

Andhra Pradesh and Orissa far away from the storm had been very heavy and persisted upto 25th causing heavy floods over the area. In the rainfall maps that follow, rainfall amounts of 1 cm or more recorded at all observatory stations in India have been plotted. Superposed on them are 300-mb streamlines. While the rainfall amounts relate to a period of 24 hours ending 0300Z of date, the 300-mb streamlines relate to the 1200Z of the previous day. This is found more suitable as 1200Z falls more or less at the middle of the 24-hour period for which the rainfall is recorded at 0300Z of date.

Fig. 15 shows the rainfall on 21st. The westerly trough was far away located along 60°E. Very heavy rainfall amounts were reported along the Coromandal coast and slightly interior due to the storm. A noticeable feature was a rainfall of 8 cm at Gopalpur far away from the storm. Rainfall on 22nd (Fig. 16) showed distinctly two rainfall maxima, one around the storm and the other over the north coastal Andhra Pradesh and adjoining Orissa. The upper trough was still far away. The rainfall for 23rd (Fig. 17) showed double maxima with heavy to very heavy falls over the north coastal Andhra Pradesh and adjoining Orissa. The rainfall on 24th (Fig. 18) showed a triple maxima—(1) near the disturbance, (2) over north coastal Andhra Pradesh, Orissa and adjoining Bengal, and (3) over northeast Madhya Pradesh and adjoining Uttar Pradesh, this being due to

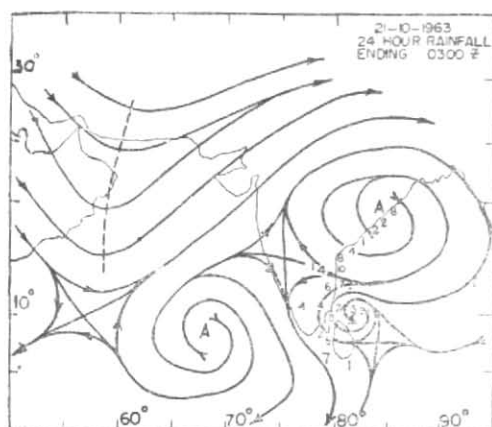


Fig. 15

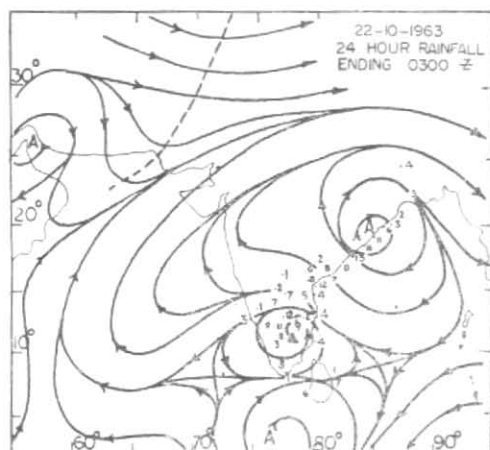


Fig. 16

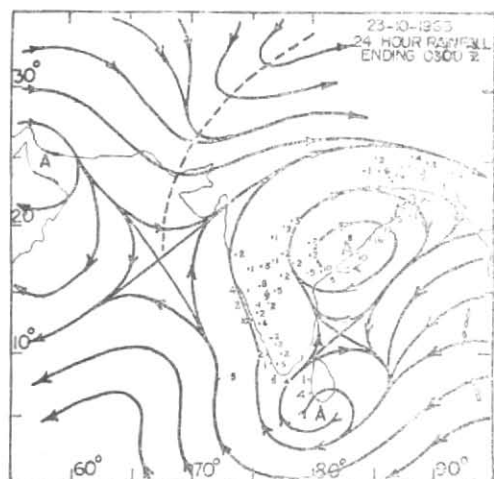


Fig. 17

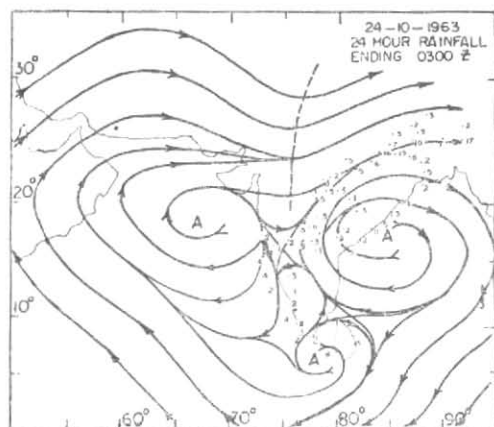


Fig. 18

westerly trough aloft. The rainfall belt due to the trough moved eastward with the movement of the trough while the rainfall due to the disturbance also moved eastward with it.

The second rainfall maximum was first observed on 21st and it lost its identity by 25th. During the period from 21st to 25th this maximum was very distinct from the rainfall associated with the tropical disturbance and the westerly trough aloft. *It can*

be seen from the streamline chart that on all these days an upper tropospheric anticyclone was lying over the area of the precipitation maximum.

Riehl (1954) discussed the case of an upper tropospheric anticyclone which intensified and was maintained by the release of latent heat of condensation and in turn was the cause of further precipitation under it. The layer 500—200 mb has been known to be most suitable in understanding the thermal

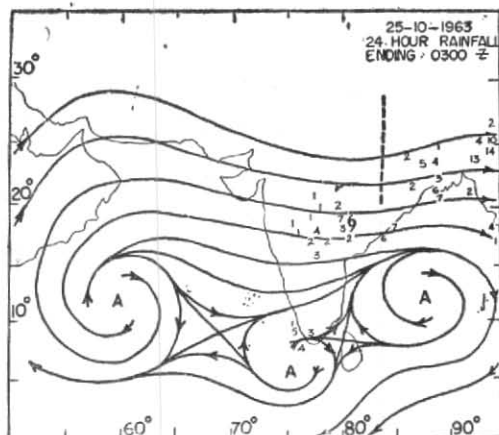


Fig. 19

structure of the upper tropospheric flow (Zipser 1964). Figs. 20 to 24 show the 500—200 mb thickness charts from 20th to 24th with *thermal winds* plotted on them. On 20th the thickness high was over the storm area in the southwest Bay. On the 21st two distinct thickness highs were seen one over the storm area and the other over coastal Andhra Pradesh and adjoining Orissa where an anticyclone lay in the upper troposphere. On 22nd only one thickness high could be seen over Orissa and adjoining north coastal Andhra Pradesh. This thermal high continued to stay there till 24th.

Figs. 25 to 28 show the total moisture charts from 21st to 24th. Even though actual rainfall amounts over the area have been discussed earlier, these charts are presented so as to bring about more clearly the similarity of the moisture and thermal fields. On 20th and 21st total moisture was largest at Madras. On the subsequent days moisture increased at Visakhapatnam and simultaneously decreased at Madras. The coincidence

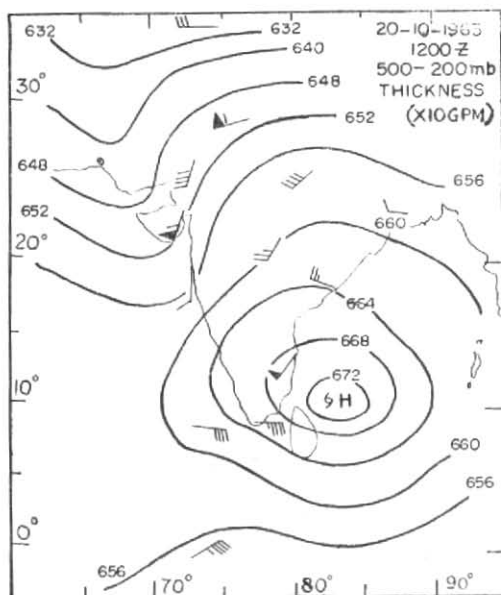


Fig. 20

of the axis of temperature and moisture is evident from the charts presented.

As shown in Figs. 5 and 6, a trough in the lower troposphere extended from the cyclone towards north-northeast and this facilitated in drawing moisture at these levels into the region under the upper tropospheric anticyclone.

On 24th the westerly trough approached the region of this warm anticyclone aloft. On the next day the anticyclone shifted southeastwards. With this the rainfall maximum which had a distinct identity became unimportant. This suggests that the second rainfall maximum occurred due to the active anticyclone aloft. The upper tropospheric anticyclone intensified as evident from the thickness charts due to release of condensation heat.

6. Recurvature

The track of the storm is shown in Fig. 3. The track is very singular in that none of the

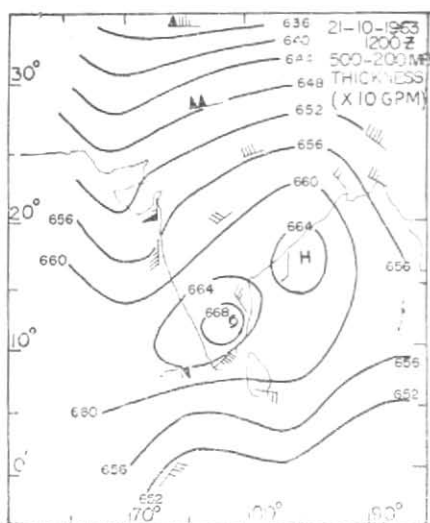


Fig. 21

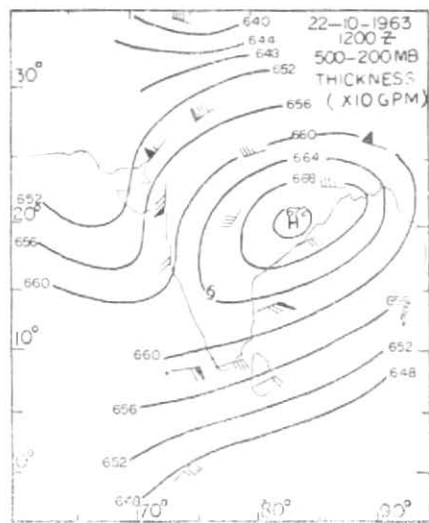


Fig. 22

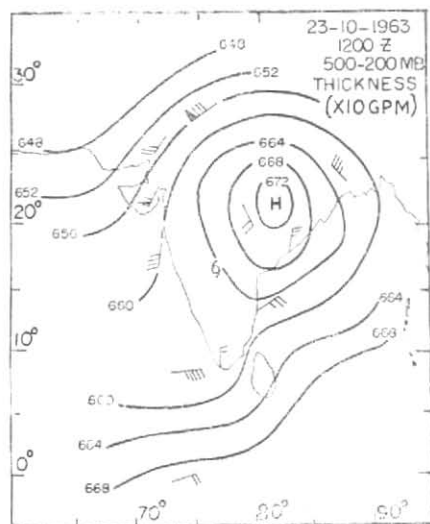


Fig. 23

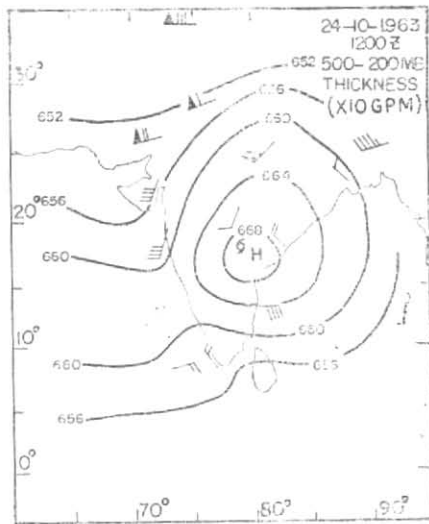


Fig. 24

tropical disturbances during the 70-year period 1891—1960 (India met. Dep. 1964) that crossed Coromandal coast recurved over the peninsula again to re-enter and re-intensify over the Bay of Bengal. Fig. 3 also shows the successive positions of the westerly trough (300 mb).

The most common cause of recurvature of tropical disturbances is by vortex interaction between a cyclone and an anticyclone. Generally while the anticyclone remain practically stationary, the cyclone travels around its periphery. While no single level can be used for steering, the steering

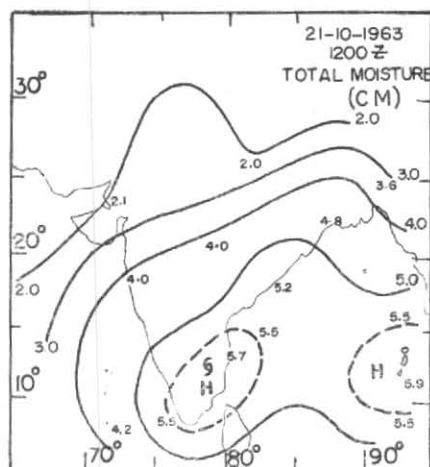


Fig. 25

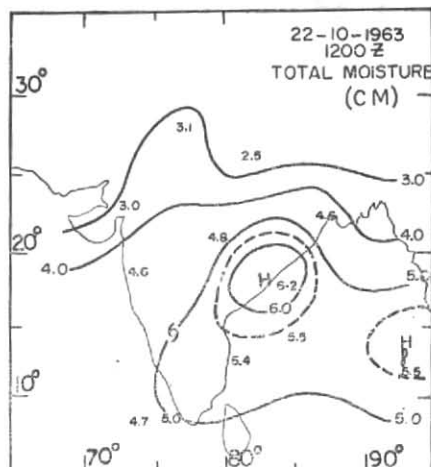


Fig. 26

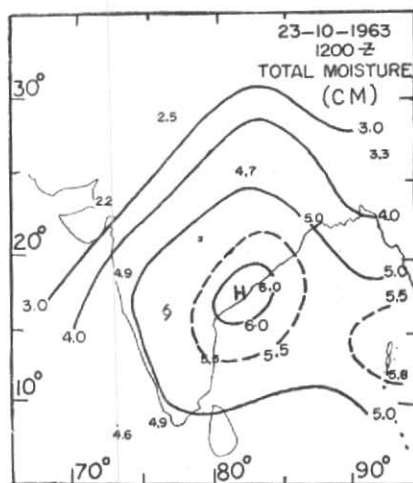


Fig. 27

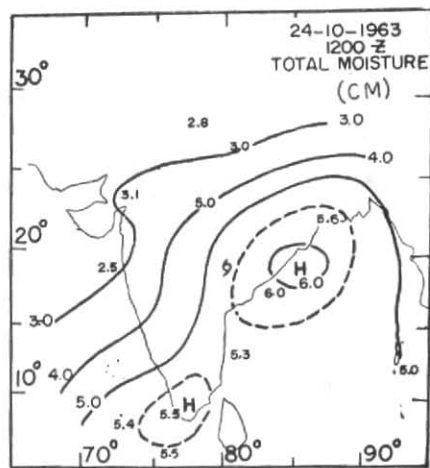


Fig. 28

level of importance is the level just above the cyclone, where it is free from vertical circulation. The system weakened so considerably that it did not extend above 500-mb level by 22nd (1200Z). From an examination of the charts it is found that the storm recurved around the 300-mb anticyclone ahead of the trough by about 0600Z of 23rd. The south-eastward shift of the anticyclone after the 24th, gave rise to generally westerly flow aloft

over Telengana, east Madhya Pradesh and Orissa and hence the disturbance moved practically eastward thereafter.

7. Conclusions

This paper is an attempt to study the structure of the circulation of a tropical cyclone in the Indian area through the entire troposphere. However, the study is much handicapped for want of a better network of

RS/RW stations around the storm. In spite of the unavoidable shortcomings, the available data have been utilised to the maximum extent possible.

Large tangential components have been noticed between 900 and 700 mb, being strongest at 700 mb. As in Hurricane ELLA, a high level of non-divergence above 400 mb is noticed in the storm. The energy content around the lateral boundary has been found to be minimum between 600 and 500 mb as is to be expected in tropics.

The areal extent of tropical cyclone circulation diminishes with height and to expect a very small sized circulation at very high levels with anticyclones all around and *cyclonic outflow* in the immediate vicinity appears reasonable.

The occurrence of rainfall maxima under the umbrella of active upper tropospheric

anticyclone during the period 21st to 24th and its disappearance with the shift of the anticyclone southeastwards is interesting. Circulations which are maintained by release of latent heat of condensation thus seem to be very important in tropics. Similar situations of weather occurring in the region of troughs developing from tropical disturbances under the influence of upper tropospheric anticyclones but far away from the tropical disturbances have been noticed along the northern Circars coast and also over the east coast of China when typhoons crossed the South China coast. Similar features, it is understood, are observed along the east coast of Australia.

8. Acknowledgement

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REFERENCES

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|-----------------------------------|------|---|
| Alaka, M. A. | 1962 | Instability aspects of cyclogenesis. Nat. Hurricane Res. Project Rep., 45. |
| Bjerknes, V. and Sandstrom, J. W. | 1910 | <i>Dynamic Meteorology and Hydrography</i> , Carnegie Inst. Publ. |
| Gangopadhyaya, M. and Riehl, H. | 1959 | <i>Quart. J. R. met. Soc.</i> , 85, pp. 278-286. |
| India met. Dep. | 1964 | <i>Tracks of storms and depressions in Bay of Bengal and Arabian Sea (1891-1960)</i> . |
| Jordan, E. S. | 1952 | <i>J. Met.</i> , 9, pp. 340-346. |
| Palmen, E. and Riehl, H. | 1957 | <i>Ibid.</i> , 14, pp. 150-159. |
| Palmer, C. E. | 1952 | <i>Quart. J. R. met. Soc.</i> , 78, p. 126. |
| Ramage, C. S. | 1955 | <i>J. Met.</i> , 12, pp. 252-262. |
| Riehl, H. | 1954 | <i>Tropical Meteorology</i> , McGraw Hill Book Co. |
| — | 1958 | On the production of kinetic energy from condensation heating. Nat. Hurricane Res. Project Rep. 22. |
| Solot, S. B. | 1939 | <i>Mon. Weath. Rev.</i> , 67, pp. 100-103. |
| Zipser, E. J. | 1964 | On the thermal aspects of developing tropical cyclones, Nat. Hurricane Res. Project Rep. 67. |