The 5–18 October 1974 disturbances in the ITCZ over west central Bay of Bengal

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ABSTRACT

During the course of the retreat of the southwest monsoon over India, the ITCZ was close to the station Visakhapatnam (17°42′N, 83°20′E), for a considerable period in the year 1974; two disturbances have passed westward in that period. Therefore, the rawin and radiosonde data at Visakhapatnam in particular gave an opportunity to make a detailed study of the two disturbances in the ITCZ. The wind, temperature and humidity structure of the disturbances and the energy ($C_pT + gZ + Lq$) distribution are presented and discussed.

Intense disturbances in the ITCZ are found to contribute not only to the direct transport of energy into the upper troposphere but also to the inflow and outflow of the mean meridional tropical circulation as hypothesized by Riehl (1969).

1. Introduction

The ITCZ/equatorial trough over the North Indian Ocean shifts as far as 23°N during the northern summer and moves back towards the equator during autumn. In July and August the equatorial trough lies along the Gangetic valley in North India and is known as the monsoon trough (Fig. 1a). While a part of the south-westerly monsoon stream directly converges into the trough on the southern side, another part turns round the tip of the trough over the head of the Bay of Bengal and flows as a south-easterly current on the northern side. In October (Fig. 1b) the equatorial trough lies across south Bay of Bengal and the trades of the two hemispheres converge into the trough. The travelling disturbances in the former monsoon and the latter equatorial troughs are the main sources of precipitation in India. The low pressure systems that form at the tip of the monsoon trough are known as monsoon depressions. During the post-monsoon season (Oct.–Nov.) some of the low pressure systems in the Bay of Bengal develop into cyclones. Several attempts have been made to study these cyclonic systems in the past.

In recent years much progress has been made in understanding the tropical disturbances by the method of spectrum analysis, particularly in the North Pacific (Yanai et al. 1968; Wallace & Chang, 1969; Nitta, 1970, 1972; and Murakami, 1971, 1972). A review of the spectral studies of tropospheric wave disturbances was made by Wallace (1971) and another review of the more recent literature has been given by Yanai (1975). Similar spectral studies were made by Subbaramayya & Bhaskar Rao (1974) over the Indian area. Their subsequent investigations during the monsoon season have revealed the existence of pronounced 7-day period disturbances in the monsoon trough.

During the period 26 September to 26 October 1974, the monsoon trough gradually moved equatorward and four low pressure systems formed successively in the East Bay of Bengal and moved along the trough toward the west. Their tracks are shown in Fig. 2. The second and the third systems moved close to Visakhapatnam, while the other two, though sufficiently far away, also affected the weather at that station. The variations of pressure, rainfall and cloud amount (0830 hrs. I.S.T.) at Visakhapatnam during the 1-month period are presented in Fig. 3. Pressure minima occurred on 29 September, 8, 15 and 28 October corresponding to the passage of the four systems. The average period of these systems is close to 7 days and thus

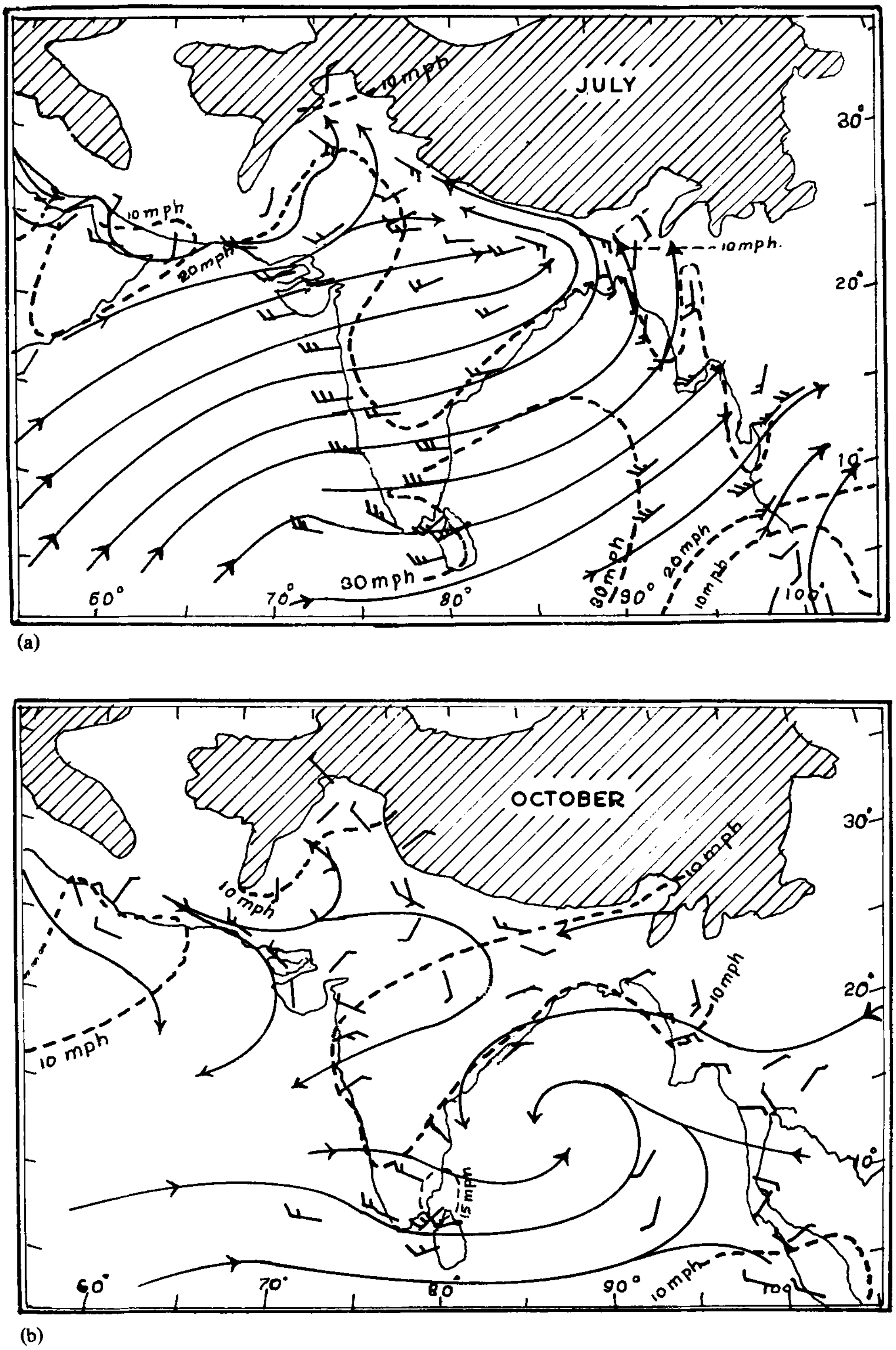

Fig. 1. Streamlines at 0.5 km level.

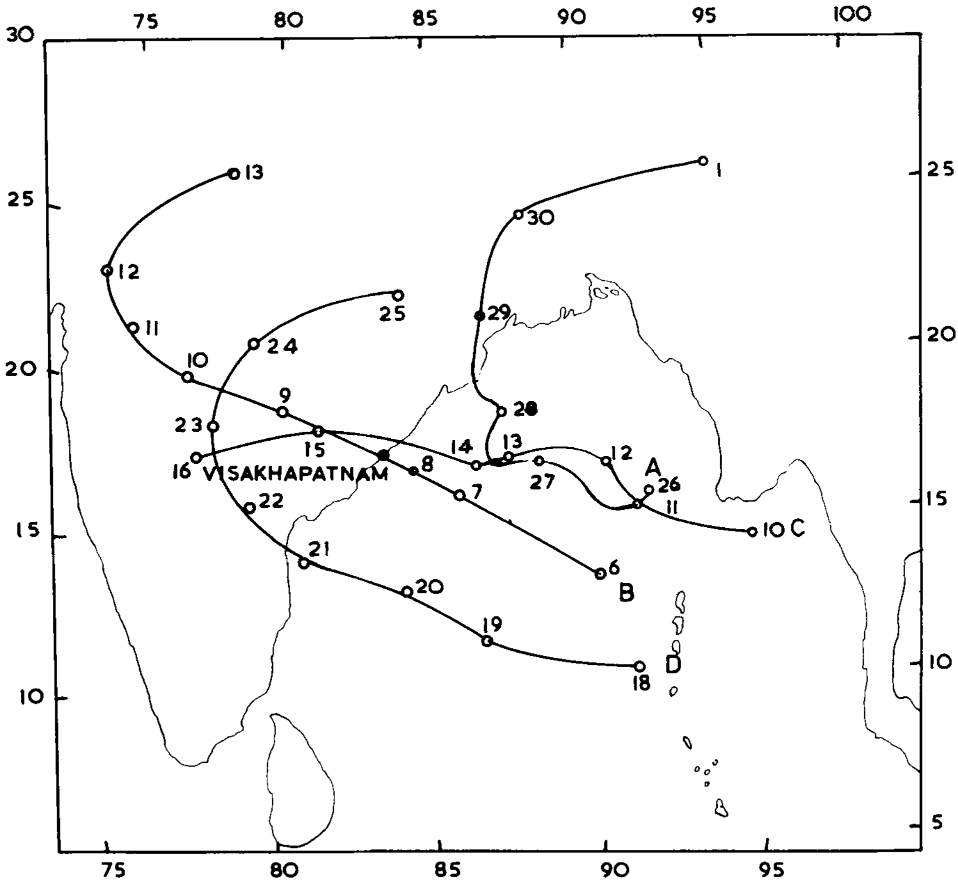

Fig. 2. Tracks of the storms (Sept.–Oct. 1974): A. 26 Sept. to 1 Oct. B. 6 to 13 Oct. C. 10 to 16 Oct. D. 18 to 25 Oct.

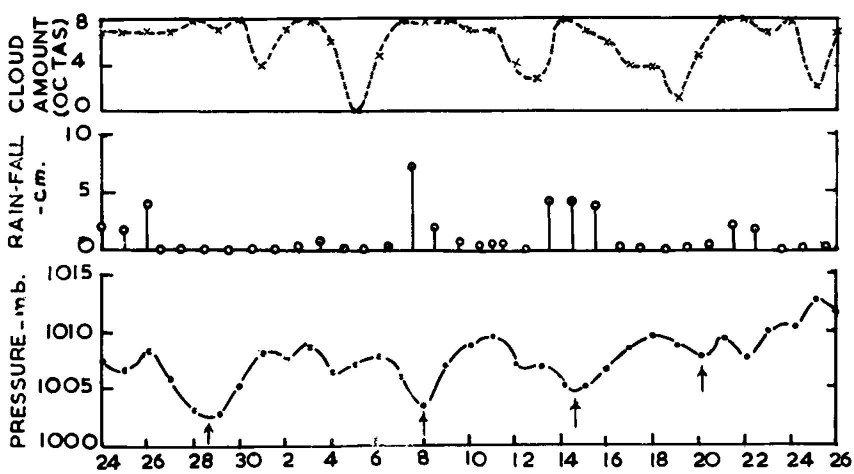

Fig. 3. Pressure, rainfall and cloud amount at Visakhapatnam from 24 Sept. to 26 Oct. 1974.

shows striking agreement with the findings of Subbaramayya & Bhaskar Rao (1974) in spite of the difference in the season of observation.

Since the two middle systems moved past Visakhapatnam, a radiosonde/rawin station, the data at that place permit a close examination that throws light on these systems. Therefore this present study has been made.

2. Data and analysis

Radiosonde and rawin observations (twice daily, 0830 and 1730 I.S.T.) taken at Visakhapatnam by the India Meteorological Department during the period 5–18 October 1974 have been mainly used in the present study. Temperature, pressure-height and wind observations up to 100 mb and dewpoint observations up to 300 mb have been available on almost all the days. Vertical time-sections have been prepared using this data, to interpret and understand the structure of the trough and ridge systems. The vertical distribution of the total energy $(C_p T + gZ + Lq)$[1] in these systems is also critically examined and discussed.

The surface synoptic and upper air streamline and contour charts prepared by the India Meteorological Department's Cyclone Warning Centre at Visakhapatnam also have been consulted.

3. Surface synoptic features

The surface synoptic charts for the period under study showed a major trough line across Central Bay and Peninsular India. The convergence of the winds associated with this trough could be easily identified as the ITCZ in the region. While the trough line was fairly linear and oriented in the WNW–ESE direction for most of the time and the low pressure systems referred to earlier moved along this trough, it was distorted during the period 11–14 when a N–S ridge was passing. The sea level pressure distribution on the 11th is shown in Fig. 4. On this day a low, undergoing recurvature was situated in the west and another low in the developing stage was in the east. The two successive low pressure systems with a clear central ridge help the estimation of the wavelength which comes to 1700 km and the corresponding wave speed is about 6 kts. But the average speed of movement of the lows, well before recurvature, according to Fig. 2 is 7.8 kts which corresponds to a wavelength of 2300 km.

[1] The kinetic energy is omitted because of its smallness in magnitude compared to the other terms.

4. Mean wind profiles

Vertical profiles of the mean zonal and meridional wind components at Visakhapatnam for the period under study are presented in Fig. 5. The mean zonal wind at the surface was a light easterly which increased with height to a strength of 8 m/s at 200 mb and 16 m/s at 100 mb. This shows a northward increase of temperature which was particularly large in the 200–100 mb layer.

The mean meridional wind was northerly below 650 mb and southerly above. They therefore may be considered to constitute the low level equatorward flow and upper level poleward flow respectively of the tropical cell. The mass circulation corresponding to the low level flow across a whole latitude circle at 17.5° N is 17.55×10^{13} g/s while that due to the upper flow up to 100 mb is 29.61×10^{13} g/s. If a compensating outflow layer is required, it is to be limited to about 220 mb. It is interesting to note that these values are comparable to those given by Riehl & Malkus (1958) for the mass circulation in the tropical cell.

5. Structure of the disturbances

5.1. *Meridional wind*

The variation of the deviation of the meridional wind component from the mean at different levels is presented in Fig. 6. To eliminate the diurnal effect the deviations from the respective morning or evening mean values have been used. The vertical axes of the troughs and the ridges are denoted by thick continuous and dashed lines respectively. It is clear that the systems have extended up to 250 mb. The axes of the first low and the following ridge had a strong westward inclination, while the second trough and ridge had only a slight inclination. A slight eastward inclination of the first trough in the surface layers is apparent. The streamline charts at different levels in fact showed a southwestward slope of the trough axis in both cases. Strong northerly winds occurred ahead of the low at very low

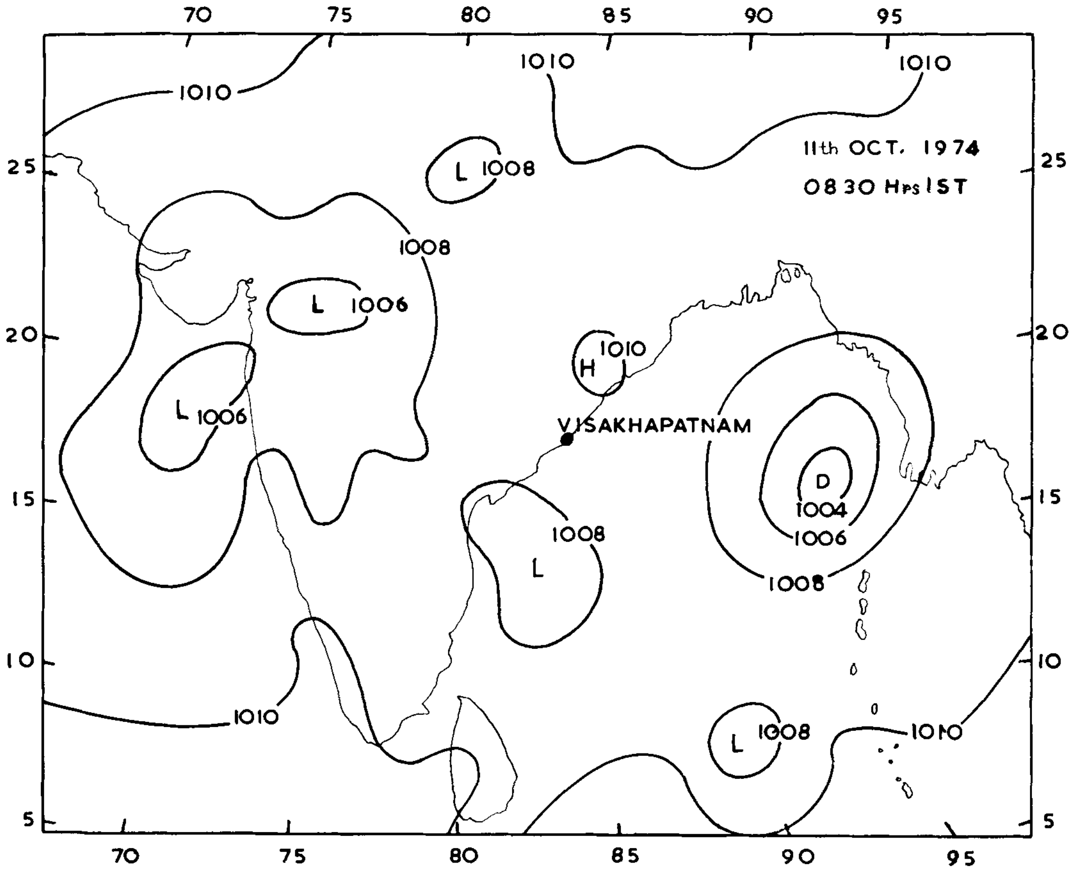

Fig. 4. Sea level pressure distribution on 11 October 1974.

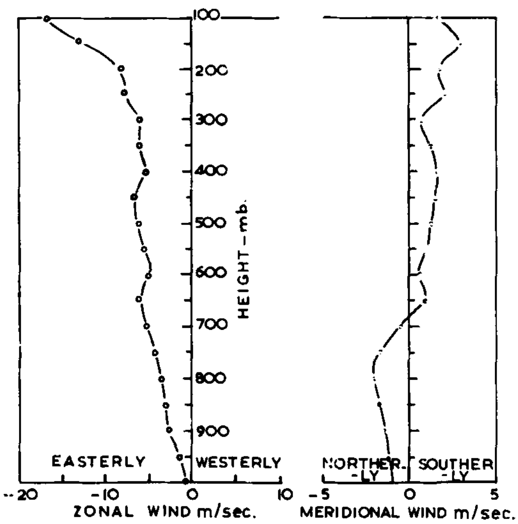

Fig. 5. Vertical profiles of mean zonal and meridional wind (5 to 18 Oct. 1974).

levels while strong southerlies occurred in the rear at relatively higher elevations. These asymmetric winds were mainly responsible for the low level mean equatorward flow and the mean poleward upper tropospheric flow. Therefore, the consequent meridional fluxes of various physical parameters and mass flux seem to be built up by these travelling systems. Whether this type of mechanism is responsible for the meridional circulation at all places round the globe at all times or occasionally at some places only is worth examining. It is to be understood that in the former case the Hadley circulation in tropics is only a statistical result while in the latter case, there are two different phases in the circulation regime, one with a real Hadley circulation and the other a statistical mean maintained by synoptic systems.

Marked changes in the meridional wind did not take place above the 250 mb level.

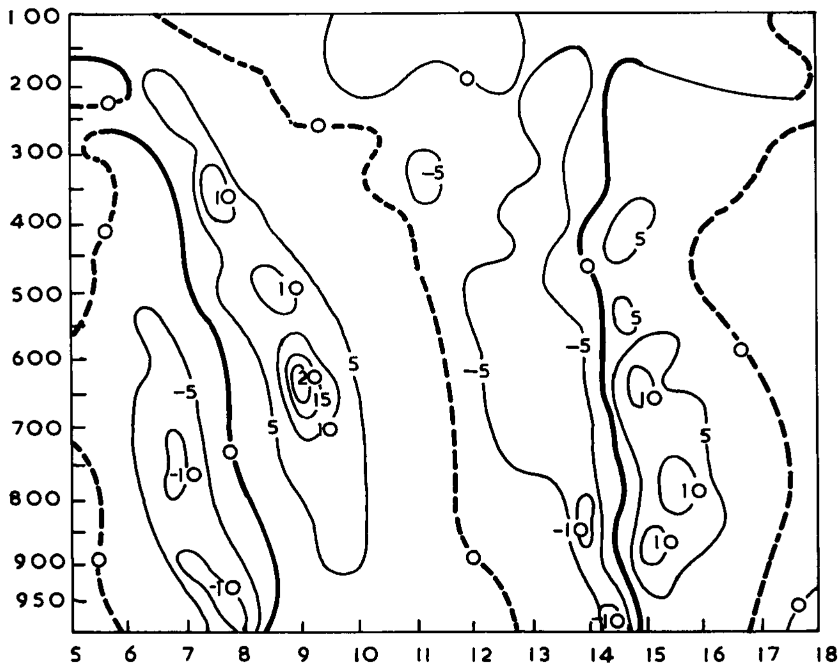

Fig. 6. Vertical time section of meridional wind anomaly (5 to 18 Oct. 1974).

5.2. *Temperature*

The evening temperatures at almost all the levels have been found to be consistently higher than the morning temperatures. To examine the temperature structure of the troughs and ridges the temperature deviations from the morning/evening mean temperatures at different levels were evaluated and their variations are presented in Fig. 7. The air was warmer above 850 mb in the immediate rear of the first trough and cooler below. The west to east increase in temperature is about 3° C across the low in the middle troposphere and is consistent with the westward slope of the wave axis with height.

The higher temperatures below 800 mb on the afternoon of the 6th were due to the air coming from the north-western region where an anticyclone was active with associated subsidence, while the lower temperatures on the 7th were due to the inflow of the cooler north-easterly winds into the cyclonic circulation. The temperature contrast of these two streams could have helped not only in building up the thermal wind leading to the northerly maximum at 750 mb, but also in the generation of kinetic energy by subjecting the north-easterly winds to a subgradient southward flow. The higher temperatures on the 8th in the middle and upper troposphere could be due to the latent heat released. The morning radiosonde ascent on this day in fact passed through a thick layer of cloud indicated by 100% relative humidity in the layers 950–750 mb and 500–450 mb, and the rainfall during the morning hours was as much as 7 cm. The cooler air situated farther away from the centre of the system indicated by the lower temperatures on the 7th and 9th could be partly because of the evaporative cooling of the light rain falling through the relatively dry air and partly due to dynamical reasons. The second low pressure system also shows essentially the same characteristics as the first, except for the lack of relatively warm air ahead of the central calm winds at low levels.

The ridge following the first low was situated entirely in warm air and no strong temperature variations existed across the system in the lower and middle troposphere. At the 300 mb level the temperature was significantly above average and it will be seen later that this was associated with extreme dryness; hence it can be attributed to subsidence. The second ridge also shows the same

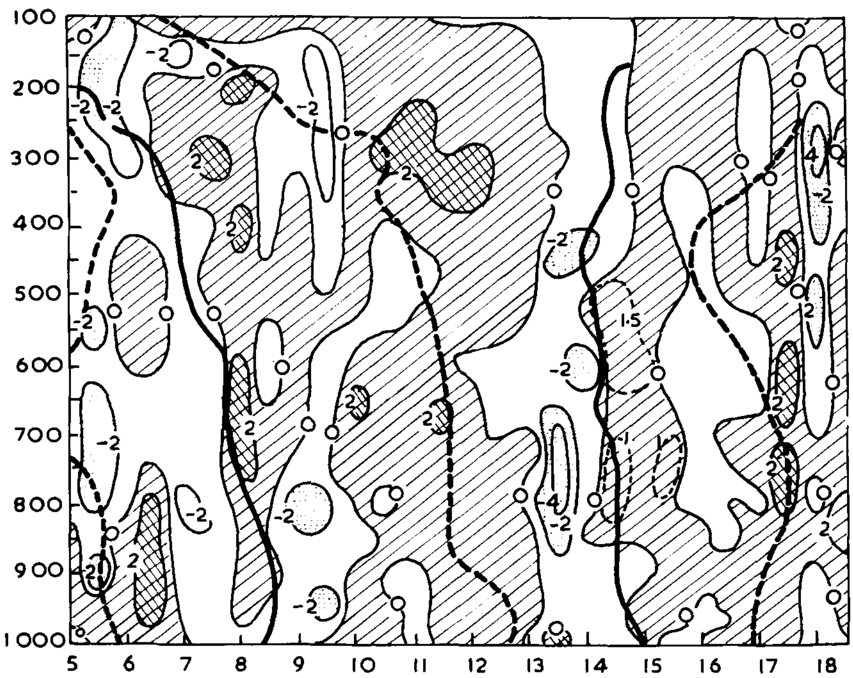

Fig. 7. Vertical time section of temperature anomaly (5 to 18 Oct. 1974) (—— trough, ----- ridge).

general features as the first one. However, significant short period variations have occurred in the middle and upper troposphere on the 17th and 18th when the winds were also light and variable.

5.3. *Humidity*

The relative humidity variations up to 250 mb level are shown in Fig. 8. The humidity was more than 80% on almost all the days at the surface and very low, about 20%, at 250 mb. The fact that the equatorial trough was close to the station at the surface and the subtropical ridge in the upper troposphere explains the observed general distribution of the humidity. The humid surface air was drawn up into the middle and even to the upper troposphere by the low pressure systems, as shown by their humid cores. The humidity was as high as 80% up to 400 mb on the 8th and up to 600 mb on the 14th. In the ridges, the humidity was very low, particularly in the upper troposphere indicating subsidence. But the still-existing downward increase of humidity shows good mixing with lower strata air. This could be due to the short period fluctuations of wind and eddy mixing. Thus, while the synoptic-scale lows in the equatorial trough carry moisture directly into the upper troposphere along their ascending plums, in the ridges also there appears to be an effective upward transport by smaller scale eddies. The vertical extension of moisture tongues from the surface on the 11th and 12th have been found to be due to cyclonic eddies of size 2° to 3° latitude diameter. The intense variations of humidity in the middle troposphere on the 16th and 18th were similarly associated with short-period wind fluctuations.

5.4. *Energy distribution*

The distribution of the total energy Q, defined earlier, in the vertical in the tropical atmosphere was discussed by Riehl & Malkus (1958). They have pointed out that the existence of its minimum in the middle troposphere is a formidable obstacle in explaining the energy transfer by the tropical general circulation and finally laid stress on the convective hot towers as a possible mechanism.

In order to understand the variation of the total energy distribution in the trough and ridge systems in the ITCZ, a vertical time-section is prepared and presented in Fig. 9. The value of the total energy

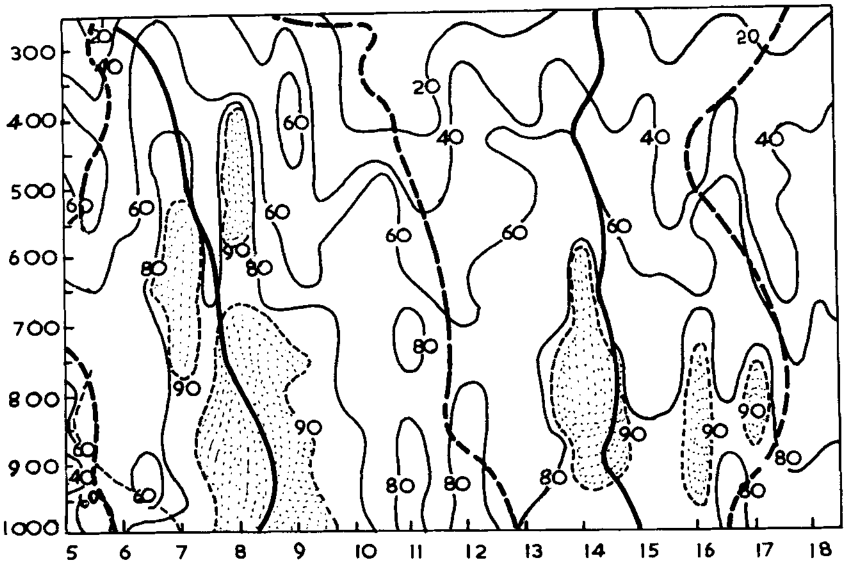

Fig. 8. Vertical time section of relative humidity (%) (5 to 18 Oct. 1974). (—— trough, - - - - - ridge)

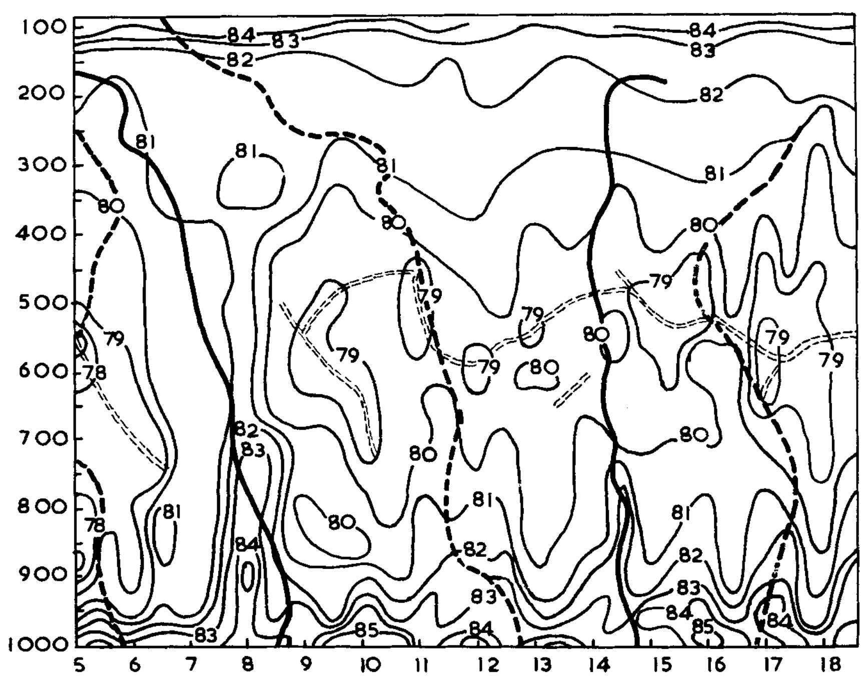

Fig. 9. Vertical time section of the total energy "Q" (5 to 18 Oct. 1974) (—— trough; - - - - - ridge; = = = = mid-tropospheric "Q" minimum).

was maximum at the surface and varied from 83.5 to 85.0 cal, higher values being observed in the afternoons. It was 84 cal at 100 mb and the minimum occurred at about 550 mb on the average and was about 79 cal. But in the region of the first low pressure system, the conditions were different. The 80 and 81 cal lines run vertically connecting the sub-cloud layer with the upper troposphere and clearly show the direct flow of energy into the upper troposphere by breaking the barrier of minimum. The breaking of the mid-tropospheric minimum is however not prominent in the case of the second low pressure system. It may be recalled that though the total rainfall associated with the second low was more, the maximum 24-hour rainfall was very high in the first low. Also, there was a pronounced vertical build-up of thick cloud as evidenced by the high relative humidity up to 400 mb on 8 October.

One interesting feature common to both low pressure systems is the existence of a wide belt of southerlies with high energy in the sub-cloud layer on the eastern side. This belt of southerlies was partly the retreating south-west monsoon current entering the cyclonic circulation.

6. Summary and conclusions

The vertical axes of the disturbances in the ITCZ over west central Bay of Bengal have a westward tilt. Strong northerlies occur at low levels to the west of the low pressure systems and strong southerlies to the east at relatively higher elevations. In the middle troposphere, higher temperatures are located to the rear of the troughs. The surface humid layer extends well into the middle troposphere in the cyclonic disturbances, while in the upper troposphere the humidity is very low at the time of the passage of the ridge systems indicating pronounced subsidence.

The mid-tropospheric energy minimum is broken in disturbances associated with heavy rainfall.

The disturbances in the ITCZ not only contribute to the direct transport of energy into the upper troposphere but also to the inflow and outflow of the mean meridional tropical circulation as hypothesized by Riehl (1969).

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ВОЗМУЩЕНИЯ ВНУТРИТРОПИЧЕСКОЙ ЗОНЫ КОНВЕРГЕНЦИИ (ВЗК) НАД ЗАПАДНОЙ ЧАСТЬЮ БЕНГАЛЬСКОГО ЗАЛИВА 5-18 ОКТЯБРЯ 1974

В период отступления юго-западного муссона над Индией в течение большей части 1974 г. ВЗК располагалась близко к станции Визакапатнам (17°42′ с.ш., 83°20′ в.д.), и два возмущения проследовали на восток за тот же период. Поэтому была возможность по радиозондовым данным в Визакапатнаме детально изучить два возмущения в ВЗК. Приводятся и обсуждаются значения ветра, температуры, влажности и энергии ($C_pT + gZ + Lq$) для возмущений. Найдено, что интенсивные возмущения в ВЗК вносят вклад не только в прямой перенос энергии в верхнюю тропосферу, но также и в среднюю меридиональную тропическую циркуляцию, что подтверждает гипотезу Рила (1969).