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Structure of a cyclonic disturbance over the south China Sea and the Malaysian region during the winter monsoon

BOON KHEAN CHEANG

Malaysian Meteorological Service, Kuala Lumpur

ABSTRACT. In this paper, the results of a synoptic compositing technique to determine the structure of a cyclonic disturbance over the South China Sea during the winter monsoon are presented. The disturbance was confined to the lower troposphere. It intensified in the presence of cold surge. This indicates a strong lateral interaction between the extratropical westerly circulation and the equatorial disturbance. A calculation of meridional gradient of potential vorticity was carried out in the region of the disturbance, to test the existence of combined barotropic-baroclinic instability.

1. Introduction

During the months of November, December and January when the northern hemisphere winter monsoon circulation is established, Peninsular Malaysia and Sarawak often experience heavy rain which brings about severe flooding. Most of the heavy rain occurrences are caused by cyclonic disturbances in the wave troughs of the lower troposphere over the South China Sea. Some of these disturbances move across Peninsular Malaysia and others are quasi-stationary. These disturbances are most intense in the lower troposphere. Due to the damage and loss of lives caused by the severe flooding, efforts have been concentrated to study the synoptic features associated with these disturbances. However, the transformation process and the dynamics of these disturbances are still poorly understood mainly because of the lack of upper air observations over the South China Sea where they usually intensify.

The purpose of this qualitative study is to show the characteristic synoptic features and the structure of a cyclonic disturbance during its intensification stage. Composite method was applied to obtain more upper air data for the computation of the fields of relative vorticity, divergence and kinematic vertical motion during its intensification stage.

To show that kinetic energy of this disturbance may be derived from instabilities in both the horizontal and vertical shears of the lower tropospheric easterly jet, which is a distinct feature, a test is carried out by studying the meridional profile of potential vorticity at 850 mb where the jet usually appears.

2. Previous studies

Lower tropospheric vortices in the tropics have been studied by many authors (Sadler 1967, Carlson 1969, Pedgely and Krishnamurti 1976). In recent years there has been considerable controversy over the origin of these vortices; *i.e.*, whether they develop from wave disturbance (Fett 1968, Yanai 1961) or in the wind shear zone between two opposing currents (Sadler 1967).

In the equatorial region, Palmer (1952) studied the equatorial easterly wave. Other than this, there are very few studies on equatorial disturbances.

In the Malaysian region, Watts (1955) has described the occurrence of heavy rainspell over Peninsular Malaysia as taking place on air-stream boundaries.

Gan (undated) noted that heavy rain occurred along the east coast of the Malayan Peninsula following the appearance of a large cold anticyclone over China with subsequent movement of a cold front into the South China Sea from China, and low level strengthening of the northeast trades. He also pointed out the presence of a zonal northeasterly flow of width about 10° latitude and a maximum strength of 15 knots or more, stretching from Guam Island in the Pacific to the vicinity of Ceylon during days of heavy rain. Equatorial westerlies were often present. He noted that there was no heavy rain in Peninsular Malaysia when tropical cyclone was present over the South China Sea north of 9°N. He also showed how Hong Kong surface pressure could be used to forecast the occurrence of heavy rain in Peninsular Malaysia.

Riehl *et al.* (1969) studied the winter monsoon weather over Vietnam but did not refer to Malaysia.

Ramage (1971) studied the heavy rain in North Borneo (East Malaysia) during the occurrence of nonfrontal surges, and attributed the rain to the presence of active Hadley cell.

All these studies on equatorial weather did not refer to the westward propagating or quasi-stationary cyclonic disturbances and the presence of low level easterly jet over the northern part of Peninsular Malaysia during the heavy rainspell. It may be true that the cause of some heavy rainspells arises from temporary juxtaposition of northern and southern hemisphere vertical circulations (Ramage 1971). Nevertheless, the presence of cyclonic disturbances in the equatorial region of the South China Sea have been confirmed by the improved network of upper air stations in Malaysia in recent years, and also by satellite pictures.

3. Synoptic features and structure of a cyclonic disturbance

The period chosen for this study was 29 December 1970 to 6 January 1971, when one cyclonic disturbance occurred over the South China Sea. This disturbance brought along widespread heavy rain to Peninsular Malaysia and the total cost of damage due to the consequent flooding amounted to about US $ 25 million. It is one of the most severe storms that Malaysia has experienced.

3. 1. *Synoptic features*

The 850 mb streamline analyses at 0000 GMT for this period are shown in Figs. 1 to 13. 900 mb, 700 mb, 500 mb. and 200 mb analyses are shown only for 3 January 1971, when the disturbance

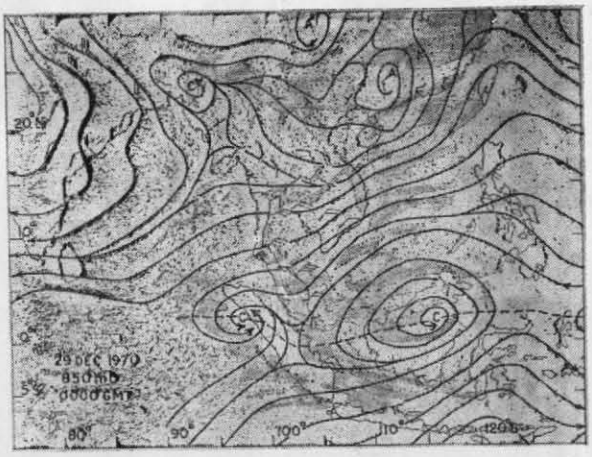


Fig. 1

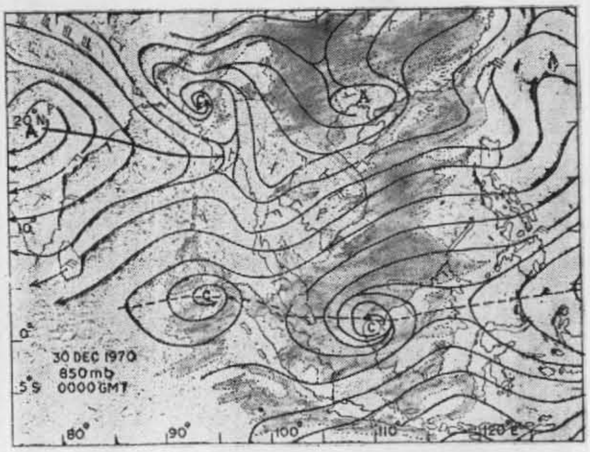


Fig. 2

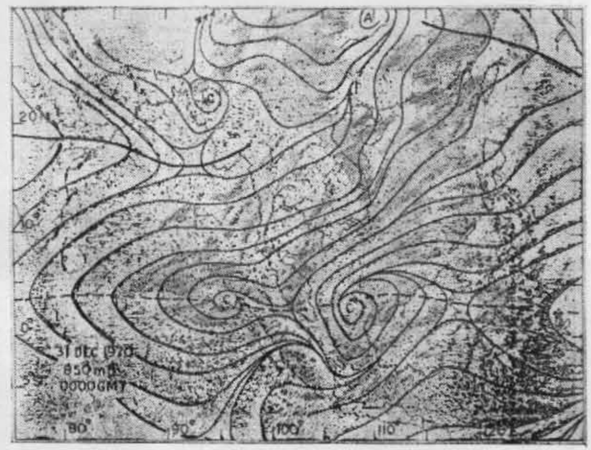
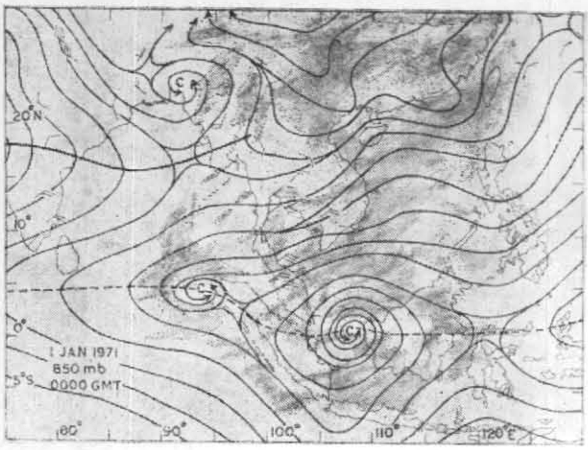


Fig. 3



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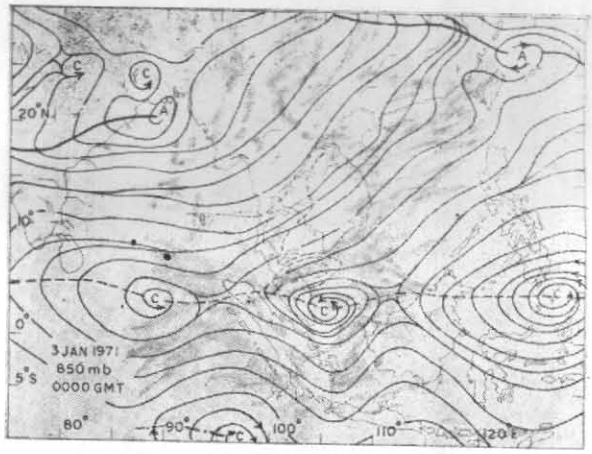

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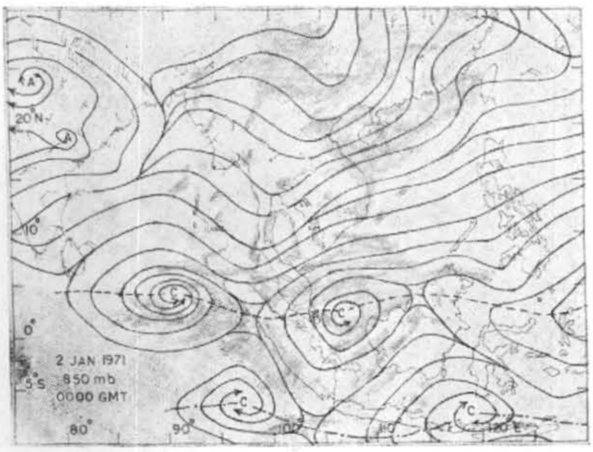
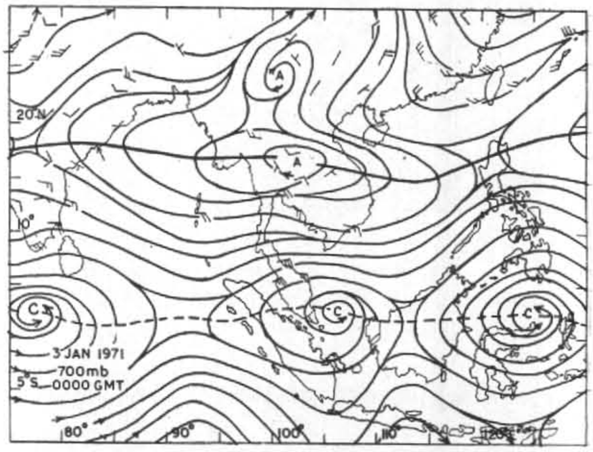


Fig. 5



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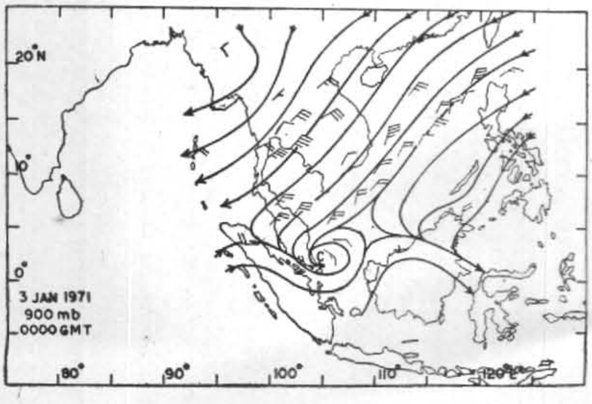


Fig. 6

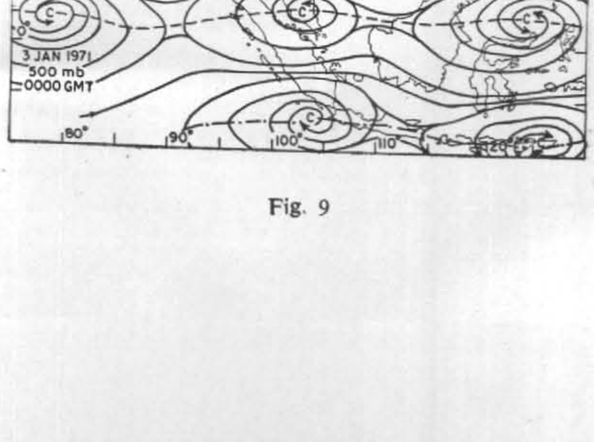


Fig. 9

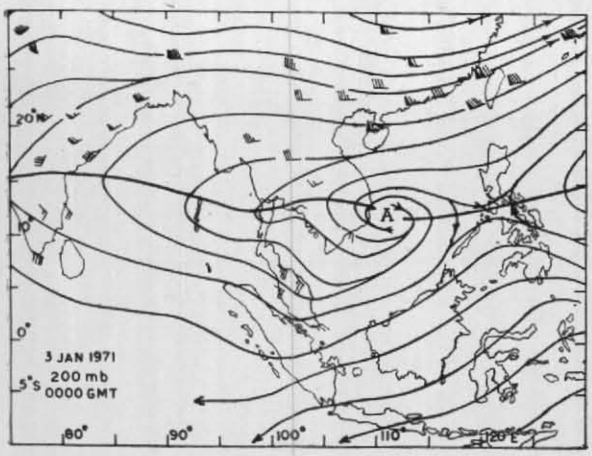


Fig. 10

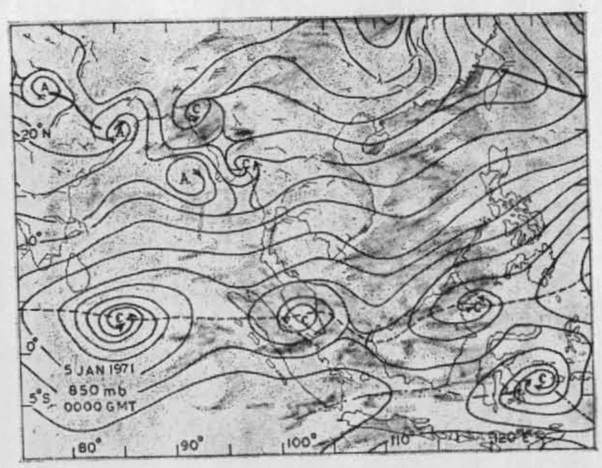


Fig. 12

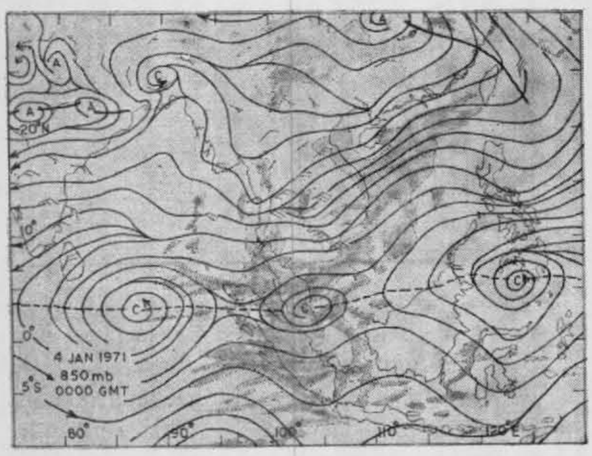


Fig. 11

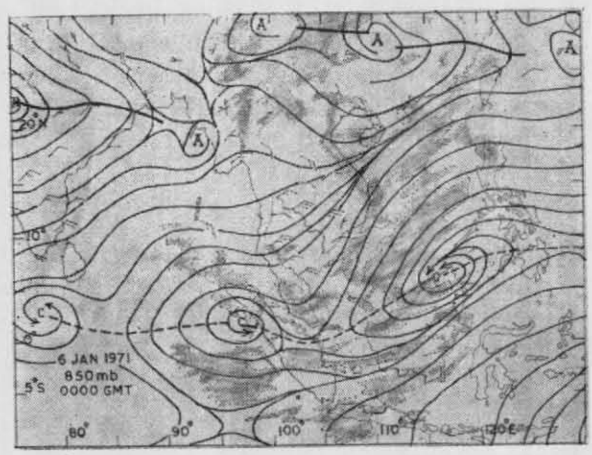


Fig. 13

intensified into a tropical depression. Cloudiness obtained from satellite pictures was shown as shaded areas in the 850 mb streamline analyses.

Fig. 14 gives horizontal time section of surface winds from ship reports from the route between 30°N and 5°N, *i.e.*, from East China Sea to South China Sea during the period 0000 GMT 29 December 1970 to 0000 GMT 6 January 1971. The 3 hourly weather along the east coast of Peninsular Malaysia during the same period is shown in the horizontal time section in Fig. 15. In this figure the equatorial shear line is indicated as dashed line. 850 mb winds at Kota Bharu (station number 48615 at 6·2°N, 102·2°E) are also shown in this figure. Total 24 hourly rainfall amount for eleven main synoptic stations in Peninsular Malaysia is shown below the date axis.

Fig. 14. South China Sea surface wind (shaded area—wind speed ⩾30 kt)

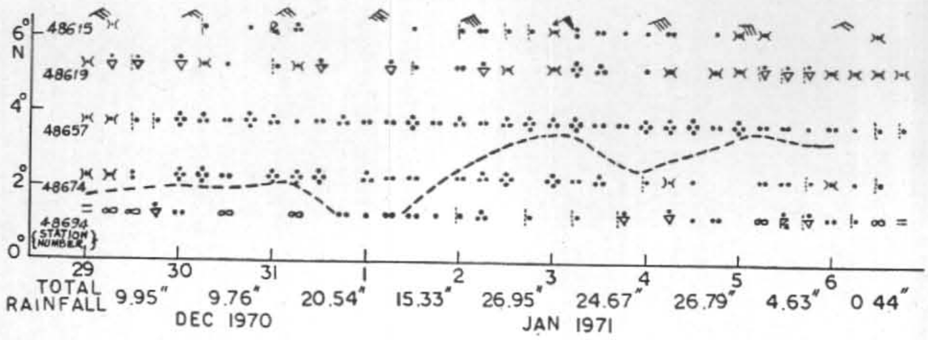


Fig. 15. 3-hourly weather along the east coast of Peninsular Malaysia

The above figures show the following significant features.

(*a*) The cyclonic vortex was clearly shown over North Borneo on the 29th. Due to lack of upper air data, it is difficult to track its origin. It moved westwards, reaching the western tip of Borneo on the 31st. On the 3rd, it intensified into a tropical depression. Its centre was located just off the east coast of Peninsular Malaysia. It hit the peninsula on the 4th and moved to Sumatra on the 6th (Figs. 1-5, 7, 11-13).

(*b*) During its intense stage, the cyclonic disturbance appeared distinctly from 900 mb up to 500 mb, with a slightly westward tilt from 700 mb to 500 mb (Figs. 6-9).

(*c*) The equatorial shear line indicated as dashed line was a persistent feature across the southern part of the peninsula throughout the period.

(*d*) An intense cold surge passed through Hong Kong on the 3rd during which the disturbance intensified into a tropical depression. This was shown by the sharp drop in dew point and increase in surface pressure at Hong Kong (Table 1). It was further proved by the breaking up of cloudiness over South China from 29th December till the 3rd January (Figs. 1-13).

(*e*) The deep cold surge was connected with the development of a sharp westerly wave trough over East China at 700 mb and 500 mb (Figs. 8 and 9). This feature was pointed out also by Riehl *et al.* (1969). These troughs moved eastwards and moved out of China on the 4th.

(*f*) Connected with this cold surge, surface winds over the South China Sea freshened with wind speed generally exceeding 35 knots (Fig. 14). Before the cold surge, surface winds over the South China Sea were steady northeasterlies of speed generally exceeding 20 knots. At 850 mb, 700 mb and 500 mb, there were easterly wind maxima of 20 knots or more over the West Pacific, and Indo China. Due to lack of upper air observations over the South China Sea, it is difficult to ascertain whether the wind maximum was a continuous belt from the West Pacific to Southeast Asia.

TABLE 1

Hong Kong surface pressure and dew point

Date	Pressure (mb)	Dew point (°C)
29 Dec 1970	1022·2	10
30 ,, 1970	1022·4	11
31 ,, 1970	1024·5	07
1 Jan 1971	1024·7	06
2 ,, 1971	1024·8	06
3 ,, 1971	1025·0	00
4 ,, 1971	1026·9	08
5 ,, 1971	1027·2	04
6 ,, 1971	1025·5	04

(*g*) Two low level northeasterly jets were noted; one running southwestwards from North Vietnam to South Thailand with speed maximum of 35 knots at 900 mb. The other one was located over the northern part of Peninsular Malaysia with speed maximum of 50 knots at Kota Bharu at 850 mb. The former jet may be the result of a gap at 17°N in the Annam range of Vietnam. Cold surge from China was able to pass through this gap and resulted in the presence of this jet (Figs. 6, 7).

(*h*) Surface temperature varied from 12°C at latitude 20°N over northern part of Indo China to 22°C at latitude 12°N. In response to this baroclinic zone caused by the sharp temperature contrast, a westerly thermal wind should develop to weaken the jet over Indo China with height. This was what was observed.

(*i*) The subtropical jet in the upper level extended from South China to Japan (Fig. 10).

(*j*) At 200 mb, speed divergence was evident in the easterlies over Malaysia on the 3rd (Fig. 10).

(*k*) When the cyclonic disturbance was located over North Borneo on 29th and 30th, there were scattered showers and thunderstorms over the South China Sea and also along the east coast of Peninsular Malaysia which is situated ahead of the disturbance. From the 31st till the 4th, convective weather persisted over the South China Sea whereas continuous heavy rain from stratiform clouds occurred mainly around the equatorial shear line over Peninsular Malaysia (Fig. 15). Convective weather activity was confined to local areas south of the low level jet at Kota Bharu. As the depression moved across Peninsular Malaysia, heavy rain around the equatorial shear line eased off. However there was still some convective weather to the rear right and rear left of the disturbance.

3. 2. *Structure of the depression — 2 and 3 January 1971*

Due to lack of upper air data over the South China Sea, composite method was applied. This method has been used by many authors (Williams 1970, Pedgley and Krishnamurti 1976). In this investigation, data at 0000 GMT from pibals, rawinsondes and radiosondes were supplemented by compositing data on the 2nd and 3rd January. Upper air data were then subjectively interpolated on a 2° grid over 20° by 20° mesh.

(*a*) *Horizontal pattern of relative vorticity, divergence and vertical motions* — Cyclonic relative vorticity was maximum near the cyclonic centre with magnitude of 8×10^{-5} s^{-1} at 850 mb (Fig. 16). This is of an order less than that found for monsoon cyclone over West Africa (Pedgley and Krishnamurti 1976). It decreased slowly upwards. Convergence (Figure is not shown here) was maximum ahead of the cyclonic centre with magnitude of 4×10^{-5} s^{-1} at 900 mb.

Vertical motions (Figure is not shown here) were estimated by the well-known kinematic method. At the lower boundary, p=1000 mb, w

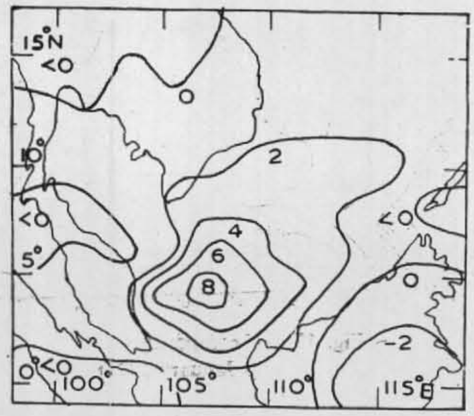


Fig. 16. Relative vorticity 850 mb (31 January 1971)

was set to zero and the continuity equation was integrated to 200 mb. It was not integrated up to 100 mb due to sparcity of data at this level. Correction to the divergence by assuming zero means in the vertical, as applied by Reed and Recker (1971) was not carried out. Up-currents were over large areas around the depression.

(*b*) *Vertical pattern of wind* — Vertical cross sections were drawn through the cyclonic centre at 4°N, 105°E.

In the north-south plane, the *u*-component field (Fig. 17) reveals the two easterly jets clearly at 850 mb; one at 6°N of stronger speed, and the other around 11°N, of weaker wind strength. Streamline analysis (Fig. 6) shows that the jet to the north had speed maximum at 900 mb. Equatorial westerlies formed a shallow wedge below the easterlies and south of 2°N. Northerly component winds (Fig. 18) were mainly in the lower and middle troposphere, whereas southerly component winds prevailed in the upper troposphere.

Vertical cross section of vorticity in the north-south plane (Fig. 19) shows deep relative cyclonic vorticity. Anticyclonic vorticity was confined north of 12°N and near the equator.

Fig. 20 for vertical motions shows large areas of up-currents south of 8°N and between 12°N and 14°N. Down-currents occurred between 8°N and 12°N and north of 14°N. This complicated feature could be due to the presence of double easterly jets, the positions of which are indicated as arrows below the x-axis in the figure.

In the east-west plane, the relative vorticity field (Fig. 21) has a very simple pattern. Maximum

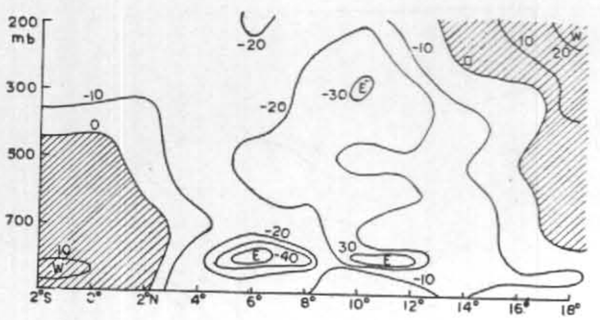


Fig. 17. *U*-components
(3 January 1971)

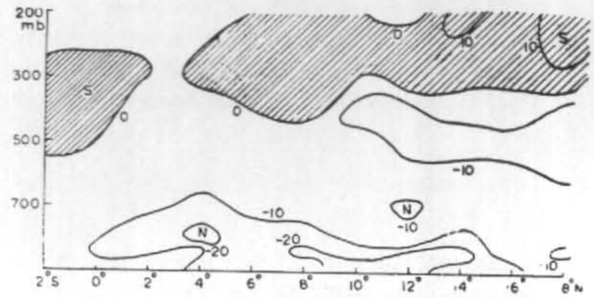


Fig. 18. *V*-components
(3 January 1971)

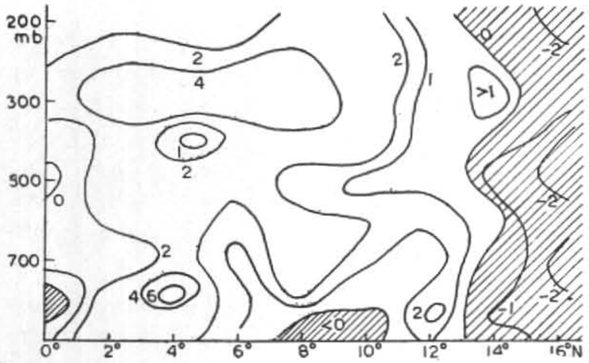


Fig. 19. Relative vorticity field (10^{-5} s^{-1})
(3 January 1971)

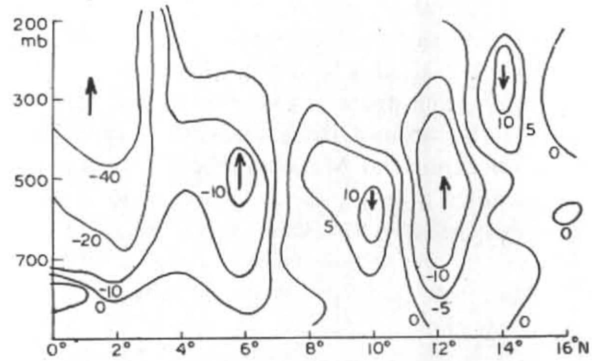
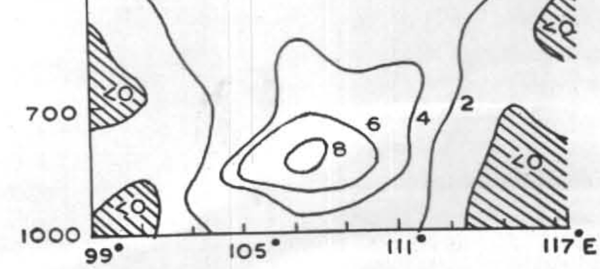


Fig. 20. Vertical motion (10^{-3} mb s^{-1})
(3 January 1971)



Fig, 21. Relative vorticity (10^{-5} s^{-1})
(3 January 1971)

DISCUSSION

U.K. Bose : Did you examine the data of any station other than Calcutta and Allahabad; for example Gwalior ?

Author : The stations used are Calcutta, Visakhapatnam, Gauhati, Nagpur, Allahabad, Ahmedabad, Bombay, New Delhi and some others in Southern India. Formally, we can apply the same method for all these stations. But we should be aware that in order to get appropriate X-Z structure including the centre of the lows, we should choose the stations which are located in mean path of lows. In addition, the power at such stations should be sufficient to get reliable results of the cross spectrum analysis. Considering above criteria, I chose Calcutta and Allahabad as proper stations for this purpose.