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Some aspects of upper tropospheric outflow from severe cyclonic storms in the Bay of Bengal and Arabian Sea as revealed in satellite pictures

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ABSTRACT. In this paper a study has been made of the essential features of the cirrus canopy of twenty cases of severe cyclonic storms in the Bay of Bengal and Arabian Sea as revealed in satellite pictures received at Bombay during the period 1966-1969. Making use of a simple model proposed by Merrit and Wexler, the nature of the distribution of the radial and tangential components of outflow in the different quadrants is examined in each case and its relation to the direction of motion of the storm is discussed.

1. Introduction

In the present paper a study has been made of the essential features of the cirrus canopy of 20 cases of severe cyclonic storms in the Bay of Bengal and Arabian Sea as revealed in satellite pictures most of which were received at Bombay during the period 1966-1969. Making use of a simple model proposed by Merrit and Wexler (1967) the nature of the distribution of the radial and tangential components of outflow as can be inferred from the edges of the overcast area is discussed for every storm studied.

According to Merrit and Wexler (1967) a cirrus canopy similar to those observed by satellites in typical hurricanes can be evolved in a period of 12 to 18 hours if we assume that cirrus that is produced at the eye wall is advected by the wind field at cirrus levels. In other words, the cirrus that is advected with anticyclonic flow pattern outside the eye wall spreads out in diffuse streamers, in sectors where radial outflow is strong whereas in some other sectors the lines of flow converge and cirrus, advected from near the eye wall, flows side by side with cloud free air. In the latter case a relative tengential wind maximum exists at the cloud edge which, therefore, appears sharp and remains almost stationary with time relative to the centre. The study of Merrit and Wexler thus showed that strong or active subsidence is not a necessary requirement to produce or maintain sharp canopy edge as has been imagined by earlier investigators (Hubert 1962, Sadler 1964 and Fett 1964).

2. Discussion and results

2.1. *Severe cyclonic storm of 21 December 1964*

The pictures of this storm taken by TIROS VIII have been studied by Kulshrestha and Gupta (1966). Fig. 1 shows the TIROS photograph of this storm (with a core of hurricane winds) on the 21st when it was near 6·5°N and 87°E. The eye of the storm is clearly visible through the cirrus canopy which was well formed as inferred from the outflow features. From the picture it can be inferred that the radial outflow is relatively at a maximum in the northwest sector where the cirrus has spread out in well defined streamers to relatively long distances from the centre. On the other hand the cirrus transport by advection is at a minimum in the southeast and east directions and the canopy exhibits sharp edges in these sectors where the tangential component of outflow should be predominent. The storm was moving westnorthwestwards and therefore, in this case the direction of motion lies in the quadrant of maximum radial outflow. The inferred directions of outflow in the vicinity of the storm are shown at a few places in the picture with broken arrows. The winds depicted at nearby observing stations refer to the 200-mb level for the nearest observation time. These have been done for every one of the storm pictures studied here.

2.2. *Severe cyclonic storm of 3 November 1966*

In this storm (Fig. 2) the cirrus outflow is such that the radial component appears to show a relative maximum both in the north and northeast directions. Well beyond the main overcast a long band mostly cirriform appears on the northwestern side running from Konkan coast to northeast India and showing striations perpendicular to wind flow at 200-mb level. We do not wish to comment on this since it is not quite relevant to our study. The radial component of outflow is relatively at minimum in the southeast sector since the edge appears comparatively sharp here.

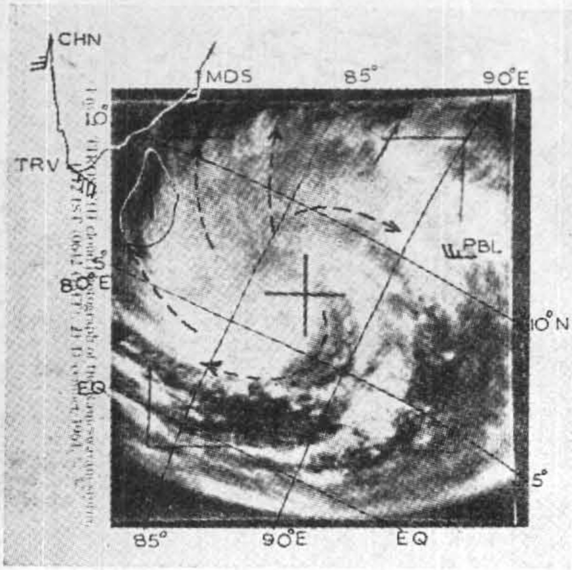

Fig. 1
Severe cyclonic storm of 21 December 1964
Time: 1212 IST

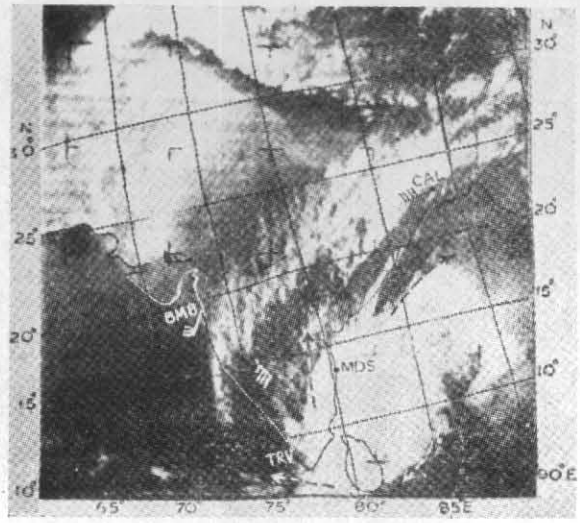

Fig. 2
Severe cyclonic storm o. 3 November 1966
ESSA II, Orbit: 3140, Time: 0845 IST

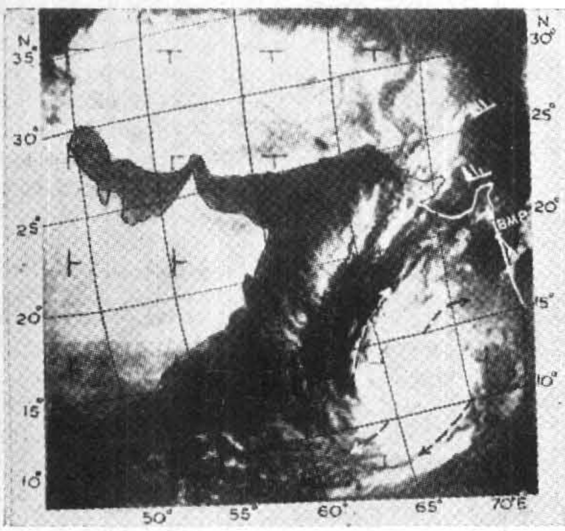

Fig. 3

Severe cyclonic storm of 8 November 1966
ESSA II, Oribit: 3204, Time: 0951 IST

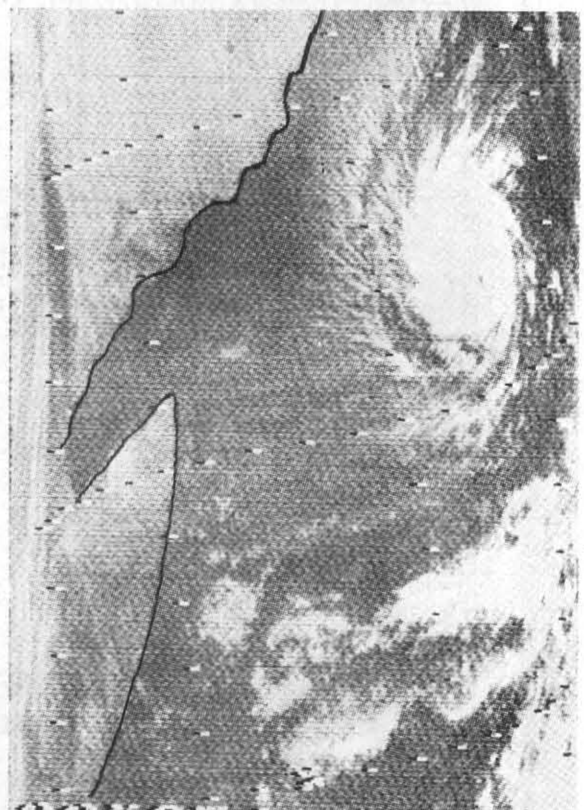

Fig. 4

Infrared picture of the severe cyclonic storm of 8 November 1966

NIMBUS II, Orbit: 2230
(By courtesy: NASA)

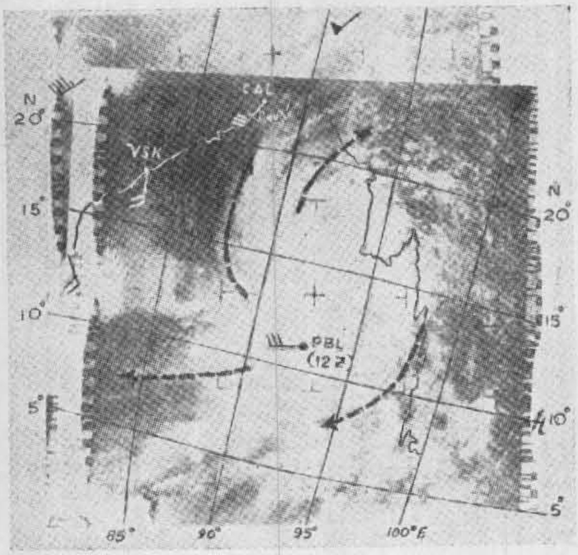

Fig. 5
Severe cyclonic storm of 17 November 1967
NIMBUS II, Orbit: 4885, Time: 1105 IST

The storm was moving westwards and in this case there is no apparent relation between the direction of motion and inferred direction of relatively maximum radial outflow.

2·3. *Severe cyclonic storm of 8 November 1966*

This storm (Fig. 3) is the same as the previous one, after it had moved over to Arabian Sea. The eye of the storm is visible (near 11° N, 67°E) through the cirrus canopy. The picture would suggest spreading of cirrus streamers to comparatively longer distances from the centre in the southwest and north directions and therefore, the radial component of outflow is relatively at a maximum in these directions. In the southeastern side the edge is comparatively sharp, and therefore the radial outflow in this direction is relatively at a minimum. The storm was moving in the northwest direction and there is no apparent relation between the direction of motion and the direction of maximum radial outflow.

An infrared picture (Fig. 4) of the storm taken by Nimbus II (received from NASA, not gridded) on the same night (18 GMT of 8 November 1966) suggests an entirely different picture of the outflow characteristics. The cirrus streamers are very clearly defined and show a clear maximum of radial component of outflow in the northwest sector (as could be inferred from the spreading of the cirrus streamers) in which lay the direction of movement of the storm. The tangential component of the outflow has a clear maximum on the eastern side where the cirrus transport by advection is minimum.

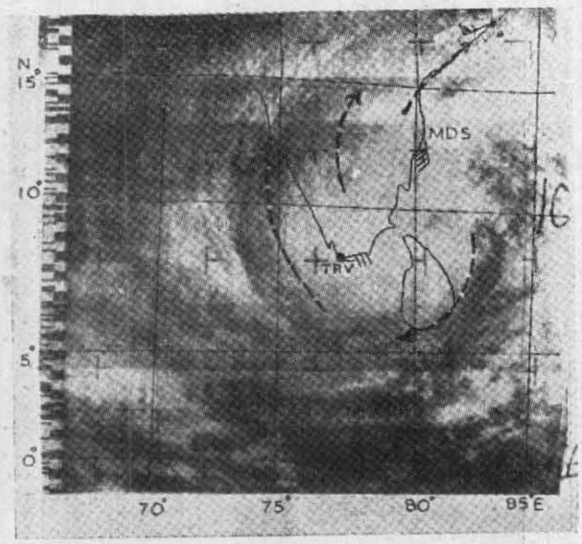

Fig. 6
Severe cyclonic storm of 7 December 1967
NIMBUS II, Orbit: 7602, Time: 1223 IST

2·4. *Severe cyclonic storm of 17 May 1967*

This storm (Fig. 5) shows the extension of the cirrus shield beyond the underlying convective structure in the western sector where the edge of the shield is fairly sharp. From the long streamers on the northern side one would infer that radial component of the outflow is at a relative maximum on the northern side. The storm centred near 15°N, 93°E was moving in a northnortheasterly direction.

2·5. *Severe cyclonic storm of 7 December 1967*

This storm (Fig. 6) shows pronounced cirrus outflow in the northwest and northern sides. The radial component of outflow appears to be a maximum on the northern side as seen by the spreading of the streamers to long distance from the centre. It is relatively at a minimum in the eastern and southeastern sides. The storm was moving northwards.

2·6. *Severe cyclonic storm of 9 May 1968*

This storm (Fig. 7) which was moving northwards and later recurved shows a well defined cirrus canopy through which the ragged eye can be seen. The western edge of canopy is fairly sharp. A radial outflow maximum on the northern side and radial outflow minimum on the western side can be inferred from the picture.

2·7. *Severe cyclonic storm of 11 November 1968*

This storm (Fig. 8) has a well defined overcast and cirrus shield. The eye of the storm can be

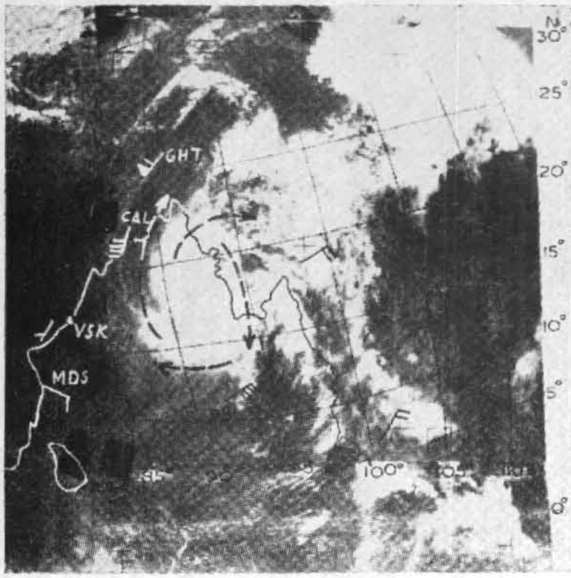

Fig. 7
Severe cyclonic storm of 9 May 1968
ESSA-VI, Orbit: 2261, Time: 0802 IST

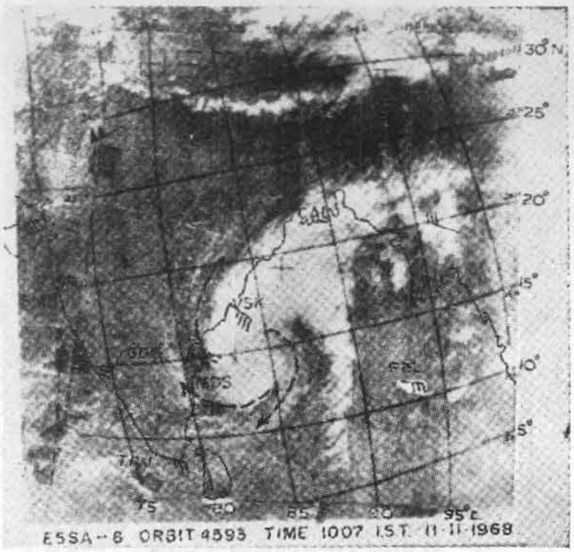

Fig. 8
Severe cyclonic storm of 11 November 1968
ESSA-VI, Orbit: 4593, Time: 1007 IST

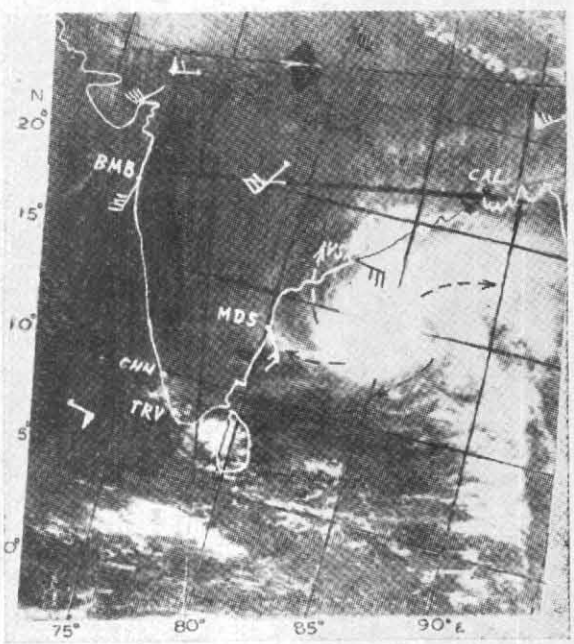

Fig. 9
Severe cyclonic storm of 6 November 1969
NIMBUS III, Orbit: 2761, Time: 1116 IST

clearly seen through the cirrus canopy which extends well beyond the underlying convective structure on the eastern side. A clear break is seen in the shield in the southeast sector where the low level band shows a sharp edge. A relative maximum of radial outflow of cirrus seems to exist on the northern side where it has spread more than in any other sector. The storm was moving northnorthwestwards and later recurved.

2.8. *Severe cyclonic storm of 6 November 1969*

This storm (Fig. 9) shows a very well organised central overcast and the cirrus canopy is well formed. The eye of the storm is clearly visible through the cirrus canopy. The extension of the cirrus canopy beyond the underlying convective structure is clearly seen on the southeast side, and the edges of the canopy on the western side are diffuse. From the picture one would infer that the relative maximum of the radial outflow component lies in the southwest to westsouthwest sector. Minimum transport of cirrus by advection has taken place on the eastern side where the tangential component seems to be predominent. The storm was moving in the westnorthwest direction.

The above descriptions illustrate our method of analysis. In the same way the rest of the storms were also examined and the sectors of maximum and minimum radial outflow were identified, qualitatively in each case with the aid of the satellite picture. Table 1 gives the particulars for all the 20 cases studied.

3. Possibility of inferring the direction of motion of the storm from satellite pictures

In her analysis of the upper wind circulation around tropical storms Jordan (1952) showed the presence at the outflow level (round 45000 ft) of radial component of the order 30 kt on the forward side of the storm, and almost complete absence of radial outflow in the rear side. She obtained this result by combining all data available at island and coastal stations during the period 1945-1951. If this picture is applicable to most of the storms we can qualitatively identify the direction of motion of the storm with the one where there is maximum radial outflow at the cirrus level as revealed in satellite picture. The method is obviously subjective since we cannot by any means identify a direction of maximum radial outflow by a method which is highly qualitative. Widger and his coworkers (1965) have pointed out to the presence often of a convective band or squall line immediately outside the cirrus canopy in the forward side and its orientation is perpendicular to the direction of motion of the storm. In our study we came across only one instance where this band was present with poor definition.

From Table 1, one can perhaps infer that in the case of recurving storms here is a predominent radial outflow in the northerly direction. This applies to cases which had already recurved at the time of observation and which recurved one day later. In the case of storms moving west, westnorthwest and northwest, it is not possible to infer any such relation between the direction of maximum radial outflow and direction of motion of the storm, though in these cases the western edge of the cirrus canopy is invariably diffuse.

TABLE 1

Date of storm	Direction of		Remarks
	Max. radial outflow	Motion of the storm	
(A) Storms moving westnorthwest and west			
26 May 1963	N	WNW	
21 Dec 1964	NW	WNW	
2 Nov 1966	NW-N	WNW	
3 Nov 1966	N & NE	W	
9 Nov 1966	WNW	WNW	
28 Nov 1966	Nil	W	The radial component was not predominent in any direction though western edge of canopy was diffuse
6 Nov 1969	SW-WSW	WNW	
7 Nov 1969	NW-N	WNW	
(B) Storms moving northwest and north			
8 Nov 1966	SW & N	NW	
8 Nov 1966	NW	NW	Infrared picture taken at 18 GMT
20 Nov 1966	N	N	
21 Nov 1966	NW	NW	
7 Dec 1967	N	N	
9 May 1968	N	N	Recurved on the 10th. Western edge of the canopy sharp
24 Oct 1968	SW	N	
11 Nov 1968	N	NNW	Recurved on the 12th
(C) Recurving storms			
30 Sep 1966	NE	NE	Western edge of canopy sharp
17 May 1967	N	NNE	Do.
18 May 1967	N	NNE	Do.
23 Oct 1967	NNE	NNE	Do.
27 Oct 1968	NNE	NNE	Northwestern edge of canopy sharp
12 Nov 1968	NW-N	NNE	

4. Conclusions

The following conclusions have emerged out of the present investigation —

1. The essential features of the cirrus canopy of severe cyclonic storms as seen in satellite pictures can be utilised to qualitatively infer the wind field at cirrus levels in the storm region where observations are normally not available.

2. Severe cyclonic storms which have recurved and those which are about to recurve, show a predominent radial outflow of cirrus in the northerly direction.

3. The western edge of the cirrus canopy of severe cyclonic storm appears sharp if the storm is

recurving either at the time of observations or recurves the next day. The same appears invariably diffuse if the storm is moving west, westnorthwest or northwest.

Acknowledgement

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DISCUSSION

SHRI G. GURUNADHAM : Away from the overcast cloud mass of the cyclone transverse bands, probably cirrus, are noticed in almost all the cases. Can you explain ?

DR. A. S. RAMANATHAN : Any good picture will show that the bands resolve into a number of cirrus streamers. In the vicinity of the overcast area they are in the direction of the wind flow.

DR. P. R. PISHAROTY : May I take it that the direction of movement of the storm is not uniquely determined by the radial outflow except when the strom is recurving to the east ?

DR. RAMANATHAN : In the case of storms with a westerly movement two sectors of relatively strong radial outflow existed and by the qualitative method used here, it was not possible to determine which of the two was more predominent. Only in the case of recurving storms there was a predominent radial outflow in the northerly direction.

SHRI G. S. GANESAN : Do you have any comments on the effect of movement of depressions on the radial outflow ?

DR. RAMANATHAN : This method is not applicable in the case of depressions. The outflow as observed at picture-time is examined in relation to the movement of storm at that time.

SHRI GANESAN : The time of the pass of the satellite and the time of winds integrated for working out the radial outflow are different. How do you justify ?

DR. RAMANATHAN : The wind field is supposed to be steady and therefore the difference of the time between the satellite picture and the synoptic observation does not matter.