

A note on the factors useful for the prediction of recurvature of storms in the Bay of Bengal

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1. Introduction

It is well known that the depressions and storms which are formed in the Bay of Bengal during the monsoon season (June to September) mostly move westnorthwestwards and they seldom take a northeasterly course. But the behaviour of the depressions and storms of pre-monsoon and post monsoon months is different; some of them move in a northwesterly direction throughout their course while others move northwestwards initially and then recurve towards north or northeast. Unless the recurvature of these storms and depressions is foreseen sufficiently in advance timely warnings cannot be issued to the shipping interests and a wrong prediction about the direction of movement of depressions and storms may lead to disastrous results. Thus one of the most important and difficult problems which an Indian Meteorologist has to face in his storm warning work for the Bay of Bengal is the recurvature of storms and depressions. The synoptic situations in the vicinity of storm centres which appear to be identical often give divergent results; in some cases recurvature takes place while in others no recurvature is observed. It has, therefore, been thought worthwhile to study the relevant weather charts of a period of ten years from 1945 with a view to finding out the significant meteorological factors which determine the recurvature of storm forming in the Bay of Bengal and suggesting a method for its prediction.

2. Theoretical discussion regarding the recurvature of storms and its prediction

Movement of a depression or a storm takes place under two systems of forces, *viz.*,

internal forces within the circulation and external forces due to the currents that surround it. The tendency of a storm to move polewards in all latitudes is due to the internal force. The second internal mechanism is the super-position of a vortex on a steering current causing small oscillations in the storm track. "Steering" and "interaction of vortices" are the two external mechanisms which determine the movement of storms. It has been found that tropical storms move in the direction and with the speed of the steering current. As for the interaction of vortices, they attract or repel each other and they rotate about a centre of gravity located on the straight line or great circle connecting them, the position of this centre depending on the relative masses of the vortices. Thus a study of the distribution of cyclonic and anti-cyclonic vortices around the storm on the surface as well as in upper air upto a height of 30,000 ft or so and the associated pressure and wind field is necessary for a correct prediction about the recurvature. The subject has been engaging the attention of many meteorologists in India and outside and they are uniformly of the same view that the recurvature of tropical cyclones is determined by the synoptic situations in the middle latitudes and the upper air structures. Simpson suggested that storms will move along "tongues of warm air" in the layer 700—500 mb that often extends 1000 miles ahead of a cyclone. According to Metchell "all tropical storms apparently seek to move northward in the northern hemisphere at the first favourable opportunity. Any tropical storm will recurve into a trough of relatively low pressure that may

TABLE 1
Number of storms and depressions in the Bay of Bengal during 1945-54

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total number	5	1	1	5	6	11	18	19	19	18	12	11
*Number which recurved	2	0	0	1	1	0	0	0	0	5	1	4

*The storms and depressions which recurved on land or while in Arabian Sea have been excluded from this table

exist in the same region where the tropical storm arrives. No storm will break through and recurve until it reaches a region where south or southwest winds prevail aloft and relatively low pressure to the northward is shown on the weather map". There are, however, cases in which the storms are found to recurve even without a relatively low pressure to the northwards or northeastwards shown on the surface chart. In such cases a solution of the problem is found either from a study of the upper air structures which exhibit a well marked anticyclone to the east of the storm or from the identification of an active front on the surface chart which shows sufficiently in advance a belt of significant precipitation and cloud towards the direction of recurvature under the interaction of two different types of air masses in spite of the absence of a relatively low pressure belt in that direction.

3. Frequencies of occurrence of storms and depressions in the Bay of Bengal and their recurvature

Table 1 gives the total number of storms and depressions which occurred in the Bay of Bengal in different months during the period 1945-54 and those which recurved among them.

It will be seen from this table that no recurvature takes place during the monsoon months and that the post monsoon months of October to January and the pre-monsoon months of April and May are favourable for recurvature.

4. Latitudinal and longitudinal distribution of recurring storms

Space distribution of the occurrence of storms and depressions in the Bay of Bengal

and that of the recurring storms during the years 1945-54 are shown in Fig. 1. The tracks of the recurring storms during those years are shown in Fig. 2. It will be seen from these figures that while storms and depressions may visit any area in the Bay of Bengal, recurvature takes place only from the area covered by latitude 10°N and 18°N , the maximum frequency of recurvature taking place from the area included by latitudes 12°N and 16°N and longitudes 82°E and 91°E . It is also significant from Fig. 2 that in post monsoon months of October to December recurvature takes place mostly from a region to the west of longitude 90°E but in pre-monsoon months recurvature takes place from a more eastern longitude.

5. Characteristic pressure fields on the surface before recurvature

A study of the pressure changes (during the period of 24 hours or since last available observations) and pressure departures at stations round the Bay of Bengal in association with the storms and depressions in the Bay during the period 1945-54 has revealed the following results—

- (a) In case of all storms and depressions which move in a direction varying from west to northwest, the significant pressure fall and negative pressure departure were directed to west or northwest from the centre of the storms or depressions throughout their life history.



Fig. 1. Space distribution of the occurrence of storms and depressions in the Bay of Bengal and that of the recurving storms during the years 1945-54

(Figures within brackets indicate the number of recurving storms)

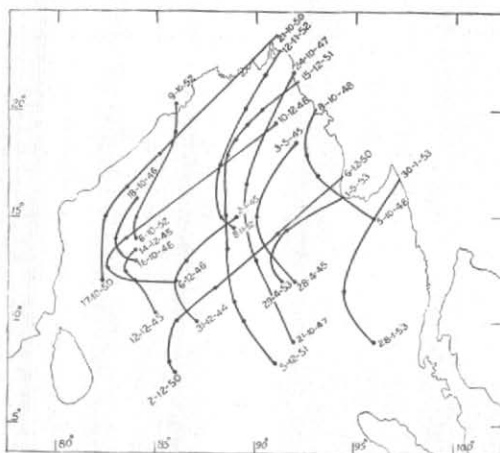


Fig. 2. Tracks of recurving storms in the Bay of Bengal during the period 1945-54

- (b) In regard to the storms and depressions which recurved towards northeast or east the significant pressure fall and large negative pressure departure were directed towards northeast or east 12 to 24 hrs before recurvature only in 25 per cent of the cases. In 75 per cent of the cases this change took place only after the recurvatures could be detected on the surface charts; before the recurvatures the negative pressure change was all the time directed towards northwest or west.

In view of the fact mentioned under item (b) above the usual pressure changes and departures plotted on the surface charts are not as useful as they should be in predicting the recurvatures. It has, however, been found that the second degree variation of pressure with respect to time at the stations in the four quadrants round a storm well before the actual recurvature is more important in predicting the recurvatures. Table 2 shows this result in respect of a few recurving storms under examination. It will be seen from Table 2 that the second degree variation of pressure about 24 hrs before the recurvature was more pronounced towards negative

value in the northeast quadrants than in southwest or northwest quadrants even though negative pressure departure or 24 hrs fall of pressure was sometimes less in magnitude in northeast quadrant than in other quadrants. These results would support the view mentioned before. A detailed analysis on the basis of pressure data from a large number of stations in the four quadrants will bring out conclusive results.

6. Precipitation and cloud fields in association with recurving storms

One of the most important features which a recurving storm indicates sufficiently in advance (12 to 18 hrs before recurvature) is the turning of the active front from west or northwest to north or northeast with an associated similar turning of significant precipitation belt and cloud field. This particular characteristic has been found in 80 per cent of the cases examined for the present analysis. In the remaining 20 per cent cases no significant front in any direction was found before the recurvature, the precipitation and cloud field being limited to a small area round the disturbances. It is well known that precipitation is essential for the maintenance of a cyclonic storm and as already stated before, the extension of a tongue of warm air towards northeast from

TABLE 2

Position from which recurvature took place	Date and time of recurvature	Pressure departure (mb)				24 hrs pressure change (mb)				Average second degree pressure change (mb) (corrected for diurnal variation) per hour ²			
		12 to 24 hrs before recurvature				24 hrs before recurvature				24 hours before recurvature			
		QUADRANT				QUADRANT				QUADRANT			
		NE	SE	SW	NW	NE	SE	SW	NW	NE	SE	SW	NW
17.5°N 88.5°E	10-12-51 0830 IST	CX.B -3	P.BLR -1	MDS -3	GPL -5	-1.4	1.6	-0.5	-2.2	-.015	.003	.001	-.002
16.5°N 89.5°E	23-10-47 0830 IST	AKB -4	P.BLR -8	MDS -2	VZG -2	-0.7	-3.9	-0.9	-0.6	-.016	-.010	.001	-.002
17.5°N 88.5°E	9-11-52 0830 IST	AKB -2	P.BLR -2	MDS -2	GPL -6	-0.4	-0.4	-0.3	-2.1	-.010	-.010	.004	-.012

the centre of the disturbance helps the recurvature. It is, therefore, obvious that the interaction of the different types of air masses ahead of the storm takes place in such a way before the recurvature that the active front is directed towards the direction of recurvature.

7. Influence of anticyclones on the recurvature of storms

The anticyclone aloft which is generally situated to the north of a westward-moving storm should shift eastward or southeastward with the recurvature of the storm. Such eastward displacement of sub-tropical ridge or anticyclone occurs most frequently when an active trough in the westerlies of considerable longitudinal extent approaches to the west or northwest of the storm centre. In an attempt to find out a relation between the positions and movements of the recurving storms and the anticyclones, the following interesting results have been found from the present analysis—

- (a) No well marked anticyclones could be detected on the surface or in the upper air up to 5000 ft over India, East Pakistan or Burma in association with most of the recurving storms and depressions in the Bay of Bengal. In a few cases (not more than 20 per cent) feeble anticyclones were found over Burma, *i.e.*, to the

east of the storms at 5000 ft or below, but no significant movements of these anticyclones were observed before the recurvature of the storm.

- (b) In association with all the recurving storms under examination anticyclones were found at a few consecutive levels between 7000 and 20,000 ft over Burma and neighbourhood, *i.e.*, to the east or northeast of the storms. In some cases these anticyclones were well marked. One common feature which was exhibited by these anticyclones before the recurvature of the storms was their eastward or southeastward shift. A typical example is shown in Fig. 3. This result is quite consistent with the theoretical consideration discussed before. (This observation is, however, subject to the limitation that the data available from Burma and East Pakistan particularly the upper air data were rather meagre).

8. Upper air structure in association with recurring storms

Upper air structure above the area covered by the cyclonic circulation on the surface was found to be different for the different recurring storms. In some cases cyclonic circulation existed even up to a height of

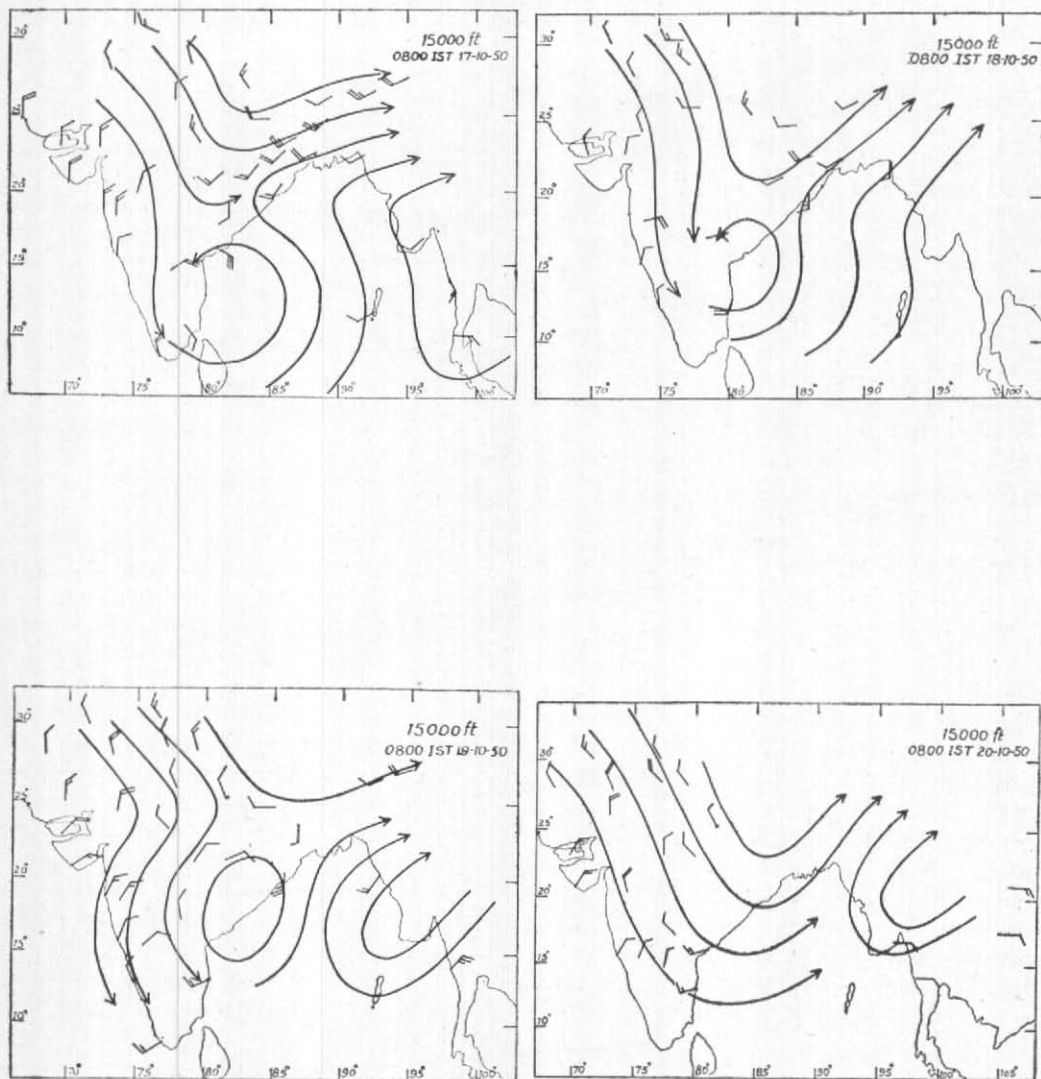


Fig. 3

15,000 ft while in others the cyclonic circulation did not even reach 7000 ft. Again the orientation of the axis passing through the centres of the circulations in different levels (as far as could be judged from the scanty upper air data available) was found to be different for different storms before their recurvature. It was, therefore, difficult to make a generalisation for the recurving storms in regard to the orientations of their axes through different layers and the wind shears which may come into play due to the inclinations of these axes.

9. Velocity of movement of recurving storms

Another interesting feature which was found in the case of the recurving storms was a retardation in their movement before recurvature. The retardation is more pronounced in the case of those storms whose angles of recurvature are large. Although the average velocity of the recurving storms during the period 1945-54 taking the full tracks of all of them was found to be about 11 miles per hour, their average velocity 12 to 18 hrs before recurvature was found to decrease considerably and did not exceed 5 mph in a number of cases. It was also observed that the movement was accelerated considerably after the recurvature with the result that in some cases the average velocity after recurvature became larger than that before recurvature.

10. Method of prediction about recurvature

From what has been discussed so far it is clear that a forecaster has to consider the

following points carefully before predicting the recurvature of a storm or depression in the Bay of Bengal—

- (a) At the time of recurvature the centre of the storm or depression is likely to be in the area covered by latitudes 10°N and 18°N .
- (b) Before the recurvature maximum pressure fall need not necessarily be directed towards northeast or east sufficiently in advance but the relative second degree variations of pressure with time towards north-east or east should be significant.
- (c) If there is any active front beyond the cyclonic circulation this front with its associated belt of significant precipitation and cloud field is likely to be shifted towards north or northeast before the recurvature takes place.
- (d) If there is any well marked anticyclone in the upper air over Burma and neighbourhood, it is likely to shift eastwards or southeastwards before the recurvature of a storm in the Bay.
- (e) Before the recurvature westerly or northwesterly movement of the storm is likely to be retarded considerably.

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