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Recurvature of tropical cyclones in the Indian seas

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सार — सन् 1961 से 1977 ई० तक पश्चिमी उत्तर एटलांटिक में उष्णकटिबंधीय चक्रवातों की प्रतिवक्रता के अध्ययन के बाद ग्रे (1981) ने तूफान के केन्द्र से 7°-11° अक्षांश/देशान्तर के अर्धव्यास में 200 एवं 900 मिलीबार की मिश्रित पवनों का उपयोग करके उष्णकटिबंधीय चक्रवातों की घूर्णी गति की प्रागुक्ति का एक निकष निर्धारित किया था। ग्रे के अनुसार घूर्णगति के 24 से 36 घंटे पहले चक्रवात की दिशा के समानांतर 200 से 900 मिलीबार के बीच के ऊर्ध्वाधिर पवन अपरूपण के घटक सीधे चलने वाले, दायीं ओर मुड़ने और बायीं ओर मुड़ने वाले चक्रवातों के लिए एक जैसी नहीं होते। इन अन्तरों का उन्होंने चक्रवातकी प्रतिवक्रता की 24 से36 घंटे पहले की प्रागुक्ति के आधार के रूप में इस्तेमाल किया। हमने इस विधि का बंगाल की खाड़ी के चक्रवातों के लिए परीक्षण किया और पाया कि प्रतिवक्रता से 24 से 36 घंटे पूर्व भीषण रहने वाले खुले समुद्र के चक्रवातों के मामले में इस विधि से भली प्रकार प्रागुक्ति की जा सकती है। सामान्य चक्रवातों या निर्बल प्रणालियों या तट के निकट की प्रणालियों के मामले में इस विधि से निश्चित प्रागुक्ति नहीं की जा सकती।

ABSTRACT. After study of recurvature of tropical cyclones in the western north Atlantic from 1961 to 1977; Gray (1981) devised criteria for prediction of turning motion of tropical cyclones using 200 and 900 mb composited winds in a radius of 7 deg.-11 deg. Lat./Long. from the centre of the storm. He showed that the components of vertical wind shear between 200 and 900 mb parallel to the direction of motion of the cyclone, are different for cyclones moving straight, turning left and turning right, 24 to 36 hours in advance of the turning motion. These differences he used as a means of prediction of recurvature of a cyclone 24 to 36 hours in advance. We tested this method for the cyclones of the Bay of Bengal and found that they are applicable in cases of severe cyclones which were so 24 to 36 hours in advance of the recurvature and were on the high seas. The results were less definite in cases of cyclones or weaker systems or systems close to the coast.

1. Introduction

The concept of steering for the movement of tropical cyclones is an old one (Riehl 1954) but there is a lot of controversy in defining the basic steering current that directs the motion. Some of the broad ideas in vogue (Srinivasan & Ramamurthy 1973) are: (*i*) High level flow, *i.e.*, 200-150 mb; (*ii*) Pressure weighted mean flow from surface to 300 mb and extending over a band of 8 deg. of Lat./Long. centred on the storm; (*iii*) Average flow in the layer from 500 to 200 mb; (*iv*) Prognostic 700 mb flow. George and Gray (1976) showed that winds at 5 deg.-7 deg. radius around a storm are representative of the close environmental flow surrounding the cyclone cloud region. They also found that 500 and 700 mb winds at this radius correlate best with storm direction for cyclones with widely different characteristics and concluded that the middle level large-scale flow is the primary steering agent for tropical cyclones. In India some numerical models have been developed (Sikka & Suryanarayana 1972, Datta & Gupta 1975) for the prediction of storm tracks using analogue method. It has also been reported (Srinivasan & Ramamurthy 1973) that pressure weighted mean winds of 500, 300 and 200 mb levels give better indication of the track of a cyclone.

Recently Chan *et al.* (1980) and Gray (1981) studied the problem of recurvature of tropical cyclones in the western north Atlantic during the period 1961-77 using vertical wind shear between 900 and 200 mb in the surroundings of the storm as a guide. They found that the components of vertical wind shear parallel to the direction of the storm motion between 200 and 900 mb in a radius of 7 deg. to 11 deg. Lat./Long. of the storm centre are significantly different for cases of cyclones moving straight, turning left and turning right, 24 to 36 hours in advance of the turning motion. They showed that for left turning storms this component of vertical wind shear is positive and for right turning storms negative, while it is zero for straight moving storms. Gray (1981) also noted that such differences in the tropospheric vertical wind shear between the three classes only exist 24 and 36 hours prior to the turn time. Shear differences disappear as the storm approaches the turn time. Hence vertical wind shear between these levels 12 hours prior to the turn time is not so well correlated with the subsequent turning motion.

He tested this hypothesis with a number of individual cases and found that if the component of wind shear between 200 and 900 mb parrallel to the storm motion is:

$>$ 5 m/sec, cyclone will be turning left ; if between

—5 & 5 m/sec cyclone will move straight and

$<$—5 m/sec, it will take a right turn,

TABLE 1

Date	Time (GMT)	Sector 1 dd/ff(kt) 850 mb	Sector 1 dd/ff(kt) 200 mb	Sector 5 dd/ff(kt) 850 mb	Sector 5 dd/ff(kt) 200 mb	Position Lat./Long. (°N/°E)	Stage	Sector 1 Vp (kt) Vp_{200} mb	Sector 1 Vp (kt) Vp_{850} mb	$X1=(Vp_{200}-Vp_{850})$ (Sector 1)	Sector 5 Vp (kt) 200 mb	Sector 5 Vp (kt) 850 mb	$X5=(Vp_{200}-Vp_{850})$ (Sector 5)	$R=(X1+X5)$
(a) Severe cyclonic storm, 3-9 November 1973 (Example 1)														
4	00	080/20	160/35	260/15	120/15	7.5/90	D.D.	—	—	—	—	—	—	—
4	12	100/20	240/35	280/15	060/20	9.5/89.5	D.D.	23.0	17.5	5.5	—10.0	—2.6	—7.4	—1.9
5	00	120/30	220/10	300/20	060/30	9.5/89.5	C.S.	7.7	15.0	—7.3	—15.0	—10.0	—5.0	—12.3
5	12	100/20	260/40	270/15	080/30	11/88	S.C.S.	6.9	3.5	3.4	—5.2	0	—5.2	—1.8
6	00	110/25	240/30	280/25	060/25	12/88	S.C.S.	15.0	8.6	6.4	—12.5	—4.3	—8.2	—1.8
6	12	120/15	240/35	300/20	120/20	13.5/88	S.C.S.	17.5	7.5	10.0	10.0	—10.0	20.0	30.0
7	00	090/35	240/25	270/10	150/20	17/88	S.C.S.	12.5	0.0	12.5	17.3	0.0	17.3	29.8
7	12	160/20	250/35	260/20	100/15	17/88.0	S.C.S.	12.0	18.8	—6.8	2.6	3.5	—0.9	—7.7
8	00						S.C.S.							
(b) Cyclonic storm, 23-28 October 1968 (Example 2)														
23	00	120/20	150/15	300/15	120/10	11.0/83	C.S.	13.0	10	—3.0	5.0	—7.5	12.5	9.5
23	12	100/30	220/20	290/25	100/40	11.5/83	C.S.	14.1	5.2	8.9	6.9	8.6	—1.7	7.2
24	00	120/25	240/20	300/20	110/15	13/83	S.C.S.	10.0	12.5	—2.5	—2.6	5.1	—7.7	—10.2
24	12	100/30	250/15	260/15	060/10	13.5/83	S.C.S.	5.0	5.2	—0.2	—5.0	2.6	—7.6	—7.8
(c) Cyclonic storm, 20-23 October 1970 (Example 3)														
21	00	110/15	220/35	300/25	120/15	16.5/87	S.C.S.	26.8	5.0	21.8	7.5	—12.5	20	41.8
21	12	110/20	220/40	280/15	120/30	16.5/87.5	S.C.S.	30.6	6.8	23.8	15.0	—1.6	16.6	40.4
22	00	100/15	240/30	330/15	100/20	17.5/88	S.C.S.	15.0	2.6	12.4	3.5	—13.0	16.5	28.9
22	12					18.5/89	S.C.S.							
(d) Cyclonic storm, 22-26 November 1976 (Example 4)														
22	00	080/15	150/20	240/15	070/35	8/91	L							
22	12	200/20	230/35	180/25	180/50	8/89.5	L							
23	00	080/25	160/30	270/15	080/20	8.5/88.5	C.S.	+10.3	24.6	—14.3	19.7	—15.0	34.7	20.4
23	12	140/10	230/30	220/15	100/30	8.5/87.5	C.S.	—23.0	6.4	—29.4	29.5	—3.2	32.7	3.3
24	00	070/25	120/35	280/10	120/20	10/84	C.S.	30.0	3.4	26.6	17.0	—6.4	23.4	50.0
24	12	060/20	160/40	300/10	120/25	10.5/83	C.S.	30.5	10.0	20.5	25.0	—10.0	35.0	55.5
25	00	060/15	180/35	290/10	080/25	12/81	C.S.	26.0	3.4	22.6	15.0	—8.6	23.6	46.2
25	12	070/10	250/20	260/10	090/35	14.5/80.5	C.S.	6.8	0.0	6.8	12.0	—6.4	18.4	25.2
26	00	060/15	220/25	240/10	060/30	15.0/79.5	C.S.	4.2	7.5	—3.5	15.0	—5.0	20.0	16.7
26	12	080/15	240/30	240/15	040/20	16.0/80.5	C.S.							
(e) Cyclonic storm, 15-19 October 1976 (Example 5)														
15	00	060/20	250/10	270/20	100/20	10.5/85	C.S.							
15	12	100/20	060/30	280/15	120/20	10.5/84.5	C.S.	26.0	+19.7	6.3	17.3	—14.8	32.1	38.4
16	00	070/20	160/40	280/15	060/20	12.5/83	C.S.	40.0	12.8	27.2	—3.5	—9.5	6.0	33.0
16	12	020/20	110/40	210/15	080/40	12.5/81.5	C.S.	37.6	6.8	30.6	39.4	—7.5	46.9	71.5
17	00	040/10	140/25	230/20	090/30	12.5/81	C.S.	12.9	+6.4	6.5	30.0	—15.3	45.3	51.8
17	12	040/15	160/25	250/20	120/25	13.5/79.5	C.S.	23.6	—2.6	26.2	25.0	—6.8	31.8	58.0
18	00	150/15	120/15	330/20	130/30	14/81	C.S.	7.5	13.0	5.5	19.0	—17.3	36.3	31.8
18	12	120/20	160/30	290/25	120/35	15.5/82	C.S.	—5.2	—13.8	8.6	—21.5	11.2	—32.7	—24.1
19	00	080/20	220/30	320/20	120/30	17/84.5	C.S.							
19	12	080/10	210/35	320/15	100/35	17.5/85	C.S.							

This scheme, inspite of many approximations involved in it, still provides a numerical method for forecasting recurvature of cyclones 24-36 hours in advance and merits further research and refinement. We have tried in this paper to test this hypothesis for cyclones in the Arabian Sea and the Bay of Bengal.

2. Method of analysis

For this analysis, Gray (1981) drew concentric circles around the centre of a cyclone at 1 deg. Lat./Long. interval and divided the circles into eight equal sectors taking direction of motion of the storm as the central line of the sector 1. Sector 1 he designated as the front sector and sector 5, the back sector for the analysis. Gray estimated average wind at 900 and 200 mb in sectors 1 and 5 between 7 deg. and 11 deg. Lat./Long. radius for each storm under study. From this average wind the components parallel (Vp) and normal (Vn) to the direction of the storm motion were found and used in the analysis. The estimates of the wind shear were made for the three cases of storm motion in the following way. Cyclones which underwent a left or right turn or moved relatively straight for a period of at least 48 hours were selected. For each turn classification, wind data for the following periods were composited : time when the storm started to turn (*turn time*-*T*) and 12, 24 and 36 hours before the turn time (*T*-12, *T*-24 and *T*-36 respectively). The turn times (*T*) correspond to 00 and 12 GMT best track positions. For a storm turning between two standard times (00, 12 GMT), the nearest standard time before the turn was taken as the turn time. For a straight moving storm, *T* was taken as the intermediate time before and after which the storm moved relatively straight for a period of at least 24 hours. Gray showed from different studies of storm motion with respect to average winds in all the eight sectors around the storm that using the average winds in sectors 1 and 5, *i.e.*, front and back sectors alone, one can describe the storm motion only slightly less accurately than the belt average values (using all sectors).

3. Data

In our study we picked up the storm tracks from the *Indian Daily Weather Report* (*IDWR*) and studied the corresponding analysed charts of Northern Hemisphere Analysis Centre. As is well known, there is great scarcity of data in the cyclone field, particularly in the upper air. Hence out of a large number of cyclone tracks of interest, one could get some data in only a few of them. We have used 850 and 200 mb winds instead of 900 and 200 mb winds as used by Gray because 850 mb winds could be directly picked up from the charts. Even in these cases winds in the sectors 1 and 5, as required for analysis, were rarely available. Estimates were made from whatever winds were available at these levels. Only those cases were chosen where some reliable estimates could be made. The method of analysis followed was the same as of Gray, described earlier. We studied cyclones both in the Bay of Bengal and the Arabian Sea but found reliable data only for some cases in the Bay of Bengal.

4. Cases studied

Discussed below are the cases of cyclones/severe cyclones which moved straight or turned right or left during their life history and where some wind data could be obtained from the charts at 850 and 200 mb levels.

4.1. *Cases I, II & III* (*Cyclone of* 3-9 *November 1973 — Bay of Bengal*)

The track of this storm is shown in Fig. 1. It can be seen that it changed its course from NW'ly to northerly at 12 GMT of 5 November '73 when it was a severe cyclonic storm. It moved on this northerly course upto 03 GMT of 8 November '73 maintaining its strength as severe cyclonic storm with a core of hurricane winds, and then suddenly turned left to NW'ly direction and crossed Orissa coast in the next 24 hours. This cyclone thus presents three turning situations : (*i*) right, at 12 GMT of 5 November '73, (*ii*) straight path from 12 GMT of 5th to 03 GMT of 8th, and (*iii*) left, at 03 GMT of 8th, all in the severe cyclonic storm stage. Table 1 (a) gives the average wind direction and speed at 850 and 200 mb in sectors 1 and 5 around the centre of the storm between 7 deg. and 11 deg. Lat/Long. radius from 00 GMT of 4th to 12 GMT of 7 November. From these wind data, components of wind parallel to the storm motion (Vp) have been calculated and from these values vertical shears (Vp_{200}-Vp_{850}) have been worked out for both sectors. Finally the resultant $Vp(R)$ from Vps of sector 1 (X1) and sector V (X5) have been calculated, following Gray. The results show the following :

(*i*) For turning right at 1200 GMT of 5 November 1973 (*T*) :

R at *T*—24	—1.9 kt (—1 m/sec)
R at *T*—36	not available as system was weak (deep depression) and did not extend upto 200 mb.

(*ii*) For straight movement from 12 GMT of 5th to 03 GMT of 8 November '73 — all in severe cyclonic stage, the intermediate time of straight motion, *i.e.*, 00 GMT of 7th, was taken as the *T* time. As per Table 1 (a), values of :

R at *T*—24	—1.8 kt (—0.9 m/sec)
R at *T*—36	—1.8 kt (—0.9 m/sec)

(*iii*) For turning left — at 03 GMT of 8 November 1973 in severe cyclonic storm stage (*T*—00 GMT of 8 November '73) :

R at *T*—24	29.8 kt (15 m/sec)
R at *T*—36	30 kt (15 m/sec)

Thus we can see that results (*ii*) and (*iii*) are significantly indicative of the desired turning as per Gray's criteria. In case (*i*) the *R* value at T — 24, *i.e.*, —1 m/sec, is not showing any turning trend and at *T* — 36, system itself was not sufficiently strong to affect 200 mb level. Hence in this case the criterion fails to predict the correct turning.

4.2. *Cases IV and V* (*Cyclone of 23-28 October 1968 — Bay of Bengal*)

Track of this cyclone is also shown in Fig. 1. It follows straight northerly path from 03 GMT of 23rd to 12 GMT of 25 October 1968 and then turns right

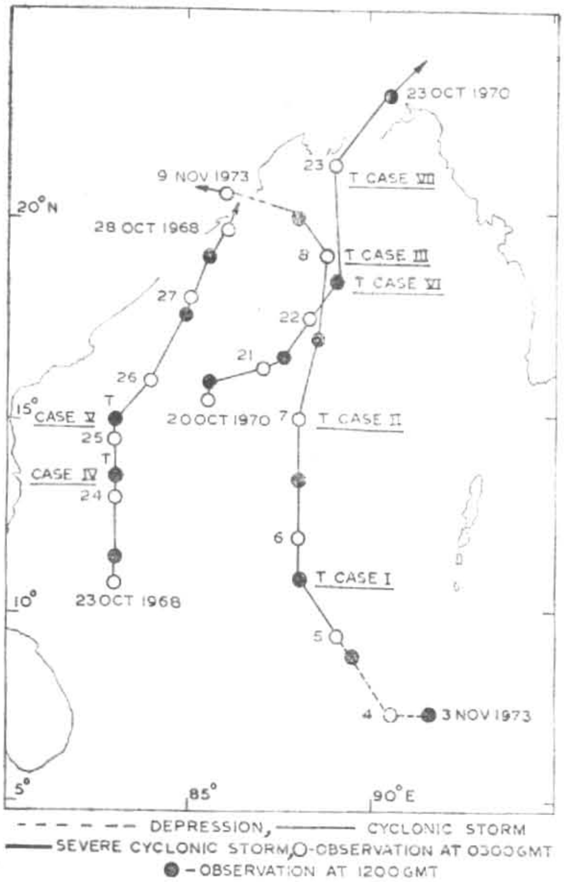

Fig. 1. Tracks of cyclonic storms : (*i*) 23-28 October 1968, (*ii*) 20-23 October 1970 and (*iii*) 3-9 November 1973

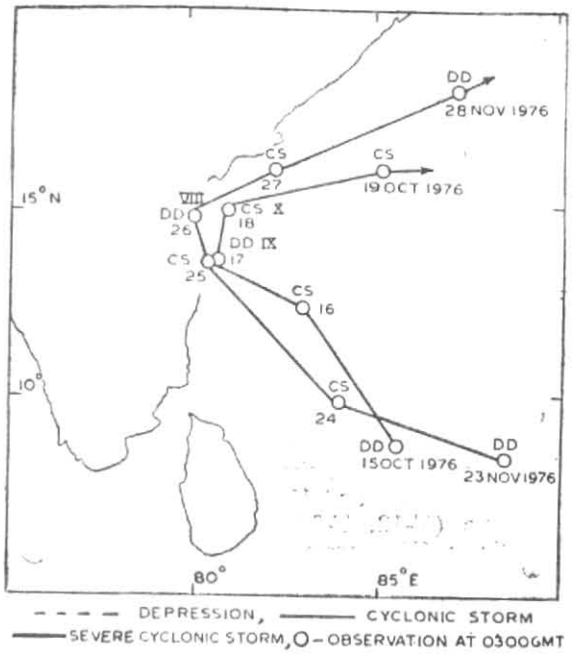

Fig. 2. Tracks of cyclonic storms : (*i*) 15-19 October 1976 and (*ii*) 23-28 November 1976

TABLE 2

Cyclones		Resultant vertical wind shear R		Turning time T		Predicted turning (including no turning) 24-36 hr in advance of turn time T			System status	Verification of result	Remarks
Period	S.N. of cases	T-36	T-24	Time (GMT)	Date	Left	Straight	Right			
3-9 Nov 1973	1	—	—1.9	12	5 Nov 73	—	St	—	D.D.-C.S., S.C.S.	Not definitive	Storm weak prior to turning
	2	—1.8	—1.8	00	7 Nov 73	—	St	—	S.C.S.	Correct	
	3	30.0	29.8	00	8 Nov 73	L	—	—	S.C.S.	Do.	
23-28 Oct '68	4	+9.5	+7.2	12	24 Oct 68	—	St	—	C.S./S.C.S.	Do.	
	5	—10.2	—7.8	12	25 Oct 68	—	—	R	S.C.S.	Do.	
20-23 Oct '70	6	41.8	40.4	12	22 Oct 70	L	—	—	S.C.S.	Do.	
	7	40.4	28.9	00	23 Oct 70	L	—	—	S.C.S.	Incorrect	Storm crossing coast
22-26 Nov '76	8	55.5	46.2	00	26 Nov 76	L	—	—	C.S.	Do.	Storm had crossed coast
15-19 Oct '76	9	38.4	33	00	17 Oct 76	L	—	—	D.D.	Do.	Storm very close to the coast
	10	71.5	51.8	00	18 Oct 76	L	—	—	C.S.	Do.	Storm close to the coast

when it was a severe cyclonic storm. So in this case, two situations were investigated : (*i*) moving straight and (*ii*) turning right. Table 1 (b) shows these results :

(*iv*) For straight motion : (*T* — 12 GMT of 24 October 1968) :

R at *T*—24	7.2 kt (3.5 m/sec)
R at *T*—36	9.5 kt (5 m/sec)

(*v*) For turning right (*T* — 12 GMT of 25 October 1968) :

R at *T*—24	—7.8 kt (—4 m/sec)
R at *T*—36	—10.2 kt (—5 m/sec)

In this case, for straight motion (N), the indications are significant. For right turn also, though they are not fully meeting the criteria of Gray, yet they are of proper sign. In other words, the persistent negative shear was indicative of turning tendency towards right.

4.3. *Cases VI & VII (Cyclone of 20-23 October 1970 — Bay of Bengal)*

Track of this cyclone is given in Fig. 1 and its wind data and shear values in Table 1(c). The cyclone was in depression stage upto 12 GMT of 19 October '70 and become a severe cyclonic storm at 03 GMT of 20th. It took a sudden right turn at 12 GMT of 20th and started moving in a NE'ly direction. At 12 GMT of 22nd it turned left and moved in northerly direction crossing West Bengal coast at about 03 GMT of 23rd. Of the three turnings only two could be investigated (*i*) at 12 GMT of 22nd when the cyclone was over the high seas, (*ii*) at 03 GMT of 23rd when it was crossing the coast. In these cases the following is the result (Table 1 c) :

(*vi*) Left turn (*T* — 12 GMT of 22 October '70) :

R at *T*—24	40.4 kt (20 m/sec)
R at *T*—36	41.8 kt (21 m/sec)

The result is highly significant and gives definitive indication of left turn 36 hours in advance.

(*vii*) Right turn (*T* — 00 GMT of 23 October 1970) :

R at *T*—24	28.9 kt (14.5 m/sec)
R at *T*—36	40.4 kt (20 m/sec)

This result indicates left turn but the storm turned right. This is probably because the storm was crossing the coast and was affected by topography and other factors. Gray's criteria were not applicable in this case.

Cases of two other cyclones which either turned very close to the coast or after crossing the coast are also similar. Their results are summarised below :

4.4. *Case VII (Cyclone of 22-26 November '76 — Bay of Bengal)*

The track of this cyclone is given in Fig. 2. It suddenly turned right at 0300 GMT of 26 November '76 and started moving NE. The turning took place after its crossing the south Andhra coast but it was a cyclonic storm before crossing and remained so afterwards also. The data and calculations for this storm are given in Table 1 (d). The result is given below :

(*viii*) Right turn (*T* — 00 GMT of 26 November '76) :

R at *T*—24	46.2 kt (23 m/sec)
R at *T*—36	55.5 kt (28 m/sec)

Thus, turning based on these values would have been to the left. But actual turning was to the right. Hence Gray's criteria are not applicable in this case also.

4.5. *Cases IX & X (Cyclone of 15-19 October 1976 — Bay of Bengal)*

The track of this cyclone is shown in Fig. 2. The storm was a deep depression at 03 GMT of 15th and intensified into a cyclonic storm in the next twenty-four hours moving in a NW'ly direction. After 03 GMT of 16th it moved on a WNW'ly course and weakened into a deep depression as it came close to Madras at 03 GMT of 17th. Then contrary to all expectations it turned right and moved in a northery direction upto 0300 GMT of 18th and intensified into a cyclonic storm again. After 03 GMT of 18th it moved on a ENE'ly course remaining a cyclonic storm. So it had two turnings : (*i*) Right turn at 03 GMT of 17 October 1976 and (*ii*) again right turn at 03 GMT of 18 October '76. The data for this cyclone are given in Table 1 (e). They show that for :

(*ix*) Right turn at *T* — 00 GMT of 17 October 1976 :

R at *T*—24	33 kt (16.5 m/sec)
R at *T*—36	38.4 kt (19 m/sec)

The results indicate left turn but the storm turned right.

(*x*) Right turn at *T* — 00 GMT of 18 October 1976 :

R at *T*—24	51.8 kt (26 m/sec)
R at *T*—36	71.5 kt (36 m/sec)

Indications are again opposite to the actual turning. In this case, the cyclone was weak and also close to the coast. It is apparent, therefore, that Gray's criteria are not applicable to cases which are not severe cyclonic storms and which are not on the high seas, away from the influence of coast.

5. Discussion

Table 2 gives the score of this analysis. It can be seen that Gray's criteria are capable of predicting correct turnng 24 to 36 hours in advance for severe cyclonic storms whose circulation extends upto 200 mb. It is not so definitive in cases of cyclones, deep depressions or depressions which might have intensified into a severe cyclonic storm only at the time of turning or about 12 hours in advance. This is because in these cases the winds at 200 mb, 24 to 36 hours in advance, were not in the grip of the system. Similar is the case for cyclones which turn after crossing the coast or close to the coast. In both the cases discussed here the turning direction is opposite of the forecast.

The reason for choosing 900 and 200 mb as the levels for this analysis, as emphasised by Gray, is that these are the levels at which satellite derived winds will be available in plenty in the cyclone area in future. Hence these criteria will be quite useful for the prediction of storm tracks using satellite data.

6. Conclusion

The following conclusions can be drawn from this analysis :

(1) The criteria developed by Gray (1981) for the prediction of recurvature of tropical cyclones in the western north Atlantic, are applicable only to severe cyclonic storms in the Bay of Bengal which attain this intensity 24 to 36 hours in advance of the turning and are on the high seas.

(2) They do not give clear, definitive indication in cases of cyclones, deep depressions or depressions and in cases of those severe cyclones which attain this intensity only at the time of turning or 12 hours in advance. This is most probably due to the weaker systems not extending their influence upto 200 mb which is the upper level under consideration in Gray's criteria.

(3) It does not also predict correctly the turning of cyclones/severe cyclones which recurve after crossing the coast or close to the coast.

References

Chan, J.C.L., Gray , W.M. and Kidder, S.Q., 1980, *Mon. Weath. Rev.*, **108**, 6, pp. 778-792.

Datta, R. K. and Gupta, R. N., 1975, *Indian J. Met. Hydrol. Geophy.*, **36**, 3 pp. 345-348.

George, J.E. and Gray W.M., 1976, *J. appl. Met.*, **15**, pp. 1252-1264.

Gray, W.M., 1981, Recent Advances in Tropical Cyclone Research from Rawin Sonde Composite Analysis; WMO Programme on Res. in Tropical Met.

Riehl, H., 1954, *Tropical Meteorology*, McGraw Hill Book Co., New York.

Srinivasan, V. and Ramamurthy, K., 1973, Forecasting Manual Part III, 4.1, India Met. Dep.

Sikka, D. R. and Suryanarayana, R., 1972, *Indian J. Met. Geophys.*, **23**, 1, pp. 35-40.