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ON THE SPEED OF MOVEMENT OF TROPICAL CYCLONES

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ABSTRACT

Assuming the short-term forecasting guidelines of Lajoie and Nicholls (1974), upper wind observations indicate that the speed of movement of a tropical cyclone along the forecast direction of motion is equal to the component along that direction of the mean 'outflow' current measured slightly ahead of the downstream end of the outer cloudband and averaged from the surface to the top of the layer of cyclonic circulation.

INTRODUCTION

Riehl and Burgner (1950) suggested that a tropical cyclone should move along the direction and with the speed of a large-scale steering current, defined as the pressure-weighted mean flow from surface to 300 mb and averaged over a band eight degrees of latitude centred on the storm. A strict evaluation of the steering current therefore requires a much larger amount of upper-wind data than is usually available. However, since the forecasting guidelines proposed by Lajoie and Nicholls (1974) and confirmed by Lajoie (1976) provide implicitly an indication of the direction of the steering current, an attempt was made to estimate its speed from a single set of observed upper winds taken at an appropriate location. This was done in the following way. The observed wind at any point in the vicinity of a tropical cyclone was regarded as the sum of three major components: the radial and tangential wind components of the synoptic-scale cyclone circulation and the large-scale steering current in which the cyclone is embedded. At distances greater than 200 km from the cyclone centre the magnitude of the first component was assumed to be negligibly small in comparison with that of the third component. It was also assumed that because of the large-scale nature of the steering current the speed of the latter did not vary appreciably with relatively small distances (200 to 500 km). Under these conditions the most appropriate location for the upper wind observations, for the purpose of determining the speed of the steering current, was taken to be just ahead of the DEOC (downstream end of the outer cloudband). At this point the tangential component of the cyclone circulation and the direction of the steering current are at right angles to one another and the speed of the current can easily be evaluated from the observed upper winds.

A slight departure from Riehl and Burgner's hypothesis was adopted; instead of averaging the flow from surface to 300 mb, the vertical average was performed from the surface to the top of the layer of cyclonic circulation.

The hypothesis was tested in the following manner. Upper winds observed slightly ahead of the DEOC were used to determine the mean flow. The component of the latter along the forecast direction of movement of the cyclone was then correlated with the observed speed of the movement of the cyclone.

DATA

Selection of upper winds

Published tracks of all tropical cyclones operating in the northern Australian region from 1964 to 1972 were examined and the dates and times of those whose centres were 300 to 600 km from and moving towards an upper-wind observing station were noted.

Upper-wind observations were selected according to the following criteria:

(a) the Rawin station had to be ahead of, but not more than 200 km from the DEOC as observed in appropriate satellite pictures taken within ±6 hours of the time of the wind report;

(b) the bearing of the Rawin station from the cyclone centre had to be not more than ten degrees from the relative direction of the DEOC from the cyclone centre;

(c) the Rawin should have reached the anticyclonic outflow layer aloft (this is defined more precisely later).

Sixteen Rawin observations met these criteria. To increase the data sample six more Rawin observations were used when the satellite pictures were taken 12 hours before time of the wind report and when there was no change in direction of the tropical cyclone for the next 24 hours, suggesting that there was no major change in the relative position of the DEOC during that period. In two other cases there were no satellite pictures and the distance of the DEOC from the cyclone centre was taken as three degrees of latitude and the relative direction from the centre was assumed to be along the straight track of the cyclone.

Observed speed of movement of tropical cyclones

The observed mean speed of displacement, averaged over 6 to 12 hours, of each of these tropical cyclones when moving along the forecast direction of movement was obtained from the published tracks. Since these cyclones were operating in the vicinity of observing stations and some of them were under radar surveillance, the mean observed speed of displacement was considered accurate to within ±1 m/s.

METHOD OF COMPUTATION

Determination of 'h', the thickness of the layer of cyclonic circulation

The layer of cyclonic circulation extends from the surface up to the level where the circulation starts to become anticyclonic. Its thickness 'h' was determined from each upper wind observation by making use of Fig 1(a), which shows the vertical structure of the circulation around a tropical cyclone. Between the surface and about 1000 m is the major inflow layer where $90^\circ < \alpha < 180^\circ$; α being the angle between the forecast direction of motion of the tropical cyclone and the wind direction and is positive when measured in a clockwise sense from the forecast direction, see Fig 1(b). From 1000 m to some upper level, which varies from 6000 to 12 000 m, the circulation vacillates between inflow and cyclonic outflow. In cyclonic outflow $0^\circ < \alpha < 90^\circ$ as shown in Fig 1(c). Above these two layers there is the major anticyclonic outflow layer where $-90^\circ < \alpha \leqslant 0^\circ$ as illustrated in Fig 1(d). This vertical structure of the circulation around the tropical cyclone, observed in the sample of data used here, is similar to that described by Riehl (1954) and others, while the conditions for anticyclonic outflow aloft follow from the model presented by Fujita et al. (1967).

When the Rawin station was exactly along the forecast direction of motion of the tropical cyclone, the layer of cyclonic circulation was assumed to extend to

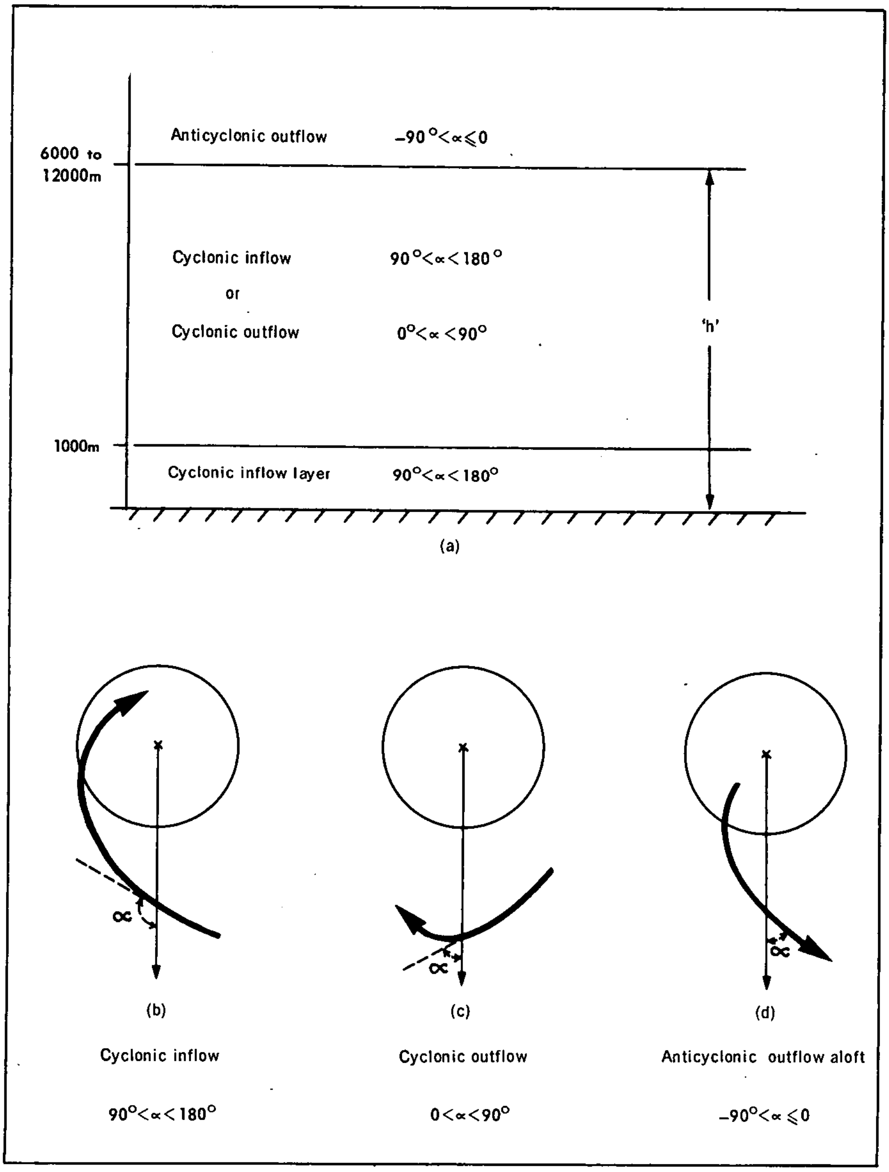

Fig 1 (a) Wind structure in the vicinity of a tropical cyclone, (b) cyclonic inflow, (c) cyclonic outflow, (d) anticyclonic outflow

Table 1 Observed movement of tropical cyclones and computed vertically average wind flow

1	2	3	4	5	6	7	8	9
					Movement of tropical cyclone		Vertically average wind (all layers)	
No	Name of tropical cyclone	Rawin station	Date	Time (GMT)	Dir	Speed (m/s)	Dir	Speed (m/s)
1	Katie	Carnarvon	28. 3.64	2315	180	5.2	053	8.3
2	"	"	29. 3.64	0540	180	5.2	076	12.3
3	Dinah	Eagle Farm	27. 1.67	2310	185	2.1	087	12.4
4	"	" "	28. 1.67	0445	185	2.1	085	12.9
5	"	" "	28. 1.67	1115	180	3.1	082	12.4
6	"	Lord Howe Is	29. 1.67	1700	140	6.0	011	9.7
7	"	" " "	29. 1.67	2315	135	8.8	013	15.6
8	Gwen	Alice Springs	5. 3.67	2300	110	11.8	327	15.9
9	"	Coffs Harbour	7. 3.67	2315	110	12.1	335	17.6
10	"	" "	8. 3.67	0515	110	12.1	345	19.7
11	Glenda	Lord Howe Is	4. 4.67	1115	165	5.2	067	16.6
12	Gisele	Noumea	6. 4.68	1100	165	6.4	023	6.9
13	Colleen	Noumea	31. 1.69	1100	140	9.4	003	9.3
14	"	"	31. 1.69	2300	155	9.8	013	11.1
15	Leonie	Albany	5. 4.69	2300	125	13.0	315	12.2
16	"	"	6. 4.69	0515	110	15.4	316	18.0
17	Low	Lord Howe Is	15. 4.69	1715	145	8.9	018	12.9
18	"	" " "	15. 4.69	2315	130	6.2	039	16.3
19	Low	Coffs Harbour	15.11.69	0515	205	15.4	027	14.5
20	Ingrid	Carnarvon	14. 2.70	2315	180	5.2	053	10.7
21	Althea	Townsville	22.12.71	2315	245	4.7	139	12.1
22	Daisy	Coffs Harbour	11. 2.72	1015	170	2.6	072	8.9
23	Emily	Eagle Farm	2. 4.72	0550	140	9.8	031	18.0
24	Ida	Noumea	2. 6.72	1100	165	11.8	029	11.6

just beneath the first level where $\alpha \leq 0$. In cases when the Rawin station was slightly off the forecast direction the bearing of the station from the cyclone centre at the time of the upper-wind observation was considered for the purpose of determining h.

Computation procedure

Each Rawin observation was divided into as many layers as there were derived winds and the thickness of each of these layers was determined. The sum of the products of the zonal component of the observed wind and the corresponding thickness of the layer was divided by 'h' to give the vertically averaged zonal wind component. A similar computation gave the average meridional wind component. These were then combined to obtain the vertically averaged wind in the layer of cyclonic circulation. The component of this resultant wind along the forecast direction of motion of the tropical cyclone was then assumed to yield the speed of translation of the cyclone centre along that direction.

RESULTS

The results of the computations are given in Table 1. In Columns 6 and 7 are given the observed direction and mean speed of displacement for each selected tropical cyclone. Columns 8 and 9 give the direction and speed of the vertically averaged flow through the layer of cyclonic circulation. The component of that wind along

10	11	12	13	14	15	16	17
Component along forecast direction - Speed (m/s)	Col 10 minus Col 7 (m/s)	Vertically average wind (outflow layers only)		Component along forecast direction (m/s)	Col 14 minus Col 7 (m/s)	Angle between Col 12 and 6	No
		Dir	Speed (m/s)				
4.9	-0.3	032	7.5	6.3	1.1	32	1
2.9	-2.3	057	9.4	5.1	-0.1	57	2
1.8	-0.3	082	9.1	2.1	0	77	3
2.1	0	081	7.9	1.8	-0.3	76	4
1.7	-1.4	079	10.0	2.0	-1.1	79	5
6.1	0.1	011	9.6	6.1	0.1	51	6
8.2	-0.6	009	14.1	8.2	-0.6	54	7
12.8	1.0	319	14.9	13.3	1.5	29	8
12.5	0.4	327	16.1	12.9	0.8	37	9
11.4	-0.7	339	17.5	11.5	-0.6	49	10
2.5	-2.7	049	10.3	4.5	-0.7	64	11
5.4	-1.0	353	7.5	7.4	1.0	8	12
6.8	-2.6	342	10.0	9.4	0	22	13
8.8	-1.0	349	11.0	10.7	0.9	14	14
12.3	-0.7	315	12.2	12.1	-0.9	10	15
16.1	0.7	316	18.0	16.1	0.7	26	16
7.7	-1.2	360	11.0	8.9	0	35	17
0.3	-5.9	359	8.1	5.3	-0.9	49	18
14.1	-1.3	027	14.3	14.3	-1.1	2	19
5.7	0.5	049	10.3	6.1	0.9	49	20
3.3	-1.4	133	10.2	3.8	-0.9	68	21
1.2	-1.4	064	7.3	2.0	-0.6	74	22
5.9	-3.9	005	13.2	9.3	-0.5	45	23
8.3	-3.5	355	11.6	11.4	-0.4	10	24

the observed direction of motion of the tropical cyclone is given in Column 10. This component, according to the hypothesis being tested, should compare well with the speed of movement of the selected cyclone in Column 7. As can be noted in Table 1, it does not; the difference between that component and the observed speed of movement of the tropical cyclone, given in Column 11, varies from -5.9 to 1.0 m/s. A pressure-weighted vertically averaged flow was also tried but the results were still less encouraging.

However, if in computing the vertically averaged flow, use is made only of those upper winds having a cyclonic outflow (i.e., when $0^{\circ} < \alpha < 90^{\circ}$) a substantial reduction in the difference between computed speed and observed cyclone speed is obtained. Columns 12 and 13 of Table 1 give the direction of speed of this vertically averaged 'outflow' wind. The component of that wind along the direction of motion of the cyclone is given in Column 14. The difference between the latter and the observed cyclone speed is given in Column 15. It was gratifying to note that for the 24 selected cyclones that difference varied from -1.1 to 1.5 m/s with an r.m.s. difference of only 0.77 m/s, well within the limits of accuracy of the data.

This result is shown in Fig 2 in the form of a scatter diagram, the observed mean speed of displacement of the tropical cyclone being plotted against the component along the observed direction of movement of the tropical cyclone of the vertically averaged 'outflow' wind. Agreement between observed and computed speeds is remarkable.

CONCLUSIONS

When a tropical cyclone is moving along a direction given by the bearing relative to the vortex centre of the DEOC, the speed of movement of the tropical cyclone appears to equal the component along the forecast direction of the mean 'outflow' current measured slightly ahead of the DEOC and averaged from surface to the top of the layer of cyclonic circulation. It must be stressed, however, that this result has been obtained from a very small sample of data, and that more observations are required to test the hypothesis.

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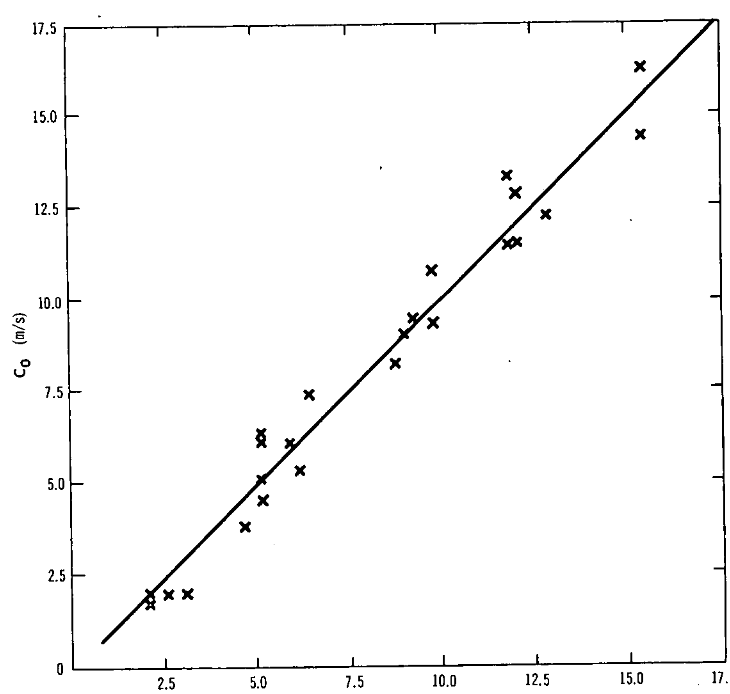

Fig 2 Relationship between C_c, the component of the vertically averaged 'outflow' current along the forecast direction of movement of the tropical cyclone (determined from upperwinds just ahead of the DEOC), and C_c, the observed speed of displacement of the cyclone centre along the same direction