ON THE MOVEMENT OF TROPICAL CYCLONES - 1954-55 SEASON

by A.K. Hannay

Central Meteorological Bureau, Melbourne

(Manuscript received 6th April, 1955)

Abstract: The tracks of all tropical cyclones in the 1954-55 season in the Australian area were collected and studied. At the same time charts were made of the zonal discontinuity at the 200 mb. level, to find out what effect this had upon the tracks of the cyclones. The zonal discontinuity is the area of separation between the broad scale westerlies and the easterlies over the equatorial and tropical regions.

In all of eight cases from January to March 1955, there was good relationship between the tracks followed by the storms and the position of the zonal discontinuity. With the tropical cyclone located well to the north of the discontinuity, a component of movement from east to west was maintained; with the cyclone located to the southward of the discontinuity, west to east movement eventuated. Cases where the discontinuity moved north or south of the cyclonic centre resulted in slowing-down or recurvature. With one notable exception, abrupt recurvature was not a marked feature of the season's cyclones, and this was associated with a persistence in position of the 200 mb. discontinuity or ridge-line.

1. INTRODUCTION

The present investigation was prompted by a Research Note in R.A.A.F. Tropical Research Bulletin No.6 (Gibbs and Whittingham 1944). This Note refers to the relation between cyclone tracks and zonal winds at cirrus level described by Vasquez (1941) who defines the zonal discontinuity as the zone of separation between the polar westerlies and the dominant easterlies over the equatorial region. Briefly his theory is that a tropical cyclone will have an east to west component of movement between the equator and the discontinuity, and when the cyclone nears the discontinuity or crosses it, "recurvature" will result. On the poleward side of the discontinuity there is a component of movement from west to east. The Tropical Research Note gave three examples in 1944 when cyclonic movements obeyed this theory, using the highest winds available at that time to locate the discontinuity.
The present investigation uses 200 mb streamline (contour) charts to identify the zonal discontinuity, and the M.S.L. analysis to locate the cyclone tracks. The exact positions of all the zonal discontinuities cannot always be certain because of the lack of rawin and radiosonde stations through the whole area northwest, north, and northeastern of Australia. At present the only such station north of the Tropics of Capricorn outside continental Australia is Mendi (for location see figures). However, some high pilot balloon observations from one or two stations in this vast area were of great value.

Meteorologists have for long been aware of some kind of steering principle in connection with forecasting the speed and direction of tropical cyclones. Since the storm circulation decreases upwards it has been customary to consider upper winds for as high as available data permits.

Strictly, steering refers to the forces that guide a small vortex imbedded in a broad steady current. The disturbance is assumed to move without change of shape or intensity, and the broad current to move without varying space or time. But the atmosphere does not fulfil these conditions. To determine the steering current quantitatively it would be necessary to subtract the pressure and wind field of the storm itself from the total fields but this has never been completely successful.

Riehl and Burgner (1950) define the steering current as the pressure weighted mean flow from the surface to at least 300 mb over a band 5 to 8 degrees latitude in width and centred on the storm. Such a calculation is impracticable if there is lack of data, both rawin and radiosonde observations being needed from at least 4 stations around the storm to provide integrated vector wind velocities at known pressure levels.

Another quantitative method rises the assumption that the 500 mb constant pressure surface approximates the mean of the steering layer.

Riehl and others (1954) have used this method in which the 500 mb height gradient is computed from north to south and from east to west across an area within 5 to 10 degrees (latitude and longitude) centred on the storm. The vector wind given by the resultant of these two gradients then represents the steering condition. This method depends upon the asymmetry of the 500 mb wind field in relation to the surface centre. In oceanic region surrounding Australia it is impossible to carry out the technique due to lack of data. However an attempt was made, in connection with this paper, to apply the method to one of the cyclones after it had reached North Queensland.
The use of a steering "level" instead of a steering "layer" is an over simplification of the problem, but it has apparently met with some success in the past. The present paper, which shows some correlation between direction of the recent eight tropical cyclones in Australasia and the position of the 200 mb. zonal discontinuity relative to the storm centre, virtually makes use of the 200 mb. level as the steering level.

The tendency to move poleward up to 1 to 2 degrees latitude per day especially by large storms, suggests internal forces, and is probably due to the variation of Coriolis's parameter across the area of the storm (Riehl 1954).

2. DISCUSSION OF THE CASES

In January 1955, two tropical cyclones affected the northwest of Western Australia, one occurred in the western Pacific, and a small cyclone affected the Thursday Island area. In February there were two in the northeast Indian Ocean, both affecting part of Western Australia in their immature and dying stages. In March, a tropical cyclone, after crossing the western Pacific, arrived in north Queensland; and another one reached the Southeast coast of Queensland before "recurring" to the eastward, and again to the westward.

The shapes of the various tracks are shown in the sketch.
FIGURE 1. Position of Zonal Discontinuity (200 mb) on dates shown.
- Cyclone Track and Dates (9am.)

FIGURE 2. Position of Zonal Discontinuity (200 mb) on dates shown.
3 - Cyclone Track and Dates (9am.)
FIGURE 3
Mean Position of Zonal Discontinuity (200 mb) from 29 Dec. to 15 Jan.
Position of Zonal Discontinuity on individual dates shown thus—
Cyclone Track and Dates (9am)

FIGURE 4
Position of Zonal Discontinuity (200 mb) on dates shown.
Cyclone Track and Dates (9am)
Figure 1 shows the track of the centre of the first December-January cyclone with positions at 24 hour intervals. The dotted lines gives the positions of the 200 mb. zonal discontinuity on the 29th, 30th and 31st, and 1st January, these dates covering the period of the storm. These lines are in the effect the ridge lines at 200 mb. between winds with easterly and westerly components and were obtained from streamline (contour) charts based upon radiowind, pilot balloon and radiosonde data.

Figure 2 shows the tracks of two other January cyclones, and positions of the 200 mb. zonal discontinuity for 10th, 11th and 12th January.

It will be noted that the two West Australian cyclones were near the zonal discontinuity at the outset (see positions of discontinuities from 29th-30th December and 10th-12th January in figures 1 and 2). Little zonal component of movement either way occurred up to 31st December and up to 13th January respectively. Up to 30th December and up to 12th January the cyclones were still near the corresponding zonal discontinuities. The second of these two storms weakened considerably from 13th January and ceased to be a tropical cyclone.

A small tropical cyclone on the northern tip of Cape York Peninsula remained quasi-stationary between 10th and 13th January. Its track is shown on figure 2. Reference to this figure shows the 200 mb. zonal discontinuity passing across or near to the storm's position on 11th and 12th. On the 10th the 200 mb. discontinuity was located approximately through New Guinea at the longitude of the storm. However only little movement from west to east occurred up to 11th.

The tropical cyclone which was generated at the eastern fringe of the Coral Sea on 31st December - 1st January had a pronounced easterly component of movement to Fiji. Its track was at all stages definitely on the poleward side of the zonal discontinuity. Beyond longitude 175 deg. E. the 200 mb. ridge line took on a much more north-south direction suggesting a northerly component of steering, and the cyclone ceased to show zonal movement after 5th-6th January. The 200 mb. winds at Nandi thereafter were as follow:

<table>
<thead>
<tr>
<th>January</th>
<th>Degrees</th>
<th>Knots</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>360</td>
<td>43</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>010</td>
<td>24</td>
</tr>
<tr>
<td>8</td>
<td>270</td>
<td>6</td>
</tr>
<tr>
<td>9</td>
<td>320</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>310</td>
<td>11</td>
</tr>
<tr>
<td>11</td>
<td>280</td>
<td>13</td>
</tr>
</tbody>
</table>
The track of this cyclone is shown in figure 3, and also the mean position of the 200 mb. discontinuity from 29th December to 15th January, covering the whole period of the storm. In addition, figure 3 shows the position of the discontinuity on certain individual days.

Two other matters are worthy of mention concerning the January cyclones. The 300 mb. isolach analysis for 2 p.m. 1st January showed the arrival of the equatorward margin of a jet stream over southwest Western Australia, the wind at Guildford being 290 deg. 115 knots. This contributed to the destruction of the West Australian cyclonic circulation of 1st January by introducing a cold convergent flow immediately to the south and southward of it. In a similar way the arrival of a westerly jet near Norfolk Island on 15th January led to the final filling up of the old "Fiji" hurricane.

Figure 4 shows the track of the first Indian Ocean tropical cyclone of February in relation to the position of the 200 mb. zonal discontinuity for 10th-12th February and for 14th, 15th and 16th February. The position of the centre was at all times south of the discontinuity and an eastward component of movement occurred. On 15th, when the discontinuity approached the centre again, zonal movement of the storm decreased.

Figure 5 gives the track (up to 25th February) of the other Indian Ocean cyclone of February. Its position was at all times well on the equatorward side of the zonal discontinuity and a marked westward movement resulted.

Figure 6 shows the track of the West Pacific cyclone for 26th February to 16th March. After developing near Rotuma (see Figures) about 26th February and reaching the northern tip of New Caledonia on 4th March, it arrived off the tropical coast of Queensland on 7th. This figure also shows the mean position of the 200 mb. zonal discontinuity from (a) 2nd to 7th, (b) 8th to 9th, (c) 10th to 12th, (d) 13th to 15th March.

On 7th March the zonal discontinuity was placed about 500 miles to the westward in the same latitude, somewhat closer to the storm than formerly, in this section of the chart. The discontinuity on 8th March moved to a position about 3 degrees north of the cyclone and on 9th was approximately above it. These events coincided with a cessation of the prolonged westward path, and between 9th and 10th, a small drift back to the eastward.

By this time the cyclone was losing intensity due to its location over uneven land and to a cutting off of the surface energy source. However on 10th, 11th and 12th it showed a slight movement to the westward again with the zonal discontinuity back to the southward (figure 6).
FIGURE 5.
Mean Position of Zonal Discontinuity on dates shown.

Cyclone Track and Dates (9am.)

FIGURE 6.
Mean Positions of Zonal Discontinuity (200 m.b.)
from 2-7, 8-9, 10-12 and 13-15 March.
Cyclone Track and Dates (9am.)
FIGURE 7
- - - - Position of Zonal Discontinuity (200 mb) on dates shown [2 pm]
- - - - Position of Zonal Discontinuity (100 mb) on dates shown [2 pm]
- - - - Cyclone Track and Dates (9 am)

FIGURE 8
Position of Zonal Discontinuity (200 mb)
each day from 24 March to 5 April [2 pm]
Dates shown thus — 31
The zonal discontinuity returned to the storm's latitude thereafter. Little further zonal movement of the center occurred. By about 15th March the disturbance ceased to be a warm-core tropical storm.

The quantitative method involving use of the 500 mb. chart as representing the steering layer was applied to this cyclone on 8th, 9th and 10th March. On these dates three radiosonde stations lay within 500 miles of the storm and two of them had rawins. The results obtained were not satisfactory, differing, particularly in speed of translation, from the actual movement of the cyclone. The network was still too sparse to allow the 500 mb. chart to be drawn objectively, so it could not be decided whether or not the 500 mb. level represented the field of translation. Again, the method may not be appropriate to a cyclone subject to frictional effects over the land.

Figure 7 shows the track of another cyclone in late March and early April. Figure 8 gives the daily positions of the 200 mb. discontinuity. The cyclone moved poleward with a westward component until 27th March. As indicated in figures 7 and 8 the storm remained to the north of the 200 mb. zonal discontinuity until approximately the afternoon of 26th when it crossed this boundary. It continued to move southwest but lost westward movement on 27th, and began to "recurve" late on 27th.

Figure 8 shows that after this, the cyclone was on the poleward side of the discontinuity. After 27th its movement was characterised by a marked west to east component. From 30th March the 200 mb. flow over the cyclone area became more southwesterly, as indicated by the following upper winds:

March 30th

<table>
<thead>
<tr>
<th>Location</th>
<th>Direction</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amberley</td>
<td>240 deg.</td>
<td>43 knots</td>
</tr>
<tr>
<td>Lord Howe Island</td>
<td>210 deg.</td>
<td>78 knots</td>
</tr>
</tbody>
</table>

March 31st

<table>
<thead>
<tr>
<th>Location</th>
<th>Direction</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amberley</td>
<td>250 deg.</td>
<td>15 knots</td>
</tr>
<tr>
<td>Lord Howe Island</td>
<td>200 deg.</td>
<td>48 knots</td>
</tr>
</tbody>
</table>

The tropical cyclone moved northeastward, and returning closer to the warm air source, deepened to a mature disturbance with cyclonic circulation up to the 200 mb. level for the first time. With this, the 200 mb. zonal discontinuity became discontinuous. That portion of it on 31st which was uninterrupted by the cyclonic circulation and which still was the boundary between the westerlies of "polar" origin and the easterlies of tropical origin moved southward, and is shown on figure 8.
Figure 7 also shows the position of the zonal discontinuity at 100 mb, on 31st March. At this level, which is approximately just below the tropopause, the zonal discontinuity was undisturbed and extended further eastward across the chart.

Being well north of the discontinuity the cyclone began to drift towards the west again. It began slowly to lose depth and intensity. It remained north of the 200 mb. zonal discontinuity on the first two days of April and was very close to it on 3rd. On 4th this boundary moved well equatorward of the cyclone (figures 7 and 8), the cyclone crossing it late on 3rd or early on 4th. By the morning of 5th April the storm lost its westerly component of movement; with the zonal discontinuity remaining well to the north of it, it began to "recurve" again to the eastward.

There appeared thus to be a time lag of 12 to 24 hours between all three crossings of the zonal discontinuity and the commencement of "recurvature".

3. **SUMMARY**

Reasonably good correlation is shown between the direction of movement of the 8 tropical cyclones of the 1954-55 season and the location of the zonal discontinuity at 200 mb. on the preceding and current day.

The relationship was such that, with the discontinuity located well to the north or south of the cyclone, zonal component of movement occurred, to the westward or eastward respectively. With the discontinuity crossing the cyclone from south to north, or vice versa, cessation of zonal movement was followed by "recurvature".

For use as a forecasting aid it is necessary to forecast the position of the discontinuity from day to day. Largely because of persistence of the boundary and of dependence of its position upon broad scale patterns in the high atmosphere, this may be a reasonable task. Furthermore, a time lag may indeed be established between crossing of the discontinuity and beginning of "recurvature" of the storms.

It should be emphasised that many more tracks of tropical cyclones need to be examined in the light of this proposition.

It is now known that mature storms can extend right through the tropopause. Thus, at this stage in its history, there is no level above the vortex, and probably within some distance of it, where the upper flow remains entirely undisturbed.
In the cases considered, however, rarely was it possible to obtain closed centres on the 200 mb geopotential surface. The only definite occasion of fairly complete "maturity" was that of 31st March.

4. ACKNOWLEDGEMENT

This investigation grew out of a suggestion by Mr. W.J. Gibbs, Superintending Meteorologist (Research), Bureau of Meteorology, Central Office.

References:

Whittingham, H.E.)
Burgner, N.M.)
Riehl, H. 1954 Tropical Meteorology.
Chap. X1, McGraw-Hill.