STUDY OF A TORNADO SITUATION IN SOUTH-WEST AUSTRALIA

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Abstract: Synoptic features leading to the development of the most severe tornado recorded in recent times in southwest Australia are discussed. In accord with previous experience the salient causative factor in the occurrence of non-summer cyclonic-type tornadoes in this region is shown to be the simultaneous advection of warm moist air from the Indian Ocean in the lower levels and cold, dry, southerly air of polar origin at a higher level. The critical relation of these conditions to the vertex of a trailing V-shaped front at the boundary of interaction is emphasized and, in retrospect, it is shown how modification of the previous sounding in the light of the anticipated changes in air masses may lead to a quantitative assessment of tornadic development.

1. INTRODUCTION

A tornado, which must rank as one of the most severe to be recorded in Western Australia, swept through dense jarrah forest near Collie, the State's major coal mining centre, 100 miles south of Perth, between 0400 hr and 0500 hr on 6 April 1960. The damage was described by a senior forestry officer as easily the most extensive he had seen in thirty years of constant surveillance of the State's vast timber preserves. The tornado cut a swathe averaging 12 chains wide along a continuous path of 20 miles.

The aerial photographs, plates 1, 2 and 3, give a graphic illustration of the extent to which the jarrah forest comprising trees up to ninety feet high was thrust aside by the tornado. Forestry officers, who arranged for utilisation of the timber within fourteen days of the storm, estimated that the volume of timber useful for milling would approximate 10,000 loads of mill logs, 3,000 poles, and 18,000 lengths of mine timber, enough to provide a year's work at a local mill.

The co-operation of State Forestry Officers, who supplied a large-scale chart of the swathe compiled from ground and aerial observations and completed a questionnaire on relevant meteorological aspects, has greatly assisted in the compilation of this case history.
Aerial photographs showing the swathe cut by the tornado near Collie on 6th April, 1960. Pictures reproduced from color transparancies taken through perspex window of Cessna aircraft, flying at 100 m.p.h. at altitude 900 ft. and looking South over track. 

Photographer D. Moore

Plate 1. General view of middle section of swathe about 10 miles from origin. Stretch shown here measures approximately three-quarters of a mile in length and 12 chains in width.
Plate 2 Path of the tornado across the road to Mummbalup. A large number of trees in foreground were also blown over.

Plate 3 Section eight miles from origin showing swathe at widest point. Bulldozers were used to clear debris along 400 yards of this road to Preston.
2. FEATURES OF THE TRACK

A plan of the tornado's path was established by a ground check in a number of places, and corrected and substantiated by a check from the air at an altitude of 900 feet using the Forestry Department's recently acquired Cessna aircraft.

The path was oriented on a bearing which varied from 110° to 130° and the swathe varied in width from a minimum of 1 2 chains to 20 chains, averaging 12 chains. Odd trees were uprooted up to a distance of 10 chains on either side of the swathe which was continuous for 20 miles. Evidence of damage extended another five miles. Near its origin the tornado traversed an appreciable water surface and was therefore almost certainly responsible for the production of an inland waterspout. The intensity of damage usually decreased whenever the tornado worked down-hill and increased on the up-hill side. The damage was classified into four categories by the Forestry Department:

(a) Uprooted trees up to four feet in diameter plus some large old stags without crowns.

(b) Trees snapped off five to ten feet from the ground.

(c) Almost complete removal of crowns from standing trees.

(d) Hidden damage, quantity not ascertained, but consisting of severe bending and twisting, causing wood stakes and separation around the growth rings.

A close examination of the standing and fallen trees showed that much of the surface bark was removed leaving residual bark surface a pink colour impregnated with dirt and fine sticks, some of which were embedded into the sapwood. Trees of about eight inch in diameter were most prone to breakage at five to ten feet above ground level. Damage close to the ground was almost negligible. The trees fell generally across the line of motion of the tornado directed towards the centre of the swathe, i.e. to the SSE on the northern side and to the NNE on the southern fringe.

3. SYNOPTIC SITUATION

During the several days prior to the tornado, an intense depression (990 mb) on a polar front moved southeast from latitude 40°S, longitude 100°E on 4 April to latitude 48°S, longitude 114°E on 5 April. This front was preceded eastward by a deepening low pressure trough, associated with a warm moist air mass characterised by dry bulb 67°F,
dew point 65°F and sea temperature 68°F measurements at latitude 30°S. The cold, dry air following the front was characterised by readings of dry bulb 55°F, dew point 45°F and sea temperature 58°F at latitude 41°S and preceded a new anticyclone (1033 mb at Amsterdam Island).

By 0900 hr, 5 April, a circulation had formed at latitude 32°S, longitude 104°E, at the vertex of a trailing (originally cold) front lying V-shaped and embracing the warm air (dry bulb 71°F, dew point 64°F, sea temperature 70°F). Meanwhile cold air (dry bulb 48°F, dew point 39°F, sea temperature 53°F at latitude 42°S) was advancing eastward, preceded by numerous reports of sferic activity south of Western Australia.

At 0000 hr, 6 April, the V-low (998 mb) was located at latitude 33°S, longitude 114°E, and thunderstorms from anvil cumulo-nimbus were reported from Cape Naturaliste. The situation at 0300 hr is shown in Fig.1. This shows the low moving eastward in Geographe Bay, closely followed by the first southern front. Between 0600 hr and 0300 hr, the wind at Cape Naturaliste backed from NNE force 6 to SW force 5 with a temperature and dew point fall of 7°F and 5°F respectively. By 0600 hr the wind at Cape Naturaliste had backed southeast, and a similar change at 0200 hr was reported later from the nearby ship, Port Wyndham. The occurrence of the tornado at Collie was fixed at between 0400 hr and 0500 hr. A second southern front crossed the southwest coast during the afternoon and by next morning the new anticyclone was established over Western Australia. Widespread thunderstorms occurred in the warm humid air as it spread over the southern part of the State ahead of the cold air. The subsequent movement of the small low is difficult to detect but it appears to have very rapidly occluded from the surface.

As the storm occurred at night no evidence of the existence of a pendant cloud was obtainable but thick heavy black cloud was observed passing over Collie at 0300 hr.

4. CAUSATIVE SYNOPTIC FACTORS

The synoptic factors which contribute to the occurrence of tornadoes, with particular reference to the Australian region, have been reviewed by the writer (1960). Briefly, the essential condition needed is the existence of a deep layer of convectively unstable air provided by moisture advection in the lower levels and cold dry air advection at a higher level. When the moist air is lifted by frontal or thermal action or by convergence it becomes easily saturated and unstable, and provides an almost spontaneous release of energy leading to the rapid development of cumulo-nimbus clouds, one or more of which may be associated with a vortex in contact with the ground. Tornadoes
Fig. 1  M.S.L. chart for 0300 hours on 6th April 1960 and isohyets for 24 hours ending 9 a.m. 6th April 1960 (Inset shows path of tornado near Collie about 0500 hours 6th April 1960).
may be classified into two types, cyclonic and convective. Cyclonic types such as the one under discussion, occur in troughs associated with intense depressions and usually in winter. Convective types occur in less intense pressure distributions, when the lifting mechanism may owe much to thermal action and the accumulation of moisture near the ground may be due to a more localised contribution. In the article referred to above it is pointed out that the advent of polar air across Australia following warm humid spells should be watched as a potential generator of tornadoes, that such outbreaks can provide both the lifting mechanism and the over-riding cold dry air, and that the identification of the warm sector at the base of a trailing cold front lying V-shaped in a deepening trough is of importance.

All these conditions were fulfilled in the formation of the tornado at Collie, the contrast between the warm moist air and the cold dry air being most noticeable.

Changes in Stability

In retrospect, it is important to examine what changes in atmospheric stability are likely to occur through the modification of the most recent regional radiosonde sounding as a consequence of the synoptic changes which are anticipated.

Fig. 2 shows three soundings. The ascent of 0700 hr 5 April at Perth indicates convective instability already existing above 800 mb (convective instability exists through a layer when the wet bulb lapse rate exceeds the S.A.L.R.) and a Showalter Stability Index value of +2. This information constitutes an alert for possible thunderstorm development. Synoptic developments during the afternoon of 5 April clearly indicated the imminent advection of warm moist air in the lower levels. Let it therefore be assumed that the air near the ground over parts of the southwest would become nearly saturated to a depth of at least 850 mb and that in so doing the temperature at that level would have cooled no lower than 11°C, the normal temperature for 850 mb in April. Again, estimations of the 700 mb and 500 mb temperatures, characteristic of the approaching polar air and modified for the latitudinal region 30°S to 35°S, are easily obtained. Assuming a lapse rate mid-way between the D.A.L.R. and the S.A.L.R. from the surface to 700 mb and the S.A.L.R. above 700 mb, temperatures of -3°C and -20°C are arrived at for the 700 mb and 500 mb surfaces respectively. This degree of cooling, although marked, is about what one might reasonably expect near Perth in a polar stream and constitutes a departure from normal of rather less than twice the standard deviation quoted in Bulletin No.42 (1953). The moisture distribution, agreed as near saturation below 850 mb, is already quite dry above the level, but may be assumed
Fig. 2 Soundings at Perth Airport at 0700 hours on 5th April 1960 and 6th April 1960 and forecast sounding of maximum instability in South-West for 5th-6th April 1960.
to remain the same or become a little drier than previously. The heavy lines indicated in Fig. 2 are therefore a representation of the maximum degree of instability one might reasonably expect to occur somewhere over the south-west in the approaching 12-24 hr period. This structure gives a Showalter value of $-7^\circ$C, which is strongly indicative of tornadic development.

**Lifting Mechanism**

It is apparent that this optimum condition will only be approached in a certain favoured location where cold air is advecting over a slower moving relatively warm shallow layer whose high moisture content is being conserved. In a dynamic winter-time situation where all the systems are in motion and where the low level moisture is being advected rather than collected locally as may occur in summer, this condition will only be realised close to where a cold front is rotating about a wave centre and when cold air is over-riding the air in the limited warm sector. It is clear also that when a cold front overtakes a small low comprising warm air at the base of a trough, the vorticity-produced convergence and the cold front combine to achieve a most effective lifting mechanism. This enables a very rapid conversion of the convectively unstable moist layer to a state of complete saturation and absolute instability of an explosive nature.

Included in Fig. 2 is the sounding at Perth for 0700 hr 6 April. It is obvious that at this time the city was still in the moist warm sector. It will be noted the Showalter Index value has decreased to about 0°C and that considerable convective instability exists above 650 mb. This sounding is clearly indicative of thunderstorm activity which had in fact commenced at 0600 hr. However, it is probable that the considerable depth of the stable very moist air had discouraged tornadic development as far north as Perth and that the lifting required to fully convert the moist air to a state of explosive instability increases with distance from the V-vertex.

From this and other cases it appears that the most probable area for tornado occurrence in the southwest is within the warm air region bounded by lines about 20 and 60 miles from the expected line of movement of the tip of the trailing front at the southern extremity of the trough.

**Effect of Wind Shear**

A condition usually postulated as essential to tornadic development is the existence of a narrow wind maximum exceeding 35 knots at about the 600 mb level and headed obliquely to the moist tongue.
The strong vertical and lateral shear above the moist layer serves to maintain a moisture discontinuity in the vertical and is probably a factor more critical in the formation of convective type tornadoes. In this tornado at Collie the upper winds showed a strong northwest flow at all levels in the development period. The rawin flight at 0200 hr 6 April at Perth indicated moderate vertical shear to 12,000 ft, where the wind velocity was 300/78 kt, but no shear above. At 0700 hr moderate vertical shear existed to 14,000 ft, where the velocity of 330/90 kt was a maximum below 25,000 ft, and a slight negative shear existed above 14,000 ft. In view of the course of the tornado of about 110°, the likely vortex steering level was 3,000 to 5,000 ft where the wind was more westerly than further aloft.

5. RAINFALL DISTRIBUTION

The rainfall followed the usual tornadic pattern, being heaviest in the area roughly parallel to and immediately to the right of the path of the tornado. The isohyets for this storm are shown in Fig. 1. The highest official registration of 211 points was recorded at Greenbushes, 30 miles south of the tornado path. The 188 points at Bunbury represented the highest 24 hr total recorded at the seaport.

6. A NOTE ON THE SHOWALTER INDEX

The lower limit of the Showalter Stability Index broadly accepted as indicative of tornadic development is -6°C. Petterssen (1956) points out certain restrictions in the use of the Index and Showalter (1953) advocates the use of the Tornado Index in conjunction with the Stability Index. The Tornado Index is mainly applicable to convective type tornadoes and American experience has indicated a high probability of occurrence when both indices reach -4°C or less.

It is probable, however, that the significance of a fixed index value changes seasonally. In Perth, for instance, if it is assumed that the temperature of the moist layer at 850 mb remains about normal, and that the influence of the polar air causes the 500 mb temperature to cool by an amount not greater than twice the standard deviation from normal at that surface, conservative upper values for the Showalter Stability Index may be obtained for various months. These are shown in Table I.

This table shows that the potential instability of the 850-500 mb thickness, indicated by the limiting values of the Index, is considerably greater in summer than winter. However, experience teaches that tornadoes occur at all times of the year and therefore it is misleading.
to expect that a constant criterion, of say \(-6^\circ C\), should be taken as indicative of tornadic development. Even if it is agreed that during the colder months development takes place when the temperature of the saturated air at 850 mb is above normal, the likely maximum value of the index remains below those for the warmer months. So that a forecast index of about \(0^\circ\) to \(2^\circ C\) in conjunction with a deep convectively unstable layer must constitute a tornado alert in cooler months.

Table I. Derivation of a probable maximum Showalter Stability Index (in degrees centigrade)

<table>
<thead>
<tr>
<th>Month</th>
<th>Normal Temp. at 500 mb for</th>
<th>Normal Temp. at 850 mb from 500 mb</th>
<th>500 mb Temp. Approx. (2^\circ) below normal</th>
<th>Showalter Stability Index (Column 4 - Column 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>18</td>
<td>-3</td>
<td>-10</td>
<td>-16</td>
</tr>
<tr>
<td>April</td>
<td>11</td>
<td>-13</td>
<td>-14</td>
<td>-20</td>
</tr>
<tr>
<td>July</td>
<td>5</td>
<td>-22</td>
<td>-18</td>
<td>-24</td>
</tr>
<tr>
<td>October</td>
<td>8</td>
<td>-17</td>
<td>-16</td>
<td>-22</td>
</tr>
</tbody>
</table>

7. SUMMARY AND CONCLUSIONS

Recognition of the following principal points noted in this study should assist in the forecasting of tornadoes, particularly in southwest Australia.

(a) Each polar outbreak is a potential generator of tornadoes.

(b) Simultaneous advection of warm moist air near the surface and cold over-riding air of polar origin into a region constitutes the condition of maximum instability associated with tornadic development.

(c) The trailing front which lies \(V\)-shaped in a trough assists greatly in defining the boundaries of the warm moist air, whether this air is advected from the Indian Ocean in the case of cyclonic-type tornadoes or accumulated locally in the case of convective-type tornadoes. The importance of preserving the continuity of this front in analysis is stressed.
(d) The most likely region of occurrence is in the warm air sector about 20 to 60 miles from the vertex of the V-front and parallel to the direction of movement of the vertex. In this area the limited depth of the moist layer permits rapid saturation and conversion to absolute instability under the combined lifting influence of surface convergence and penetration of the first burst of cold southerly air. Past experience indicates that the region within 100 miles of the coast between Perth and Cape Naturaliste is a favoured area for the occurrence of tornadoes.

(e) The drawing of a forecast sounding indicative of the probable maximum instability during the period of anticipated air mass changes, and the assessment of the limiting values of the Showalter Stability and Tornado Indices, is desirable.

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REFERENCES

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