SYNOPTIC ANALYSIS AND RAINFALL
ESTIMATION IN A NON-FRONTAL STORM

by

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Summary

On October 27, 1952, a depression crossed the
Australian Great Dividing Range giving probably
more than 5 inches of rain per 24 hours in the
Tooma Valley on the north-western side of the Snowy
Mountains. Synoptic analysis shows that the cyclone
developed within a horizontally quasi-homogeneous
moist air mass. The surface development coincided
with the arrival of a low pressure trough in the
upper troposphere. Geographic effects upon the
rainfall pattern are discussed. In the appendix,
a method is developed of estimating maximum poss-
ible rainfall intensities in storms of this type.

SYNOPTIC ANALYSIS.

From the 23rd to the 26th October, 1952, the whole of
South Eastern Australia was covered by a layer of moist air
which had drifted in from the Tasman Sea. The depth of this
easterly drift was about 5,000 feet. At that height there was
no marked gradient and the 850 mb. surface was almost horiz-
ontal. Higher up, at 700 mbs and above, the flow over the
whole continent was from the west, building up to considerable
speeds at 300 mbs. The soundings from Laverton and Rathmines
for the 25th October (see Fig. 4a), as well as extensive layers
of altostratus and other upper clouds indicate that these upper
westerlies were also comparatively moist.

Fig. 1 shows the surface situation at 3 p.m. on 26th
October. Pressure distribution over the continent is rather
flat with numerous small lows, one of which in the Riverina
was to develop later into the cyclone which is the subject of
this study. It is also of some interest to note the tropical
low north of Willis Island. It deepened later, simultaneously
with its southern counterpart.

Fig. 2 shows the pressure distribution eighteen hours
later at 9 a.m. on 27th October. By then the situation had changed rather dramatically. Cyclonic vorticity has become concentrated in two very active circular depressions. There is still no sign of any frontal discontinuity.

Fig. 3 represents the 500 and 300 mb surfaces at 2 p.m. on 25th, 26th and 27th October. The broad westerly flow on both these surfaces is well in evidence. The significant feature is the comparatively flat trough which is seen on the 25th over Western Australia. Deepening of the Southern and Northern surface depressions occurred simultaneously with the approach of this upper trough over the area. By the afternoon of 27th, after the surface deepening had occurred, closed depressions had become established at both 500 and 300 mbs.

There were no upper air soundings within the actual area of the southern development. Rathmines is to the north and Laverton to the south. Both show (Fig. 4a) on the 25th October, very moist air masses with an approximately saturated adiabatic lapse rate. Laverton, which is about 5 degrees nearer to the pole, is slightly colder, but is obviously in the same air mass. There is no appreciable change on the 26th. On the 27th (Fig. 4b) there is some evidence of subsidence at Rathmines, which is well to the north of the development. Laverton, to the south-west of the centre, has also warmed up. This is due to the arrival of air which has come south around the cyclone.

The successive positions of the southern cyclonic centre are plotted in Fig. 5, which also shows the approximate topography of the region (2,000 and 3,000 foot contours). The dotted line AA gives the direction of the cross-section represented in fig. 6 which will be discussed below. The positions of the centre at 9 a.m. and 9 p.m. E.S.T. are numbered and the pressure is given in the following table:

<table>
<thead>
<tr>
<th>Position</th>
<th>Time</th>
<th>Central Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9 p.m. 24th October</td>
<td>1016 mb.</td>
</tr>
<tr>
<td>2</td>
<td>9 a.m. 25th</td>
<td>1013 mb.</td>
</tr>
<tr>
<td>3</td>
<td>9 p.m. 25th</td>
<td>1013 mb.</td>
</tr>
<tr>
<td>4</td>
<td>9 a.m. 26th</td>
<td>1010 mb.</td>
</tr>
<tr>
<td>5</td>
<td>9 p.m. 26th</td>
<td>1004 mb.</td>
</tr>
<tr>
<td>6</td>
<td>9 a.m. 27th</td>
<td>994 mb.</td>
</tr>
<tr>
<td>7</td>
<td>9 p.m. 27th</td>
<td>995 mb.</td>
</tr>
<tr>
<td>8</td>
<td>9 a.m. 28th</td>
<td>996 mb.</td>
</tr>
<tr>
<td>9</td>
<td>9 p.m. 28th</td>
<td>1000 mb.</td>
</tr>
<tr>
<td>10</td>
<td>9 a.m. 29the</td>
<td>1001 mb.</td>
</tr>
</tbody>
</table>
As deepening took place, the southern cyclone, which had been almost stationary until then, began to move away rapidly towards the south south east. This is in contrast to the behavior of frontal wave depressions which tend to slow down while deepening.

Attempts to work out trajectories of the air at various levels from chart to chart are necessarily unreliable because of vertical movements, condensation and the general scantiness of upper air data. As far as can be judged, the surface air that was on the morning of the 28th close to the cyclone centre came from the East, from the Tasman Sea, with a path via eastern and southern Victoria. At the 500 mb level the air came from the west. It probably was over the ocean south of Western Australia some 48 hours earlier. At 300 mb, air arriving over the area of development came from the Indian Ocean, entering the continent about the latitude of Geraldton.

RAINFALL.

It is not possible to produce an orthodox precipitation analysis with depth duration curves because of the comparatively rapid passing of the storm. The main rainfall period was shorter than the 24-hour interval at which rainfall is read, and the single recording rain gauge then in operation within the storm area was at Tumut Pond, in a deep mountain valley where rain is much affected by the topography.

Indirect evidence suggests that the most intense rainfall occurred in the northern sector of the moving storm, where it was accompanied by westerly and south-westerly winds. This was definitely the case at Tumut Pond. The most intense falls there, amounting to 34 points, were recorded during 30 minutes from 23.20 hours to 23.49 hours on the 27th. In the six hours between 22.00 and 03.59 the Tumut Pond rain gauge recorded 231 points, or more than half of the total storm rainfall at Tumut Pond. At that time the centre of the storm was well to the south east, and the gradient wind was definitely south west. Further evidence for the concentration of rainfall in the northern sector of the moving cyclone is produced by the fact that stations sheltered from the south-west, such as Corryong in the lee of the Victorian mountains, or Cooma, experienced only a little rain.

Fig. 6 shows actual rainfall figures for the 24 hours up to 9 a.m. on the 28th, along a line from Griffith in the Riverina plains across the mountains to Nimmitabel. The direction of this line is shown in fig. 5. It is to the north of the path of the centre and diverges from it by about 30°. Fig. 6 indicates that out in the plains, the cyclone produced on the average.
about 1" of rain. The amount of rain increased towards the Snowy Mountains. It was 222 points at Batlow, and reached its observed maximum at Tumut Pond, with 457 points. Only 35 points were recorded on the other side of the mountains, in the rain shadow at Cooma.

It is of interest to note that Tumut Pond is only 3,800 feet and that it is protected from the West and South-west by the narrow Toolong range, which is more than 5,000 ft. in height. The high rainfall recorded at Tumut Pond must have been due to a spillover effect. The moist air rose and condensed on the western side, but the freezing level was about 10,000 ft. and the level of rain formation must have been even higher. During its long fall to the ground, the drops were driven by the wind across the range to Tumut Pond and Kiandra. It is possible that the greatest rainfall occurred on the upper western slopes of the Toolong range, though no records are available from there.

A formula for point rainfall intensities is quoted by A. K. Showalter (1945) in the "Handbook of Meteorology", p. 1026.  
\[ \frac{dR}{dt} = 0.143 \rho_c w_c (\gamma_c - \gamma_t) \]

where: \( \frac{dR}{dt} \) = intensity of rainfall over unit area in inches/hour. 
\( \rho_c \) = air density at condensation level, grams/m\(^3\) 
\( w_c \) = vertical velocity at condensation level, m/s. 
\( \gamma_c \) = mixing ratio at condensation level, grams/gram. 
\( \gamma_t \) = mixing ratio at top of updraft, grams/gram.

The particular configuration with the range at right angles to the wind allows us to test this formula in the present instance.

The ground rises by about 4,000 ft. to 4,500 ft. in 18 miles from the plains to the Toolong Range. The gradient wind was about 30 m.p.h. The average vertical velocity of the surface layers was hence of the order of 120 ft. per minute, or 2 ft. per second. Cloud base was probably at a pressure level of about 900 millibars. Assuming \( \gamma_t \approx 0 \), and \( \gamma_c = 9 \) grams per kg, we derive from the formula a rainfall intensity of about 89 points per hour. This is slightly more than peak rainfall intensities observed at Tumut Pond, but it may have well been reached in actual fact on the western side of the Toolong Range.

Application of the same formula would suggest that out on the plains the vertical velocity at condensation level was
probably, on the average over the day, of the order of 1.2 ft.
per second.

**MAXIMUM POSSIBLE RAINFALL AT TUMUT POND.**

Estimation of the highest possible rainfall that can be expected from storms of a particular kind are of considerable interest to weather forecasters and to engineers.

The simplest estimate involves an adjustment based on the maximum content of precipitable water that could be found in the area under consideration. From figures given by J. Walpole (1951) we may expect a maximum surface dew point of about 70°F at the western foot of the Snowy Mountains. This agrees with observed summer sea surface temperatures in the Australian Bight. The depth of precipitable water in a saturated pseudo-adiabatic atmosphere with this dew point is 2.27 inches. During the storm analysed here the air was more or less saturated with an adiabatic lapse rate. But the surface dew point in the Murray plains was only 59°F which corresponds to 1.31 inches of precipitable water. We might here conclude that in the optimum case the rainfall would have been increased by a factor of \( \frac{2.27}{1.31} \approx 1.73 \).

On the basis of this consideration it could be expected that in a storm with the same kinetic pattern, but with a maximum moisture content, the rainfall at Tumut Pond should have been about 8" in 24 hours or 4" in the six hours of maximum precipitation. This conclusion is likely to be an underestimate. With higher moisture content, more heat of condensation becomes available. This will be accompanied by a higher level of kinetic energy, greater vertical velocity and hence more intense rainfall.

Calculations given in the appendix suggest that, as a first estimate in regions where no detailed analysis is practicable, the rainfall for a given type of storm may be assumed to vary as the square of the mixing ratio at condensation level. In the present case, mixing ratio at 900 mbs, was about 9 g/kg and the maximum value that may be expected is 14.5 g/kg. To estimate a maximum rainfall from a storm of this type, observed rainfall intensities are multiplied by \( \frac{14.5}{9} \approx 2.6 \). This gives maximum estimated intensities at Tumut Pond of 6" per six hours, or about 12" in twenty-four hours.
ACKNOWLEDGMENTS

Acknowledgment is made to the Deputy Director Commonwealth Meteorological Branch N.S.W. for the use of charts and maps, and to the Snowy Mountains Hydro-Electric Authority for assistance in preparing the draft.

REFERENCES:


WALPOLE, J. 1951 Generalised Estimate of Maximum Possible Rainfall (Australia) (C.W.B. roneoed paper, Melbourne)

APPENDIX

MAXIMUM RAINFALL IN STORMS OF A PARTICULAR TYPE

The following analysis suggests that the maximum possible rainfall for a given type of storm is roughly proportional to the square of the mixing ratio at condensation level. This conclusion is based on two fundamental assumptions:

(a) Only storms of the same geometrical proportions are considered. The ratio of vertical to horizontal velocity does not vary.

(b) The rate of change of potential and internal energy during the storm, and the work of the pressure forces at the boundary, is comparatively small.

Both assumptions probably exclude frontal perturbations and hence limit the possible usefulness of the analysis to storms in horizontally quasi-homogeneous air masses.

For a given region of the atmosphere, the equation of energy may be written in the form

\[ \frac{dQ}{dt} = \frac{d}{dt} \left[ U + P + I \right] + F + W \]

where A is the mechanical equivalent of heat; \( \frac{dQ}{dt} \) the amount of heat added; U, P and I the kinetic, potential and internal energies, F the effect of friction and W the work of the pressure forces along the boundary.

Assumption (b) reduces this equation to

\[ A \frac{dQ}{dt} \sim \frac{dU}{dt} + F \]
From Assumption (a) follows

\[
\frac{dU}{dt} \sim \frac{1}{2} \alpha \bar{\rho} \frac{dw^2}{dt} = \alpha \bar{\rho} w \frac{dw}{dt}
\]

where \( \bar{\rho} \) is the mean density, and \( \alpha \) is a proportionality factor which depends on the geometrical configuration of the system and which has the dimension of a volume \( \text{cm}^3 \). The vertical velocity \( w \) may be interpreted either as the mean velocity of the ascending air or as the velocity in some particular region - say close to condensation level.

For the frictional factor we obtain from dimensional considerations in the same way

\[
F \sim \bar{\rho} klw^2
\]

The symbol \( \bar{\rho} \) represents here a generalised coefficient of eddy viscosity (dimension \( \text{cm}^2 \text{sec}^{-1} \)) and \( l \) may be chosen as the height of the tropopause or some other length characteristic for the dimension of the storm.

The equation of energy may be written:-

\[
(1) \quad A \frac{dQ}{dt} \sim \alpha \bar{\rho} w \frac{dw}{dt} + \bar{\rho} klw^2
\]

The heat gain \( \frac{dQ}{dt} \) is also connected with the rate of condensation. If it is assumed that a fixed proportion of all condensed water falls as rain we have:-

\[
(2) \quad \frac{dQ}{dt} = -\gamma \frac{dR}{dt}
\]

where \( S \) is the area of ground surface under the air volume under consideration, \( L \) the mean latent heat, and \( \frac{dR}{dt} \) the rate of precipitation \( (\text{g cm}^{-2} \text{sec}^{-1}) \). In view of assumption (a) this may also be written:-

\[
(2') \quad \frac{dQ}{dt} \sim L^2 \frac{dR}{dt}
\]

The last variable may be connected with \( w \) by Showalter's formula:-

\[
(3) \quad \frac{dR}{dt} \sim \rho_0 w (\gamma_c - \gamma_t)
\]

where \( \gamma_0 \) and \( \gamma_t \) are again the humidity mixing ratios at condensation level and on the top of the updraft.
For brevity's sake we set:—

\[ \frac{A L c_0}{c} = j \]

A combination of (1), (2) and (3), division by \( \Theta w \), and rearrangement gives then:

\[ \alpha \frac{dw}{dt} \sim 1^2 j(\gamma_c - \gamma_t) - klw \]

which can be integrated easily:

\[ w \sim \frac{1}{k} (\gamma_c - \gamma_t) + Ce^{- \frac{1kt}{\alpha}} \]

During considerable periods of the storms, conditions will tend to remain quasi-stationary and the last equation reduces then to:

\[ (5') \quad w \sim \frac{1}{k} (\gamma_c - \gamma_t) \]

The omission of the exponential term simply implies that all the liberated heat of condensation is used to overcome the effect of friction. Equation (5') could have been reduced immediately from a basic equation of the form

\[ \frac{AdQ}{dt} = F \]

However, it is thought that the present longer derivation which brings in the exponential term, is more suggestive of the actual physical process.

The result confirms the intuitive view that the velocities in a convectional storm of a given type will tend to be proportional to the amount of condensation as expressed by the difference \( \gamma_c - \gamma_t \) and to the height of the storm. They will be inversely proportional to the coefficient of eddy viscosity.

Introduction of (5') into (3) gives:

\[ \frac{dR}{dt} \sim \frac{1}{tp} \frac{1}{k} (\gamma_c - \gamma_t) \]

As \( \gamma_c \gg \gamma_t \) in the comparatively low latitude of Australia, this may be simplified into:

\[ \frac{dR}{dt} \sim \frac{1}{tp} \frac{1}{k} \gamma_c^2 \]

which is the result set out at the beginning of this analysis. The value of \( l \) is not likely to vary excessively under Australian conditions.

It is clearly necessary not to lose sight of the limitation of this analysis. Any results obtained from it are at best approximate. The method, however, may help to obtain a first and rapid estimate of maximum flood rainfall at areas where little other data are available.
M. S. L. Chart for 1500 hours E.S.T. 26.10.52
Figure 2

M.S.L. Chart for 0000 hours E.S.T. 27.10.52
Figure 3a - Upper Air Charts for 0400 G.M.T. 25.10.52
Figure 3b - Upper Air Charts for 0400 G.M.T. 26.10.52
Figure 3c - Upper Air Charts for 0400 G.M.T. 27.10.52
Figure 4 - Radiosonde for Rathmines and Laverton

0400 GMT 25, 10, 52

0400 GMT 27, 10, 52