A STUDY IN FORECASTING FOG AT ESSENDON AIRPORT

by R. Maine

Central Office, Bureau of Meteorology, Melbourne

(Manuscript received September 1962)

Abstract: Meteorological data mainly available at and before 1800 EST are processed with the aim of producing a prediction system for the occurrence of fog conditions between 1800 EST and 0900 EST through midnight at Essendon Airport. Prediction parameters selected are based on aerological soundings and surface observations, and must be initially screened representativeness before use in the system. In the sample of data chosen the method produced 71 percent successful decisions of the occurrence of fog and 95 percent success for non-occurrence of fog verified from the three-hourly synoptic reports. These percentages are supported by an independent test conducted for data of June and July 1962.

1. INTRODUCTION

Fog is internationally defined as: "a hydrometeor consisting of a visible aggregate of minute water droplets suspended in the atmosphere near the earth's surface... reducing (horizontal) visibility below one kilometer.... When composed of ice crystals it is called 'ice fog'." Similarly 'mist' is defined as: "a hydrometeor consisting of an aggregate of microscopic and more or less hygroscopic water droplets suspended in the atmosphere.... It reduces visibility to a lesser extent than 'fog'."

For the purposes of this study a period of fog was taken to be any period during which fog was actually reported at the station, or during which the base of stratus was less than 300 ft covering more than 4/8 of the sky for two or more consecutive 3-hourly synoptic observations. A fog condition is defined as one in which either fog or mist, as defined immediately above, occurs during the period 1800 EST to 0900 EST.

The main purpose of this study was to develop objective or semi-objective means to forecast the occurrence of fog during the hours 6 p.m. to about 6 a.m. local time, with the use of observational data available at or before 6 p.m. local time. The problem of timing the occurrence of fog is deferred for later study, since it clearly presents a more difficult problem than prediction of occurrence irrespective of time.

2. SYNOPTIC SITUATIONS CONDUCIVE TO FOG

The occurrence of fog at Essendon is mainly nocturnal in character and is most frequent during May, June and July (Loewe 1944). The type of fog usually conforms to the advection radiation group (Petterssen), requiring low level advection of moist air having suitable properties to bring about sufficient radiational heat loss for fog to develop. There are occurrences where fog has formed during the day, but these have usually resulted from stratus developing during a period of continuous rain in advance of a front or trough line. The front or trough subsequently passes Essendon, intensifying the fog if wind gradients and
Fig. 1 (a) Area encircling 1400 - 1500 EST 1000 ft wind vectors preceding fog at Esmondia in June.

Fig. 1 (b) Area encircling 1400 - 1500 EST 1000 ft wind vectors preceding fog at Esmondia in July.
moisture conditions are suitable in the rear. A continuous overcast with rain during the day followed by clearing at night, will usually result in foggy conditions. However, both this type and the previously mentioned type have received only passing consideration in this study, since firstly the majority of fogs affecting Essendon are directly associated with high pressure systems and radiation conditions, and secondly measurements of prediction parameters are most likely to be unrepresentative of the air mass during periods of rain and passage of troughs or fronts.

On the basis of the reported fog frequencies for Essendon this study has been confined to the months which are most affected by fog. Most of the fog conditions have occurred in association with the pressure pattern in which a ridge from an anticyclone lay in or just south of the Great Australian Bight and moved or developed in a southeasterly direction, i.e. the main movement or development area lay south of Essendon. The ridge or high to the south of Essendon could be associated with a low pressure system or trough in the easterlies, located anywhere from Lord Howe Island to central northern New South Wales and southern Queensland. This situation was mainly responsible for the predominance of southeasterly winds prior to fog conditions at Essendon, seen diagrammatically in Fig. 1 (a).

The approach of a simple cell of high pressure over Essendon, or just to the north of it, was largely responsible for the southwest winds which preceded fogs appearing in the southwest quadrant of Fig. 1 (a). In other cases, a well developed high pressure system was located just east and south of Essendon, with a ridge extending northeasterwards to the northern Great Australian Bight. A low or trough in the easterlies was present over southern Queensland or near Lord Howe Island and a deep southern low pressure system located south of the Bight. Usually, either the low south of the Bight moved northeasterwards (cutting off by anticyclogenesis upstream in sympathy with the existing anomalous anticyclonic formation east of Melbourne) or the easterly low or trough intensified, with the result that the existing east or northeast gradients in the ridge over Essendon were weakened and a cell of high pressure became cut off to the west or northwest of Essendon. The later movement and development of the resultant col area determined the regions affected by fog. Depending on the position of the col axes and the timing of the development then, this situation was capable of producing either the light east to northeast winds or southwest winds at 1000 feet prior to fog development.

A few occasions of fog have been observed to result after the movement northeast of a 'cut-off' low from the Bight area over inland Victoria. Such a low would be initially accompanied by rain but after crossing the coast the circulation will decay leaving slack wind gradients. If this situation continues for any length of time, nocturnal radiation conditions usually become sufficient to result in areas of fog, since unusual amounts of moisture would be retained in the atmosphere. Situations of this type would normally therefore be preceded by northeast to east winds.

Fog forecasting aids which have been reported as successful, e.g. George (1960), Craddock and Pritchard (1951), require as an important initial step that they be applied only on occasions when fog is likely in some degree. That is, some subjective judgement is required in the first place as to whether a given weather situation is likely or not to produce fog. It is an additional aim of this paper to attempt to make this decision more objective.

3. DATA SELECTION PROCEDURE

The initial attempt at an objective selection procedure for days of fog likelihood was made on June data of nine years during the period 1950 to 1960. The available 1400 EST or 1500 EST wind speeds and directions at 1,000 feet above Essendon Airport were plotted on a polar diagram irrespective of whether or not fog had occurred during the following night and morning. Following this, all wind vectors at 1500 EST or 1400 EST which were followed by fog during the hours 1800 EST (0800 GMT) to 0900 EST the following morning were noted. A favoured area was immediately apparent and is shown in Figure 1 (a). Only one fog in the whole of the sample was preceded by winds outside this area and this one was associated with continuous precipitation.

The main part of the preferred area was in the southeast wind quadrant. An additional polar diagram could be plotted at this stage, using all surface winds associated with fog or no fog from the area defined in figure 1 (a), and from this could be calculated a condi-
<table>
<thead>
<tr>
<th></th>
<th>June</th>
<th>July</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Obs.</td>
<td>No. of fogs</td>
</tr>
<tr>
<td></td>
<td>253</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>94</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>78</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>64</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>44% fogs</td>
<td></td>
</tr>
</tbody>
</table>
tional probability of a fog occurring should the surface wind vector lie in an area defined by the surface wind. However, since it was intended to treat other parameters besides wind, the data in the preferred area of figure 1 (a) were screened for special weather conditions before proceeding any further. These special weather conditions were those which effectively masked the significance of the 3 p.m. and 6 p.m. surface observations and the radiosonde ascent, and consisted of fog or precipitation at observation time or an air mass change after the time of the radiosonde ascent.

When screening was carried out some of both fog and no fog observations were lost; these numbers are indicated in Table 1 after the test for utility of the observations. The percentage of fogs in the number removed by this screening (June data) was 50 per cent, but since the total number is small this percentage figure would probably be too unstable to be used as an estimate of the likelihood of fog following rain at the afternoon observation. The remaining observations after screening were taken and the 1000 feet wind vector again plotted and a new smaller area (see Fig. 2 (a)) defined. The percentage of fogs in the area was about 37.

The dependence on the surface wind was then taken into account by plotting surface wind vectors corresponding to all the points within the area of Fig. 2 (a), to give the area shown in Fig. 3 (a) as the most likely area associated with fog. The percentage of fogs in this area was now 44 with considerably higher percentages (65) inside the area defined by the dotted central portion of Fig. 3 (a).

Table 1 demonstrates the use of Figs. 1 (a), 2 (a), 3 (a) in the analysis and the implication of these figures towards fog prediction at Essendon for June. The numbers in the left hand column in Table 1 represent the total number of days or observations under consideration at each stage and the corresponding numbers to the right indicate the number of fogs at each stage. This selection procedure was repeated for July and the corresponding wind boundaries are given in Figs. 1 (b), 2 (b) and 3 (b), and relevant numbers in Table 1. When both 1000 ft wind and surface wind lie within the areas bounded by the dashed curves of Figs. 2 and 3, the efficiency of the selection procedure is much greater than the overall percentage quoted in Table 1, and when the points lie between the dashed and solid curves, the efficiency of selection is less than the value quoted. It was noted, however, that the numbers of fogs and no fogs were less in these outer areas.

Figs. 1 and 3 are capable of selecting nights of fog likelihood to a sufficient degree to enable further discrimination to be carried out, using other variables important to the formation of fog. One of their obviously important qualities is that they define air streams which have mainly had a maritime trajectory. It should be noted that the diagrams do not admit all such air streams which come from over the sea, for almost any wind south of east and west at Essendon will have had a maritime trajectory.

To illustrate further the character of fogs at Essendon, a plot of the 0600 EST surface winds on the nights of fog was made for the points which lay within the area defined by the 1000 feet winds as in Fig. 2 (a). The result was as shown in Figs. 4 (a, b) with the higher percentage of occurrence of fog inside the dashed curve. It seems obvious therefore that the vast majority of fogs at Essendon result in air which has been moved in over the coast and north of Essendon during the day and returned during the night. This may result in fog when the heat balance is such that there is a sufficient loss of heat in the low layers.

The results of Figs. 1 (a) and (b) have been combined in Fig. 5 and those of Figs. 3 (a) and (b) in Fig. 6 for ease of reference in conjunction with prediction diagrams presented in Figs. 7 to 9.

4. CORRELATION PROCEDURE

George (1960) has stated that his fog prediction method based on aerological soundings should not be rigidly applied to single station fog forecasting, and he has developed this method to suit an area of considerable size for which measurements taken from the radiosonde sounding are representative. The method of attack in this investigation was similar to that of George and an assumption was made that his method could reasonably be expected to account for a large number of fog occurrences at a particular station near the point of ascent of the radiosonde.
Fig. 2 (a) Area enclosing 1400 - 1500 EST 1,000 ft wind vectors preceding fog at Essendon in June - data screened to remove special weather conditions.

Fig. 2 (b) Area enclosing 1400 - 1500 EST 1,000 ft wind vectors preceding fog at Essendon in July - data screened to remove special weather conditions.
Fig. 3 (a) Area enclosed by 1800 EST surface wind vectors preceding fog occurrences in June as in Fig. 2 (a)
Fig. 4 (a) Area enclosed by 0600 EST surface wind vectors preceding fog occurrences in June as in Fig. 2 (a)

Fig. 4 (b) Area enclosed by 0600 EST surface wind vectors preceding fog occurrences in July as in Fig. 2 (b)
No radiosonde ascent was available for Essendon Airport, but the ascent made at Laverton (11 n.m.i. southwest of Essendon) was taken to be a representative measurement of air mass properties affecting Essendon. Due to a change in the radiosonde release time after 1955, a sub-sample of radiosonde flights prior to 1956 was chosen during which the release time was about 2 p.m. This time was well suited for the development of aids based on radiosonde parameters. Instead of adhering strictly to George’s method, certain changes were made, viz. instead of parameters being measured over the lowest 50 mb they were measured from surface to 950 mb and instead of using the so-called stability parameter the surface dewpoint has been used. This last does not bear any apparent resemblance to the stability parameter. However, the four parameters chosen here do represent fairly completely the state of the atmosphere as depicted by the Skew T-log F aerological diagram.

The parameters were:

(a) Surface to 950 mb temperature difference,
(b) Surface to 950 mb dewpoint difference,
(c) Mean separation of dry bulb and dewpoint over the layer 950 mb to surface,
(d) Surface dewpoint obtained by extrapolation of line joining the 950 mb dewpoint and the mean dewpoint of the layer surface to 950 mb, plotted at the mid-pressure of the layer, (or, as used in a later section, the mean of the adjusted dewpoints for 3 p.m. and 6 p.m.).

To test the usefulness of these parameters a sub-sample of June data was treated, consisting of all available days prior to 1956 where the 1000 ft and surface winds were within the areas of Figs. 1 (a) and 3 (a) respectively. The parameter (a) was plotted against (b) and the points representing fog occurrence specifically marked. The basic line which best separated fogs from no-fog conditions was then fitted according to the observations, using also the knowledge that stable lapse rates of temperature are more conducive to fog.

This line was usually a straight line. A family of lines was then drawn in this (a), (b) diagram (they were in fact lines of constant (a) - (b)) and each line given arbitrarily chosen weights $A = 0, 1, 2$ etc. according to the relative likelihood of fog. Each point was therefore associated with a weight $A$ which was used in subsequent correlation.

A similar procedure was carried out with parameters (c) and (d) and weighting factors $B = 0, 1, 2, 3$ etc. assigned to the lines. A diagram was made by plotting the values $A$ against $B$ for each point for the June sample with the following result:

63 percent of fogs in the area designated "fog".
80 percent of no-fogs in the area designated "no-fog".

These percentages refer to the number of cases of June data lying within the limits of Figs. 1 (a) and 3 (a).

A further factor in fog formation (George 1960) was considered, viz. the turbulent transfer of heat from upper to lower levels during the night; this tends to dissipate the fog. Such an increase in turbulent heat flux may be brought about naturally by an increase in the surface wind, which may be either related to a strengthening of the land breeze, an increase in the pressure gradient, or both. An attempt was made to consider the effect of increased turbulent transfer objectively by estimating the 0600 EST geostrophic wind speed from the 1800 EST m.s.l. pressure chart and the 3 hourly isallobaric field over South Australia, New South Wales, Tasmania and Victoria. The 3-hourly isallobaric pattern drawn at 0.5 mb intervals was added graphically to the 1800 EST m.s.l. isobaric chart. This estimate of the 0600 EST wind field would in ordinary circumstances be only a first approximation to the morning geostrophic wind, but was considered adequate by itself here in view of the fact that most fog synoptic situations are generally slowly moving and developing. A test was carried out on the synoptic situations for the June days whose 1000 feet wind vector at 1400 EST was in the area of Fig. 2 (a). It was found that estimates of wind speed were correct to within $\pm 5$ kt on about 70 percent of occasions and directions were within $\pm 22^\circ$ on nearly all occasions. In view of
the above performance figures, the actual wind speed was not considered to have effectively changed unless it increased or decreased by more than 5 kt. Thus, instead of using the estimated wind, in the following the actual wind at 0600 EST has been used with the above acceleration limitations.

Effective increases (decreases) in turbulent transfer were considered to occur with wind increases (decreases) in excess of 5 kt. New and equal displacements were given to the points in the A, B diagram such that the points moved towards or away from the fog area for a decrease or increase in wind respectively. These equal displacements were arrived at by a trial and error procedure which ceased when maximum possible separation of fogs from no-fogs was obtained.

If the wind speed remained constant overnight and was less than or equal to 10 kt, then a point corresponding to this condition was given zero increment; if, however, the speed remained constant but was greater than 10 kt, equal A, B displacements were allotted such that their magnitude was between zero and that allotted for an increase in the wind.

These considerations, although crude, nevertheless indicated a significant improvement and the percentage of fogs within the "fog" area in this somewhat small sample now rose to 80 percent and the percentage of no-fogs in the "no-fog" area to 90 percent. This therefore demonstrated that availability of later data could, when considered with data at the initial time, establish a trend in the meteorological process and enable provision of a better empirical forecasting aid than would be possible using data at an initial time only. However, since this additional information itself must be predicted before it is used, the overall effectiveness of the aid at the initial time must suffer.

The change of radiosonde release time from about 1400 EST to 0900 EST after 1955, however, rendered impractical the particular method of predicting fog occurrence developed above. The earlier release time of 0900 EST presented a new problem of how best to utilise relevant data from the sounding, in combination with latest available (and reliable) surface observations. In the calculation of temperature and dewpoint differences, radiosonde readings were used at the upper level (950 mb) and Stevenson screen 1500 EST observations of temperature and dewpoint at the surface. This was done for all data during June, from 1956 to 1960. In order to have data as homogeneous as possible in the pooled sample extending from 1950 to 1960, the same procedure was used for the sample of afternoon radiosonde soundings prior to 1956.

Exactly the same correlation procedure as previously described was than used to obtain an A, B diagram, but consideration of the effect of increasing or decreasing turbulent heat transfer was postponed. The final result gave 53 percent of fogs in the "fog" area (i.e. the 1000 ft wind vector and the surface wind vector are in the appropriate areas) and 93 percent no-fogs in the "no-fog" area. For July a similar result was obtained, viz. 54 percent fogs in the "fog" area and 87 percent no-fogs in the "no-fog" area.

The use of Stevenson screen dewpoints (un aspirated) suggested that an improvement in performance might be achieved if some better estimates of the dewpoint were calculated knowing the ventilation rate in the screen. Consequently it was decided to attempt to adjust the normal screen dewpoint determinations for actual wind flow past the wet bulb. This did not result in any appreciable improvement, no doubt due to the inability to estimate wind speed in the screen from observations from the Dines anemometer and the effect of other factors such as radiation. For these reasons this approach is probably not worth pursuing, but the introduction of more sophisticated methods of measurement of dewpoint would be most profitable.

In a further attempt to improve results, the dewpoint measurements at 1500 EST and 1800 EST were averaged in order to reduce the effects of spatial and temporal variations (see Stewart 1955).

The previous June and July data were revised and the correlation procedure was repeated using the same form of weighting factors A and B as in the previous calculations. The results improved slightly to give for identical final areas in the A, B diagram:
Fig. 6 Area enclosing 1800 EST surface wind vectors at Essendon during June and July [Figs 3(a) and 3(b) combined].

Fig. 5 Area enclosing 1500 EST 100 ft wind vectors at Essendon during June and July [Figs 1(a) and 1(b) combined].
June - 65 percent fogs in the "fog" area counting mists as no-fog,
90 percent no-fogs in "no-fog" area,

July - 55 percent fogs in the "fog" area counting mists as no-fog,
93 percent no-fogs in the "no-fog" area.

The separate samples for June and July were now combined. The family of
weighting lines used for the (a), (b) diagram were sloped at +45° (the weights became therefore simple differences (a) - (b)) and this factor was calculated without the aid of a diagram. In the case of the (c), (d) diagram, the family of lines was chosen to suit the observations more reasonably and is given in Fig. 7. Since the lines are weighted arbitrarily a further diagram, Fig. 8, is needed to convert the components A and B into a categorical "yes" or "no" forecast.

Regarding now mist as a fog condition (see 'Discussion' below), of which there were about three pure cases in the sample of 45 "fogs", the final diagram, Fig. 8, produced:

71 percent of fogs in the "fog" area, and
96 percent of no-fogs in the "no-fog" area.

It is emphasised that these percentages refer to the number of cases lying within the limits defined by Figs. 5 and 6.

5. DISCUSSION

(a) "Mist"

It should be noted that all percentages, except those immediately above, which have been calculated so far exclude mist, which is a degree of fog condition, and any forecasting aid which is supposed to forecast fog efficiently should also be capable of at least a reasonable discrimination of mist conditions. In this study it was impossible for the system to clearly distinguish mist from fog conditions, of indeed thick fog from fog patches. Points corresponding to no-fog conditions were scattered fairly evenly over most of the A, B diagram, and it appeared that, although the conditions for fog had been approximately defined, there was still interplay of other factors which on any one night, given suitable temperature and moisture parameters, could swing the balance towards or away from the generation of fog. The most obvious factors which were capable of doing this were changes in cloud coverage and wind accelerations. The latter effect has been discussed in Section 4.

(b) Effect of Cloud

The effect of cloud, because of extensive re-radiation from its under surface, results in a reduced rate of cooling at the ground, thus giving a similar net effect to increased turbulent heat flux downward from accelerating winds. However, although it is believed the effect of these factors can be clearly demonstrated, only limited objective assistance can be gained by attempting to incorporate these factors into an aid to forecasting fog.

It is interesting to note that nearly all of the observations of "no-fog" conditions falling in the "fog" area of Fig. 8 were heavily overcast nights, during which the minimum temperature did not fall below about 41°F and also not below the fog point. These observations clearly point out the main defect of the method of forecasting fog thus far. It is also of interest to note that a large proportion of the points falling in the "no fog" area were associated with dew and frost.

The various diagrams have demonstrated the conditions which are necessary for the formation of fog, but are not entirely sufficient. When a thick layer of cloud is present throughout the night in an air mass which may in its surface layers have a high fog potential, there is sufficient back radiation from the upper cloud layer to retard the fall of temperature at the surface to such a degree that the fog point is not reached. Since there is no completely reliable method of forecasting whether cloud existing in the afternoon will clear before mid-
Fig. 7 Family of curves obtained by plotting parameters (c) and (d) with weighting factors.
night, little can be done to rectify the errors in fog prediction which will result from this source.

Forecast of minimum temperature and of fog point may reasonably be attempted (Craddock and Pritchard 1951). This approach makes a method of forecasting minimum temperature a mandatory one and although the procedure is entirely logical it cannot be always used in practice. The method has been attempted for Essendon but little success was achieved (Maine 1962). However, since some success has been attained in forecasting fog with the value of the factor B, it is likely that B itself will be significantly correlated with the drop in temperature on fog-free nights. (This has not been tested).

(c) Type of Fog Condition and Timing

A decision will be required as to whether the forecast should be issued in terms of fog, mist or low stratus. There were too few occasions of mist reported to define what criteria were necessary for its development; however, mist did appear to be associated with near zero values of A. It is argued that if the fog condition is met, then the over-riding heat transfer process, which determines whether fog or stratus forms, is the turbulent heat flux due to the wind. What is required is a representative wind for the night, i.e. a constant wind which would produce a heat transfer equivalent to the actual wind effects. This is a very difficult parameter to estimate from initial conditions but was attempted (see Section 4) by estimation of the 0600 EST geostrophic wind. The effects of the 1400 EST 3,000 ft wind speed and the 0300 EST 3,000 ft wind speed have been correlated and some direction effects included. Figures 9 (a) and (b) represent the pattern of the 44 observations of fog treated for June and July. Figure 9 (b) would therefore be of most use in deciding what type of fog condition to forecast.

It has been suggested by Orr (1957) that the so called katabatic wind has a marked influence on the production of fog and some attempt has been made to investigate this. Pearce (1962), following some numerical solutions of the differential equations of motion for the sea breeze, has applied dimensional analysis to calculate an approximate solution to the time of onset, depth of penetration inland, etc., and suggests that his results which have been well confirmed by observations may be applied to the opposite thermal circulation, viz. the land breeze. It was assumed that the katabatic, as mentioned by Orr, is primarily a land breeze circulation, although it must receive some contribution from katabatic sources, under certain synoptic situations, from the ranges which are some ten miles distant from the airfield.

An approximate time of onset was deduced from equations listed by Pearce, using the cooling rate between 1800 EST and 2100 EST, together with Pearce's constants and the actual on-shore 1000 ft wind components at 1500 EST. Although the calculated estimates of land breeze commencement times were very approximate, a surprising number of cases with a moderate southerly on-shore component were associated with a theoretical time of commencement of the land breeze in excess of eleven hours from sunset and in fact 6 a.m. surface winds were still southerly on these occasions.

The earliest time of onset of the land breeze at the station was taken to be calculated from:-

\[ H_t = k U^2 \]

where \( H_t \) is the loss of heat up to onset time, \( U \) the onshore component and \( k \) a constant. The value of \( H_t \) itself was assumed to be given by

\[ H_t = (k T^2)t \]

where \( t \) is the time interval from commencement of cooling and \( T \) the temperature drop from 1800 EST to, say, 2100 EST. It was noted that when the calculation was performed for nights on which fog developed, long period fogs (duration in excess of 5 hours) were mainly observed with times of commencement of the land breeze before midnight and shorter period fogs (duration less than 5 hours) with times of commencement after midnight. There were, however, considerable deviations from this general observation.
Fig. 9 (a) Relationship of 1500 EST and 0300 EST 3,000 ft wind with character of fog at Essendon.

Fig. 9 (b) Relationship of 1500 EST and 0300 EST 3,000 ft wind in categories with character of fog at Essendon.
In the fog forecasting aid discussed in this paper it is apparent that the fog dissipating effect of the land breeze has been considered in the 1000 ft wind and surface wind diagrams. In like manner the amount of cooling is expected to be dependent to some extent upon the factors implicit in B (Fig. 7). However, a most important factor in cooling, namely the cloud effect, is not explicitly treated in the aid and it has already been shown that the method breaks down with a heavy overcast condition.

A preliminary investigation was made into timing the commencement of fog conditions using the parameters involved in fog occurrence. Little success was obtainable by methods of timing involving dewpoint spread and cloud cover, and it did not seem that any immediately obvious relationship was obtainable. Special concentration on the landbreeze effect, however, may reveal a practical source of timing in view of the results above.

(d) Independent Test of the System

A small scale test of the method was attempted for all days of the months June and July, 1962.

Application of Figs. 5 through to 8, as required for all days of June, gave an expected fog condition for Essendon from the data of 11th and 26th June and no expectation on all other days. There were showers at Essendon about 1500 EST 11th June, and showers in the area between 1500 and 1800 EST. The day should therefore have been excluded from consideration; but instead the 1800 EST temperatures alone were used in the diagrams, rather than the mean of the 1500 EST and 1800 EST measurements, and the data of this day was then processed as usual. No showers affected conditions on 26th June, and both the above days had data giving a fog condition from the diagrams.

Application of the observed 1500 EST 3,000 ft wind and the 0300 EST 3,000 ft wind (which in actual circumstances would be estimated) resulted in a decision to forecast fog patches for Essendon on the mornings of 12th and 27th June.

The observations at Essendon airport, which is manned continuously, did not in fact reveal fog on any occasion during June. However, the Victorian Divisional Office observations were also consulted, and the only days during the month on which a fog condition was reported were the mornings of 12th and 27th June. These consisted of mist and fog patches in the distance during the period 0600-0900 EST on 12th June and continuous mist reported from 0001-0600 EST on 27th June.

Observations were not made at Laverton at 0300 EST or 2400 EST and only occasionally at 2100 EST, and although no fog condition was recorded during June, absence of fog cannot be ascertained with certainty.

The following are the results of the independent tests on July 1962, using the system.

The 1000 ft wind diagram (Fig. 5) selected the 2nd, 6th, 8th, 9th, 10th, 11th, 12th, 13th and 15th of July as days preceding nights of possible fog. The second wind diagram (1800 hr surface wind) rejected the data of the 2nd.

Applying the aerological data to the remaining diagrams, a fog condition based on the data of the 6th, 8th, 9th, 10th, 11th and 13th was indicated.

Fog conditions actually occurred at Essendon on the mornings of the 9th, 10th, 11th, and at either Melbourne or Essendon on the mornings of 9th to 12th.

In further detail, the data of the 6th gave a forecast of thick fog using the diagrams. No fog was reported at either Essendon or Melbourne on the 7th. On an inspection of the m.s.l. synoptic charts for the night of the 6th and morning of the 7th, it was seen that a high pressure cell with axis oriented east/west moved directly over the State. This had the effect of bringing light westerly winds and a cloudy to overcast sky of strato-cumulus throughout the night. The minimum temperature reported at Essendon was 42°F. The nearest fog reported was at Echuca and Sale. This error illustrates the importance of forecasting changes in or to overcast cloud conditions.
The data of the 8th gave a forecast of patches of fog and/or stratus. An anticyclone was located on the 1800 EST m. s. l. chart south of Tasmania and the wind circulation over the State was mainly southeast to east. On the morning of the 9th fog was widespread over Victoria, with Essendon reporting fog and stratus from midnight to about 11 a.m. Melbourne reported mist, fog patches, and stratus during the same period.

The data of the 9th gave a forecast of fog patches and/or stratus again. At 6 p.m. on the 9th a high pressure centre was located southeast of Tasmania but a low pressure centre was developing northwest of Lord Howe Island. The winds were mainly easterly over Victoria and morning fogs were reported from the southeastern parts. In the northern parts gradient winds were too strong and prevented fog formation. At Essendon mist was reported at 2100 hr, developing into fog patches by early morning and clearing about 10 a.m. on the 10th. Melbourne reported fog.

The data of the 10th resulted in a forecast of thick fog. The high pressure system was still located southeast of Tasmania, showing little movement. The low near Lord Howe Island was moving slowly southeastward and intensifying, causing gradient winds to freshen along the eastern Australian coastlines. Coastal fogs and mists occurred next morning mainly in western Victoria. Fog patches were reported at 9 a.m. at Essendon on the 11th, while Melbourne also reported fog patches. It was readily apparent that the 3 a.m. 3,000 ft wind at Essendon on the morning of the 11th, 120° 2 kt, did not match the geostrophic speed estimated from the isobar spacing, indicating a fresh easterly wind. This light reported wind was the cause of the thick fog hind-cast.

The data of the 11th gave a result of fog patches and/or stratus. No fog was reported from Essendon but mist occurred at Melbourne from midnight to just before midday of the 12th. In this case the low in the northern Tasman Sea moved further eastward causing winds to slacken and gave morning coastal fogs in eastern and western Victoria.

The data of the 12th gave a negative fog forecast and again no fog was reported from Essendon but mist was reported from Melbourne. The evening m. s. l. charts showed a mature low pressure system in the east central Tasman Sea and a weak ridge of high pressure over Victoria. Scattered morning mists and fog patches occurred over Victoria.

The data of the 13th was associated with a point in Fig. 8 which was just inside the lower boundary of the fog area. The 3 a.m. 3,000 ft wind was not reported, but an estimate would have resulted in a forecast of mist and/or stratus. No fog was reported at either Essendon or Melbourne. Scattered coastal mists and fogs occurred over Victoria during the morning of the 14th. Gradient winds veered westerly and freshened in advance of a trough of low pressure which passed Melbourne at about 3 p.m. on the 14th.

6. CONCLUSIONS

The diagrams, Figs. 5, 6, 7, 8 and 9, constitute the aid to forecasting the occurrence of fog at Essendon.

It is obvious from Table 1 that on more than half the occasions it will not be necessary to advance past Fig. 5, and indeed the limits of this figure are so simple they may easily be memorised.

Set out below is the detailed sequence of steps which are necessary for the forecasting of fog at 1800 EST for the period 1800 EST to 0600 EST.

1. Check if 1500 EST 1000 ft wind is in the fog-likely area of Fig. 5 for the given month - if not forecast no fog.

2. Check if 1800 EST surface wind is in the area of Fig. 6 - if not forecast no fog.

3. Check if rain has occurred at 1500 EST or 1800 EST, or if a front has passed the station since radiosonde release time or will pass before 0600 EST - if not proceed to Step 4. If so, there is about a 50 percent chance of fog next morning. The decision to forecast a fog must be aided by normal subjective techniques.
4. (a) Subtract the 0900 EST 950 mb dewpoint from the 950 mb temperature;
(b) subtract the mean of 1500 EST and 1800 EST screen dewpoints from the 1800 EST screen temperature;
(c) average (a) and (b);
(d) plot (c) against mean 1500/1800 EST dewpoint in Fig. 7 to obtain factor B.

5. (a) Subtract the 0900 EST 950 mb temperature from the 1800 EST screen temperature (°C);
(b) subtract the 0900 EST 950 mb dewpoint from the mean of 1500 EST and 1800 EST screen dewpoints;
(c) obtain the difference (A) between (a) and (b);
(d) plot A against B in Fig. 8. If the resultant point with co-ordinates (A, B) is in the lower area, forecast no fog. If not proceed to Step 6.

6. Calculate the 0600 EST gradient wind by graphical addition of 3-hourly isallobars (1500-1800 EST) to the 1800 EST m. s. l. chart (or by any other method of extrapolation of the pressure field). Consider this as representative of the 0300 EST 3,000 ft wind and apply to Fig. 9 to determine the type of forecast.

The above procedure is expected to result in a correct forecast of the predominant type of fog condition to be met during the period 1800 EST to 0900 EST in near 70 percent of issues of a fog forecast, in the long run.

The following points should be noted:

(a) If overcast low or middle cloud is expected to persist throughout the night, no fog should be forecast, even if positively indicated through to Fig. 8.

(b) Failures may be due to the use of incorrect or unrepresentative data, e.g. the occurrence of rain at or just prior to observation times, which will affect dewpoints and temperatures.

(c) The results described are based on aerological data mainly taken at 0900 EST. Availability of a later sounding should lead to significant improvement.

ACKNOWLEDGEMENTS

The author wishes to express appreciation for some useful suggestions contributed by Mr. J. N. McRae, also to Mr. D. P. Orr for preliminary discussions and for providing a copy of his unpublished paper on fog forecasting at Essendon. In particular, acknowledgment is due to Mr. T. Wigley for the analysis of much of the data, and to Messrs. G. Chan, R. Weinert, K. Melcherts and others for the extraction and preparation of data from station records.
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Reference</th>
</tr>
</thead>
</table>