PREDICTING THE LIKELIHOOD OF FOG AT MELBOURNE AIRPORT

Harvey Stern* and Kevin Parkyn
Victorian Regional Office, Bureau of Meteorology, Australia

1. INTRODUCTION

The main technique that is currently used in fog forecasting for Melbourne Airport is one developed by Goodhead (1978).

The Goodhead (1978) technique predicts the *fog onset time* at Melbourne Airport. The present paper describes a new technique that may be used to predict the *probability of fog occurrence* there.

2. BACKGROUND

2.1 The Goodhead (1978) Technique

The Goodhead (1978) technique is graphical in application. The previous afternoon's wet bulb depression and low level wind at a nearby station are combined with indicators of the synoptic-scale circulation to provide an estimate of whether or not fog is likely to form and, if so, at what time.

It was developed on 5 years of April to August data between 1972 and 1976 and is presently used as a forecast guidance tool in the Australian Bureau of Meteorology's Victorian Regional Forecasting Centre.

2.2 Automation of Aviation Forecasts

Most of the work that has been carried out in Australia towards providing automated forecast guidance has focussed upon weather elements contained in forecasts for the general public (Stern, 1980; Dahni *et al.*, 1984; Woodcock, 1984; Dahni, 1988; Dahni and Stern, 1995; Stern, 1996). Relatively little such work has been carried out towards providing guidance for aviation forecasting.

Progress has been made outside Australia towards the automation of aviation forecasts by employing highly sophisticated statistical techniques (Haalman *et al.,* 1997, Knüpffer, 1997a&b; Richter, 1997). This progress has been achieved using Model Output Statistics (MOS).

However, Brunet *et al.* (1988) found that Perfect Prog (PP) forecasts perform better than MOS forecasts for short-term predictions.

*Corresponding author address: Harvey Stern, Victorian Regional Office, Bureau of Meteorology, Box 1636M, Melbourne, 3001, Australia; e-mail: H.Stern@bom.gov.au

Brunet *et al.* (1988) also note that PP forecasts possess the overwhelming advantage of portability of the system when the driving model changes.

For these reasons the PP approach is used in the development of the technique described herein.

2.3 Purpose

The purpose of the present paper is two-fold. Firstly, a synoptic classification of fog situations is presented. Secondly, a new technique to predict the *probability of occurrence* of fog that is based on aspects of the *onset time* technique is described.

3. DISCUSSION

3.1 The Synoptic Classification

The system of synoptic classification for southeastern Australia is that first referred to by Treloar and Stern (1993). The basis for the synoptic classes, or types, is the direction, strength and curvature of the surface flow. These characteristics are determined from a grid of pressure values depicted by Figure 1. Lamb (1972) devised a similar system of synoptic classification for the British Isles.

The types (Table 1) are determined as follows:

The strength of the flow is divided into four categories. Defining *a* and *b*, respectively, as the 0900 hours EST pressure differences:

(a) Smithton [41°S 145°E]-Hay [35°S 145°E]; and,
(b) Gabo Is [38°S 150°E]- Mt Gambier [38°S 141°E],

which reflect easterly and northerly gradient wind components, the categories are:

(1) light L, where $a^2+b^2(hPa)^2 \le 1$;
(2) weak W, where $16 \ge a^2+b^2(hPa)^2 > 1$;
(3) moderate M, where $81 \ge a^2+b^2(hPa)^2 > 16$; and,
(4) strong S, where $a^2+b^2(hPa)^2 > 81$.

Where the strength is *L,* the direction is said to be variable (V); otherwise:

(a) where $a>0$ the direction of the surface flow is $(\pi/2)$-artan(b/a) divided into 4 octants (NNE,ENE, ESE,SSE); otherwise,
(b) where $a \le 0$, the direction of the surface flow is $(3\pi/2)$-artan(b/a) divided into 4 octants (SSW, WSW,WNW,NNW); unless,
(c) the direction of the surface flow places it on the boundary between two octants, in which case the direction is the first of the series: NNW,NNE,WNW,ENE,WSW,ESE,SSW,SSE.

The cyclonicity of the flow is determined by whether or not the pressure at Melbourne [38°S 145°E] is greater than that at Forrest [31°S 128°E]. If (Melbourne pressure)>(Forrest pressure) then the flow is anticyclonic (*A*); otherwise, it is cyclonic (*C*).

3.2 Frequency of fog

Fog occurs quite frequently at Melbourne Airport with some synoptic types (Table 1, and Figures 2 and 3). For example, there is fog associated with 18% of the occurrences of the synoptic type "weak ENE cyclonic". By contrast, there has never been a fog in association with some other synoptic types, for example, the synoptic type "strong NNW anticyclonic".

3.3 Logit Regression

The new technique uses logistic regression and was developed using 22 years of data between 1971 and 1993. The skill displayed by the logistic regression technique is verified using 54 months of independent data between January 1994 and June 1998. In a logit regression model (StatSoft, 1995) the predicted values for the dependent variable will never be less than or equal to 0, nor greater than or equal to 1, regardless of the values of the independent variables. This is accomplished by applying the following regression equation

$$y=(\exp(a+\Sigma b_i x_i))/(1+(\exp(a+\Sigma b_i x_i)))$$

where 'y' is the dependent variable, the x_i are the independent variables, and a and the b_i are constants.

In operation, where 'y' is a yes/no variable, the equation yields the probability of occurrence of a particular phenomenon.

3.4 The New Technique

In developing the new technique, the previous afternoon's dewpoint (x_1) and temperature (x_2) are combined with a "length of night" parameter, (x_3), defined as |month-6|, in a set of regression equations.

The equations are developed on data associated with the 19 synoptic types for which there are sufficient data and sufficient "fog" cases (at least 3), and for which the derived statistical relationship is significant at the 10% level.

TABLE 1 (opposite column) The synoptic types: L, W, M, and S correspond to light, weak, moderate and strong flow; V, NNW, WNW, etc. correspond to variable flow, and flow from the eight octants; and, *C* and *A* correspond to cyclonic and anticyclonic flow. Frequency of fogs for each type is given in brackets.

Synoptic Type	**Flow Strength**	**Flow Direction**	**Flow Cyclonicity**
1(0%)	*L*	V	*C*
2(3%)	*L*	V	*A*
3(3%)	*W*	NNW	*C*
4(7%)	*W*	NNW	*A*
5(2%)	*W*	WNW	*C*
6(3%)	*W*	WNW	*A*
7(1%)	*W*	WSW	*C*
8(1%)	*W*	WSW	*A*
9(2%)	*W*	SSW	*C*
10(5%)	*W*	SSW	*A*
11(5%)	*W*	SSE	*C*
12(10%)	*W*	SSE	*A*
13(7%)	*W*	ESE	*C*
14(6%)	*W*	ESE	*A*
15(18%)	*W*	ENE	*C*
16(11%)	*W*	ENE	*A*
17(7%)	*W*	NNE	*C*
18(7%)	*W*	NNE	*A*
19(1%)	*M*	NNW	*C*
20(1%)	*M*	NNW	*A*
21(2%)	*M*	WNW	*C*
22(2%)	*M*	WNW	*A*
23(2%)	*M*	WSW	*C*
24(2%)	*M*	WSW	*A*
25(2%)	*M*	SSW	*C*
26(1%)	*M*	SSW	*A*
27(4%)	*M*	SSE	*C*
28(5%)	*M*	SSE	*A*
29(10%)	*M*	ESE	*C*
30(4%)	*M*	ESE	*A*
31(7%)	*M*	ENE	*C*
32(11%)	*M*	ENE	*A*
33(6%)	*M*	NNE	*C*
34(9%)	*M*	NNE	*A*
35(1%)	*S*	NNW	*C*
36(0%)	*S*	NNW	*A*
37(0%)	*S*	WNW	*C*
38(0%)	*S*	WNW	*A*
39(0%)	*S*	WSW	*C*
40(2%)	*S*	WSW	*A*
41(0%)	*S*	SSW	*C*
42(0%)	*S*	SSW	*A*
43(6%)	*S*	SSE	*C*
44(5%)	*S*	SSE	*A*
45(6%)	*S*	ESE	*C*
46(0%)	*S*	ESE	*A*
47(17%)	*S*	ENE	*C*
48(5%)	*S*	ENE	*A*
49(5%)	*S*	NNE	*C*
50(4%)	*S*	NNE	*A*

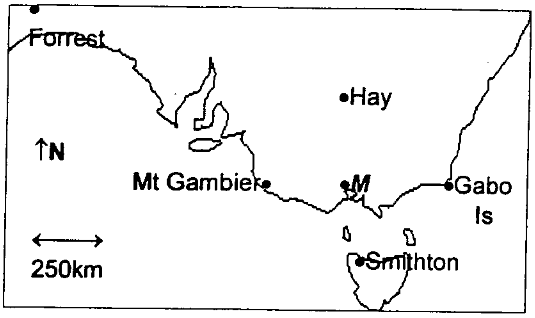

FIGURE 1 Diagram depicting the grid of locations used to determine synoptic characteristics around Melbourne (**M**).

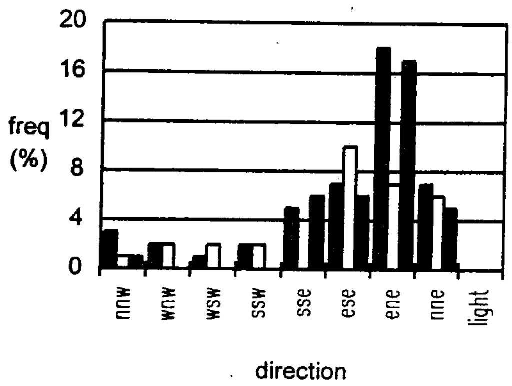

FIGURE 2 Frequency (%) of fogs associated with each direction for weak (left column), moderate (middle column), and strong (right column) cyclonic synoptic flow, and for light and variable cyclonic synoptic flow.

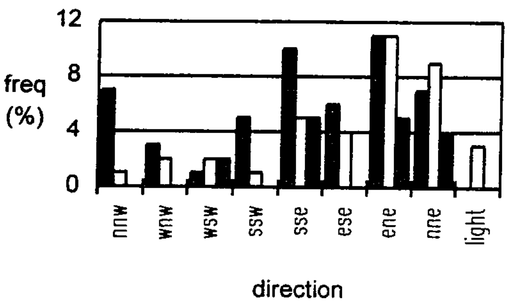

FIGURE 3 Frequency (%) of fogs associated with each direction for weak (left column), moderate (middle column), and strong (right column) anticyclonic synoptic flow, and for light and variable anticyclonic synoptic flow.

For these synoptic classes, which encompass 53% of all cases and 62% of "fog" cases, the relevant equation, the coefficients of which are given in Table 2, is then used to provide a forecast of fog probability. For the other synoptic classes, the fog probability is set at the climatological normal for that type (Table 1, and Figures 2 and 3).

TABLE 2 The Equations' Coefficients.

Synoptic Type	*a*	b_1	b_2	b_3
4	-2.347	0.423	-0.241	0.056
12	-4.254	0.553	-0.110	-0.426
13	2.272	0.359	-0.376	-0.740
14	-0.968	0.253	-0.102	-1.094
16	-2.241	0.335	-0.101	-0.455
20	-2.559	0.308	-0.289	0.422
23	-5.267	0.281	-0.088	0.127
24	-7.984	0.248	0.206	-0.785
27	0.921	0.167	-0.301	-0.281
28	-1.216	0.286	-0.217	-0.272
29	-0.097	0.184	-0.145	-0.572
30	-1.301	0.141	0.030	-1.770
32	-0.697	0.052	0.048	-0.988
33	-5.794	0.357	-0.092	0.179
34	-0.582	0.225	-0.193	-0.016
43	-1.476	0.059	-0.050	-0.466
48	-2.103	0.326	-0.146	-0.488
49	7.588	0.383	-1.355	1.913
50	-0.142	0.356	-0.341	0.058

3.5 Illustrative Examples of the New Technique

Two examples of the technique are now given:

Example 1.

Tomorrow's synoptic type is expected to be Synoptic Type 2 (Light Variable Anticyclonic). Table 2 indicates that a prediction equation is not available for this synoptic class. Read off the percentage of fog cases in Table 1 to yield a probability of fog of 3%.

Example 2.

Tomorrow's synoptic type is expected to be Synoptic Class 16 (Weak ENE Anticyclonic). Table 2 indicates that a prediction equation is available for this synoptic class. Today's 3PM Melbourne Airport temperature and dewpoint are 13°C and 11°C respectively. Today's month is June. Note that the absolute value of the difference between 6 and 6 is 0. Refer to Table 2 in order to obtain the coefficients in the equation. The equation yields a probability of fog of 53%.

4. EVALUATION

4.1 Industry Requirements

It is necessary for the terminal forecast to indicate that fog is expected if the probability of fog occurrence is ≥50%. If the probability of fog occurrence is ≥30% but <50%, that probability needs to be indicated in the terminal forecast. If the probability of fog occurrence is ≥1% but <30%, that probability needs to be indicated in a special advice, referred to as "Code Grey", that is provided to the major airlines. There are two categories of "Code Grey" advice - one category when the probability of fog occurrence is ≥15% but <30%, the other category when the probability of fog occurrence is ≥1% but <15%. Forecasters have the discretion of being more specific than just simply indicating which broad category of "Code Grey" advice is appropriate.

4.2 Evaluating the Technique

The industry requirements are taken into account in evaluating the technique. This is achieved by dividing the forecasts into the above forecast probability ranges. An additional category of very low forecast probability (≥1% but <5%) has been "carved off" the lower probability category of "Code Grey" advice, in order to provide an indication of the technique's performance in such circumstances.

Figures 4 and 5 respectively summarise the performance of the technique on all 47 fog "observed" cases, and all 1595 fog "not observed" cases between January 1994 to June 1998.

A χ^2 test applied to the data presented in Figures 4 and 5 shows that the differences in the two sets of frequencies is significant at the 1% level. This demonstrates that the technique displays skill in an absolute sense. On 70% of these 1642 events, the forecast fog probability was superior to an estimate based on the monthly fog climatology, this proportion being significant at the 1% level. This demonstrates that the technique displays skill relative to climatology.

An evaluation was made of all *available* official forecasts of fog, issued at approximately 3pm, between January 1994 and June 1998 (80% of the 1642 issued during that period), made up of 41 fog "observed" cases and 1277 fog "not observed" cases.

Figure 6 presents the relationship between the technique's PODs and FARs if one uses probability cut-offs of ≥1%, ≥5%, ≥15%, ≥30%, ≥40% and ≥ 50% to predict the categorical occurrence of fog.

The PODs and FARs derived from the official forecasts also are presented in Figure 6.

They suggest that applying the technique with a 30% cut-off yield a POD of 19% and a FAR of 76%, provided the following day's synoptic type is correctly forecast (which it isn't always). Official forecasts with the same cut-off yield a POD of 29% and a FAR of 80%. The FARs are high because some forecasts of "fog" are followed by low cloud, not fog. Applying the technique with a 40% cut-off yield a POD of 15% and a FAR of 61% - corresponding official figures are 17% and 63%. Applying the technique with a cut-off of 50% yield a POD of 11% and a FAR of 58% - corresponding official figures are 15% and 59%.

From these data, one may conclude that an encouraging level of skill is displayed by the technique. The official data, however, reflect a degree of conservatism that leads to higher PODs and higher FARs than those of the technique.

5. CONCLUSION

5.1 Summary

A simple and new technique has been shown to display an encouraging level of skill when compared with that displayed by the current official forecasts.

5.2 Future Work

A prediction of *fog onset time* (as per the Goodhead (1978) technique) and *fog clearance time* are not included in the new technique. This is because we are in the process of establishing a computerised data base of hourly observations for the entire period of record (at present, only a 3-hourly data base is available for the entire period of record).

Once the computerisation of the hourly observations is complete, it is planned to further develop the *probability of fog occurrence* technique so that it also includes a prediction of *fog onset time* (as per the Goodhead (1978) technique) and a prediction of *fog clearance time*. The use of additional predictors, such as those representing static stability, will also be tested. It is then proposed to extend the technique to other aerodromes and to other weather elements included in aviation forecasts, with a view to developing a comprehensive system of automated forecasting guidance for Australian aviation.

Acknowledgements. The authors take great pleasure in thanking Harry Goodhead, and other Victorian Regional Office colleagues, for many useful discussions on the work, and Geoff Feren and Mark Williams, who reviewed the paper.

6. REFERENCES

Brunet, N., Verret, R. and Yacowar, N. 1988: An objective comparison of model output statistics and "perfect prog" systems in producing numerical weather element forecasts. *Wea. Forecasting*, **3**, 273-283.

Dahni, R. R., de la Lande, J. and Stern, H., 1984: Testing of an operational statistical forecast guidance system. *Aust. Met. Mag.*, **32**, 105-106.

Dahni, R. R., 1988: The development of an operational analogue statistics model to produce weather forecast guidance. *Ph. D. Thesis, Depart. of Meteorology, University of Melbourne.*

Dahni, R. R. and Stern, H., 1995: The development of a generalised UNIX version of the Victorian Regional Office's operational analogue statistics model. *BMRC Res. Rep. 47, Bur. Met., Australia.*

Goodhead, H. M., 1978: An objective method for predicting fog and mist at Melbourne Airport. *Airmet Papers, Canberra Meteor. Soc., Roy. Meteor. Soc. (Aust. Branch), Canberra 1978.*

Haalman, D., Richter, B. and Knüpffer, K., 1997: Automatic real time aviation and MOS forecasts. Preprint Volume: *3rd European conf. applications in meteorology*, September 23-26, 1997, Lindau.

Knüpffer, K., 1997: Automation of aviation forecasts - the projects auto-TAF and auto-GAFOR. Preprint Volume: *7th conf. aviation, range and aerospace meteorology*, February 2-7, 1997, Long Beach, California.

Knüpffer, K., 1997: Automation of aviation forecasts - auto-TAF and grid-point MOS. Preprint Volume: *3rd European conf. applications in meteorology*, September 23-26, 1997, Lindau.

Lamb, H. H., 1972: British Isles weather types and a register of the daily sequence of circulation patterns 1861-1971. *Geophys. Memoir 116, HMSO, London.*

Richter, B., 1997: Operational use of MOS forecasts in general aviation (GAFOR). Preprint Volume: *3rd European conf. applications in meteorology*, September 23-26, 1997, Lindau.

StatSoft, 1995: Statistica for windows, Volume 3. *StatSoft, Inc., Tulsa, Oklahoma.*

Stern, H., 1980: The development of an automated system of forecasting guidance using analogue retrieval techniques. *M. Sc. Thesis, Depart. of Meteorology, University of Melbourne.*

Stern, H., 1996: Statistically based weather forecast guidance. *Ph. D. Thesis, School of Earth Sciences, University of Melbourne.*

Treloar, A. B. A.. and Stern, H., 1993: A climatology and synoptic classification of Victorian severe thunderstorms. Preprint volume: *4th International conf. southern hemisphere meteorology and oceanography*, March 29-April 2, 1993, Hobart.

Woodcock, F., 1984: Australian experimental model output statistics forecasts. *Mon. Wea. Rev.*, **112**, 2112-2121.

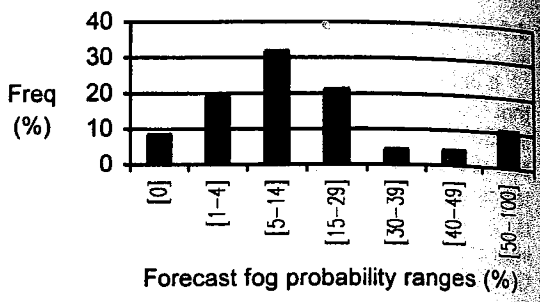

FIGURE 4 Frequency (%) of forecast fog probabilities for all fog "observed" cases.

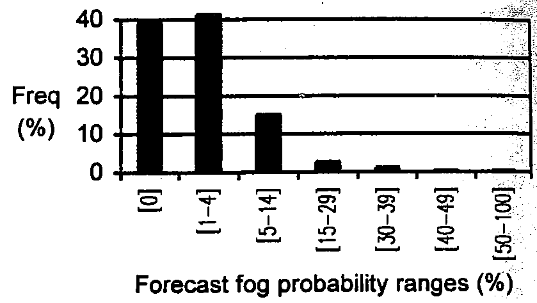

FIGURE 5 Frequency (%) of forecast fog probabilities for all fog "not observed" cases.

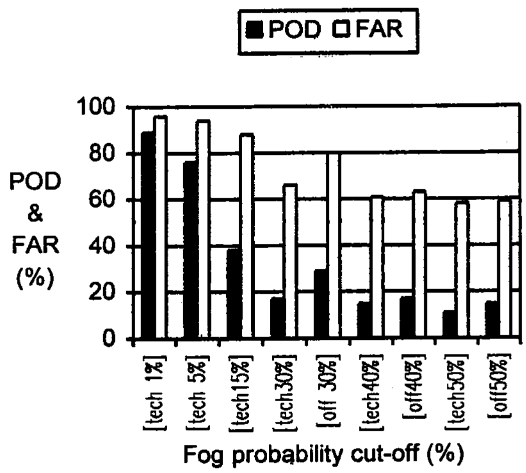

FIGURE 6 A comparison between the new technique's PODs and FARs for different fog probability cut-off criteria, and those of the official forecasts (with the cut-off set at 30%, 40% and 50%).