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Application of Fuzzy-Logic NWP Fog Guidance to Perth Fog Forecasting Decision Support System

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Abstract

An objective Fuzzy-logic based NWP fog guidance is developed for Perth Airport. Its performance over a five year period is assessed to be useful in cool season. A rule-based fog forecasting decision making process incorporating this guidance and other fog tools demonstrated its superiority, on average, to any of the tools used individually. This process led to the development of a more streamlined IT infrastructure called Fog Forecast Decision Support System for Perth Airport.

1. Introduction

Fog forecasting is an important issue at Perth Airport (31.58°S, 115.49°E, altitude 20m), the largest airport along the southwest coast of Australia. Although fog is an infrequent weather phenomenon there, any unforecast fog events will be detrimental to international long-haul flights due to the lack of suitable alternate airports for diversion. Even the closest ones - Learmonth Airport to the north and Adelaide Airport to the east are still three hours away.

Fog can form at Perth Airport in many different synoptic conditions: pre-frontal, post-frontal, in between fronts, slow-moving or east-drifting cut-off lows to the south etc. Often the key drivers to fog formation are precipitation followed by radiative cooling but the development of nocturnal winds over uneven terrain frequently determines the location and timing of fog formation [2].

For quite a long time, synoptic pattern recognition and physical reasoning by a forecaster are the primary fog forecasting approaches for Perth Airport. The lack of objectivity and heavy reliance on experience and local knowledge of a forecaster made it difficult for the Western Australia Regional Forecasting Centre (WARFC) to achieve a more consistent fog forecasting performance. Although various NWP models from overseas and Australia are available to the centre, their primary function is to help forecasters with their identification of synoptic conditions conducive to fog rather than to provide direct and reliable fog forecasts.

To take advantage of the constantly improving NWP model performance and to provide forecasters with an additional forecasting tool that is both objective and independent, in 2003 a fuzzy-logic based NWP fog guidance for Perth Airport was developed. Since then, it has become an essential tool to WARFC in their routine aviation fog forecasting. In the meantime, the introduction of the guidance has prompted the centre to adopt a more structured fog forecast process that makes use of the guidance and other tools in a systematic way. Recently this process has led to the development of a streamlined IT infrastructure called Fog Forecasting Decision Support System (FDSS) for Perth Airport.

This paper will first provide background information regarding fog events and forecast products for Perth Airport. The NWP fog guidance will then be described and discussed. This will be followed by the introduction of the structured forecast process and FDSS. Discussion and Summary will be provided at the end.

2. Background

2.1 Fog Definition

The meteorological definition of a fog is that the prevailing horizontal visibility is less than 1000m. However because aviation forecasting is more concerned about the weather conditions below the Special Landing Alternate Minima (SLAM) and because of difficulty in ascertaining whether visibility reduction over a sector could lead to widespread fog event, WARFC and this paper define a fog event as when the minimum visibility for any sector is at or below SLAM condition, i.e., 2000m for Perth Airport. According, this paper defines a mist event as the minimum visibility being larger than 2000m but equal to or less than 5000m.

2.2 Fog Climatology

Figure 1 provides the fog event monthly distribution based on the 22-year observation dataset between 1988 and 2009. It is apparent that fog is more frequent in cool months between April and October with the average of 1.5 fog events per month and the total of 10.4. For the warmer months between Nov and Mar, the average is only 0.3 per month and the total is just 1.3. Therefore it is convenient to define two “fog seasons”- warm and cool with the warm season being Nov to Mar inclusive and cool season being Apr to Oct inclusive.

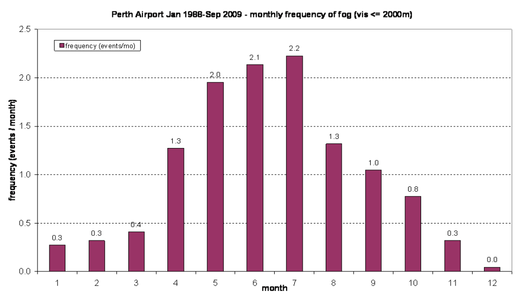

Figure 1: Perth Airport monthly distribution of the observed fog events based on the 22-year observations from 1988 to 2009.

2.3 Fog Forecast Products

For long lead-time aviation forecasting, two products are issued for major airports in Australia, the Code Grey advices and Terminal Area Forecasts (TAFs). TAFs are the standard products for the international aviation community and are issued at 6-hourly interval in UTC or zulu time (Z), namely 00Z, 06Z, 12Z and 18Z, plus any amendments. However Code Grey advice is unique to Australia. It is specially designed to help long-term planning of long-haul flights by providing advice on the small but non-negligible chance of such aviation hazardous weathers as fog, low cloud and thunderstorm. While TAFs are used for forecasting fog probability of 30% or higher, the Code Grey advices are used when fog probability is between 1 to 29%. In practice, the probability of 5, 10% or 20% are normally specified on Code Grey advices.

The critical products to long-haul flight planning are the 06Z TAF and the 06Z Code Grey advice. They are used to forecast whether fog is likely the next morning.

3. Fuzzy-Logic NWP Fog Guidance

While NWP models can provide useful fog-sensitive fields such as relative humidity, pressure gradient and wind for forecasters to assess fog risk likelihood, very few can directly simulate the detailed fog process for operational fog forecasting application [3]. In the face of this, forecasters are looking for a tool that can produce fog forecasts automatically and objectively from the best NWP model available to them.

3.1 Fuzzy-Logic Concept

A fuzzy-logic approach is considered suitable for this purpose because it caters for both model inaccuracy and the inexact relationship between a fog predictor and the likelihood of fog occurrence. For example, it is uncertain that the wind speed of 6 m/s will definitely lead to a no-fog event. However, it is appropriate to say that this wind strength is more likely associated with a no-fog event than a fog event.

Use of fuzzy-logic concept gained popularity in recent years. It has been used in the classification of atmospheric circulation Patterns [1]. Hansen [4] reported a sophisticated analog method using fuzzy-logic concept to forecast ceiling and visibility for 190 airports in Canada.

3.2 NWP Model

The **MESO_LAPS_PT125** (**MESO**scale **L**imited **A**rea **P**rediction **S**ystem **P**oin**T 125**) is chosen because it was the highest resolution and arguably the most accurate operational model available for Australian region at the time of development between 2001 and 2003. This model belongs to the LAPS model family developed by Puri et al. [6]. Some of its specifics include a horizontal resolution of 0.125° (~12.5km), 29 levels in vertical, running twice daily at 00Z and 12Z out to 48 forecasting hours.

3.3 Fog Predictors

To be chosen as a fog predictor, it needs to meet two criteria. The first is that it is sensitive to fog occurrence thus providing better distinction between fog and no-fog events. The second is that the model is capable of simulating it well so that the modelled value behaves similarly to the observed one as far as assigning a fuzzy function value is concerned.

Extensive investigation of observations and the archived **MESO_LAPS_PT125** model dataset in the cool season identified the following four predictors for the 00Z guidance.

- Mean wind speed at 200m above mean sea level (AMSL) overnight
- Bias-corrected minimum dew point depression at 200m and 600m AMSL overnight. Bias is calculated as the dew point depression difference between the observed and modelled value at around 60m AMSL at analysis (i.e., 00Z).
- Bias-corrected minimum dew point depression difference between the +24 forecast hour and analysis at 600m AMSL.
- Minimum dew point depression difference between the +24 forecast hour and analysis at 200m and 600m AMSL.

Here overnight refers to the time that fog is most likely present, i.e., between 15 and 24Z. Apart from the wind speed, the other three predictors are not totally independent to each other. These boundary layer dew point depressions and their overnight trend are considered important to fog. Their interdependency is considered by the reduced weighting when combining fuzzy functions for final fog risk outcome.

An apparent absence from the list is the surface dew point depression. This is because that the model has large errors in predicting surface parameters and that the surface dew point depression generates high false alarms even from observations. Many rain events correspond to low dew point depression but don't necessarily lead to fog events.

For the 12Z guidance, some change to the predictor list is made with increased emphasis on observations due to the proximity to the fog onset. The list is as follows.

- Mean wind speed at 200m above mean sea level (AMSL) overnight
- Bias-corrected minimum dew point depression at 200m AMSL overnight.
- Observed dew point depression at 60m AMSL at analysis (i.e. 12Z)
- Minimum dew point depression at 200m AMSL overnight

3.4 Fog Risk Categories

Four fog risk categories are classified in the guidance aimed at matching them with the WARFC's fog forecast decision categories of NoFog, low percentage fog forecast on code grey advice (hereafter as Code Grey) and prob30 or higher fog forecast on TAF (hereafter as Prob30). They are F0, F5, F15 and F30 representing increased fog risk from very low to high.

3.5 Fuzzy Functions

Fuzzy function for each predictor is generated after the synergetic consideration of behaviour of both observational and model data in their predictability of fog events. More weight has been given to observations to ensure that future improvement in model performance will naturally lead to the improved fog guidance without having to adjust the fuzzy functions. The function ranges from 0 to 1, representing the degree of likelihood of a fog risk category from unlikely to very likely.

Figure 2 provides an example of fuzzy functions for each fog risk category of F5, F15 and F30. No function is provided for F0 category because it is always unity when a predictor does not even score any fuzzy function for F5. In the example, it is when the minimum dew point depression difference is at least 5 degrees.

Taking a value of 3 degrees, three fuzzy function scores can be worked out from the graph. This is 0.85 for F5, 0.4 for F15 and 0 for F30, representing high chance for F5, medium chance for F15 and no chance for F30.

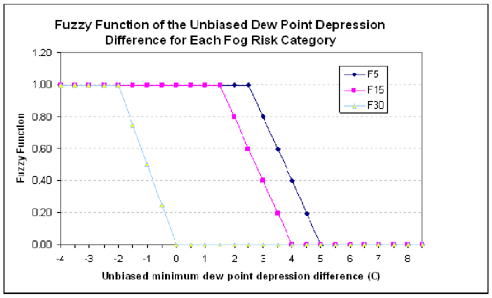

Figure 2: Fuzzy function plot for the 00Z guidance predictor of the minimum dew point depression difference between the +24 forecast hour and analysis at 200m and 600m AMSL

3.6 Fog Risk Outcome

Once a fuzzy function is assigned to each fog risk category for each predictor, a composite fuzzy function is produced for each fog risk using a fuzzy rule. Essentially this rule is to find the lowest fuzzy function out of the four predictors for each fog risk category with more weighting given to the wind speed predictor due to the interdependence of the other three.

The final fog risk outcome is then decided by finding out which fog risk category attracts the highest composite fuzzy function.

3.7 Performance and Discussion

Five year (2004-2008 inclusive) archived guidance outcomes are used to assess the performance of the guidance. Only the 00Z guidance is assessed because it is the long lead-time fog forecasting that is more important to long-haul flights.

Figure 3 displays the distribution of the percentage of times when a particular fog risk forecast is made and fog is observed. The distribution looked encouraging for cool season but not the warm season. In cool season, there is a clear increase trend from the lower risk categories of F0 and F5 to F15 and F30. For example, there is 15% chance that when F30 is forecasted, fog will be observed. This compared with the 2% times that a fog is observed when a F5 is forecasted. The 2% percentage for F0 and F5 forecast categories are however not satisfactory even though it looked like a small percentage. This is because when multiplied by the number of forecasts in these two categories, the number of times that fog is observed but unforecasted is actually not small.

For warm season, the performance is quite poor. Apart from the F0 category which is at the desired very low percentage, little distinction is made among three other categories with the highest percentage only 3% coming from FM15. As discussed earlier, fog only occurs about once per warm season and the guidance is developed based on the cool season datasets. Therefore, the guidance is not suited for warm season fog forecasting. If insisting on using it, then the categories of F15 and F30 should be treated as if they were F5.

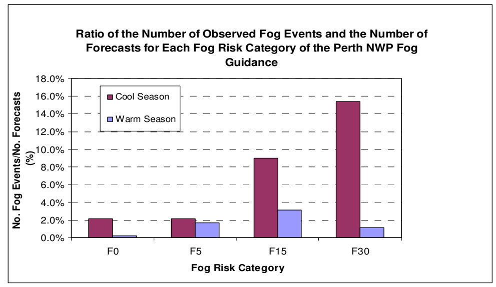

Figure 3: Ratio of the number of observed fog events and the number of forecasts for each fog risk category of the fuzzy-logic based guidance

4. Forecasting Process and FDSS

Thompson [7] demonstrated that improved accuracy may be achieved when optimally combing independent forecasts. The availability of more tools including this guidance has prompted WARFC to investigate if fog forecasting performance can be improved through a rule-based decision making process.

There are three main forecasting tools that WARFC identified as useful for Perth Airport fog forecasting. They are the synoptic pattern matching and human reasoning (generically known as subjective method), the GASM which is the analog method based on modeled data and the guidance just introduced (for simplicity, hereafter the name NWPFOG is also used). The subjective method asks a forecaster to check if and how well the current synoptic pattern matches with any of the known fog-conducive patterns. It then allows the forecaster to make subjective assessment of fog risk likelihood even if the pattern is not favorable to fog. Once this is done, this method is treated the same as the other two methods in the rule-based decision making process with slightly more weighting given in certain situations.

This process has led to the development of the web-based system recently called FDSS that streamlines the process from data input, to methods, to rule-based final outcome and to the ultimate forecast decision. All data used are archived for view or verification.

The performance of the 06Z FDSS is compared with that of the 00Z NWPFOG which the 06Z FDSS requires, for the same 5-year period of 2004 to 2008 for cool season only. In FDSS, the NWPFOG fog risk categories are assigned to one of the three forecast categories with F0 and F5 corresponding to NoFog, F15 to Code Grey and F30 to Prob30.

Figure 4 compares the percentage of fog being observed out of all forecasts of a category from NWPFOG and FDSS. While little difference can be found in Prob30, significant improvement can be found in FDSS in the NoFog category. FDSS reduces the NWPFOG percentage of 2% down to almost zero. There is also difference in Code Grey percentage between the two but this is not considered as important.

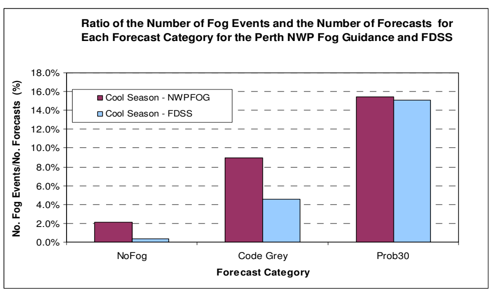

Figure 4: Comparison between NWPFOG and FDSS on the ratio of the number of fog events and the number of forecasts for each forecast category for cool seasons of 2004 -2008.

To illustrate more clearly how significantly FDSS has improved on the NWPFOG results, the frequency of the observed fog events captured by each forecast decision is plotted on Figure 5. It showed that NWPFOG missed more than 20% of the total number of fog events which is unacceptable to airlines particularly considering how important Perth Airport is to them. On the other hand, FDSS only missed 3%. While still not ideal, this is a significant improvement over NWPFOG.

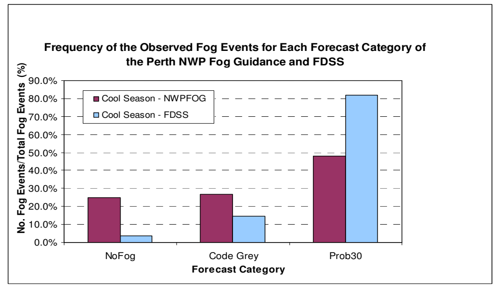

Figure 5: Comparison between NWPFOG and FDSS on the ratio of the number of fog events and the total number of fog events for each forecast category for cool seasons of 2004 -2008. The NoFog category equates missed fog events.

5. Discussion and Summary

This paper first provided some background information about the importance of fog forecasting at Perth Airport, the largest one over the southwest Australia. It then described the method and performance of a fuzzy-logic based NWP fog guidance for Perth Airport. Following that, the structured fog forecasting process which recently evolved into a web-based IT system called FDSS was introduced.

The performance of the guidance is shown to be reasonably satisfactory in cool season but not so in warm season which the guidance is not designed for. Although the guidance demonstrates a clear upward trend in its ability to capture more of the fog events when moving risk category higher, the percentage is too high for category F0 and F5. This shortcoming is alleviated by the structured process and later FDSS, further confirming that it is possible to improve forecast accuracy when optimally combining independent forecasts.

Future work will target both the guidance and the FDSS system. The guidance has now been adapted to the new modeling system called ACCESS due to the imminent cease of the LAPS model family. The new guidance is expected to perform better than the current version but detailed verification is required before further development work is carried out. The current FDSS system relies on the rule-based decision making process which may be improved by the introduction of Bayesian Network. Such a network has been shown by Newham et al [5] powerful to improve the fog forecasting performance for Melbourne Airport.

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