Evaluation of numerical model forecasts of visibility and fog at Australian Airports

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EXECUTIVE SUMMARY

1. Visibility, dew point depression (DPD), and fog fraction fields predicted by the ACCESS city-scale models are evaluated relative to observed fog and mist conditions at eight Australian airports over the period 2011-2015.

2. Of the three fields evaluated, predictions of the visibility field are least accurate, partly as a result of the method used to diagnose this field, and partly as a result of errors in model-predicted meteorological fields. The diagnosis may be improved through experimentation with tuning parameters, while improvements in the representation of the environment may increase the accuracy of the model-predicted fields.

3. While model predictions of DPD are relatively good for Canberra airport, this may result from a cancellation of errors in the predicted air temperature and dew point temperature fields at this location. An outstanding finding is that predictions of fog at Hobart and Perth airports are poor.

4. Objective evaluations show that the prediction of the fog fraction field is relatively good, but the usefulness of this field is limited by frequent false alarms.

5. Errors in the air temperature and dew point temperature fields and in the timing of the DPD minima indicate that an investigation is required into the representation within the ACCESS model of surface and vegetation properties in the vicinity of the Australian airports investigated here.
1. INTRODUCTION

Low visibility conditions caused by fog in the vicinity of busy airports are problematic for the aviation industry because they cause flight delays and cancellations, which have a negative economic impact and are an inconvenience to passengers. Therefore, accurate forecasting of low visibilities associated with fog over airports provides economic benefits to the aviation industry. A significant amount of research and development conducted by scientists at the United Kingdom Meteorological Office (UKMO) has gone into developing a scheme to directly estimate visibility from fields forecast by their numerical weather prediction (NWP) models (Wright 1997a,b, Clark et al. 2008, Claxton 2013, Boutle et al. 2016). In this scheme, visibility is diagnosed from model-predicted meteorological fields (air temperature, total water, pressure, and aerosol mixing ratio) at the screen level height. The scheme operates by hydrating the provided aerosol field so that it is in equilibrium with the atmospheric humidity, and the visibility is then computed based on the fog droplet size and the number density. Further details are provided in the next section.

While UKMO forecasters benefit from direct estimates of the visibility field (Boutle et al. 2016), forecasters at the Australian Bureau of Meteorology do not consider this field because past experience has shown that it is not highly accurate over locations in Australia. To allow Bureau forecasters, the aviation industry and the Australian public to benefit from direct estimates of the visibility field, it is necessary to investigate why this field has not been well forecast over Australia. The first step in addressing this problem is to objectively assess the accuracy of the visibility field to establish a benchmark and to guide subsequent improvements.

This report evaluates the ability of the Bureau’s numerical weather prediction model to correctly predict meteorological fields associated with observations of fog and mist over Australian airports. The fields of interest are visibility, the difference between air temperature and dew point temperature at the screen level, also referred to as dew point depression (DPD), and fog fraction. Comparisons of model-predicted fields with observations provide information on three broad points. First, this evaluation documents and identifies deficiencies in the performance of the model in predicting each field. Second, the accuracies of the predicted fields are compared. Third, the relative performance of predicting these fields between airports is presented, which allows identification of locations that require most attention in rectifying errors. Together, these points can be used to support and guide future model improvements.
2. DIRECT ESTIMATIONS OF VISIBILITY

Visibility is a diagnostic variable, estimated directly from model-predicted meteorological fields (air temperature, total water, pressure, and aerosol mixing ratio) at the screen level height. The scheme operates by hydrating the provided aerosol field so that it is in equilibrium with the atmospheric humidity. Visibility is then computed based on the fog droplet size and the number density. This section provides some details on the method used to estimate visibility.

Visibility, \( V \), is diagnosed using an exponential scattering law based on Koschmeider (1924), as shown by Equation 1. The liminal constant, \( \varepsilon \), is equal to 0.02 according to Clark et al. (2008), but a value of 0.05 is defined in the model code discussed in Section 3.3. The scattering coefficient, \( \beta \), defined by Equation 2a, contains two components. The first is the extinction coefficient of clean air and the second is due to aerosols (Clark et al. 2008). In the theoretical absence of aerosols, the extinction coefficient of clean air is defined as a constant, given by Equation 2b, to ensure that a visibility no greater than 100 km is diagnosed. The extinction coefficient due to aerosols is a function of relative humidity (RH) and the dry aerosol mass mixing ratio, \( m \), given by Equation 3. In this equation, \( N \) is the aerosol number density and \( r_m \) is the volume mean droplet radius, and \( \beta_0 \) is defined by Equation 4. The term \( \eta \) is defined by Equation 5 but is assigned a value of 0.75 while \( Q \) is set equal to 2.0. The water droplet radius is found by solving Equation 6. In this equation, \( r_{\text{mod}} \) is the dry aerosol mean volume radius, \( q_{\text{TOTAL}} \) is the total water and \( q_{\text{SAT}} \) is the saturation specific humidity. Equation 6 describes the equilibrium between the hydrated aerosol, or water droplets, and the environmental RH (Claxton 2013), and is solved using Newton-Raphson iteration. The mean droplet radius is related to RH using the Kohler curve (Pruppacher and Klett 1978, Claxton 2013), given by Equations 7. In Equation 7a, \( A \) is a constant related to the surface tension of water (1.2 x 10\(^{-9}\) m). The value of \( B \), the activation parameter, is 0.5 according to Wright (1997a) and Clark et al. (2008) but in the model code discussed in Section 3.3, the value of \( B \) is 0.14. The response of an aerosol particle to the atmospheric humidity depends on whether the particle has been activated into a water droplet (Claxton 2013). That is, activated and deactivated particles require different computations, with details provided by Wright (1997a,b), Clark et al. (2008), and Claxton (2013).

\[
V = -\frac{\ln \varepsilon}{\beta_{\text{TOTAL}}} \quad (1)
\]

\[
\beta_{\text{TOTAL}} = \beta_{\text{AIR}} + \beta_{\text{AEROSOL}} \quad (2a)
\]

\[
\beta_{\text{AIR}} \approx 2.9957 \times 10^{-5} \quad (2b)
\]

\[
\beta_{\text{AEROSOL}} = \beta(RH,m) = \beta_0 N r_m^2 \quad (3)
\]

\[
\beta_0 = \pi Q \eta = 1.5\pi \quad (4)
\]
\[ \eta = \frac{\bar{r}^2}{r_m^2} = 0.75 \quad (5) \]

\[ q_{TOTAL} = q_V + q_{LIQUID} = RH(r_m, r_{md})q_{SAT} + q_{LIQUID}(r_m) \quad (6) \]

\[ RH = \exp \left[ \frac{A}{r_m} - \frac{B}{R - 1} \right] \quad (7a) \]

\[ R = \left[ \frac{r_m}{r_{md}} \right]^3 \quad (7b) \]

3. DATA AND METHODS

3.1 Airports

Model forecasts are evaluated at eight Australian airports. These locations include seven capital city airports, Adelaide, Brisbane, Canberra, Hobart, Melbourne, Perth, and Sydney. In addition, Wagga Wagga airport was included because there was a special observations program conducted during 2015.

3.2 Observations

Observations at each airport for the period 1 January 2011 to 31 December 2015 are represented using hourly meteorological aerodrome report (METAR) data archived by the Bureau. Hourly data are used to match the one-hourly model forecast data. Glickman (2000), Spellman (2013) and the World Meteorological Organisation (WMO) Codes Handbook (WMO 2016) state that the visibility in fog is less than 1 km. Spellman (2013) notes that mist reduces the visibility to a lesser extent than does fog, and Glickman (2000) states that the visibility during mist is 1 km or more. Observations of fogs and mist are classified here based on observed visibilities, as either fog or one of two types of mist, as shown in Table 1. These three weather types are used throughout this report. In addition, observations of all types of recorded precipitation, including for example, showers, rain, snow, and thunderstorm, are classified here in a single class that is labelled as “precipitation”. Other weather types that are not relevant to this study, including unrecorded types of weather, no weather, and observations of smoke and haze, are classified here in a single class referred to as “not recorded”. To compare model predictions with the observed data at the eight airports, model data are extracted from the model grid at the grid point that is closest to each airport.
Table 1  Definitions of fogs and mists based on observed visibilities. Note that 10 km is maximum visibility reported in a METAR.

<table>
<thead>
<tr>
<th>Weather type</th>
<th>Observed visibility, V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fog</td>
<td>V &lt; 1 km</td>
</tr>
<tr>
<td>Mist1</td>
<td>1 km ≤ V ≤ 5 km</td>
</tr>
<tr>
<td>Mist2</td>
<td>5 km &lt; V ≤ 10 km</td>
</tr>
</tbody>
</table>

3.3 ACCESS model

The Bureau operates numerical weather prediction models that are part of the Australian Community Climate and Earth System Simulator (ACCESS) suite (Australian Bureau of Meteorology (ABOM) 2010, Puri et al. 2013). These models are based closely on the UKMO’s Unified Model (Cullen 1993; Davies et al. 2005; Rawlins et al. 2007). Predictions made using Australian Parallel Suite (APS) versions 0 and 1 of the ACCESS city models (ABOM 2010, 2013b) are assessed in this study. The APS1 ACCESS city models, upgraded from APS0 on 8 October 2013, operate with a horizontal grid spacing of approximately 4 km, and are specifically employed to provide relatively high-resolution forecasts for Australian capital cities compared with the relatively lower resolution of the APS1 regional (~12 km) and global (~40 km) models (ABOM 2012, 2013a, 2013b).

The ACCESS city models are coupled to the Joint UK Land Environment Simulator (JULES) to simulate fluxes of heat, moisture and gases between the atmosphere and the land surface (Best et al. 2011, Clark et al. 2011). Within each model grid box, a variety of land surface types can be represented: five vegetation types and four non-vegetated surfaces. A separate surface energy balance is computed for each of these surface types, and then a weighted sum provides the mean fluxes for each model grid box.

ACCESS model forecasts beginning at 00 UTC each day are assessed in this report. Each model forecast covers a period of 36 hours, from 00 UTC on the current day to 12 UTC on the following day. To avoid the temporal overlap of forecasts produced from separate model simulations, the data from each forecast are limited to a 24-hour period, beginning at 0600 UTC during the first forecast day and ending at 0559 UTC on the following day. As hourly forecasts are required to correspond to the hourly observations noted previously, the forecast data are extracted at twenty-four times, beginning at 0600 UTC on the first day and terminating at 0500 UTC on the following day. In the current work, this 24-hour period is referred to as a fog day when fog is observed at least once during this period.

3.4 Fields Evaluated

Evaluations of the accuracy of model predictions are based mainly on three fields: visibility, DPD, and fog fraction. In addition, values of screen level air temperature and dew point temperature are considered in additional evaluations of the accuracy of the DPD field.

The visibility field is diagnosed from model-predicted meteorological fields (air temperature, total water, pressure, and aerosol mixing ratio) at the screen level height. The accuracy of this field is
evaluated using observations of visibility recorded at each airport. Incorrect values of model-predicted visibility may result from inaccuracies in the simulated meteorological fields, from errors in the formulation used to diagnose the visibility, or both.

The observed DPD field is obtained by computing the difference between air temperature and dew point temperature observed at the screen level. The model-predicted DPD field is found by computing the difference between model-predicted values of air temperature and dew point temperature at the screen level.

Another field produced by the ACCESS model that is relevant to forecasting of fog is fog fraction. This field represents the fraction of a grid box with a visibility below the 1 km (Wright 1997a, b). Values range from 0 to 1. While model predictions of visibility and DPD can each be compared with the respective observed values, values of fog fraction are assessed in this report by considering, first, the distribution of values, second, the occurrence of non-zero values corresponding to observations of fog and mist, and third, the occurrence of fog fractions above selected thresholds corresponding to observed fog.

4. VISIBILITIES PREDICTED BY THE ACCESS MODEL

Temporal-mean values of visibility produced by the ACCESS model are compared with observed values for the eight airports in Figure 1. Three specific weather types are considered (fog, mist1, mist2), with the addition of the broad class containing types of precipitation and the “not recorded” class. The aviation industry benefits from accurate forecasts of low visibilities. At all eight airports, the observed visibility is lowest corresponding to the fog class, with values less than 1 km. The model-predicted mean values in this class are much larger, ranging from approximately 8 to 16 km, indicating that the model does not perform well in predicting visibilities associated with fog. In general, across all classes of weather, mean values of model-predicted visibility are greater than the observed mean values. For the “not recorded” class, the mean observed visibility is 10 km, the maximum value recorded in a METAR. The highest mean predicted values are found in this class, with values ranging from approximately 25 to 30 km. In this class, differences between the predicted and observed values are not important because under clear conditions the METAR contains visibilities up to a maximum of 10 km, rather than an accurate indication of the true visibility.

Visibilities corresponding to fog conditions are now examined in more detail. The percentage occurrences of model-predicted and observed visibilities over a range of distances corresponding to fog are shown in Figure 2. Observations show that most visibilities occur in the range from 0.1 to 1 km, with a peak between 0.1 and 0.5 km at Melbourne, Perth, Sydney and Wagga Wagga, and a peak between 0.5 and 1 km at Adelaide, Brisbane, Canberra and Hobart. At all airports the model-predicted visibility maxima are greater than 10 km, demonstrating that the model predictions differ greatly from the observed values. Canberra has the best result, with the lowest percentage of model-predicted visibilities greater than 10 km (Figure 2c), while Hobart has the highest (Figure 2d).

For the two classes of mist (Figures 3 and 4), the observed values are consistent with the definitions in Table 1. The model-predicted visibilities are often greater than 10 km, and as such do not correspond well to the observed values. At most airports during observed mist conditions, a small percentage of
the cases have visibilities less than 1 km. In these cases, the model has predicted fog during the observed occurrence of mist, a forecast of fog that is considered to be a false alarm.

Figure 1  Mean observed visibility for five weather types and corresponding ACCESS model forecasts of visibility at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports, for the period 2011-2015. The numbers of observations corresponding to each weather type are shown near the top of the frame.
Figure 1 (continued): Mean observed visibility for five weather types and corresponding ACCESS model forecasts of visibility at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports, for the period 2011-2015. The numbers of observations corresponding to each weather type are shown near the top of the frame.
Figure 2  Percentage occurrences of observed and model-predicted values of visibility corresponding to observed fog at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 2 (continued): Percentage occurrences of observed and model-predicted values of visibility corresponding to observed fog at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
Figure 3  Percentage occurrences of observed and model-predicted values of visibility corresponding to observed mist1 at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 3 (continued): Percentage occurrences of observed and model-predicted values of visibility corresponding to observed mist1 at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
Figure 4 Percentage occurrences of observed and model-predicted values of visibility corresponding to observed mist2 at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 4 (continued): Percentage occurrences of observed and model-predicted values of visibility corresponding to observed mist2 at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
5. DPDS PREDICTED BY THE ACCESS MODEL

As errors in the visibility field may result from inaccuracies in the model-predicted meteorological fields, from errors in the formulation used to diagnose the visibility, or both, it may be informative to assess the ability of the model to accurately forecast fog at the screen level. In this section, model-predicted DPDs are compared with observed values.

Mean values of observed and model-predicted DPDs at the eight airports are shown in Figure 5 corresponding to five types of weather. Overall, for observed fog, the mean error is approximately 0.5°C, with the model failing to produce values that are as low as those observed. The largest mean error occurs for Hobart. For the two classes of mist, the errors in the DPD field are generally less than approximately 0.5°C, with the largest mean errors occurring for Perth.

In more detail, distributions of observed and predicted DPDs during observed fog (Figure 6) show that the model has the ability to produce values over the same approximate range of values as those observed. This is very different from the relatively poor agreement between predicted and observed values of visibility in Figure 2. Although Figure 6 shows that the predicted distributions for all eight airports extend to higher values of DPD than those observed, the peak in the predicted distribution at each airport generally occurs in the same bin as, or in a bin adjacent to, the peak in the observed distribution. Exceptions are Hobart and Perth, and Brisbane to a lesser extent, where the predicted distributions are shifted to higher values relative to the observed distributions.

Subjective assessment of distributions at each airport corresponding to the two classes of mist (Figures 7 and 8) suggests that there is generally a better agreement between the observed and model-predicted distributions during mists than during fog. Before discussing objective assessments of the agreement between observed and predicted distributions (Section 6), it is useful to also consider the frequency of types of weather corresponding to DPDs (Figure 9). In this diagram, each individual column represents a total of 100%. Note that this representation differs from the presentations in Figures 6, 7 and 8 in which data were distributed across a range of DPDs. In Figure 9, for observed DPD values less than 0.5°C, fog and mist accounts for less than approximately 57% of the total occurrence of weather types at any one airport, with largest percentage occurrences at Hobart (57%), Adelaide (48%) and Brisbane (43%) (Figures 9a, 9b and 9d). Moreover, fog is observed no more than approximately 26% of times when DPD is less than 0.5°C, with a maximum at Hobart (Figure 9d). At the other airports, fog occurs when the DPD is less than 0.5°C with frequencies ranging from approximately 6 to 19%. The data in Figure 9 demonstrate that DPD is just one of multiple variables that influence the formation of fog.
Figure 5  Mean observed DPD for five weather types and corresponding ACCESS model forecasts at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports, for the period 2011-2015. The numbers of observations corresponding to each weather type are shown near the top of the frame.
Figure 5 (continued): Mean observed DPD for five weather types and corresponding ACCESS model forecasts at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports, for the period 2011-2015. The numbers of observations corresponding to each weather type are shown near the top of the frame.
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Figure 7  Percentage occurrences of observed and model-predicted values of DPD corresponding to observed mist1 at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
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Figure 8  Percentage occurrences of observed and model-predicted values of DPD corresponding to observed mist2 at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 8 (continued): Percentage occurrences of observed and model-predicted values of DPD corresponding to observed mist2 at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
Figure 9  The percentage occurrence of observed weather types corresponding to observed DPDs for the period 2011-2015, at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports. Each individual column represents a total of 100 %.
Figure 9 (continued): The percentage occurrence of observed weather types corresponding to observed DPDs for the period 2011-2015, at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports. Each individual column represents a total of 100%.
6. AGREEMENT BETWEEN MODEL-PREDICTED AND OBSERVED VALUES

The agreement between observed and model-predicted distributions of visibility across all of the bins for each respective weather type in Figures 2, 3 and 4 is computed and expressed as a percentage for each airport (Figure 10, black bars). That is, within each bin of each distribution, the lowest value of the two fields (model-predicted and observed) is found, and then these minimum values are summed across all bins of the distribution, providing a measure of the agreement, with possible values ranging from 0 to 100%. The agreement between observed and predicted values of DPD is also computed for the distributions in Figures 6, 7 and 8, and displayed using grey bars in Figure 10. These results provide a measure of the relative accuracy of the two fields. While the results in Figure 10 may vary depending on the particular subjective choice of bins used in constructing the distributions, multiple bins have been employed across the relevant range of values within each distribution and may therefore be expected to produce a reasonably reliable measure of the agreement between observed and model-predicted values. Alternative objective assessments are presented later in Section 16.

A broad assessment of the results in Figure 10 shows that the model has a greater ability to accurately predict DPD than visibility. The model has a good ability to predict DPD during mist at most locations (Figure 10b and 10c), but less ability to predict this same field at times when fog is observed (Figure 10a). The lowest agreements in the DPD field during fog occur at Hobart and Perth, followed by Brisbane, while for both classes of mist, the lowest agreement is found at Perth.
Figure 10  Percentage agreement between observed and model-predicted values of visibility (black bars) and DPD (grey bars), for (a) fog, (b) mist1, and (c) mist2, at each airport. Agreements derived from the distributions in Figures 2-4 and 6-8.
7. CONTRIBUTIONS TO ERRORS IN DPD

The contributions of errors in the predicted air temperature and dew point temperature fields to errors in the DPD field are examined here. Mean differences between model-predicted and observed air temperatures and between model-predicted and observed dew point temperatures are computed for each of the eight airports corresponding to the five classes of weather considered in this report (Figure 11). For fog (Figure 11a), the largest mean error in the predicted air temperature field, a value greater than 3ºC, is found at Canberra. The mean error in the predicted dew point temperature field at this location is also relatively large, greater than 2.5ºC. However, the combination of these two errors means that the prediction of DPD at Canberra during observations of fog is relatively accurate compared with other airports, as indicated by Figure 10a. Other airports that each display an outstanding positive bias are Hobart and Wagga Wagga. For Wagga Wagga, although errors in both temperature fields are relatively large, the combination of these errors produces small errors in the DPD field, as noted previously for Canberra. However, for Hobart, the predictions of the DPD field are relatively poor (Figure 10a), a result associated with a mean error of approximately 2ºC in the predicted air temperature field and of approximately 1ºC in the dew point temperature field (Figure 11a). Another airport with a poor prediction of DPD during fog is Perth (Figure 10a), which is explained by the data in Figure 11a showing that Perth has a relatively large difference between the mean error in air temperature and the mean error in dew point temperature.

For mist conditions (Figures 11b and 11c), the largest differences between mean errors in air temperature and dew point temperature occur at Perth, consistent with the relatively low agreements between model predictions and observations in Figures 10b and 10c. As found during fog conditions (Figure 11a), the mean errors in the two temperature fields at Canberra and Hobart during mist conditions (Figures 11b and 11c) are relatively large. Consideration of the other two classes of weather, precipitation and not recorded conditions (Figures 11d and 11e), demonstrates that the mean errors in the two temperature fields vary depending on the type of weather and the location. For example, during precipitation, the largest difference between the mean error in the air temperature and the mean error in the dew point temperature fields is found at Sydney (Figure 11d), while the errors at Canberra and Hobart are relatively small. For weather not recorded (Figure 11e), Hobart and Wagga Wagga both display outstanding positive mean errors in the dew point temperature field.

The results presented in this section provide some insight into the complexity of accurately predicting air temperature and dew point temperature, and therefore DPD and fog. For example, while the mean errors in the temperature fields are large at Canberra, the DPD that results from these fields provides a superior prediction than the DPD that results from the smaller mean errors in the temperature fields found at Hobart. Additionally, the nature of the errors varies depending on the weather conditions. It may be useful to closely examine surface properties within the model grid, such as soil properties, vegetation details, terrain height and slope, at each location to confirm that, apart from numerical schemes employed within the model, the basic static elements of the environment are represented as accurately as possible within the model. After completing this elementary examination, soil moisture and numerical schemes, involving, for example, vertical diffusion coefficients and prediction of overhead cloud, could be examined.
Figure 11 Mean differences and standard deviations between model and observed values of screen level air temperature (red) and between model and observed values of screen level dew point (black), for each of the eight airports, corresponding to five weather types, (a) fog, (b) mist1, (c) mist2, (d) precipitation, and (e) weather not recorded.
8. FOG FRACTION PREDICTED BY THE ACCESS MODEL

Distributions of model-predicted values of fog fraction corresponding to observed fog are shown in Figure 12 for each of the eight airports. From the total possible range from zero to one, predicted values generally range from zero to more than 0.6. Notable features are the relatively high frequencies (> 30 %) of predicted values of fog fraction equal to zero at Hobart, Perth, and Sydney. At Hobart, this feature is accompanied by a narrow distribution, with a maximum predicted fog fraction of approximately 0.3. Distributions of predicted fog fraction corresponding to observations of mist (Figures 13 and 14) contain a range of values generally similar to those for fog in Figure 12. The occurrence of predicted fog fractions equal to zero increase for mist1 relative to fog, with frequencies greater than 30 % at five of the eight airports (Figure 13). For mist2, distributions for six of the eight airports contain frequencies greater than 30 % for predicted fog fractions equal to zero.

The occurrence of non-zero values of the predicted fog fraction field are compiled in Figure 15 for the fog and mist weather types, with the addition of the precipitation and not recorded weather classes. For fog conditions (Figure 15a), predictions of non-zero values of fog fraction are lowest for Hobart, Perth and Sydney. The relatively poor performance of the fog fraction field at these three airports is also found corresponding to both classes of mist (Figures 15b and 15c). The additional consideration of the precipitation and not recorded classes of weather in Figure 15 demonstrates the good general ability of the ACCESS model to predict non-zero values of the fog fraction field during fog and mist (Figures 15a-c) relative to these two other weather types, for which the frequencies are much lower (Figures 15d and 15e). The frequencies of non-zero fog fractions corresponding to observations of fog and mist range from approximately 41 % to 88 %, while for precipitation the frequencies range from approximately 7 % to 26 %, and approximately 4 % to 15 % when there was no recorded weather.
Figure 12  Percentage occurrences of model-predicted values of fog fraction corresponding to observed fog at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 12 (continued): Percentage occurrences of model-predicted values of fog fraction corresponding to observed fog at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
Figure 13  Percentage occurrences of model-predicted values of fog fraction corresponding to observed mist1 at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 13 (continued): Percentage occurrences of model-predicted values of fog fraction corresponding to observed mist1 at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
Figure 14  Percentage occurrences of model-predicted values of fog fraction corresponding to observed mist2 at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 14 (continued): Percentage occurrences of model-predicted values of fog fraction corresponding to observed mist2 at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
Figure 15  Percentage occurrence of non-zero values of model-predicted fog fraction at each airport, corresponding to five weather types, (a) fog, (b) mist1, (c) mist2, (d) precipitation, and (e) weather not recorded.
9. OBSERVED AND MODEL-PREDICTED VISIBILITIES

Pairs of observed and model-predicted visibility data are presented for all weather types in a scatter diagram for each airport in Figure 16. For both observed and model-predicted visibilities, a maximum value of 10 km is applied to all data. At each airport, the points along the horizontal line equal to the model-predicted visibility of 10 km correspond to observed visibilities ranging from 0 to 10 km. Those along the vertical line equal to an observed visibility of 10 km correspond to a wide range of model-predicted visibilities. These wide distributions provide some indication of the disagreement between the observed and model-predicted values of visibility. Putting aside the points corresponding to 10 km, the remaining points are scattered widely with no apparent relationship between observed and predicted values. For every airport, there is an absence of a cluster of points near to a hypothetical diagonal line representing equal observed and predicted values. This demonstrates the lack of agreement between the observed and predicted values.

As the prediction of low visibilities associated with fog is of interest here, consider points corresponding to observed visibilities ranging from 0 to 1 km. Some of these points do correspond to model-predicted visibilities less than 1 km, but there are many other points with model-predicted visibilities ranging from approximately 2 to 9.5 km. This is illustrated well in Figures 16c, 16e, and 16h. Objective evaluations of these model-predicted values of visibility are presented later in Section 16.

The relationship between model-predicted and observed visibilities is investigated further by computing the ratio of model-predicted to observed values at each airport. These individual points, again for all weather types, are shown in Figure 17 corresponding to observed visibilities. It is not important to consider the wide distribution of ratios corresponding to the reported visibility of 10 km because this value is assigned for visibilities greater than 10 km in METAR reports, and therefore it does not represent a meaningful comparison between model-predicted and observed values of visibility.

In Figure 17, model-predicted visibilities would be considered accurate if points were distributed along the horizontal dashed line corresponding to a ratio equal to unity. However, at the eight airports, most points lie above this line, indicating that model-predicted visibilities are too high relative to observed values. The distributions of points indicate that there is a general increase in the ratio as the observed visibility decreases. Although this suggests that disagreements between model-predicted and observed values of visibility are generally greatest when observed visibilities are lowest, this pattern occurs at least partly because the value of the ratio is increased when there is division by relatively small observed values. While the ratios corresponding to observed visibilities less than 1 km mostly indicate that the model-predicted values are approximately ten to one hundred times too large, there are also points present for most airports showing that the predicted visibilities are approximately ten times too small. This point demonstrates that inaccuracies in the model-predicted visibility field are not just the result of a consistent bias.
Figure 16  Scatter diagram of observed visibility versus corresponding model-predicted visibility data for all weather types, at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 16 (continued): Scatter diagram of observed visibility versus corresponding model-predicted visibility data for all weather types, at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
Figure 17  Scatter diagram of observed visibility versus the ratio of model-predicted visibility over observed visibility, for all weather types, at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 17 (continued): Scatter diagram of observed visibility versus the ratio of model-predicted visibility over observed visibility, for all weather types, at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
10. RELATIONSHIPS BETWEEN DPD AND VISIBILITY

Points representing the relationship between observed DPD and observed visibility for all weather types are shown in Figure 18 for each airport. As previously, the 10 km visibility represents all visibilities greater than this distance. In these diagrams, the observed points are scattered very widely, demonstrating the difficulty in understanding and simulating this relationship. It is also important to recognise that parameters other than DPD also contribute to fog formation. For example, at every airport, observed visibilities corresponding to a DPD of 0.5°C range from approximately 0 to 10 km. In an attempt to extract further information from the points in this diagram, the mean observed visibility is computed for each DPD bin of width 0.25°C. Only visibilities less than 10 km are considered in this calculation because the recorded value of 10 km is an arbitrary representation of clear conditions. The mean relationship for each airport, shown by the dashed line, indicates that the visibility decreases from approximately 6 km down to 3 km as the DPD falls below approximately 1°C towards 0°C. While the relationships provided by this line are consistent with the general expectation that the visibility is reduced when condensation and fog formation are most likely, it does not, of course, represent the many physical processes that produce the wide scatter of points displayed in this diagram. The two dotted lines in each frame, corresponding respectively to one standard deviation above and below the mean relationship, provide some representation of the scatter. Corresponding to the lowest DPD bin considered, in which values range from 0°C to 0.25°C, the mean visibility at the eight airports ranges from approximately 2 to 4 km, while the dotted lines provide values in the range from approximately 0 km to 7 km. In the absence of more precise guidance, it may be useful to consider a range of possible values of visibility, rather than attempting to predict a single value.

Model-predicted DPDs and corresponding model-diagnosed visibilities for all weather types are shown in Figure 19 for each airport, with the 10 km value of visibility representing values greater than or equal to this distance. In contrast to the observed points that were scattered widely with little evidence of a relationship between the DPD and the visibility (Figure 18), the model-predicted data in Figure 19 are not scattered widely and appear to display a relatively clear relationship between DPD and visibility at each airport. For a DPD of approximately 0.5°C, where the visibility is approximately 10 km, the visibility decreases to near zero as the DPD decreases to approximately 0.2°C. Note that the model-diagnosed visibility is not derived from a simple relationship that depends only on the DPD, even though the generated values shown here may suggest that this could be the case. Also note that tuning factors present in the visibility scheme may alter the precise distribution of points shown in Figure 19. In addition to the differences between observed and predicted data in terms of the degree of scatter, the mean relationship based on the observed data (dashed lines in Figure 18) is very different from that suggested by the distribution of model-predicted points in Figure 19. The data in Figure 19 also indicate that a model prediction of DPD that is less than 0.5°C would produce a prediction of visibility that is less than 10 km. A future step is to look into how the scheme that is used to diagnose the visibility from the meteorological fields produced by the ACCESS model may be improved or tuned.
Figure 18  Scatter diagram of observed DPD versus observed visibility, for all weather types at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports. The dashed line represents the mean relationship between the DPD and visibilities less than 10 km. The dotted lines represent departures from the mean by plus and minus one standard deviation, respectively.
Figure 18 (continued): Scatter diagram of observed DPD versus observed visibility, for all weather types at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports. The dashed line represents the mean relationship between the DPD and visibilities less than 10 km. The dotted lines represent departures from the mean by plus and minus one standard deviation, respectively.
Figure 19  Scatter diagram of model-predicted DPD versus model-predicted visibility, corresponding to all observed weather types at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 19 (continued): Scatter diagram of model-predicted DPD versus model-predicted visibility, corresponding to all observed weather at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
11. EMPIRICAL RELATIONSHIP BETWEEN VISIBILITY AND DPD

The mean and standard deviation data presented for each airport in Figure 18 are compiled here with the aim of producing an empirical relationship between visibility and DPD. The mean relationships between observed DPD and observed visibility for all eight airports are displayed together in Figure 20a. The corresponding standard deviations are shown in Figure 20b. A suggested fitted curve, defined by Equation 8, is displayed by the solid black line in Figure 20c. To employ the simple form of Equation 8, it is necessary to assume that visibility equals zero when DPD equals zero. The grey lines in the background of Figure 20c are the mean values for the eight airports as shown previously in Figure 20a. The black dashed lines indicate the respective values above and below the mean curve by one standard deviation. The standard deviation is defined as a linear relationship between DPD and visibility, given by Equation 9. This is displayed by the black line in Figure 20d, with the standard deviation from the eight airports represented by the grey lines in the background. Although Equation 10 may capture the broad relationship between observed DPD and visibility, it is important to note that fog does not necessarily form as DPD approaches zero, as demonstrated by the occurrence of weather types other than fog and mist corresponding to values of DPD below 0.5°C in Figure 9.

\[ V_{\text{MEAN}} = a \Delta T^b \]  
\[ V_{\text{SD}} = c \Delta T + d \]  
\[ V = a \Delta T^b \pm (c \Delta T + d) \]

where \( V \) is visibility in units of km,

\( V_{\text{MEAN}} \) is the mean value,

\( V_{\text{SD}} \) is the standard deviation,

\( \Delta T = T - T_{\text{DEW}} \) °C is the DPD,

\( a = 5.68 \) km °C⁻¹,

\( b = 0.29 \),

\( c = -0.27 \) km °C⁻¹,

\( d = 2.45 \) km.
Figure 20  (a) mean relationships between observed DPD and observed visibility from each of the eight airports, (b) standard deviation of relationship between observed DPD and observed visibility from each of the eight airports, (c) empirical mean relationship between observed DPD and observed visibility, plus and minus one standard deviation, (d) empirical representation of standard deviation.

12. VISIBILITIES PREDICTED DURING FOG DAYS

The distributions of observed and model-predicted visibilities presented in Figure 2 were constructed based on model-predicted values corresponding to each hour that fog was observed. Such an assessment overlooks the possibility that the model produced a potentially useful forecast, but predicted fog too early or too late relative to observed fog. In this section, distributions are constructed using the minimum value of the observed visibility and the minimum value of the model-predicted visibility that occur during each fog day (defined in Section 3.3).
The set of distributions considered previously (Figure 2) is now compared with the new set of distributions based on minima during fog days (Figure 21). The distributions of observed values are similar between the two sets. However, distributions of the model-predicted values show reductions in the occurrence of visibilities greater than 10 km when minima are considered during fog days. Although this is a positive result, distributions of model-predicted visibilities at all eight airports still contain values that are too high (> 1 km) relative to observations. The distributions for Hobart and Perth (Figures 21d and 21f) continue to contain high (> 50 %) frequencies of model-predicted visibilities greater than 10 km. Agreements between the observed and model-predicted distributions are evaluated objectively in Section 14.

Figure 21 Percentage occurrences of observed and model-predicted values of minimum visibility found during fog days at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 21 (continued): Percentage occurrences of observed and model-predicted values of minimum visibility found during fog days at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
13. DPDS PREDICTED DURING FOG DAYS

Following consideration of the visibility field in the previous section, distributions are constructed here for the DPD field using the minimum observed value and the minimum model-predicted value that occur during each fog day. Compared with the set of distributions presented previously based on hourly data corresponding to fog observations (Figure 6), the new set of distributions based on minima during fog days (Figure 22) contains increased occurrences of DPDs with lower values, in both the observed and predicted fields. The differences between the observed and model-predicted distributions at Brisbane, Hobart and Perth evident in Figures 6b, 6d and 6f, noted in Section 5, have been reduced by using the approach of selecting minima during fog days, shown in Figures 22b, 22d and 22f, respectively. Agreements between observed and model-predicted distributions are discussed further in the following section.
Figure 22 Percentage occurrences of observed and model-predicted values of minimum DPD found during fog days at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 22 (continued): Percentage occurrences of observed and model-predicted values of minimum DPD found during fog days at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
14. AGREEMENT BETWEEN MODEL-PREDICTED AND OBSERVED VALUES DURING FOG DAYS

Agreements between the observed and model-predicted distributions in Figures 21 and 22 constructed based on minima found during fog days are computed here for each of the eight airports, for both the visibility and DPD fields. The agreements for the visibility field (Figure 23a, black bars) generally range from approximately 20 % to 30 %, although values for Hobart, Melbourne and Perth are below this range. Compared with the previous assessment based on data corresponding to observations of fog (Figure 10a, black bars), the agreements have generally increased for the visibility field by considering values throughout fog days. This suggests that model errors might be partly attributable to errors in timing of the prediction of low visibility during fog. Changes in the agreements between data displayed in Figures 10a and 23a (Figure 23b) show that improvements in agreements between observed and predicted visibility (Figure 23b, black bars) are greatest for Adelaide, Brisbane and Sydney, while the agreement has decreased for Melbourne. There is no improvement for Hobart, remaining with an agreement of zero percent, while the improvement for Perth is relatively small. Therefore, while some locations show improvement associated with prediction of timing of minimum values of visibility, predictions of visibility at Hobart and Perth remain relatively inaccurate, indicating that model errors at these locations are associated with issues within the model other than simply relatively early or late formation of fog.

For the DPD field, agreements between observed and model-predicted distributions (Figure 23a, grey bars) have generally improved through consideration of minimum values during fog days, relative to the assessment based on hourly values (Figure 10a). In both assessments, the agreement for the DPD field at each airport is higher than the agreement based on the visibility field. The two airports with the lowest agreements are Melbourne and Perth (Figure 23a), while in the previous assessment, Brisbane, Hobart and Perth were outstanding locations with low agreements (Figure 10a). Figure 23b (grey bars) shows that there were relatively large improvements in finding agreement between observed and predicted distributions of DPD at Brisbane, Hobart and Perth by employing the fog day. While the agreement based on the visibility field is low at Hobart and Perth (Figures 10a and 23a), the results here indicate that errors in the prediction of the DPD field may be partly due to timing of the minimum value during a fog day.
Figure 23  (a) percentage agreement between minimum observed and minimum model-predicted values of visibility (black bars) and DPD (grey bars), during fog days, at each airport. Agreements derived from the distributions in Figures 21 and 22, and (b) differences between agreements in Figures 10a and 23a, for each airport.
15. TIMING OF PREDICTIONS DURING FOG DAYS

Consideration of minimum values of visibility and DPD during fog days, discussed in the preceding sections, provides the opportunity to examine the relative timing of observed and model-predicted minima. Distributions of the occurrence of the time of predicted visibility minima relative to the time of the observed minima during fog days are presented in Figure 24 for the eight airports. A visual inspection of these distributions indicates in general that visibility minima are forecast to occur prior to observed minima. These results are summarised in Figure 26a, where totals of the respective percentage occurrences of early, correct and late forecasts are computed. This diagram confirms that forecasts of minimum visibilities are most often forecast to occur too early (blue bars greater than 50 %). Exceptions are Canberra and Melbourne, where predictions of the timing of visibility minima are relatively good, and Hobart, where predicted minima most often occur too late.

For the DPD field at each airport, distributions of the occurrence of the time of the forecast minima relative to those observed during fog days are presented in Figure 25. The results summarised in Figure 26b show that minimum values of DPD are most often predicted to occur too early at Adelaide and Perth, but too late at Canberra, Hobart and Wagga Wagga. A relatively good result in terms of predicting the timing of DPD minima on fog days is found for Melbourne. Note that the evaluation discussed in this section considers only the timing of the minima, not a comparison of the observed and predicted values as discussed in Sections 12 and 13.
Figure 24 Percentage occurrence of relative timing of minimum values of model-predicted visibility compared with timing of minimum values of observed visibility during fog days, at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 24 (continued): Percentage occurrence of relative timing of minimum values of model-predicted visibility compared with timing of minimum values of observed visibility during fog days, at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
Figure 25 Percentage occurrence of relative timing of minimum values of model-predicted DPD compared with timing of minimum values of observed DPD during fog days, at (a) Adelaide, (b) Brisbane, (c) Canberra, and (d) Hobart airports.
Figure 25 (continued): Percentage occurrence of relative timing of minimum values of model-predicted DPD compared with timing of minimum values of observed DPD during fog days, at (e) Melbourne, (f) Perth, (g) Sydney, and (h) Wagga Wagga airports.
Figure 26 Percentage occurrences of early/correct/late timing of (a) minimum visibility, and (b) minimum DPD, during fog days, at each airport.
16. OBJECTIVE EVALUATION OF MODEL PREDICTIONS

Skill metrics are used here to objectively evaluate the accuracy of model predictions of visibility, DPD and fog fraction. The metrics employed are described below in Section 16.1. Results are discussed for each of the three predicted fields in Sections 16.2 to 16.4, respectively.

16.1 Skill metrics

The metrics employed are probability of detection (POD) and false alarm rate (FAR), defined by equations 11 and 12, respectively, based on Wilks (1995). These metrics depend on the construction of a contingency table, the cells of which contain aggregates of the numbers of predicted and observed values that are above or below a selected threshold. The table contains four cells, as shown by Table 2. H is the number of Hits or correct forecasts, F is the number of False Alarms, M is the number of Missed forecasts, and Z is the number of correct predictions of non-observed events.

\[
POD = 100 \frac{H}{H + M} \quad (11)
\]

\[
FAR = 100 \frac{F}{F + H} \quad (12)
\]

For objective assessment of the visibility field, a threshold of 1 km is used. A Hit is recorded in the contingency table when both observed and predicted values are below this threshold. For the DPD field, a Hit is recorded when both observed and predicted values are below the threshold of 0.5°C. For the initial assessment of the fog fraction field, a Hit is recorded when the predicted fog fraction is greater than zero and the visibility is less than 1 km. Additional assessments of the fog fraction field are made using higher fog fraction thresholds (0.1 and 0.5). When assessments are made for fog days, the minimum observed and the minimum predicted values found during each fog day are compared with the threshold values stated here for each field to fill the contingency table.

Table 2 Contingency table to assess accuracy of model predictions, showing the number of Hits (H), False Alarms (F), Misses (M), and correct predictions of events that are not observed (Z).

<table>
<thead>
<tr>
<th>Predicted: Yes</th>
<th>Observed: Yes</th>
<th>Observed: No</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Z</td>
<td></td>
</tr>
</tbody>
</table>
16.2 Objective evaluation: visibility

Values of the POD and FAR from the evaluation of model predictions of visibility for the eight airports are displayed in Figure 27a. The PODs are highest for Canberra, Melbourne and Wagga Wagga, although no value is greater than 40%. The POD is equal to zero for Hobart, while Adelaide, Brisbane and Perth all have PODs less than 10%. The FAR for most airports is greater than approximately 80%, with a relatively low value of approximately 60% for Canberra but a value of 100% for Hobart.

The PODs are higher when the fog day is employed to detect minima, although the value for Hobart remains equal to zero (Figure 27b), and the next-lowest value of approximately 15% is for Perth. Values of the POD are greater than 30% for Adelaide, Canberra, Melbourne, Sydney and Wagga Wagga. There are zero false alarms for the visibility field during fog days because each fog day is defined by a value of visibility less than the threshold value of 1 km.

16.3 Objective evaluation: DPD

The POD and FAR are assessed for the DPD field using a threshold of 0.5°C (Figure 28a) with no consideration of visibility or the presence of fog. The highest POD is approximately 50% for Canberra, while values are above 30% for Adelaide, Melbourne and Wagga Wagga. Values are approximately 10% for Perth and Sydney, while a value of zero is found for Hobart. Values of the POD are generally higher for predictions of the DPD field than for the visibility field, although values are relatively low at Hobart, Perth and Sydney for both fields. FARs for most airports are near or greater than approximately 70%, with a value of 100% for Hobart and near-100% for Sydney. The lowest FAR of approximately 40% is found for Canberra.

When fog days are considered, the PODs are much higher for most airports (Figure 28b). For six of the eight airports, PODS are above 70%. This is a good result, indicating that the model has some ability to correctly predict low DPDs during fog days, although not with the correct timing. Relatively low values of the POD during fog days are found for Hobart and Perth. The value for Perth is approximately 50%. For Hobart, the POD is less than 10% and the FAR is above 80%. The FAR for Sydney is also relatively high, approaching 40%, while at most locations it is near zero.

16.4 Objective evaluation: fog fraction

Values of the POD metric are higher across all eight airports when the fog fraction field is assessed (Figure 29a), relative to evaluations of the visibility and DPD fields discussed above. The lowest POD is found for Hobart, with a value of approximately 40%, followed by Perth at approximately 50% and Sydney near 60%. The other five airports have POD values greater than 70%. The high POD values found here may be partly due to the use of a fog fraction threshold equal to zero, which also means that the FARs are high, greater than 80%, for all airports. When fog days are considered, values of the POD metric are relatively high for the fog fraction field (Figure 29b), with values greater than 70% for all airports. Consistent with previous results, the lowest values are found for Hobart and Perth.
When objective metrics are recomputed using values of the fog fraction threshold greater than zero (thresholds of 0.1 and 0.5, respectively), smaller values of the POD are found for each airport (Figures 29c and 29e), while FARs remain relatively high. For a fog fraction threshold of 0.1, FARs are greater than 80% at all airports, and for a fog fraction threshold of 0.5, FARs are greater than 60%. For fog days, there are also decreases in the values of the POD at each airport as the fog fraction threshold is increased above zero (Figures 29d and 29f).

Overall, the model appears to have some ability to predict low values of fog fraction (~0.1) associated with observed fog, but is less successful in generating moderately higher values (~0.5). For all values of the fog fraction threshold examined here, the FARs are consistently high (> 60%), meaning that model-predictions of non-zero values of the fog fraction field must be interpreted carefully.
Figure 27  POD and FAR, at each airport, for (a) visibilities less than 1 km, and (b) minimum visibilities less than 1 km during fog days.

Figure 28  POD and FAR, at each airport, for (a) DPDs less than 0.5°C, and (b) minimum DPDs less than 0.5°C during fog days.
Figure 29   POD and FAR, at each airport, for (a) non-zero values of fog fraction, (b) fog fractions greater than zero during fog days, (c) fog fractions greater than or equal to 0.1, (d) fog fractions greater than or equal to 0.1 during fog days, (e) fog fractions greater than or equal to 0.5, (f) fog fractions greater than or equal to 0.5 during fog days, evaluated relative to observed visibilities less than 1 km.
17. SUMMARY AND RECOMMENDATIONS

Visibility, DPD, and fog fraction fields predicted by the ACCESS city-scale models have been evaluated relative to observed fog and mist conditions at eight Australian airports over the period 2011-2015.

Visibilities predicted by the model are generally too high. As accurate values of visibility depend on both the accurate simulation of meteorological fields and an accurate method used to diagnose the visibility from those fields, it is useful to consider both of these contributors. In this report, the key meteorological field examined is the screen level DPD. Evaluations of the DPD field show that it is predicted with a higher accuracy than the visibility field, indicating that at least part of the error in the visibility field is produced from the method used to diagnose the visibility. This may be overcome by examining the method used to diagnose the visibility, including experimenting with tuning parameters. The fog fraction field produces higher values of the POD than both the visibility and DPD fields, but its usefulness may be limited by the associated high FARs.

Objective evaluations of the DPD field show that the accuracy of predicting this field may be improved by considering the minimum value forecast throughout a fog day, rather than the value predicted corresponding to observations of fog. Errors in the timing of the minimum value of the DPD during a fog day may be due to inaccurate simulations of heat and moisture transfer at the surface, possibly a result of inaccurate representation of surface and vegetation properties. Model-predicted minimum values of DPD occur most often too early relative to observed minima at Adelaide and Perth airports, and too late at Canberra and Hobart airports.

In general, model predictions of visibility, DPD and fog fraction are most accurate at Canberra airport, followed by Melbourne and Wagga Wagga, while the least accurate forecasts are found at Hobart and Perth airports. Although predictions of the DPD field are relatively accurate for Canberra, evaluations of the air and dew point temperatures reveal that errors in both of these temperature fields are relatively large but often cancel to produce a relatively accurate forecast of DPD. Therefore, while model predictions of fog would probably benefit from a close examination of elementary surface and vegetation properties at Hobart and Perth, forecasts at other locations, even Canberra, may also benefit from such an examination.

Based on the evaluations conducted here, the following recommendations are made:

1. Errors in the DPD field need to be reduced so that the model produces more accurate forecasts of fog formation. Such an improvement depends partly on the representation of physical processes in the model, such as turbulent diffusion and cloud formation (Boutle et al. 2016). Horizontal and vertical resolutions also affect these processes and tuning of these processes (Boutle et al. 2016). The representation of the environment, such as surface properties and vegetation, also has an important impact on accurate prediction of fog. The suitability of these fields used in the ACCESS model to represent the environment in the vicinity of Hobart, Perth (Potts and Roux 2016, Roux 2017), and even Canberra airports requires some examination and confirmation.
2. Until there is a good level of capability in both simulating processes associated with the formation of fog (such as accurate predictions of DPD noted in the point above) and diagnosing the visibility, it may be useful to represent uncertainties in the visibility field by providing forecasts that cover a range of likely values of visibility rather than a single value.

3. The evaluation of fields presented here for eight Australian airports should be repeated for more recent versions of ACCESS such as APS2 and APS3.

18. ACKNOWLEDGMENTS

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19. REFERENCES


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