Temperature Forecast Analysis for Winter 2022

January 2023

A report assessing the forecast precision and accuracy of AEMO's operational weather providers in the National Electricity Market from 1 May 2022 to 30 September 2022

Important notice

Purpose

This report has been prepared to:

- Give the weather service providers used by AEMO Operational Forecasting an insight into their comparative temperature forecast performance in the NEM during the 2022 Winter period.
- Give any intending weather service providers information to assist with assessment of the relative performance of their forecasts.
- Facilitate discussion and ongoing improvement of temperature forecast accuracy.

This report is generally based on information available to AEMO as at 19 January 2022 unless otherwise indicated.

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Abbreviations

Term	Description
AP	Airport
C	Celsius
DPV	Distributed photovoltaic
HA	Hours ahead
LOR	Lack of reserve
MAE	Mean absolute error
MW	Megawatts
NEM	National Electricity Market
OP	Olympic Park
RERT	Reliability and Emergency Reserve Trader
VRE	Variable renewable energy
WT	West Terrace

Glossary

Term	Description
Accuracy vs. precision	Accuracy refers to the closeness of an actual temperature measurement to the forecast value. Precision is the frequency at which a forecast error is reproduced. Therefore, a set of forecast outcomes could be precise in that its errors fall within a narrow range, and a set of forecast outcomes are both accurate and precise when that small range of errors are close to the actual measurement.
Dry-bulb temperature	The temperature of air measured by a thermometer freely exposed to the air but shielded from radiation and moisture.
Electricity demand (operational demand)	The sum of scheduled, semi-scheduled, and significant non-scheduled generation connected to the National Electricity Market.
Forecast error (^{o}C)	Forecast temperature minus actual temperature
Mean Absolute Error (MAE)	The calculated average of the absolute (unsigned) forecast error. Mean absolute error is only used in reference to temperature forecast error (^{o}C) in this paper.
Net Forecast Bias	Aggregate count of days where each hourly interval was either negative (actuals > forecast) or positive (actuals < forecast) assessed over the coldest 10% of days.
Rolling forecast horizon	A forecast that is always created X hours ahead of the actual observation. For example, for a 4 hour ahead rolling forecast horizon, the observation at 12:00 pm was forecast at 8:00 am, and the observation at 4:00 pm was forecast at 12:00 pm.

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Executive summary

This report examines the temperature forecast performance of AEMO's three contracted weather service providers in the National Electricity Market (NEM) from 1 May to 30 September 2022 (defined as "Winter 2022" for the purpose of this analysis). It has been prepared to facilitate discussion and ongoing improvement of temperature forecast precision and accuracy to support power system operation and the broader energy industry and may be used by weather service providers as a reference to benchmark performance.

Following a multi-vendor procurement process, AEMO successfully onboarded a new weather service provider (Provider B) in February 2022 to replace an underperforming former provider. This strategy yielded favourable results, with AEMO's analysis confirming that Provider B performed best across three of the four forecast horizons in Winter 2022. AEMO strives to attain the most accurate forecasting data and will continue to work with the meteorological industry through avenues such as the Temperature Forecast Analysis reports[1] to promote and achieve ongoing improvement.

The weather stations analysed in this report are Adelaide West Terrace (WT) (South Australia), Amberley (Queensland), Archerfield Airport (AP) (Queensland), Bankstown AP (New South Wales), Hobart AP (Tasmania)[2], Melbourne AP (Victoria), Melbourne Olympic Park (OP) (Victoria), Penrith Lakes (New South Wales) and Sydney AP (New South Wales). These weather stations were selected as they have the largest influence on demand forecasts for their respective NEM regions. The report considers temperature forecast accuracy and precision at the 1, 4, 24, and 72 hour ahead (HA) rolling forecast horizons.

The key findings from this analysis were:

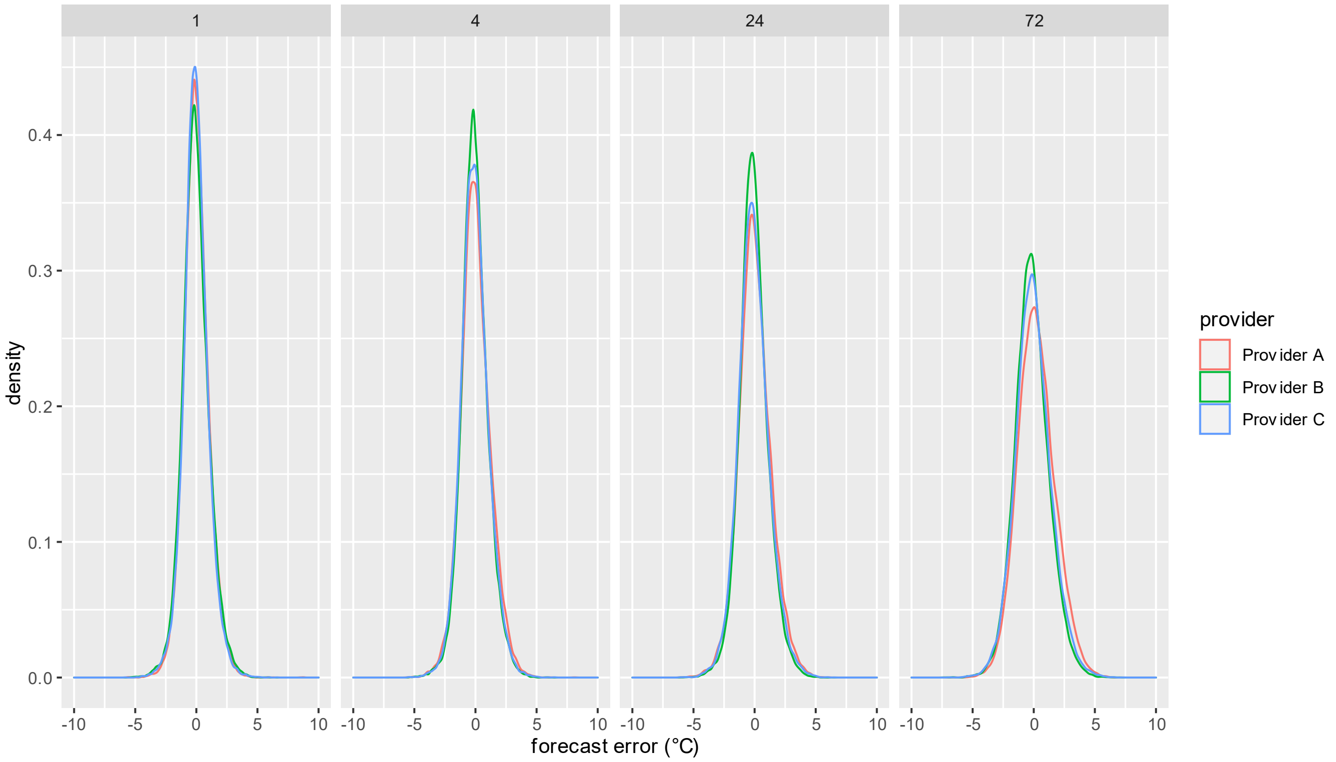
- Provider B was the best performing across the 4, 24 and 72 HA forecast horizons, but underperformed in the 1 HA forecast horizon.
- Compared to Winter 2021, Provider A improved in the 1 HA forecast horizon while the performance of Provider C degraded.
- A systematic over-forecasting bias was evident for all providers in extreme cold temperatures.
- Penrith continued to be the most challenging location to forecast for all providers.

This report also includes a case study of forecasting performance in Queensland on 4 and 5 July 2022, when extreme cold conditions were experienced. This case study demonstrates the challenges experienced by all weather service providers in forecasting extremely low temperatures, and highlights the impact on operational demand forecasts on the day of other types of error, such as modelling, variability, and rooftop photovoltaic (PV) error.

[1] At https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/operational-forecasting/load-forecasting-in-pre-dispatch-and-stpasa.

[2] In August 2022, the Bureau of Meteorology changed its Hobart Airport site to a new location (previous code 94008 to new code 94250), which AEMO began using in October 2022 for Tasmanian operational demand forecasts.

Figure 1 1, 4, 24, 72 HA Winter performance comparison across major weather stations, all providers, all temperatures



AEMO will use this analysis to aid operational decision-making and draw weather service providers' attention to areas where improvements are desirable. This will support existing initiatives between AEMO and the weather forecasting industry, which include:

- Redevelopment of AEMO's Projected Assessment of System Adequacy (PASA) to be probabilistic and include weather uncertainty margins in reserve calculations.
- Enhancing the national observational network around renewable energy zones (REZs) to improve forecasting and situational awareness capabilities in line with anticipated needs of future market operations.
- Developing forecasting tools to increase situational awareness of weather risks specific to power system assets and operation.
- Investigating the direct use of solar irradiance in demand forecasting to capture increased electricity demand due to heat island effects in major metropolitan areas.
- Finalising a review of the provider weightings in the Demand Forecasting System (DFS), with the aim of increasing the contribution of Provider B to the resultant demand forecast.

Contents

Figures

1 Introduction

This report examines the temperature forecast accuracy of AEMO's three weather service providers in the National Electricity Market (NEM) from 1 May 2022 to 30 September 2022 (defined as "Winter 2022" for the purpose of this analysis)[3]. This report aims to highlight the differences in forecasting performance between Winter 2021 and Winter 2022, while also drawing new performance insights from the Winter 2022 period. The report is part of a series of biannual *Temperature Forecast Analysis* reports available on the AEMO website for summer (1 December to 31 March) and Winter periods since 2018[4].

This report has been prepared as a resource for weather service providers to benchmark their forecast performance, and to facilitate discussion and ongoing improvement of temperature forecast precision and accuracy to support system operation and the broader energy industry.

Review and analysis in 2022 led to the replacement of one of AEMO's previous weather service providers. A new weather service provider (Provider B) was onboarded in February 2022. Provider B's performance was assessed for the first time across a full period for this report with strong results, demonstrating that AEMO's multi-vendor procurement approach is effective in acquiring the most accurate data in the market.

The report considers temperature forecast accuracy and precision at the 1, 4, 24, and 72 hour ahead (HA) rolling forecast horizons. The weather stations analysed in this report are Adelaide West Terrace (WT) (South Australia), Amberley (Queensland), Archerfield Airport (AP) (Queensland), Bankstown AP (New South Wales), Hobart AP (Tasmania)[5], Melbourne AP (Victoria), Melbourne Olympic Park (OP) (Victoria), Penrith Lakes (New South Wales) and Sydney AP (New South Wales). These weather stations were selected as they have the largest influence on demand forecasts for their respective NEM regions.

This report also includes a case study to discuss the impact extreme cold temperatures had on electricity demand in Queensland on 4 and 5 July 2022. Winter 2022 also included a period of low reserve conditions in the NEM between 10 June and 24 June 2022 during which the spot market was suspended. While not discussed in this report, the impact of weather during this period is included in the NEM Market Suspension incident report[6].

Sensitivity of electricity demand to temperature

The performance of a temperature forecast must be understood with reference to its impact on electricity demand. The accuracy of temperature forecasts is most critical for operational demand forecasting when demand is high, generation reserves are low, or when a small change in temperature results in a large change in demand. These conditions are often encountered on hot summer and cold winter days, meaning it is important for providers to produce accurate and precise temperature forecasts on these days.

[3] All analysis refers to time in Australian Eastern Standard Time (AEST).

[4] At https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/operational-forecasting/load-forecasting-in-pre-dispatch-and-stpasa.

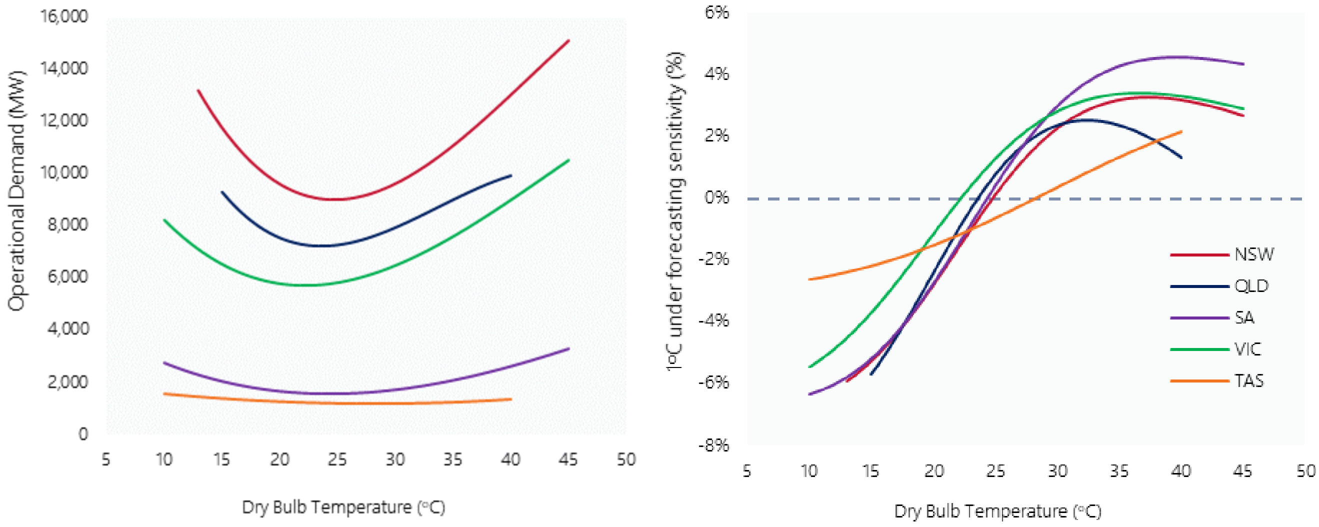
[5] In August 2022, the Bureau of Meteorology changed its Hobart Airport site to a new location (previous code 94008 to new code 94250), which AEMO began using in October 2022 for Tasmanian operational demand forecasts. Before making this change, AEMO replaced the actuals from 94008 with the latest available forecast, which was used in demand model training and for the analysis in this report.

[6] At https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/market_event_reports/2022/nem-market-suspension-and-operational-challenges-in-june-2022.pdf

Figure 2 shows the absolute and proportional change in operational demand recorded with reference to temperature for each NEM region, to provide context for the results in this report[7].

Electricity demand has different temperature sensitivity in each NEM region due to factors such as climate and the mix of residential, commercial, and industrial load. In addition, the same demand forecast error will have different operational impacts for different regions. Since each region has limited local generation and interconnector capacity, percentage changes in demand must be understood in conjunction with absolute demand changes.

Figure 2 Weekday maximum daily operational demand against maximum dry bulb temperature (left) and percentage change in demand for a 1°C under-forecasting deviation (right) for each NEM region, 2018-21



[7] This analysis shows the relationship of maximum daily dry bulb temperature values with maximum daily operational demand on weekdays between 1 January 2018 and 31 December 2021. The temperature readings were taken from the primary weather station for demand forecasting in each region (New South Wales – Bankstown Airport, Queensland – Archerfield, Victoria – Melbourne Olympic Park, South Australia – Kent Town/Adelaide West Terrace, Tasmania – Hobart Airport). Adelaide West Terrace was used after the Bureau of Meteorology decommissioned Kent Town on 31 July 2020.

2 Winter forecast performance

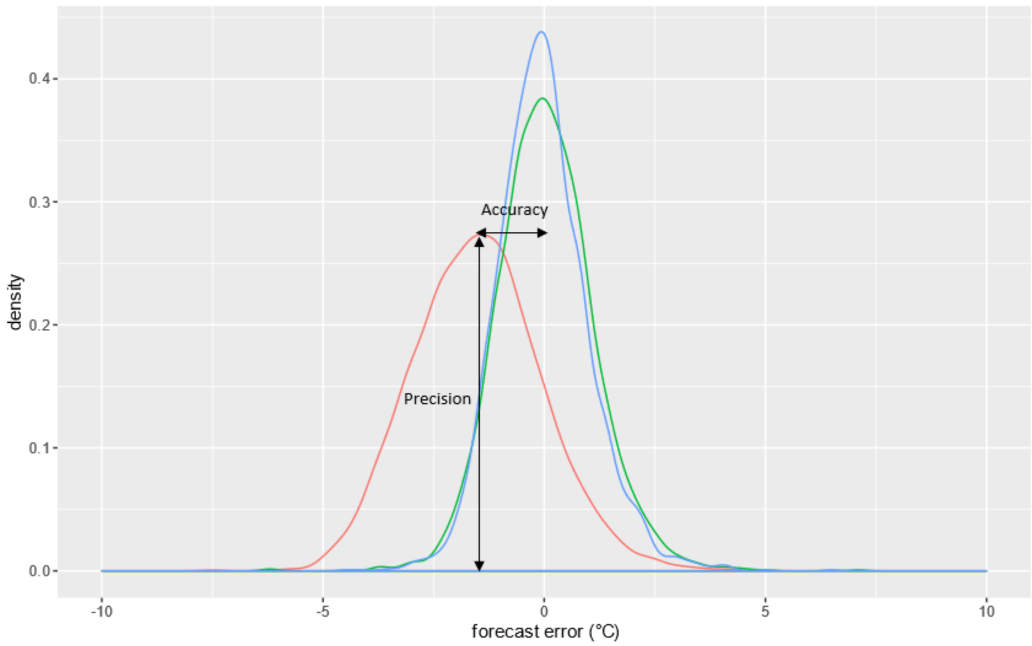
This section contains a selection of temperature forecasting performance insights for Winter 2022 in the NEM. Results supporting major insights are included in this section, with additional results included in appendices A1 and A2. This report studies temperature forecast performance at the 1, 4, 24, and 72 HA rolling forecast horizons.

Guide to interpreting error density plots

Many of the results in this section and in Appendix A1 are displayed as error density plots, like Figure 3 below. These figures can be interpreted as follows:

- The **x-axis shows forecast error**. Positive values indicate over-forecasting (the forecast temperature exceeded the actual temperature), and negative values indicate under-forecasting (the forecast temperature was lower than the actual temperature).
- The **y-axis shows error density**. This reflects the relative rate of a forecast error occurring. For each forecast error, the error density will be between 0 and 1, and the area under each curve equals 1.
- The **height of the error density peak captures the level of forecast precision**. The higher the peak, the greater the forecast precision and the smaller the expected deviation from the level of error. In Figure 3, the forecast distribution in blue has the highest precision and the forecast distribution in red has the lowest precision.
- The **position of the peak captures the forecast accuracy** with respect to a forecast error of zero. The further the peak is from zero error, the lower the accuracy, and the larger the tendency for over- or under-forecasting on average. In Figure 3, the forecast distribution in red is less accurate than the forecast distributions in green and blue.

Figure 3 Accuracy and precision in the error density plot – example



Appendix A2 contains intraday mean absolute error (MAE) profiles for weather stations as well as net forecast bias profiles. The net forecast bias profiles show the net number of days where each hourly interval was either negative (actuals greater than forecast) or positive (actuals less than forecast) assessed over the coldest 10% of days. The net forecast bias and MAE do not explicitly feature in the main report. Forecasts are provided for each hour of the day and for each provider.

2.1 Overall performance

Weather conditions in Winter 2022

In 2022, the national mean temperature exceeded the 1961-1990 average by 0.36° Celsius (C), with areas including south-east Australia, Cape York Peninsula and Gulf Country in Queensland recording above average maximum temperatures. Meanwhile, southern Queensland and the adjacent inland northern New South Wales experienced cooler than average maximum temperatures. Mean minimum temperatures were also well above average for Cape York Peninsula and Gulf Country in Queensland while central and north-eastern South Australia recorded cooler than usual minimums.

A strong cold front affected south-eastern Australia in early June and brought cool conditions in the unstable south-westerly air stream. This drove maximum temperatures 2-3°C below average over large areas of the south-east, including record low maximum temperatures in Tasmania on 7 and 8 June 2022.

In Queensland on Monday 4 July, the Winter peak operational demand reached a record 8,716 megawatts (MW) with a maximum temperature of 14.0°C observed at Archerfield. This was the second time during Winter 2022 that the 2008 record Winter demand of 8,212 MW was exceeded. In late winter, the ever-increasing installed capacity of distributed photovoltaic (DPV) systems coincided with favourable conditions and facilitated a record NEM winter minimum operational demand on Sunday 28 August of 14,159 MW. This was coincident with South Australian and Victorian minimum operational demand records, which were driven by mild maximum temperatures of 22.3°C at Adelaide West Terrace and 20.8°C at Melbourne OP.

Winter 2022 rainfall was 4% above average for Australia as a whole. Flooding affected Gippsland (Victoria) and north-eastern Tasmania during early June and the first half of August. An east coast low brought significant flooding to Sydney and surrounding areas of New South Wales during early July, and daily rainfall records were set at many stations including 305.0 mm at Taree Airport on 7 July 2022 (Bureau of Meteorology, 2022)[8].

Overall Winter 2022 performance insights

Figure 4 and Figure 5 show the performance comparison of 2021 and 2022 Winter periods across all studied weather stations for Providers A and C. Provider B was analysed in the Winter 2022 period only, as they were onboarded in February 2022. Key insights include:

- **Provider B demonstrated the most accurate and precise overall performance**. This was observed for the 4, 24 and 72 HA horizons across all temperatures in Winter 2022, as well as when considering performance at the lowest 10% of temperatures. Provider B however demonstrated the lowest precision and accuracy in the 1 HA forecast horizon.

8 Bureau of Meteorology (2022). *Australian seasonal summary*. [online] Australian Government Bureau of Meteorology. Available at http://www.bom.gov.au/clim_data/IDCKGC2AR0/202208.summary.shtml. Accessed 29 December 2022.

- **Compared to Winter 2021, Provider A improved while the performance of Provider C degraded in the 1 HA forecast horizon.** Provider A had the greatest improvement in the 1 HA forecast horizon, whilst the performance of Provider C degraded. In Winter 2022, the performance of Provider A and C across all other forecast horizons were consistent with their respective Winter 2021 performances.
- **At the lowest 10% of temperatures, all providers showed a tendency to over-forecast** across the 4, 24 and 72 HA rolling forecast horizons in Winter 2022 (Figure 4, Figure 5). This tendency also occurred at the lowest 10% of temperatures in Winter 2021 for Provider A and Provider C (Figure 5). Provider B was newly assessed in Winter 2022 and exhibited a similar over-forecasting bias to Provider C.
- **Penrith Lakes continued to be the most challenging station to forecast.** All providers exhibited lower precision at Penrith Lakes compared to other sites when assessed over all temperatures, as in Winter 2020 and Winter 2021. The precision of Provider A improved slightly in the 1 HA and 4 HA forecast horizon performance in Winter 2022 compared to Winter 2021.

Figure 4 Winter 2021 and 2022 performance comparison across major weather stations, all providers, all temperatures

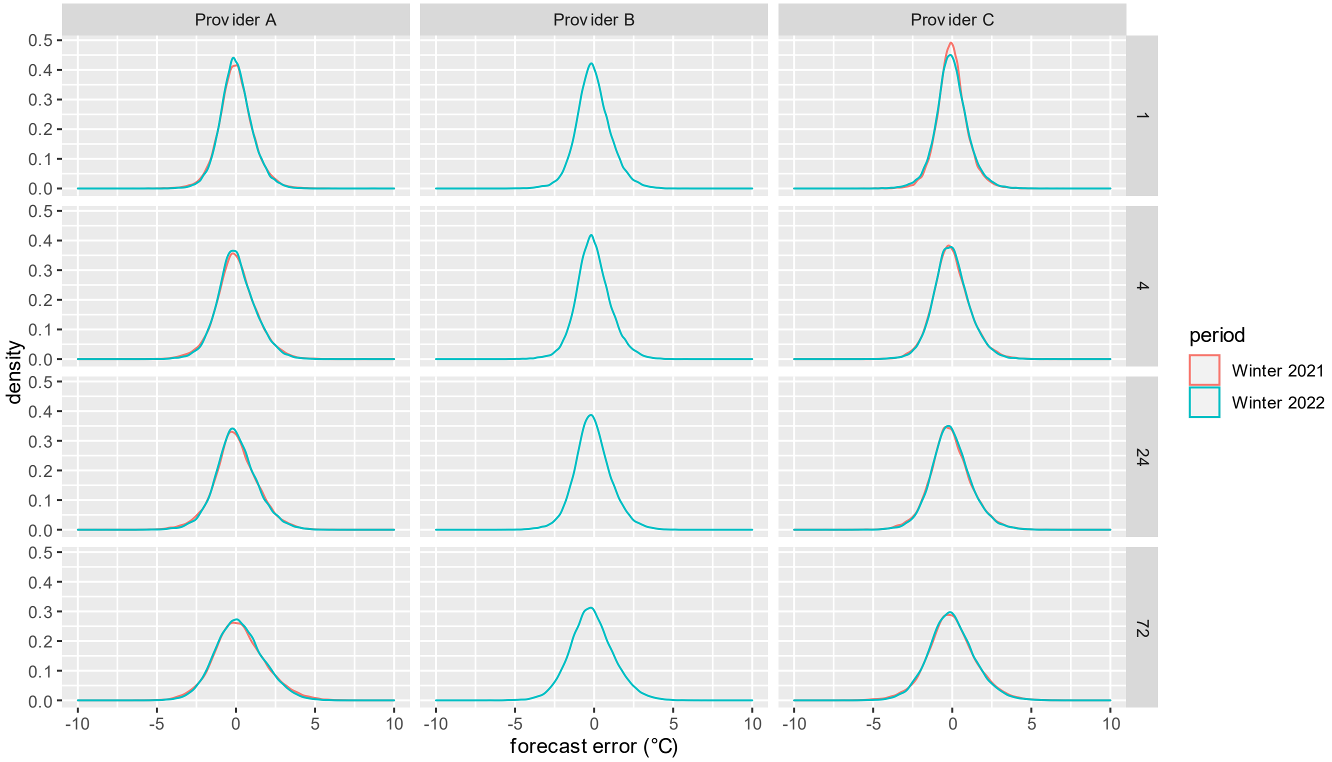
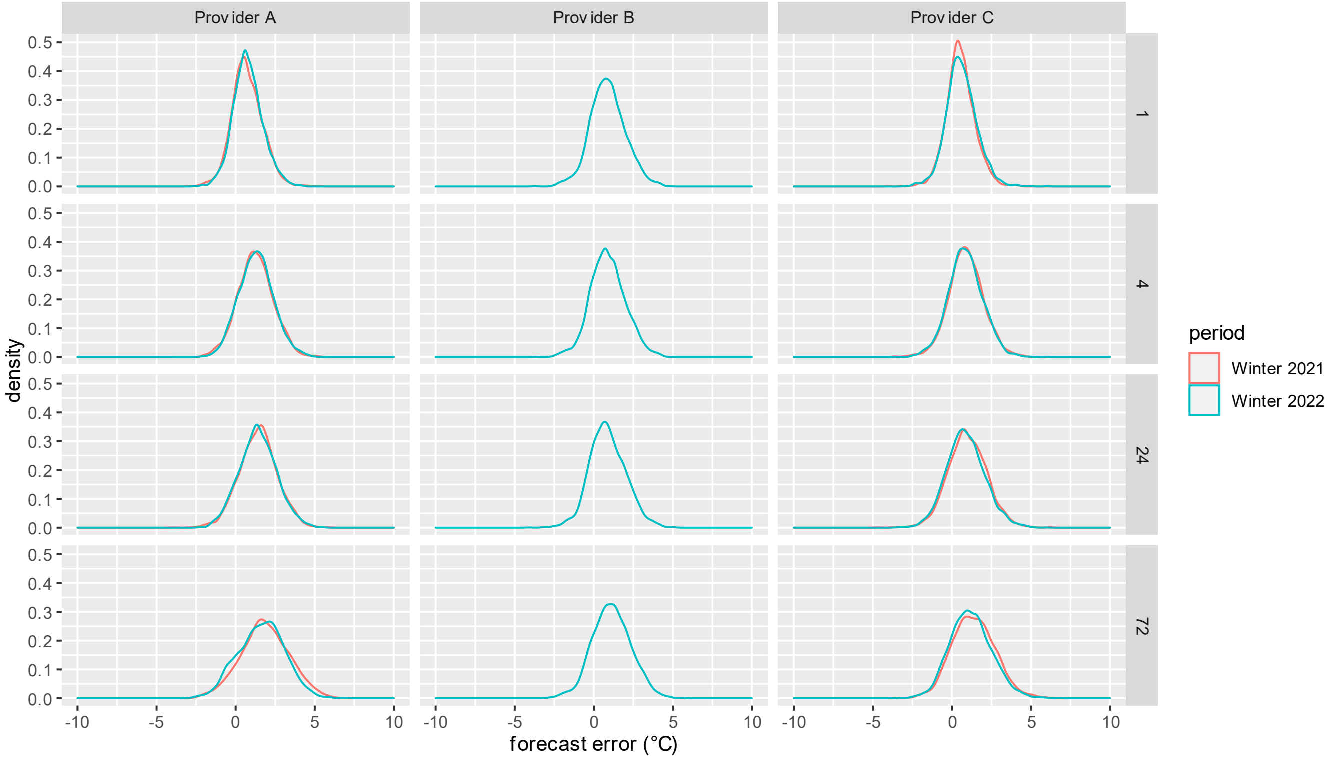


Figure 5 Winter 2021 and 2022 performance comparison across major weather stations, all providers, lowest 10% of temperatures



2.2 Provider B forecast performance

Provider B had the most accurate and precise performance overall, but underperformed in the 1 HA forecast horizon.

Provider B performed best overall in Winter 2022 in terms of accuracy and precision across the 4, 24 and 72 HA rolling forecast horizons, as seen in Figure 6. This outperformance of the other providers was observed across all stations for the 4 and 24 HA forecast horizons, and across the 72 HA with only two exceptions: Hobart and Penrith Lakes.

Provider B also exhibited the best overall performance in extreme cold temperatures in the 4, 24 and 72 HA forecast horizons (Figure 7). The performance of Provider B was outstanding in terms of precision and accuracy at Adelaide West Terrace (Figure 8) compared to the other providers when assessed over all temperatures.

Provider B underperformed, however, in the 1 HA ahead forecast horizon across all stations, and this underperformance was exacerbated in extreme cold temperatures (Figure 7). It was noted by users of the forecast feeds that Provider B tended not to auto-regress to recent observations, a strength when riding through mesoscale conditions such as showers driving sub-1 HA temperature variability, but a weakness when handling synoptic situations such as a cool change.

Provider B is currently exploring model updates to optimise the 1 HA forecast horizon while retaining the skill the model has 4 HA and beyond.

Figure 6 Winter 2022 performance comparison across major weather stations, all providers, all temperatures

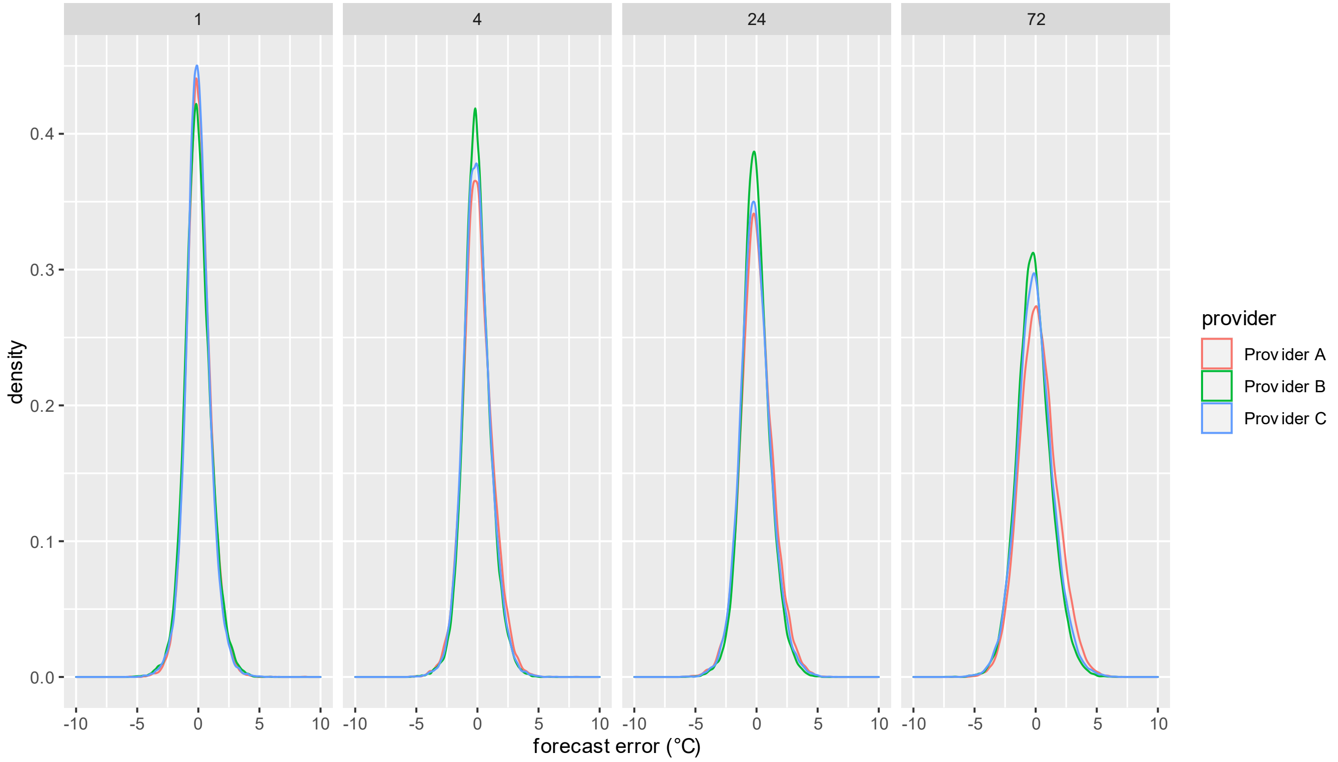


Figure 7 Winter 2022 performance comparison across major weather stations, all providers, lowest 10% of temperatures

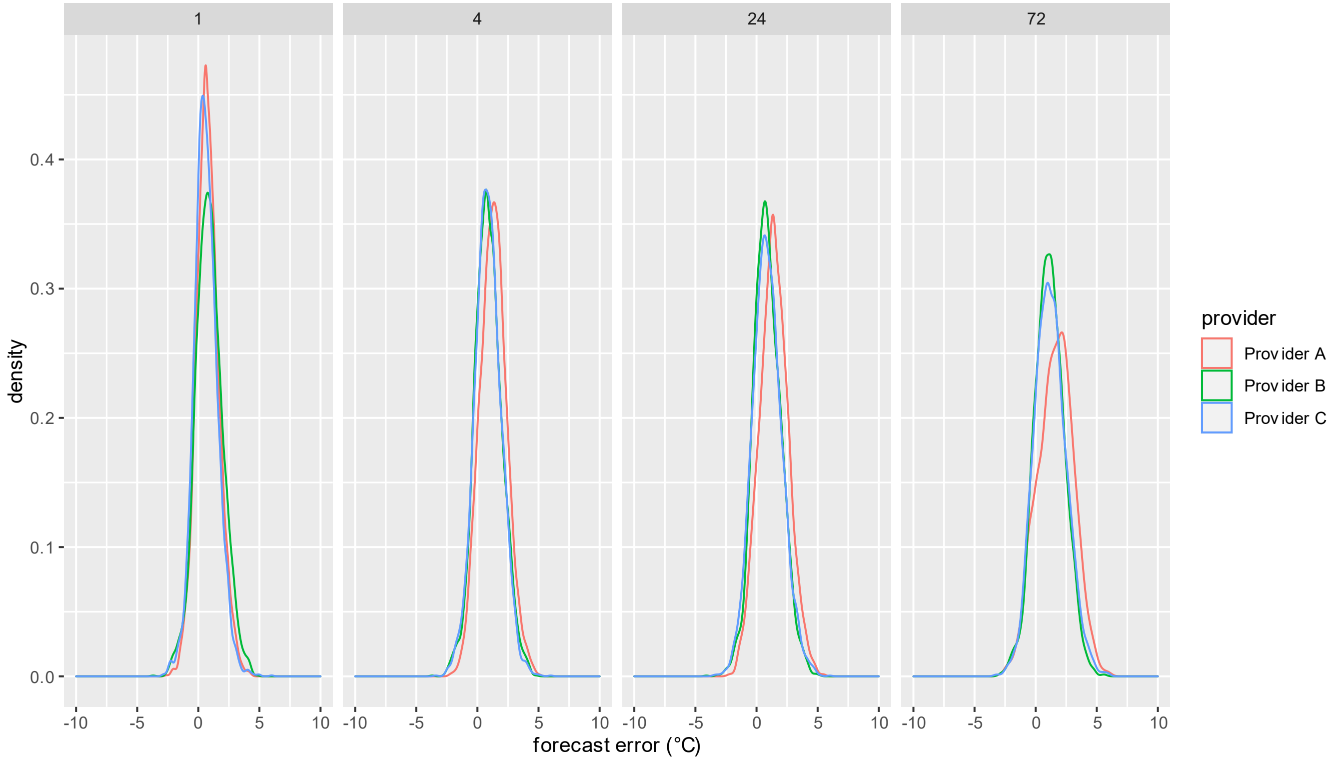
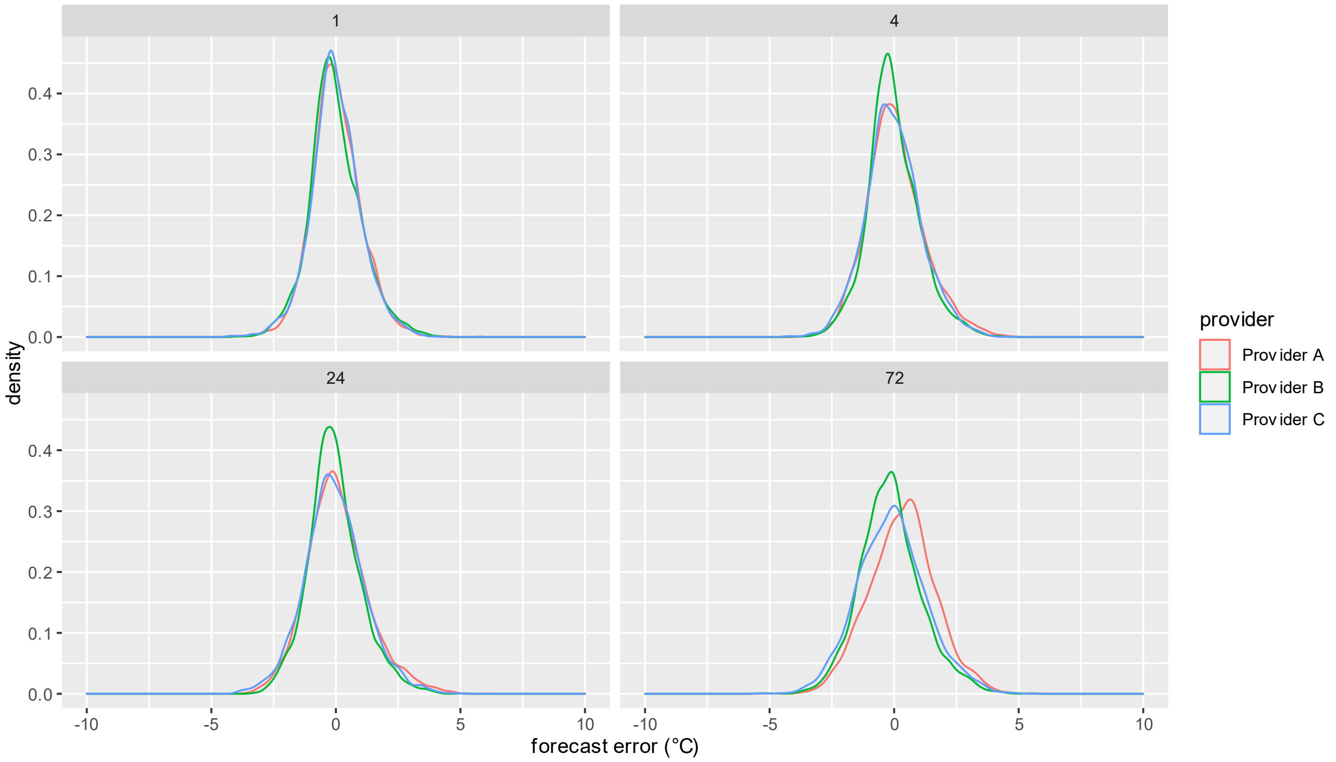


Figure 8 Winter 2022 performance comparison at Adelaide West Terrace, all providers, all temperatures



2.3 Performance of Provider A and Provider C

Provider A had the greatest improvement in the 1 HA forecast horizon compared to Winter 2021, while the performance of Provider C degraded. The performance of Provider A and Provider C in 2022 across all other forecast horizons was largely consistent with their respective 2021 performances.

Provider A demonstrated a marginal improvement in forecasting precision across all forecast horizons, most notably the 1 HA as seen in Figure 4. This follows a significant improvement in accuracy and precision from 2020 to 2021[9]. Provider A was the most precise when forecasting extreme cold temperatures in the 1 HA forecast horizon, surpassing the precision of Provider C.

Provider A maintained and slightly improved on its performance for all temperatures and extreme cold temperatures from the 2021 season. However, there was a marked reduction in forecast accuracy between Winter 2020 and Winter 2021[10] when forecasting the lowest 10% of temperatures. Thus Provider A has reduced accuracy in both Winter 2022 and Winter 2021 when compared to Winter 2020.

The reduction in the performance of Provider C in forecasting extreme cold temperatures was only visible in the 1 HA forecast horizon (Figure 5) and there was a similar degradation in the 1 HA performance assessed over all temperatures (Figure 4). The performance of Provider C was otherwise consistent between Winter 2021 and

[9] Temperature Forecast Analysis for Winter 2021, at https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/operational-forecasting/load-forecasting-in-pre-dispatch-and-stpasa.

Winter 2022. Precision and accuracy in forecasting temperatures at Melbourne OP was observed for both Provider A and Provider C in Winter 2022 compared to Winter 2021 (Figure 9, Figure 10).

Figure 9 Major weather stations, Provider A, all Winter temperatures 2021 and 2022, 24 HA

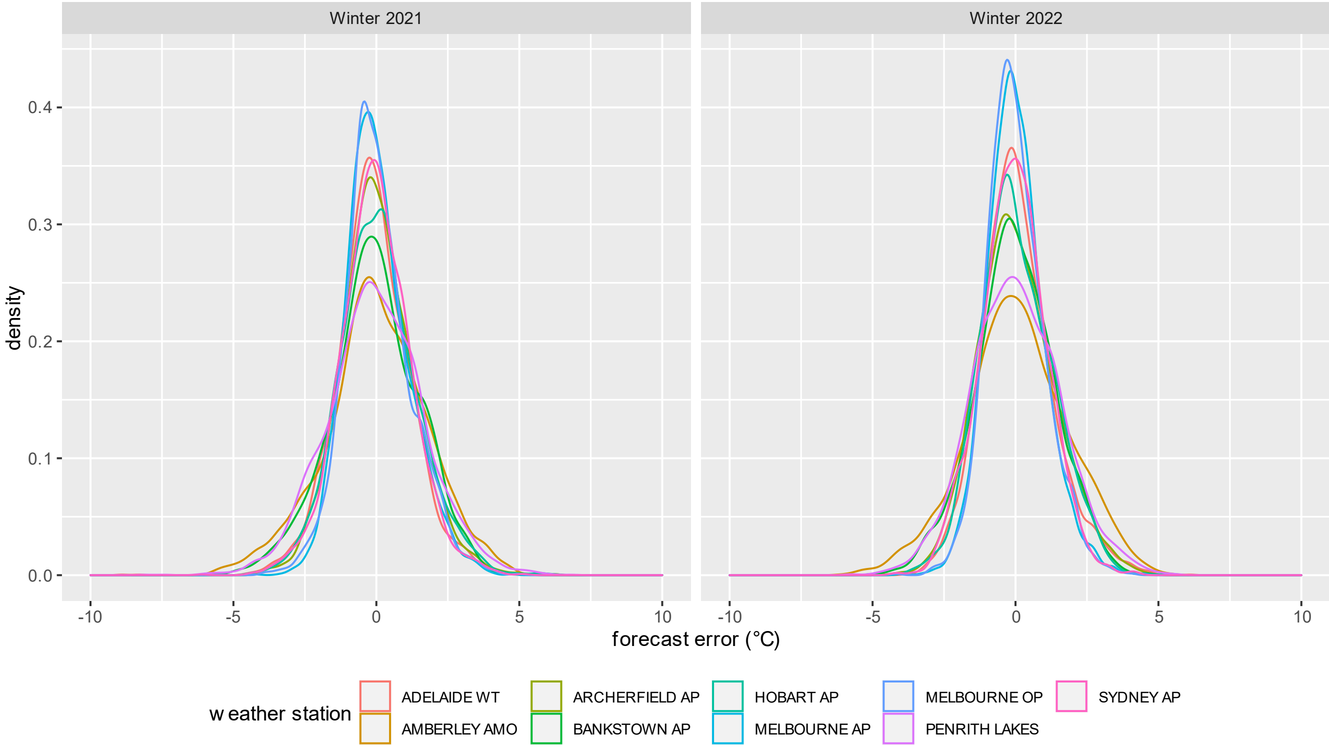
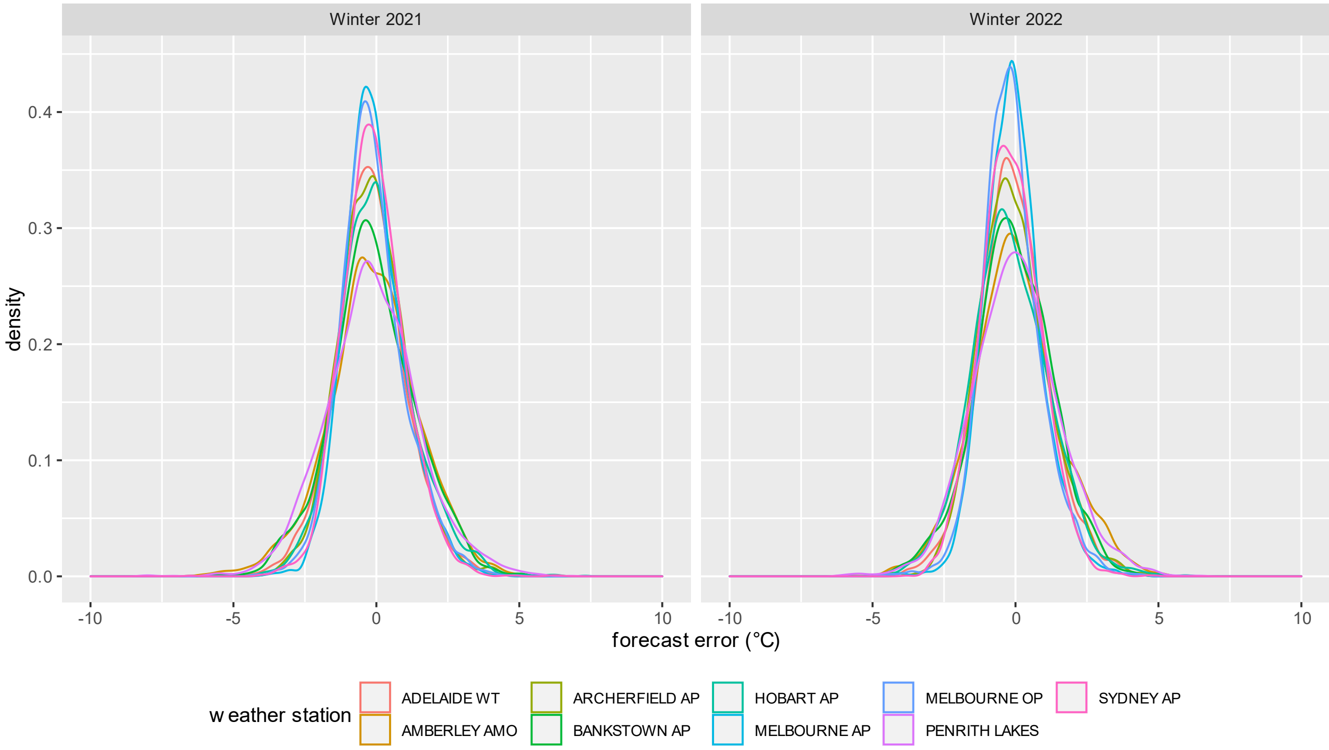


Figure 10 Major weather stations, Provider C, all Winter temperatures 2021 and 2022, 24 HA



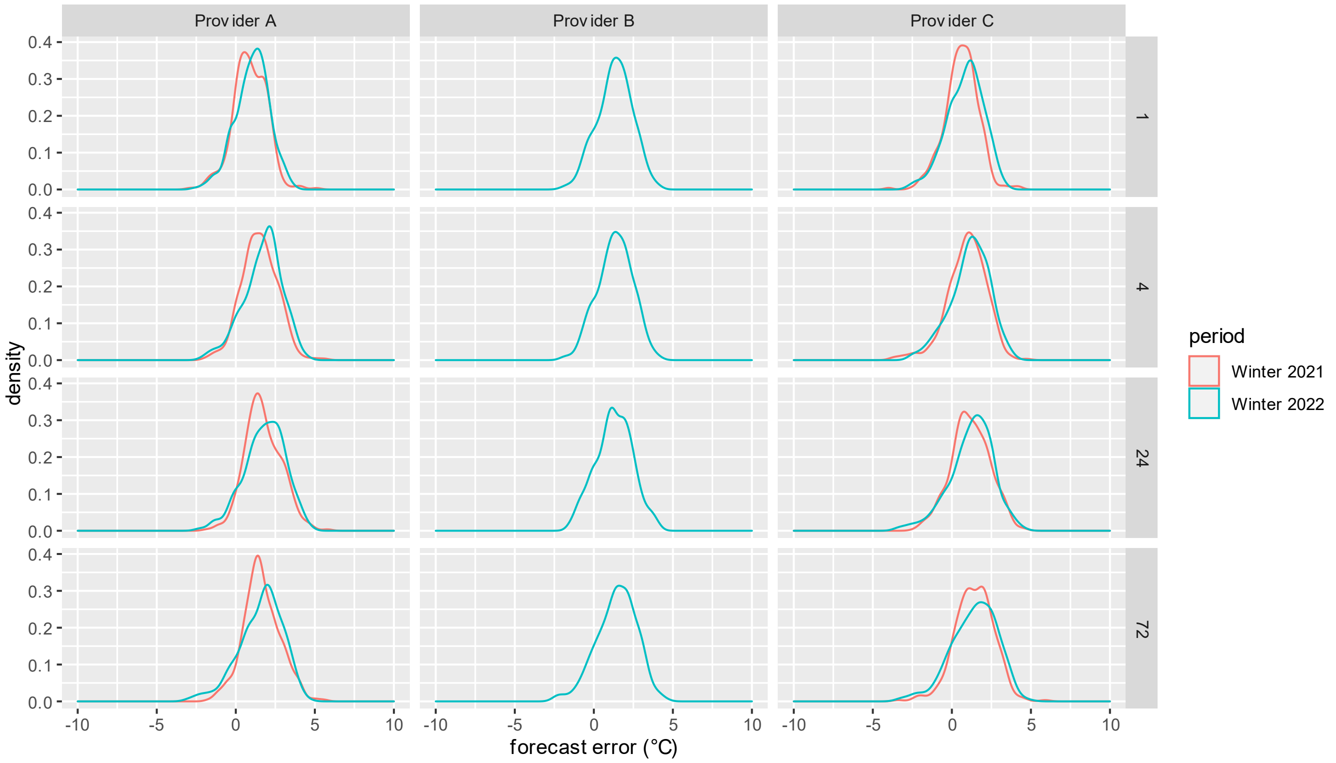
2.4 Systematic over-forecasting of extreme cold temperatures

A systematic over-forecasting bias is evident for all providers in extreme cold temperatures

Error density plots were reasonably centrally distributed in Winter 2021 and 2022 when assessed over all temperatures, however a systematic over-forecasting bias is observed for all providers in the bottom 10% of temperatures in both periods. Provider A and Provider C both exhibited respective biases of consistent magnitude between the 2021 and 2022 seasons. Provider B, newly assessed in 2022, had an over-forecasting bias of similar magnitude to Provider C in the 4, 24, and 72 HA forecast horizons, with a more exacerbated over-forecasting bias in the 1 HA forecast horizon (Figure 5).

Provider A notably exhibited the largest over-forecasting bias in 2022 bottom 10% of temperatures, departing from the performance of Provider B and Provider C significantly in the 72 HA forecast horizon (Figure 5). The over-forecasting bias was largest at Adelaide West Terrace in extreme cold temperatures for all providers, with performance degrading between Winter 2021 and Winter 2022 for Provider A and Provider C (Figure 11).

Figure 11 Winter 2021 and 2022 performance comparison at Adelaide WT, all providers, all temperatures



2.5 Penrith Lakes continues to be challenging to forecast in Winter

In the Temperature Forecast Analysis for Winter 2020 and 2021 reports[10], Penrith Lakes was identified as being one of the most challenging weather stations to forecast.

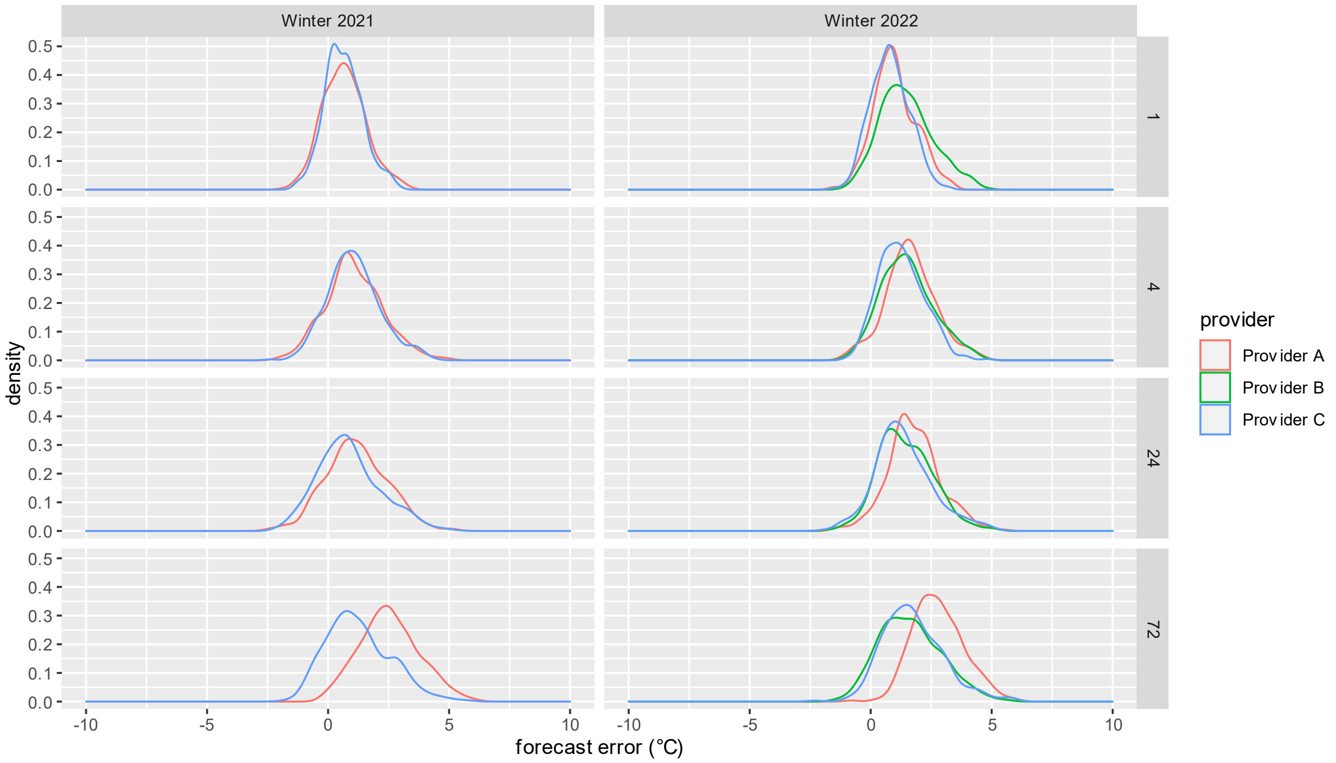
In Winter 2022, Penrith Lakes was again identified as the location forecast with lowest precision compared to other sites for Provider B and Provider C, and second lowest for Provider A.

[10] Temperature Forecast Analysis for Winter 2021 available at https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/operational-forecasting/load-forecasting-in-pre-dispatch-and-stpasa.

In comparison to Winter 2021 performance:

- A slight improvement in forecast precision was observed for Provider A in the 1 HA and 4 HA forecast horizons.
- The performance change for Provider C was immaterial (Figure 12).
- The 2022 analysis was the first Winter assessment period to include Provider B, thus their performance cannot be benchmarked against previous seasons.

Figure 12 Winter 2021 and 2022 performance comparison at Penrith Lakes, all providers, lowest 10% of temperatures



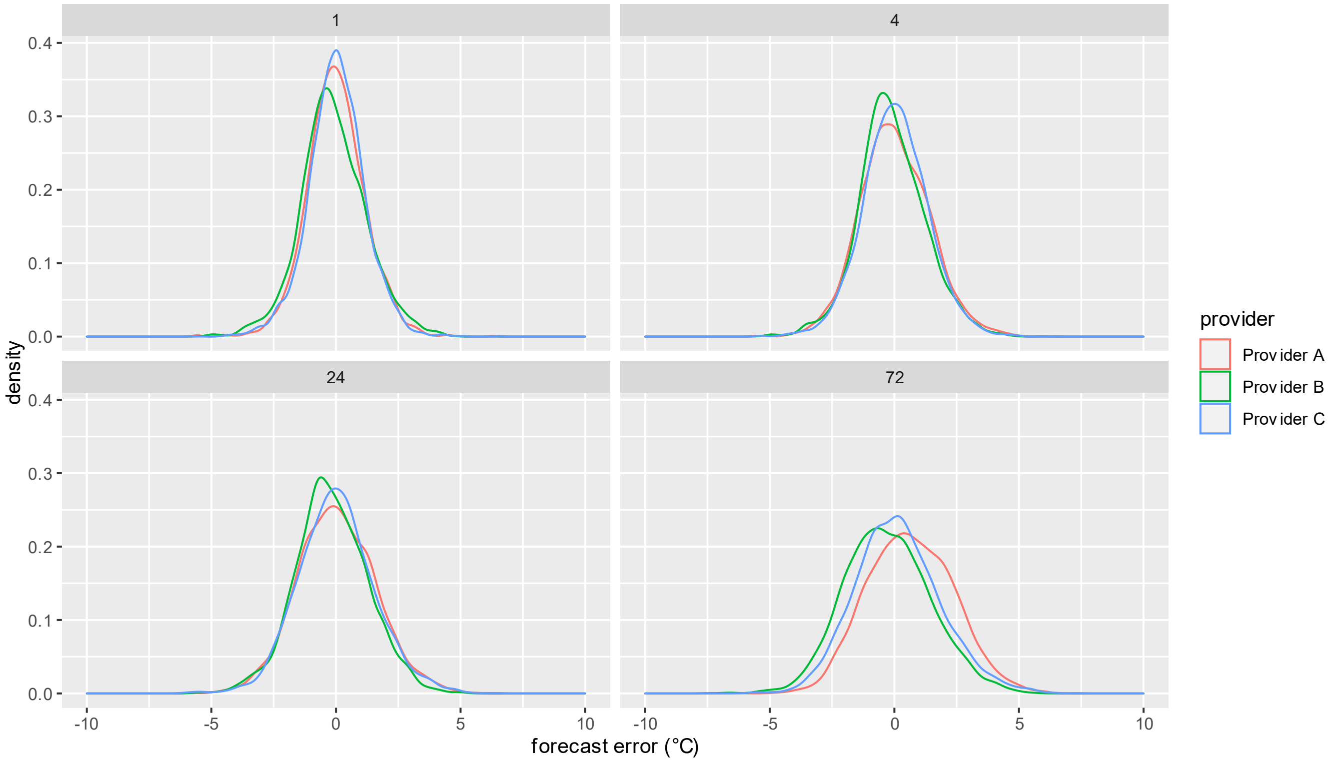
In Winter 2022 the newly onboarded Provider B was identified as having the highest precision in the 4 HA and 24 HA forecast horizons, coincident with the largest under-forecasting bias (Figure 13). In the 1 HA and 72 HA forecast horizons, Provider C had the highest precision coincident with the lowest bias (Figure 13).

In extreme cold temperatures, temperature forecast precision at Penrith Lakes was more comparable to each of the providers respective model skill at other sites:

- Performance at Penrith Lakes in extreme cold temperatures was much lower than Sydney AP.
- Provider B exhibited the lowest precision forecasting the bottom 10% of temperatures across all forecast horizons, a contrast to its strong performance aggregated over all sites (Figure 12).

Complex topographical influences on weather may contribute to reduced model performance at the location. Because the temperature at Penrith Lakes was identified as the most coupled to New South Wales residential demand of all major New South Wales stations at 29.3% (Sydney AP was second at 23.0%), an improvement in forecast performance at this location is desirable.

Figure 13 Winter 2022 performance comparison at Penrith Lakes, all providers, all temperatures



2.6 Intraday insights

These insights were derived from Intraday MAE profiles, and the Net Forecast Bias profiles. The MAE profiles show the magnitude of the absolute average error for each hourly interval, while the Net Forecast Bias profiles show the aggregate net count of days where each hourly interval was either negative (actuals greater than forecast) or positive (actuals less than forecast).

The 1 HA forecast horizon was analysed for Provider B, because this was the only forecast horizon in which its precision and accuracy was outperformed when assessed across all stations by Provider A and Provider C. The MAE of Provider B was higher than the other providers between midnight and 7.00 am at Archerfield, Hobart AP West, Penrith Lakes and Adelaide West Terrace. This is coincident with the expected time of minimum temperature and shows Provider B had a particular weakness during the early hours of the morning in the 1 HA forecast horizon at these locations.

An increase in MAE by Provider A was observed at Amberley AP between midnight and 8.00 am for the 4, 24 and 72 HA forecast horizons that was quite anomalous to Provider A's MAE during the rest of the day (Figure 14). This was observed across all temperatures as well as when isolating the analysis to the bottom 10% of coldest days.

For the coldest 10% of days, all providers were observed to have a net positive forecast bias around the time of maximum temperature and a net negative forecast bias around the time of minimum temperature across all stations. This was particularly pronounced for Amberley, as seen in Figure 15, with Provider B exhibiting the largest net error at this station during the morning and midday hours.

MAE profiles for major weather stations can be seen in Appendix A2.

Figure 14 Amberley Airport, intraday MAE profile, all providers, Winter 2021 and 2022, all time horizons, all temperatures

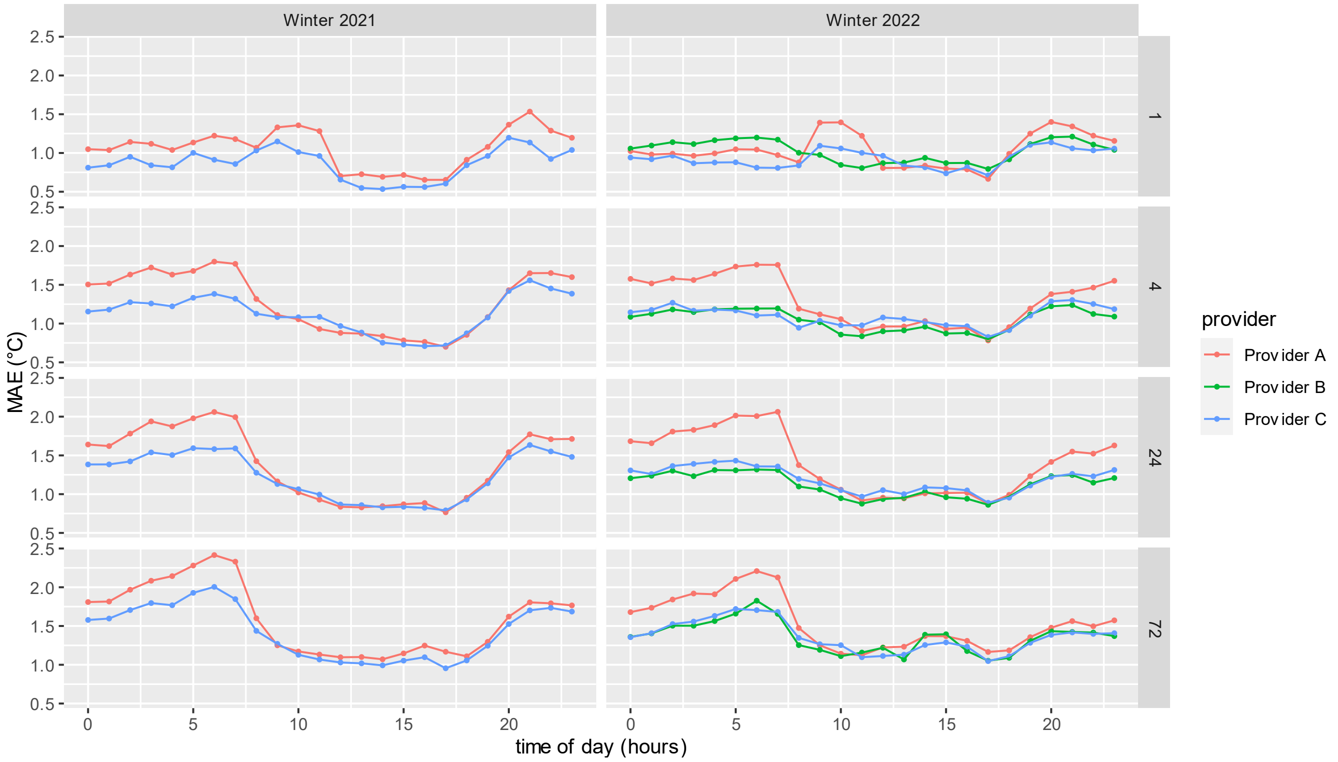
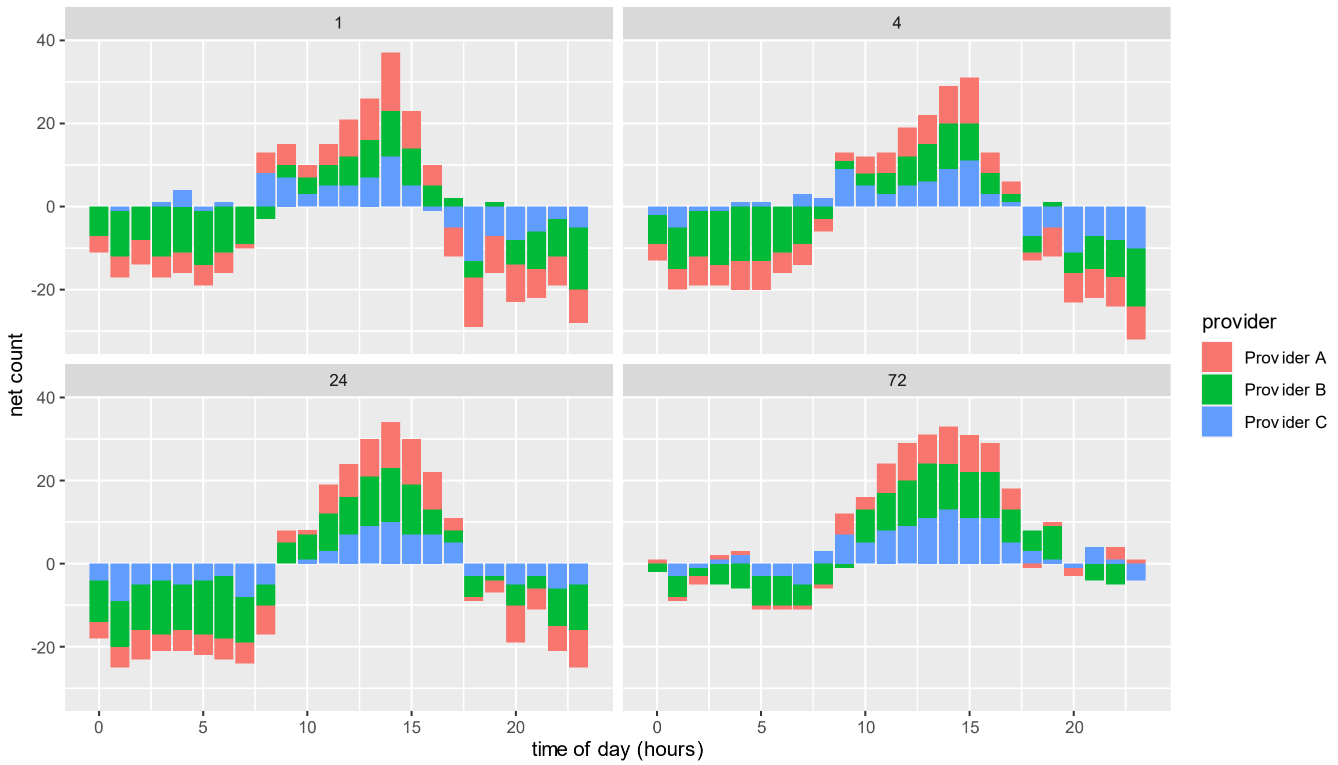


Figure 15 Amberley Airport, net forecast bias, all providers, coldest 10% of days



3 Case study: Queensland on 4 and 5 July 2022

This case study:

- Explores the temperature forecasts of sequential cold days in Queensland on Monday 4 July and Tuesday 5 July 2022, and the subsequent impacts on demand forecasting and supply management.
- Demonstrates the impact on demand forecasting when a combination of error attributions – such as inaccurate temperature forecasts at both the long- and short-term horizons, DPV deviations, and inherent model deviations – coincide.

AEMO is continuing to work with the weather forecasting industry to develop tools to provide situational awareness in the near term to improve forecasting techniques.

Temperature forecasts and outcomes

In July 2022, Queensland observed cooler than average daytime temperatures across most of the region, making it overall the coolest winter since 2007. Monday 4 July and Tuesday 5 July 2022 were the two coldest days of the month, with some sites experiencing their lowest July mean daily temperature on record or their lowest July mean daily maximum temperature for at least 20 years.

On 4 and 5 July 2022, Archerfield AP reached a maximum temperature of 14.0 °C and 13.5°C, respectively, and Amberley reached 13.1°C and 13.7°C, respectively. Archerfield AP and Amberley are two of the heaviest weighted weather stations in the southern Queensland demand forecast model due to the proximity of these stations to major load centres. The accuracy of the temperature forecasts at these stations therefore has the largest impact on the demand forecast.

On 4 July 2022, the morning temperatures at both Archerfield AP and Amberley were significantly under-forecast in the 4 and 24 HA horizons by all weather providers. Provider A and C began to adjust in the 1 HA horizon, however Provider B remained at a similar under-forecast level in the 1, 4 and 24 HA horizons. During the middle of the day, the 72 HA horizon was significantly over-forecast, and in the afternoon all providers had difficulty in capturing the lower observed temperatures in all horizons. Evening temperatures were better captured in the shorter horizons, particularly by Provider C at both weather stations.

Similar observations were made on 5 July 2022, however morning temperatures in the shorter horizons at Archerfield AP were captured well by all providers. Evening temperatures were captured well by Provider C at Archerfield AP again, however were under-forecast by all providers at Amberley.

On cold temperature days, operational demand is elevated by increased residential heating load. This impact has shown to be amplified due to increased residential load following changes to working arrangements as a result of COVID-19.

Figure 16 Forecast temperatures at various horizons against actual temperature observations for each provider at Archerfield AP on 4 and 5 July 2022

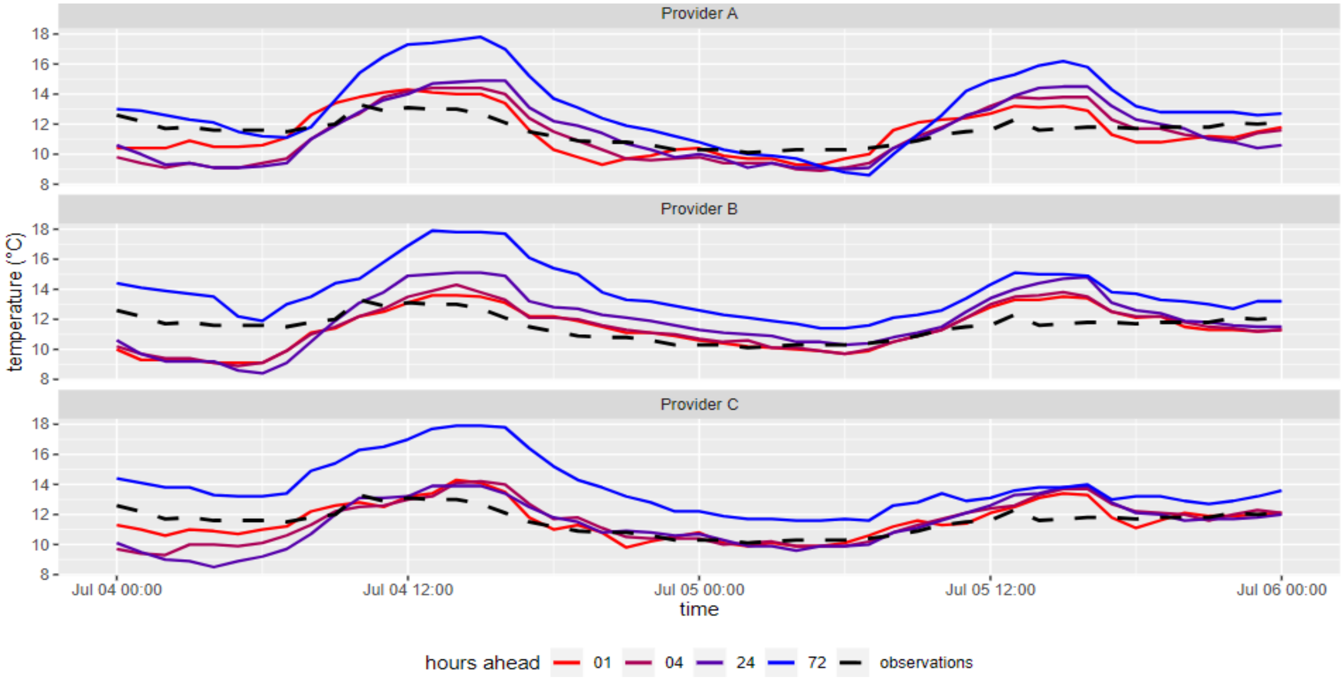
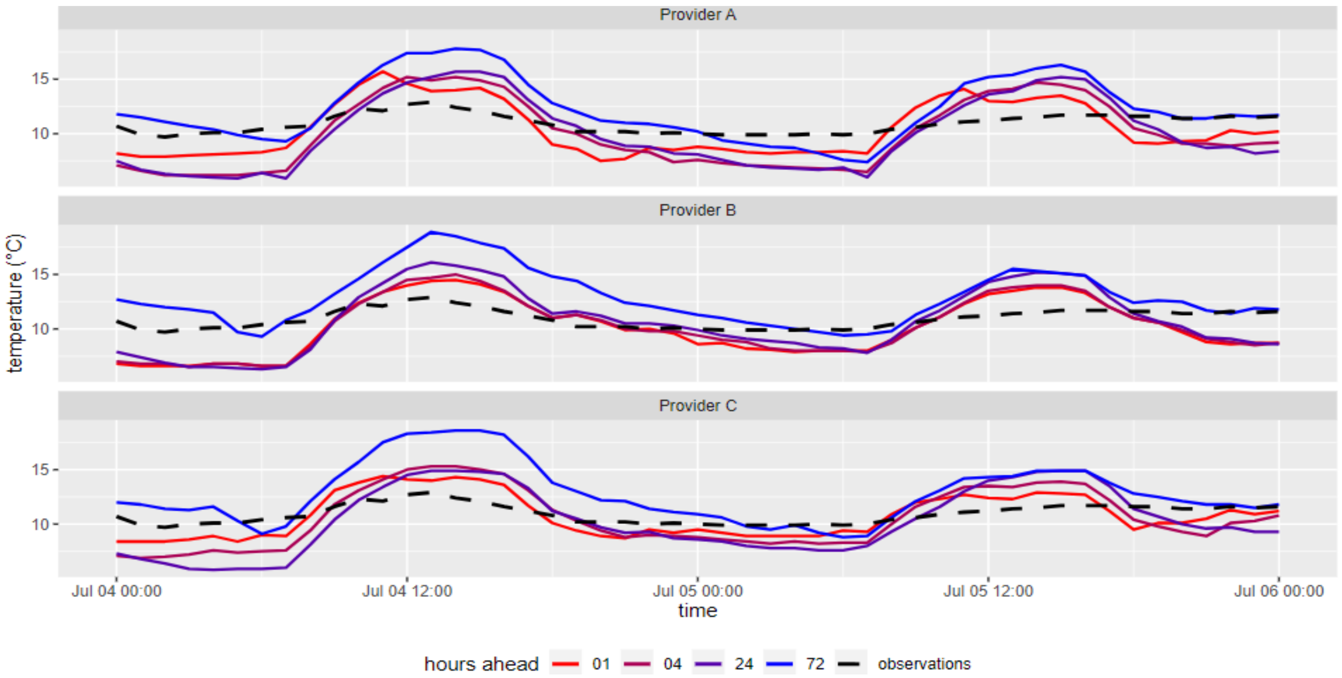


Figure 17 Forecast temperatures at various horizons against actual temperature observations for each provider at Amberley on 4 and 5 July 2022



Demand forecasts and outcomes

The first day of extreme cold conditions (4 July 2022) drove Queensland operational demand to peak at 8,716 MW, surpassing the previous maximum winter operational demand record of 8,255 MW set earlier in winter on 9 June 2022. The record observed on 9 June 2022 was the highest winter demand since 2008, when it reached 8,212 MW. The following day, the peak demand was forecasting a similar demand to the peak on 4 July, however recorded 8,625 MW as it was lowered by the activation of the Reliability and Reserve Trader (RERT)[11] mechanism and demand side response facilitated by Energy Queensland that was activated due to Lack of Reserve (LOR) conditions.

On both days, the main error attributions that contributed to the deviation between forecast and observed demand were model, variability and DPV error.

- Model error is the inherent deviation not captured by the demand forecast model.
- Variability error is defined as the deviations of forecast inputs (such as temperature and humidity).
- DPV error is the deviation of estimated actual DPV generation from the forecast.

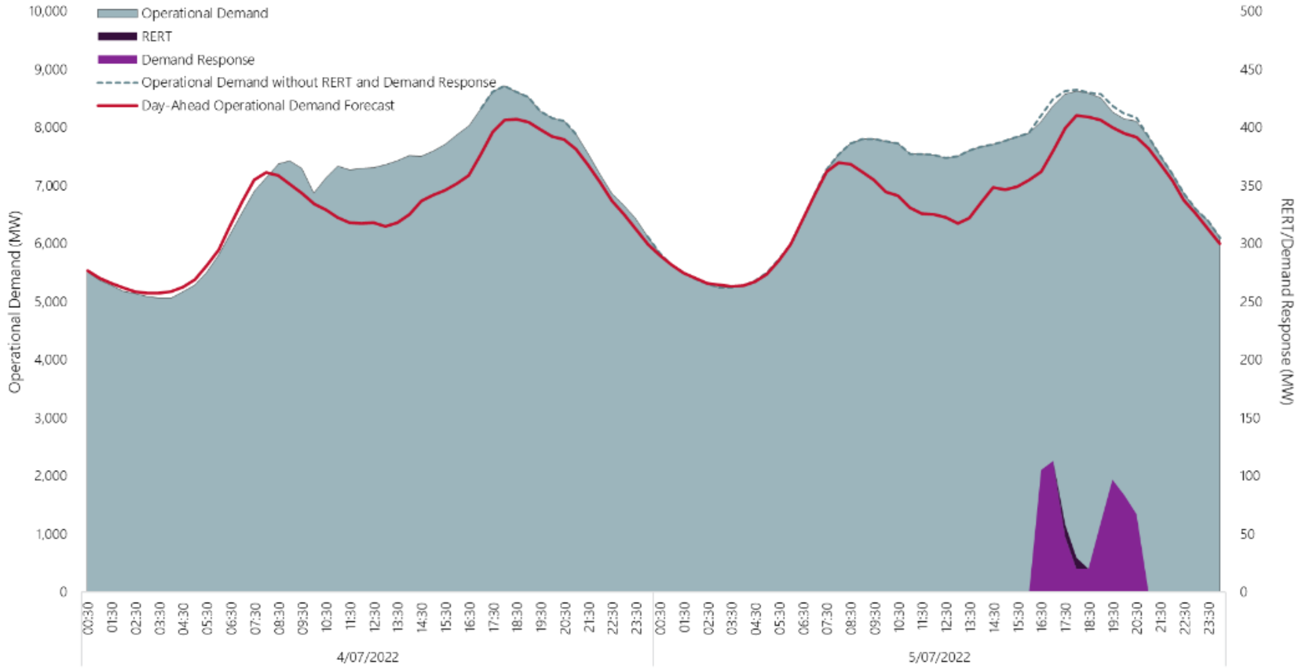
Figure 18 shows the deviation between the day-ahead operational demand forecast and the observed demand in Queensland on 4 and 5 July 2022. On both days, from the morning peak through to the evening peak, operational demand came in higher than the day-ahead forecast. In the morning, operational demand was under-forecast due to a combination of all the errors listed above. As the temperatures were under-forecast across the morning, the variability error balanced out the DPV error (due to cloudier conditions than forecast), with the model error making up the remainder of the deviation.

Across the middle of the day, under-forecasting remained persistent due to all errors and was exacerbated due to the significant over-forecasting of temperatures in all horizons at Archerfield AP and Amberley weather stations.

Leading into the evening peak, variability error continued to play a significant role with temperatures remaining over-forecast in all horizons, particularly on 5 July 2022. The increase in demand due to lower observed temperatures on both days resulted in LOR conditions, which were significant enough to trigger the activation of RERT and demand side response on 5 July 2022.

[11] AEMO, RERT Activation Quarterly Report Q3 2022, at https://aemo.com.au/-/media/files/electricity/nem/emergency_management/rert/2022/rert-activation-quarterly-report-q3-2022.pdf?la=en.

Figure 18 Queensland day-ahead operational demand forecast, observed demand, RERT and demand response on 4 and 5 July 2022



4 Conclusions

The results and insights presented in this report supplement the findings of previous Temperature Forecast Analysis reports and will continue to aid operational forecasting and decision-making at AEMO. This report will be shared with current and intending weather service providers to draw attention to areas of improvement and help assist in benchmarking performance.

The key findings of this report are:

- Provider B was the best performing across 4, 24, 72 HA timeframes, but performed worst in 1 HA timeframe. MAEs examined in the 1 HA time frame revealed that Provider B has a weakness in the early hours of the morning at this timeframe.
- Provider A improved in the 1 HA timeframe compared to Winter 2021, while Provider C's performance degraded in this timeframe. Provider A and Provider C results were otherwise consistent with the Winter 2021 results.
- A systematic over-forecasting bias is evident for all providers in extreme cold temperatures. Adelaide West Terrace exhibited the largest over-forecasting bias of all stations for all providers.
- Penrith continues to be the most challenging location to forecast for all providers and is of key interest to AEMO as it drives the largest residential load in NSW.

AEMO is continuing to work with the weather forecasting industry to ensure weather forecast tools are developed for the purposes of energy forecasting as well as addressing the key challenges identified in this report. Initiatives include:

- Redevelopment of AEMO's Projected Assessment of System Adequacy (PASA) to be probabilistic and include weather uncertainty margins in reserve calculations.
- Enhancing the national observational network around renewable energy zones (REZs) to improve forecasting and situational awareness capabilities in line with anticipated needs of future market operation.
- Developing forecasting tools to increase situational awareness specific to weather risks to power system assets and operation. Including overlaying severe weather risk, alerting for near-term ramping of variable renewable energy (VRE), and classification of day types for managing the impact of DPV variability on power system operations.
- Investigating the direct use of solar irradiance in demand forecasting to capture increased electricity demand due to heat island effects in major metropolitan areas.
- Finalising a review of the provider weightings in the Demand Forecasting System (DFS) with the aim of increasing the contribution of Provider B in the resultant demand forecast.

The next Temperature Forecast Analysis report, focusing on summer 2022-23, will be published later this year.

A1. Error density plots

A1.1 Station comparison by provider

Figure 19 Major weather stations, Provider A, bottom 10% Winter temperatures 2021 and 2022, 24 HA

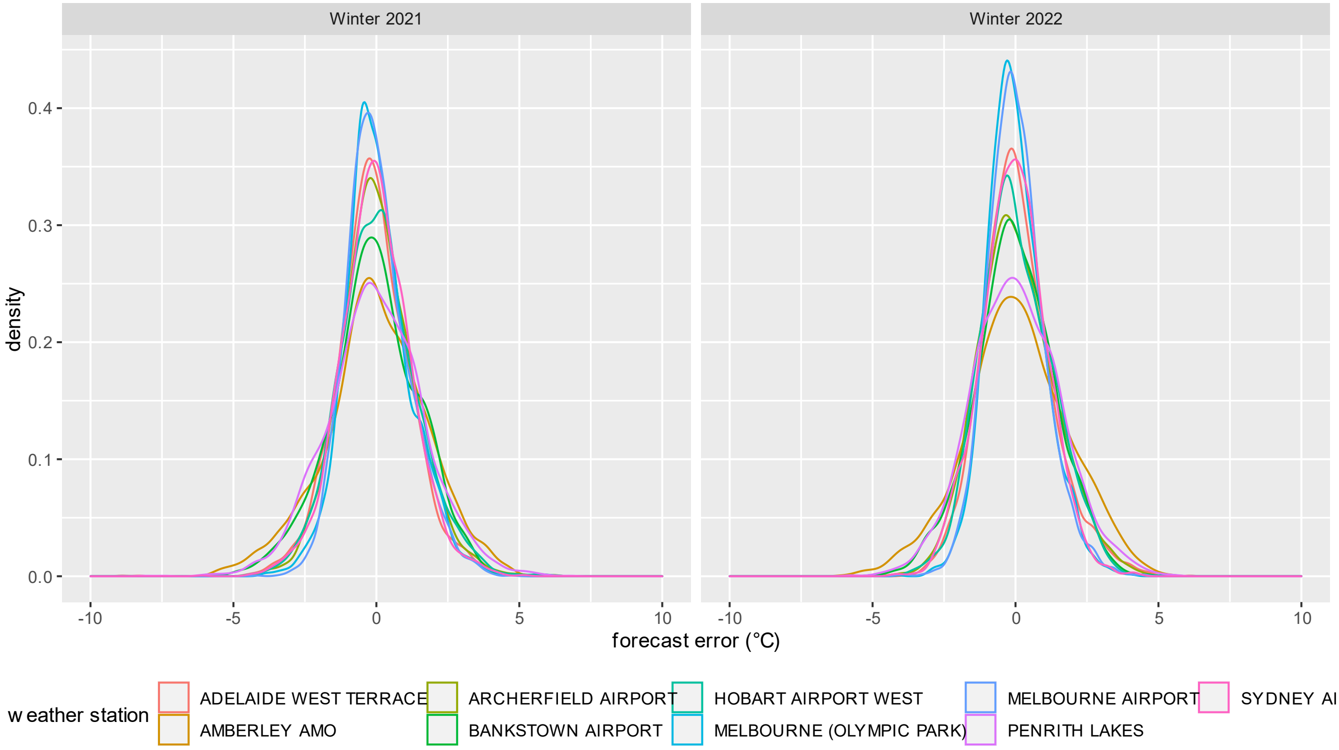


Figure 20 Major weather stations, Provider B, bottom 10% Winter temperatures 2021 and 2022, 24 HA

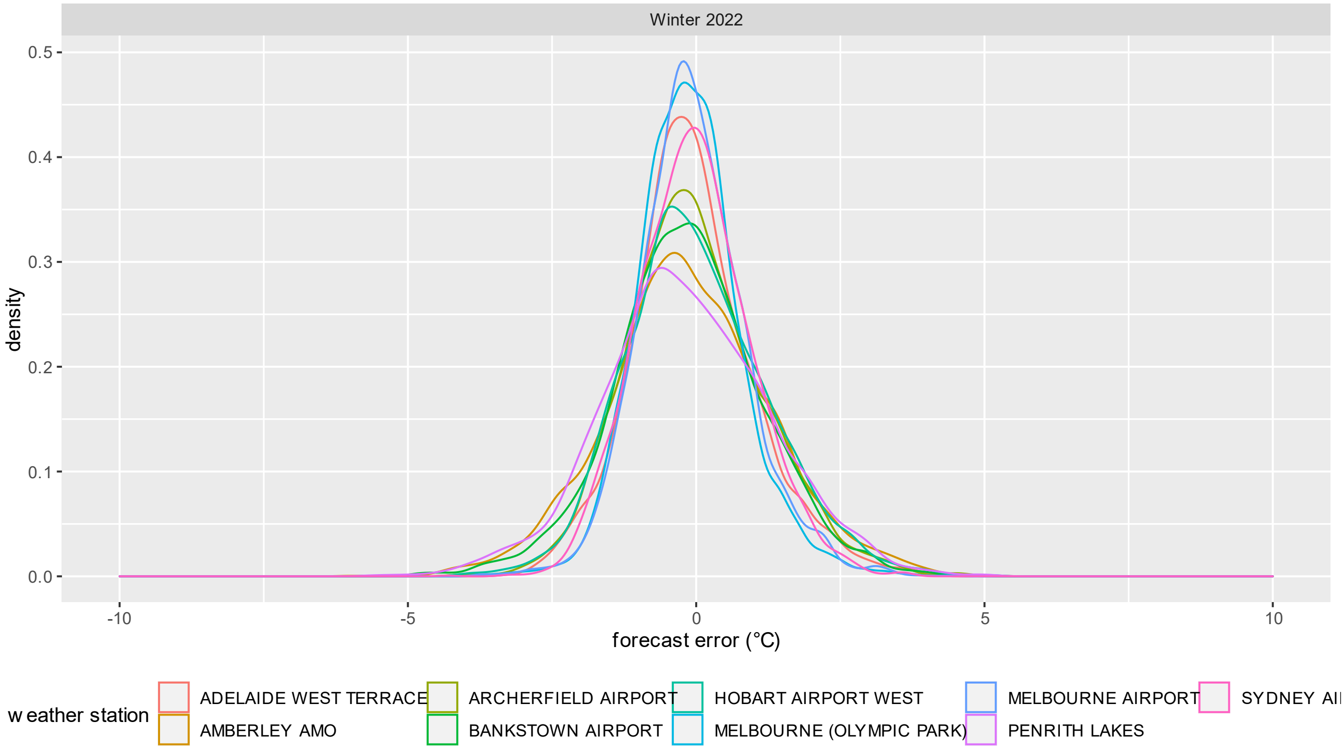
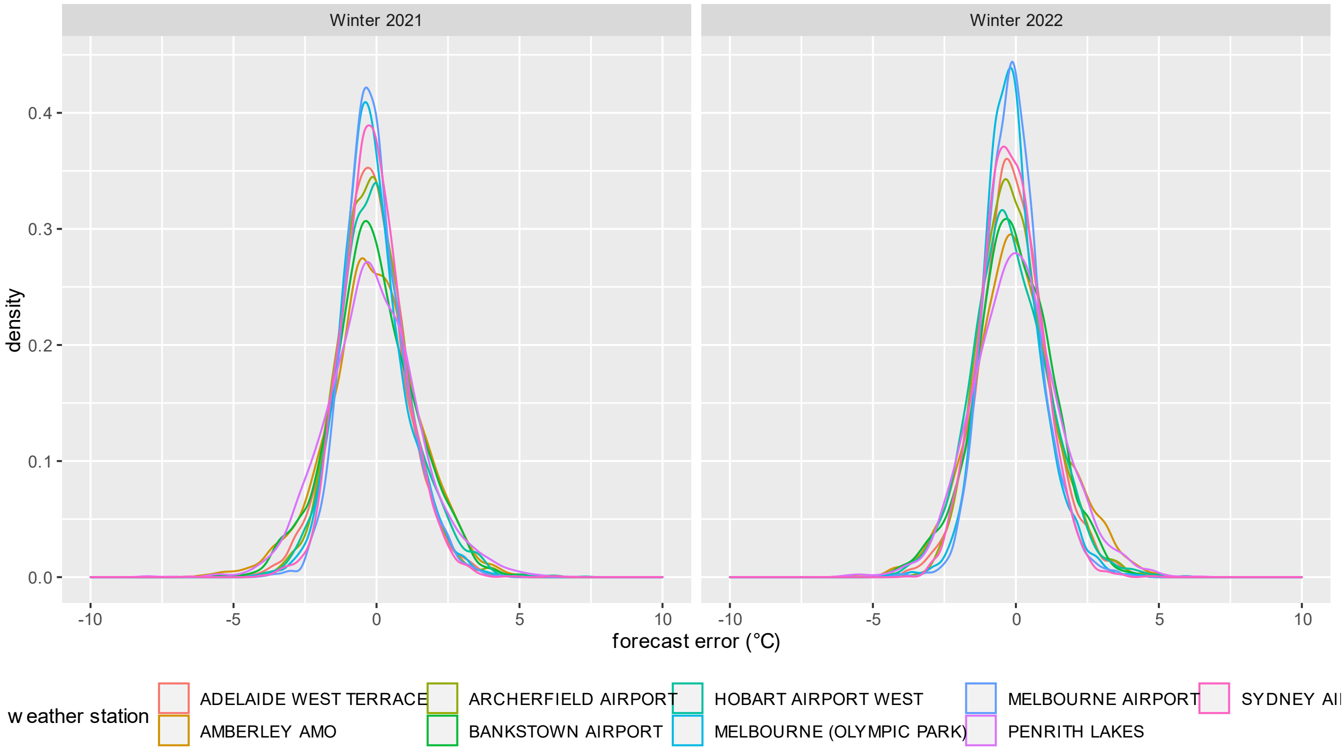


Figure 21 Major weather stations, Provider C, bottom 10% Winter temperatures 2021 and 2022, 24 HA



A1.2 Provider comparison by weather station

Figure 22 Adelaide WT, all providers, all Winter temperatures 2021 and 2022, all time horizons

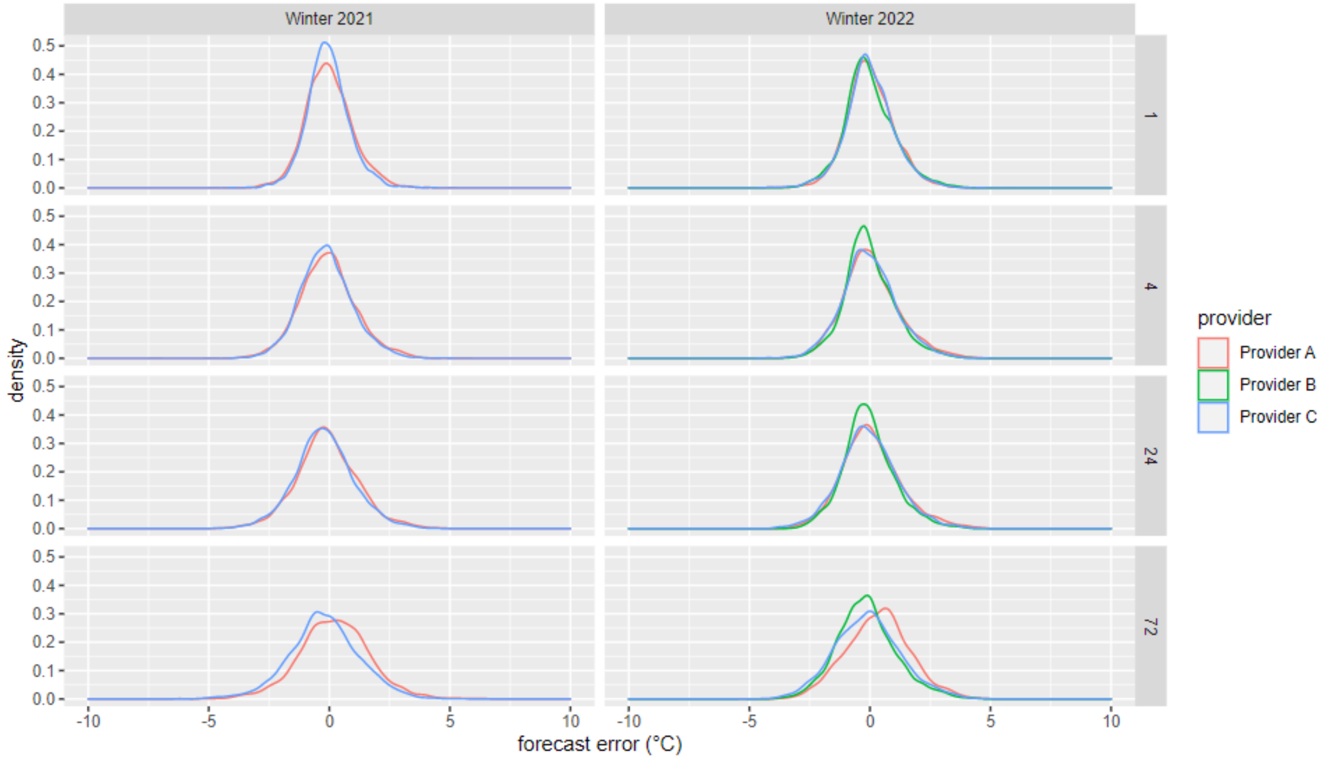


Figure 23 Archerfield AP, all providers, all Winter temperatures 2021 and 2022, all time horizons

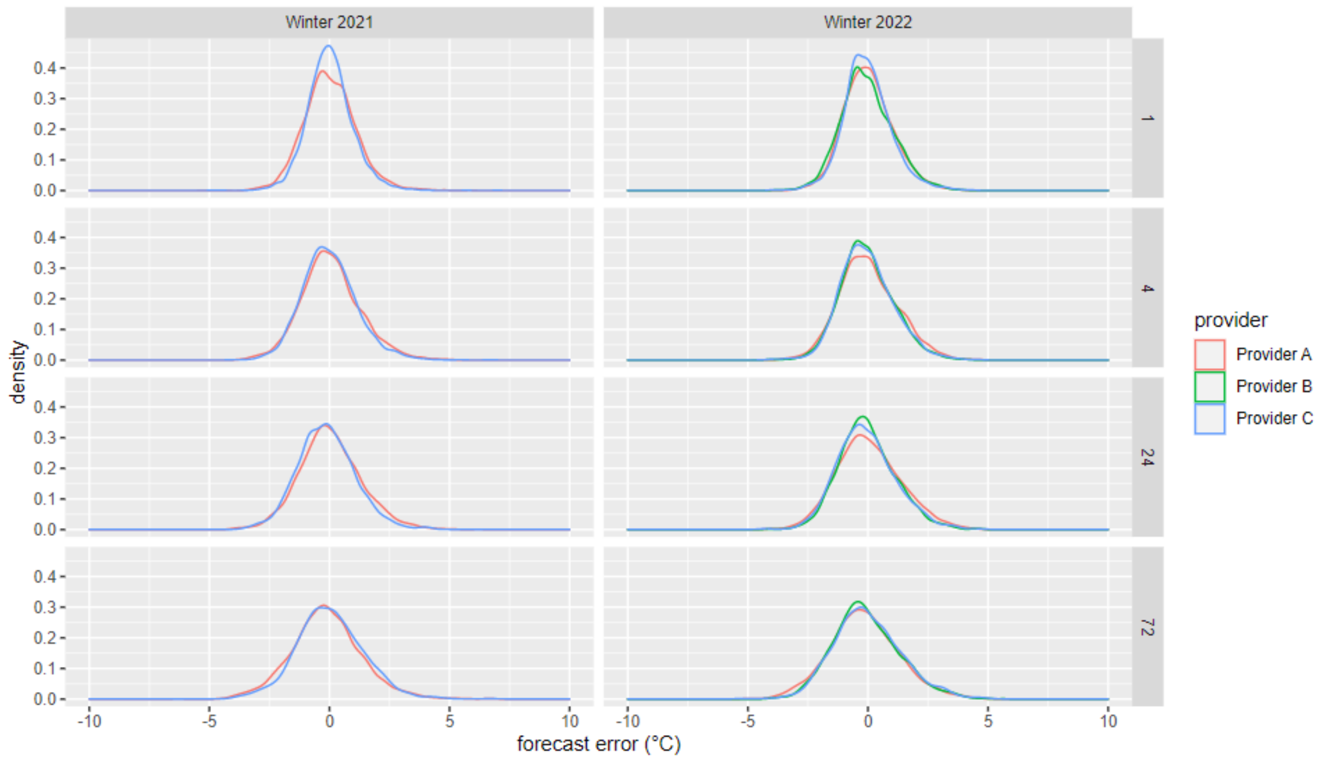


Figure 24 Bankstown AP, all providers, all Winter temperatures 2021 and 2022, all time horizons

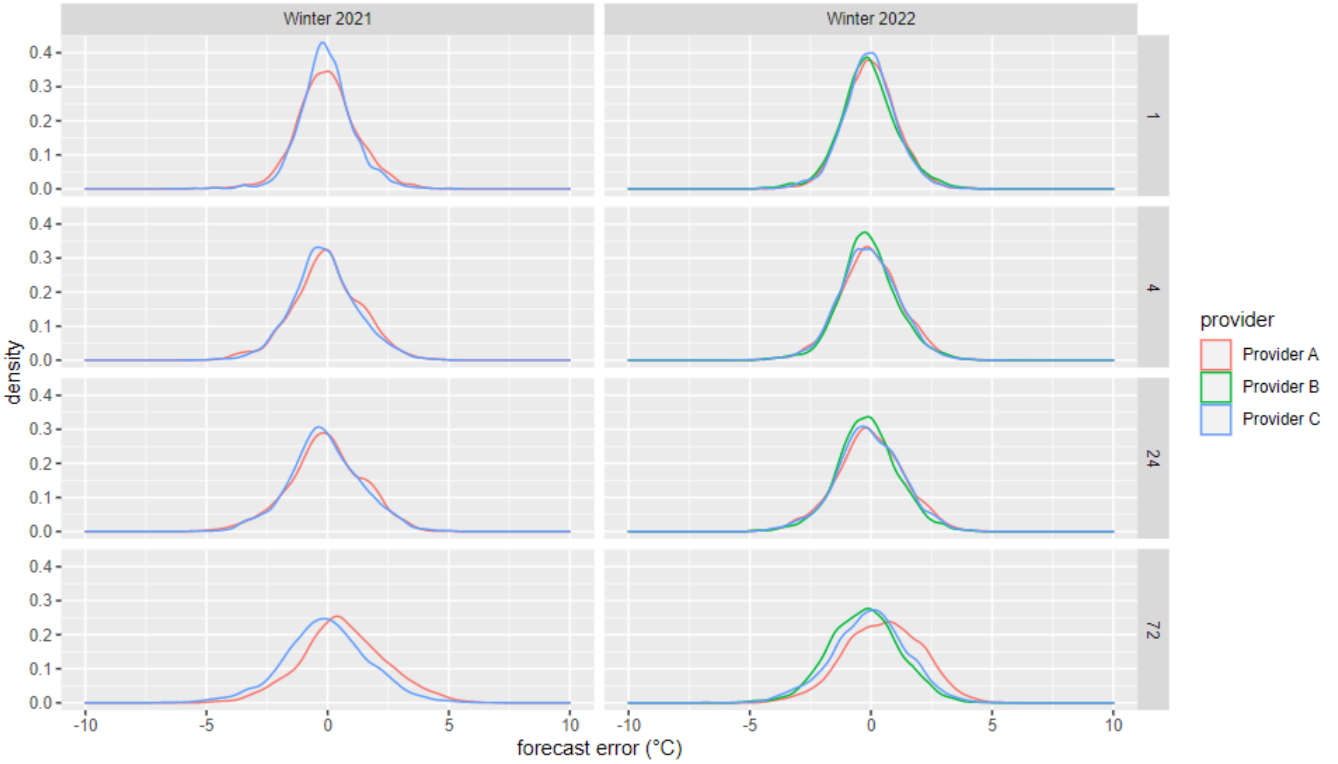


Figure 25 Hobart AP, all providers, all Winter temperatures 2021 and 2022, all time horizons

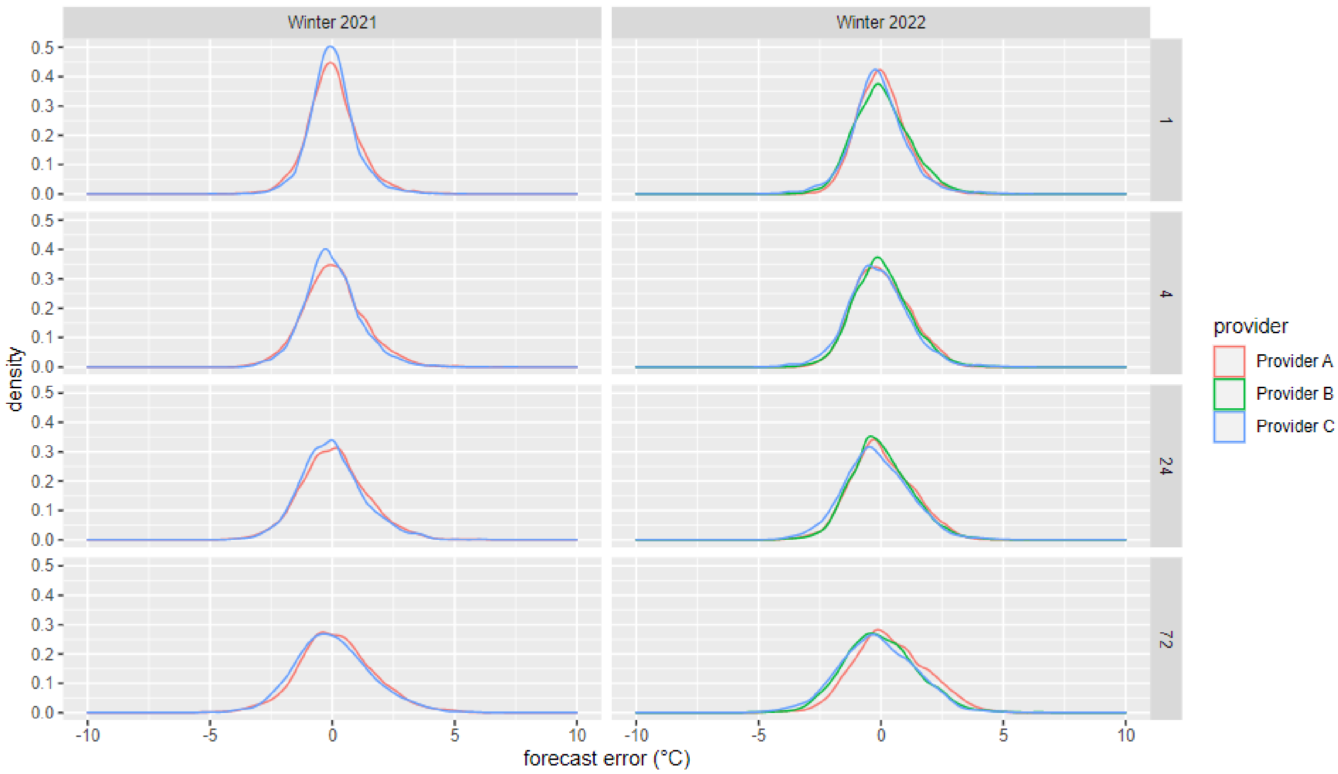


Figure 26 Melbourne AP, all providers, all Winter temperatures 2021 and 2022, all time horizons

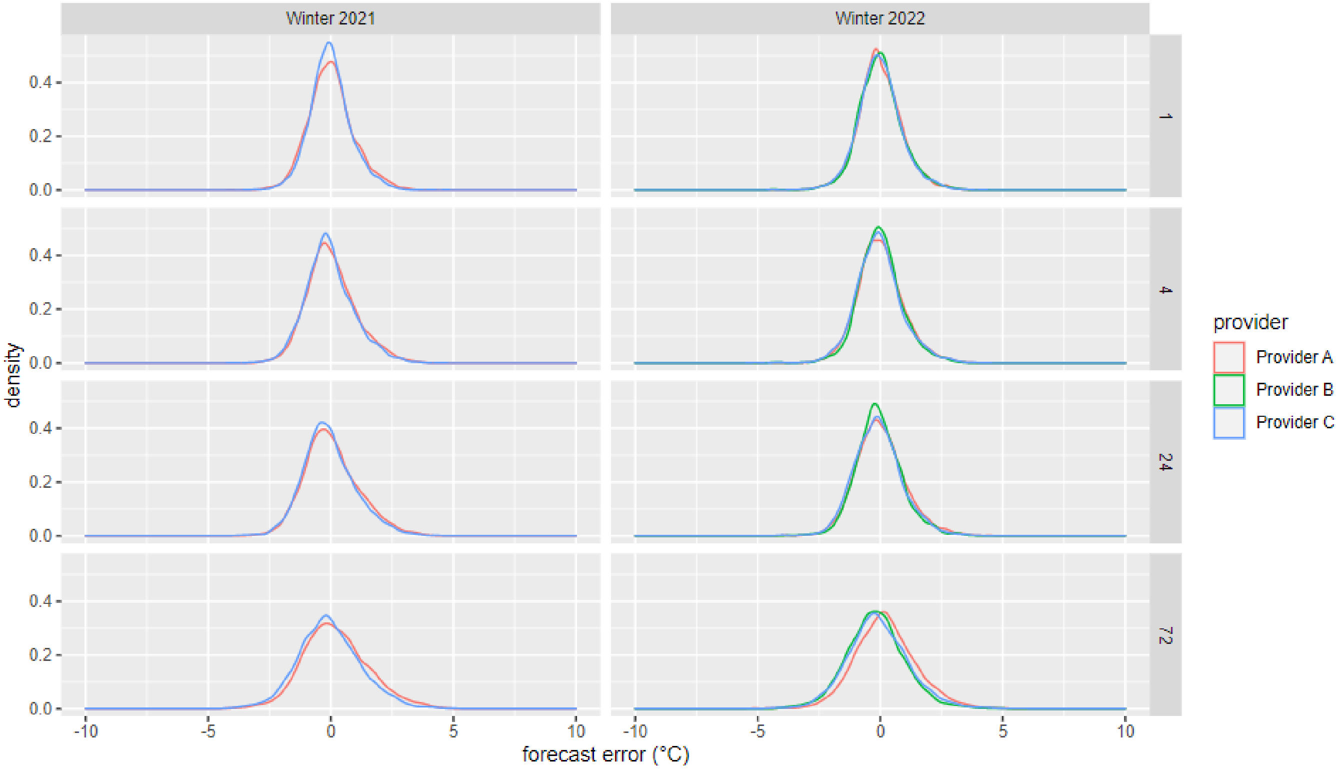


Figure 27 Melbourne OP, all providers, all Winter temperatures 2020 and 2021, all time horizons

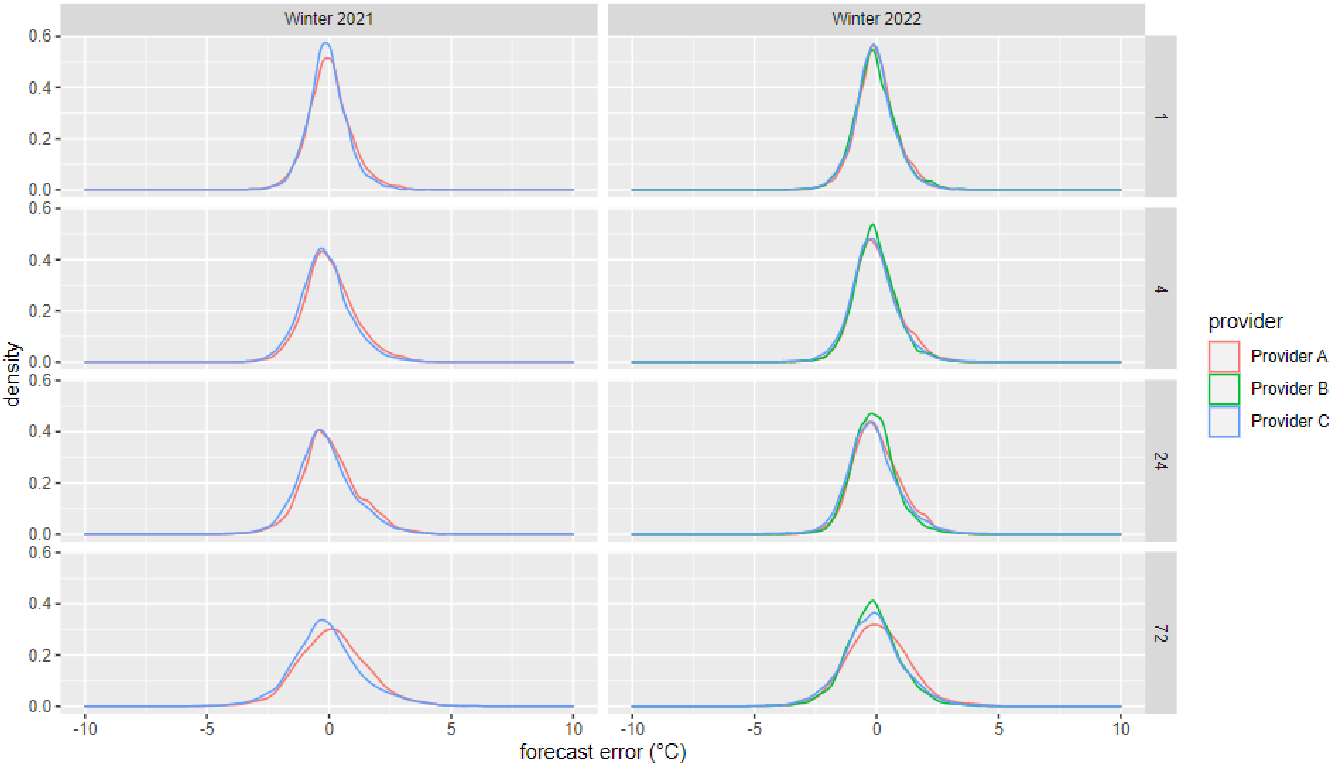


Figure 28 Penrith Lakes, all providers, all Winter temperatures 2021 and 2022, all time horizons

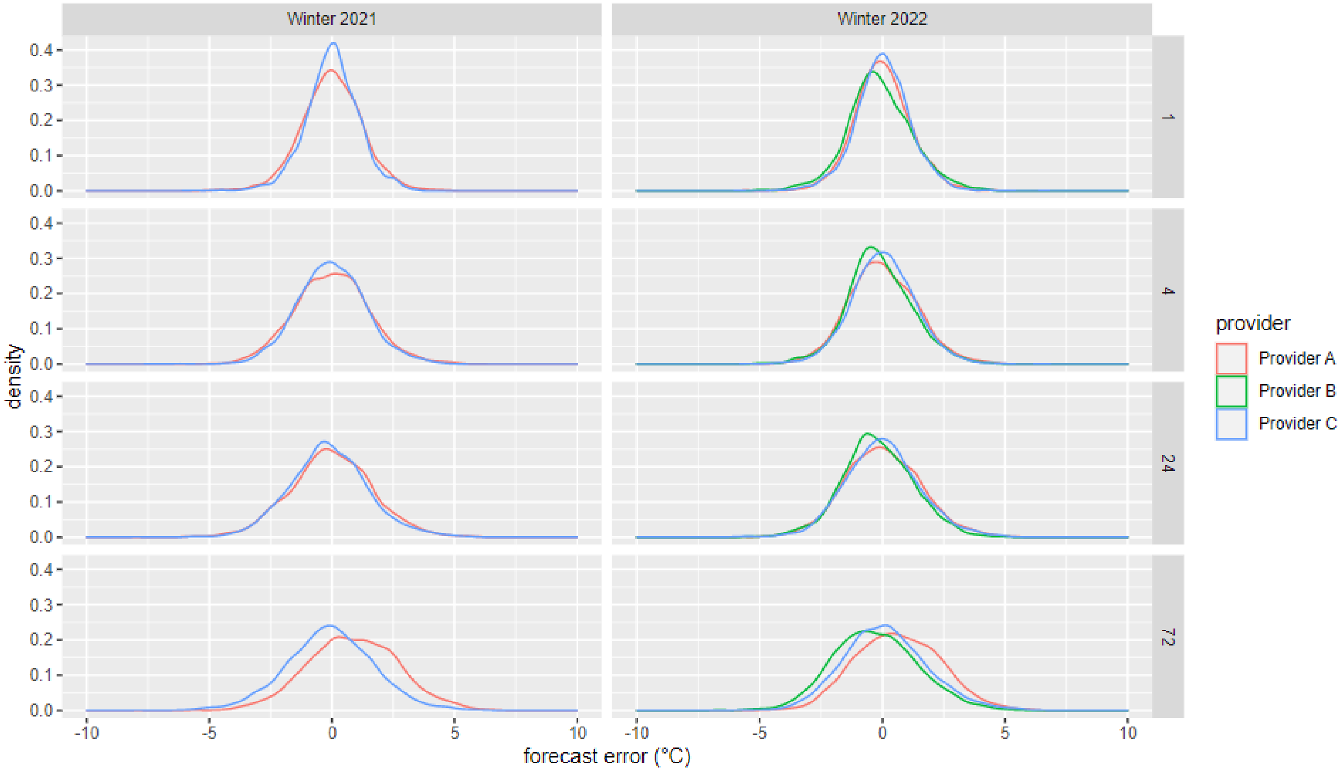
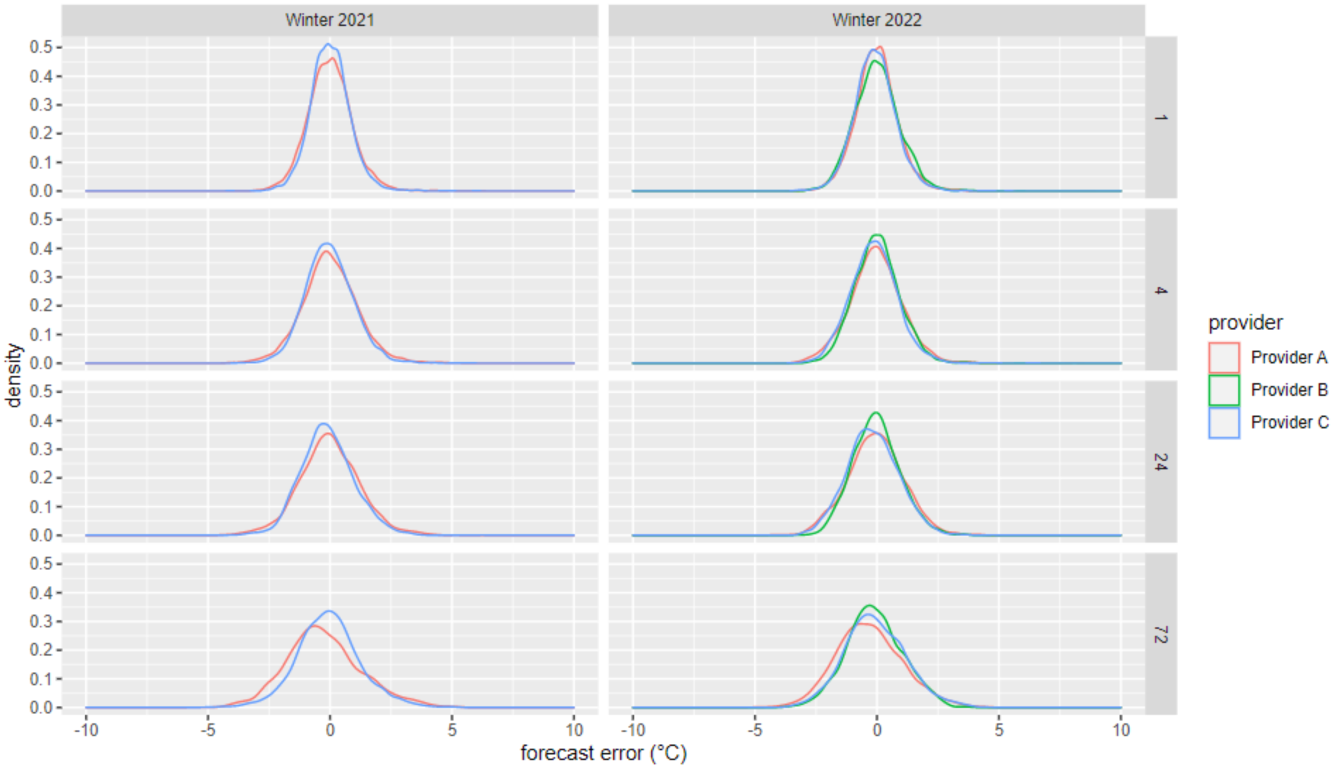


Figure 29 Sydney AP, all providers, all Winter temperatures 2021 and 2022, all time horizons



A2. Intraday MAE profiles

Figure 30 Adelaide WT, intraday MAE profile, all providers Winter 2021 and 2022, all time horizons, lowest 10% of temperatures

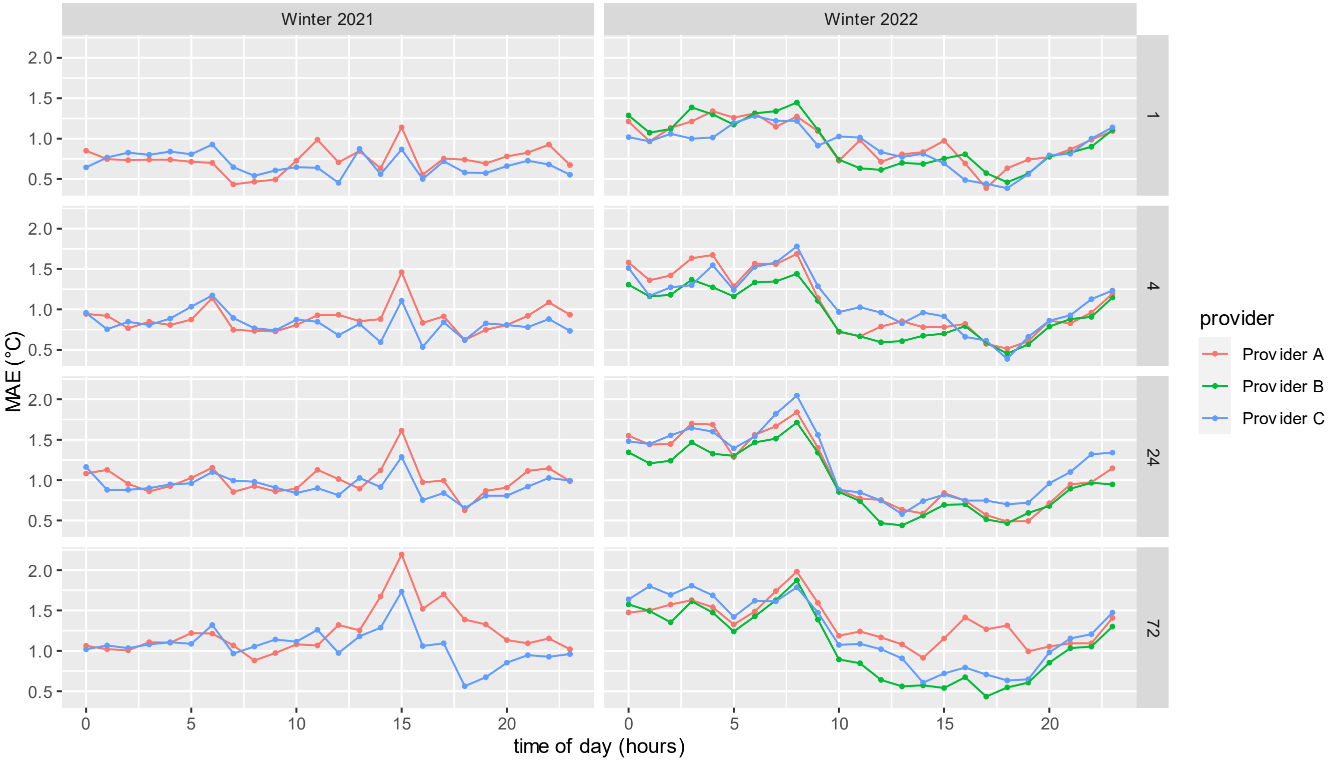


Figure 31 Amberley, intraday MAE profile, all providers, Winter 2021 and 2022, all time horizons, lowest 10% of temperatures

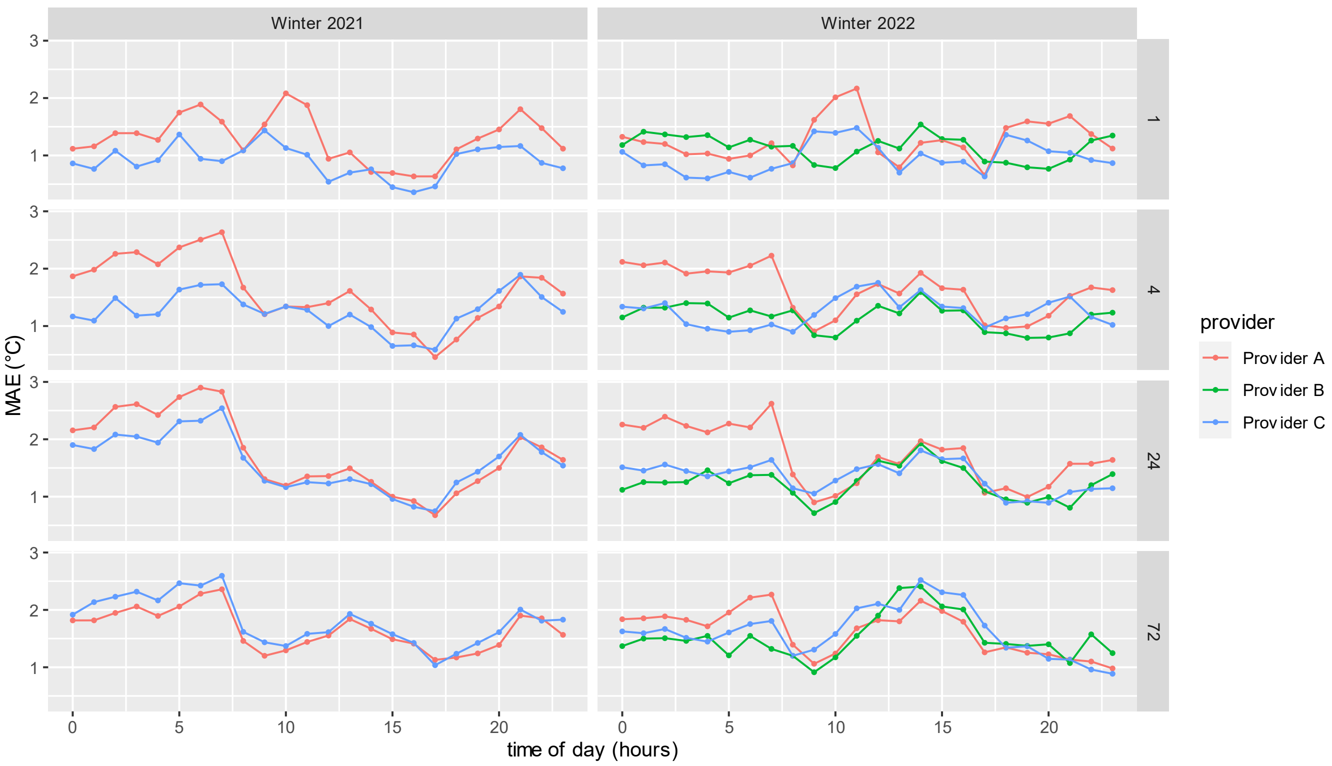


Figure 32 Archerfield AP, intraday MAE profile, all providers, Winter 2021 and 2022, all time horizons, lowest 10% of temperatures

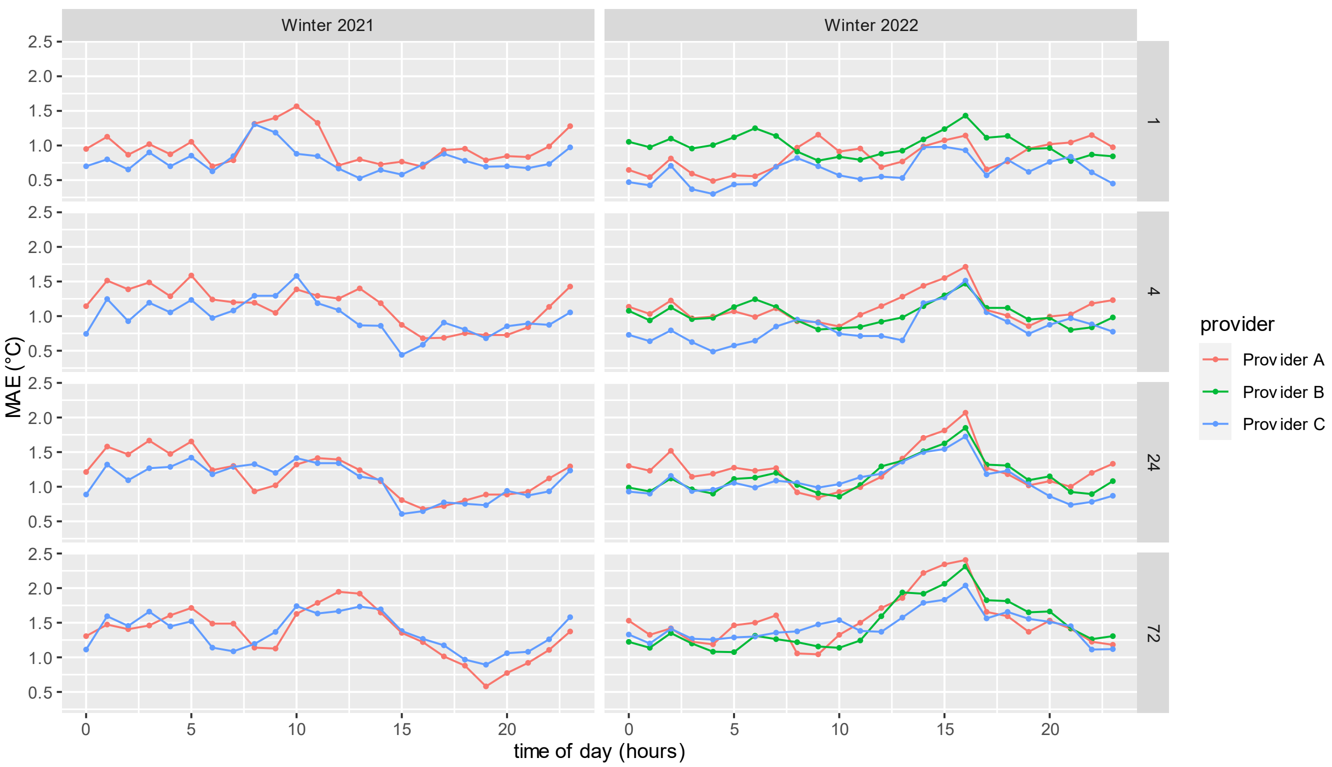


Figure 33 Bankstown AP, intraday MAE profile, all providers, Winter 2021 and 2022, all time horizons, lowest 10% of temperatures

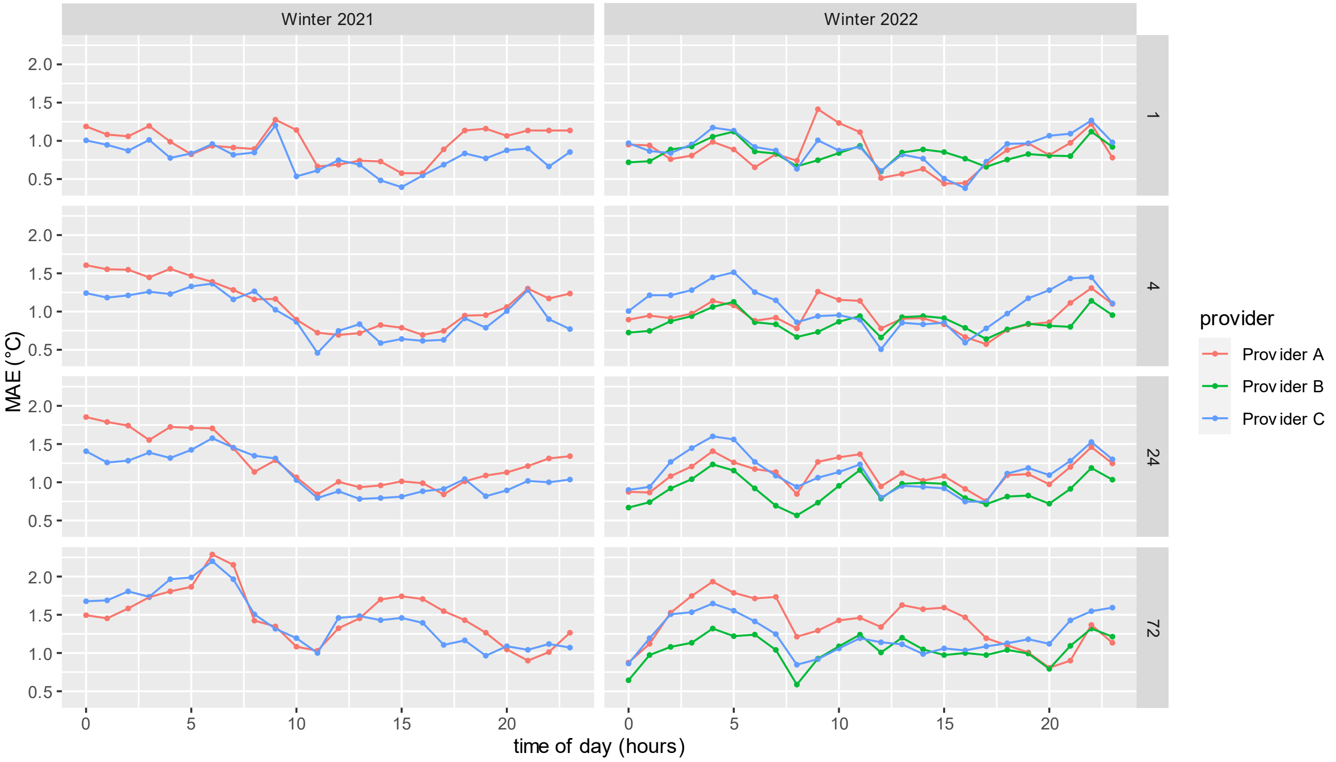


Figure 34 Hobart AP, intraday MAE profile, all providers, Winter 2021 and 2022, all time horizons, lowest 10% of temperatures

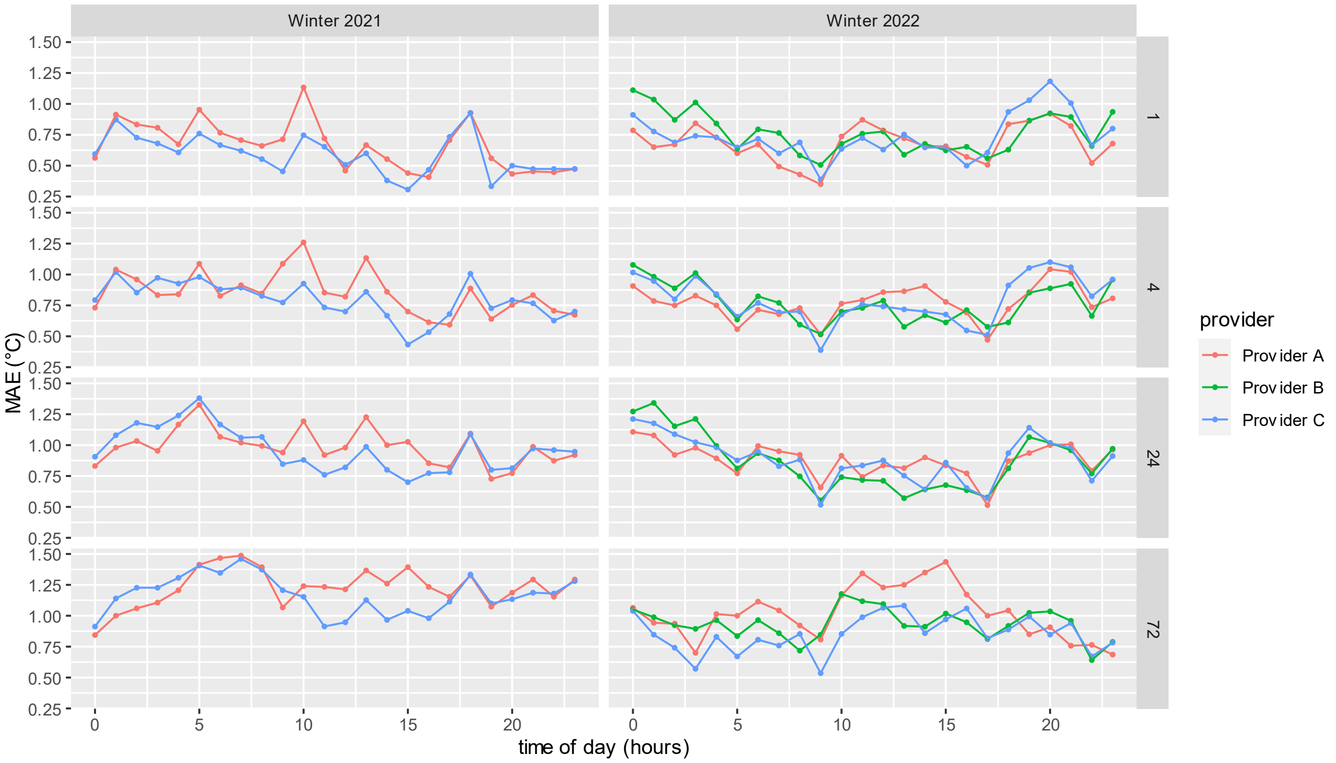


Figure 35 Melbourne OP, intraday MAE profile, all providers, Winter 2021 and 2022, all time horizons, lowest 10% of temperatures

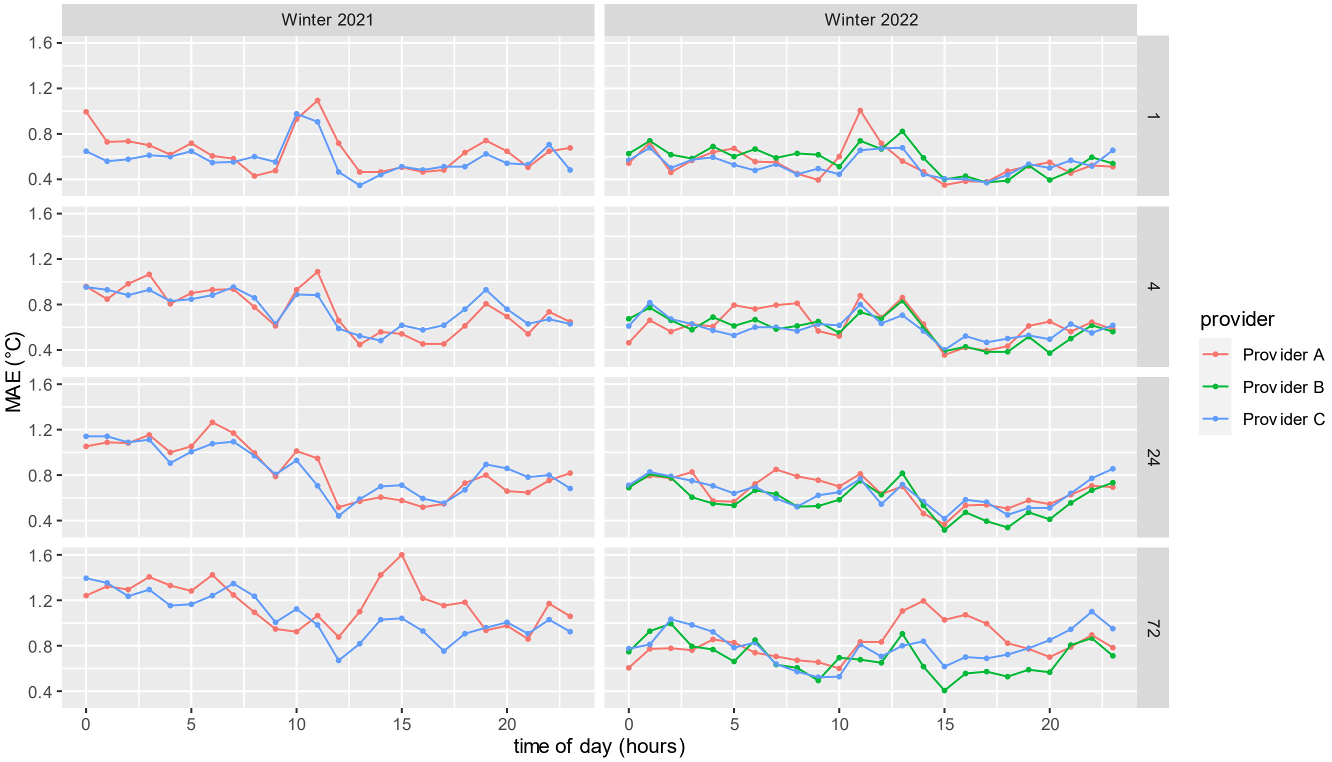


Figure 36 Melbourne AP, intraday MAE profile, all providers, Winter 2021 and 2022, all time horizons, lowest 10% of temperatures, lowest 10% of temperatures

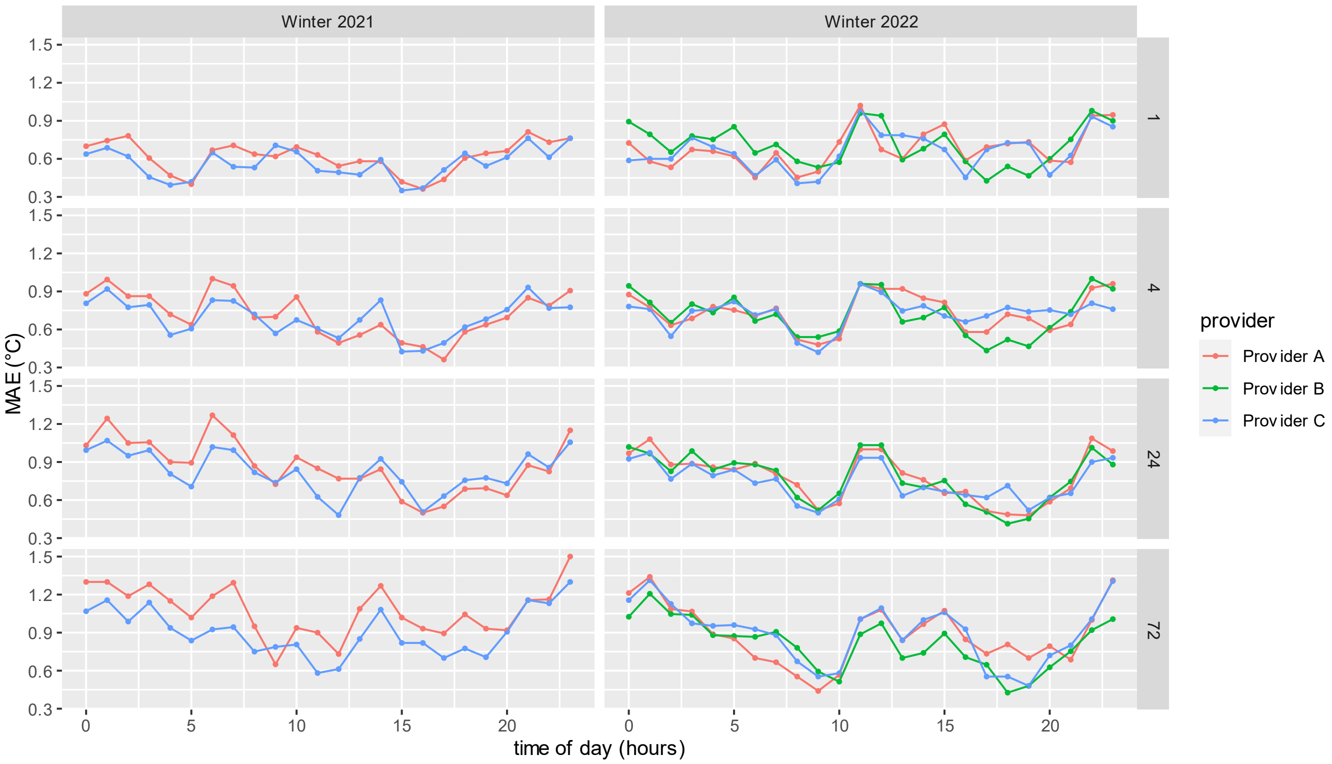


Figure 37 Penrith Lakes, intraday MAE profile, all providers, Winter 2021 and 2022, all time horizons, lowest 10% of temperatures

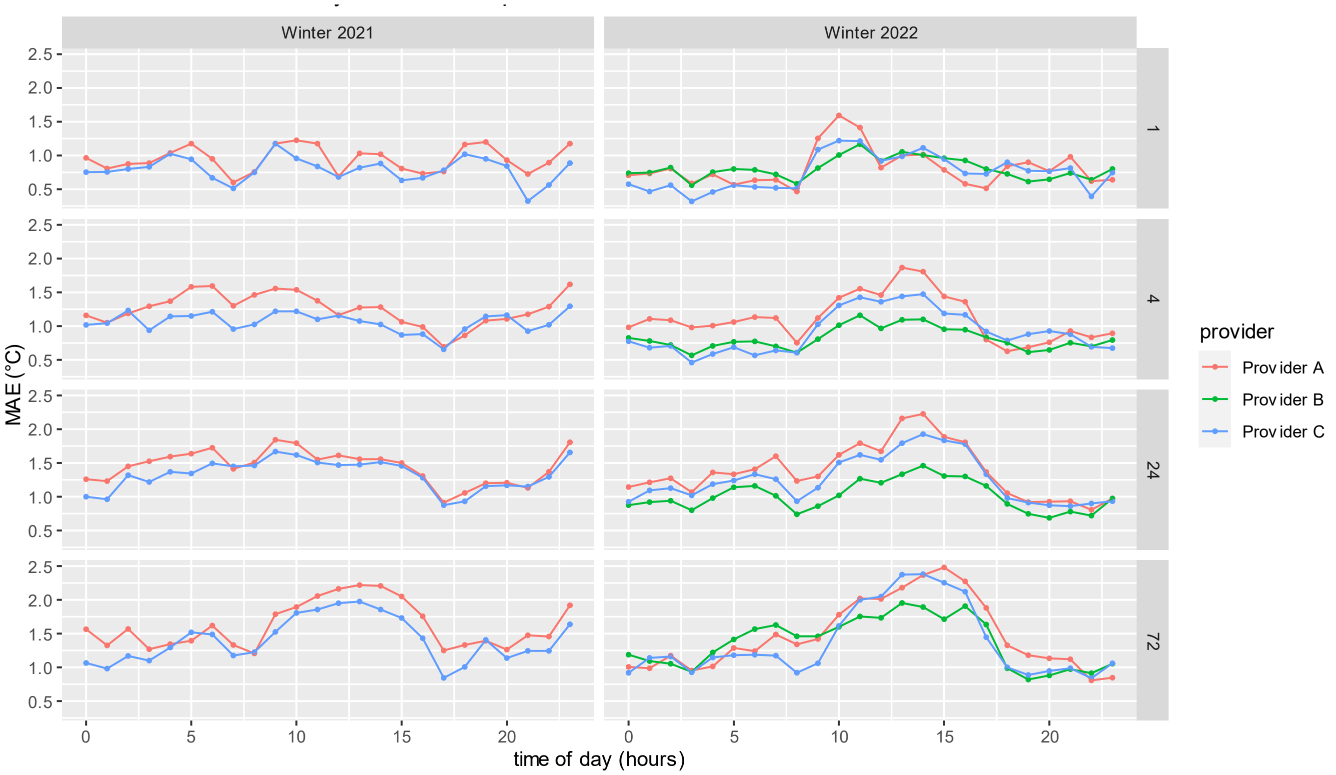


Figure 38 Sydney AP, intraday MAE profile, all providers, Winter 2021 and 2022, all time horizons, lowest 10% of temperatures