

Recent Developments in Incorporating Weather for Operational Forecasting at AEMO



Andrew Akman

Principal Data Scientist - Operational Forecasting

Australian Energy Market Operator

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Agenda

- Introducing AEMO & Operational Forecasting
- Trends Important for Operational Forecasting
- The Weather Toolkit
- Spotlight on Recent Developments for Incorporating Weather
- Upcoming work and Strategic Initiatives



Introducing AEMO & Operational Forecasting

About AEMO

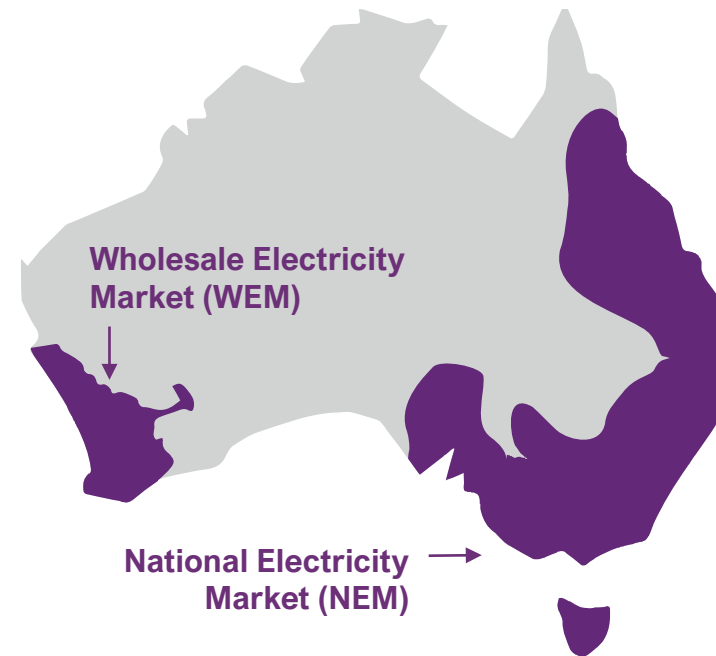
- AEMO is a member-based, not-for-profit organisation.
- We are the independent energy market and system operator for the National Electricity Market (NEM) and the WA Wholesale Electricity Market (WEM), and system planner for the NEM.
- We also operate retail and wholesale gas markets across south-eastern Australia and Victoria's gas pipeline grid.



AEMO Services is an independent subsidiary of AEMO, established in 2021 to enable the transparent provision of advisory and energy services to National Electricity Market jurisdictions.



Electricity



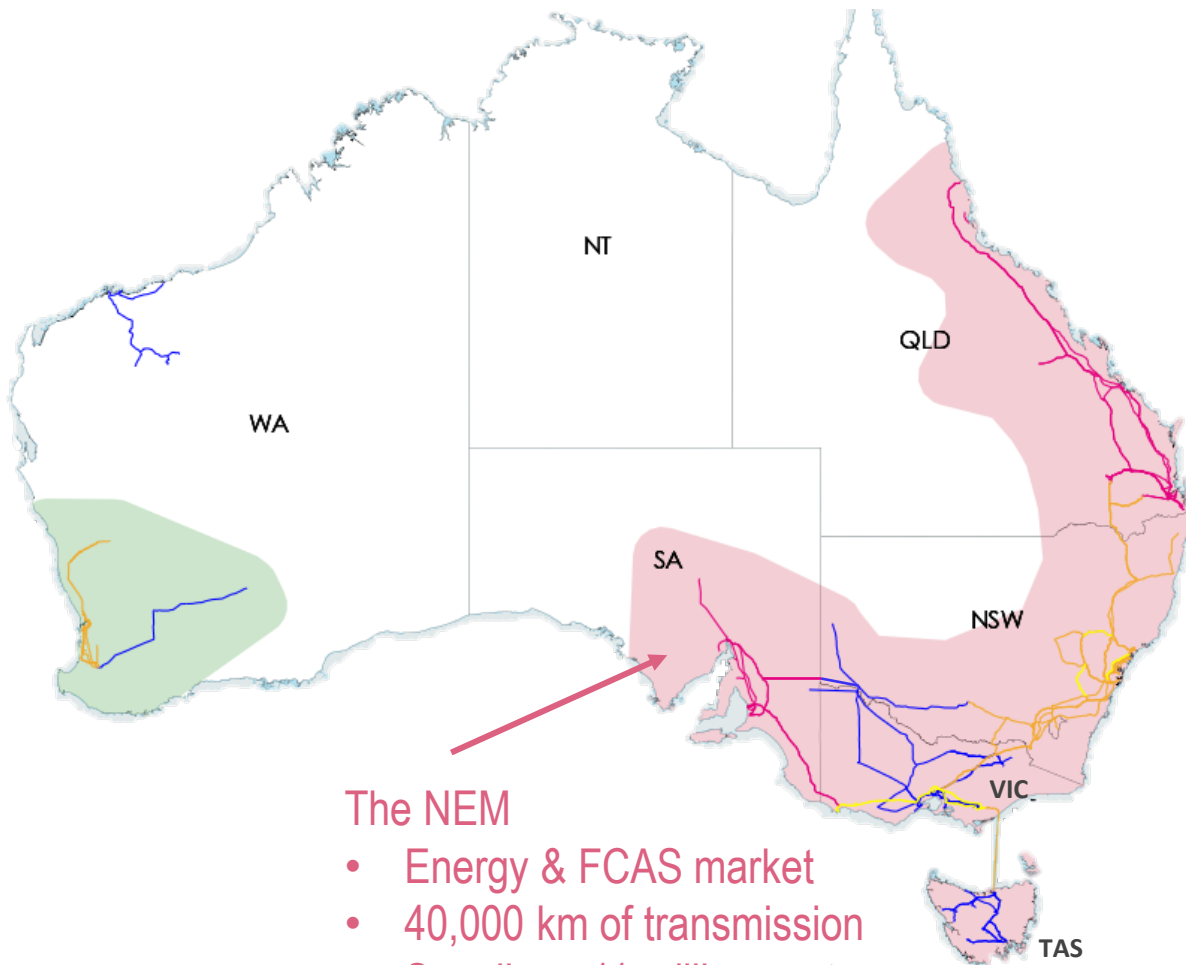
Gas



Declared Wholesale Gas Market (DWGM)

Short Term Trading Market (STTM) and Gas Supply Hub (GSH)

National Electricity Market (NEM)



The NEM

- Energy & FCAS market
- 40,000 km of transmission
- Supplies ~11 million customers
- 71 GW of generation capacity

Population **23.5 million**

NEM Max Demand **35,796 MW**

NEM Min Demand **10,073 MW**

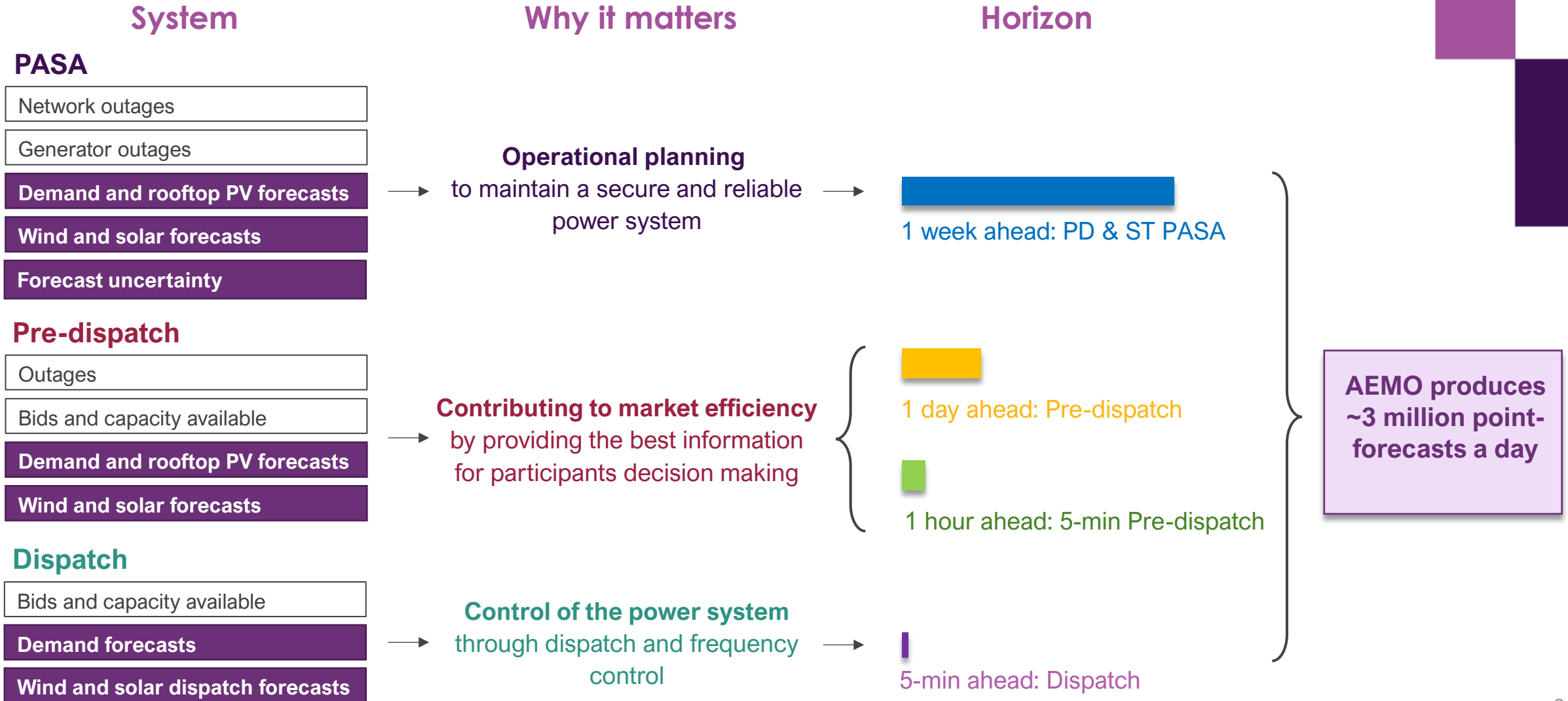
Wind Capacity **13,613 MW**

Solar Capacity **11,637 MW**

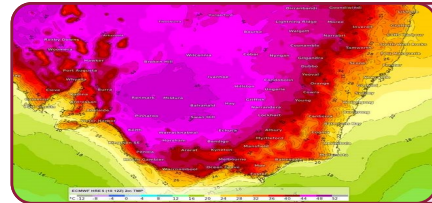
Rooftop Solar Capacity **22,780 MW**

Approximately **3.5 million** homes have a solar system

Operational Forecasting – Our Forecasts

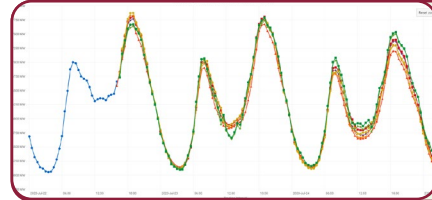


Managing Operational Forecasts



Check the weather, demand, wind & solar for the day

Weather risks and possible scenarios are assessed by analysts, with information provided by meteorologists and data from our data science team. The demand, wind and solar forecasts are reviewed by the analysts.



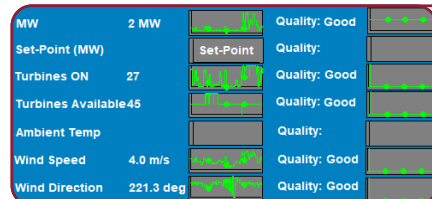
Translate the weather forecasts into power system impacts

How the weather will impact demand, wind and solar is interpreted by the analysts, and any severe weather risks which could damage assets or limit generation is assessed.



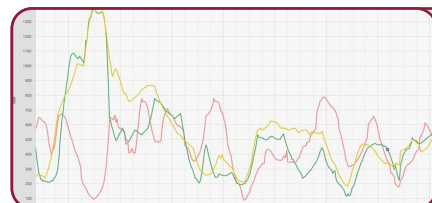
Communicate the forecast & associated risks

The forecast outcomes and weather-related risks are communicated to the wider business including our real time control room through a variety of methods.



Assist in the management of wind and solar farms, help manage the demand forecasts, monitor the current situation

Wind and solar forecast issues are investigated, and generation risks are communicated. Demand forecasts are continually monitored and managed with our real time control room.



Review the outcomes of the day, adjust for tomorrow

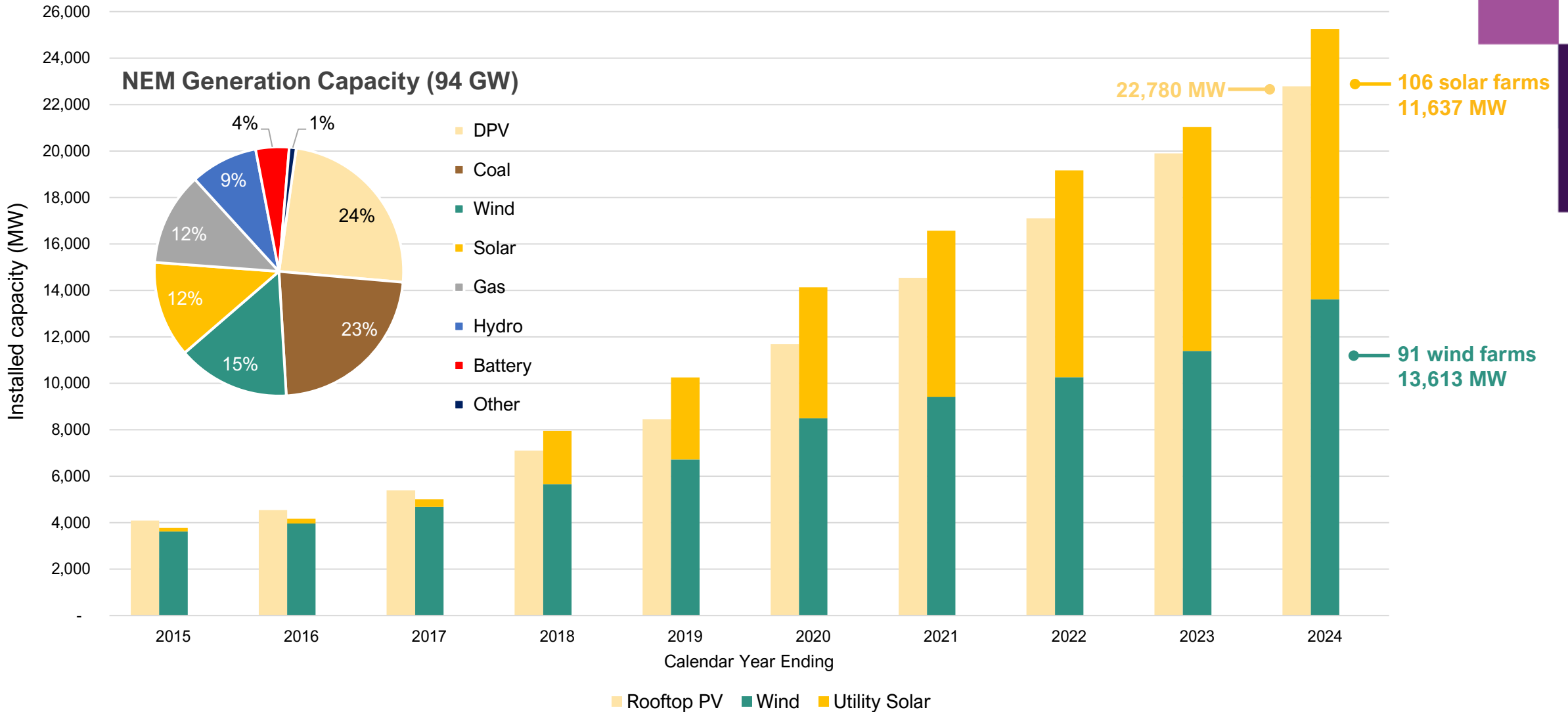
Any demand forecast adjustments are made and managed, and the forecast models are continually improved and monitored.

Trends Important for Operational Forecasting

- Growth in Variable Renewable Energy (VRE)
 - Growth in Distributed Rooftop PV (DPV)
- Evolving Shape of the Demand Profile
 - Operational vs. Underlying Demand changes
 - Daytime Minimum Demand Records
 - Increasing number of Low Demand Periods

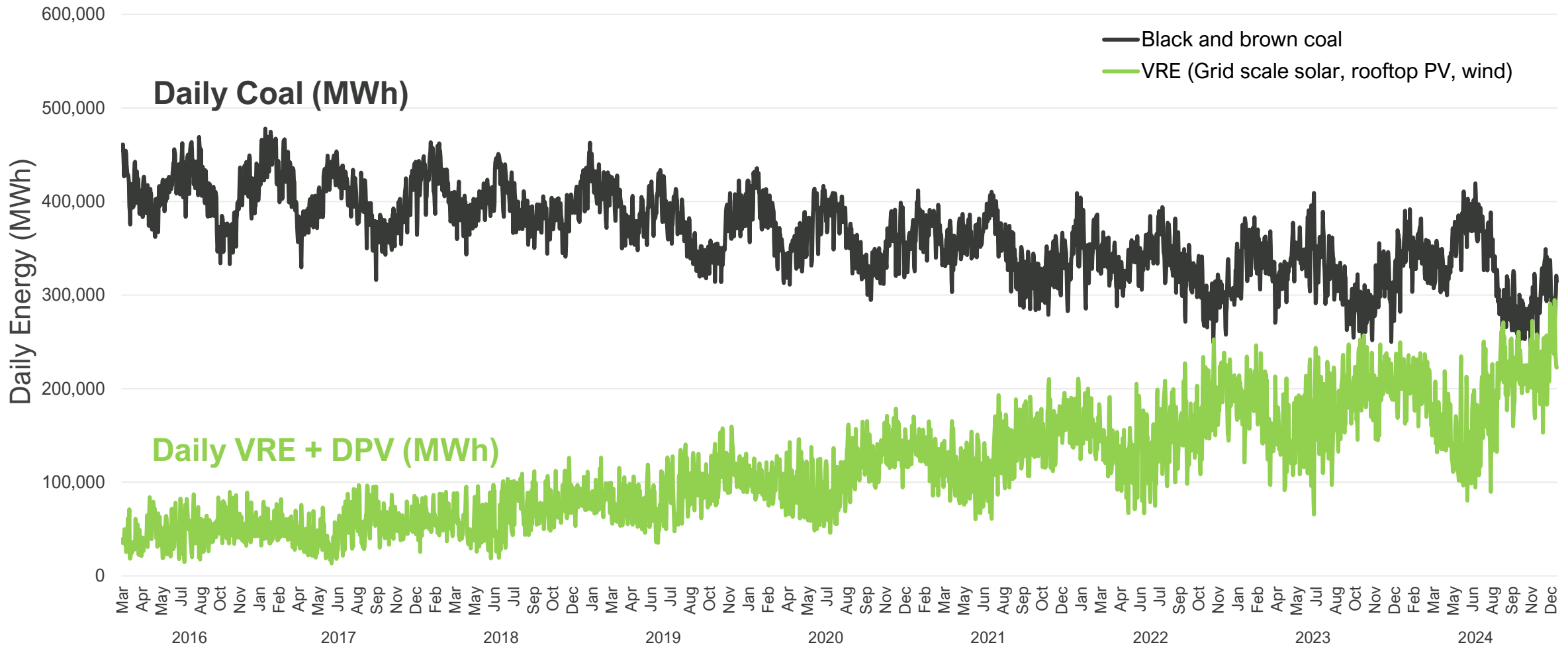
Growth in Variable Renewable Energy

VRE & DPV installed capacity 2015 to 2024



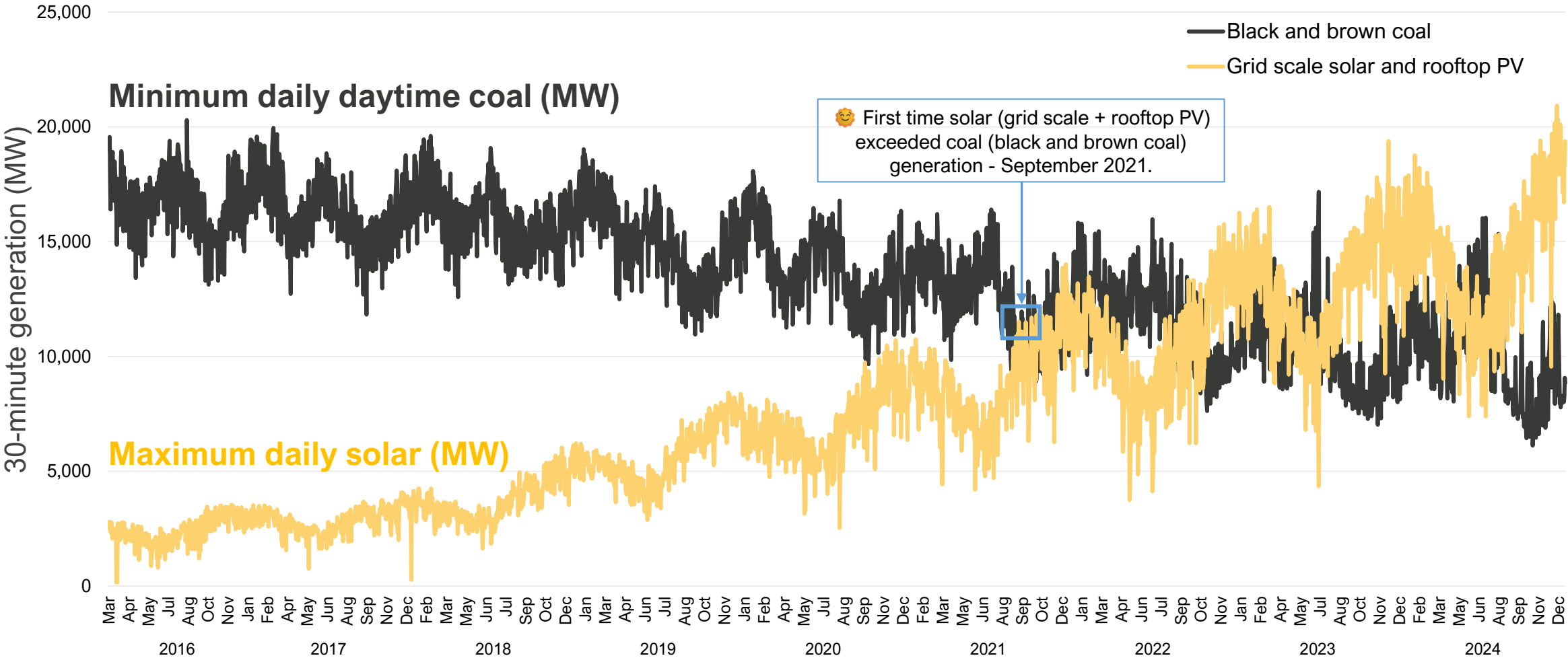
Growth in Variable Renewable Energy

The energy from DPV and VRE has increased over time and is approaching the energy provided by conventional coal.



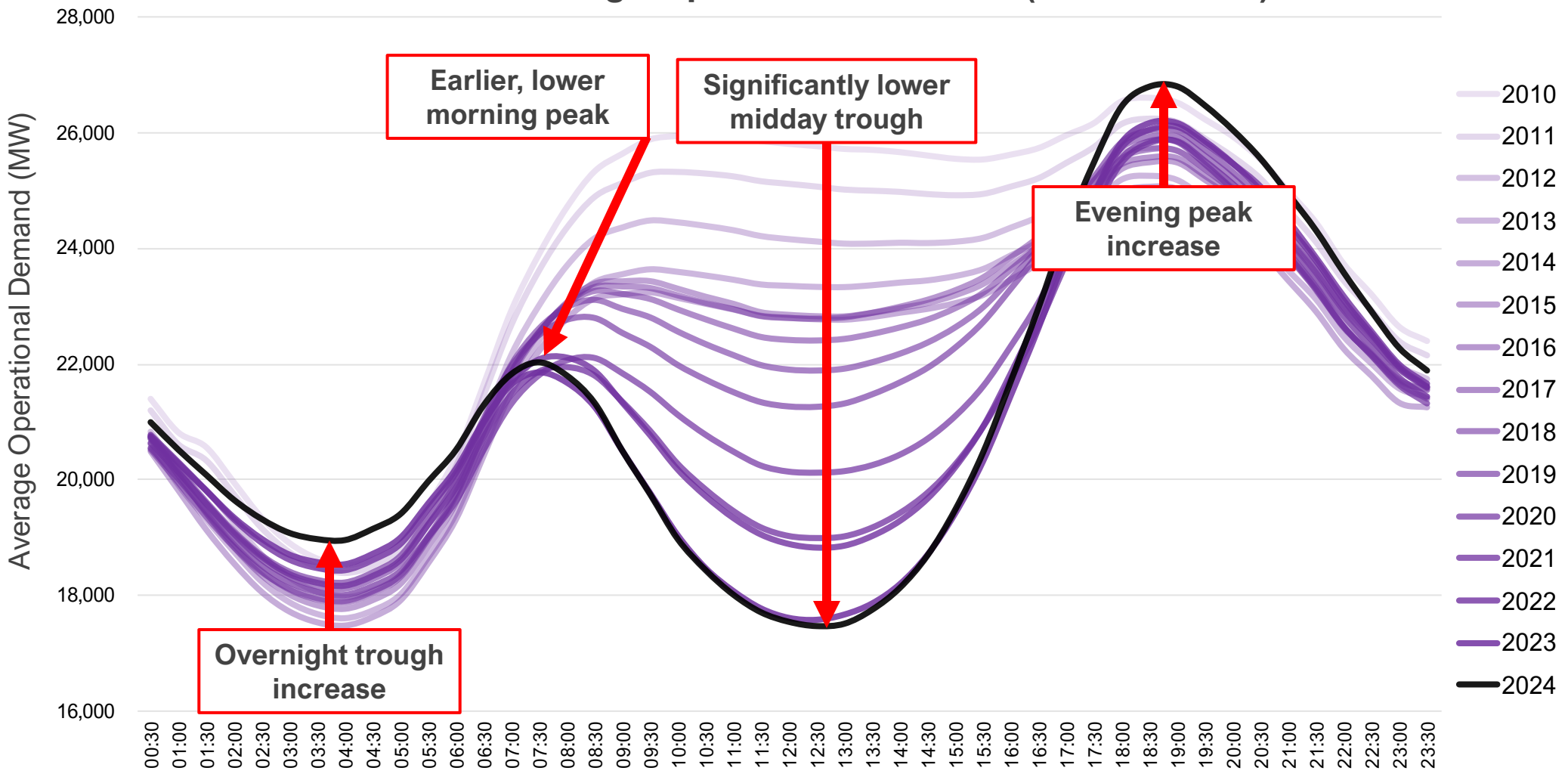
Growth in Variable Renewable Energy

Combined large scale solar and distributed rooftop PV is becoming the predominate generation source during the middle of the day across the NEM.



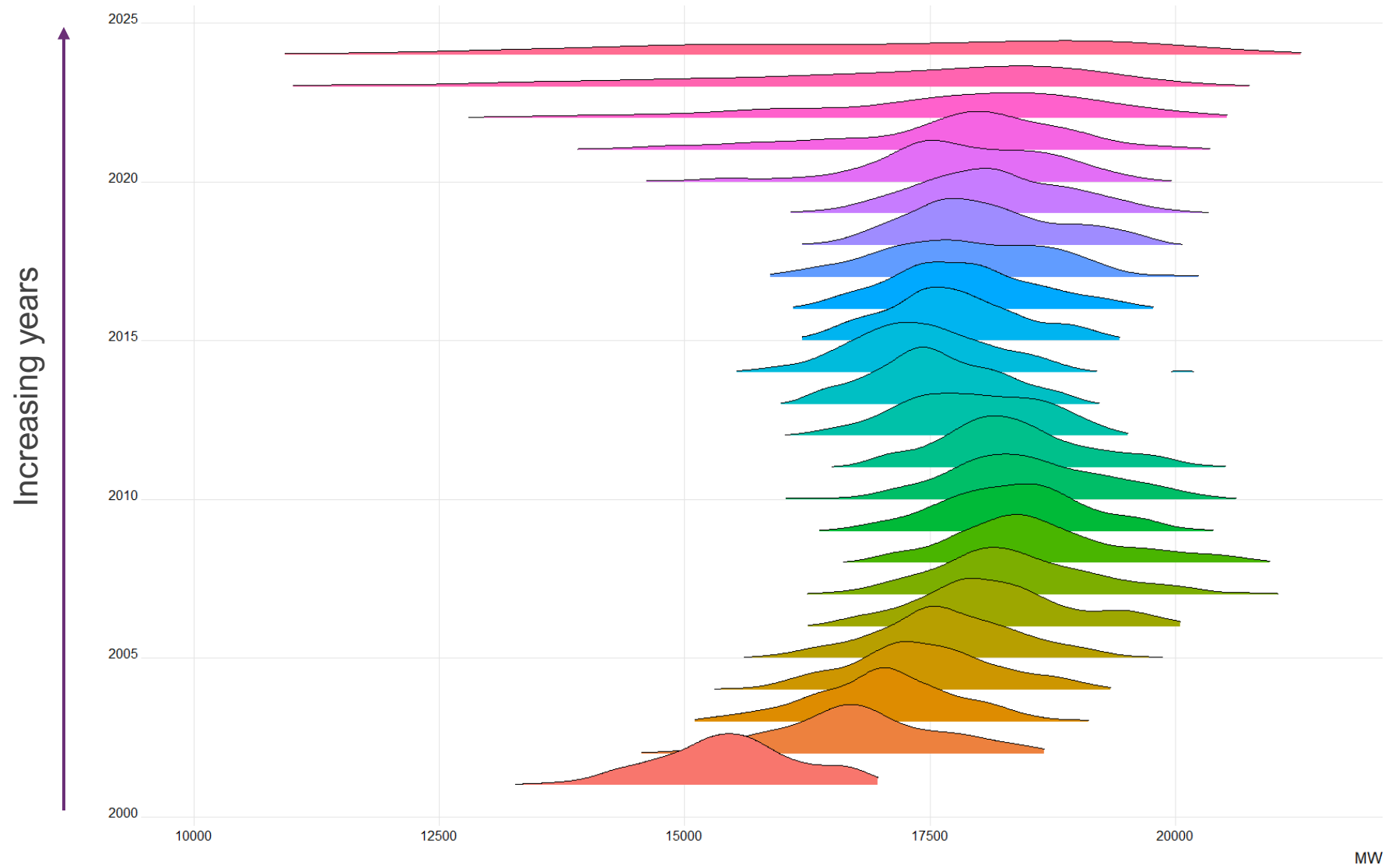
Evolving Shape of the Demand Profile

NEM Average Operational Demand (2010 to 2024)



Evolving Shape of the Demand Profile

Distribution of daily NEM minimum demands for calendar years 2000 to 2025



Evolving Shape of the Demand Profile

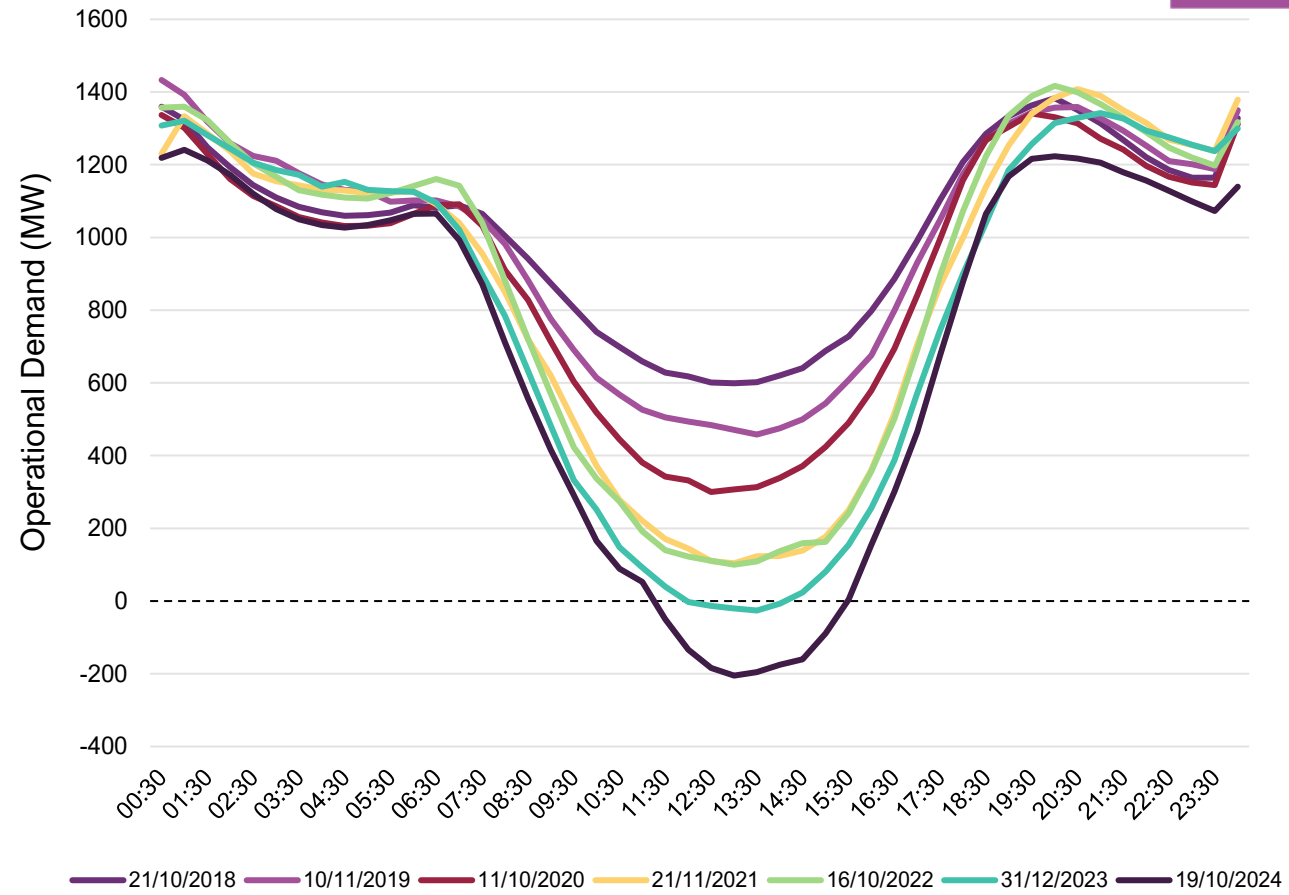
23 GW of Distributed PV (DPV) capacity in the NEM.

DPV is distributed, largely passive, and operationally “invisible”

Growth in distribution connected capacity is changing the shape and trend in operational demand.

DPV curtailment and activated CER is starting to influence the shape of operational demand.

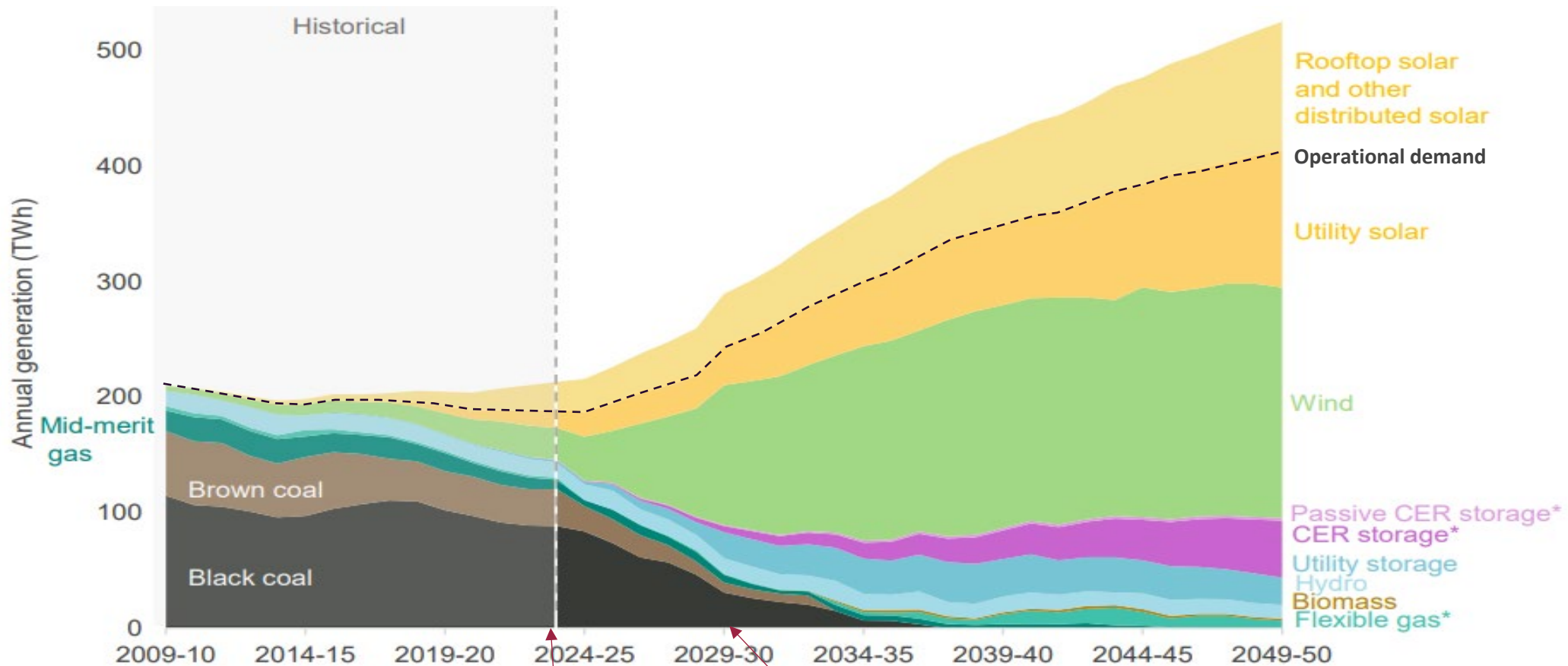
Minimum Operational Demand records in South Australia since 2018



| Min demand | 599 MW | 458 MW | 300 MW | 104 MW | 100 MW | -26 MW | -205 MW |
|--------------|--------|----------|----------|----------|----------|----------|----------|
| DPV capacity | 967 MW | 1,182 MW | 1,510 MW | 1,826 MW | 2,053 MW | 2,374 MW | 2,583 MW |

Impact of The Energy Transition on Operational Forecasting

AEMO's 2024 ISP step change scenario



Today, around 28% of operational demand is met by large-scale VRE

By 2030, close to 60% will be met by large-scale VRE, increasing the reliance on VRE forecasts

*"Flexible gas" includes gas-powered generation and potential hydrogen capacity.
 *"CER storage" means consumer energy resources such as batteries and EVs.

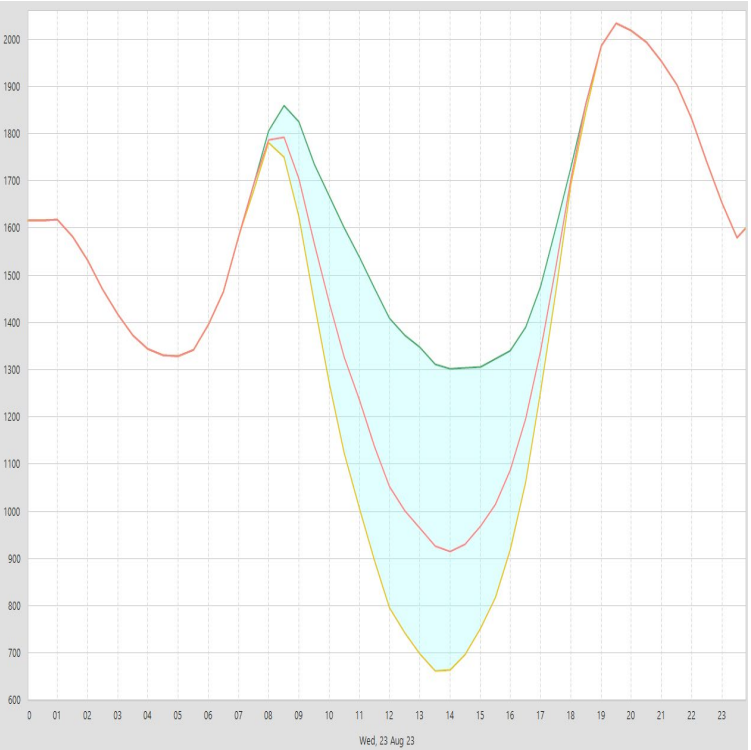
Weather Toolbox

AEMO's suite of weather tools and situational awareness information.

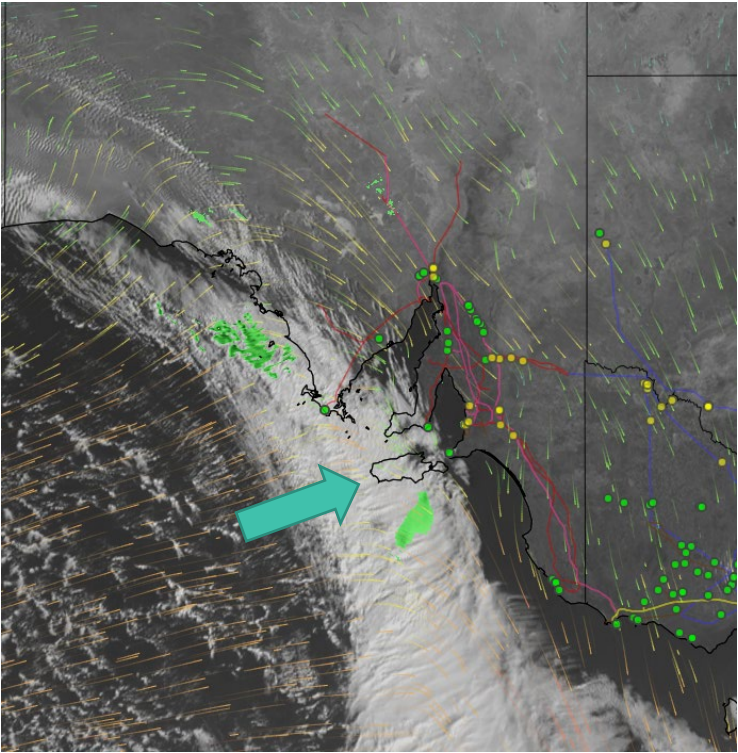
Variability and Uncertainty in Weather

We can't forecast our way out of uncertainty – operational envelopes, situational awareness and real-time monitoring are required to navigate forecast uncertainty

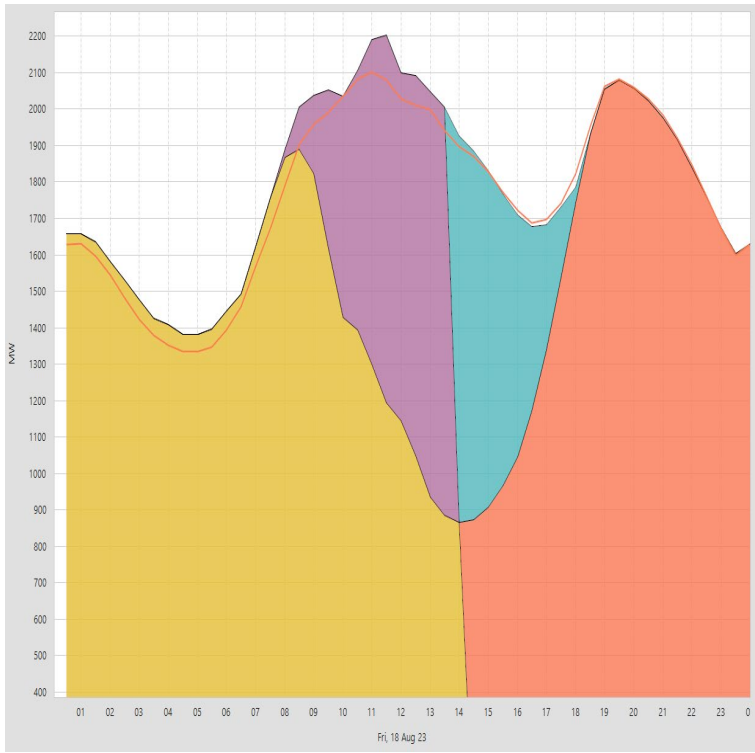
Communicate probabilistic envelopes & uncertainty day-ahead



On-day weather monitoring & situational awareness



Assess impact on underlying demand & attribute error



Weather Toolbox for the NEM

1. Hourly forecasts for demand forecasting

- 4 weather providers (2 for DFS)
- 94 weather stations (38 for DFS)
- 13 weather concepts
- POE 10 & 90 forecasts

2. Situational Awareness

- Gridded forecast data from 2 global NWP
- Ensemble forecast data from high resolution NWP
- Energy sector thunderstorm & severe weather forecasts
- High resolution synthetic radar and cloud forecasts
- Cloud ramping risk assessments

3. Operational

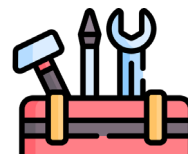
- 187 wind and solar farms providing real time weather data
- Minutely observations from 520 weather stations
- Real time Lightning and wind gust observations

4. Meteorologist support

- Five embedded meteorologists
- Daily weather briefing packs from 3 providers
- Verbal event briefings

5. External Alerting & Frameworks

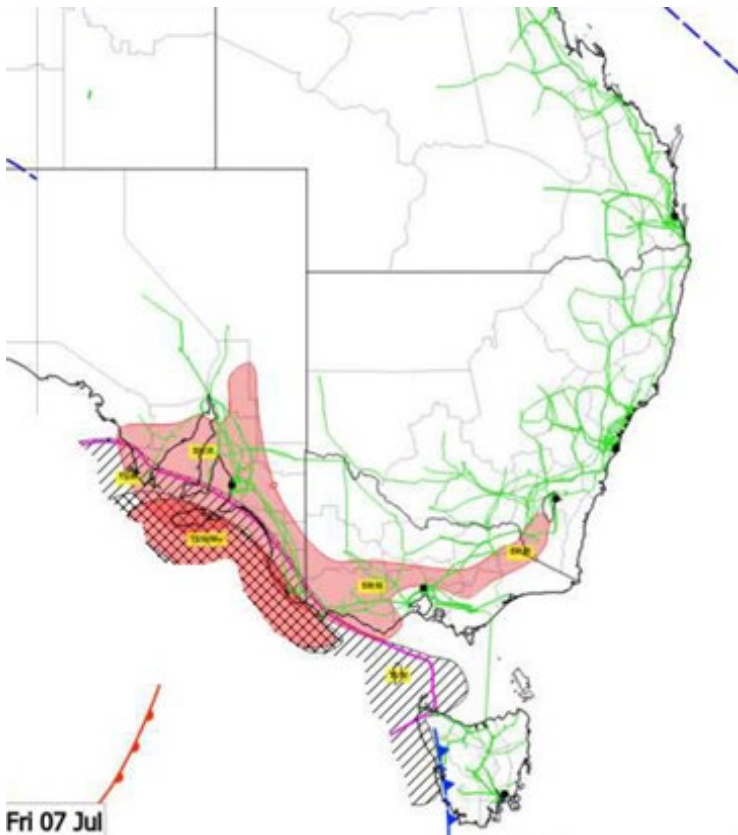
- NEM Local Temperature Alerts ([Link](#))
- Abnormal Condition Reclassification Criteria ([Link](#))



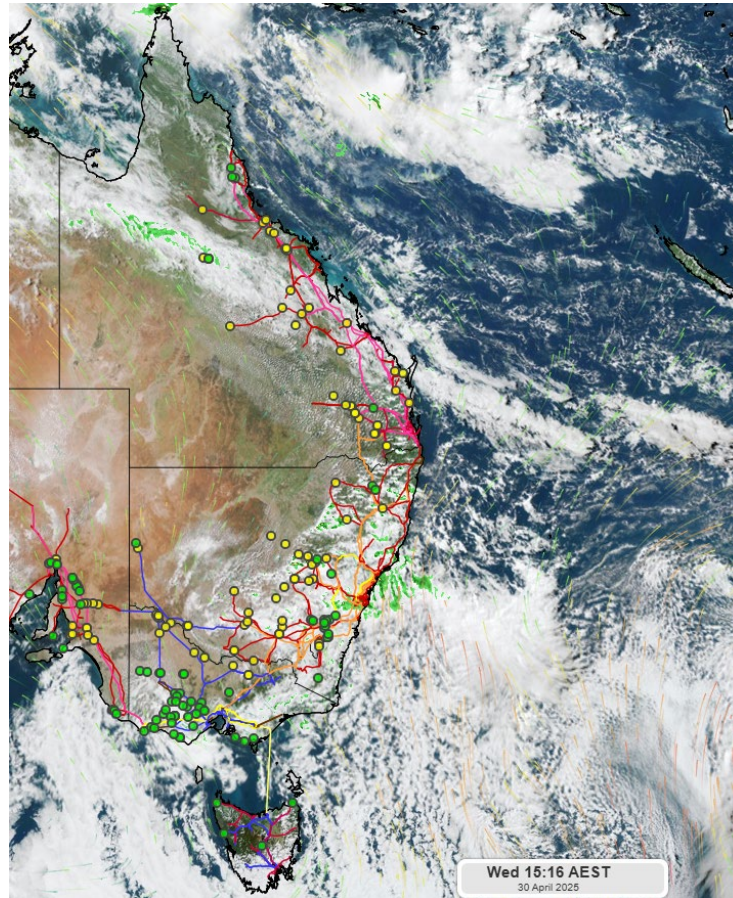
Ensembles are another tool in the toolbox ...

Weather Tools – Meteorologist Support

Severe Weather Information



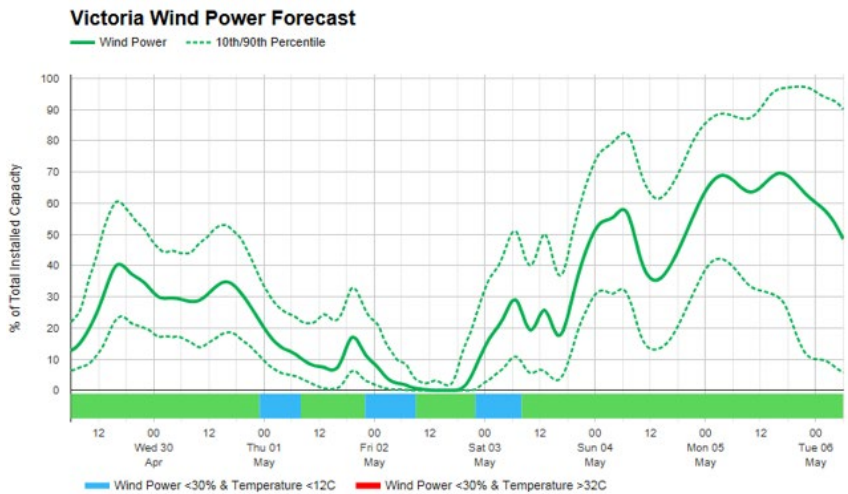
Bespoke Monitoring Tools



Cloud Risks

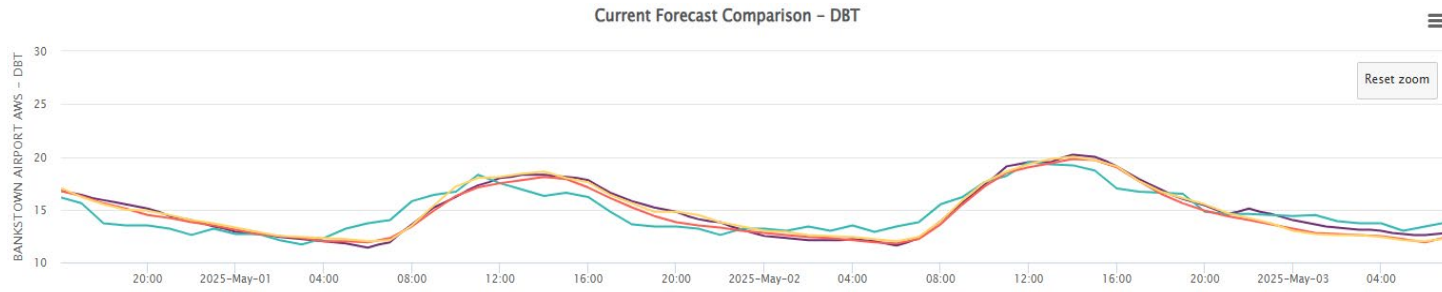
| Hazard | D0: Ridge | D1: Pre-frontal Cloudband |
|---------------------------|-----------|---------------------------|
| Cloud Ramp Risk | Very Low | Very Low |
| Cloud Volatility Risk | Moderate | Very Low |
| Slow Cloud Clearance Risk | Moderate | Low |

VRE Availability

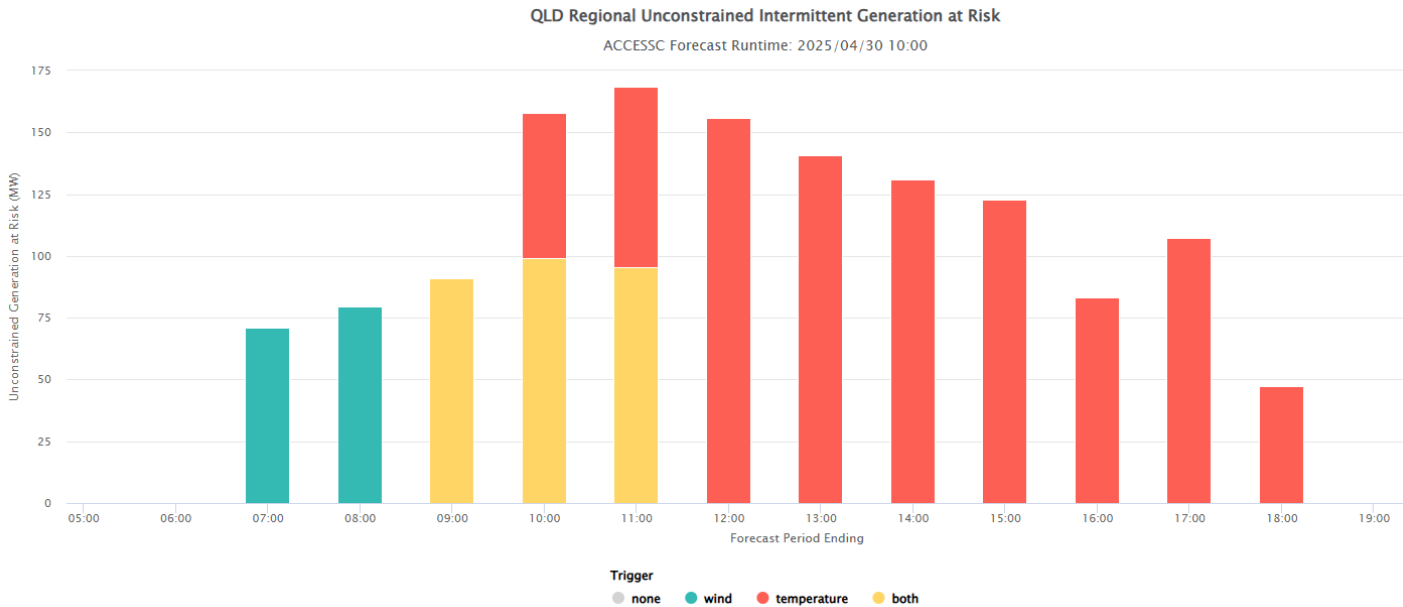


Weather Tools – Data Science Support

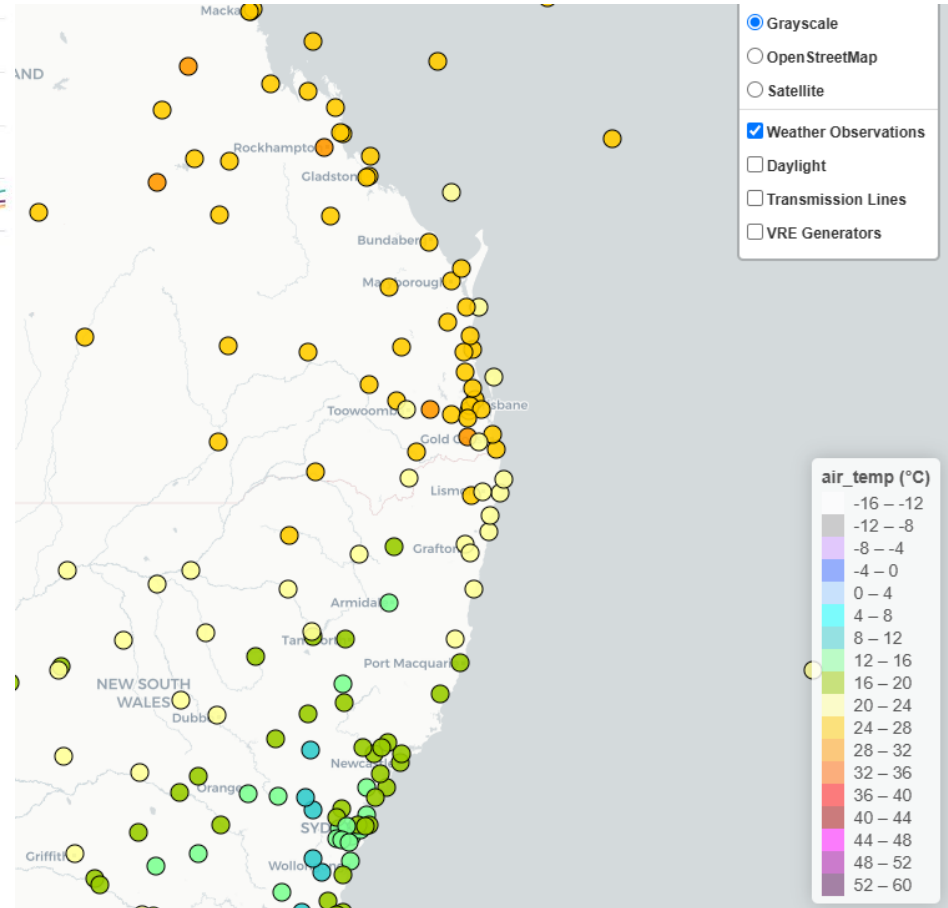
Weather Forecast Comparisons



VRE Risks



Temperature Monitoring



Spotlight on Recent Developments for Incorporating Weather

Spotlight on

Energy Sector Weather Outlook (ESWO) Reports



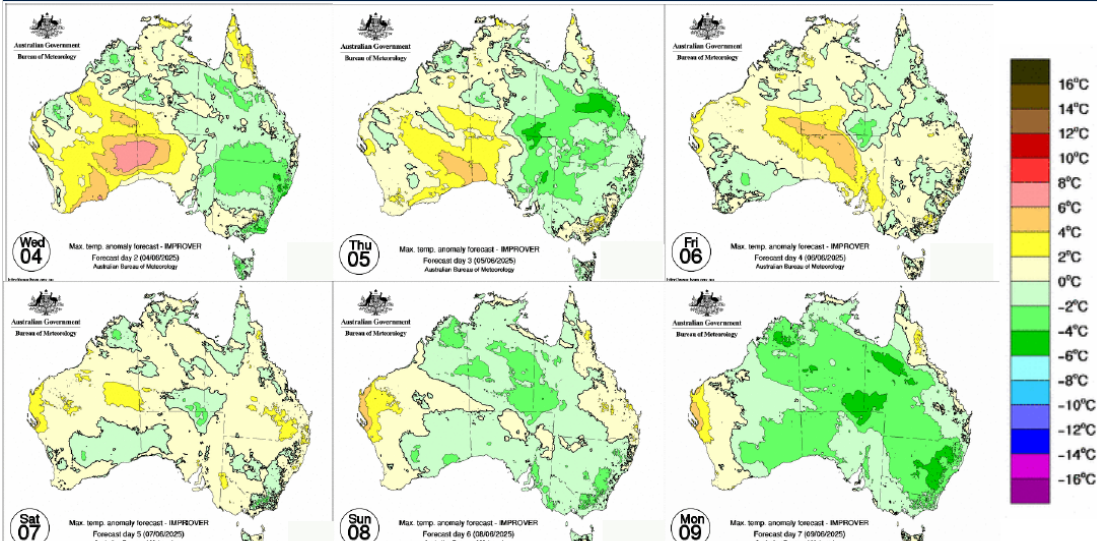
ESWO Morning Report



Energy Sector Weather Outlook

Tuesday, 3 June 2025

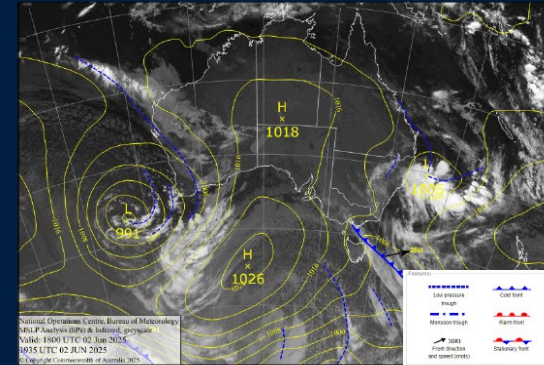
Max Temp Forecast Anomalies



Overview

- Cool but generally settled conditions for much of the NEM over the coming days.
 - Some isolated storm activity possible about coastal parts of NSW today and tomorrow.
- More wet and windy weather for SW WA, with a deep low generating moderate rainfall across the south of the state today and tomorrow.
 - Storms likely around the SW with a risk of isolated severe storms.
- A succession of strong cold fronts expected for SE Aus later this week, as the WA low redevelops in the Bight from Friday and into the weekend.
 - Strong to damaging winds and gusty showers/storms across SA/Vic/Tas during this period, including a risk to Adelaide and Melbourne.

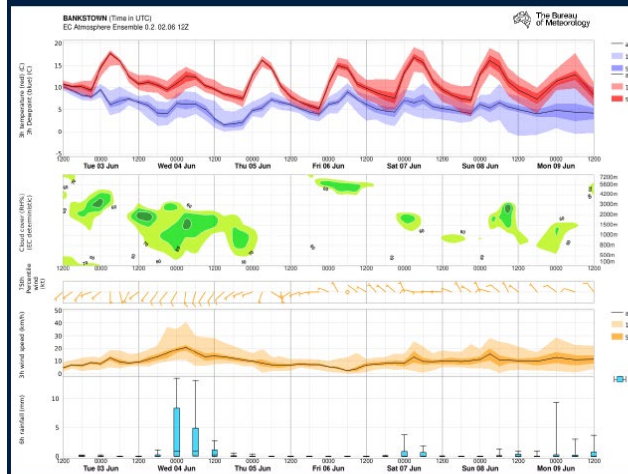
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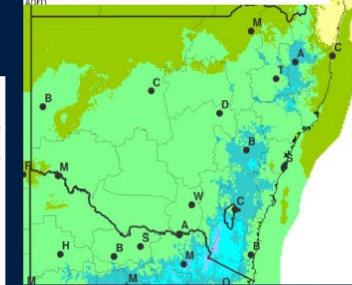
Tuesday, 3 June 2025

OFFICIAL

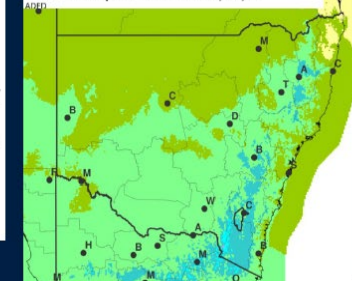
NSW: Weather Data



2m Max Temperature for Wednesday 04 June (°C)



2m Max Temperature for Thursday 05 June (°C)



ESWO Morning Report

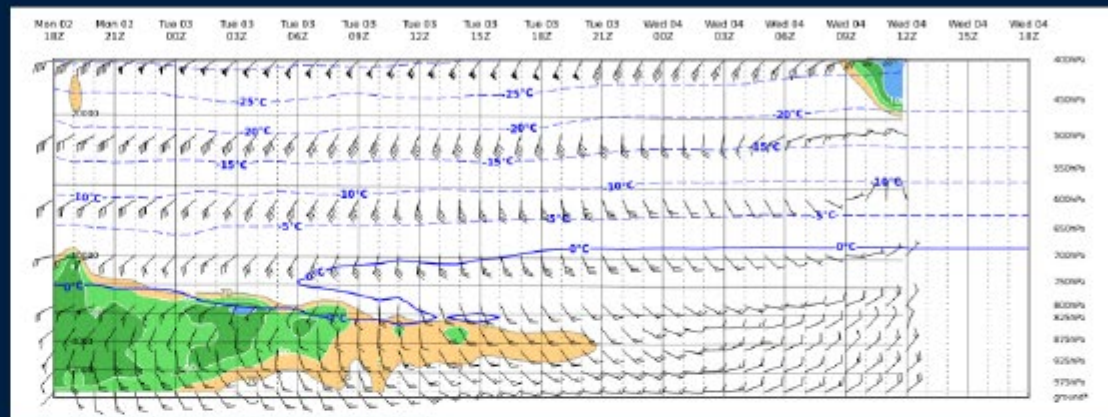
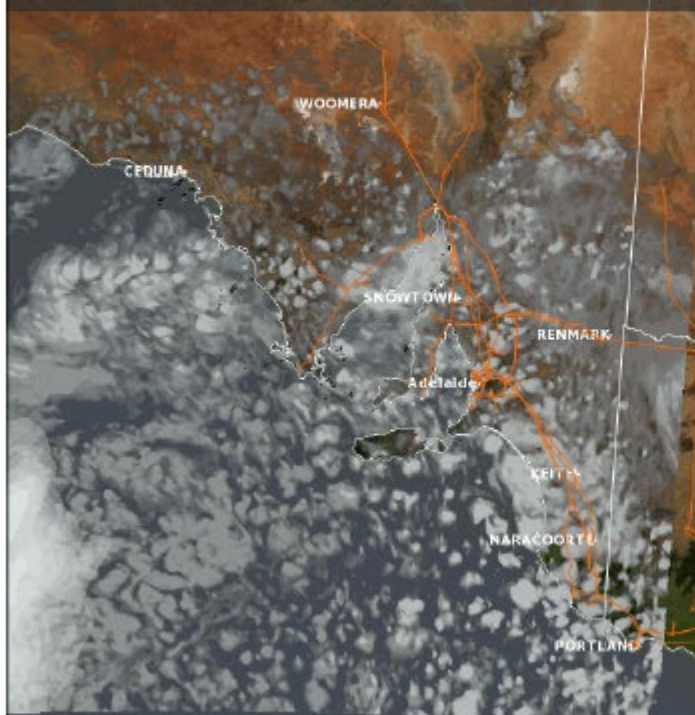
SA DPV Disruption

Additional detailed assessment for Adelaide, considering the probabilities of:

- Cloud Ramp Risk (High rate of change, high magnitude change)
- Cloud Volatility Risk (High rate of change, low magnitude)
- Slow Cloud Clearance Risk (Low rate of change, high magnitude)

Tuesday 03 Jun 2025 13:00 AEST

Synthetic Cloud - Access C (AD) (06 UTC 20250602)



Access-C Relative Humidity Cross-Section for Adelaide Airport (Time in UTC).

| Hazard | D0: Ridge | D1: Ridge |
|---------------------------|-----------|-----------|
| Cloud Ramp Risk | Very Low | Very Low |
| Cloud Volatility Risk | Low | Very Low |
| Slow Cloud Clearance Risk | Low | Very Low |

| Chance of Hazard | High (>50%) | Moderate (21-50%) | Low (5-20%) | Very Low (<5%) |
|------------------|-------------|-------------------|-------------|----------------|
|------------------|-------------|-------------------|-------------|----------------|



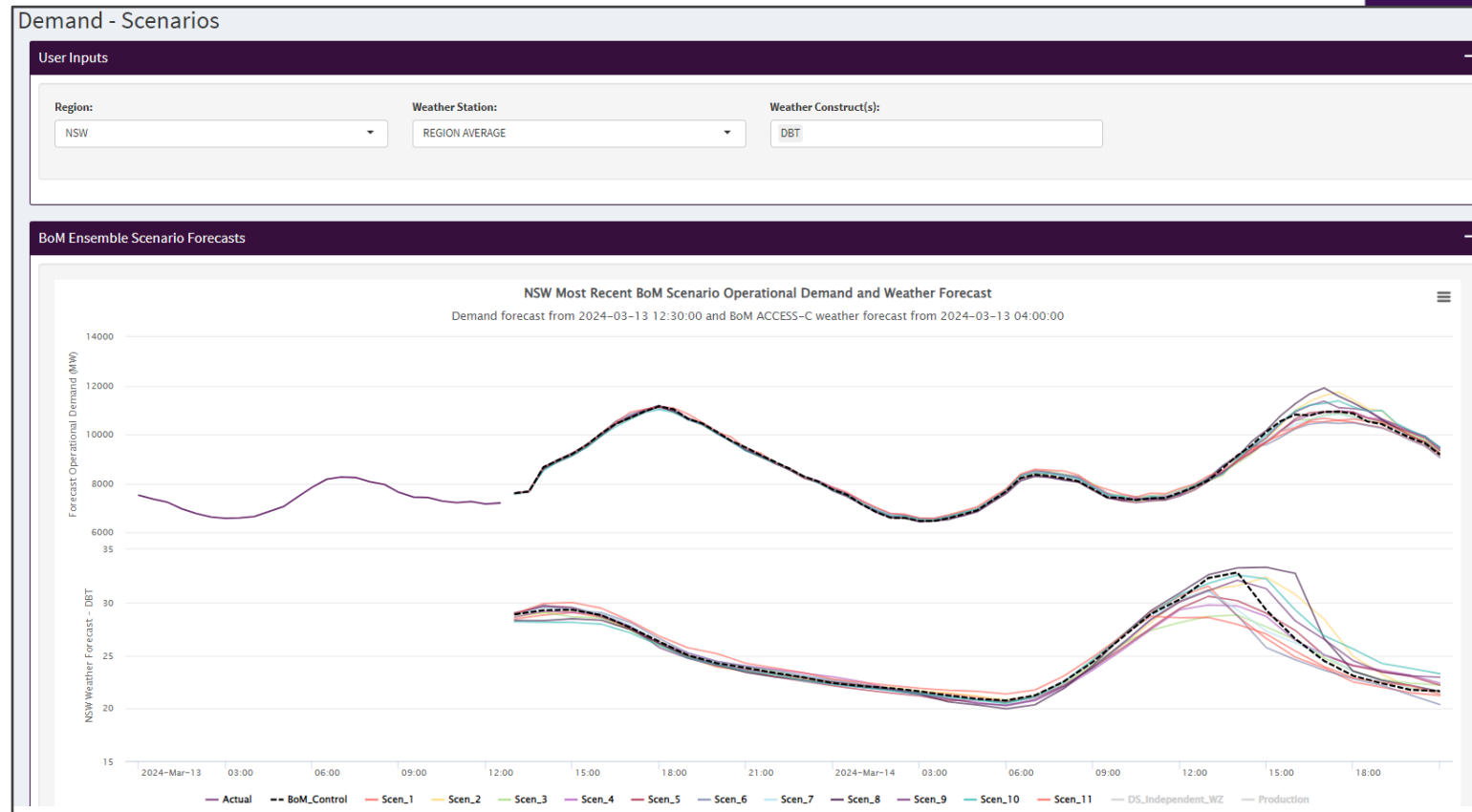
Spotlight on

Weather Scenario Tool

Weather Scenario Tool

A novel method to translate the operational impact of each weather scenario for increased situational awareness and preparedness.

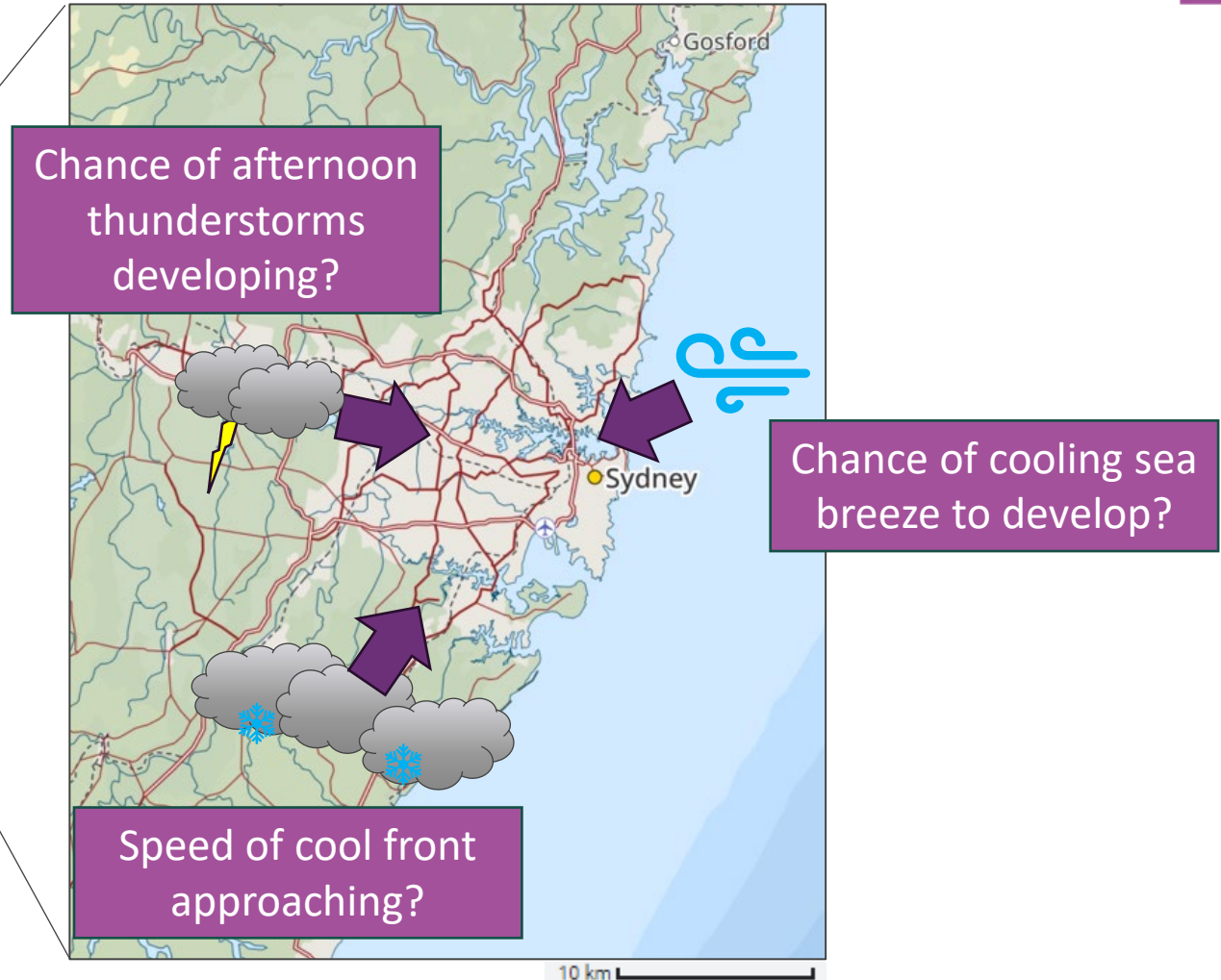
- High-resolution gridded (2.2km) forecasts for 12 ensemble members (including control).
- Updated every 6 hours, covering 36 hours of the horizon at one hour resolution, for eight interdependent weather concepts.
- Highly tailored for 38 DFS point weather station forecasts for direct input into demand models.
- Passed into best performing Machine Learning model to translate ensemble spread into demand spread for assessment.
- Provides a physically representative spread of possible weather outcomes used for decision making.



Weather uncertainty and demand risks: New South Wales example



Sydney is the largest city in New South Wales (NSW) and its weather the key driver for the demand in the state. On hot summer demand days, weather risks are often significant, with some examples shown to the right.

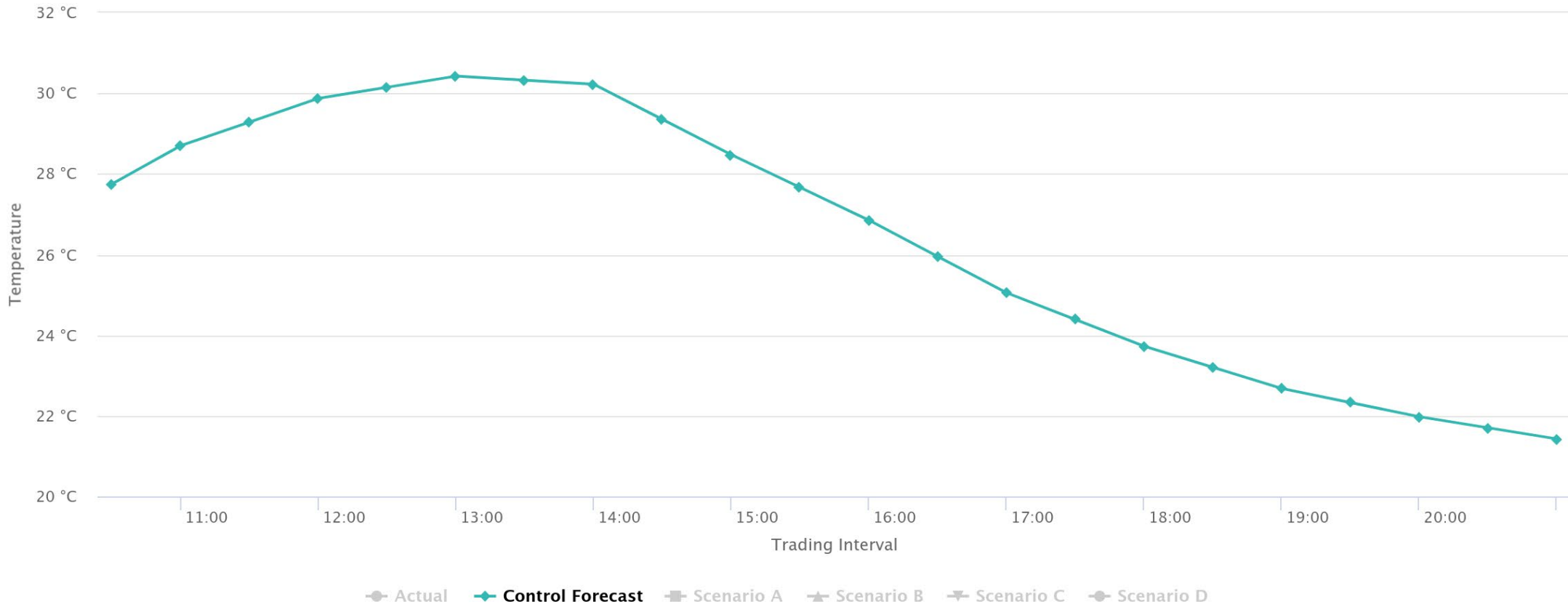


Weather Scenario Case Study

New South Wales – 14th March 2024

Bankstown (NSW) Temperature Scenarios - March 14

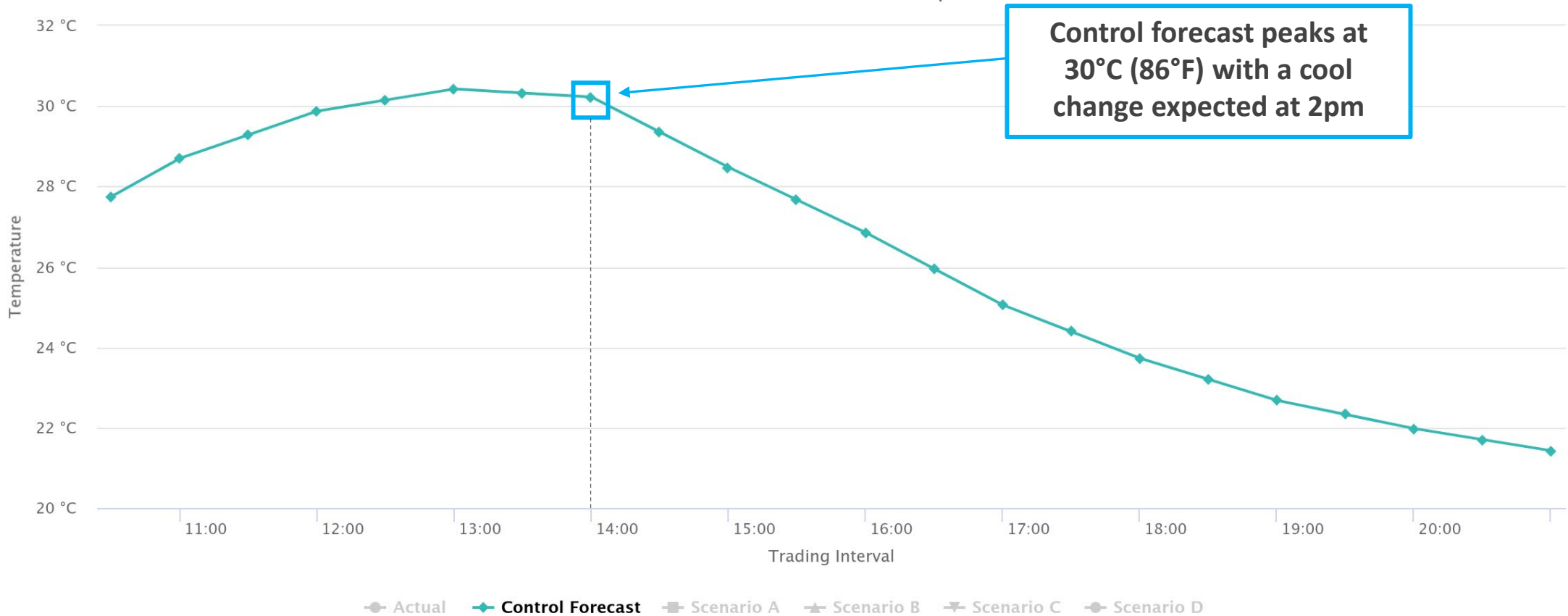
Scenarios Produced: March 13 12:30pm



Weather Scenario Case Study New South Wales – 14th March 2024

Bankstown (NSW) Temperature Scenarios – March 14

Scenarios Produced: March 13 12:30pm



Control forecast peaks at 30°C (86°F) with a cool change expected at 2pm

Weather Scenario Case Study

New South Wales – 14th March 2024

Bankstown (NSW) Temperature Scenarios – March 14

Scenarios Produced: March 13 12:30pm

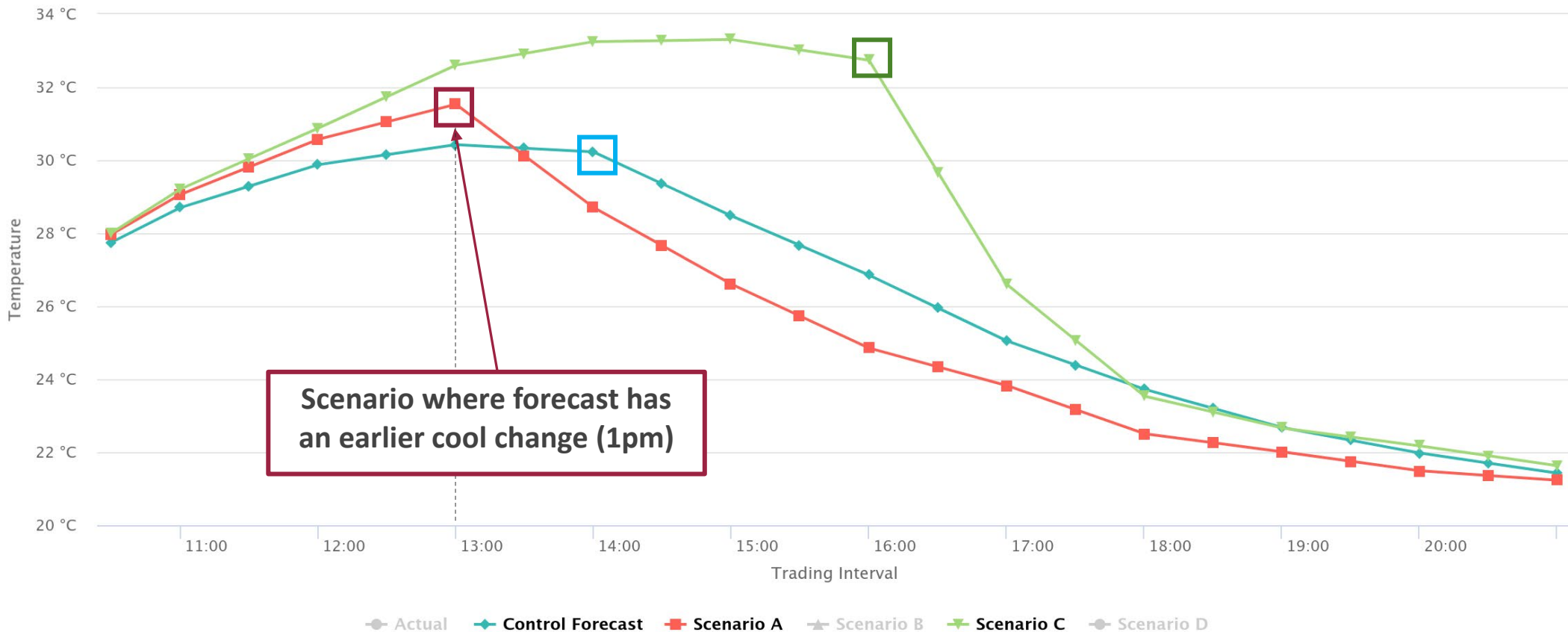


Weather Scenario Case Study

New South Wales – 14th March 2024

Bankstown (NSW) Temperature Scenarios – March 14

Scenarios Produced: March 13 12:30pm

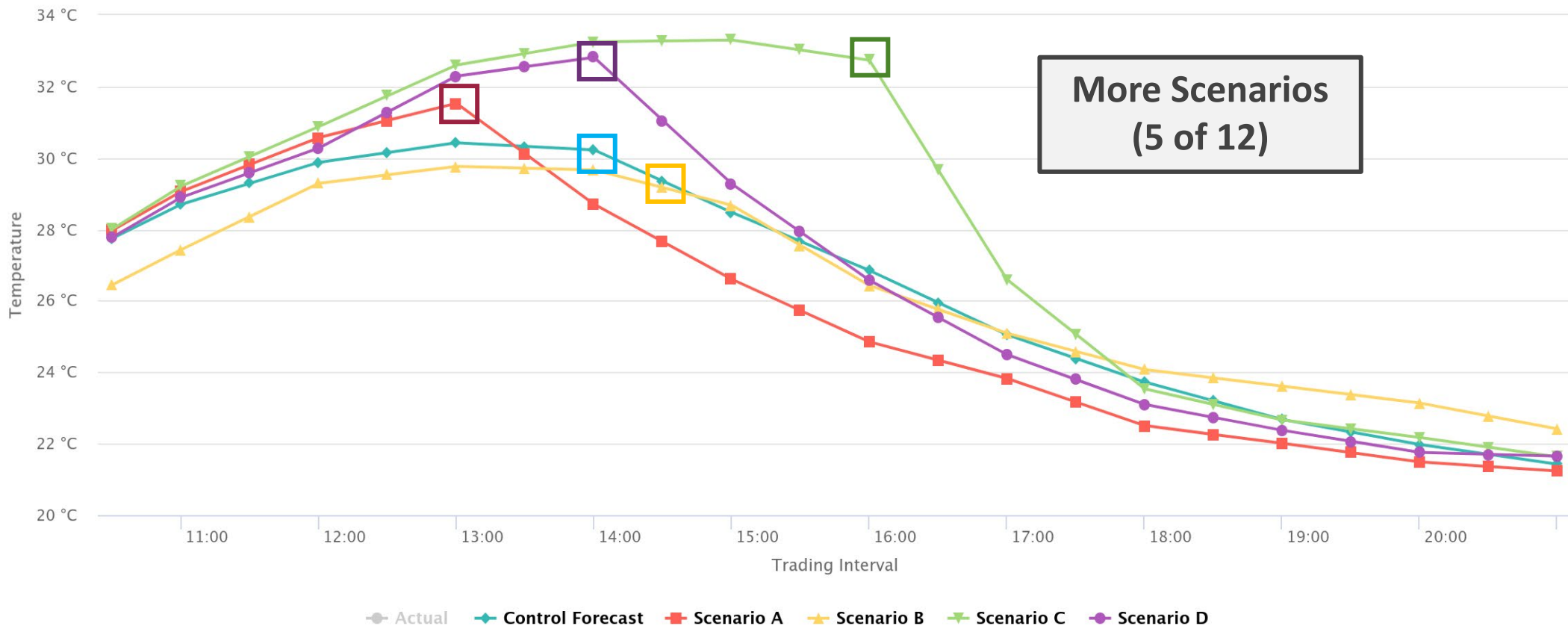


Weather Scenario Case Study

New South Wales – 14th March 2024

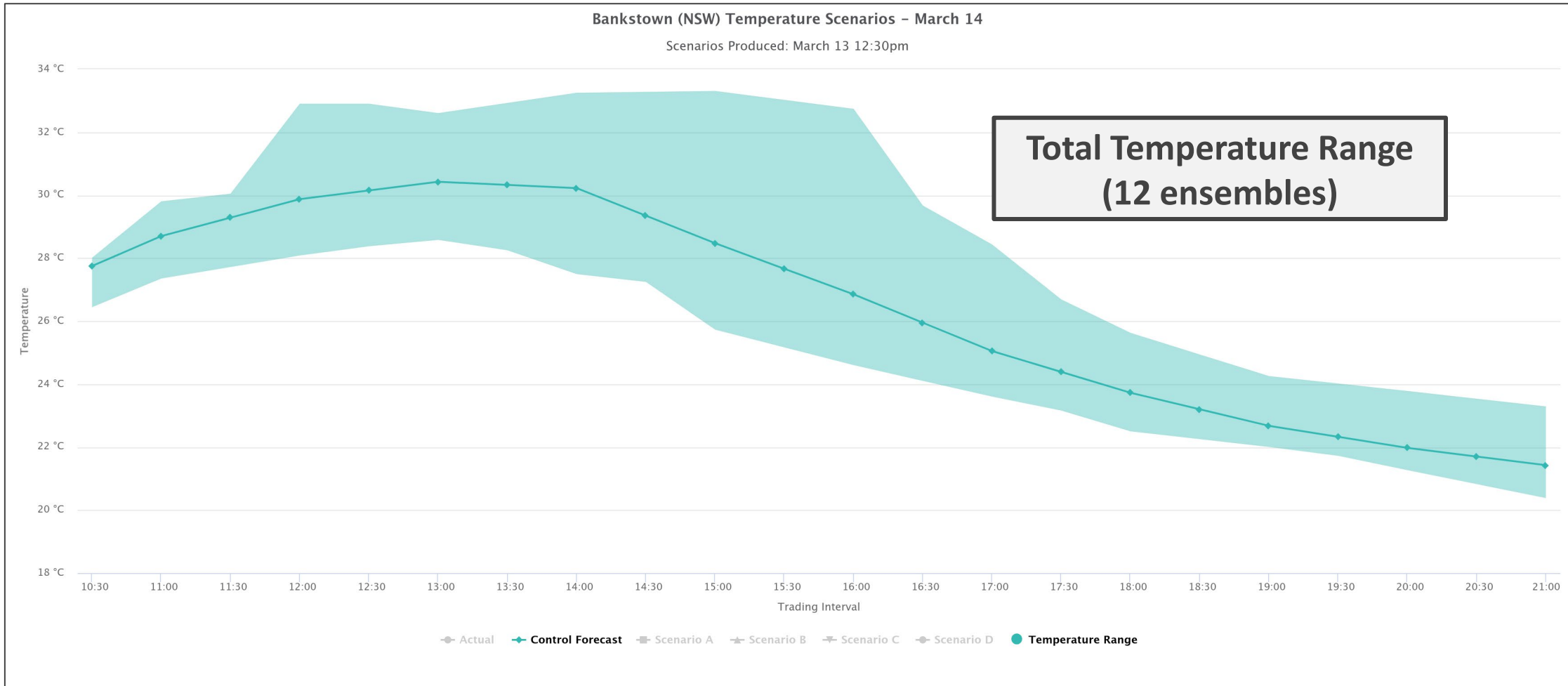
Bankstown (NSW) Temperature Scenarios - March 14

Scenarios Produced: March 13 12:30pm



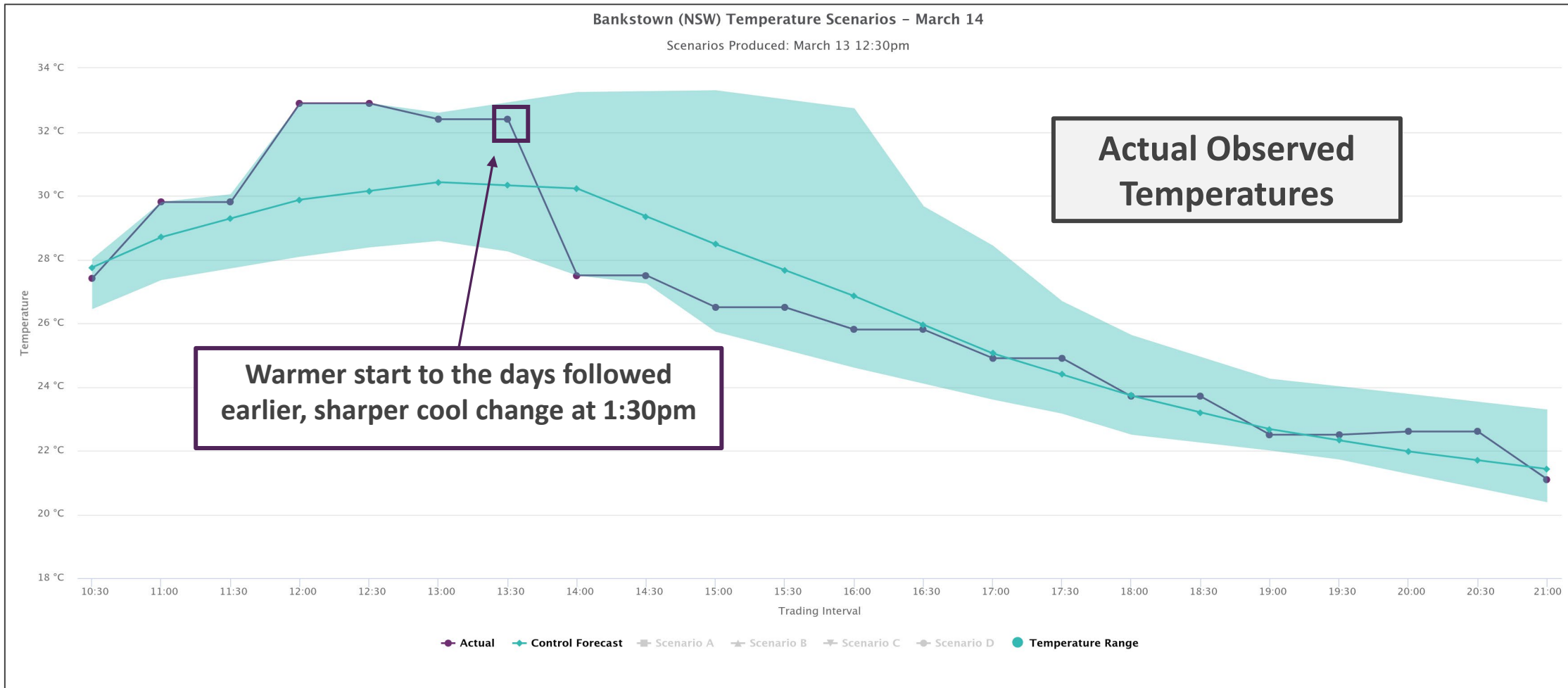
Weather Scenario Case Study

New South Wales – 14th March 2024



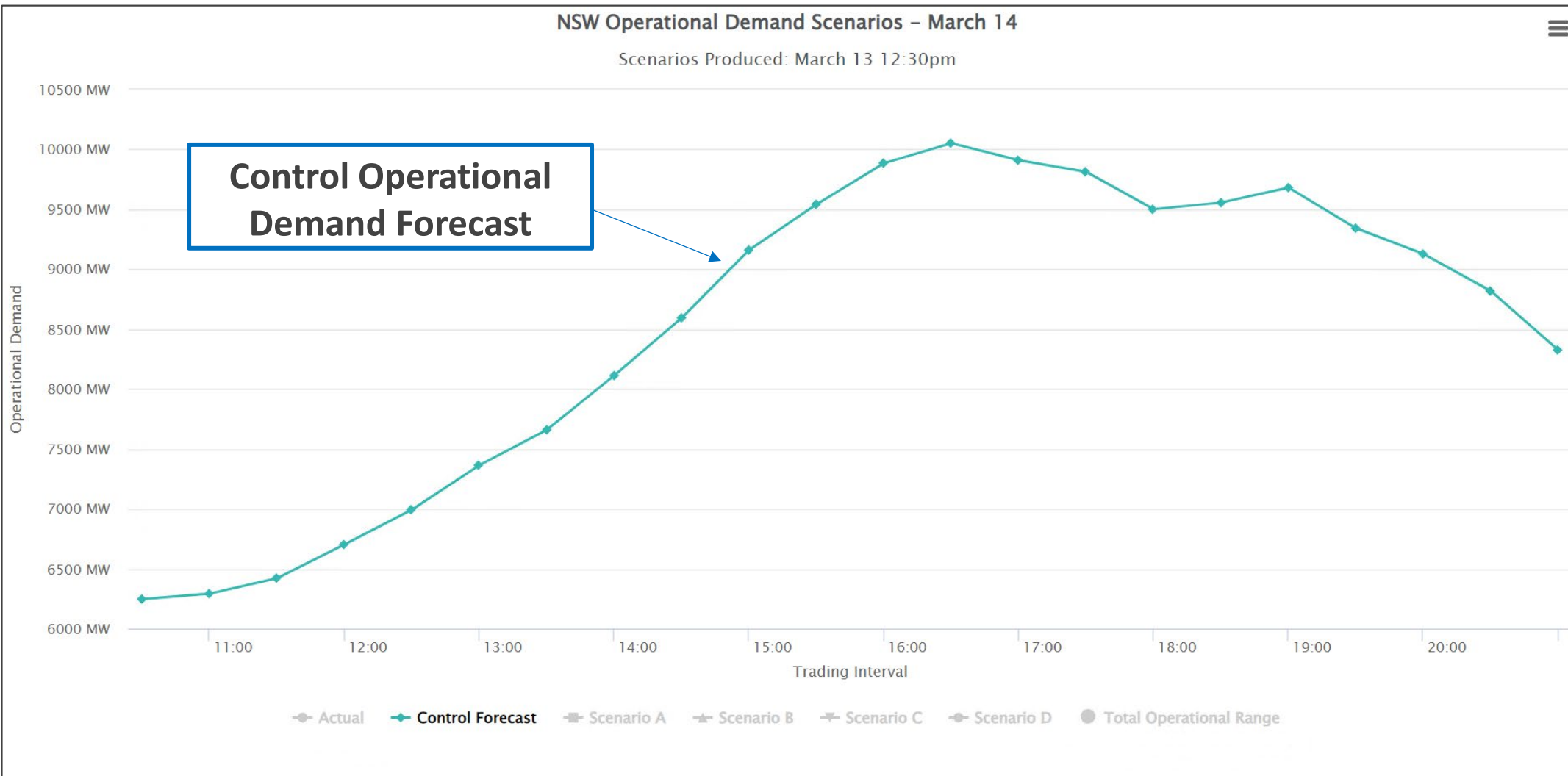
Weather Scenario Case Study

New South Wales – 14th March 2024

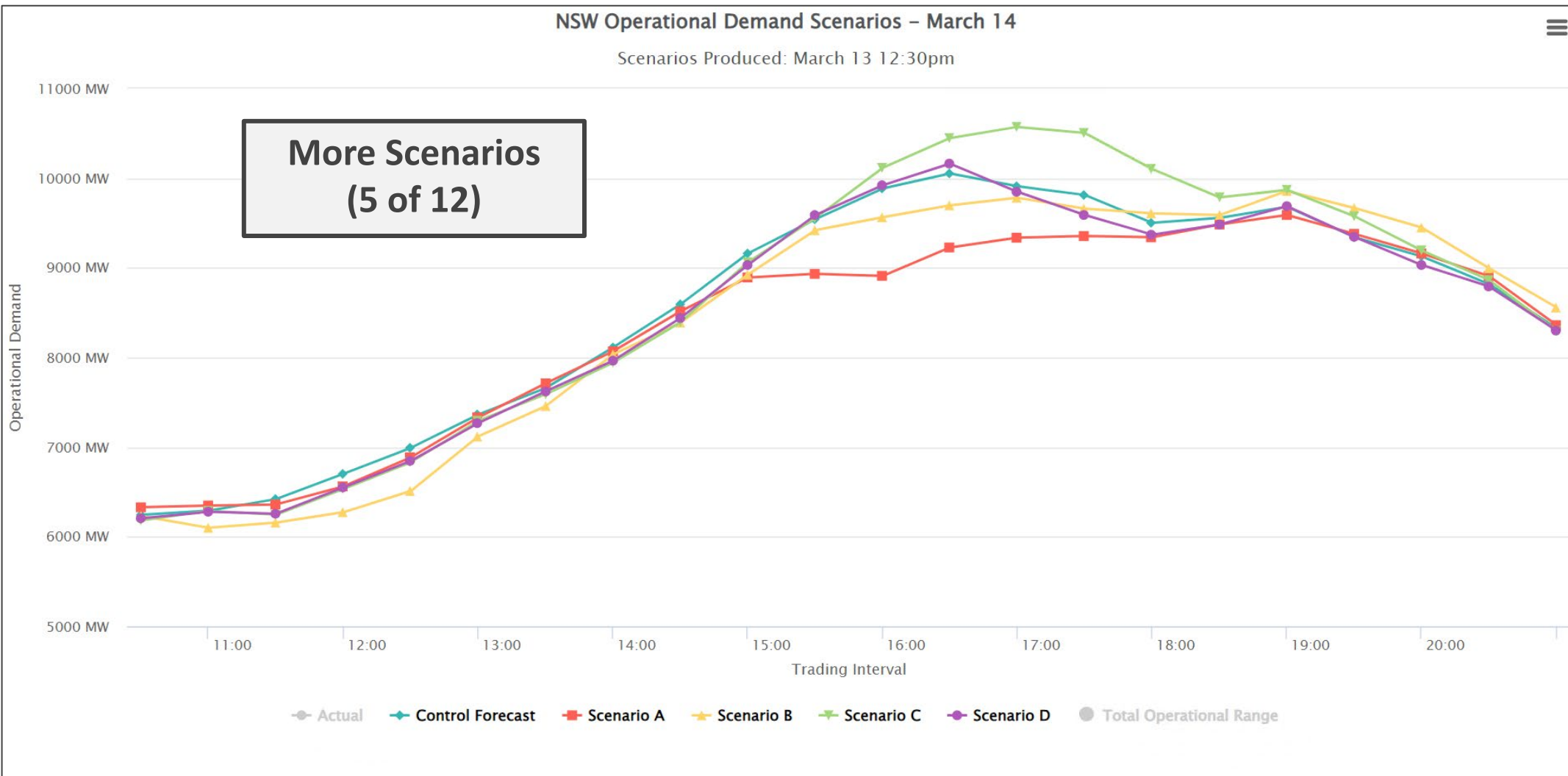


Weather Scenario Case Study

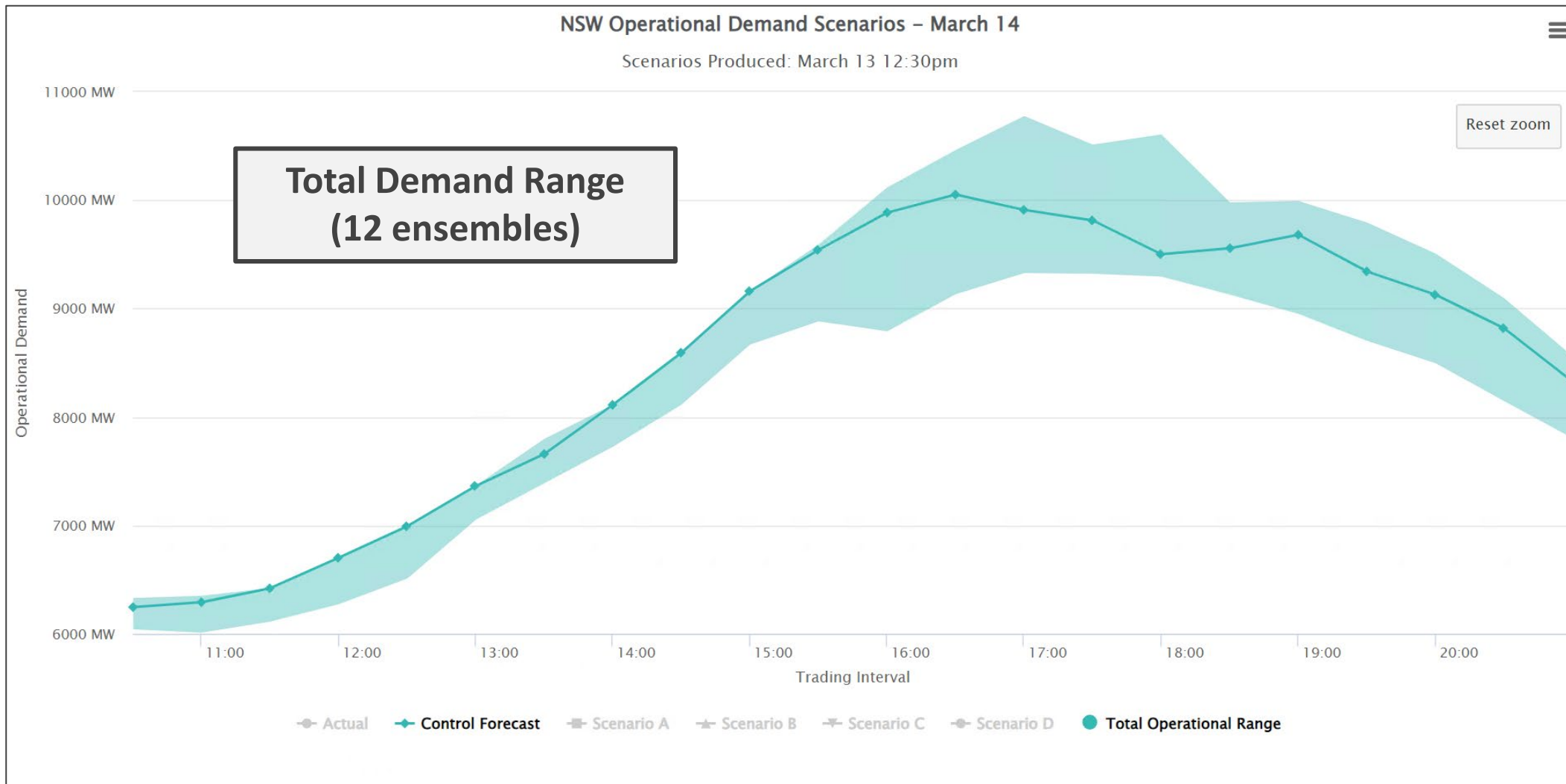
New South Wales – 14th March 2024



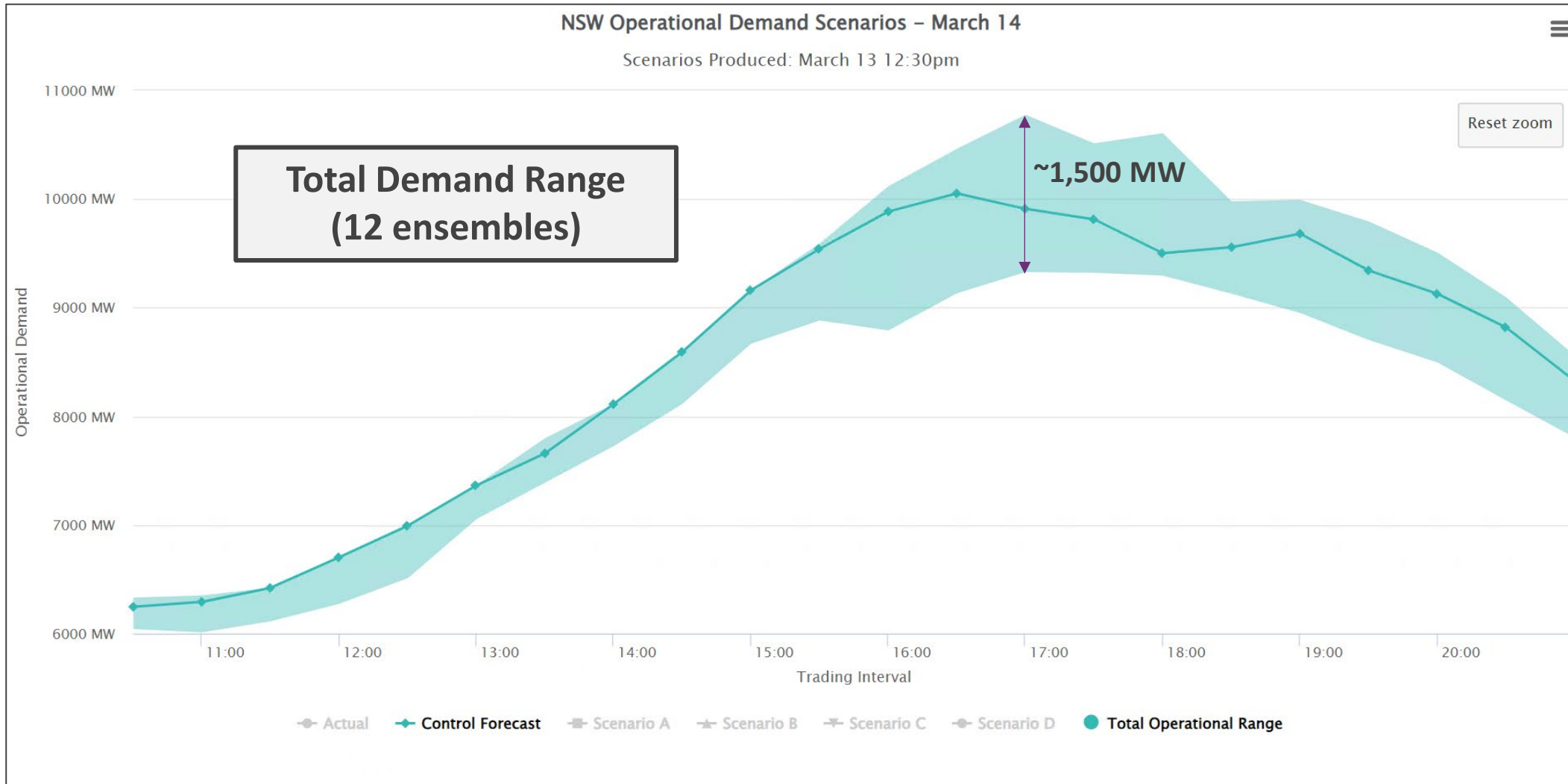
Weather Scenario Case Study New South Wales – 14th March 2024



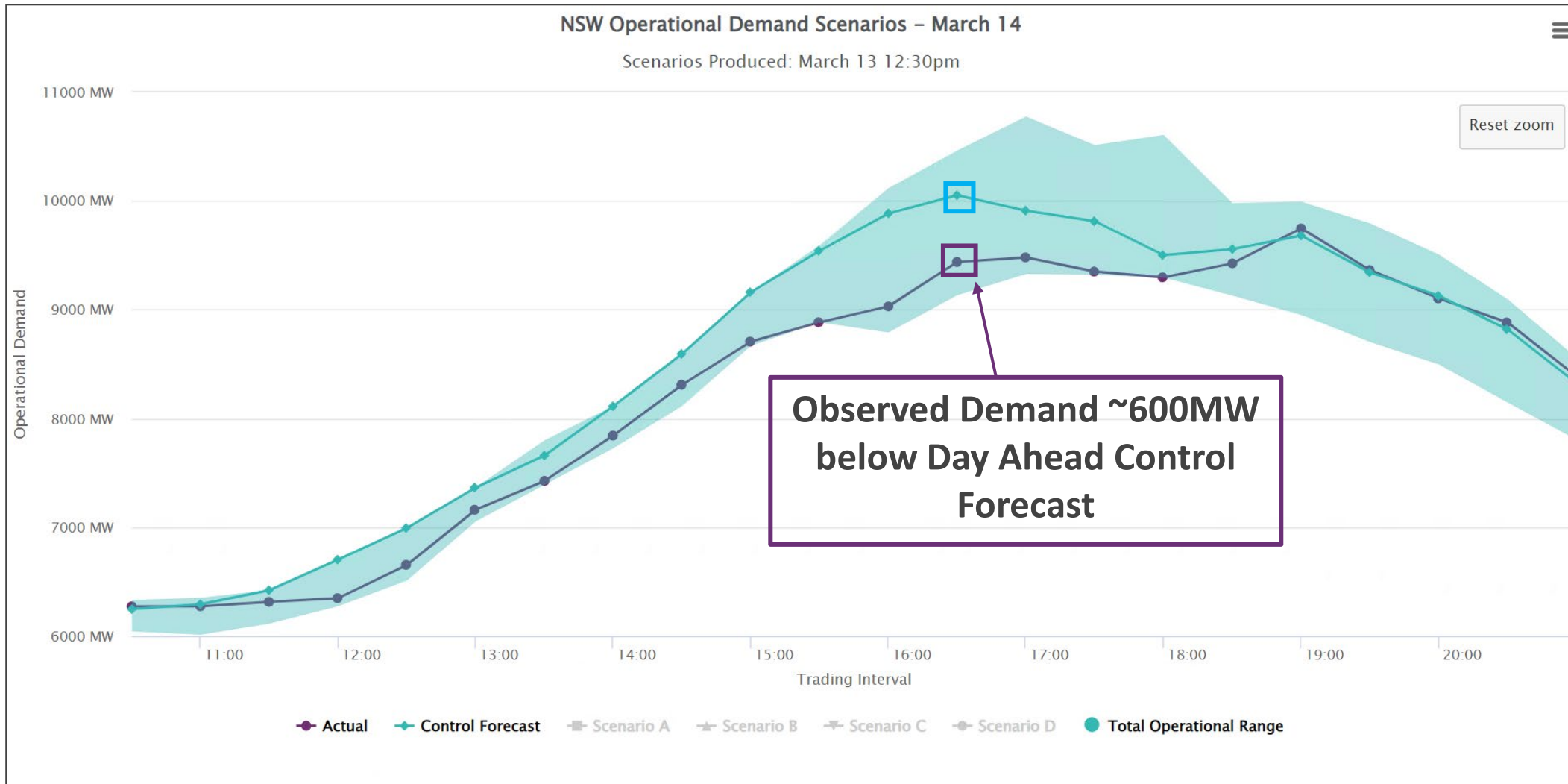
Weather Scenario Case Study New South Wales – 14th March 2024



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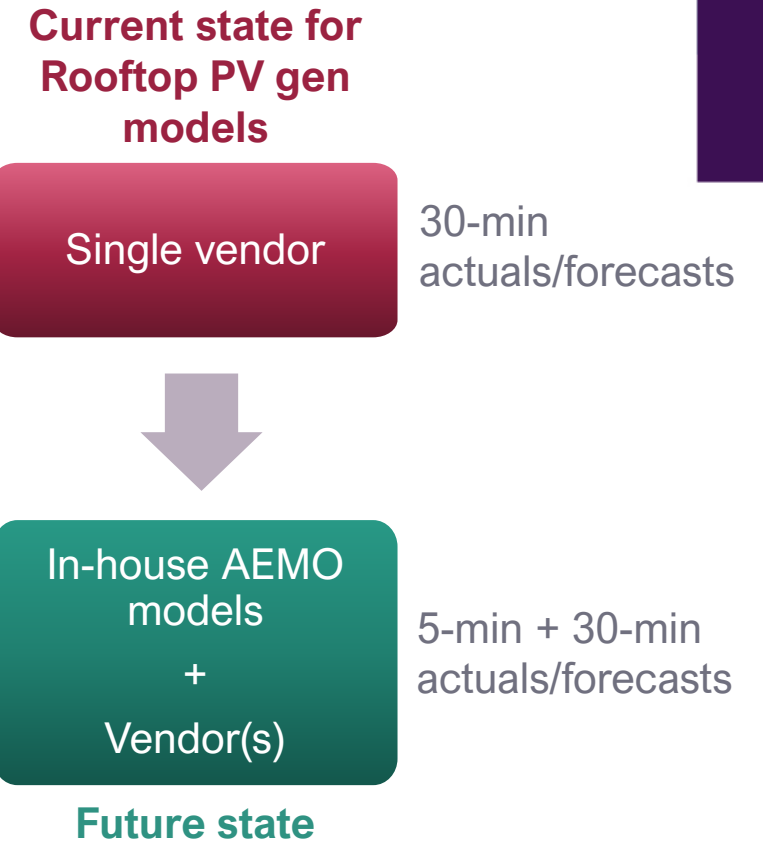


Spotlight on

DREFS – 5min Rooftop PV Estimated Actuals & Forecasts

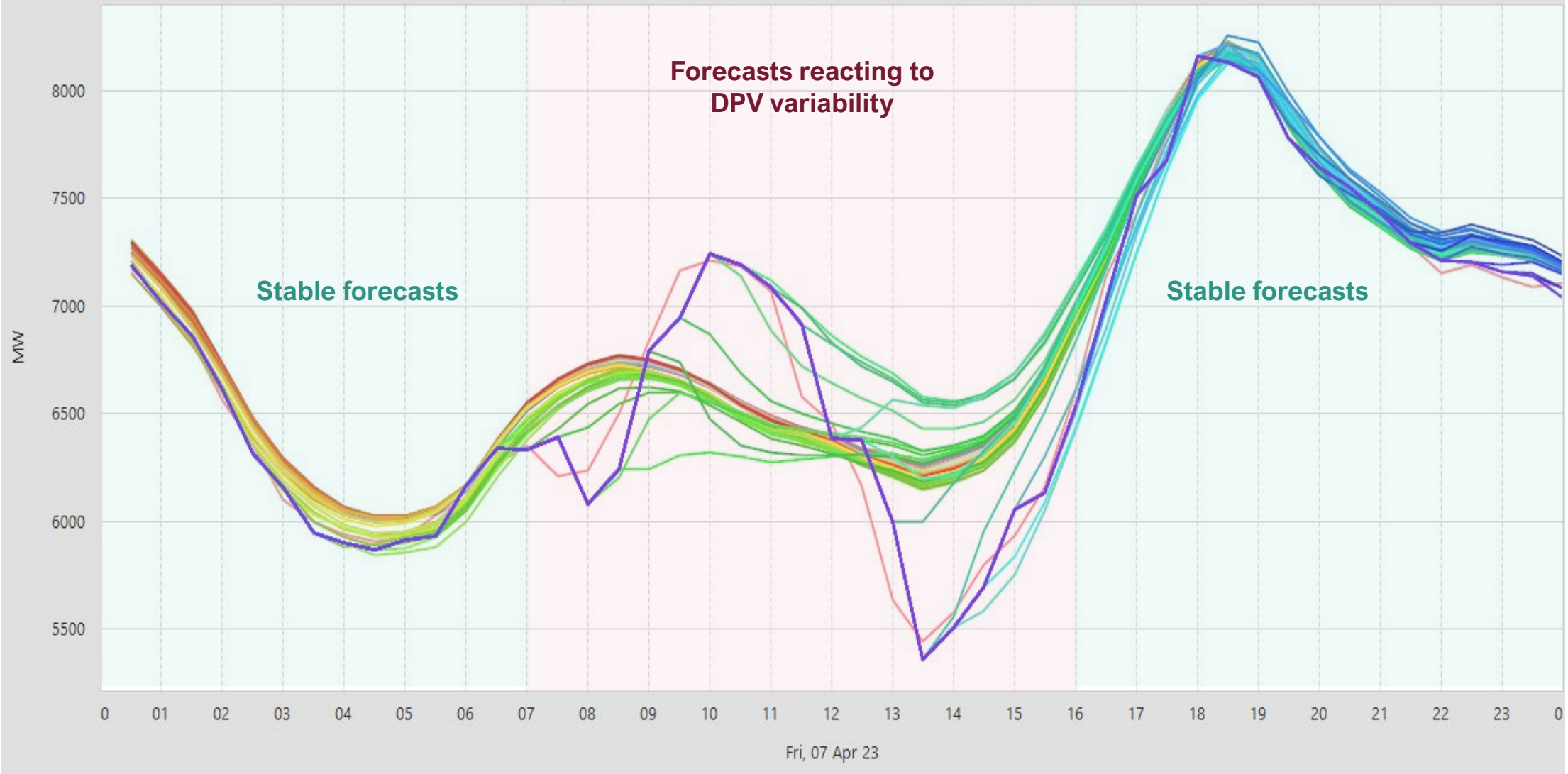
DREFS - Update to Rooftop PV actuals and forecast models

- AEMO is uplifting the Rooftop PV forecasting system to transition from a single vendor-based approach to a multi-vendor approach, that includes an in-house forecasting system developed by AEMO
- This also includes adding 5-minute estimated rooftop PV generation actuals and 5-minute forecasts for DS and 5MPD constraints
- Several benefits such as improved redundancy, reduced latency of creating the estimated actuals, and greater awareness of rooftop PV generation uncertainty
- AEMO’s current plan is for implementation by December 2025



Variability and Uncertainty in Rooftop PV

Sequence of DFS Area Forecasts - Overlaid (NSW1)



DREFS - 5min DPV Estimates

Supply - Rooftop Solar

Plot inputs

Region

SA

Date range

2025-06-07

to

2025-06-07

Load data

Download DREFS actuals

Date range

2025-06-07

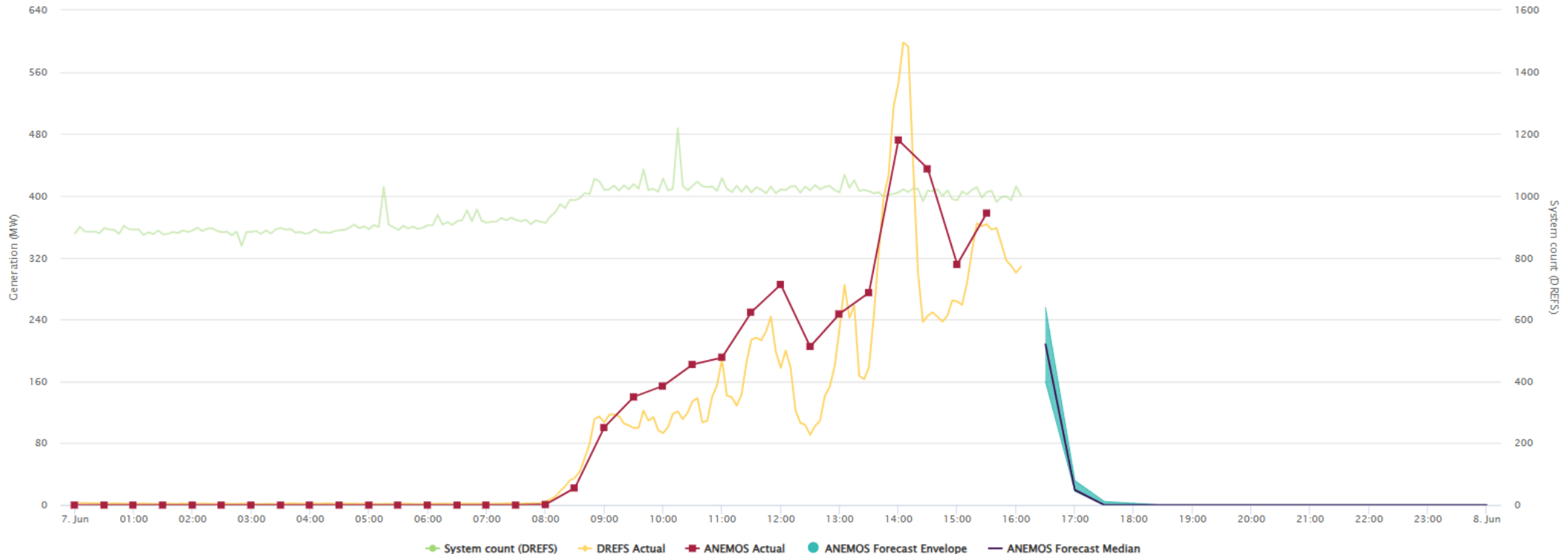
to

2025-06-07

Download

Rooftop actuals and forecasts

SA



Spotlight on

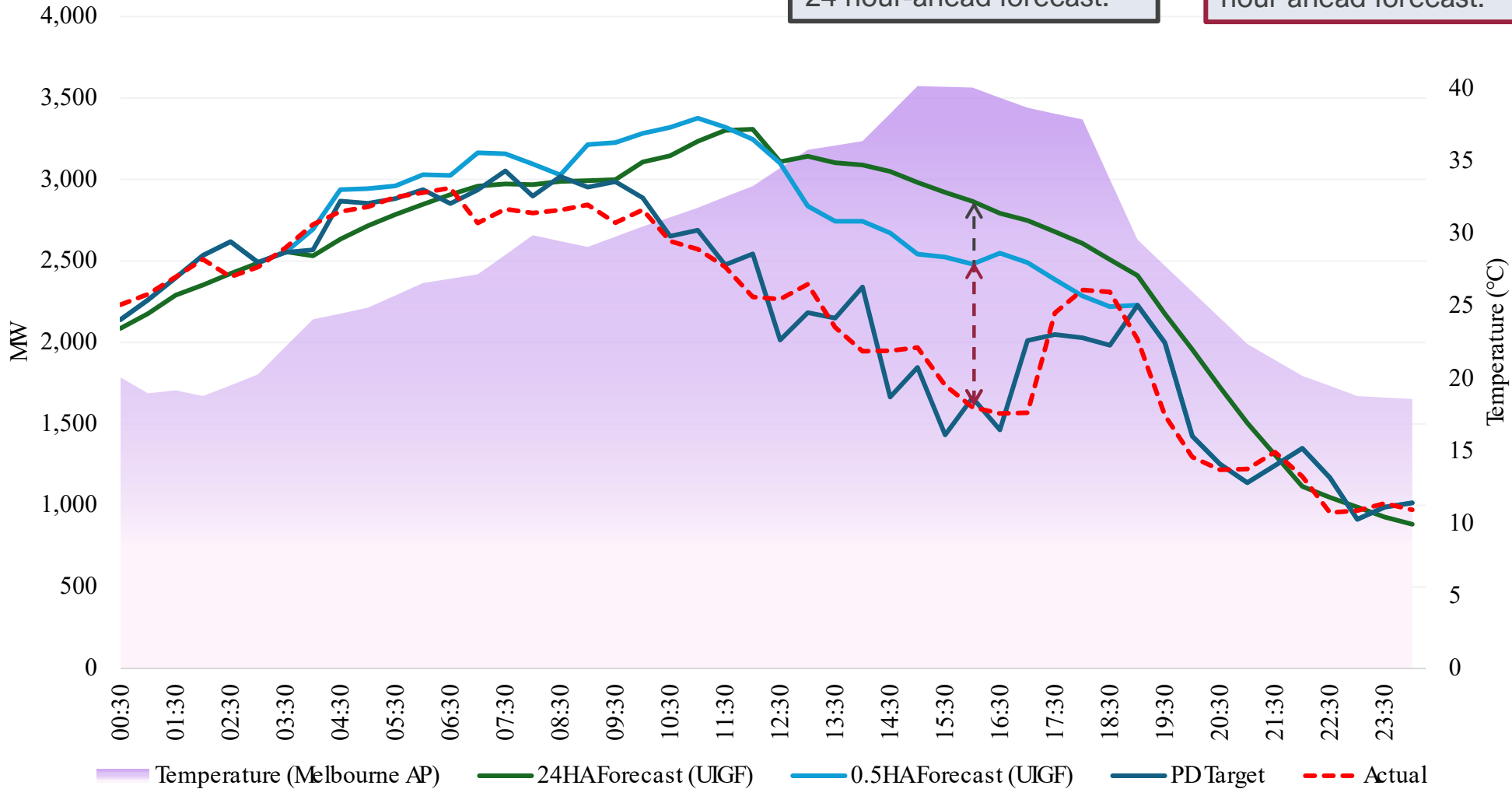
Wind at Risk Tool

Wind at Risk: High-Temperature Wind Turbine Cut-Out

Victoria (16 December 2024)

1,263 MW shortfall in wind generation relative to 24 hour-ahead forecast.

983 MW shortfall in wind generation relative to half hour ahead forecast.



Wind at Risk Tool

Supply - Wind at Risk

Inputs

Select Region:

NSW

Choose Weather Model

Access-C ECMWF Excarta

Wind Threshold (%)

30

Temperature Threshold (%)

90

Regional Risk

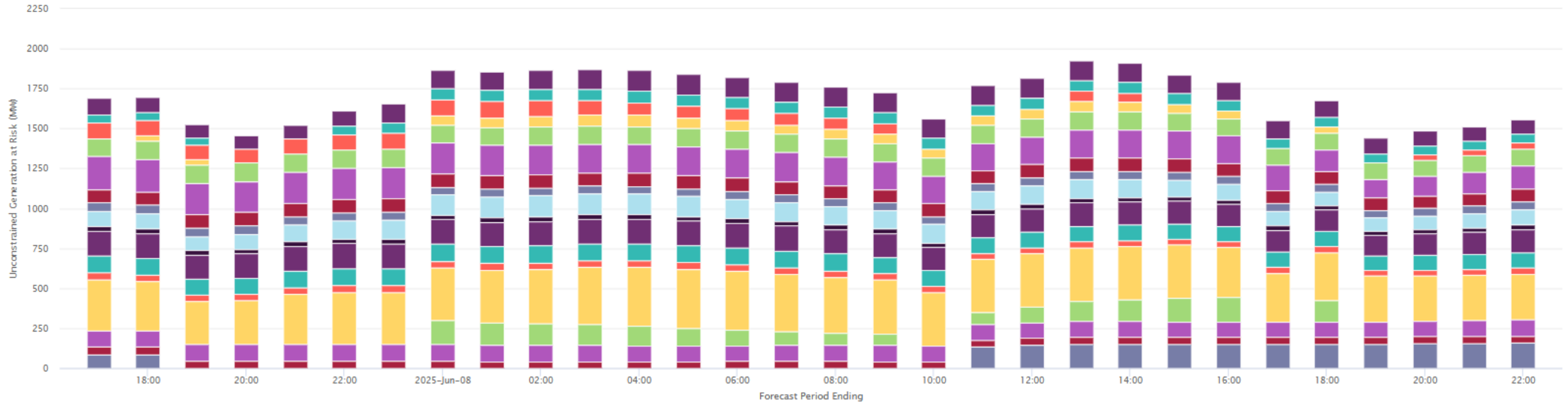
Generators at Risk

Generator Weather Forecast

Farm Metadata

NSW Generators Unconstrained Intermittent Generation at Risk

ACCESSC Forecast Runtime: 2025/06/07 10:00



Upcoming work and Strategic Initiatives



Upcoming work and Strategic Initiatives

We are continuing to work across the weather forecasting industry to ensure weather forecast tools are developed for the purposes of energy forecasting. Initiatives include:

- Redevelopment of AEMO's Projected Assessment of System Adequacy (PASA) to be probabilistic and include weather uncertainty margins in reserve calculations.
- Establishment of new weather observation stations located with renewable energy zones (REZs) near remote variable renewable energy (VRE) generators and in metropolitan heat islands to support weather forecasting.
- Enhancing our Weather Scenario Tool of probabilistic weather forecasts from providers to improve situational awareness and better represent extreme weather risk and operational envelopes in demand forecasts.
- AEMO's NEM Local Temperature Alerts process, recently updated in October 2023, and updates to AEMO's abnormal conditions reclassification criteria to include actions for severe weather phenomena.
- Considering a fourth provider which utilises AI-powered models with higher spatial and temporal resolution than conventional models to forecast wind speed, irradiance, and temperature for energy forecasts.
- Refining our demand forecast models to better reflect load growth and DPV sensitivity

Thank You

Contact Information

Andrew.Akman@aemo.com.au

Operational.Forecasting@aemo.com.au



For more information visit

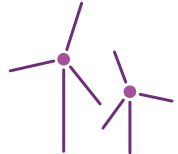
aemo.com.au

Appendix

Wider Operational Forecasting Functions



Situational awareness for control room and wider AEMO



Supporting AEMO's onboarding and connections process



Provide input to Market Reform initiatives



Reporting and documentation



Ongoing improvement of tools and processes

Spotlight on

NEM Local Temperature Alerts

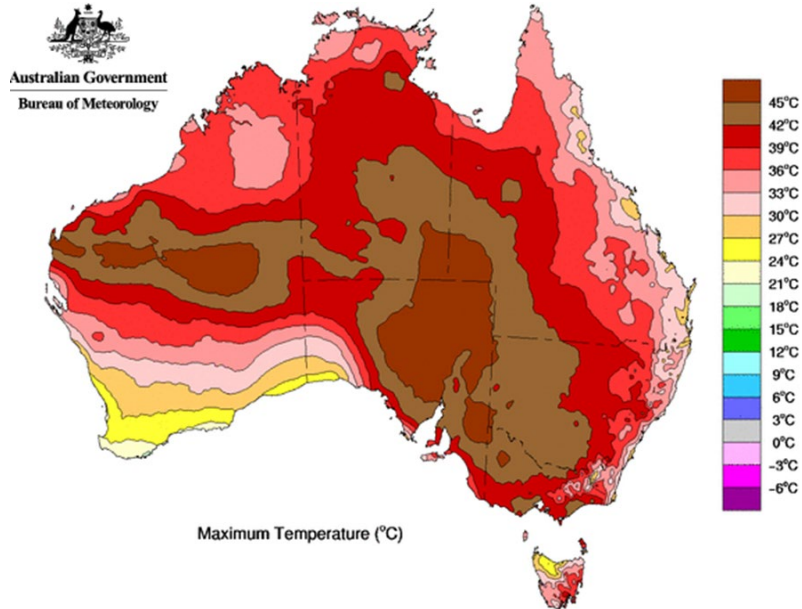
What high impact weather do we need to predict and manage for?

- Destructive winds from super cell thunderstorms, convective downbursts, tornadoes, or tropical cyclones knocking down transmission towers.
- Bushfires and lightning strike threats to double-circuit transmission lines.
- Extreme temperatures or sustained high winds resulting in widespread wind turbine derating and/or cutting out events.
- Extreme multiday heat waves, coupled with elevated humidity, driving record levels of electricity demand.
- Strong and sudden cool changes dropping temperature and causing sharp drops in electricity demand.
- Cloud bands, storm fronts, or dust & smoke crossing metropolitan centres or solar eclipses causing large swings in distributed rooftop PV generation.
- Extended periods of low wind and irradiance resulting in VRE droughts.

Extreme Weather Impacts



More extreme storms can damage transmission network equipment e.g. convective downbursts

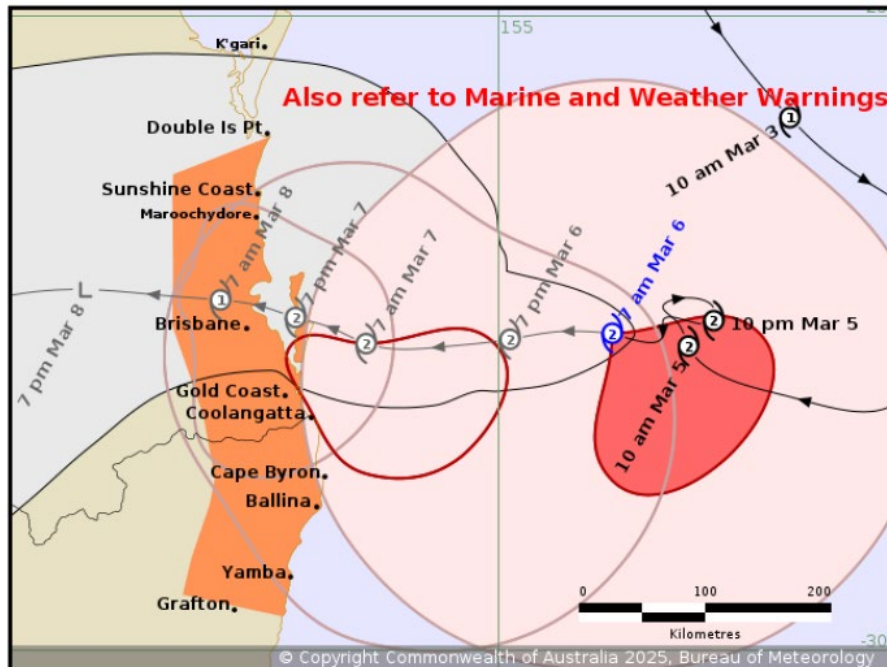
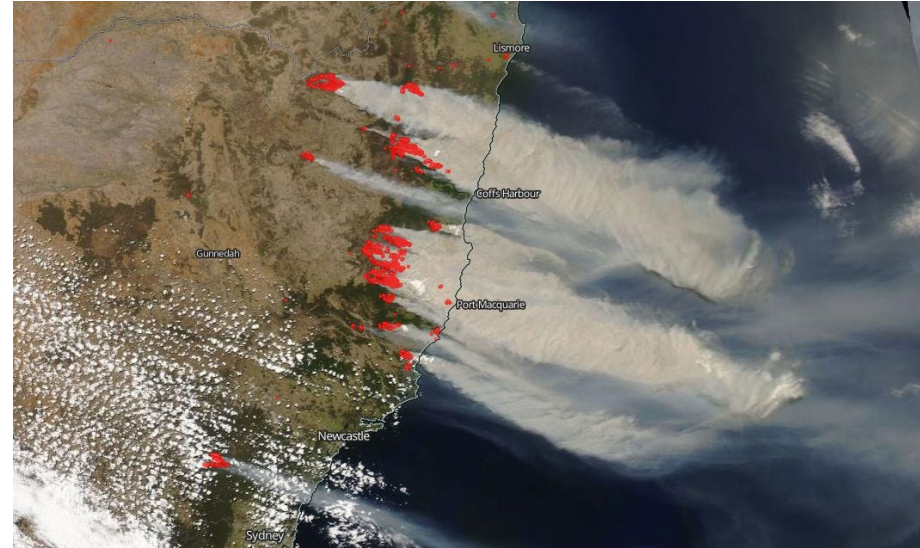


Heat waves, humidity and the timing of cool changes affect the accuracy of peak demand forecasts, and extreme temperatures can cause high-temperature wind farm derating and cut-out, on the days when the power system is under the most stress

Extreme Weather Impacts



2019-2020 Summer bushfires saw extensive attenuation of solar farm and rooftop PV output due to smoke

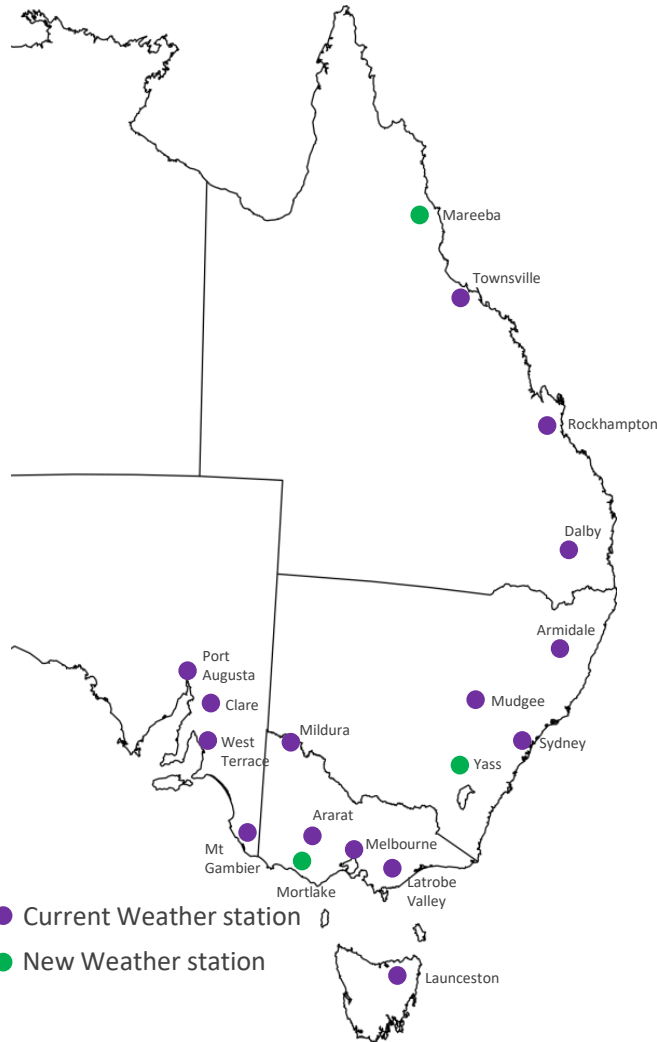


TC Alfred brought unprecedented damage to southeast Queensland and northeast NSW which brought forecasting challenges as homes prepared and business shut down

Key Challenges

- The need for true ensembles and probabilistic forecasts, based on physically representative and interdependent weather scenarios.
- Weather providers minimising average error in deterministic forecasts, therefore struggling to capture extremes and abrupt changes.
- Weather forecasts not updating quickly enough to pick up on changes, e.g. abrupt cool changes or irradiance changes due to cloud.
- Weather observation infrastructure centred around load and not developing generation such as Variable Renewable Generation (VRE).
- Timing, severity, and location of severe weather not forecast well ahead of time (e.g. high-end thunderstorms and destructive convective weather).

NEM Local Temperature Alert Market Notice



106736 GENERAL NOTICE | 17/03/2023 10:06:22 AM

NEM Local Temperature Alerts for QLD, SA, VIC from 17 Mar 2023 to 21 Mar 2023

AEMO ELECTRICITY MARKET NOTICE

AEMO's weather service provider has issued forecast temperatures equal to or greater than the NEM Local Temperature Alert Levels for listed weather stations below.

QLD
 Dalby Ap (37+ Deg C): 17th Mar

SA
 Port Augusta Ap (39+ Deg C): 17th Mar, 18th Mar

VIC
 Mildura Ap (39+ Deg C): 18th Mar

The NEM Local Temperature Alert Levels are:

Launceston Ti Tree Bend: 33 Deg C, Dalby Airport: 37 Deg C, for all other selected weather stations: 39 Deg C.

AEMO requests Market Participants to:

- review the weather forecast in the local area where their generating units / MNSP converter stations are located and,
- if required, update the available capacity in their dispatch offers or availability submissions consistent with the forecast temperatures.

- When forecast temperatures are equal to or greater than NEM Local Temp thresholds in the next five days, AEMO publishes a market notice.
- The market notice reminds generators and/or the MNSP to review the available capacities in their dispatch offers or availability submissions consistent with the forecast temperatures.

An Ensemble of Weather Information ...

Ensemble

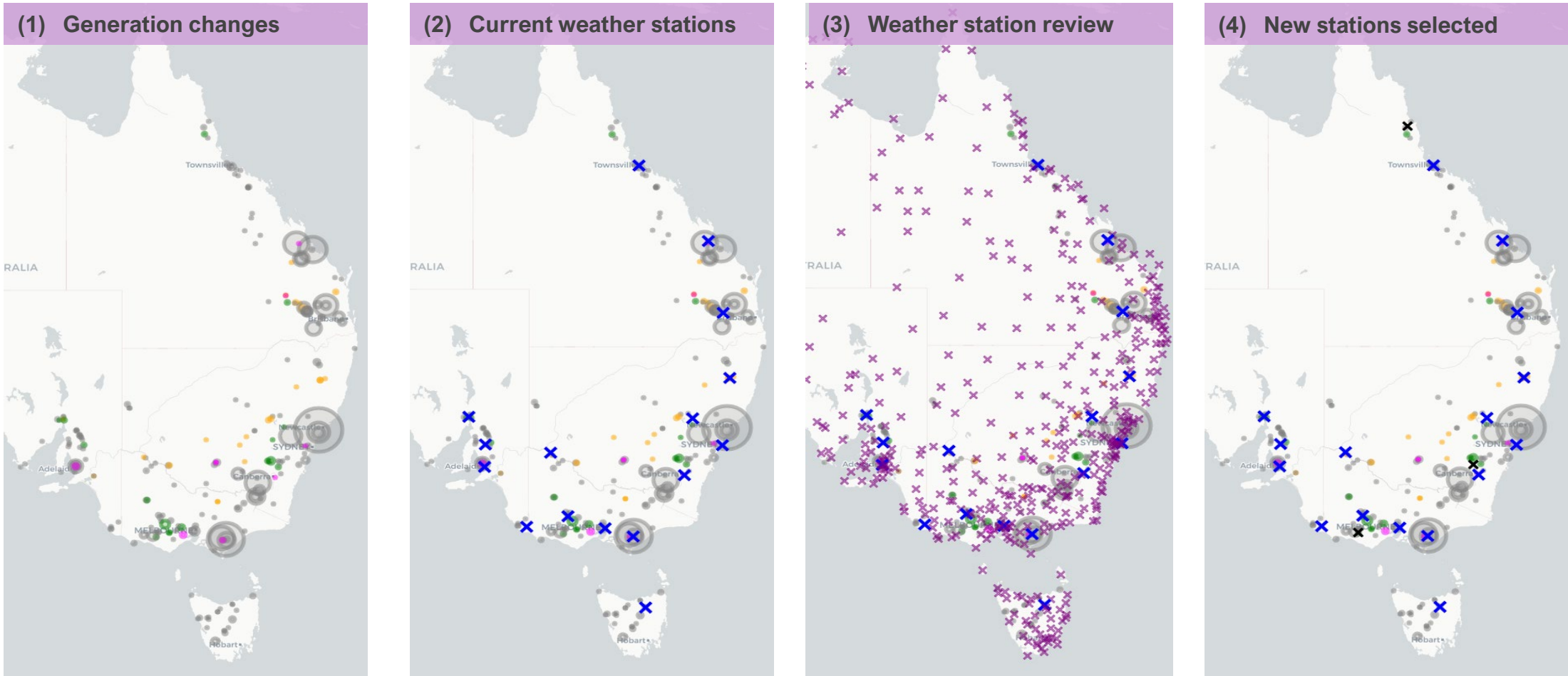
- *A group of items viewed as a whole rather than individually.*
- *A group of similar systems, or different states of the same system, often considered statistically.*



Operational Forecasting

- *Multiple weather providers for energy forecasting*
- *Several scenarios of possible weather from each provider*
- *A suite of weather tools for situational awareness & monitoring*

NEM Local Temperature Alerts



Generators connected at last review (grey) were mapped against generators connected since last review (coloured)



Current reference weather stations were mapped against previous and new generators



A review of all available weather stations was conducted to identify potential changes



New weather stations identified to represent new or existing generation clusters