A Screening Framework for Climate-Adjusted Dispersion Meteorology

Evaluating NARCliM2.0 SSP2-4.5 projections against observed interannual variability

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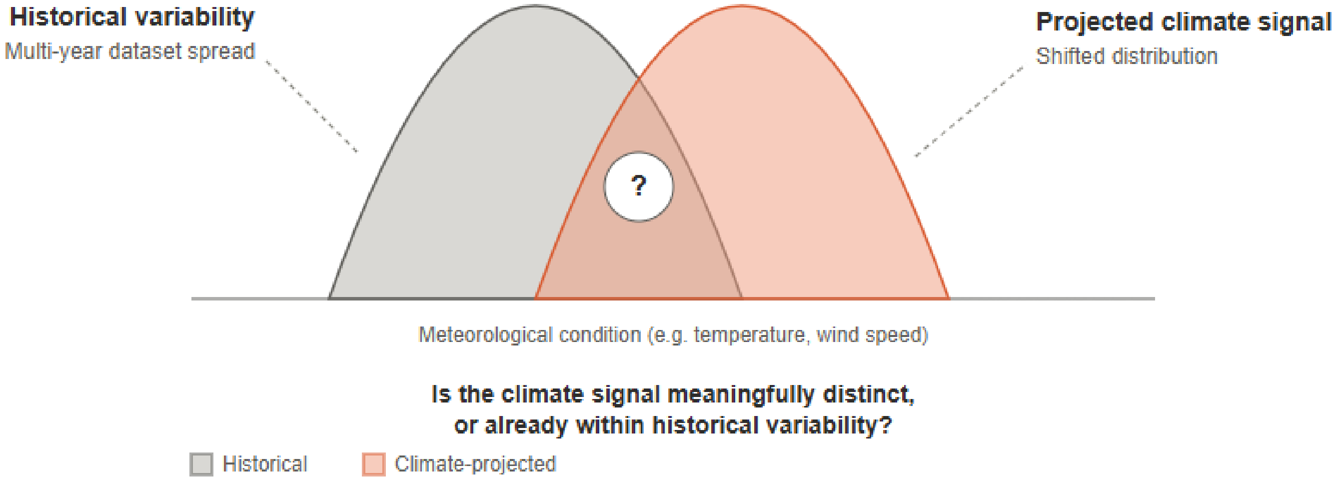
Bright ideas.
Sustainable change.

Introduction - Why does this matter?

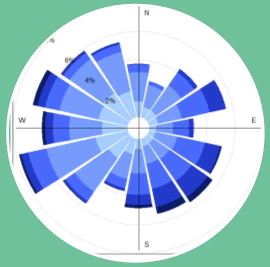
- Climate change can alter the meteorological conditions that drive dispersion models, including wind speed, wind direction and atmospheric stability.
- Since these parameters directly control how pollutants are transported and diluted, any climate-driven shift in local meteorology is an important consideration for air quality assessments that are predicting future impacts.
- Air quality assessments typically rely on historical meteorological data for dispersion modelling
- Multi-year datasets or single representative years used to characterize historical meteorological variability
- Dispersion modelling is often predicting a future year scenario
- **Key question:**



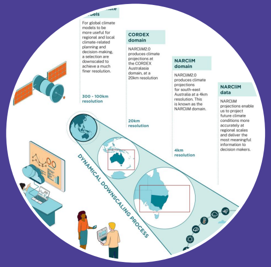
Study overview

Bankstown AWS 2016-2025

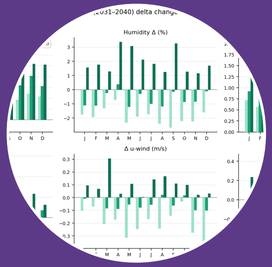
(10-year, hourly dataset)



Representative year selection

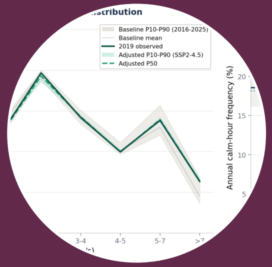


NARCliM2.0 SSP2-4.5 delta change factors (Δ)



Climate adjusted meteorology

(10th, 50th and 90th percentile)



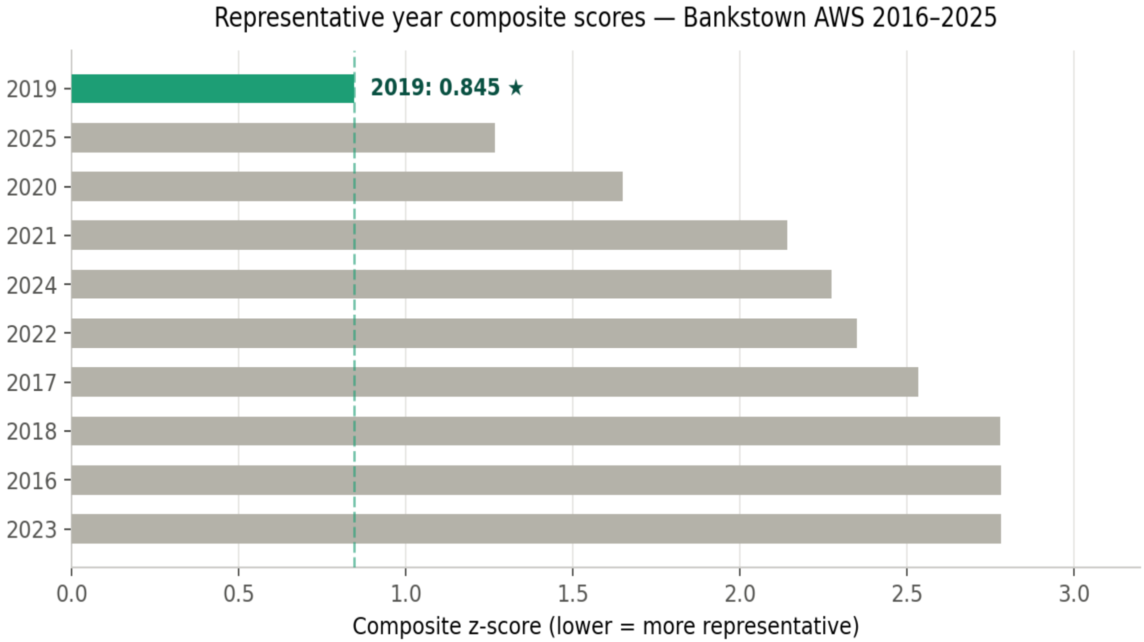
Evaluation vs 10-year baseline (Δ/SD framework)

Methodology — Dataset: Bankstown AWS (Station 066137)

- 10 years of hourly observations: 2016–2025 (87,671 records)
- **Variables:**
  - temperature
  - wind speed
  - wind direction
  - rainfall
  - pressure
- The 2016–2025 baseline period experienced effects of the El Niño-Southern Oscillation.
  - Major El Niño 2018–20
  - Contains a strong La Niña period spanning 2020–23
  - A moderate El Niño in 2023–24

Results — Representative year selection

- **Statistical comparison:** Kolmogorov–Smirnov (KS) statistic vs pooled 10-year record for wind speed, temperature, rain, pressure
- **Wind diagnostics:**
  - Annual and seasonal calm-hour frequency
  - 16-sector wind direction RMSE vs average 10-year reference
  - Wind speed frequency distribution (7 bins)

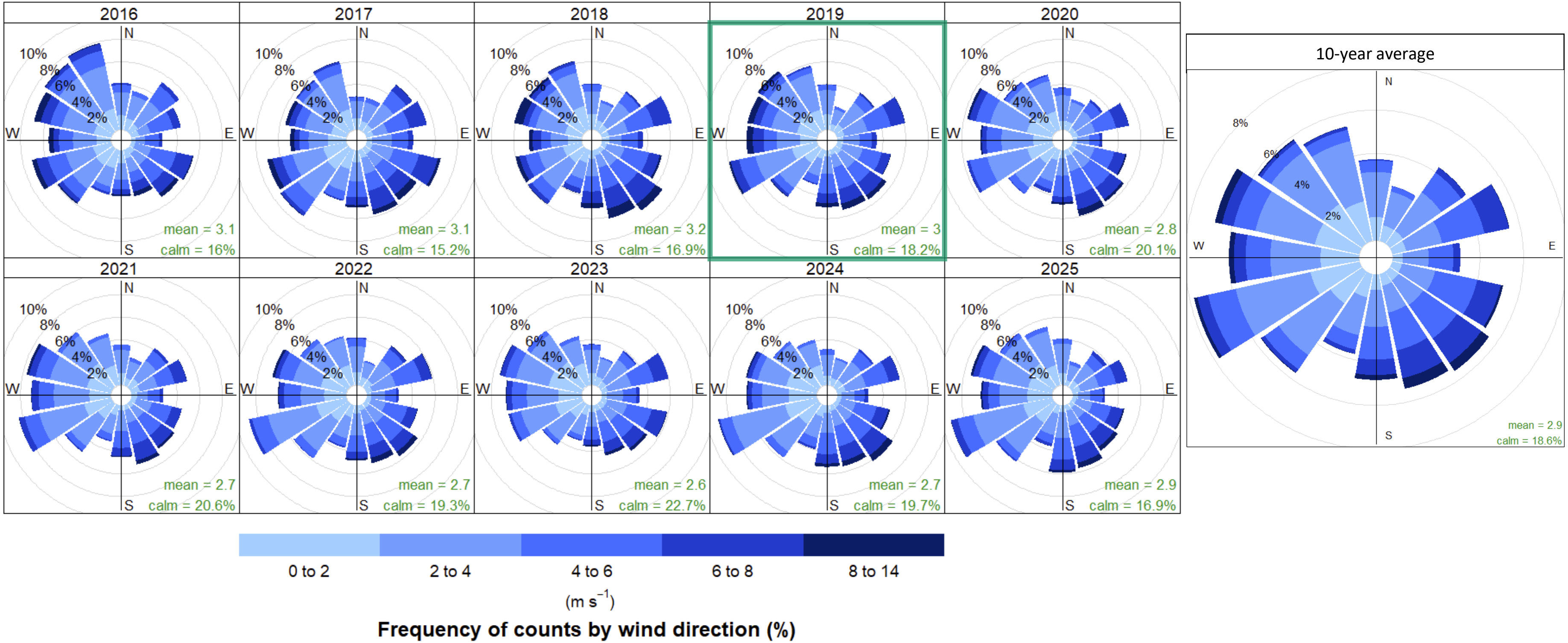


2019 selected ★

Composite score	**0.650**
KS wind speed	**0.020**
WD RMSE	**0.490**
Annual calm	**18.2%**

10-yr mean calm: 18.6%

Results —10-year wind variability

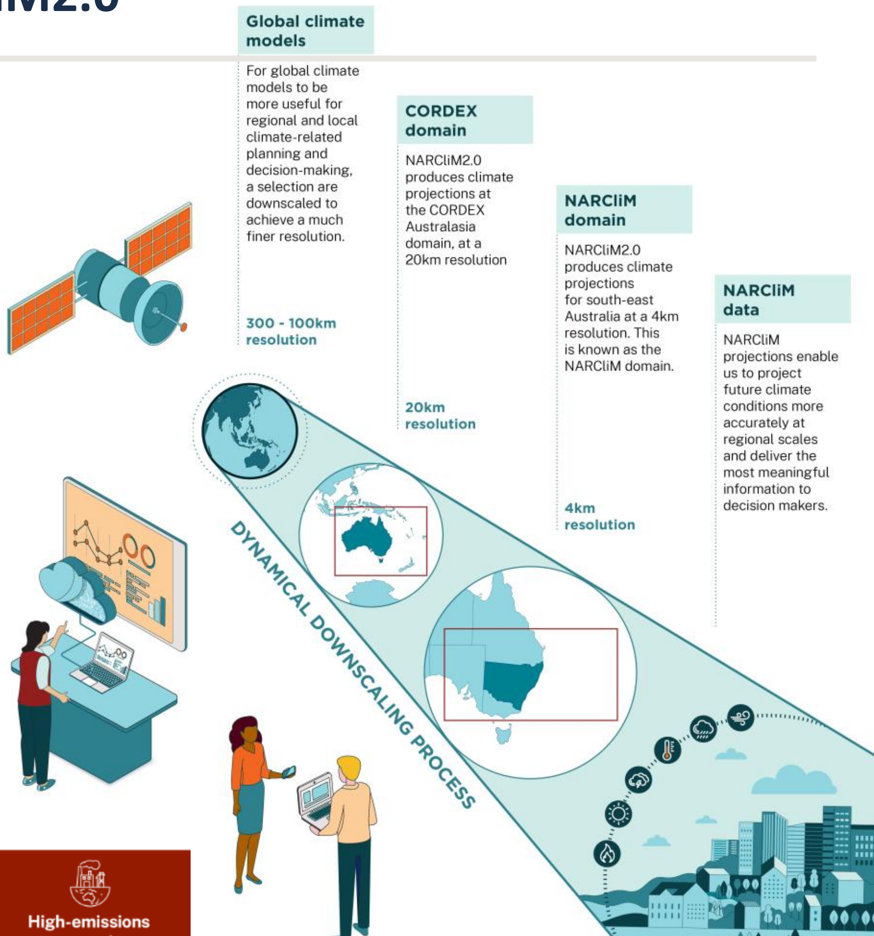


★ winds are distributed across both the WSW–W and SE sectors

Methodology — Climate projections: NARCliM2.0

- **NSW and Australian Regional Climate Modelling project 2.0 (NARCliM2.0):** 10-member regional ensemble at 4 km over south-east Australia

Domain	South-east Australia
Resolution	4 km (convention permitting)
Downscaling	• 5 Coupled Model Intercomparison Project Phase 6 (CMIP6) Global Climate Models (GCMs) and • 2 Weather Research and Forecasting (WRF)
Scenario	SSP2-4.5: medium emissions scenario
Time period	• Historical baseline: 1995-2014 • Near-term: 2031–2040



Downscaling in NARCliM | AdaptNSW

Methodology – Deriving adjustment scenarios

For each of the 10 ensemble members, **monthly deltas (Δ)** were computed by differencing each member's future period mean against its own historical baseline

1

The **Δ** were derived for each variable by taking an approach of either:

★ **Absolute:** future – baseline

★ **Proportional:** future/ historical

2

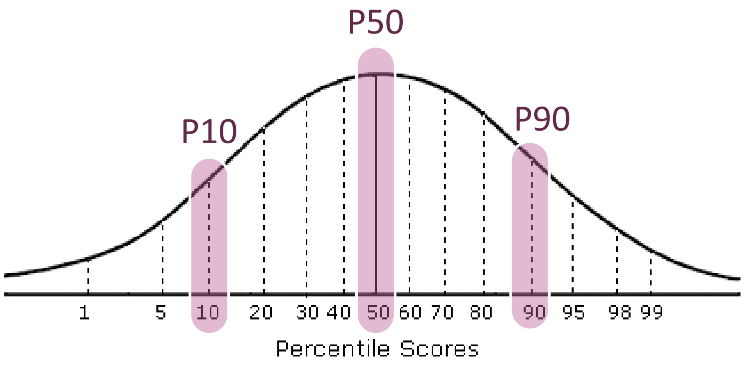
The 10 member deltas were ranked **per variable per month**

3

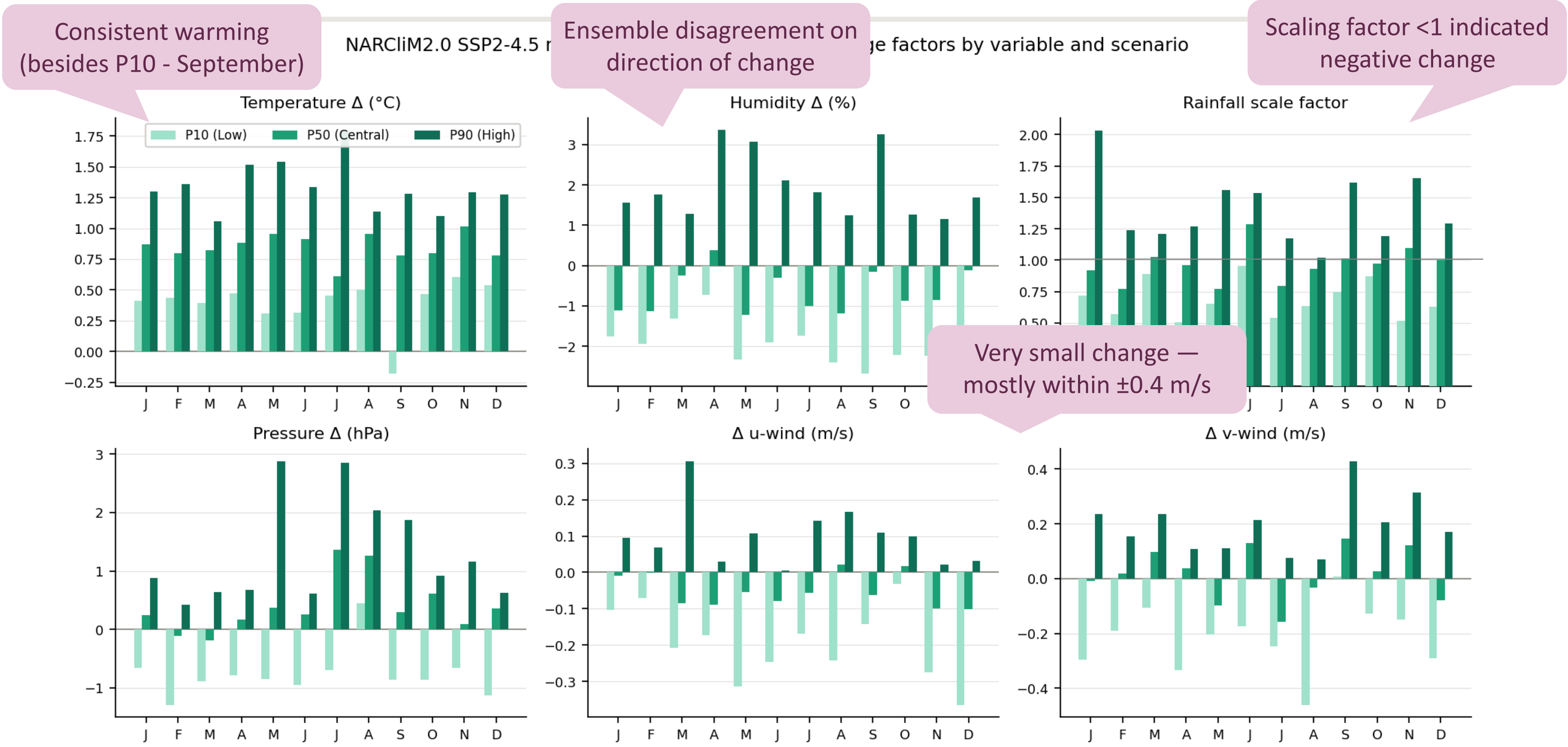
The **10th**, **50th** and **90th percentiles** were extracted independently for each meteorological variable

GCM	Future 1931-2040	Baseline 1995-2014
ACCESS-ESM1-5 – **R3**	Member 1	Member 1
ACCESS-ESM1-5 – **R5**	Member 2	Member 2
EC-Earth3-Veg– **R3**	Member 3	Member 3
EC-Earth3-Veg– **R5**	Member 4	Member 4
MPI-ESM1-2-HR– **R3**	Member 5	Member 5
MPI-ESM1-2-HR– **R5**	Member 6	Member 6
NorESM2-MM– **R3**	Member 7	Member 7
NorESM2-MM– **R5**	Member 8	Member 8
UKESM1-0-LL– **R3**	Member 9	Member 9
UKESM1-0-LL– **R5**	Member 10	Member 10

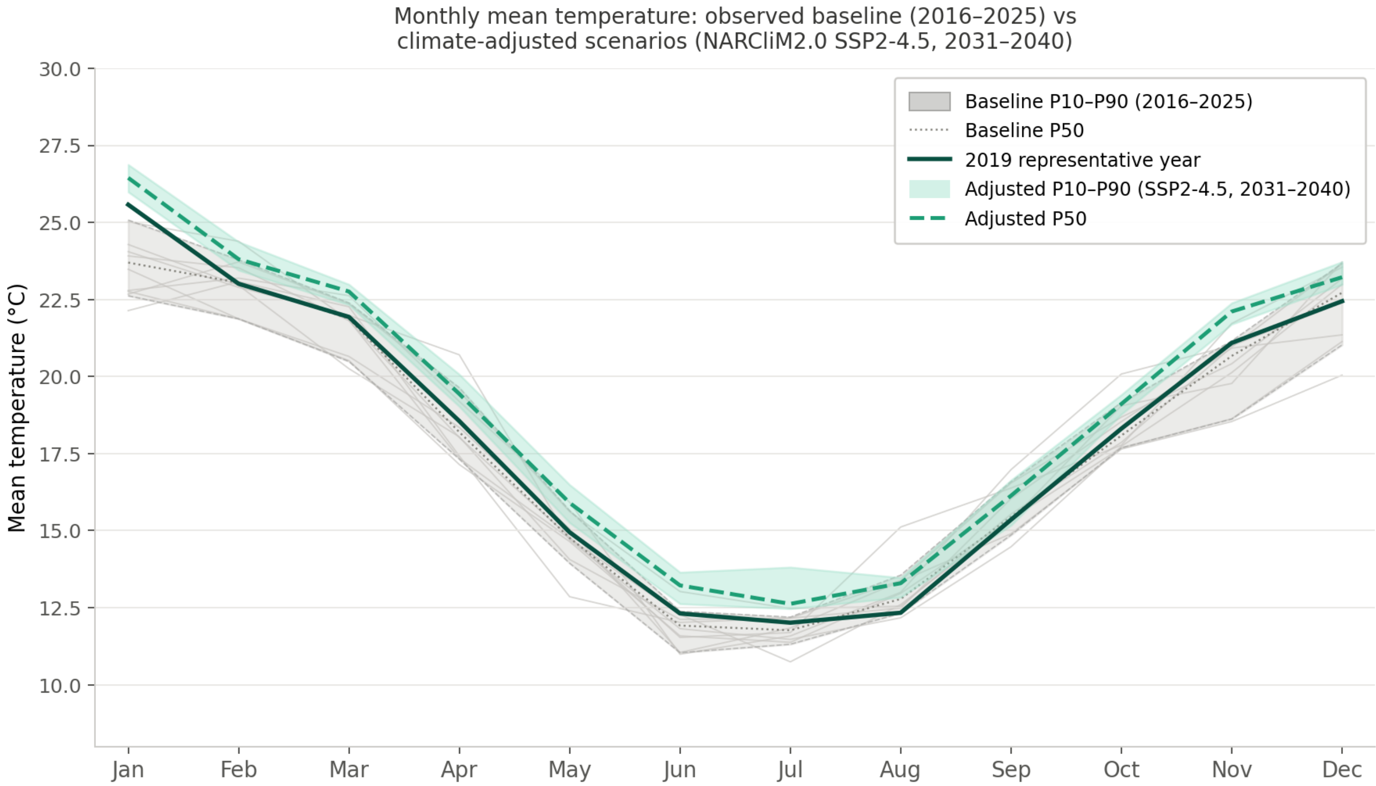
Temperature
Humidity
Pressure
u- wind component
v- wind component
Rainfall – scaled to preserve dry days



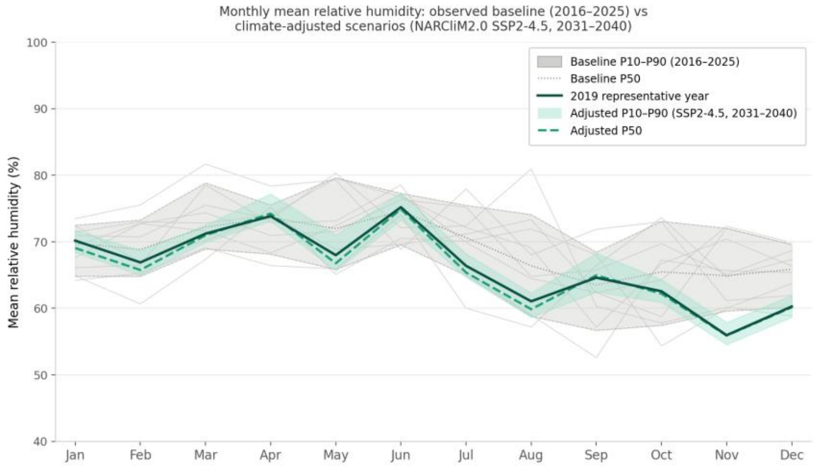
Results — NARCliM2.0 delta change factors

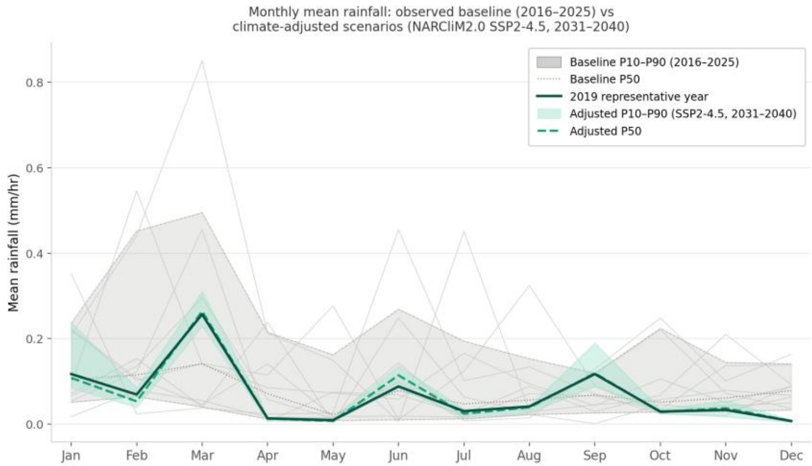


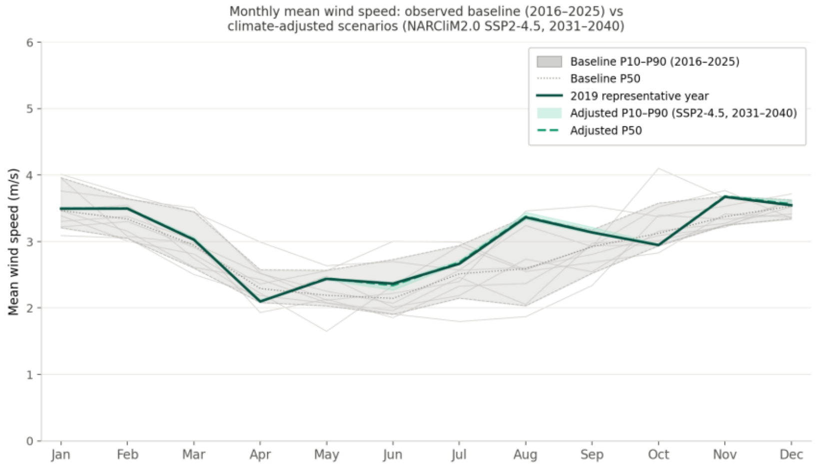
Results: Climate-adjusted temperature vs baseline

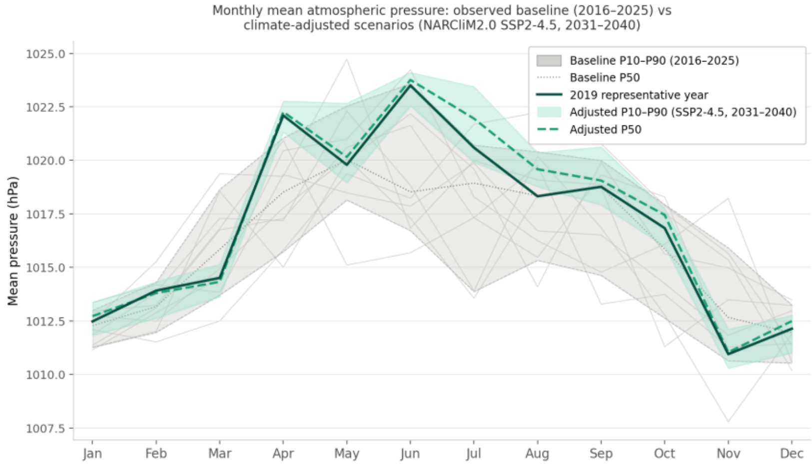


Results — Climate-adjusted meteorology vs baseline









Results — Climate signal evaluation: Δ/SD results

- For each variable, month and scenario the climate signal was quantified as:

  Δ/SD = (adjusted monthly mean − baseline monthly mean) ÷ baseline interannual standard deviation

- averaged across all 12 months to give a single annual mean value per variable per percentile scenario.

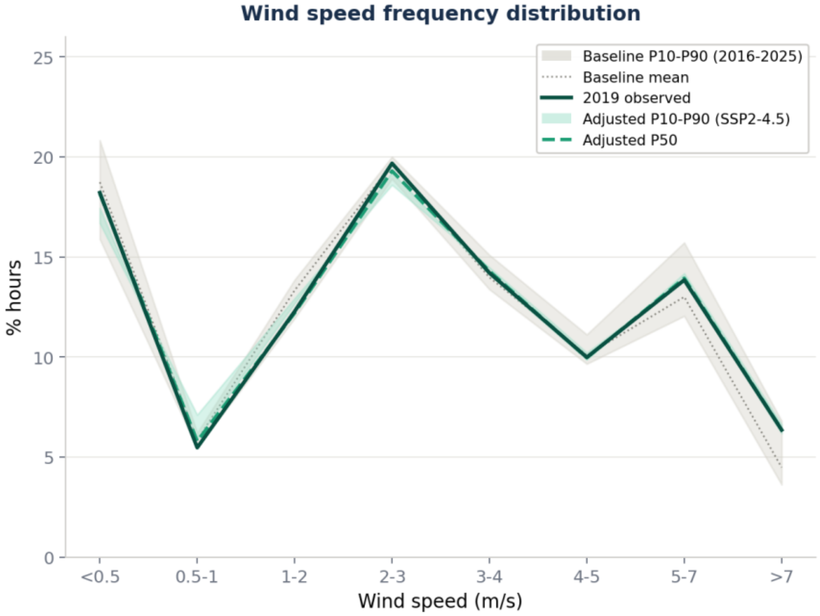
Variable	10th percentile	50th percentile	90th percentile
Pressure	-0.08	0.56	**1.00**
Rainfall	-0.63	-0.45	-0.11
Relative humidity	-0.80	-0.53	0.03
Temperature	0.73	**1.28**	**1.92**
Wind speed	-0.71	-0.79	-0.66

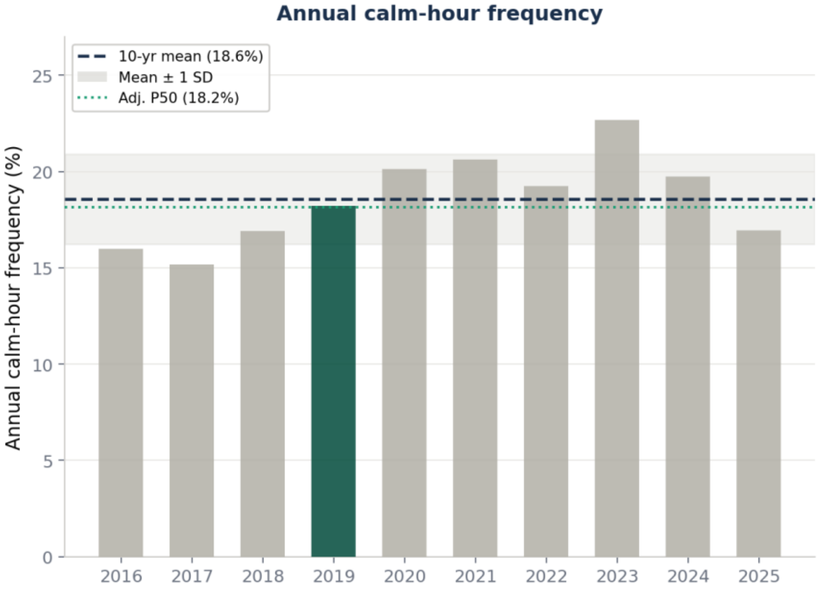
Colour: light green (±0.5–1.0) approaching limits; dark green (>±1.0) beyond observed variability. Negative values indicate a reduction.

- **Temperature: P50 (+1.28) and P90 (+1.92) exceed 1.0 SD — beyond observed interannual variability in several months**
- Wind speed: all scenarios < 0.5 SD — dispersion-relevant wind regime not materially altered at near-term horizon
- Rainfall: negative signal (slight drying), approaching bounds for P10

Results — Wind speed distribution and calm-hour frequency

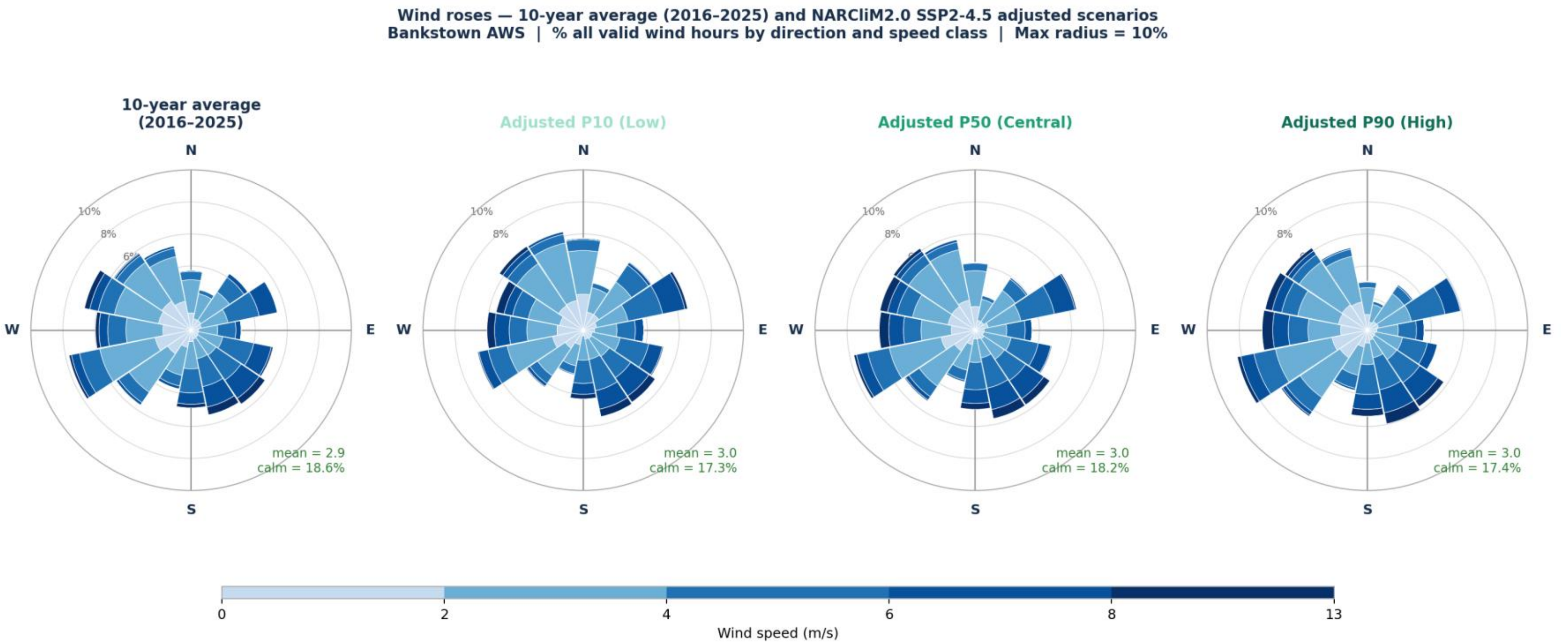
- **Wind was evaluated using additional metrics beyond Δ/SD given its particular importance for dispersion modelling:**
- **Wind speed frequency distribution** — the percentage of hours in each of seven speed bins was compared between the baseline, 2019 observed, and adjusted scenarios
- **Calm-hour frequency** — the percentage of calm hours (below 0.5 m/s) was computed annually and by month for the baseline, 2019 observed, and all adjusted scenarios





Results — Wind direction frequency

- **Wind direction** — directional frequency roses were produced for 16 compass sectors comparing 2019 observed against the three adjusted scenarios, with the directional change quantified via the 16-sector RMSE against the pooled 10-year reference



Conclusion

Does near-term climate change affect the met data we use for air quality assessment?

Key findings:

- Temperature — projected warming **exceeds** the bounds of observed variability even at the near-term horizon
- Pressure — **approaches observed variability** threshold at 90th percentile
- Rainfall and humidity — slight drying tendency in 50th percentile, all values **within observed variability**

- Wind speed — signal is **negligible**, within observed variability
- Wind direction — dominant WSW–W and SE regime **fully preserved** across all adjusted scenarios
- Calm frequency —**no material change** to low-dispersion conditions

What this means for air quality practitioners:

- For **wind-driven** dispersion assessments — historical met data remains adequate at the near-term horizon
- For **temperature-sensitive** assessments (stability, plume rise, buoyancy) — climate adjustment should be considered

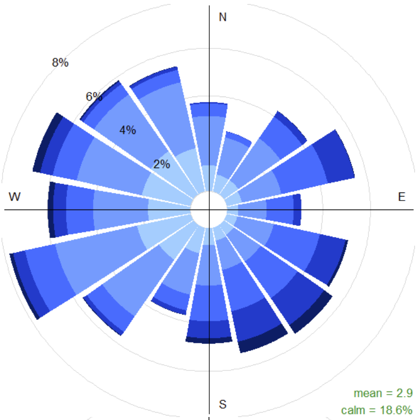
The framework:

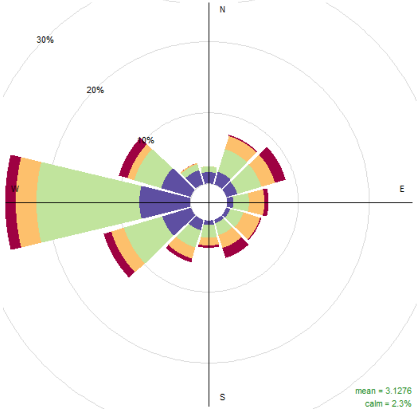
- Transparent and reproducible screening approach
- Applicable to any site with multi-year observed meteorological data

Limitations

- The Bankstown AWS **does not comply with AS/NZS 3580.14**, which specifies more stringent siting and exposure requirements for air quality meteorological monitoring.
    - The primary practical limitation is a relatively **high calm-hour frequency** (10-year mean approximately 18.6%)

- Wind speed and direction were adjusted together using the projected changes in the **eastward and northward wind components** from NARCliM2.0, rather than adjusting wind speed directly.
- This approach keeps **wind speed and direction physically consistent** with each other.
    - A side effect of this method is that the resulting wind speed change tends to be smaller than the raw component changes might suggest.
    - As when winds blow from multiple directions (i.e. Bankstown Airport AWS) a change in one component has less effect on total wind speed than it would at a site where wind blows predominantly from a single direction (i.e., Taree Airport AWS).





Future work

- Now that we have the framework set up: do the result **differ for varying stations** – particularly wind components
- Evaluation of **mid-century (2041–2060)** to understand how the signal changes with time
- Investigation of **seasonal and annual wind changes** as opposed to monthly
- The temperature signal may have implications for **stability class** and would be worthwhile exploring

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Thank you | Questions welcome | mbehn@ramboll.com

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Climate projections — NARCliM2.0 SSP2-4.5

- The NARCliM2.0 delta factors for wind are Δuas and Δvas — the projected change in the monthly mean eastward and northward wind components. For the near-term period under SSP2-4.5 at Bankstown, these values are very small — mostly within ±0.1 to ±0.3 m/s for both components in the central scenario, and only slightly larger for the P90.
- When you apply those tiny component shifts via vector decomposition, the resulting change to wind speed and direction is correspondingly tiny. The reason the NARCliM2.0 ensemble projects so little change in near-surface wind at Bankstown is physically plausible — the large-scale circulation changes under moderate warming at near-term horizons are small relative to the local wind variability driven by synoptic patterns, sea breezes, and terrain effects that dominate at any individual location.
- Climate models consistently show that near-surface wind speed is one of the least sensitive variables to greenhouse gas forcing at near-term horizons, particularly in mid-latitude coastal locations like Sydney.
- There is also a structural reason the range appears especially small:
    - The P10–P90 spread on the adjusted scenarios reflects the spread across the 10 ensemble members in their projected Δuas and Δvas values. Because those component deltas are small and the ensemble members broadly agree that the wind signal is weak, the spread between P10 and P90 is narrow — there is not much for the members to disagree about.
- This is actually one of the key findings of your paper — at the near-term horizon, the wind regime (which is most critical for dispersion modelling) is not materially altered, whereas temperature already shows a detectable signal. That asymmetry is the scientifically interesting result.

Results — Wind speed distribution and calm-hour frequency

Treatment of calm hours

- Calm hours were excluded from all directional calculations
- Calm hours were retained in all non-directional calculations:
    - Calm frequency statistics
    - Wind speed frequency distributions
    - The Δ/SD evaluation for wind speed

Why calm frequency matters for dispersion modelling

Calm hours drive unfavourable dispersion conditions. A site with high calm frequency therefore has more hours of potentially poor dispersion, making calm frequency one of the most important meteorological parameters for an air quality assessment.

Findings

The 10-year baseline mean calm frequency at Bankstown was 18.6%, ranging from 15.2% (2017) to 22.7% (2023). The 2019 representative year recorded 18.2%, the closest of any candidate year to the 10-year mean. Across the three adjusted scenarios, calm frequency ranged from 16.7% to 18.2%, confirming that the near-term NARCliM2.0 SSP2-4.5 climate signal does not materially alter the frequency of low-dispersion conditions at this location and time horizon.