Comparison of Measured and Modelled Boundary Layer Heights in the Upper Hunter Valley, NSW

CASANZ Clean Air Conference, Cairns QLD

31 August – 2 September 2026

Handan Sariyonca

Department of Climate Change, Energy the Environment and Water

The Department of Climate Change, Energy, the Environment and Water acknowledges the Traditional Custodians of the land and pays respect to Elders past, present and future.

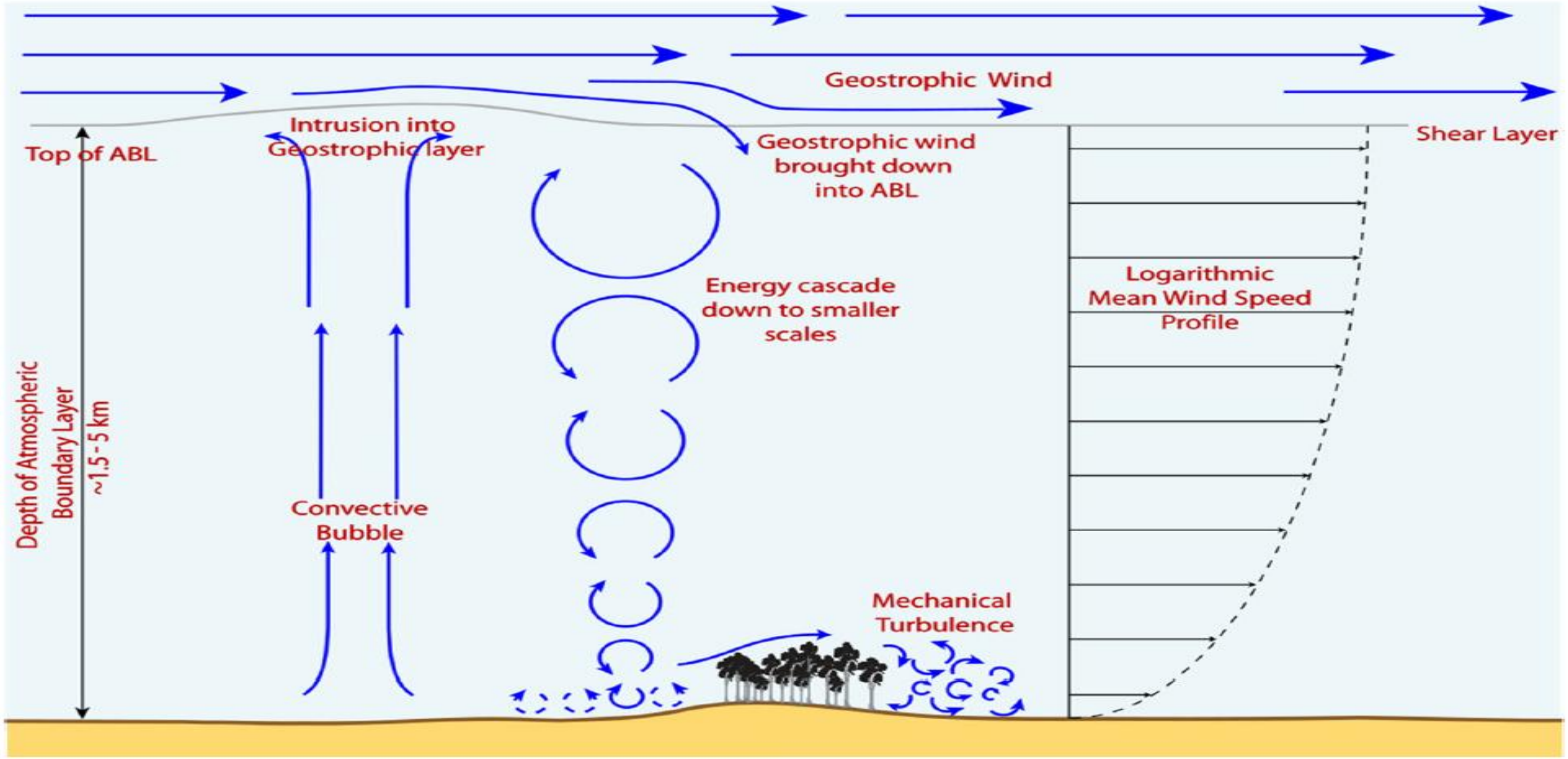
We acknowledge and pay our respects to the Traditional Custodians of this region, the Djabugay; Yirrganydji; Buluwai; Gimuy Walubara Yidinji; Mandingalbay Yidinji; Gunggandji; Dulabed and Malanbara Yidinji; Bundabarra and Wadjanbarra Yidinji; Wanyurr Majay; Mamu; and Ngadjonji peoples.

We recognise Australian Aboriginal and Torres Strait Islander peoples' unique cultural and spiritual relationships to place and their rich contribution to society.

Artist and designer Nikita Ridgeway from Aboriginal design agency – Boss Lady Creative Designs, created the People and Community symbol.

NSW GOVERNMENT

Planetary Boundary Layer (PBL)

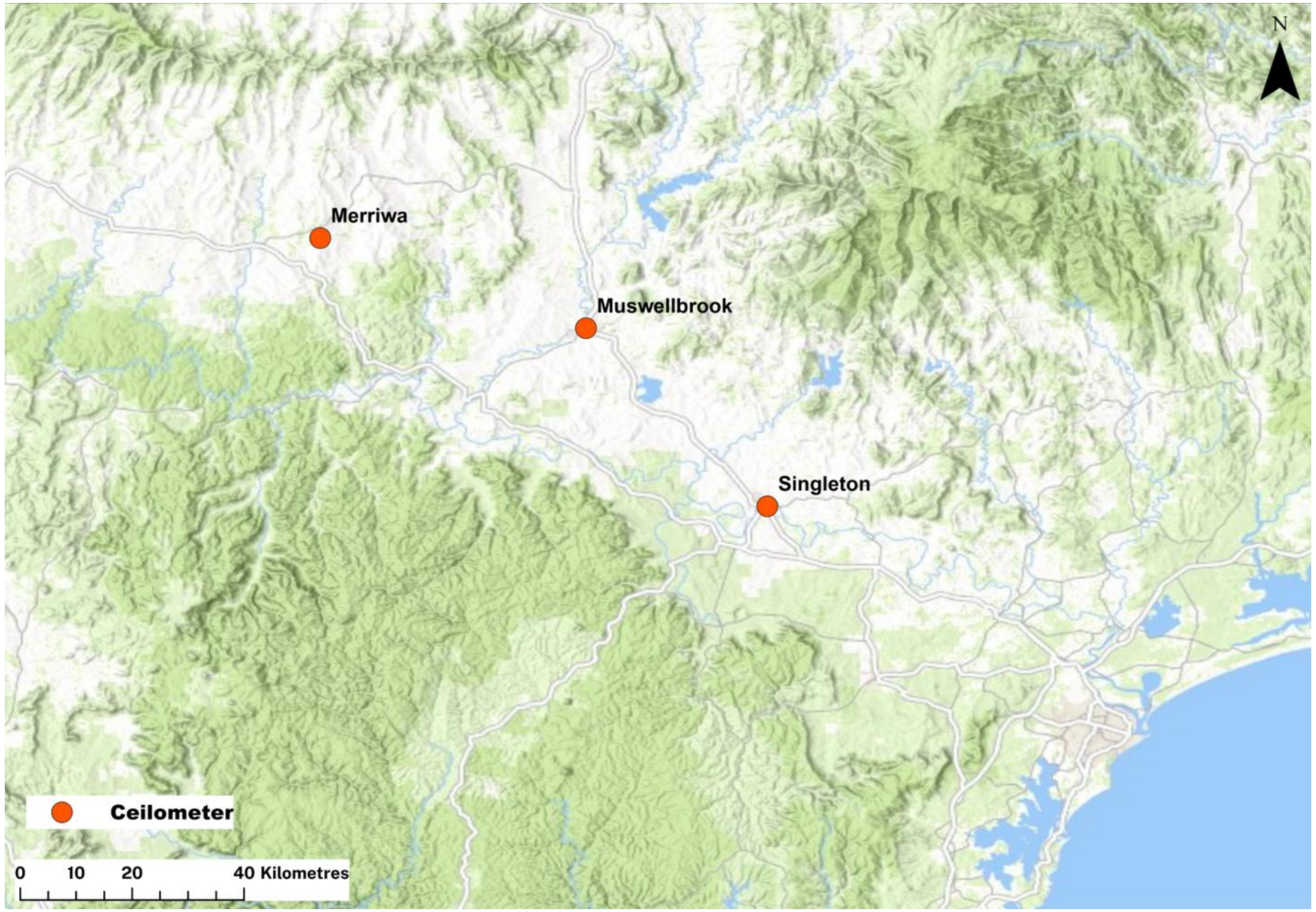


Sourced: Sullivan (2017).

Why PBL heights important for modelling?

- **Meteorological processes** essential for air-quality/greenhouse gas (GHG) modelling.
- **PBL influences** pollutant dispersion/transport, vertical mixing, temperature, moisture, and wind
  - Accurate PBL important for reliable results
- **Air-quality/GHG** model **performances** evaluated against observations.
  - Comparison WRF, CALMET PBL heights with ceilometer observations identify model strengths, limitations, and opportunities for improvement.
  - Reduce the uncertainties

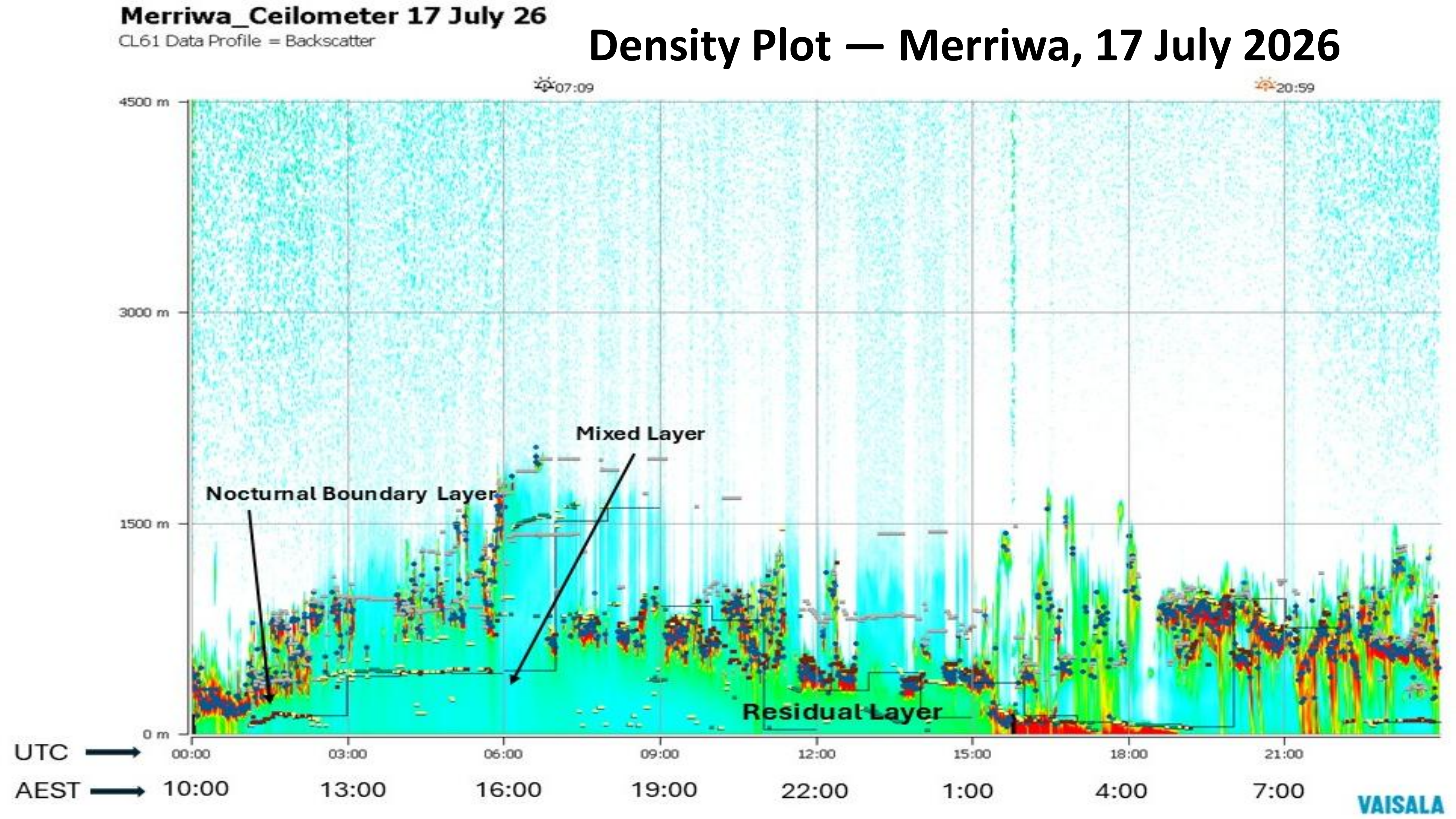
Upper Hunter Ceilometer Sites and Instrument Specification



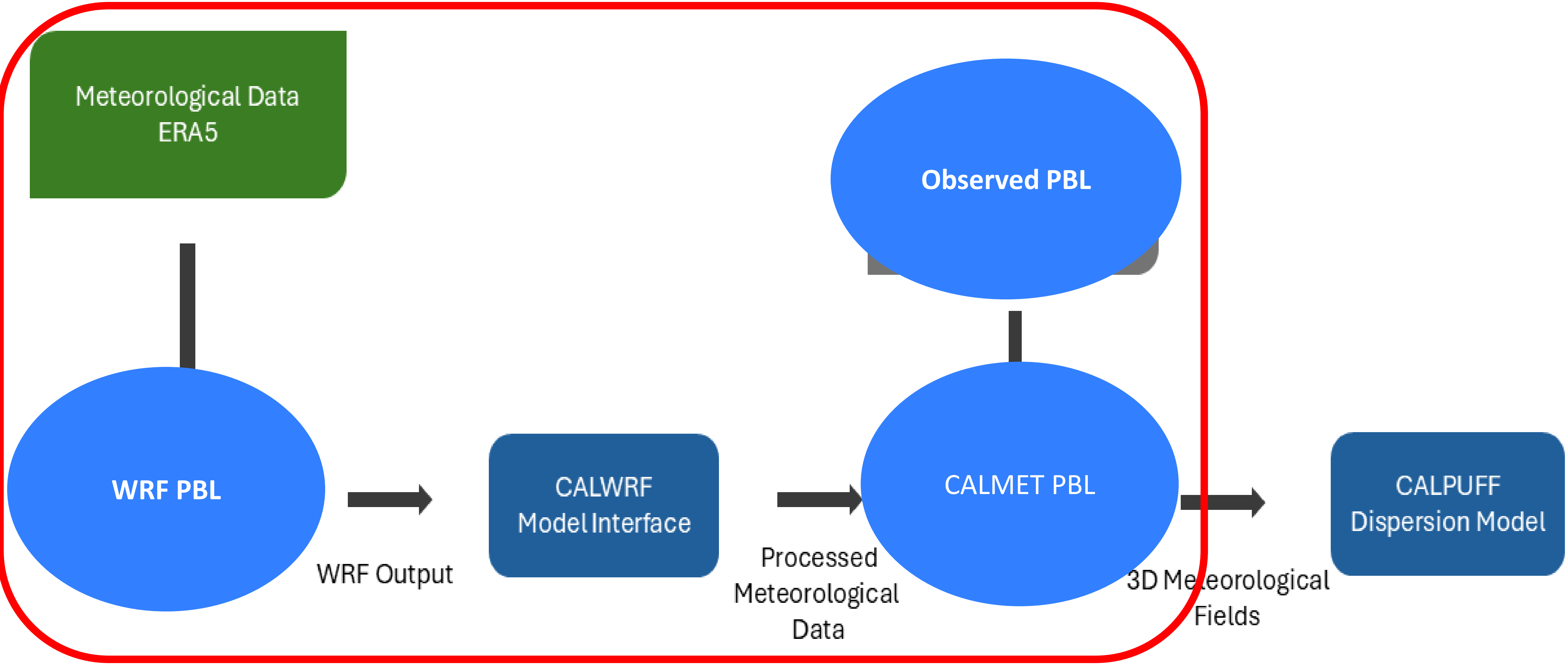
Location	Distance from coast (km)	Elevation (m)	Ceilometer type (range, resolution, interval)
Merriwa	153 km	406 m	Vaisala Lidar Ceilometer CL61, up to 15.4 km, 4.8 m, 5 s
Muswellbrook	110.9 km	145 m	
Singleton	70.4 km	42 m	

NSW GOVERNMENT

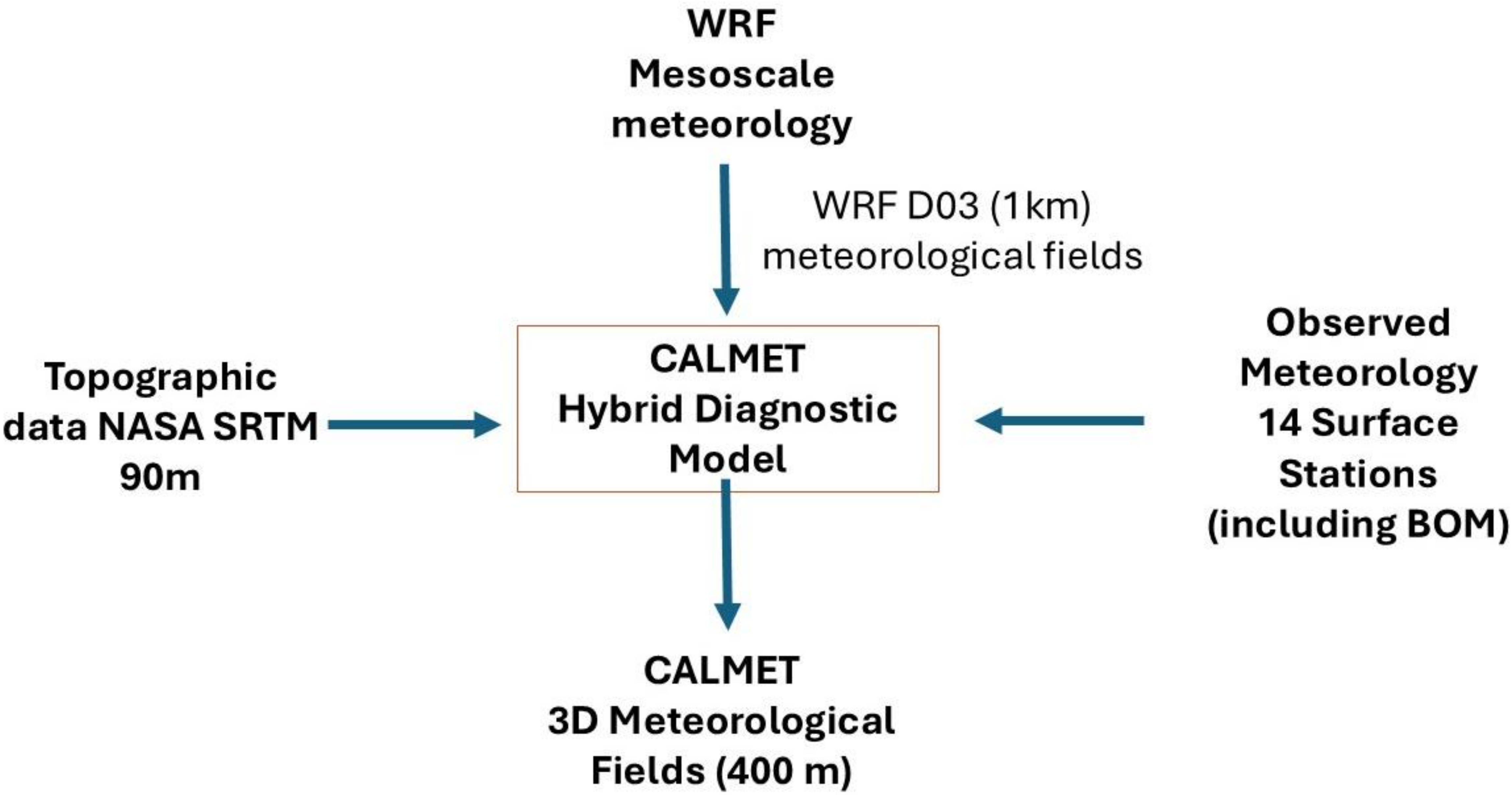
Density Plot — Merriwa, 17 July 2026



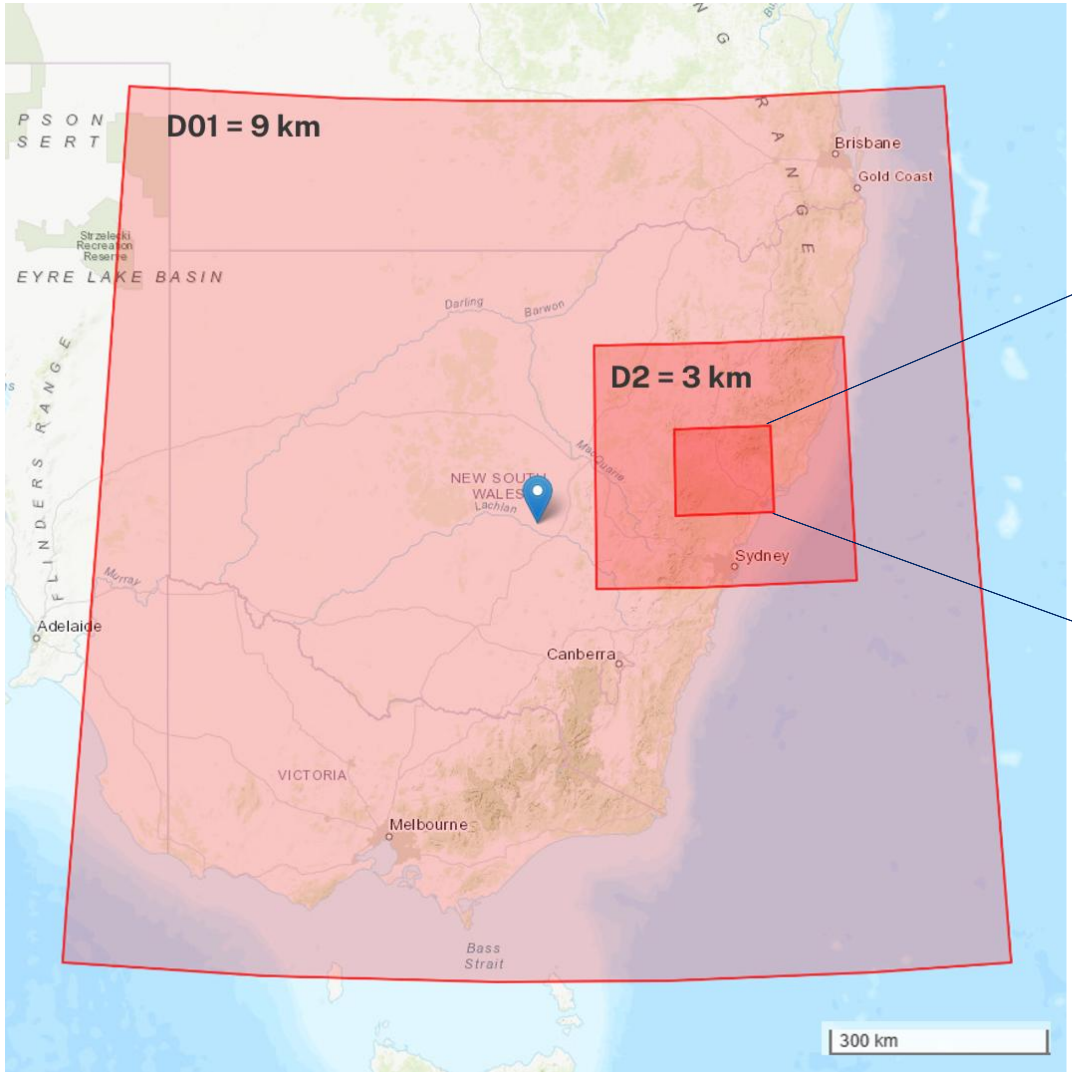
Workflow of the WRF/CALPUFF Models



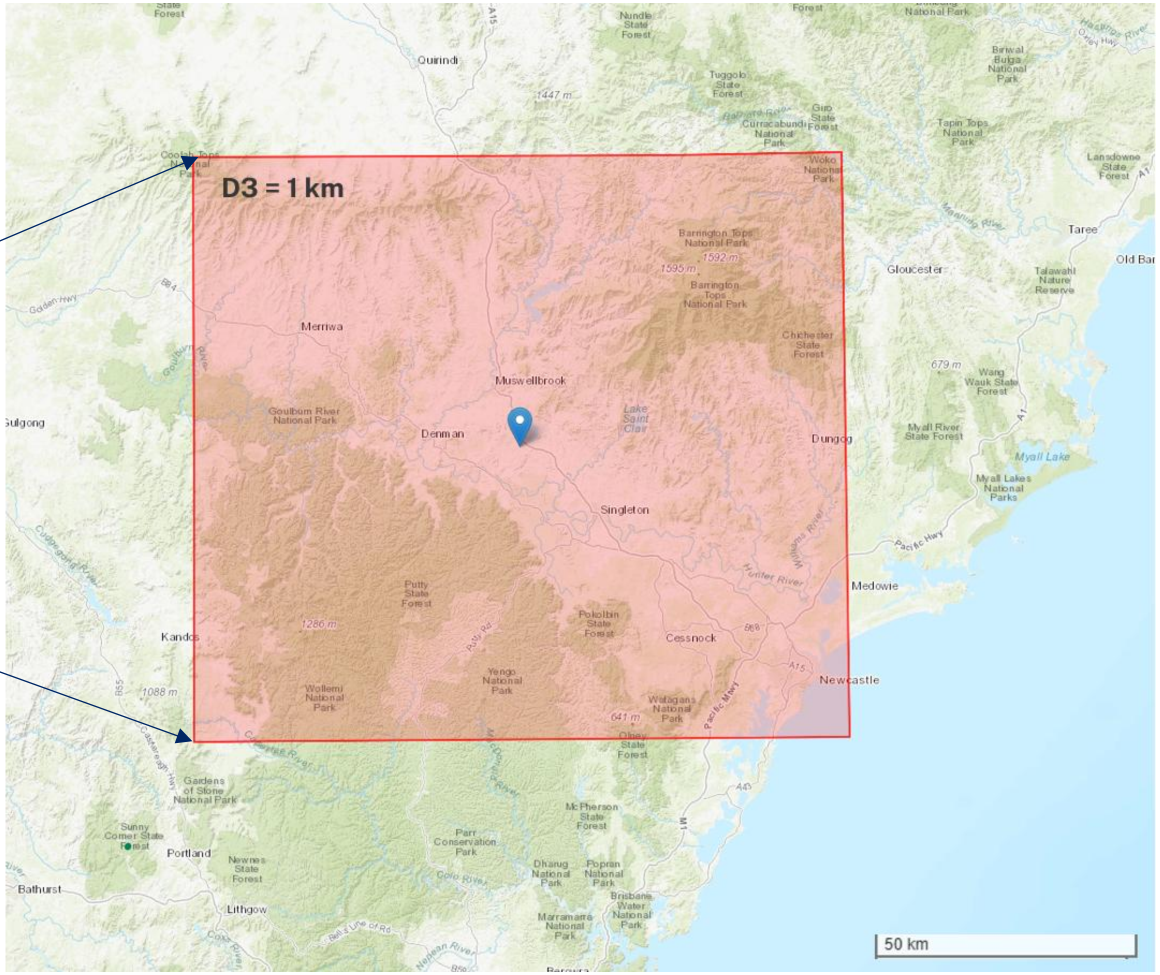
WRF–CALMET Coupling and Integration of Observations



WRF Model Domains and Study Location



Nested WRF domains:D01 (9 km), D02 (3 km), and D03 (1 km).



The innermost domain (D03), 1 km over the study region.

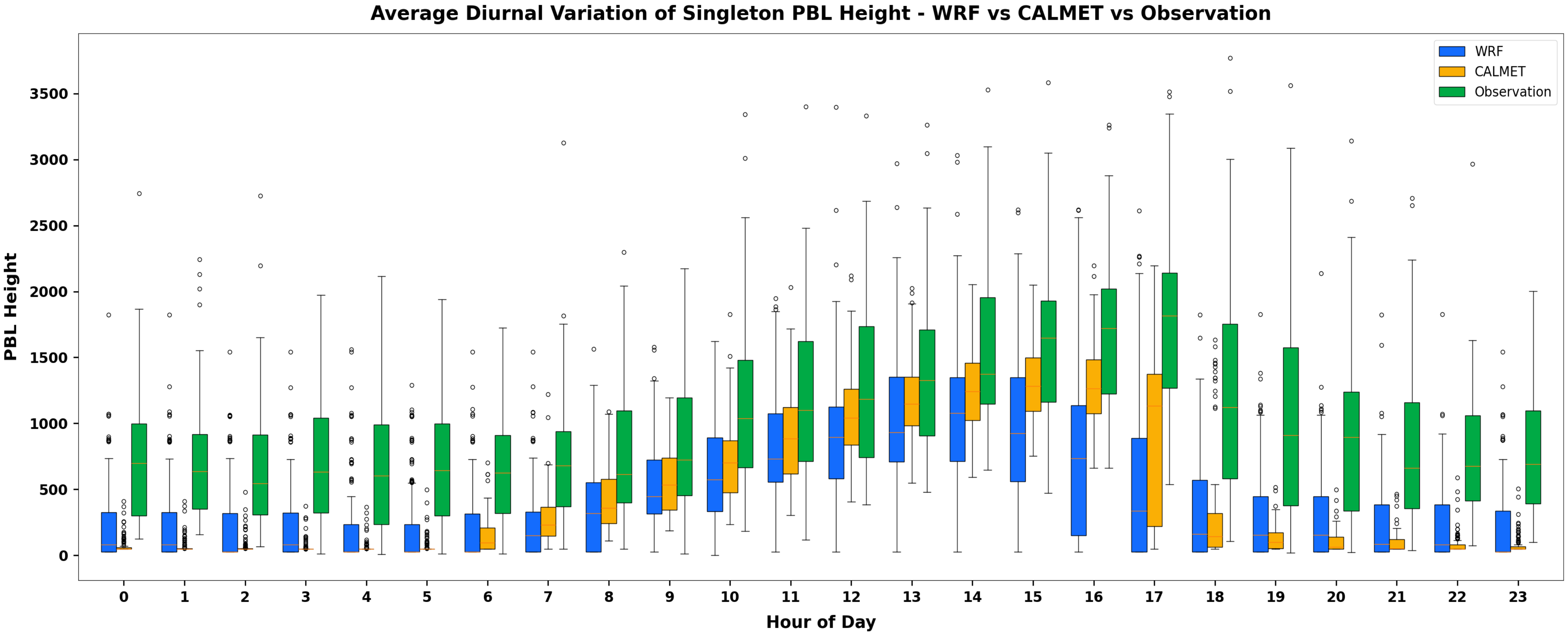
NSW GOVERNMENT

WRF & CALMET Configurations

WRF Mesoscale Model Configuration	Domain 1	Domain 2	Domain 3
Model	WRF Model Version 4.5.1		
Simulation Period	01 January 2026 – 31 July 2026		
Alias	nsw	ensw	upperhunter
Grid size (e_we × e_sn)	165x165	145x139	166x148
Resolution	9 km	3 km	1 km
Input & Output Interval	3 hr (input), 60 min (output)		
Number of vertical layers	46 vertical layers		
Planetary boundary layer (PBL) scheme	MYJ (Mellor-Yamada-Janjic scheme)		
Domain Bounds	140.05°E–156.50°E, 39.78°S–26.15°S	148.82°E–153.16°E, 34.04°S–30.36°S	150.27°E–151.72°E, 33.02°S–31.79°S

CALMET Diagnostic Model Configuration	
Model	Model Version 5
Horizontal grid	250 × 250 cells
Grid spacing	400 m × 400 m
Model domain	100 × 100 km
Vertical layers	8 layers
Model top	2 km
Surface observation influence (RMAX1/RMAX2)	5 km
Observation/Step-1 weighting (R1/R2)	2 km
Terrain data	SRTM (~90 m resolution)

Modelled and Observed PBL Comparison



PBL heights at Singleton, January–April 2026.

Statistical Comparison of WRF Modelled and Observed PBL Height

Statistic	Results	Comments
Mean Observation	1108 m	Observed PBL relatively high
Mean WRF PBL Height	527 m	WRF predicted much lower PBL height
Bias (WRF – Observation)	-581 m	WRF strongly underestimates PBL height
MAE (Mean Absolute Error)	874 m	Large average prediction error
RMSE (Root Mean Squared Error)	1128 m	Large errors, with larger errors weighted more strongly
Correlation (R)	-0.203	Very weak negative relationship
R^2 (R-squared)	0.041	WRF explains only ~4.1% of the observed variability
P-Value	<0.001	Correlation is statistically significant, but the relationship is still very weak

Statistical Comparison of CALMET Modelled and Observed PBL Height

Statistic	Results	Comments
Mean Observation	1176 m	Observed PBL relatively high
Mean CALMET PBL Height	499 m	CALMET predicted much lower PBL heights
Bias (CALMET – Observation)	-677 m	CALMET strongly underestimates PBL height
MAE (Mean Absolute Error)	989.3 m	Large average prediction error
RMSE (Root Mean Squared Error)	1196.1 m	Large errors, with larger errors weighted more strongly
Correlation (R)	-0.211	Very weak negative relationship
R^2 (R-squared)	0.045	CALMET explains only ~4.5% of observed variability
P-Value	<0.001	Correlation is statistically significant, but the relationship is still very weak

Strengths and Weaknesses of the PBL Schemes

- WRF uses MYJ:
  - **Common PBL scheme**
  - **Good performance:** Stable and low-turbulence conditions
  - **Systematic PBLH underestimation** *(Banks & Baldasano, 2016; Ma et al., 2024)*

  - Adjusting the thresholds in TKE MYJ closure may improve PBLH.

  - **Any PBL scheme performance:**
    - depend on time of day
    - varies with complex terrain and land-use
    - atmospheric stability conditions

- CALMET
  - Observation data improve PBL → 14 stations + BOM Data
  - Higher resolution → 400 m
  - Terrain and land use adjustments → better local representation

Key Findings & Future Work

- **WRF and CALMET**:
  - Capture the general daytime PBL evolution,
  - Underestimate PBL height - night and transition periods.

- **Future Work**:
  - Test different WRF PBL schemes.
  - Improve land-surface and surface-layer parameterizations (surface heat fluxes and nighttime cooling).
  - Use Barra2 into WRF to assess improvement.
  - Observation assimilation in WRF for better PBL evolution.
    - Identification of better and poor performing PBL configurations
    - Selection of periods with closer model–observation agreement
    - Exclusion of periods with poor model performance
    - Optimisation of the modelling framework
  - Longer periods scenarios
  - CALMET sensitivity runs, optimize PBL height.
  - Assess robustness of models in complex terrain.

References

Sullivan, AL 2017, ‘Inside the Inferno: Fundamental Processes of Wildland Fire Behaviour Part 2: Heat Transfer and Interactions’, *Current Forestry Reports*, vol . 3, pp. 150-171, DOI: 10.1007/s40725-017-0058-z.

Lopez-Coto, I, Hicks, M, Karion, A, Sakai, RK, Demoz, B, Prasad, K & Whetstone, J 2020, ‘Assessment of planetary boundary layer parameterizations and urban heat island comparison: impacts and implications for tracer transport’, *American Meteorological Society*, vol. 59, pp. 1637-1653.

Julaha, K, Zdímal, V, Holubová S, A, Komínková, K & Zíková, N 2024, ‘Boundary layer and mixing layer height: models vs. ground-based measurements intercomparison’, Atmospheric Research, vol. 315.

Stull, RB, 1988, ‘An Introduction to Boundary Layer Meteorology’, 680 Kluwer, Dordrecht, Holland.

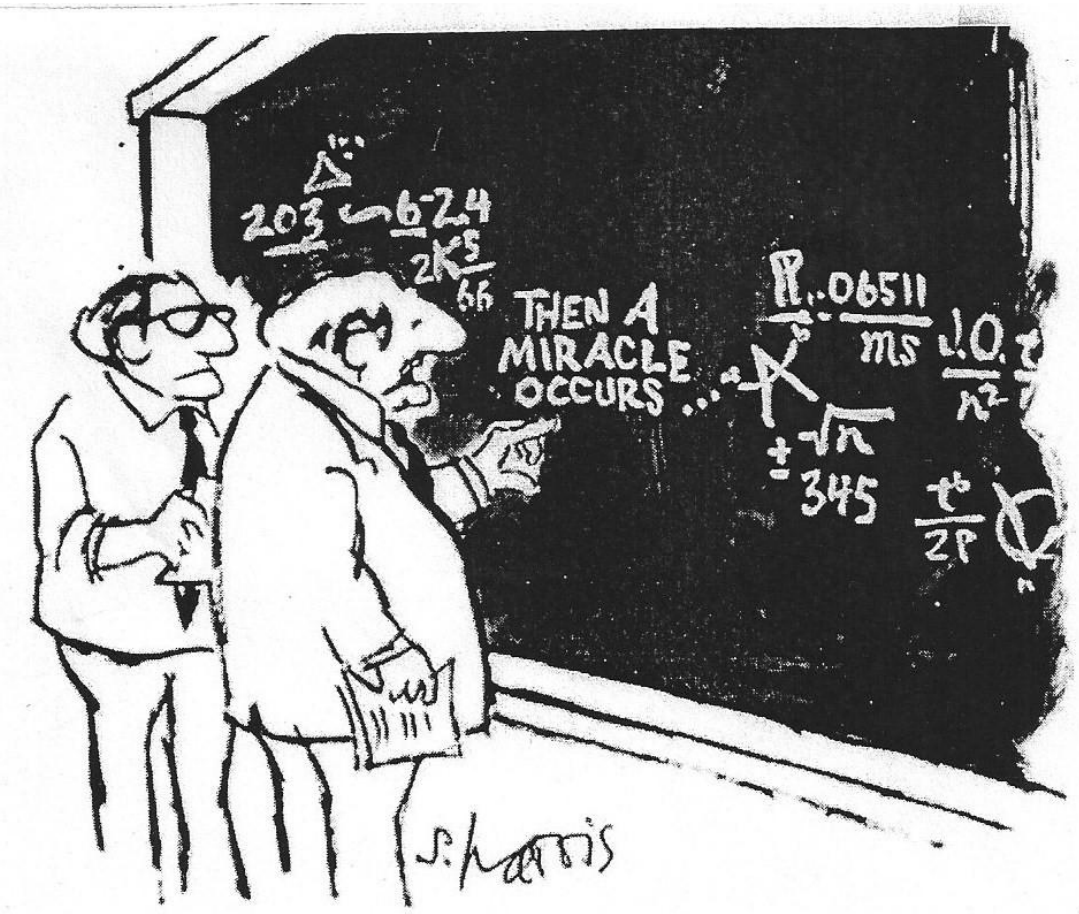
Zhang, H, Zhang, X, Li, Q, Cai, X, Fan, S, Song, Y, Hu, F, Che, H, Quan, J, Kang, L & Zhu, T 2020, ‘Research progress on estimation of the atmospheric boundary layer height’, *J. Meteor. Res.*, vol. 34, pp. 482–498, doi: 10.1007/s13351-020-9910-3.

Banks, RF & Baldasano, J 2016, ‘Impact of WRF model PBL schemes on air quality simulations over Catalonia, Spain’, *Science of the Total Environment*, vol. 572, pp. 98–113, https://doi.org/10.1016/j.scitotenv.2016.07.167.

Ma, M., Tang, J., Ou, T. & Zhou, P. 2023, ‘High-resolution climate projection over the Tibetan Plateau using WRF forced by bias-corrected CESM’, *Atmospheric Research*, vol. 286, article 106670, https://doi.org/10.1016/j.atmosres.2023.106670.

Tang, S., Huang, S., Yu, H., Gu, M. & Tang, J. 2020, ‘Impact of horizontal resolution in CALMET on simulated near-surface wind fields over complex terrain during Super Typhoon Meranti (2016)’, *Atmospheric Research*.

Thank you !!!



"I think you should be more explicit here in step two."

from *What's so Funny about Science?* by Sidney Harris. (1977)