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BARPA-C: Convective-scale regional climate modelling in Australia

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BARPA-C Australian Climate Downscaling

Motivation

- Australia's climate is highly variable with extreme weather events
- Increasing need for robust fine-scale present and future climate information
- Convective scale: explicitly resolving vertical motion with 1-4 km grid-spacing
  - Potential local-scale benefits to hazard representation: aspects of thunderstorms, extreme winds, high intensity short duration rainfall, fire weather
  - New model configurations come with new climate testing requirements
  - R&D is required before CPM projections products can be trusted
- Goal: be ready to produce hazards projections from CMIP7 using CPM-based downscaling, starting 2027.

Agenda

- BARPA-C: Experimental design
- BARPA-C: Spectral Nudging and the monsoon dry bias
- BARPA-C: Added value over BARPA-R

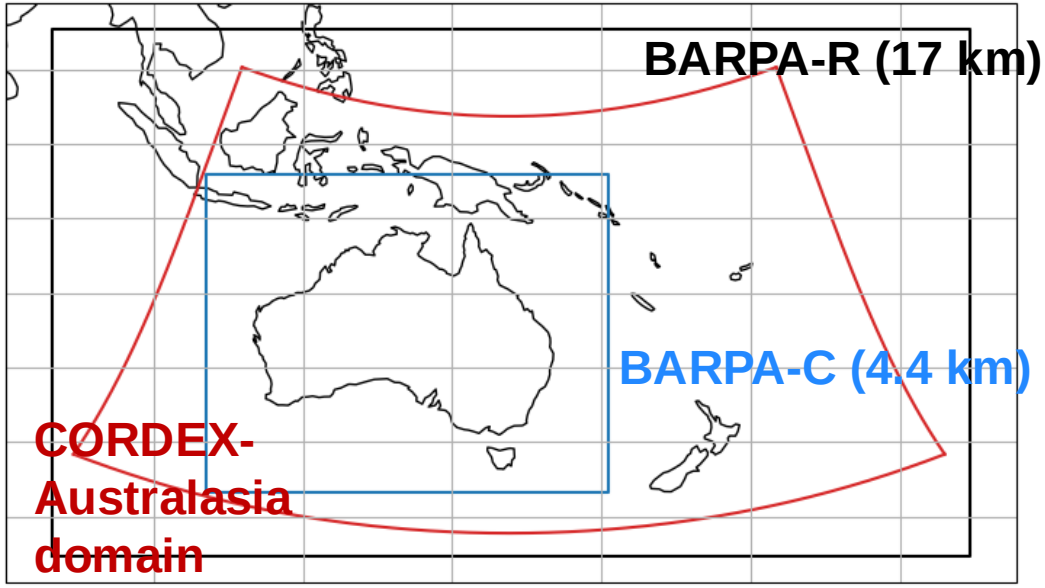
Experimental Design

Model Configuration

- 0.04deg (1348x1068), L70/40km top, nested in BARPA-R
- UMv13.0, RAL3.2 configuration with local ancillary changes based on ACCESS-A (NWP)
- ACCESS-A style ancillaries
- GHGs, volcanic, EasyAerosol radiative forcing
- With and without spectral nudging: 12-hour timescale, 1500 km length-scale, U, V, T above boundary layer

Experiment runs

- Evaluation runs: 10-year BARPA-R-ERA5 boundary conditions
- CMIP6 runs: BARPA-R-CMIP6 boundary conditions for historical and SSP3-7.0
- 2 model scenarios: wetting and drying
  - ACCESS-ESM1.5 (r6i1p1f1)
  - EC-Earth3 (r1i1p1f1)



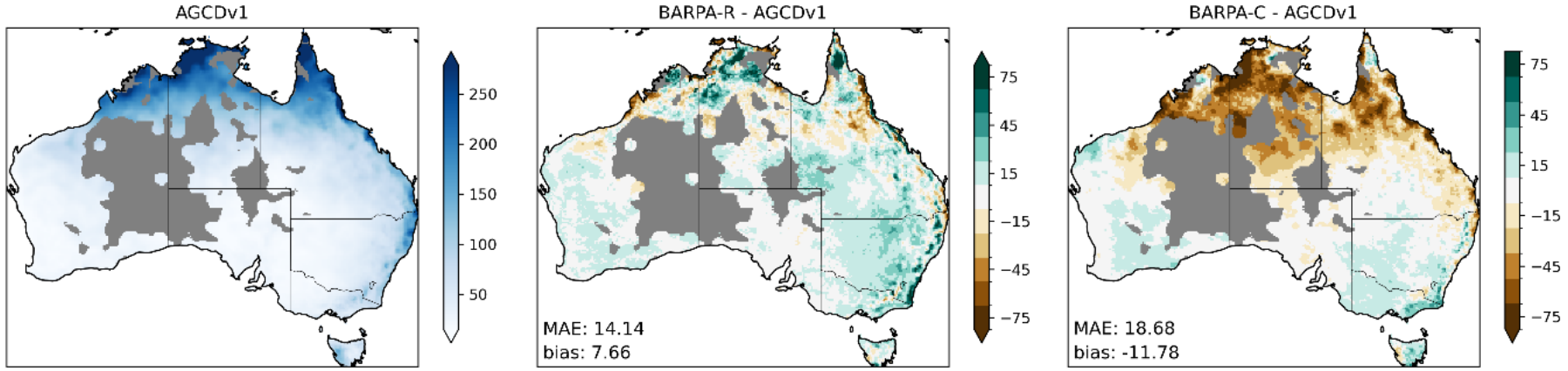
Experiment Name	Driving GCM	Time Period	Notes
BARPA-C FR	ERA5	2013-2022	Free Run
BARPA-C SN	ERA5	2013-2022	Spectral Nudging
BARPA-C ACCESS	ACCESS-ESM1.5	1995-2004, 2050-2060	Spectral Nudging
BARPA-C ECE3	EC-Earth3	1995-2004, 2050-2060	Spectral Nudging

Spectral Nudging and the monsoon dry bias

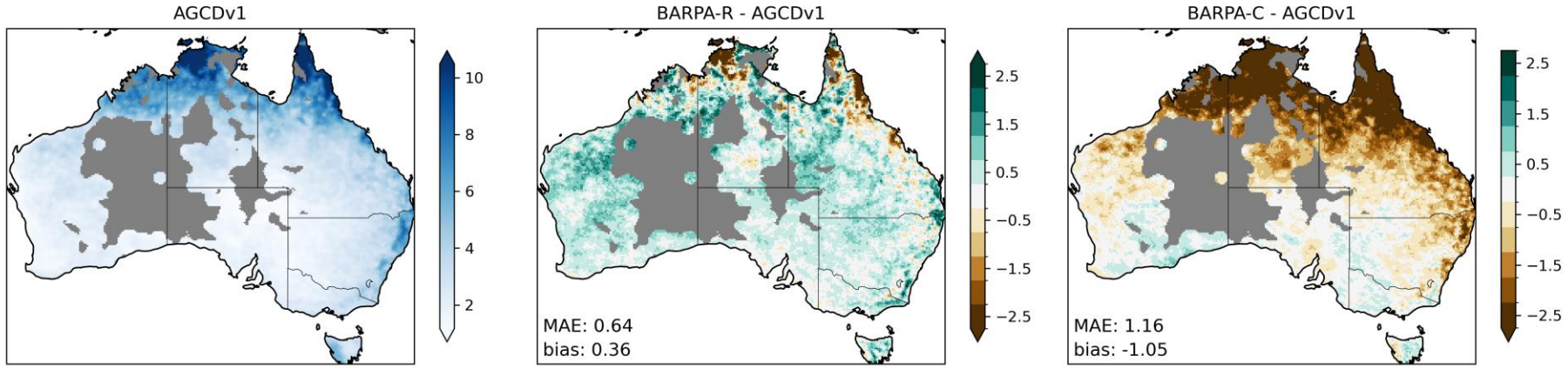
BARPA-C dry bias in Free running simulations

- Reduced monsoon rainfall
- Northward shift of monsoon shearline
- Too few tropical cyclones in northern Australia
- Drier soil moisture

Rain Rate – mm/month (DJF)



Consecutive Wet Days (DJF)



Spectral Nudging

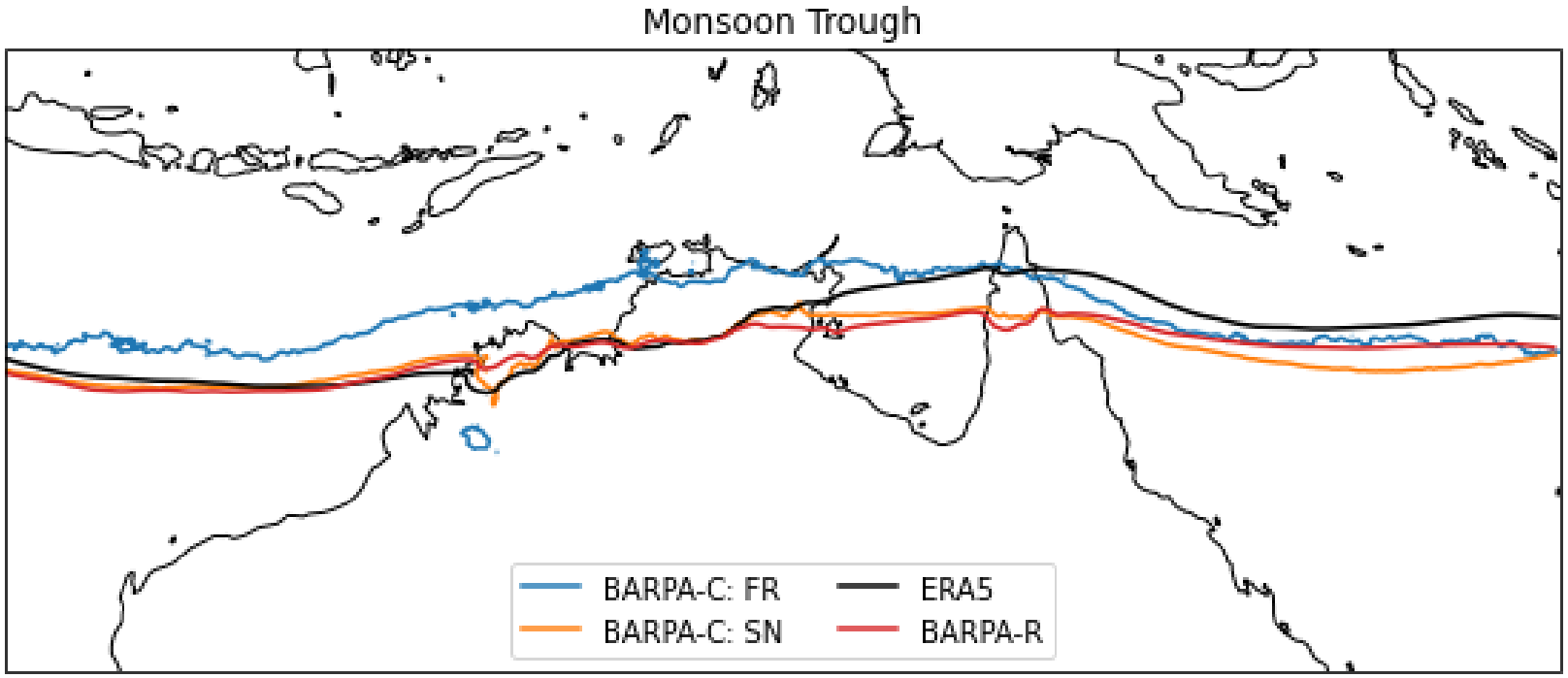
- Update equation during model integration

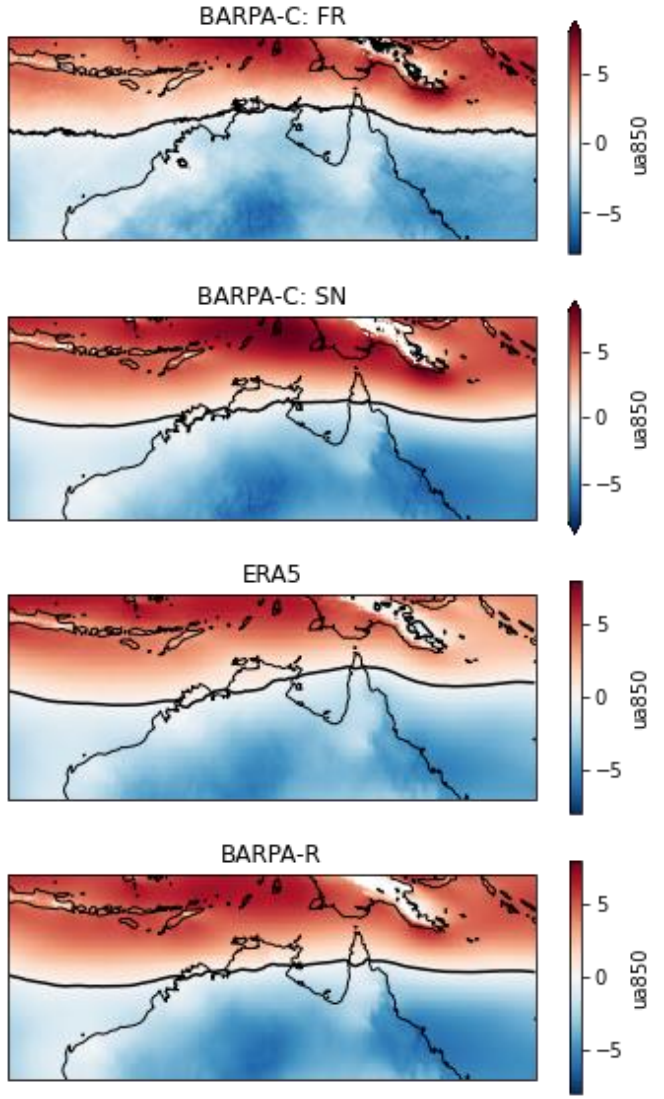
$$\phi'(t_n) = \phi(t_n) - \frac{\text{ndg\_freq}}{\text{ndg\_relax\_value}} (\Delta\phi(t_n) * w[\text{ndg\_length\_scale}])$$

2 x 1D convolution Gaussian filter (Uhe & Thatcher, 2015)

Parameters	Values
ϕ	U, T, V
Model levels	~850 hPa to 10 hPa
Ndg_freq (time steps to apply nudging)	Applying hourly
Ndg_relax_value (nudging strength)	"e1" = 1h e-folding time (harder nudging) "e6" = 6h (soft) **"e12" = 12h (very soft)**
Ndg_length_scale (cutoff length scale)	"Lam035" -> 2250 km **"Lam02" -> 1500 km** "Lam014" -> 900 km

DJF Mean State UA850 and Monsoon Trough Position (2012-2020)

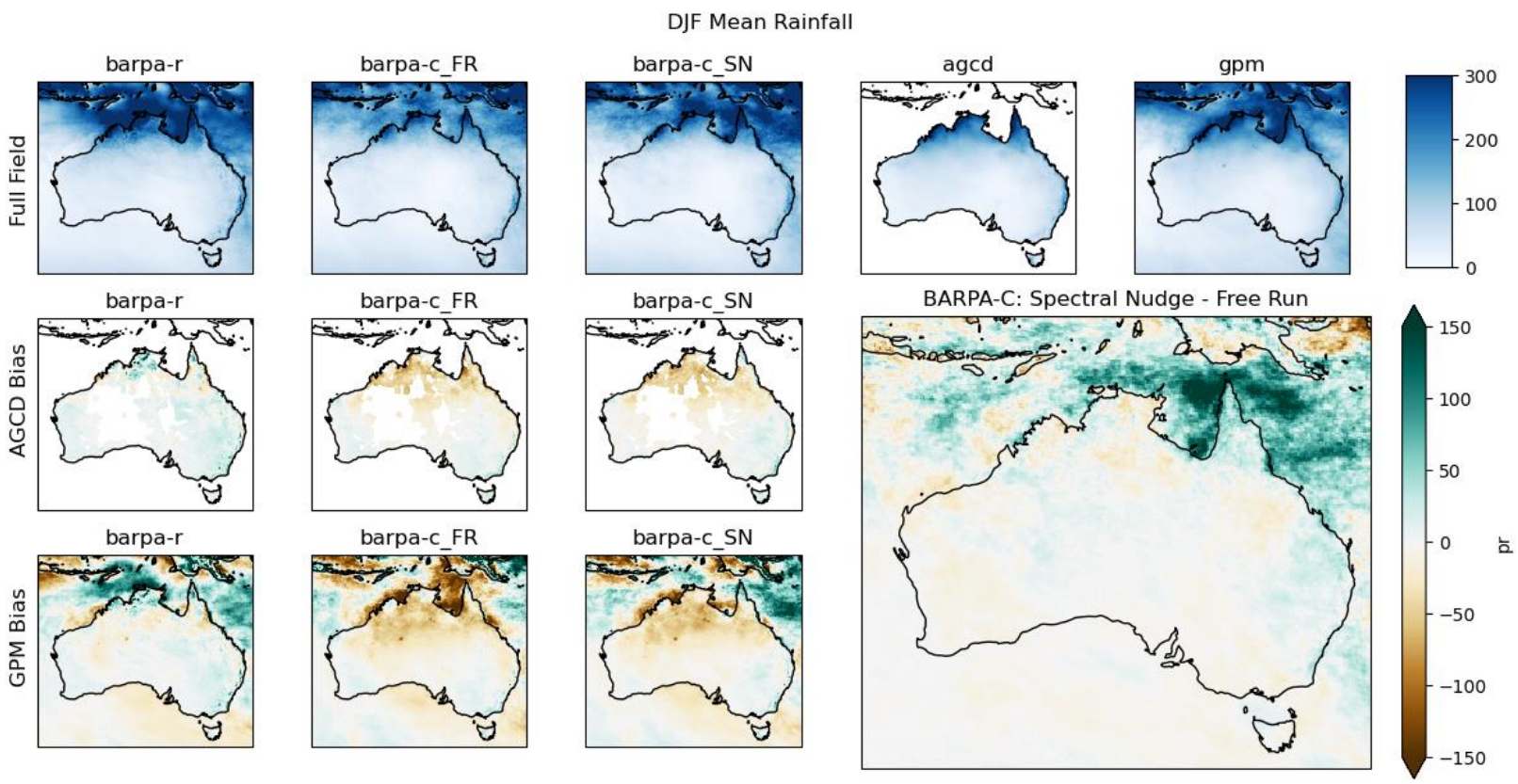


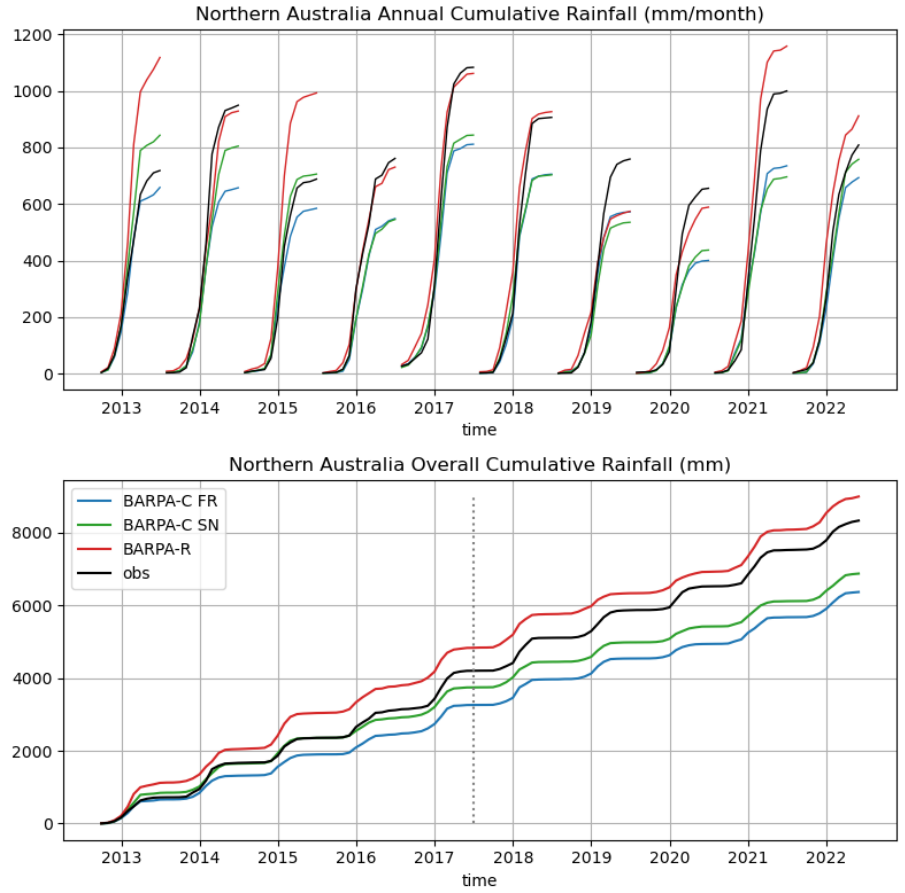


Spectral nudging has moved the mean-state monsoon trough southwards to align better with ERA5 over the top end

Mean State Precipitation

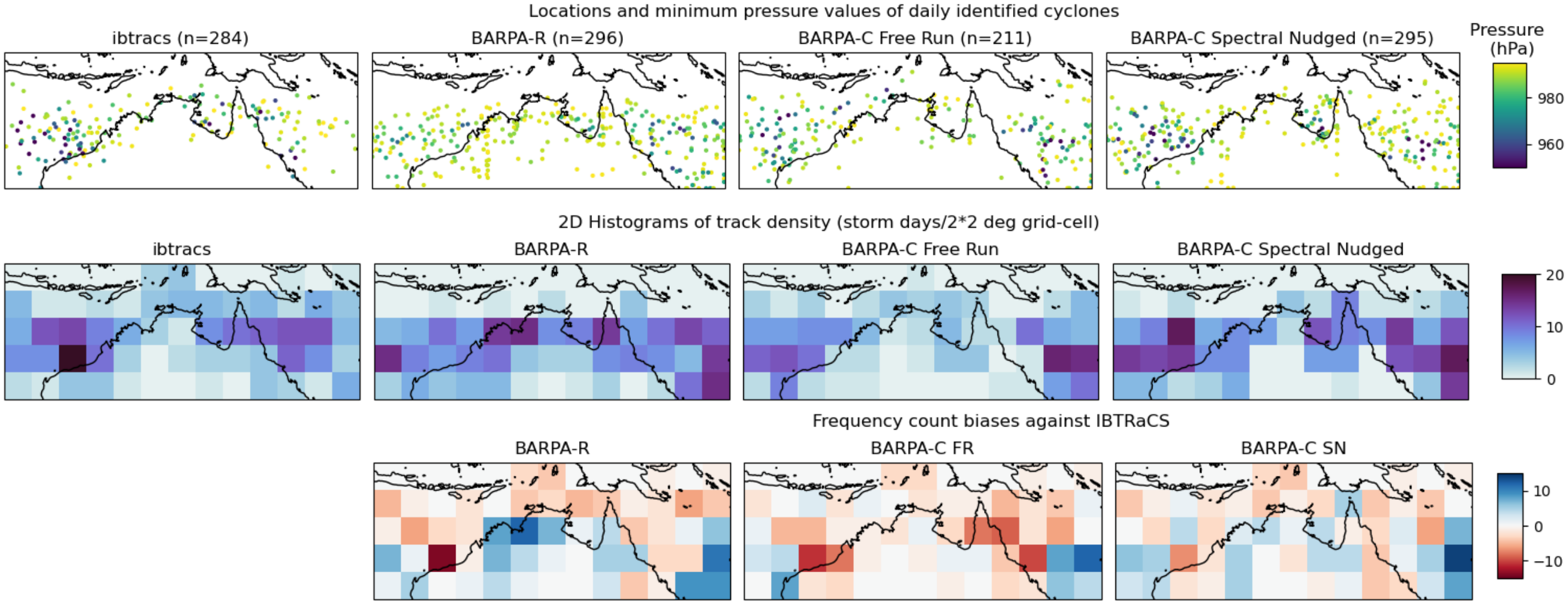
FR: Free run
SN: Spectral Nudged (e=12hr)
Time: 2012-2022





Spectral Nudging improves monsoon rainfall over the ocean but has not really impacted it over land.

Tropical Cyclone Track Frequency (2012-2020)



Spectral nudging has improved the frequencies of cyclones near central and western Australia.
All BARPA models have too many tropical cyclones in the Coral Sea due to the WP surface temperature issue.

Hypotheses

Land Surface Feedbacks

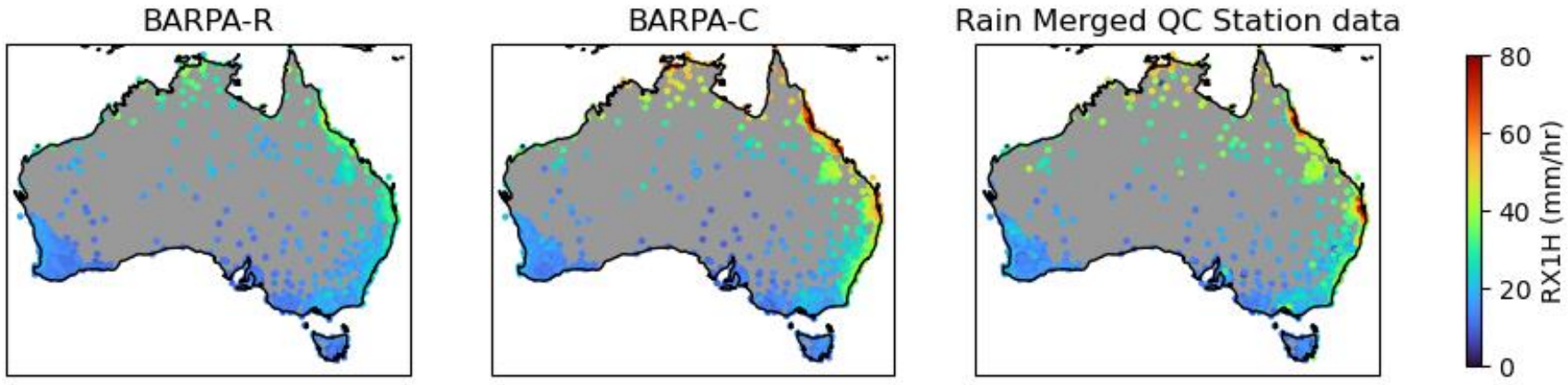
- Low rainfall certainly leads to lower soil moisture, but lower soil moisture can also sometimes lead to lower rainfall, creating a positive feedback loop.
- CPMs often have less efficient rainfall infiltration due to increased rainfall intensity and heterogeneity.
- We have also updated land use types: less trees, more grasses/shrub/bare soil, leading to more transpiration from soil levels 2&3.
    - 40 to 60-day trials indicate land use changes cannot fully explain the dry bias, but may still be exacerbating the problem.
    - Pathway forward: More trials

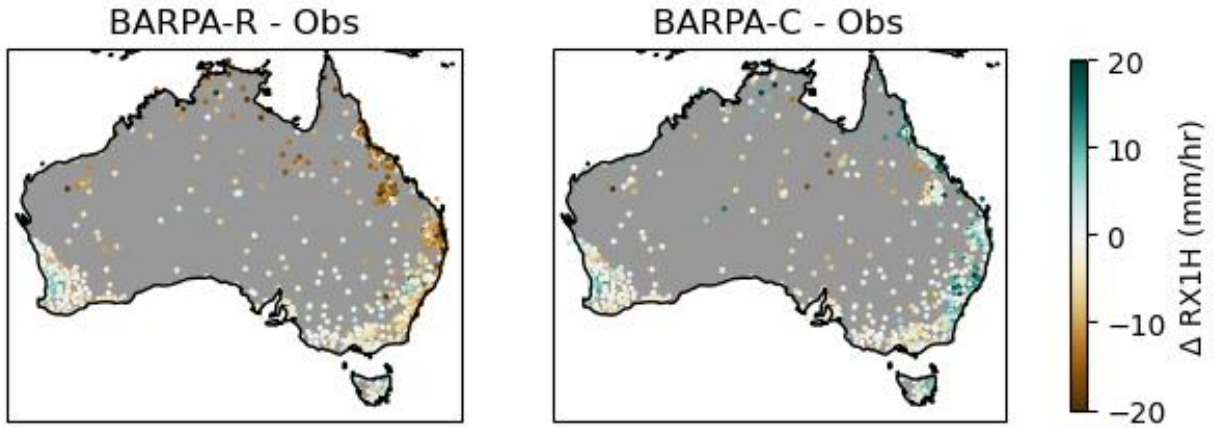
Representation of Shallow Convection

- RAL3.2 does not include a representation of sub grid-scale convection.
- Since our grid-spacing is quite coarse (4km), this may have detrimental impacts on the lifecycles of convection over land, causing a shortening of wet-spell lengths.
- In progress: checking the diurnal cycle of cloud cover in BARPA-C and the simulation of wet-spell lengths.
- Pathways forward: the Unified Physics configuration under development at the momentum partnership will include scale-aware representation of shallow/sub-grid scale convection.

Added Value over BARPA-R and Representation of Hazards/Extremes

Short Duration High Intensity Precipitation (RX1H)

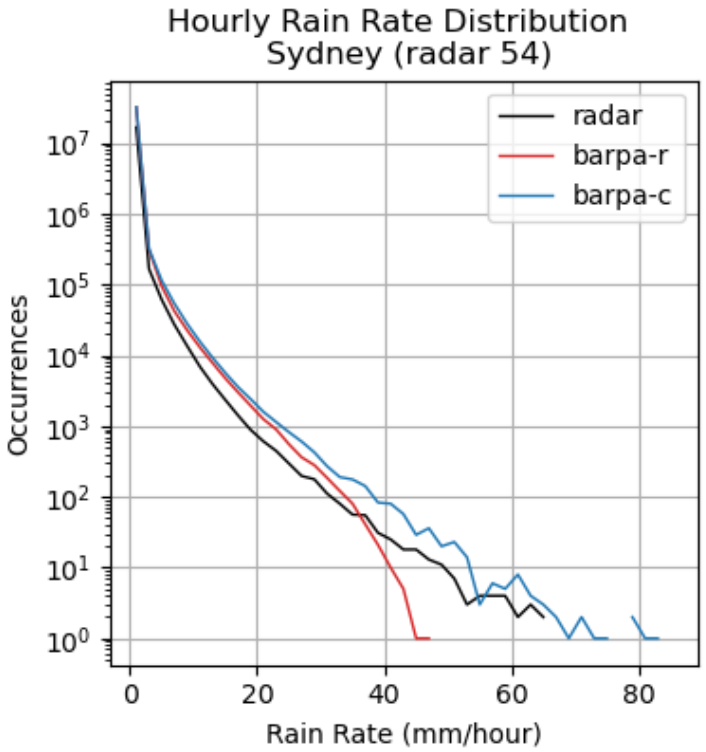


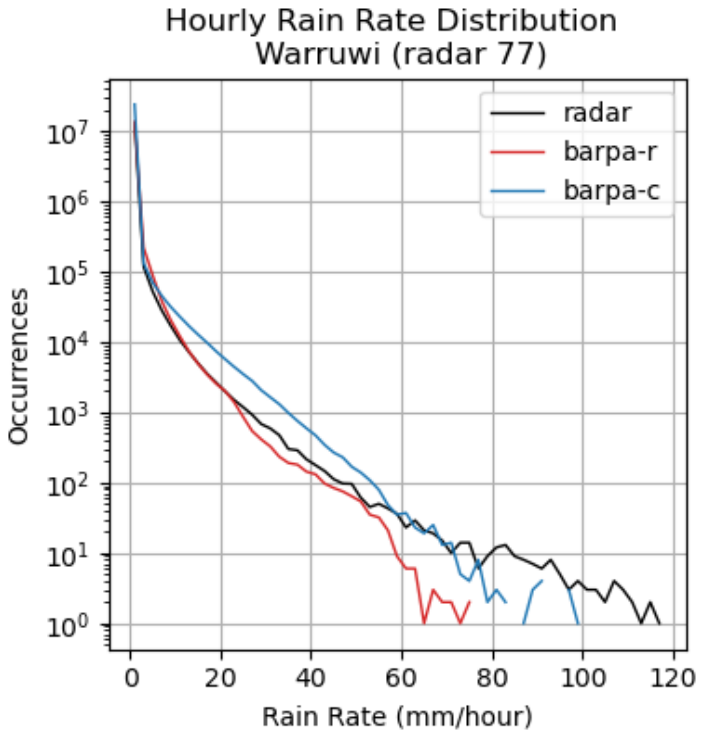


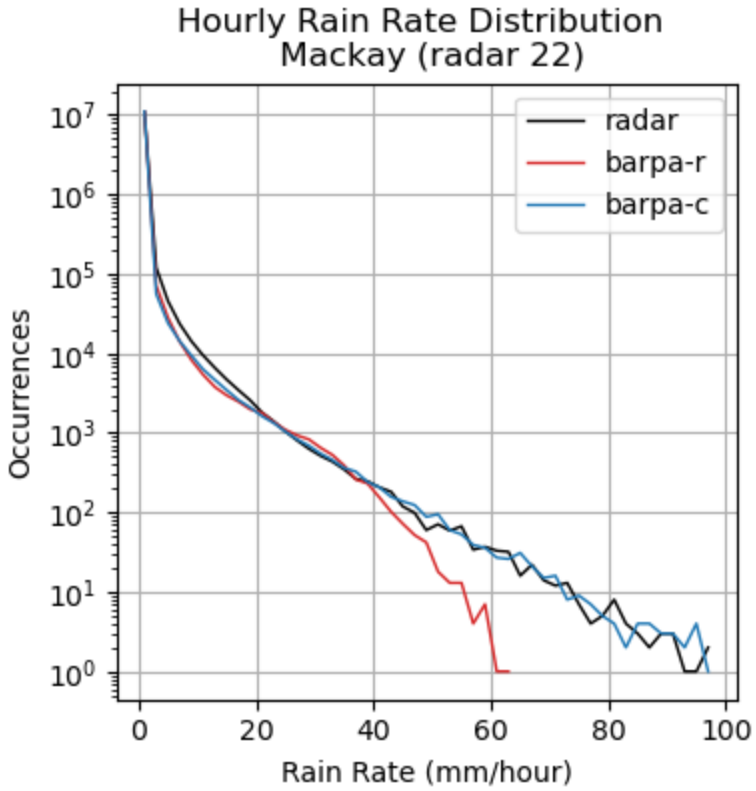
*Obs data from Blair Trewin

- Figures compare 10-year mean of annual max hourly precip to station data (nearest neighbour)
- Strong improvement in representation of RX1H (short duration high intensity precipitation) in BARPA-C.
- Distinct regions of high RX1H: tropics and east coast.

Distribution of hourly rainfall at radar locations



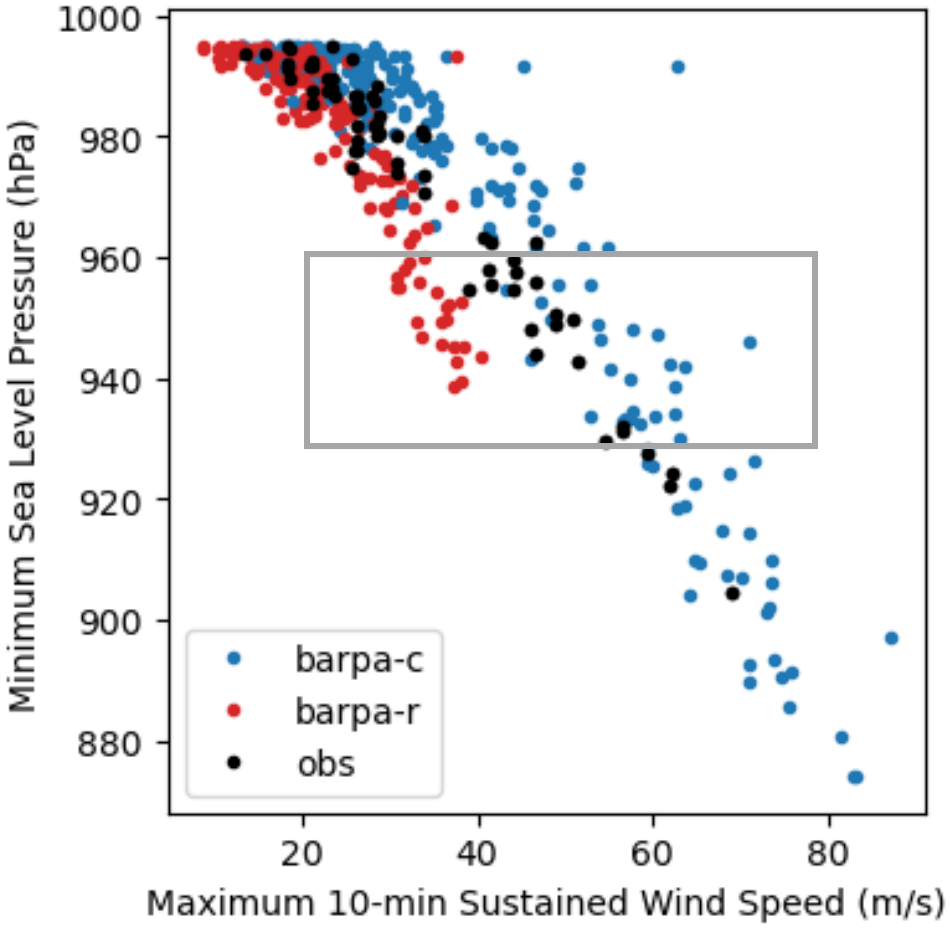




Distribution tails are improved in hourly rainfall data

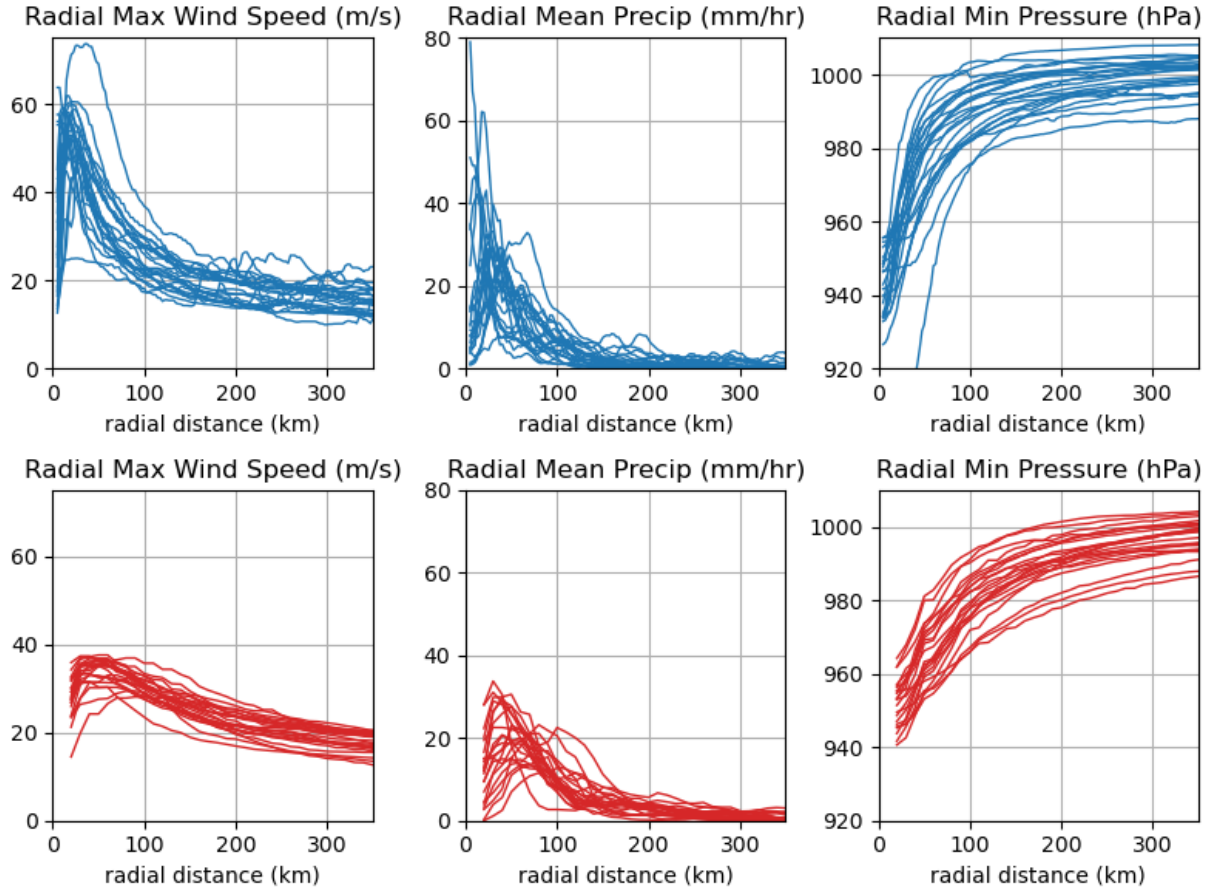
Tropical Cyclone Wind Speed – Pressure Relationship

Wind Speed Pressure Relationship



*Obs/model count comparison not fully comparable

Radial Structures



Tropical cyclones show higher wind speeds and minimum pressures. Eye-walls and "well-shaped" pressure minima are present in BARPA-C

BARPA-C Summary

- ACS is developing and testing BARPA-C as a convective-scale climate downscaling model using RAL3.2.
- We've been investigating a persistent mean-state dry bias in the Australian monsoon which develops on climate-timescales. Possible causes:
  - ~~Monsoon circulation dynamics~~
  - Land-surface interactions
  - Model physics, subgrid-scale convection
- Despite setbacks, we're seeing large improvements in the representation of
  - Short duration extreme rainfall
  - Tropical cyclones

Future Steps

- Land use type testing: extended ERA5-driven run using IGBP vegetation fraction rather than CCIv2.
- GCM downscaling
  - 10-year time-slice experiments from ACCESS-ESM1.5 and EC-Earth3
  - Investigate projections of short duration high intensity rainfall
  - Collaborate with ACS hazards team to prototype convective-scale hazard indicators
  - Investigate 'ensemble boosting' techniques using machine learning
- Package testing
  - Test new RAL4/LFRic/UP configurations from the Momentum Partnership as they emerge.

Meanwhile, the BARRA-C2 reanalysis has powered ahead. Key surface variables are now published on project ob53.

The Bureau of Meteorology

Thank you

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