Storm Attributes for Weather Forecasting and Climate Research in Australia

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The Bureau of Meteorology

1. Introduction

- Severe thunderstorms represent a major hazard in many parts of the world, including Australia, yet remain challenging to forecast due to their small size and the complex dynamics governing their formation and evolution
- Traditional methods for predicting these storms rely on the identification of favourable environments for their development, using coarse-resolution global or regional model output
- While this approach remains extremely valuable, particularly for medium-range forecasting, the advent of convection-permitting NWP models allows for a more direct assessment of severe thunderstorm potential
- The Bureau's convection-permitting ACCESS-C/CE models (Fig. 1) output a range of *storm attributes*: diagnostics designed to quantify characteristics of explicitly simulated convection
- Storm attributes are also being produced as part of the convective-scale components of the Bureau's new regional reanalysis (BARRA-C2) and regional climate projections (BARPA-C)
- Here we introduce the various storm attribute diagnostics and highlight their applications in operational forecasting and climate research

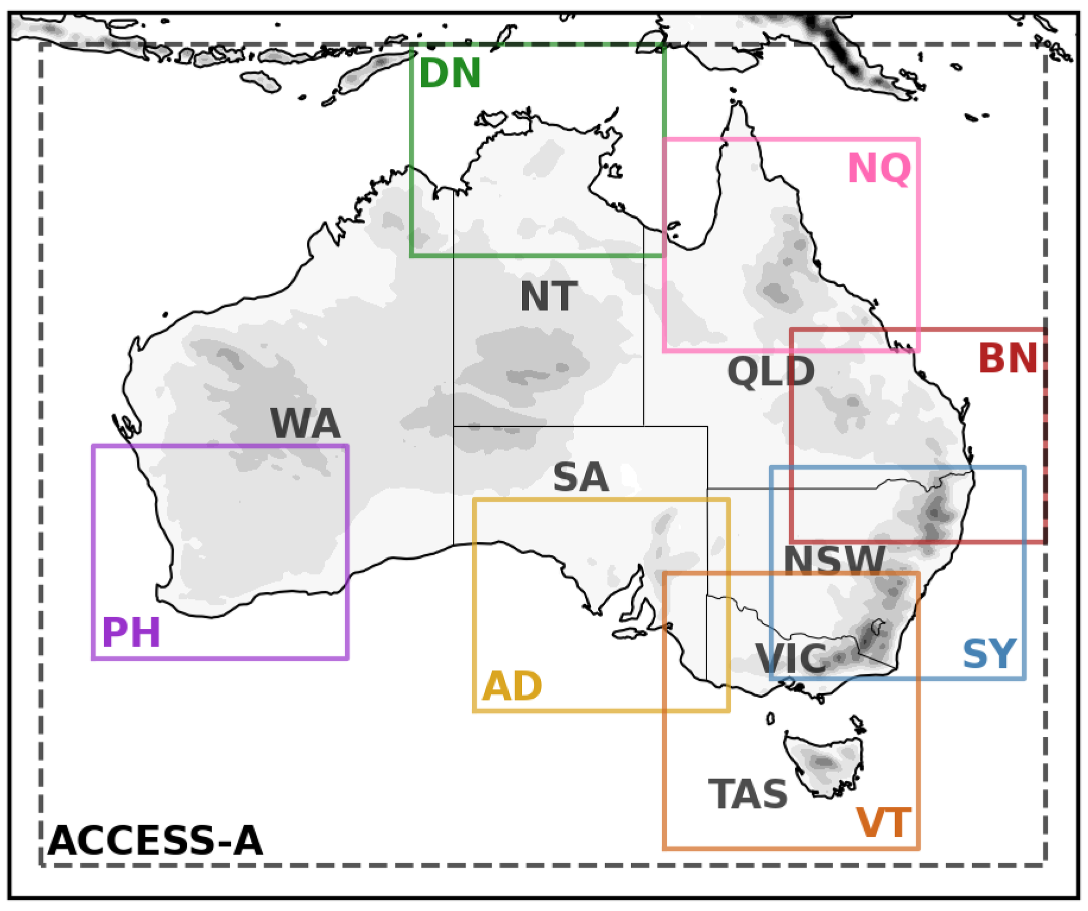

Figure 1. Map of Australia showing surface topography (from ACCESS-G; shaded at 250 m intervals), states and territories, and the ACCESS-C/CE model domains (coloured boxes). Dashed box shows the domain of the planned ACCESS-A/AE model, which will eventually replace the ACCESS-C/CE models.

2. Storm Attributes

- The ACCESS-C/CE models produces a total of six unique storm attributes, all of which are output as hourly maximum / minimum / mean fields (HMFs), with a subset also available as instantaneous fields every 10 min (Table 1)
- HMFs are derived by computing the relevant statistic over all model time steps across a given hour (Kain et al. 2010) and provide information on storm evolution and intensity during this period
- Updraft helicity (UH) in the layer from 2 to 5 km above ground level (AGL) can be used to identify deep rotating updrafts (supercells)
- UH is output as hourly minimum (UH25min) and maximum (UH25max) fields, which capture cyclonic and anticyclonic supercells, respectively; a "total" updraft helicity (UH25tot), computed as the absolute maximum of UH25min and UH25max, captures both types of supercell simultaneously
- Figure 2 shows example HMFs for UH25tot, WMAX, DMAX, REF1, CREF, and LFR for a severe thunderstorm event in NSW on 14 October 2021

Table 1. List of storm attributes output by the ACCESS-C/CE models

Attribute	Description (units)	10 min	HMFs
UH25	2–5 km AGL updraft helicity ($m^2\ s^{-2}$)		Max + Min
WMAX	Column-maximum updraft speed ($m\ s^{-1}$)		Max
DMAX	Column-maximum hail diameter (m)	✓	Max
REF1	Simulated reflectivity at 1 km AGL (dBZ)	✓	Max
CREF	Simulated composite reflectivity (dBZ)	✓	Max
LFR	Lightning flash rate (flashes s^{-1})	✓	Mean

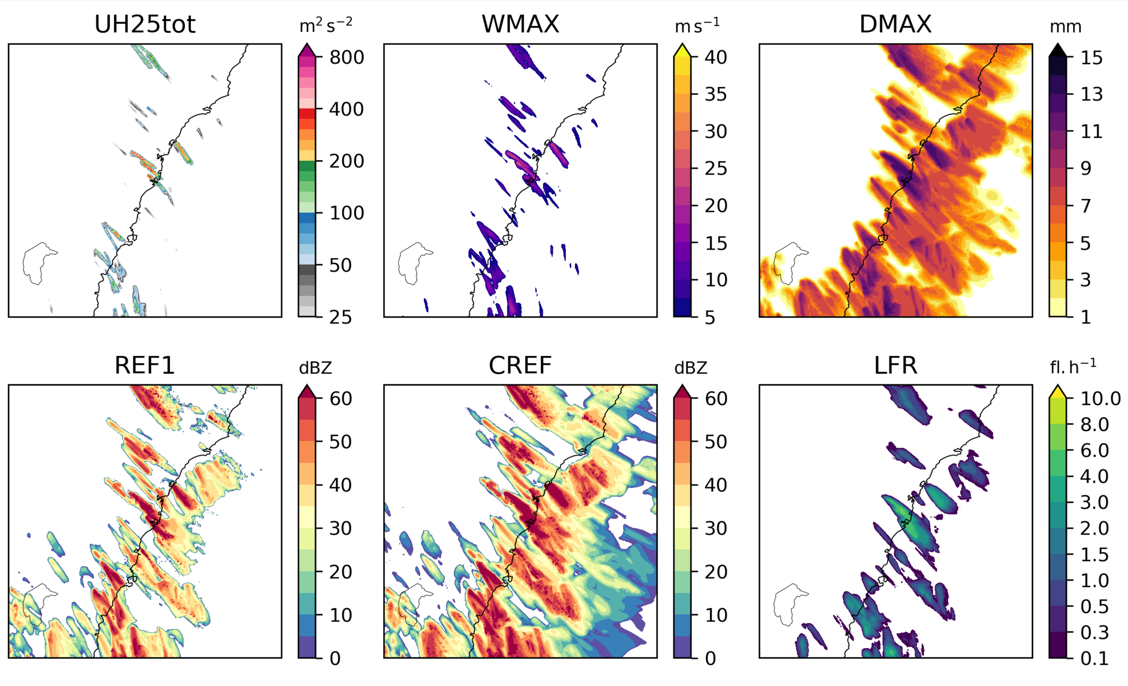

Figure 2. Example storm attribute HMFs: (a) hourly absolute maximum ("total") 2–5 km AGL UH (UH25tot); (b) hourly maximum column-maximum updraft speed (WMAX); (c) hourly maximum column-maximum hail diameter (DMAX); (d) hourly maximum simulated reflectivity at 1 km AGL (REF1); (e) hourly maximum composite reflectivity (CREF); and (f) hourly mean lightning flash rate (LFR). Data are from the control member of ACCESS-SYE for the 18 UTC run on 13 October 2021 at a lead time of 13 h (valid 07 UTC on 14 October).

3. Post-Processing and Visualisation

- Time-aggregated HMFs are produced for rolling 3-hour (00–15 UTC, 01–04 UTC, etc.), "full-day" 24-hour (15–15 UTC), and "rest-of-day" 15-hour (00–15 UTC) periods as the maximum (or minimum) of the hourly values
- For ACCESS-CE, additional ensemble diagnostics are derived for each temporally aggregated HMF:
  - *Ensemble maximum* – The (absolute) maximum value across all ensemble members
  - *Neighbourhood maximum ensemble probability (NMEP)* – Smoothed ensemble probability of a storm attribute exceeding some threshold within a fixed radius of each grid point (Schwartz and Sobash 2017)
- NMEP thresholds for each storm attribute (Table 2) were selected based on preliminary verification against radar and lightning observations for the Brisbane and Sydney domains during the 2020/21 warm season
- For some storm attributes, a secondary lower threshold was included to identify weaker but potentially still severe storms
- The neighbourhood radius for each NMEP (Table 2) was selected based on values used in the US or, in the case of LFR, to match existing lightning guidance from the Calibrated Thunder system
- Following Roberts et al. (2020), a variety of methods are used to visualise the ensemble fields:
  - *Postage stamps* – Instantaneous storm attributes or HMFs plotted separately for each ensemble member in a grid
  - *Paintball plot* – Areas where a storm attribute exceeds some threshold shaded, with different colours for each ensemble member
  - *Ensemble summary plot* – Ensemble maximum or paintball plot overlaid with NMEP contours
  - *Monopoly plot* – Paintball plot overlaid with NMEP contours, encircled by postage stamps for each ensemble member (Fig. 3)

Table 2. NMEP thresholds and neighbourhood radius for each storm attribute.

Attribute	Primary Threshold	Secondary Threshold	Radius
UH25	250 $m^2\ s^{-2}$	150 $m^2\ s^{-2}$	40 km
WMAX	30 $m\ s^{-1}$	20 $m\ s^{-1}$	40 km
DMAX	12 mm	-	40 km
REF1	65 dBZ	50 dBZ	20 km
CREF	65 dBZ	50 dBZ	20 km
LFR	1 flash h^{-1}	-	10 km

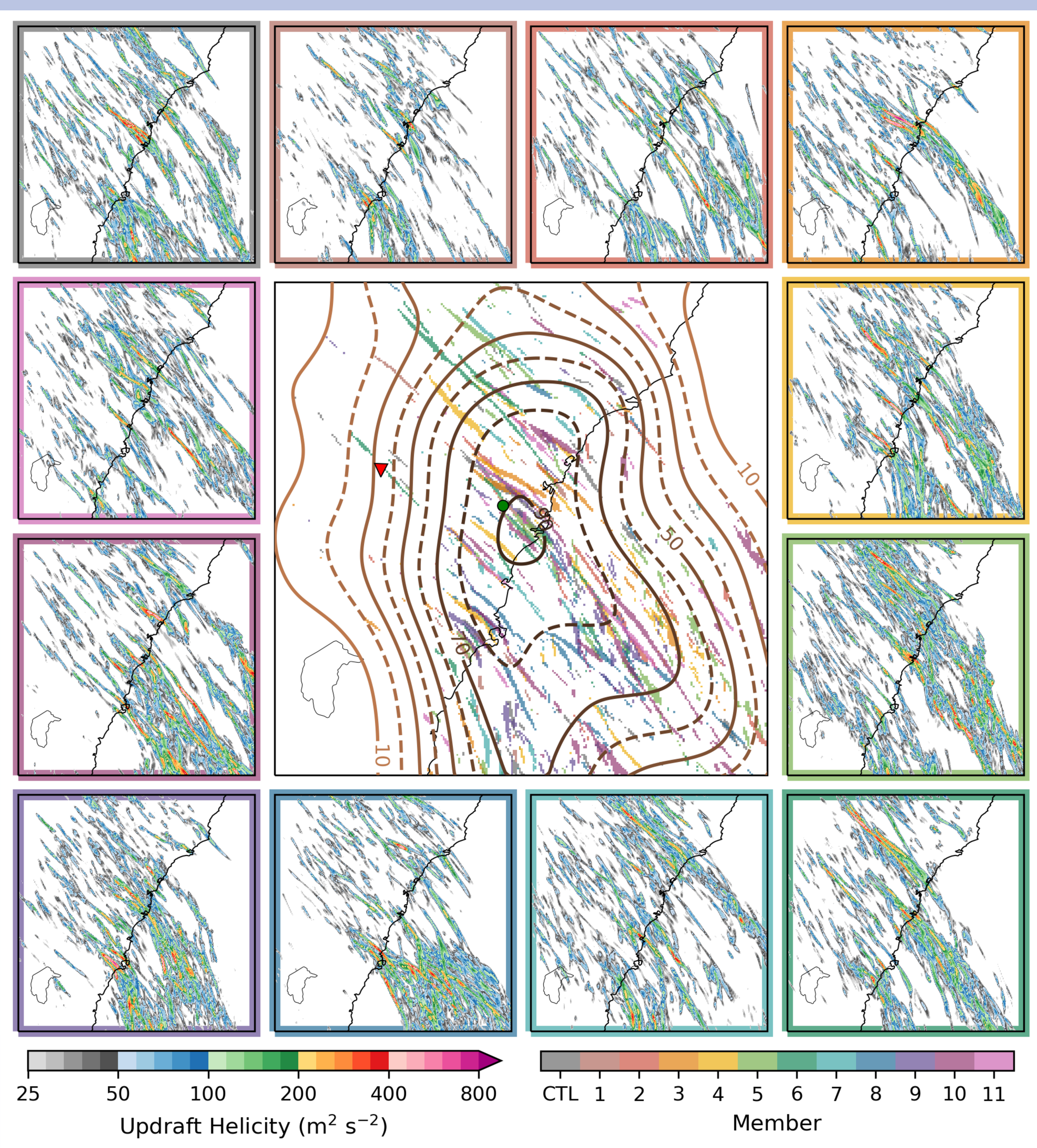

Figure 3. Example monopoly plot for 15-hour absolute maximum ("total") 2–5 km updraft helicity (UH25tot). Outer panels show UH25tot from each ensemble member and central panel shows a paintball plot with 40-km NMEP contours overlaid (both computed using a threshold of 200 $m^2\ s^{-2}$). Data are from the ACCESS-SYE model for the 18 UTC run on 13 October 2021 at lead times of 6–21 h (valid 00–15 UTC on 14 October). Red triangle and green circle indicate tornado and severe hail reports, respectively.

4. Verification

- All storm attributes except LFR were verified against quality-controlled and gridded S-band radar observations for the Brisbane and Sydney domains:
  - UH25tot, WMAX, and DMAX were verified against the maximum expected size of hail (MESH; Witt et al. 1998)
  - REF1 and CREF were verified against low-level (2.5 km above radar level; ARL) and composite (2.5–20 km ARL maximum) reflectivities
- LFR was verified against lightning observations from the Weatherzone Total Lightning Network for all domains except North Queensland
- UH25tot and WMAX show skill in identifying severe hail (MESH > 30 mm) for thresholds around 250 $m^2\ s^{-2}$ and 30 $m\ s^{-1}$, respectively (not shown)
- The parameterisation of hail size does not appear to work well with the existing ACCESS microphysics scheme, which strongly limits the skill of DMAX in identifying severe hail (not shown)
- Simulated reflectivities show a pronounced positive bias, with unrealistically high maximum values of ~100 dBZ (Fig. 4)
- For all domains except Darwin, LFR displays at least modest skill and discrimination for thresholds of 1–2 flashes h^{-1}; however, performance varies significantly between domains (Fig. 5)

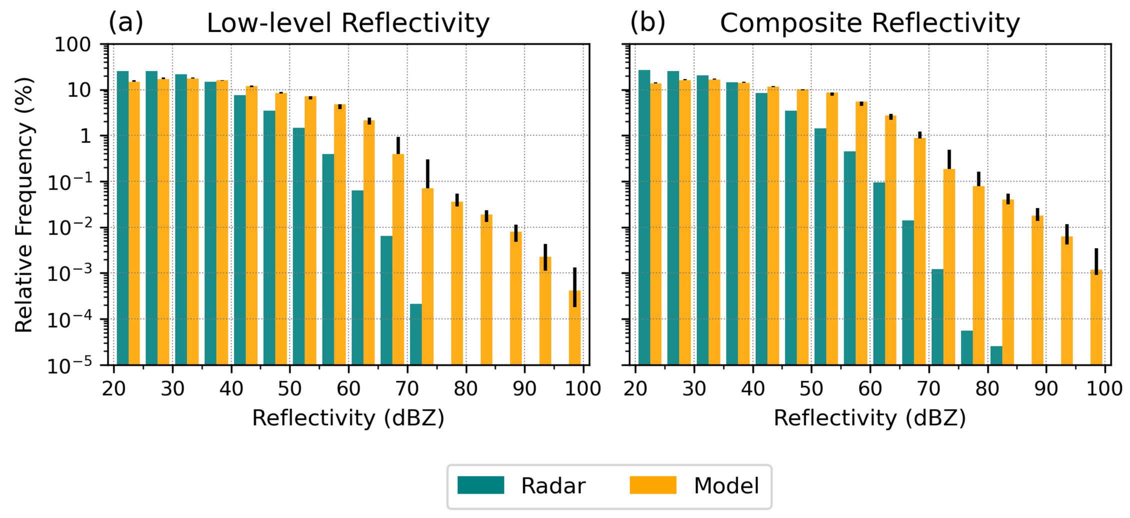

Figure 4. Histograms showing the frequency distribution of radar observed and simulated (a) low-level and (b) composite reflectivities above 20 dBZ. Model data are from the 12 UTC runs of ACCESS-BNE for the period 3 December 2020 to 28 February 2021. Radar data are from the Mt Stapylton, Marburg, Grafton, and Gympie radars and were extracted from the Australian Unified Radar Archive (Soderholm et al. 2022). Simulated reflectivities are from the control member with the range across the ensemble shown by narrow black bars.

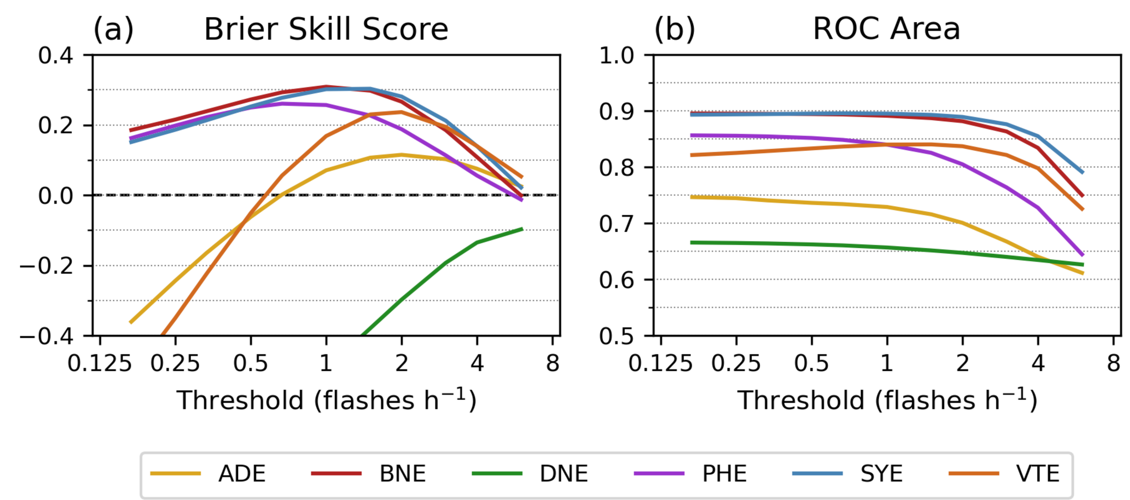

Figure 5. (a) Brier skill score and (b) relative operating characteristic (ROC) area for lightning flash rate (LFR) NMEPs plotted as a function of LFR threshold. Results are shown for the ADE, BNE, DNE, PHE, SYE, and VTE domains. Model data are from the 12 UTC runs from 17 December 2020 to 15 March 2021. Observed lightning data are from the Weatherzone Total Lightning Network.

5. Climate Applications

- In support of the Australian Climate Service (ACS), the Bureau has recently completed a high-resolution (~4.4 km grid spacing) regional reanalysis for Australia (BARRA-C2; Su et al. 2024)
- High-resolution regional climate projects, downscaled from a subset of CMIP6 models, are currently being produced using the same domain and resolution (BARPA-C)
- Storm attributes (excluding DMAX) are being produced as part of both modelling efforts, allowing for an assessment of the climatology of simulated thunderstorms and their historical and future trends
- The reanalysis can also be used to investigate major historical events; an example for the Brisbane "Halloween hailstorm" of 31 October 2020 is shown in Fig. 6

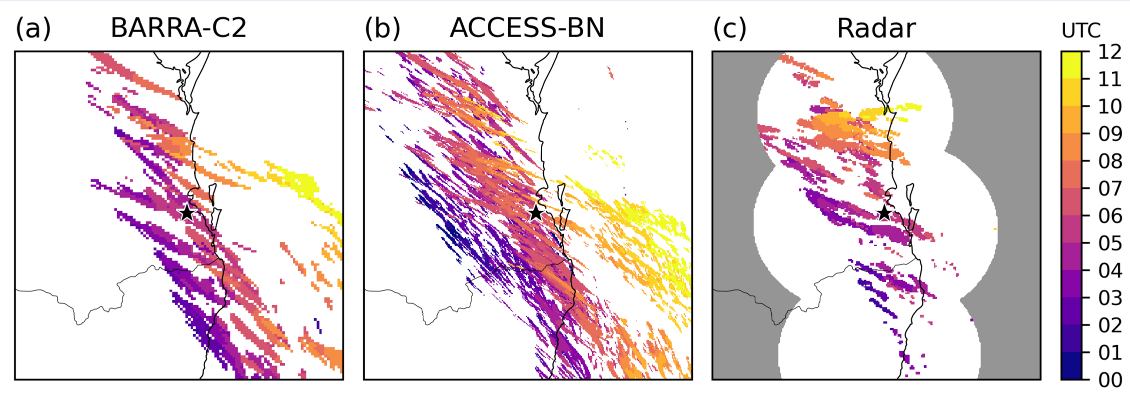

Figure 6. Comparison of time-aggregated total 2–5 km updraft helicity (UH25tot) from (a) BARRA-C2 and (b) ACCESS-BN against (c) radar-observed maximum expected size of hail (MESH) over southeast QLD / northeast NSW for the period 00–12 UTC on 31 October 2020. Values above a threshold (25 $m^2\ s^{-2}$ for UH25tot from BARRA-C2; 75 $m^2\ s^{-2}$ for UH25tot from ACCESS-BN; 30 mm for MESH) are shaded according to the latest time the threshold was exceeded at each grid point. ACCESS-BN data are from the 12 UTC run on 30 October 2020. Radar data are from the Mt Stapylton, Marburg, Grafton, and Gympie radars and were extracted from the Australian Unified Radar Archive (Soderholm et al. 2022). Grey shading in (c) shows areas outside radar coverage. Black star shows the location of Brisbane.

6. Summary & Outlook

- Raw and post-processed storm attributes from the ACCESS-C/CE models have been available to forecasters for the past two warm season and are now routinely used in operations
- Further verification of storm attributes is needed, covering multiple warm seasons and encompassing all ACCESS-C/CE domains
- The thresholds used to create NMEPs will need to be revisited based on additional verification and following any future model upgrades
- The planned ACCESS-A/AE model (Fig. 1) will provide guidance on the risk of thunderstorm and severe weather across all of Australia
- Storm attributes from BARRA-C2 and BARPA-C will soon be made available via the National Computational Infrastructure (NCI)

References

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