Response to Reviewer Comment 1 for Convection-permitting climate model representation of severe convective wind gusts and future changes in southeastern Australia

Reviewer comment 1

The manuscript "Convection-permitting climate model representation of severe convective wind gusts and future changes in southeastern Australia" by Brown et al. investigates how future convective wind gusts might change over Southeastern Australia. Previous research suggests that surface hazards from thunderstorms, like severe convective winds (SCWs), may alter with climate change, yet global climate models struggle to resolve these due to their small scale, leading to uncertain projections. The authors find that SCW events using a convection-permitting climate model (BARPAC-M) over southeastern Australia for December–February, and comparing with a regional parent model (BARPAR) improved representation of extreme wind gusts in BARPAC-M but overestimation of SCW frequency, particularly in certain environments. Projected changes in SCW frequency for 2050 show uncertainties, with potential decreases under certain conditions and increases under others, highlighting the complexity of future SCW trends in the region. The study is very well structured, and written, and the images and text are of high quality. The differentiation of wind gusts into different categories adds a lot of novel insights about model biases and future climate change impacts on these extremes. This is one of the best-written and interesting papers that I have read in a while. I have only a couple of minor suggestions for changes and recommend publishing this manuscript after those are addressed.

Thank you for this review and providing comments and suggestions on the manuscript, including the positive feedback on our approach. We will respond to your comments below.

General comment

Adding more discussion on the importance of climate internal variability on your results would be beneficial. You mention the high degree of spatial and temporal variability of convective gusts already but making the role of internal climate variability more explicit would be important (see e.g., Deser et al. 2012). Internal climate variability could easily be the dominant source of uncertainty in your future climate projections.

Deser, C., Phillips, A., Bourdette, V. and Teng, H., 2012. Uncertainty in climate change projections: the role of internal variability. Climate dynamics, 38, pp.527-546.

We agree with the reviewer that the role of internal climate variability should be mentioned, especially in the context of high spatial and temporal variability of severe convective wind events that is discussed in the submitted manuscript. We have included a paragraph on this in the Discussion of the revised manuscript, as shown below, that is also aimed to address similar comments from another reviewer:

"The uncertainties related to extreme wind events mentioned above could also be associated with internal climate variability, including natural modes of variability such as the El Nino-Southern Oscillation (ENSO) and others, that could potentially affect the future projections presented here more generally. Internal variability can be a source of uncertainties in future climate projections (Deser et al., 2012) as well as in historical trends of severe thunderstorm environments for this region (Allen and Karoly 2014). Uncertainties from internal variability could be exacerbated by the relatively short 20-year period used for the analysis here, noting that this was the maximum period of data available for use and that these data were used in previous research such as described in Dowdy et al. (2019). Simulating long periods with convection-permitting models is very computationally demanding, as noted by previous studies that have used temporal windows of about 10-15 years length for future projections of severe convection (Gensini and Mote, 2014; Ashley et al., 2023). Future work to provide convection-permitting climate model simulations over longer periods will be beneficial, including with a larger sample helping to reduce the influence of internal climate variability (e.g., associated with ENSO) on estimates of longer-term climate changes. In addition, the relationships between SCW events and individual modes of climate variability in this region are relatively uncertain, with conflicting results for severe convection based on lightning and hail observations, and severe thunderstorm environments (Allen and Karoly, 2014; Dowdy, 2016; Soderholm et al., 2017; Dowdy 2020). Future work towards revealing these relationships could likely provide additional insights on the potential impact of internal climate variability on historical and future trends in convective hazards, including severe wind gusts".

Allen, J. T. and Karoly, D. J.: A climatology of Australian severe thunderstorm environments 1979 – 2011 : Inter-annual variability and ENSO influence, International Journal of Climatology, 34, 81–97, https://doi.org/10.1002/joc.3667, 2014

Ashley, W. S., Haberlie, A. M., and Gensini, V. A.: The Future of Supercells in the United States, Bulletin of the American Meteorological Society, 104, E1–E21, https://doi.org/10.1175/BAMS-D-22-0027.1, 2023.

Dowdy, A.: Seasonal forecasting of lightning and thunderstorm activity in tropical and temperate regions of the world, Scientific Reports, 6, 1–10, https://doi.org/10.1038/srep20874, 2016

Dowdy, A., Brown, A., Pepler, A., Thatcher, M., Rafter, T., Evans, J., Ye, H., Su, C.-H., Bell, S., Stassen, C. (2021). Extreme temperature, wind and bushfire weather projections using a standardised method. In Bureau Research Report – BRR055.
http://www.bom.gov.au/research/publications/researchreports/BRR-055.pdf

Dowdy, A.J., 2020. Climatology of thunderstorms, convective rainfall and dry lightning environments in Australia. *Climate Dynamics*, *54*(5), 3041-3052, https://doi.org/10.1007/s00382-020-05167-9 .

Gensini, V. A. and Mote, T. L.: Estimations of hazardous convective weather in the United States using dynamical downscaling, Journal of Climate, 27, 6581–6589, https://doi.org/10.1175/JCLI-D-13-00777.1, 2014.

Soderholm, J., McGowan, H., Richter, H., Walsh, K., Weckwerth, T. M., and Coleman, M.: An 18-year climatology of hailstorm trends and related drivers across southeast Queensland, Australia, Quarterly Journal of the Royal Meteorological Society, 143, 1123–1135, https://doi.org/10.1002/qj.2995, 2017.

Specific Comments

1. Is BARPAC-M online or offline nested into BARPAR? The online nesting would have the benefit of providing higher-temporal resolution at the lateral boundaries which generally reduces that spatial spinup in the high-resolution domain.
   Thank you for providing this interesting point. BARPAC-M was run offline, with the revised manuscript text now noting the following "The convection-permitting model used here is a part of the broader BARPA modelling framework from the Australian Bureau of Meteorology (Su et al., 2021) … The BARPAC-M simulations were run after the full time period of BARPA-R simulations were completed. BARPAC-M can therefore be considered an offline simulation with no feedback into the BARPA-R simulation". We will also pass this comment on to the Bureau of Meteorology modelling group that are running the BARPA simulations, in case they might consider online nesting for their future planning of convection-permitting simulations, noting the benefits mentioned in this review comment.

2. How did you account for boundary effects in BARPAC-M? Do you use a sponge zone and did you exclude boundary grid cells from the analysis?
   Yes it used a sponge zone, with that zone excluded from the analysis. The revised manuscript text now notes the following "The BARPAC-M simulations use a sponge zone for the lateral boundary nesting in the BARPA-R simulations, with analysis excluding data from that sponge zone, as was also the case for the BARPA-R simulations nested in ERA-Interim (Su et al 2021)."

3. L100: It is optimistic to assume that the resolved gust in BARPAR is 10-min if you have a 5-min time step. I would assume that your resolved temporal scales are at least 4Dt based on numerical considerations and model diffusivity.
   In the text referenced by the reviewer, it was not our intention to infer that BARPA-R can resolve gust processes on 10-minute scales. Instead, we meant to explain that the difference in output between BARPAC-M (maximum 3-second wind gust over all time steps in a 10-minute period) and BARPA-R (instantaneous 3-second wind gust at 10-minute intervals) should not impact the comparison between the two model configurations, given that the BARPA-R time step is relatively coarse compared with the 10-minute output frequency. We have made this clearer by including the following in the revised manuscript:

   "Parameterised 3-second wind gust output is saved at 10-minute intervals in both models. For BARPAC-M, the 10-minute output represents the maximum 3-second gust over all model time steps. In contrast, for BARPA-R, the 10-minute output represents the wind gust from a single model time step, based on a model time step of 5 minutes. For the purposes of comparing the two model configurations, the BARPA-R 3-second gust distribution based on instantaneous

10-minute output is expected to be similar to a 10-minute maximum, given the relatively coarse model time step of 5 minutes, but with slightly lower mean and extreme values. This is demonstrated in Supplementary Material (Section S1) by resampling observational wind gust data to 5-minute intervals, where a bias of around -1.0 to -0.5 m/s is introduced using 10-minute instantaneous observed gusts relative to 10-minute maximum observed gusts. However, this bias is not expected to significantly impact the analysis of extreme wind gusts associated with convection, where spatial resolution and physical process representation are most relevant when comparing between models."

4. In the analysis of Fig. 2 you directly compare the grid cell wind gust from the models with observed gusts at point locations. Should the model be able to capture point-scale wind gusts? I would assume that the model wind speed should be lower than that observed at point locations since the model is representing a spatial (e.g., grid cell) average wind gust, which in case of ERA5 and BARPAR is a quite large area.
   This is a good point raised by the reviewer, and is not one that we address directly in the manuscript (although we do re-size the BARPAC-M grid to investigate the impact of grid cell size). We have now mentioned this as a disclaimer in the manuscript when introducing the analysis of Figure 2:

   "Here we compare the wind gust intensity distribution between each of the BARPA hindcast model configurations, the forcing model (ERA-Interim), and observations measured from AWS. … It should be noted that the observations used here are representative of a single point location, compared with each of the model datasets that are intended to represent a grid cell average. Therefore, some differences between the observed wind gust distribution and model distributions should be expected, including lower model wind speeds for local wind gust events at station locations in general. The effect of model grid spacing will be investigated later in this section for BARPAC-M".

   And when discussing the results for ERA-Interim:

   "ERA-Interim is shown to realistically represent wind gust percentiles up to around 15 m/s, while significantly underestimating percentiles above this. This is likely due to the large grid cell area of this model dataset, as mentioned above in relation to comparing with point observations".

5. 3: Maybe using a log y-axis would make this figure easier to read.
   We agree, and have changed the y-axis to a log scale. Thank you for the suggestion.

6. L223: Why are you using the 6 km speed here? Are you assuming that this is the source height of downdrafts?
   We use the 0-6 km mean wind speed as an estimate of the background wind that is likely relevant for storm motion and horizontal momentum available for downdrafts, although downdrafts might initiate much lower than this height in

some cases. We also already use this data for the event clustering, so it is readily available for the analysis of the ratio of the peak surface wind gust to the background wind speed. We have inserted the following text into the revised manuscript to communicate this:

"A 0-6 km layer is chosen as this is likely representative of the background flow relevant for vertical mixing by downdrafts and storm motion, with wind speed data over this layer already available based on its application for event clustering (see Supplementary Material Section S2)".

7. 6: Please add a legend that describes the circle sizes.
   We have added a legend. Thank you for the suggestion.