General Comments:

This study presents a comprehensive analysis of extreme precipitation events in West Antarctica using a mini-ensemble of three state-of-the-art kilometer-scale regional climate models (RCMs). The authors effectively demonstrate that high-resolution RCMs are crucial for capturing the complex interactions between atmospheric rivers (ARs) and the region's topography, which significantly influences precipitation patterns and phase transitions. The study provides valuable insights into orographic uplift, latent heat release, and the formation of supercooled liquid precipitation, contributing to a deeper understanding of precipitation dynamics in this climatically sensitive area.

I find this study to be well-executed and interesting, addressing an important gap in climate modeling for polar regions. The work is valuable for its use of high-resolution modeling to explore the drivers and impacts of ARs in West Antarctica. However, some clarifications and details are needed to strengthen the findings. Overall, I would consider these changes to be minor, as the study is already well-structured and offers valuable insights into the dynamics of extreme precipitation events in West Antarctica.

Specific Comments:

Abstract:

- Line 18-19: Better to quantify the "severely underestimated" and provide more detail on the difference. For example, "In contrast, ERA5 reanalysis data underestimate snowfall by 40-60% compared to in situ measurements, highlighting the limitations of coarse-resolution reanalysis in capturing localized precipitation events."
- Line 24-25: I would clarify what "resolution insensitive" means and elaborate on the significance of this finding. For example, "Our results demonstrate that RCM-simulated snowfall shows limited sensitivity to spatial resolution, while simulated rainfall increases by up to 50% in 1 km resolution models compared to 12 km models, suggesting that fine-scale modeling is essential to capture rainfall variability accurately."

Introduction:

- Line 70-72: Better to highlight the mechanisms leading to rainfall. Suggestion: "…This is primarily due to warm air advection and moisture convergence facilitated by ARs, which elevate temperatures and increase the likelihood of liquid precipitation." Also, please add these two recent publications to highlight the AR-driven rainfall events in Antarctica:
    - Bromwich, D. H., and Coauthors, 2024: Winter Targeted Observing Periods during the Year of Polar Prediction in the Southern Hemisphere (YOPP-SH). Bull. Amer. Meteor. Soc., 105, E1662–E1684, https://doi.org/10.1175/BAMS-D-22-0249.1.
    - Bozkurt, D., Carrasco, J., Cordero, R., Fernandoy, F., Gómez, A., Carrillo, B., Guan, B., 2024. Atmospheric river brings warmth and rainfall to the northern Antarctic Peninsula during the mid-austral winter of 2023. Geophysical Research Letters, 51, e2024GL108391, https://doi.org/10.1029/2024GL108391.

- Line 70-7Line 92: I think it is good to specify the dates of case studies or at least to mention summer/winter events.
- Line 91-95: I suggest rewriting the main motivation of the study i) clarifying the research gap, ii) specifying the novelty and relevance, and iii) emphasizing the broader impact in a clearer way. Also, please clarify what is meant by "mini-ensemble.":
    - "This study uses a mini-ensemble of three state-of-the-art kilometer-scale RCMs to explore the interactions between ARs and the TG and PIG ice shelves in the ASE during two extreme precipitation events—a summer and a winter case study. The study aims to quantify the precipitation deposited by ARs, including rain, which can significantly affect the SMB and stability of these ice shelves. Additionally, we evaluate the performance of these high-resolution RCMs in capturing the dynamics of extreme precipitation events in this climatically sensitive region, where in situ observations are limited. By understanding the drivers and impacts of AR-induced extreme precipitation, this work seeks to determine the extent to which ice mass loss from these critical ice shelves and glaciers can be mitigated or exacerbated by changes in accumulation patterns."

Method:

- Line 150: Can you please add which version of Polar-WRF was implemented?
- Line 165-170: Which specific variables of ERA5 were used for downscaling? For instance, were SST and SEAICE data provided by ERA5 or another satellite product?
- Line 175-180: Can you please add the temporal resolution of the observational data?
- Line 184-186: Does the SNOWPACK model use directly in-situ measurements in Cavity Camp and Channel Camp described in 2.3? Or any other data source?
- Also, it would be useful if you can label the location of in-situ measurements in Fig. 1 or Fig. 2.

Results:

- Line 201: How do you define extreme precipitation in this study? I couldn't find relevant information in Section 2.
- Line 203-205: Interesting to see above 0°C temperatures during the winter case. Do you have any available atmospheric measurements (radiosonde profile)?
- Line 268-273: For the readers, it would be really useful to have a plot showing AR origin, origin and characteristics (e.g., axis, landfall) to better understand these lines as well as discussions in the next paragraph.
- Line 279-283: Following my previous point, can you quantify the impact of the spatial variability in AR landfall locations on the snowfall distribution across the TG ice shelf, particularly between the Cavity and Channel Camp stations? Specifically, how does the timing and trajectory of each AR event correlate with the differences in observed accumulation at these two locations?
- Line 285-301: Given the observed discrepancies in snowfall estimates between SNOWPACK, RCMs, and ERA5, especially in the summer case, can you elaborate on how the representation of AR dynamics (e.g., moisture transport, phase transitions) differs

among the models? How might these differences contribute to the underestimation of snowfall?

- Line 302-310: Is it possible to provide an estimation of the potential uncertainty in the SNOWPACK accumulation totals due to unmeasured processes (e.g., melt, sublimation, wind erosion)? A brief discussion on this would be useful.
- Line 327-328: Please simplify the sentence for clarity. "The lower precipitation estimates from the satellite data, compared to the multi-model mean of the RCMs, likely result from the satellite product's coarse resolution (0.1° × 0.1°, approximately 12 km) and the challenges in detecting precipitation over cold, snow-covered surfaces."
- Line 337-340: Better to break this into two sentences for clarity. "The RCM 5th-95th percentile range suggests that these models capture some of the spatial heterogeneity indicated by differences between Cavity and Channel. However, the time series at grid points corresponding to each station's location (not shown) are very similar, indicating unresolved spatial variations below the 1 km grid scale or inadequately represented processes."
- Line 346-356: Have you considered evaluating the impact of using different temperature thresholds to diagnose rain in SNOWPACK and how this might influence the discrepancies between the snowfall totals estimated by SNOWPACK and the RCMs? A brief discussion on the potential effects of this diagnostic choice could help clarify its implications for your surface mass balance estimates.
- Line 374: Change to "Figures 3a and 3b" for consistency.
- Line 380-382: Please strengthen this by providing a brief explanation of the specific conditions (e.g., exact temperature ranges) that suggest mixed-phase precipitation. This would clarify why mixed precipitation is "likely."
- Line 420 and Fig. 5: Considering that Polar-WRF (Figure 5g) shows more extensive rainfall over the PIG ice shelf than MetUM (Figure 5f), could these differences be linked to how each model simulates the intensity and landfall of ARs over the region?
- Line 465: For clarity and precision, modify to: "temperatures remain below freezing along the TG transect."
- Line 491-497: The observed supercooled liquid precipitation reaching up to 2500 m (Figure 6) suggests unusual atmospheric stability or cloud dynamics. I think this is very interesting, and it would be good to see a detailed vertical profile of temperature, humidity, and wind within these ARs provide further insights.
- Line 496: It is not clear to me what exactly means "This same effect."
- Line 520-540 and Fig. 7: Figure 7 indicates a high rain-to-snow ratio over certain regions, particularly over steep slopes. Is there a possibility that the model is overestimating liquid precipitation due to its handling of mixed-phase clouds or inadequate representation of ice nucleation processes? Could this observation suggest a potential bias in how the model simulation handles phase transitions during AR events?
- Line 585: Rewrite to improve clarity: "The absolute maximum temperatures are also lower, with median air temperatures over the PIG and TG ice shelves approximately 10°C lower in ERA5 than in the RCMs (Table 2)."

Conclusions:

- Line 620-664: Considering the computational trade-offs mentioned, what resolution do you propose as the optimal balance between accuracy and efficiency for simulating extreme precipitation events in regions with complex topography like West Antarctica? Could a dynamic resolution approach, where finer grids are applied only in regions of steep topography or during periods of intense precipitation, provide a more efficient modeling strategy?
- Line 620-664: I suggest highlighting the necessity of conducting sensitivity experiments by altering key microphysical parameters, such as cloud droplet number concentrations and ice nucleation rates, to evaluate their impact on precipitation phase transitions. This would help identify which microphysical processes most significantly influence the partitioning between rain and snow in the region.

Technical Corrections:

- In several sections, the text refers to complex atmospheric processes (e.g., supercooled liquid precipitation, seeder-feeder mechanisms) without fully explaining their implications or how they are represented in the models. Adding brief explanations or providing context would improve clarity, particularly for readers less familiar with these concepts.
- Line 374: Change "Figure 3b, d" to "Figures 3a and 3b" for consistency.
- Line 386: Use consistent hyphenation: "ground-truthing" or "ground truth."
- Line 550: Correct "Ars" to "ARs."
- Line 606: Remove the extra punctuation after "Abel et al., 2017."