Author's Responses to comments on *"Brief communication: Reanalyses underperform in cold regions, raising concerns for climate services and research"*

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The authors would like to thank the reviewer for their constructive feedback and thorough assessment of our manuscript. Below, we provide a point-by-point response to each comment, reviewer comments are given in black, responses are given in blue. Additionally, we have included details of how we addressed these changes in a potential revised submission. Revised figure/table are presented at the end of our responses.

Responses to RC1

Cao and Gruber investigate the performance of five modern reanalyses (JRA-3Q, ERA5, MERRA-2, JRA-55 and NCEP2) over cold regions, with a focus on air temperature and snow water equivalent (SWE). The manuscript has been revised and addresses many of the comments that myself and the other referee had, resulting in a more robust analysis of the deficiencies of reanalyses over cold regions. I recommend that the manuscript be published following a few minor changes listed below.

Specific Comments

- P1, L22: Why are reanalyses of higher importance over cold regions? It would be helpful to make the connection to spatial and temporal gaps in the observational record here.
  Response: We reworked Paragraph 2 & 3 to clarify:

  Understanding cold regions is important for informing local climate-change adaptation and climate action globally. Their climate conditions and dynamics, however, can be subject to disagreement. For example, previous studies suggested that the climate signal in cold regions could be different depending on the datasets used (Huang et al., 2017, Wang et al., 2017) and concluded that the 'warming hiatus' in the Arctic may be an artifact. Other studies report the performance of reanalyses for specific variables and places (e.g., Graham et al., 2019, Cao et al., 2020, Fang et al., 2023, Lan et al., 2025). This is because many cold-region processes react nonlinearly to changes near 0 °C due to the ice-water phase transition, their analysis and simulation are extra sensitive to errors. In addition to these challenges, sparse in-situ observations increase the need and importance for atmospheric reanalyses as a tool for supporting climate research and services. While the quality of reanalyses is expected to be lower in cold regions, their quality is also less well known than elsewhere.

- Table 1, Page 4: Could the authors include the values of the spread for each variable over the study region as a whole? This would provide a strong visual contrast between performance over cold regions, and performance elsewhere.
  Response: the overall spread for the cold and non-cold regions were added to Table 1. In addition, the MAAT spread are revised to be one-decimal, and SWE_{max} to be integer.

- P5, L110-114: If the difference between the 4DVar and all 5 reanalyses is not statistically significant, I would argue that this suggests that they are comparable; similar to what is mentioned for maxSWE. I suggest that the authors mention that the spread of the MAAT and relative maxSWE for the 4DVar is similar to that of all 5 products. Instead, focus on the main differences (i.e. that the spread for MAAT is up to 45% larger over cold regions, and that parametric uncertainty is an order of magnitude smaller than the structural uncertainty, etc.
  Response: we revised as below:

Compared to all five reanalyses, the $MAAT_s$ spread (1.3, 0.3–2.9 °C) and its trend (0.13, 0.04–0.24 °C dec^{-1}) for the 4DVar reanalyses are still significant in cold regions, and the average ensemble spread is up to 45% greater than that of other regions (Table 1, Figure 1 and 2), indicating the inherent issues regarding to the complex ice-related processes.

- P6, L145-147: The authors mention the importance of cold regions to understanding how the climate system responds to future changes. Do the authors have any suggestions for future research on the most critical changes that could be made to address the degraded performance over cold regions? I feel like this aspect is missing from the implications section.
  Response: we agree. The suggestions for future research are added at the end of the manuscript (Sec. 4 Implications).

  We hope our analysis will help raise the awareness of how important cold-regions processes may be for NWP and reanalyses, and thus encourage greater focus on studies of individual cryosphere elements (e.g., Cao et al., 2022, Meloche et al., 2022) to inform research leading to future improvements in NWP.

Technical Comments

- P6, L152: Replace "ERA5 is from Climate Data Store" with "ERA5 is from the Climate Data Store"
  Responses: Revised.

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Table 1: The spread of mean annual air temperature ($MAAT_s$, °C) and relative maximum snow water equivalent ($maxSWE_s$, %) for the areas occupied by specific cryosphere elements.

Cryosphere element		$MAAT_s^{all}$	$MAAT_s^{4DV}$	SWE_s^{all}	SWE_s^{4DV}
Overall	Cold regions	1.5 (0.5–3.0)	1.3 (0.3–2.9)	105 (51–206)	101 (56–186)
	Non-cold regions	0.8 (0.3–1.5)	0.5 (0.1–0.9)	–	–
Ice sheets & glacier		2.3 (1.1–3.6)	2.0 (0.6–3.8)	197 (172–207)	154 (93–190)
Snow cover		0.8 (0.3–1.4)	0.5 (0.1–1.2)	80 (53–115)	72 (50–105)
Permafrost		1.0 (0.5–1.7)	0.8 (0.2–1.5)	75 (50–108)	83 (54–123)
Seasonally frozen ground		0.7 (0.2–1.3)	0.4 (0.1–0.8)	72 (49–106)	79 (52–108)

Values are reported as mean (10th to 90th percentile).
Superscripts distinguish all five (all) reanalyses and the three 4DVar modern reanalyses (4DV), only.