Quantifying Spatiotemporal and Elevational Precipitation Gauge Network Uncertainty in the Canadian Rockies

Bertoncini and Pomeroy (2024)

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Author Comment 1

***Note that authors responses are in blue.**

RC1 Comments

Manuscript Title: Quantifying Spatiotemporal and Elevational Precipitation Gauge Network Uncertainty in the Canadian Rockies

General review: Bertoncini and Pomeroy quantify uncertainty in precipitation estimates using a network of in-situ precipitation gauges in the triple continental divide area of the Canadian Rockies, a region where precipitation can vary immensely across elevation bands and differently, depending on storm systems. Using the WMO guidelines for station density in mountainous areas, the authors transform and back-transform precipitation data (for normalized distribution), quantify a cumulative distribution function, and use a kriging and lapse rate approach to calculate and track precipitation standard deviation and coefficient of variation across space and time. In this way, the authors are able to determine areas where precipitation estimates are more and less uncertain and the areas where added in-situ observations would be most valuable in the future (e.g., relatively higher elevations). Much of the analysis, and thus manuscript text, includes a very clear description of the methodology used. I include no major changes to the workflow and thank the authors for their thorough depiction of the work in text and figures and for making the important and relevant connection to downstream hydrology. Limitations to the work, including the select reanalysis product, could be further discussed. As could a connection to other spatially distributed precipitation products. Otherwise, the small number of minor suggested changes I have made are with respect to clarifying language around some of the statistics (e.g., when uncertainty “rose” vs. “fell”) and domain description. The following line-by-line comments should provide more clarity with these items, with the goal of better emphasizing the importance and value of this work, which I envision will serve as a frequent reference for many future projects.

Thank you for these general comments.

Line-by-line comments

Line 121: Please define the threshold used to determine “continuous lower elevations.”

Thank you for the suggestion. The thresholds for continuous lower elevations were based on passes that make the transition to other sections of the Rocky Mountains. More details about these passes were given in Lines 121-123. The indicated sentence was also changed to "The south and north boundaries were defined based on regions of continuous lower elevations (i.e., passes) that make the transition to other sections of the Rocky Mountains." for clarity.

Line 157: Please describe why the ERA5-Land reanalysis product was selected over other similar products.

Thank you for the comment. ERA5-Land reanalysis product was used because it had all the variables necessary for snowfall undercatch correction at a reasonable, not optimal, spatial resolution and accuracy while spanning the whole study period between 1991 and 2020. Other products exist for the region, but they only cover part of the study period. For instance, the Regional Deterministic Reforecast System (RDRS) only spans between 1980 and 2018 (Gasset et al., 2021), and the WRF historical run in the region only covers between 2000 and 2015 (Li et al., 2019). The following sentence was added in Line 167 to better describe the choice of ERA5-Land: "ERA5-Land was chosen because it spanned the whole study period with reasonable accuracy and spatial resolution. Similar reanalysis products in the region only cover part of the study period, e.g., the Regional Deterministic Reforecast System (RDRS) covers 1980-2018 (Gasset et al., 2021) and the WRF historical run covers 2000-2015 (Li et al., 2019)."

Line 186-188: Please provide a rationale for implementing this transformation and then later back-transforming with respect to the need for a normalized distribution prior to kriging.

Thanks for the suggestion. A distribution that resembles a normal distribution is a requirement for kriging interpolation. The sentence in Lines 188-189 was modified to "This transformation was necessary to approximate daily precipitation that usually has a log-normal distribution skewed to zero to a Gaussian distribution, which is a requirement for kriging interpolation." as an explanation of the need for transformations. The back-transformation is just to see the results in mm/day again. The sentence in Lines 193-194 was changed to "All the kriging interpolation and uncertainty calculations are performed in the transformed data (P_Z), which are back-transformed at the end of the analysis for results in mm/day." for clarity.

Figure 2: Suggest, within the associated text, interpreting the two panels for readership. I.e., what does a daily precipitation value of 60 mm versus 2 (unitless) mean with respect to CDF? Also please specify where these example data came from.

Thank you. The following sentence was added at the end of the paragraph associated with this figure: "At the 80th quantile of the CDF, a precipitation value of ~ 20 mm in the non-transformed space represents a precipitation value of ~ 1 in the transformed space." The figure caption was also changed to “Example of daily precipitation data normal score transformation for available gauges on 2019-06-20.” to indicate this example is from our available gauges for that specific date.

Line 232: Please specify why the lapse rate relationships (and associated rate caps) in the Marmot Creek Research Basin have been selected here.

Thank you for the suggestion. Marmot Creek Research Basin has been selected because it is one of the most well-placed vertical profiles of snowfall gauges and it has a long precipitation lapse rate time series within our precipitation database. The following sentence “This vertical gauge profile was selected for its central placement and long precipitation lapse rate time series” was added at the end of this paragraph for clarification.

Line 280-281: Please list average change values associated with each area when mentioning, “Uncertainty fell in Montana” and “uncertainty rose in the upper Bow River basin”, etc. It would also be helpful to read additional details on these areas – similar to the way Mount Robson was listed as the study domain’s highest peak.

Thank you. This paragraph will be revised and include more statistics when mentioning uncertainty increases and decreases inside the study domain. We will also include more local information on why these uncertainty differences exist.

Like 345: Please define “very significant.”

Thank you for the recommendation. The following sentences were changed to better clarify this reference’s findings: “Brunet and Milbrandt (2023) have demonstrated that optimally designed networks usually favour the placement of new gauges in mountain regions of Alberta and British Columbia, Canada. Brunet and Milbrandt’s study suggests that, in some cases, the placement of two to three gauges can have a very significant impact on reducing network uncertainty. For instance, improving network areal coverage from ~ 1600 to ~ 1300 km^2/gauge can decrease current network uncertainty close to an optimally designed network created from a blank slate in Alberta.”

Line 411-414: Within the previous discussion section, suggest the authors point to identified limitations to the methods and/or provide a clear rationale. The series of steps taken within the methodology is well cited, but could be better defended – e.g., why ordinary and indicator kriging over other methods used in the introduction? The answer may be because these methods are frequently used – not just in past studies but in ongoing snowpack and hydrologic modeling research and operational applications. On that note, it would be impactful if the authors linked this approach to modeled or satellite-based precipitation products, which likely use some of these in-situ observations and cover these domains.

Thank you for this suggestion. We will include more details about the methods' limitations and a clearer rationale in the Results and Discussions section. We will also better describe the selection of techniques in the Material and Methods section. The choice of kriging techniques was due to their ability to provide an estimate of interpolation uncertainty. For comparison purposes, we will include a more direct link between our precipitation and uncertainty estimates with current modeled and satellite-based precipitation products.

References

Brunet, D. and Milbrandt, J. A.: Optimal Design of a Surface Precipitation Network in Canada, J. Hydrometeorol., 24, 727–742, https://doi.org/10.1175/JHM-D-22-0085.1, 2023.

Gasset, N., Fortin, V., Dimitrijevic, M., Carrera, M., Bilodeau, B., Muncaster, R., Gaborit, É., Roy, G., Pentcheva, N., Bulat, M., Wang, X., Pavlovic, R., Lespinas, F., Khedhaouiria, D., and Mai, J.: A 10 km North American precipitation and land-surface reanalysis based on the GEM atmospheric model, Hydrol. Earth Syst. Sci., 25, 4917–4945, https://doi.org/10.5194/hess-25-4917-2021, 2021.

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