

Referee Comment to: "From Snow Depth to Streamflow: Reducing Snowfall Uncertainty in Alpine Headwaters with Sentinel-1 based snow depth retrievals"

Summary

This study aims to improve the GEOframe-NewAGE hydrological model by assimilating Sentinel-1 C-band snow depth observations to tackle the sparse distribution of precipitation gauges in mountainous regions. The approach is tested in two catchments in the Italian Alps. The methodology encompasses a probabilistic ensemble approach (particle filter batch smoother), in which the snowfall correction factor and other model parameters are varied to get optimal parameter settings through a probability distribution function and subsequent weighting of these functions, utilizing the satellite data to calculate the likelihood function. The snow-corrected hydrological model is then validated against a kriging-only model, highlighting strong improvements in precipitation estimates, discharge biases and timings and their correlation to observations.

General Remarks & Decision

The study presents an interesting approach for assimilating satellite data in hydrological modelling to substantially improve snow depth and, as a consequence, discharge modelling in alpine catchments. Applications for this methodology are widespread and could greatly benefit the community using semi-distributed hydrological models. While the underlying science is plausible and the major part of the methodology is adequately described, the manuscript text, general presentation, discussion, as well as the literature review (to a lesser extent) need substantial revisions and are unpolished as of now. I therefore recommend reconsideration after major revisions before publishing in TC.

Major Comments

- **State of the manuscript running text and figures:** In the current state, the running text as well as some figure colorbars and font sizes need substantial improvement. I think the work you have done is quite interesting and your underlying approach deserves a better presentation. I tried to highlight as much as possible in the minor comments, starting from rephrasing to placing some text blocks in different sections, etc.
- **Unbalanced proportion of Methods and Discussion:** Many sentences in the Results section should go in the Methods section. Doing so would highlight that the length of the Results & Discussion section is disproportionate compared to other parts of the manuscript. I recommend to deepen the Discussion, the Results itself are adequately described. Some ideas on what to discuss are stated here:
 - Include Fig. A2 in the manuscript: The KGE results, in my opinion, deserve a spot in the main manuscript. You could add similar boxplots of the validation period as well.
 - Figure 5: Can you interpret the results? Why are some years overestimated and some are underestimated? Does it have something to do with the number of heavy precipitation days?
 - Figure 6: How do these precipitation correction factors relate to other studies, e.g. [Avanzi et al. \(2021\)](#) or [Herrnegger, Senoner, and Nachtnebel \(2018\)](#). I think you are in good agreement, that is worth pointing out.
 - Add a discussion about conversion from SWE to snow depth as potential limitation, as snow density assumptions are not trivial.
- **Literature and Undercatch section in the Introduction:** At the current manuscript state, the introduction lacks proper citation in critical statements. I tried to refer to those statements in the minor comments and recommend to enhance your references. I further recommend to add one paragraph of (solid) precipitation measurement errors in gauges (undercatch) and how your approach can also help mitigating that problem. See works of e.g. [Kochendorfer et al. \(2017\)](#) and others.
- **Missing section on kriging methodology:** I think how you generate spatial data from ground-observed precipitation deserves either a section in the Methods or in the Appendix. This is not a straightforward step and needs proper description, and potentially even further analysis.
- **Appendix or Supplement:** The Appendix is added directly to your published article, whereas a Supplement will be provided as a separate document. Given the amount of figures in their Appendix, it seems like the authors rather wanted to provide Supplementary material instead of an Appendix. I recommend to change that throughout the manuscript. Further, a reordering of the Supplement should be done, in the order of mentions in the manuscript.

Minor Comments

- Figure referencing: In the main text, Figure panels should be mentioned like "Fig Xa" and not "Fig X(a)", so without the brackets.
- Equation layout: Equations are part of the main text and should have a comma or period after stating them.
- L24: Remove "The" before "high-quality".
- L26: The sentence "However, precipitation data..." requires a citation. What about other data sources like gridded precipitation data?
- L28: The sentence "Despite its strengths..." also needs citations, ideally more than one.
- L31ff: The introduction would benefit in naming and describing some gridded precipitation products, which stem from such kriging methods.
- 36ff: I think you should also comment on model spatial resolution being one of the reasons why precipitation is not accurately captured in mountainous regions. You hint at it by stating "capturing orographic effects", but this deserves a more prominent position.
- L39: Remove "s" from "Earth observations data".
- L42: The sentence "Additionally,..." also needs citations.
- L45ff: Split sentence.
- L53ff: Split sentence.
- L64: "states" instead of "summarizes"?
- L69ff: "Cold Continental Climate" should be all lower case.
- L70: °C and not °.
- L 74: "region's susceptibility" instead of "region susceptibility".
- L74ff: Citation of the data set necessary.
- Figure 1: Increase size of the colorbar. Further, the bin size of 165 m seems arbitrary, so why not use more natural bin sizes, e.g. 250 m? Caption: Double notion of the red outline should be removed. The sentences "The headwaters...", "In this study..." and "The distribution..." should go into the main text.
- L79: Citation of the data required.
- L88: The link is leading to a non-existing website and should not be in the main text. Cite properly.
- L90: Move "S1A and S1B" after "mission".
- L95: Remove "it uses"
- L100: Space between "500" and "m".
- Remove Link from main text.
- Figure 2: Increase colorbar size substantially, I think you could put all panels in one row by removing the axis labels as the projections is irrelevant here.
- L108: What components?
- L112: Change "delineates the allocation" to "separates"?
- Fig 3: Not all variables are declared properly: Please note, what T (temperature obviously, just for good measure) and the symbol in the triangle in Fig 3c mean. Also, what do the black dots and does the empty circle in Fig 3c try to symbolize?
- L122 and L123: Add comma after the equations.
- L128: Move the sentence "For a detailed..." after the equations.

- Figure 4: Great flowchart! "Assimilation" should be lower case in the legend.
- L148: Insert "the" before GEOframe model.
- L149: Change to "with the key difference, that data assimilation...".
- L155: "100 particles of α_S ".
- L155: Past tense - "indicated".
- L162: Comma after equation.
- L167: I think you can cut this sentence and then just add rephrase the sentence before: "The weights are determined by comparing the predicted snow depth state of the particle to the observed Sentinel-1 snow depth retrievals."
- L168: "...where Z are Sentinel-1...".
- L174: Remove (Eq. 5) and write ":".
- L175: Period after the equation. I think N_{obs} was never defined.
- L176: You can already define w_j^+ here, so you don't need to do it in L179. The likelihood function and N_{ens} is also already defined.
- L178: Comma after equation.
- L181: "...snow depth values using Sentinel-1 retrievals, as illustrated by Fig. 4." Then you can delete the following sentence.
- L185: HRU is never used again, you can delete the abbreviation.
- L187: "...model's snow component..."
- L189: How is the average catchment snow depth used in the assimilation?
- L191: I think you should replace "storms" with heavy snowfall events. Or you properly define it (like daily precipitation i X mm).
- L196 - L198: I think these two sentences can be deleted.
- L203 - L206: Introductory sentences are not needed. Your motive on why you perform this analysis is well described in the Introduction.
- L206ff: How did you compare ground measurements and satellite snow depth?
- L209: Fig. 5 should be Figure 5 at the start of a sentence. Better wording: "Figure 5 presents how..."
- Figure 5: Error in the legend ("Sentine-1"). Tiny numbers next to the colorbar. I recommend to change storms for snowfall events. Further, you can streamline the caption by putting "for a subcatchment within the Aosta Valley catchment" at the end of the first sentence.
- Figure 6: The second sentence in the caption should be in the running text. I think this plot could also be single column.
- L211 - L212: Already stated in Fig 5 caption. Can be deleted.
- L213 - L216: Should go in the methods section. Also, remove period before "(see Eq. 2)".
- L217: Which study area? Specify if Aosta or Piemonte.
- Figure 7: I think you cannot give one letter to one column. Better do a-c for the first column etc. Also, you could move the colorbars to a better position (e.g. horizontal on the bottom). In the caption, change "derived from (a) the kriging" to "derived (a) from the kriging". Also, the sentence ",highlighting that..." should go in the running text.
- L221 - 222: Your kriging approach deserves a whole subsection in the Methods section and should not be stated here.

- L227: "(see the dark red catchments in Fig. 7)".
- L228: Replace "Owing" with "Due".
- L229: State explicitly, that Fig A1 shows a similar elevation trend as Fig 7.
- L232-L239: Rephrase the whole paragraph. You are essentially repeating L219ff.
- Fig 8: Great results! Can you specify, on what time step you are validating the corrected snowfall? Is it on a daily basis?
- L249 - L259: Very good description of the hydrological model, which however belongs to the Methods section.
- L263: "yield" instead of "yielded".
- L267: Insert "to observations" after "red and green time series".
- L268: Remove space before period.
- L270: Streamline to "The correlation between observed and simulated discharge during spring and summer...".
- L272: "baseline model"
- Section 4.3: The first part might fit better in the Conclusions, as it is already a summary of your study. It is very well written, though! Limitations can stay here.
- L280: Remove "potentially", I think this is a very definite uncertainty, as you also included potential dates with wet snow.
- L282: Again, remove storm events or state a definition.
- L284: To my understanding, you did modify the total precipitation, as it is a sum of rain and snow? I think this sentence needs correction.
- L286: What do you mean with "snow model states?"
- L291: Add "...associated snow parameters in a particle filter batch smoother approach."
- L298: Remove Brackets.
- L306: Replace ";" with ", where".

References

- Avanzi, F., Ercolani, G., Gabellani, S., Cremonese, E., Pogliotti, P., Filippa, G., ... Juglair, S. (2021, April). Learning about precipitation lapse rates from snow course data improves water balance modeling. *Hydrology and Earth System Sciences*, 25(4), 2109–2131, <https://doi.org/10.5194/hess-25-2109-2021> Retrieved 2025-09-05, from <https://hess.copernicus.org/articles/25/2109/2021/>
- Herrnegger, M., Senoner, T., Nachtnebel, H.-P. (2018, January). Adjustment of spatio-temporal precipitation patterns in a high Alpine environment. *Journal of Hydrology*, 556, 913–921, <https://doi.org/10.1016/j.jhydrol.2016.04.068> Retrieved 2025-08-08, from <https://linkinghub.elsevier.com/retrieve/pii/S0022169416302657>
- Kochendorfer, J., Nitu, R., Wolff, M., Mekis, E., Rasmussen, R., Baker, B., ... Poikonen, A. (2017, July). Analysis of single-Alter-shielded and unshielded measurements of mixed and solid precipitation from WMO-SPICE. *Hydrology and Earth System Sciences*, 21(7), 3525–3542, <https://doi.org/10.5194/hess-21-3525-2017> Retrieved 2024-11-27, from <https://hess.copernicus.org/articles/21/3525/2017/>