General comments

The authors present a comprehensive evaluation of high-resolution snowpack simulations forced with globally available datasets, in particular coarse resolution meteorological data downscaled to the model grid. Thus, the study showcases a generic tool for performing snow cover simulations in any region of the world efficiently and with low effort. The simulations presented in the study, performed for the Tuolumne River catchment (Sierra Nevada, USA), were evaluated against high-resolution snow water equivalent (SWE) data derived from Lidar measurements of snow depth and modelled bulk snow densities. The simulations show promising results with comparable performance as satellite-derived snow characteristics for the study basin. In contrast to the remote sensing observations, the snow model results are always available, which is a significant advantage over the occasional satellite retrievals.

Overall, appropriate methods are used in the study and the results are relevant and promising. However, the presentation and discussion of the results sometimes lacks clarity and depth in my opinion. The description of the results deserves a few more details, whereas the discussion requires stronger links to the results themselves (foremost by including more references to specific figures). Furthermore, the paper should likely also be improved language-wise, preferably by a native English speaker. In spite of the shortcoming listed above, the paper is pleasant to read, contains a wealth of interesting results and is a valuable contribution to the snow modelling community. Detailed comments are listed below.

We thank the reviewer for the careful evaluation of our work. We appreciate the positive comments and relevant suggestions. We can implement every suggestion in a revised manuscript as detailed below.

Specific comments

Page 1, line 13: Consider changing “sourcing” to using and “climate” to “meteorology”.

ok

Page 1, line 18: Change from “snow depth to Sentinel-1 snow depth retrievals” to “snow depth to Sentinel-1 retrievals”.

ok

Page 1, abstract: The concluding sentence of the abstract should be improved. One option would be to add a sentence stating directly that the snow model provides results anywhere at anytime in contrast to satellite retrievals.

We propose to reformulate the last sentence:

However, Sentinel-1 snow depth products are sparse and often masked during the melt season, whereas ERA5-SnowModel provides spatially and temporally continuous SWE.

Page 2, line 34: Please also cite Lievens et al. (2022) and adapt the sentence accordingly.

ok

Page 2, line 46: Include the missing “have”: “There reanalyses have also…”

ok

Page 2, lines 59-60: The sentence “However, the evaluation of these simulations relied on sparse in situ observations or MODIS snow cover area” seems incomplete. What is the drawback with these observations and why are more studies needed? Is it the coarse resolution of MODIS snow covered area?

Our intention was to highlight that these data do not allow to validate the spatial distribution of the snow depth or SWE across the landscape.

We propose to remove “However,” to make the paragraph clearer:

The evaluation of these simulations relied on sparse in situ observations or MODIS snow cover area (...) However, these in situ or remote sensing datasets did not allow a thorough evaluation of the model ability to capture snow mass across the landscape

Page 3, lines 68-79: Consider adding the spatial resolution of the model simulations already here.

ok

Page 5, lines 00-01: Please mention the physical reason why the satellite retrievals do not provide data during the snowmelt period and add a reference supporting the statement.

We propose to add the following sentence and references:

When the snowpack is wet, there is a larger absorption and reflection of the microwave signal emitted by Sentinel-1 which greatly decreases the performances of the C-SNOW algorithm (Lievens et al., 2019; Tsai et al., 2019).

Page 5, line 06: Important, the statement “…50 m SWE is less than 0.01 m w.e” needs a reference.

The reported accuracy on the 3 m snow depth products is 0.08 m (Painter et al., 2016) and from spatially intensive sampling, the reported accuracy for the 50m snow depth products is < 0.01 m (Painter et al., 2016, Figure 15). There are no published references for the 50 m SWE product. However, for a 1m deep snowpack and a conservative 10% uncertainty in snow density (20-50 kg/m3), we estimate the uncertainty of the 50m SWE products to be 0.02 - 0.05 m w.e

Page 5, line 15: What is “grassland rangeland”?

It is the SnowModel class name for herbaceous vegetation (graminoids and forbs).

Page 7, line 40: Consider changing from “Appendix Table A1” to “see Table A1 in appendix”.

ok

Page 7, line 58: Consider changing to “very coarse resolution of approximately 31 and 9 km (Fig. 1 and 2)”.

ok

Page 7, lines 62-63: Consider changing to “…the snow depths given by ASO, Sentinel-1, and ERA-SnowModel were…”.

ok

Page 8, lines 65-66: Please reformulate these two sentences. The second sentence needs to reference the first, otherwise it is not clear for what the performance metrics were computed.

We propose the following reformulation : *We computed the distributed residuals by subtracting the ASO snow depth from both SnowModel simulations and Sentinel-1 data. We averaged the residuals to compute the bias for each date. We also computed the standard deviation of the error and the RMSE over the catchment for each date .*

Page 8, line 76-78: Please reformulate the sentence. It is too long and hard to read.

ok

Figure 3: Consider using dashed lines for ERA5 and ERA5-Land.

ok

Page 9, lines 84-85: It is likely not needed to describe the lines here since this information is already provided in the legend of the figure.

ok

Page 9, line 89: The sentence “Considering the entire simulation period, 10% of the cells have an RMSE above 0.5 m w.e.” seems somewhat misplaced and is hard to understand.

This is the transition between the catchment scale analysis to the pixel scale analysis.. It will be rephrased in the paper with : *We computed a map of RMSE using all the 49 validation dates we have between 2013 and 2019. 10% of the cells in this map have a RMSE above 0.5 m w.e*

Page 10, lines 1-2: Why were these two dates selected for the analysis?

We propose to clarify this point in the revised manuscript as follows:

We aimed to distinguish the model performance in terms of accumulation and ablation processes to better separate the sources of uncertainties in future studies. Therefore we selected a date before the melting season (April 01) and a date near the end of the melting season (May 27).

Figure 5, caption: Why is the second date not mentioned in the caption?

This was an oversight. We will correct this.

Page 11, line 14: Is “mean residuals” the same as bias?

yes it is. It will be rephrased with “*mean of residuals (bias)*” in the revised manuscript.

Page 11, line 25: Consider changing to “…resolution using upscaled ASO…”.

ok

Page 11, lines 28-29: What does “these missing values are propagated at 1 km resolution” mean?

We resample the ASO products by averaging all pixels inside a square cell of 1 km. If there is at least one missing value among the contributing pixels, a missing value is attributed to the target 1 km cell.

Page 11, line 30: Is not the exact area used between the methods or the dates, or both?

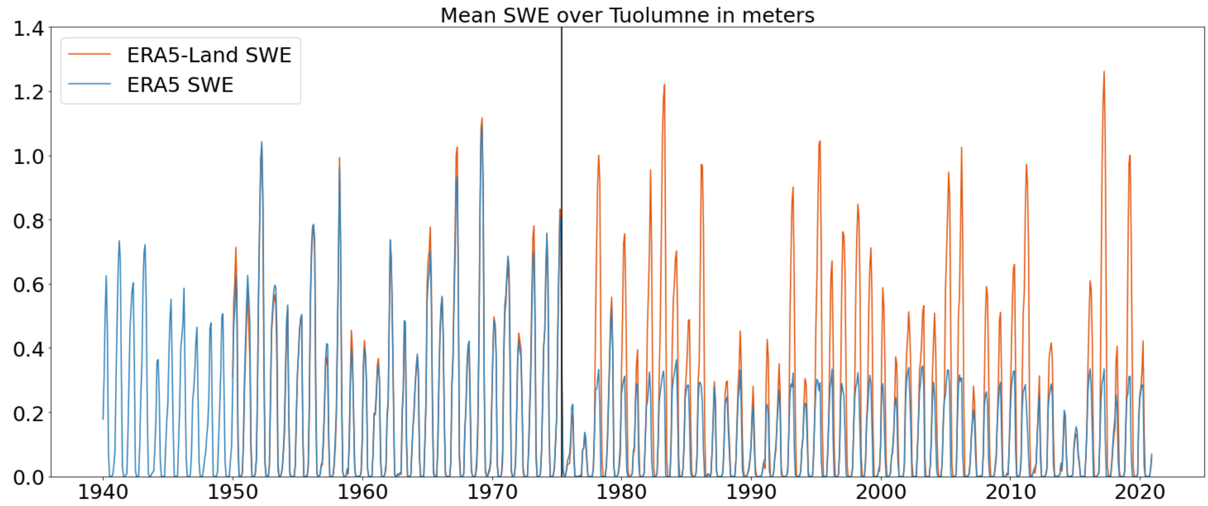
Both : all the pixels shown in figure 6 are taken into account in Table 1. For ERA5-SnowModel, the mask is the same for the three dates because the missing values are due to the missing values in the ASO data. With Sentinel-1, the missing values are due to i) the missing values in the ASO and ii) the missing values in the Sentinel-1 algorithm.The second one are time dependent and therefore the statistics in Table 1 are not computed on the same area from one date to another, nor on the same area as ERA5-SnowModel.

Figure 7: Consider merging Table 7 into this figure by including texts with the statistics. For an example of what I propose, see Figure 5 in Fontrodona-Bach et al. (2023). The scatter plots could potentially also be improved by showing the scatter density, just like the left panels in the Figure 5 by Fontrodona-Bach et al. (2023).

We will merge Table 1 and Figure 7 as suggested. However, the numbers of points are not sufficient to make nice density plots (2D histograms). It would add unnecessary information (colorbar) and decrease the readability of the plots.

Page 13, line 53: What discontinuities in ERA5 SWE? Are these visible in Figure 3?

They are not visible in Figure 3. There are some discontinuities in the ERA5 SWE appearing in 1976 due to the implementation of new snow depth products into the ERA5 assimilation scheme. When these products are assimilated, ERA5 caps the snow depth data at 1.4 m to avoid an overestimation of the snow depth (personal communication from Patricia de Rosnay, ECMWF). This creates a strong discontinuity in the ERA5 snow time series (see figure below). Because the meteorological forcings would not be impacted by this threshold on snow, using this pipeline could be a way to bypass this discontinuity. However, other meteorological variables in ERA5 might also be affected by the growing number of data assimilated (Bengtsson et al., 2004).



Page 14, line 58-59: Please improve the language of the sentence “We find an overestimation of snow accumulation in high elevation however which occurs only above 3000 m asl”.

We suggest to reformulate:

We find an overestimation of snow accumulation at high elevations, specifically occurring above 3000 m asl.

Page 14, lines 66-67: Avalanches move snow from higher to lower altitudes but does not reduce snow amounts. Please rephrase the sentence.

High elevation and steep slopes are prone to avalanches thereby reducing the accumulated snow in these areas during the winter season (Quéno et al., 2023)

Page 14, lines 75-77: Please refer to Figure 5.

ok

Overall, as mentioned in the general comments, provide more links in the discussion to results by adding appropriate cross-references to figures and tables.

We will follow this suggestion in the revised manuscript with : *This result is in line with Muñoz-Sabater et al. (2021) who find better performances of ERA5-Land than ERA5 between 1500 m and 3000 m a.s.l. because 68% of the Tuolumne River catchment is in this elevation band.*

Page 15, lines 91-93: The sentence is formulated awkwardly. What does “carries 68 % of the Tuolumne River catchment” mean?

It meant that 68% of the catchment has an elevation between 1500 m and 3000 m. Rephrased in the new manuscript

Page 15, lines 1-2: This statement requires at least one reference.

We will add this reference to the sentence in the manuscript : (Margulis et al., 2019)

Page 15, line 6: What is hard to understand about the error patterns of Sentinel-1 compared to the other methods?

Figure 7 shows that Sentinel-1 snow depth dataset seems to represent quite accurately the spatial variability inside the catchment, although we note a slight underestimation for all three dates before the melting period (2017 and 2019) and after it (2018). There is no clear pattern in the errors that emerge from these three dates.The modeling approach with ERA-5 (Land) and SnowModel yields similar performances in terms of snow depth as the C-SNOW product on the same dates. However, two patterns appear on Figure 7 for these approaches. i) The simulations with ERA5 and SnowModel are mostly centered around a negative bias constant with the observed snow depth before the melting period (2017 and 2019), probably representing a small negative bias in the ERA5 precipitation. ii) The simulations with ERA5-Land SnowModel seem to cap at 4 m which could be the result of the two consecutives downscaling in the precipitations : the combination of an underestimation of ERA5 precipitation and its downscaling, plus the limitation of the elevation difference between ERA5-Land stations and the DEM so the MicroMet precipitation factor can not enhance enough the high resolution precipitations

Page 15, lines 11-14: What has the first part of the sentence about errors has to do with the second part about model differences? Please split this sentence into two, and improve the language.

There are different error sources in the three methods which are neither insignificant nor prohibitive for an operational use. The key difference is that the model provides temporally continuous SWE, snow depth and other relevant variables like snowmelt runoff, whereas C-SNOW snow depth products are temporally sparse and often masked during the melt season.

Page 16, lines 34-35: Consider providing a short description for each components of this tool since many readers start by reading the conclusions of a paper.

It uses SnowModel/MicroMet to downscale meteorological variables from ERA5 before computing accumulation and ablation processes using other SnowModel submodels.

Page 16, line 38: What does the “0.08 m” refer to?

Indeed, this was not clear, we will reformulate as follows:

Based on 49 reference SWE surveys spanning seven contrasted hydrological years, we find that the ERA5-SnowModel combination simulates well the SWE at the scale of the Tuolumne river catchment, with RMSE of 0.06 m (and 0.08 m with ERA5-Land) and correlation of 0.99 (with both datasets)

Page 16, lines 34-43: Example of paragraph that likely needs language improvements.

Technical comments

Page 3, line 70: Misplaced white space in 50 m.

ok

Page 7, line 39: Missing whitespace.

ok

Page 7, line 56: Missing comma after additionally.

ok

Page 15, line 92 and 93: Wrong reference format.

ok

References

Fontrodona-Bach, A., Schaefli, B., Woods, R., Teuling, A. J., & Larsen, J. R. (2023). NH-SWE: Northern Hemisphere Snow Water Equivalent dataset based on in situ snow depth time series. Earth Syst. Sci. Data, 15(6), 2577-2599. https://doi.org/10.5194/essd-15-2577-2023

Bengtsson, L., Hagemann, S., and Hodges, K. I.: Can climate trends be calculated from reanalysis data?, J. Geophys. Res. Atmospheres, 109, https://doi.org/10.1029/2004JD004536, 2004.

Lievens, H., Demuzere, M., Marshall, H.-P., Reichle, R. H., Brucker, L., Brangers, I., de Rosnay, P., Dumont, M., Girotto, M., Immerzeel, W. W., Jonas, T., Kim, E. J., Koch, I., Marty, C., Saloranta, T., Schöber, J., and De Lannoy, G. J. M.: Snow depth variability in the Northern Hemisphere mountains observed from space, Nat. Commun., 10, 4629, https://doi.org/10.1038/s41467-019-12566-y, 2019.

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Tsai, Y.-L. S., Dietz, A., Oppelt, N., and Kuenzer, C.: Remote Sensing of Snow Cover Using Spaceborne SAR: A Review, Remote Sens., 11, 1456, https://doi.org/10.3390/rs11121456, 2019.