Reply to Reviewer #1

The authors present the S3M model, which is a spatial, hydrology oriented cryospheric model using a hybrid physics-based and temperature-index approach. S3M describes seasonal snow and can also account for glacier evolution.

This manuscript presents a detailed model description of the current S3M version (v5.1). All equations, definitions, assumptions, references as well as the required input are thoroughly described. There is a user manual in the Appendix. An evaluation is presented for an inner-Alpine valley (Aosta valley), including calibration and performance analysis. The manuscript is therefore interesting and valuable for a broad range of scientists and practitioners. The source code was uploaded on github and is also available on Zenodo (including doi number).

The manuscript is well written and can be easily followed. The authors have done a great job in presenting this comprehensive model suite. I have only a few issues with regards to the model evaluation, which should be addressed before publication. The largest question I have is with regards to the years used to evaluate the model as opposed to the years used to calibrate the model.

> We thanks Reviewer #1 for their constructive comments. We are happy that the Reviewer appreciated that "all equations, definitions, assumptions, references as well as the required input are thoroughly described", as this was exactly our aim here: writing an extensive and exhaustive description of all aspects of this model, rather than providing only a cursory overview that left many small details hidden in the source code.
>
> All requested revisions are feasible and we will work in this direction as soon as the interactive discussion will be finalized.

Evaluation years are supposed to be 2004-2009 and 2019 (as indicated in line 496-498). However, in Figure 6 (Section 3.3), evaluation is shown for the calibration years 2013-2019. Figure 9 (line 572-573) also shows a mix of wy used for evaluation consisting of wy used for calibration and those not used for calibration. Please correct in line 496-498 and so on or/and restrict the evaluation to the non-calibrated years throughout the results sections.

> This is a very valid point by the Reviewer and we will correct wording regarding Figure 6 as suggested. We will also try to add the rest of the 2020 water year to Figure 6, although data availability for that year is somewhat limited due to the COVID-19 pandemic and the associated restrictions to movement and so field work.
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> Regarding Figure 9, we will specify that those data were not directly involved in model calibration, although they were taken during water years that were involved in model calibration in terms of snow data.

Figure 5d: Was the simulation data for the evaluation with peak-snow-depth courses rounded, or why does this data set has these sharp steps/lines in it? Please explain.

> Thanks for this question. This is because the spatial resolution of that evaluation dataset is much finer than the spatial resolution of the model (say, ∼60 m vs. ∼220 m, respectively),

as visible in Figure 2c. We performed the evaluation by comparing snow-course data with the concurrently predicted SWE within the same modeling pixel, which means that a number of snow-course data were essentially compared against the same modeling value. This is evident by noting that sharp lines are generally horizontal in Figure 5d, because the same modeled SWE is compared to a variety of observed SWE. We will add these pieces of information to the main text and the caption of Figure 5 for clarity.

Evaluation at Torgnon study plot (section 3.3): Could you add some performance statistics or mean day differences for reproducing the timing of peak of accumulation and onset/end of ablation?

Sure, these will be added to the main text as requested.

Figure 7e and Line 552-553: What is the reason that we only see the aspect impact on spatial SWE due to shortwave radiation in one valley in the south of the Rutor glacier? Is it a color bar issue or are there other reasons that this is not visible in the valleys further to the west? If it is a color bar issue, please consider to illustrate the spatial impact differently.

Owing to this model including incoming shortwave radiation in addition to air temperature, aspect impact is implicitly included by design, and our development work (in particular that related to the development of the radiation-modulating factor) showed that this impact is correctly implemented. At the same time, a number of factors should be considered when evaluating results in Figure 7, the most important one being that our weather-distribution and snow-assimilation approaches currently augment precipitation and assimilated SWE for two hydropower-relevant catchments in Aosta valley, one of which is that indicated by the Reviewer in their comment. Details on this procedure as well as reasons behind this operational choice are discussed in Avanzi et al. (2021). The result is that spatially distributed SWE for those regions is generally larger than nearby valleys for the same elevation, which may lead to a colorbar issue as the Reviewer noted. While this factor does not affect the overall spirit with which this evaluation is presented (providing "guidelines on how to calibrate S3M in a real-world case study and how to validate and interpret model results for the snow and the glacier component"), we will add this context to the main text and will work on a better figure (and/or rephrase lines 552-553).

Figure 9d: Should the number of the shown symbols correspond to the number of stake measurements shown in the individual panels? There are only two green dots shown in 9c but 8 blue crosses in 9d (i.e. for the Petit Grapillon)?

This is because of repeated measurements taken cross multiple water years as the same location. We will clarify this in the caption of Figure 9.

Line 595: Maybe presenting the correlation coefficients between Δhg and elevation would be more intuitive?

Agreed, this will be included.

Why does S3M not scale the diagnostic variables of a grid cell, such as predicted grid cell runoff, with current fractional snow-covered area for that grid cell?

Thanks for this question. The current assumption in S3M is that simulated SWE and so snowpack runoff are representative of spatially averaged snowpack conditions across the simulated pixel, regardless of *how much* of that pixel is actually covered by snow. This is coherent with, e.g., current practice in many hydrologic models where incoming precipitation is assumed representative of spatially averaged precipitation across the simulated pixel. Having said that, we agree with the Reviewer that adding fractional snow cover and so a full snow-depletion curve (with the associated hysteresis) is an important direction of future development. This will be added to the Discussion section.

Eq. (13c): Do you mean p_s =1 - p_r instead of p_f = 1 - p_r ?

Correct, this will be fixed.

Line 217: Maybe consider changing to: m rad is set to zero if the equation above predicts a negative value.

Line 425: Change "piel" to pixel.

Line 441: Maybe rephrase "..develop for several kilometers.." to "..extend over several kilometers.."?

Yes, we will fix these.

Figure 7, caption: It might be helpful to indicate for which region the spatial averages are shown. I assume it is the entire region as shown in Fig. 3a.

Correct, it is the entire region. We will specify this.

Line 587ff and Figure 11: Please consider referencing that this glacier is located in Fig. 3c (if it is indeed) or describe its location within the Aosta model region, e.g. in the northern part of Aosta valley.

Yes, it is part of the considered region (immediately below the North arrow in Figure 3a). We will highlight it in the revised manuscript.

References

Avanzi, F., Ercolani, G., Gabellani, S., Cremonese, E., Pogliotti, P., Filippa, G., Morra di Cella, U., Ratto, S., Stevenin, H., Cauduro, M., Juglair, S., 2021. Learning about precipitation lapse rates from snow course data improves water balance modeling. Hydrology and Earth System Sciences 25, 2109–2131. URL: https://hess.copernicus.org/articles/25/2109/2021/, doi:10.5194/hess-25-2109-2021.