Answer to Editorial Office

We thank the Editorial Office for their comments.

Concerning the ROR, the Meteorological Research Division of Environment and Climate Change Canada is based in Dorval, Canada. Ottawa (Canada) corresponds to the main location of Environment and Climate Change Canada. At this stage, it is not clear to us which city should be used.

As requested, the figures of the paper have been systematically checked for color-blindness. Therefore, the colors used on Figures 3, 4, 6, 7, 8 and 10 have been changed. Figure S8 has also been adjusted in the Supplementary material.

Answer to Editor in Chief

We thank the Editor in Chief of GMD for his comments regarding the compliancy of our manuscript with the policy of the journal and the need to guarantee the replicability of our results. Following these comments, the section “Code availability” has been heavily revised and references to permanent repository have been added for the SVS2 code as well as well a reference to a repository that gathers the scripts and data used to generate all the figures of the revised manuscript.

The modified 'Code and Data Availability' in the revised version of the manuscript reads as:

The SVS 2 .0 code used for the point scale applications at Snow Crested Butte is available in a permanent repository: https://doi.org/10.5281/zenodo.14859640 (Vionnet et al., 2025a). The SVS 1.0 code is also available in this repository. The SVS 2.0 code used for the distributed simulations presented in this paper is available from https://doi.org/10.5281/zenodo.16740463 (Vionnet et al., 2025b). Scripts and data to produce the figures in this paper as well as SVS 1.0 and SVS 2.0 configurations files are available from https://doi.org/10.5281/zenodo.16760830 (Vionnet et al., 2025c). This repository also contains the observations used to evaluate the distributed snowpack simulations (snow pit data and GMASI snow cover data). ERA5 atmospheric forcing have been obtained from https://doi.org/10.24381/cds.adbb2d47 and https://doi.org/10.24381/cds.143582cf as detailed in Vionnet et al. (2025c).

The other freely-available datasets used in this work are:

ERA5-Land data: https://doi.org/10.24381/cds.e2161bac

ERA5/Crocus dataset: https://doi.org/10.5281/zenodo.10943718

Global map of snow darkening coefficient for the snowpack model Crocus (Gaillard et al., 2024): https://doi.org/10.5281/zenodo.14194990

Snow Crested Butte dataset: https://doi.org/10.5281/zenodo.6618553

Note that this revised section does not appear as modified in the revised manuscript in track-change mode due to a deficiency in the Latex package used to track the modifications.

Datasets that have been made available to support the paper.

Vionnet, V., Leroux, N., Fortin, V., Abrahamowicz, M., Woolley, G., Mazzotti, G., Gaillard, M., Lafaysse, M., Royer, A., Domine, F., Gauthier, N., Rutter, N., Derksen, C., & Belair, S. (2025a). Code of the land surface scheme Soil Vegetation and Snow version 2 integrated in the MESH platform. Zenodo. https://doi.org/10.5281/zenodo.14859640

Vionnet, V., Leroux, N., Fortin, V., Abrahamowicz, M., Woolley, G., Mazzotti, G., Gaillard, M., Lafaysse, M., Royer, A., Domine, F., Gauthier, N., Rutter, N., Derksen, C., & Belair, S. (2025b). Code of the land surface scheme Soil Vegetation and Snow version 2 integrated in the ECCC Surface Prediction System. Zenodo. https://doi.org/10.5281/zenodo.16740463

Vionnet, V., Leroux, N., Royer, A., Domine, F., Fortin, V., Abrahamowicz, M., Woolley, G., Mazzotti, G., Gaillard, M., Lafaysse, M., Gauthier, N., Rutter, N., Derksen, C., & Belair, S. (2025c). Scripts and data to produce figures for the SVS2 paper submitted to GMD [Data set]. Zenodo. https://doi.org/10.5281/zenodo.16760830

Answer to Reviewer 1

We thank Reviewer 1 for their comments. We provide here our responses to those comments and describe how we addressed them in the revised manuscript. The original reviewer comments are in normal black font while our answers appear in blue font. The line numbers mentioned below correspond to the line numbers in the manuscript in track-change mode.

The authors provide a comprehensive description of SVS2, including significant developments such as a revised snow albedo scheme, novel physical parameterizations for Arctic snowpack properties, and a new forest canopy module. They then demonstrate its capability to simulate snowpack properties, including microstructure, across extensive geographical regions. In general, this manuscript is well-written and suitable for publication in GMD. However, my major concern is that the authors have not clearly explained the impacts of these improvements on enhancing model performance.

Special comments:

1. Line 535: Why did the authors apply normalization of total depth to each pair of simulated and observed profiles?

Normalization is applied to the profiles to allow a direct comparison between them as in Woolley et al. (2024). First, the thickness of the simulated layers is uniformly scaled so that the simulated snow depth corresponds to the observed snow depth. The observed and adjusted simulated profiles are then re-sampled on the same vertical layer grid of 1 mm thickness to allow for a direct comparison between density and SSA of both profiles. Such normalization corresponds to the first step of the evaluation methods proposed by Lehning et al. (2001) and Viallon-Galinier et al. (2020) when comparing simulated and observed snow profiles. The additional adjustment of layer thickness used in Viallon-Galinier et al. (2020) to account for potential vertical shift of layers between the two profiles was not considered in our study since this method has not been tested when evaluating SSA.

The following sentences have been added in Section 3.2.3 of the revised manuscript (L 564-568):

For the selected profiles, simulated layer thicknesses were uniformly scaled to match the observed snow depth. Both the observed and scaled simulated profiles were then re-sampled onto a common 1 mm vertical grid to enable direct comparison, following the approach of Woolley et al. (2024). This normalization represents the initial step in the evaluation framework proposed by Lehning et al. (2001) and Viallon- Galinier et al. (2020) for comparing simulated and observed snow profiles.

2. Line 467 states that a dew point temperature threshold of 0 °C was used to separate total precipitation into liquid or solid precipitation in point-scale simulations. Line 510 mentions that precipitation phase in distributed simulations was determined based on hydrometeor temperature derived from downscaled air temperature and humidity. What is the difference between these two methods, and why were different methods applied in this study?

The precipitation partitioning method (PPM) based on the dew point temperature threshold at 0 °C assumes that all the precipitation falls as rain (snow) above (below) this threshold. This PPM has been selected for the point-scale application at Snow Crested Butte since this PPM was used by Bonner et al. (2022) when preparing the reference meteorological forcing dataset at Snow Crested

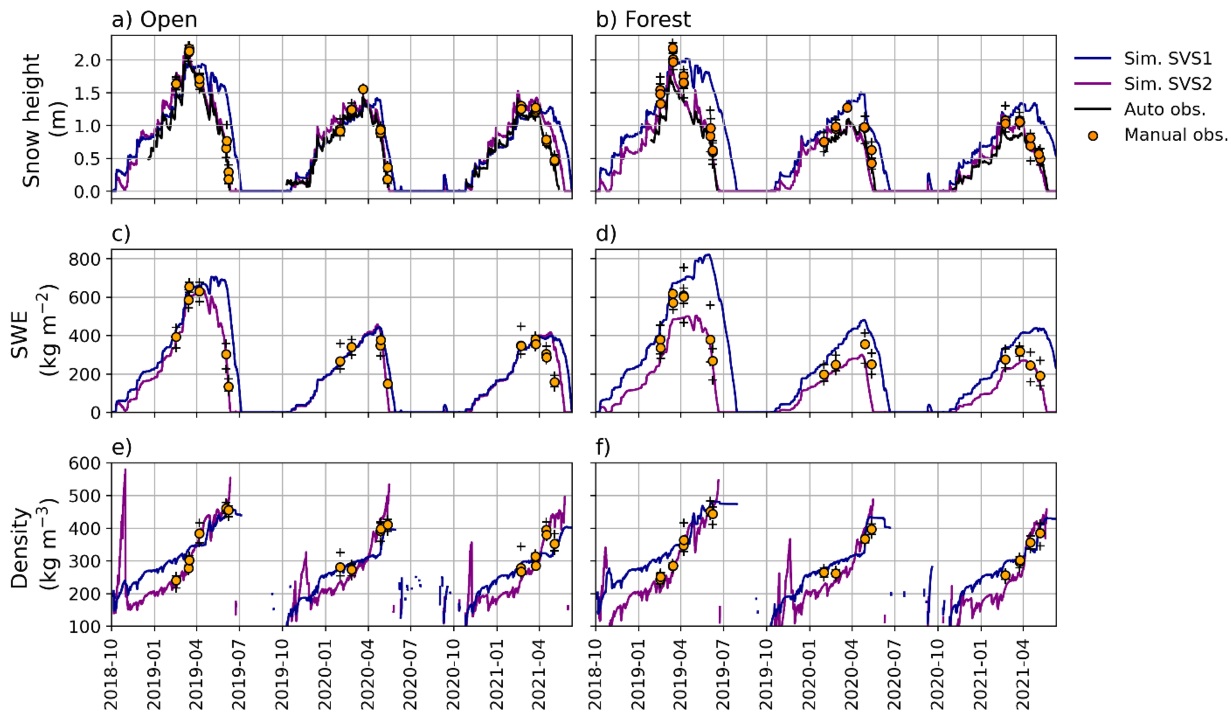
Butte. We decided to use the same approach since the main motivation of the point-scale simulation was to evaluate SVS1 and SVS2 using a reference meteorological forcing characterized by an uncertainty as low as possible. We therefore followed all the recommendations of the team that has prepared the dataset. A similar approach was taken in the context of the ESM Snow MIP project (Menard et al., 2019) where the phase partitioning was provided by the respective teams in charge of the different experimental sites involved in this project.

On the other hand, for the distributed simulations, we used the method of Harder and Pomeroy (2013) that relies on psychrometric energy balance of a falling hydrometeor to estimate the ratio of liquid to solid precipitation. This method has been selected since it has been used with success for different applications in cold regions hydrology across Canada (Western Canadian Cordillera: Marsh et al., 2024; New Brunswick: Leroux et al., (2023); Boreal Forest in Saskatchewan: He and Pomeroy (2023); Quebec: Aygun et al., (2022); northern Yukon: Krogh and Pomeroy (2021)). The following sentence has been added in Section 3.2.2 of the revised paper (L537-538):

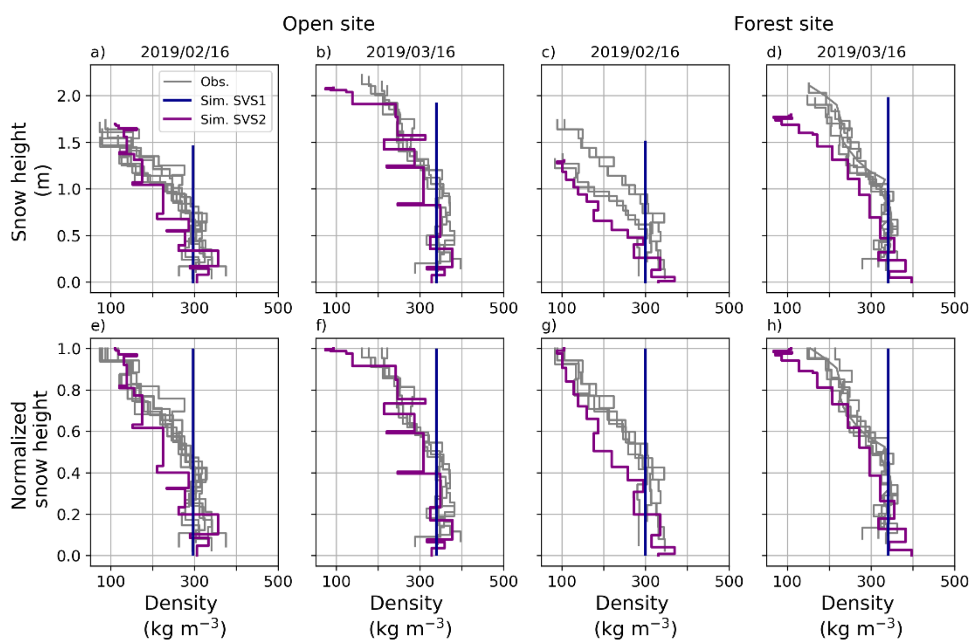
The method of Harder and Pomeroy (2013) has been extensively used when simulating cold regions hydrology across Canada (Aygun et al., 2022; Leroux et al., 2023; Marsh et al., 2024).

3. In section 4.1 "Point-scale evaluation at Snow Crested Butte", the authors present an evaluation of the model in point-scale mode at Snow Crested Butte. They conducted simulations at both the open site and the forest site, with comparisons to on-site measurements. However, they mainly present the results simulated by SVS2/Crocus without explaining how the new forest canopy module enhanced simulation performance. A comparison between SVS1 and SVS2 is recommended to highlight the role of the new forest canopy module.

We thank Reviewer 1 for this suggestion. Simulation results with SVS1 at Snow Crested Butte have been added in the revised manuscript. Figures 3 and 4 of the paper were revised to show results with SVS1. A table summarizing the performances of SVS1 and SVS2 has also been added to the revised paper. These new figures and table are shown below. Finally, the SVS1 configurations output files for SVS1 were added to the Zenodo archive containing the scripts and data used to generate the figures of the paper.



Revised version of Figure 3 with the revised caption: Simulated (with SVS1 in blue and SVS2 in purple) and observed snow height, SWE, and density between October 2019 and June 2021 at (a,c,e) the open site and (b,d,f) the forest site at Snow Crested Butte (USA). The black line in (a,b) represents the snow height measured by automatic sensors at each station, the circles represent the mean measurements and the + signs represent the minimum and maximum measurements.



Revised version of Figure 4 with the revised caption: Simulated (with SVS1 in blue and SVS2 in purple) and observed vertical snow density profiles in (a, b, e, f) the open site and (c, d, g, h) the forest site at two different dates during the 2018/19 winter season at Snow Crested Butte. The first row shows raw vertical profiles whereas the second row shows normalized profiles where the thickness of the layers in each observed and simulated profile is normalized by total snow height.

Table 3. Error metrics (Bias and RMSE) for the simulations of bulk snowpack properties (snow depth, SWE and bulk density) with SVS1 and SVS2 at Snow Crested Butte between October 2019 and June 2021. Measurements from automatic stations, snow courses and snow pits have been used to compute the errors metrics. Values in bold represent the best error metric among the two models for each variable and for each location (open and forest).

Source	Variable	Unit	Metric	Open SVS1	Open SVS2	Forest SVS1	Forest SVS2
Automatic stations	Snow depth	m	Bias	0.14	**0.13**	0.45	**0.05**
			RMSE	0.30	**0.17**	0.50	**0.13**
Snow courses	Snow depth	m	Bias	0.21	**0.04**	0.33	**-0.16**
			RMSE	0.45	**0.14**	0.43	**0.19**
Snow pits	Snow depth	m	Bias	0.20	**0.07**	0.30	**-0.16**
			RMSE	0.42	**0.15**	0.42	**0.22**
	SWE	kg m^{-2}	Bias	84.5	**14.7**	146.7	**-72.1**
			RMSE	153.8	**64.0**	191.6	**86.5**
	Bulk density	kg m^{-3}	Bias	-6.7	**3.2**	23.0	**-7.1**
			RMSE	39.6	**31.7**	33.3	**31.2**

We have updated Section 4.1 of the revised manuscript to include the comparison between SVS1 and SVS2. The 1st paragraph of Section 4.1 is now written as (L 587-598):

Figure 3 presents a comparison between observations and simulations with SVS1 and SVS2 of snow height, SWE, and bulk snow density at the open site and below the forest at Snow Crested Butte. SVS2 accurately reproduced the multi-year evolution of bulk snowpack properties with error metrics that are systematically improved compared to SVS1 for the open and forested sites (Table 3). In open terrain, SVS2 simulates more accurately the snow melt dynamics and the date of snow disappearance compared to SVS (Fig. 3a). Such limitation of SVS1 has been identified in Leonardini et al. (2021). In the forest, SVS2 simulated a lower peak SWE than in the open due to sublimation of intercepted canopy snow and slightly underestimated observed peak SWE for the three winters (Table 3). On the other hand, SVS1 overestimated peak SWE in the forest due to the absence of snow interception and a tendency to underestimate snow melt (Leonardini et al., 2021). Finally, SVS2 better captured the increase in bulk snow density with time than SVS1 leading to improved error metrics (Table 3).

The following text (in bold) has also been added to the 2nd paragraph of Section 4.1 (L601-602):

Figure 4 compares the simulated and observed vertical profiles of snow density for two dates of winter 2018/2019. SVS2 performed well in simulating increased snow density with snow depth, ***a feature that the one-layer scheme in SVS1 could not capture by design.***

4. The model did not accurately simulate the grain type of each layer, which is reasonable considering uncertainties in the observed snow type and in the model's snow grain diagnostics. My question is: if the simulation of grain type was unsatisfactory, was the

inclusion of complex snow microstructure necessary? To what extent can the complex microstructure configuration improve model performance?

The comparison between observed and simulated snow grains at Snow Crested Butte is presented in this paper to illustrate the capabilities and limitations of a detailed snowpack scheme such as Crocus. This comparison is only based on one point-scale simulation and cannot be considered as a general conclusion to say that the simulation of snow grain type with Crocus is unsatisfactory. This comparison also highlights current gaps in our understanding of snow microstructure, such as the representation of depth hoar layers, as well as processes that were misrepresented by the model, including the formation and persistence of melt-form layers. In addition, the simulation of snow grain type is not the main motivation of including a snowpack scheme such as Crocus into SVS2. Indeed, SVS2/Crocus is currently developed in the context of the Terrestrial Snow Mass Misson (Derksen et al., 2021), a mission in preparation to retrieve SWE from space. A proper retrieval from SWE at Ku-band (e.g. Montpetit et al., 2025) requires a-priori quantitative information about the snow microstructure (mainly density and SSA) that are used in the optimization process. Therefore, in SSV2/Crocus, we are more interested by the simulation of the quantitative variables that characterize snow microstructure than by the more qualitative variable such as snow grain type that are more often used in the context of avalanche hazard forecasting. Therefore, the complex snow microstructure provided by Crocus is needed in the context of snow remote sensing and will allow in the near future the assimilation of radar backscatters and/or received SWE that will improve model simulation of bulk snowpack properties.

5. Lines 591-593: Why can the Arctic configuration also improve simulations for sites below the treeline?

The Arctic configuration of SVS2/Crocus proposed by Woolley et al. (2024) contains two sets of modifications: (i) modifications increasing the compaction of surface snow due to high wind speeds (through modified parameterizations of snowfall density and wind packing) and (ii) modifications concerning the impact of Arctic vegetation. When activated, the first set of modifications is activated over the full simulation domain whereas the effects of Arctic vegetation are only activated where this vegetation is present (above the treeline). For this reason, the Arctic configuration of SVS2/Crocus through the wind-related modifications affects the evolution of the snow cover throughout the whole domain. Our results show that this configuration improves the density of the upper snow layer in regions outside the Canadian Arctic, suggesting that it can potentially be used for simulations across Canada.

In the revised manuscript, the following sentence has been added in Sect. 2.2.1 describing the Arctic configuration (L 215-217):

When activated, these modifications that increase the compaction of surface snow due to high wind speeds affect simulations over the whole domain (even in regions located outside the Arctic).

In the Results section, we also clarified why the Arctic configuration also improves simulations for sites below the treeline (L 632-633):

The Arctic configuration (Arc_LAP) strongly improved model results. It removed most of the negative bias in the density of the upper snowpack and decreased the median RMSE (Fig. 6e) for the sub-

Arctic locations (KU and QTU) but also for sites located below the treeline (SI, TQS, SC and TQN; Fig. 2). ***These improvements result from the modifications in the Arctic configuration that increase the compaction of surface snow due to high wind speeds and that are active over the whole simulation domain (Sect. 2.2).*** *Similar improvements for ….*

6. The authors note that SVS2 has been previously applied in several studies, including Woolley et al. (2024), and they make comparisons with Woolley et al. (2024) throughout almost all parts of the manuscript. What, then, are the scientific advances of this study compared to Woolley et al. (2024)?

Woolley et al. (2024) have evaluated the Arctic configuration of SVS2/Crocus using point scale simulations at Trail Valley Creek (Northwestern Territories, Canada). The work of Woolley et al. (2024) relies on previous developments with Crocus evaluated at a few other sites in the Canadian Arctic (Cambridge Bay and Bylot Island in Nunavut, Umijuaq in Quebec) by Domine et al. (2016a), Royer et al. (2021b) and Lackner et al. (2022). Our study builds on these previous works and presents the first distributed applications of SVS2 that include the work of Woolley et al. (2024) and contains:

1. An evaluation of in-situ snowpack properties across multiple sites (13 for density and 6 for SSA) including sites that are not located in the Arctic to inform about the spatial transferability of this configuration.
2. An evaluation of the impact of the Arctic configuration on the snow melt-out date across a domain that extends from southern Quebec to the north of the Canadian Arctic.

We have added a new paragraph at the beginning of Section 3 (L 465-480) to explain the context of the simulations carried out in this paper and explain our original contribution:

This section describes two simulation strategies used to evaluate SVS2/Crocus performance. First, point-scale simulations were performed to investigate the canopy module and its effects on simulated snowpack properties. These simulations also included comparisons with SVS1 to demonstrate model improvements. Second, spatially distributed simulations covering a domain spanning from southern Quebec to the Canadian Arctic were conducted to evaluate both the revised albedo parameterization in SVS2/Crocus and the Arctic snow parameterizations. Prior to this work, these modifications had been tested only at the point-scale. The distributed simulations provided an opportunity to assess these parameterizations across large spatial scales and diverse snowpack types within the domain. These simulations enabled us to (i) quantify how the albedo parameterization of Gaillard et al. (2025) affects snow melt dynamics throughout the domain and (ii) evaluate the spatial applicability of both the default and Arctic configurations of SVS2/Crocus for estimating vertical profiles of snow properties (SSA and density). Results from the distributed simulations were also compared against reference snow products used as benchmarks.

7. The authors refined the snow albedo parametrization and indicated that they incorporated significant developments such as a revised snow albedo scheme. However, in the Results section, they did not demonstrate the impacts of such developments on model performance.

The revised snow albedo parametrization is described in detail in Gaillard et al (2025) which contains an evaluation of the impact of this new parametrization on simulated snow albedo using point-scale simulations. Gaillard et al. (2025) showed that, on average, this updated parameterization improved snow albedo simulations by 10% at ten experimental sites with the largest improvements found in the Arctic (more than 25%). This result is mentioned in Section 2.2.2 when describing the new parametrization. Our SVS2 paper submitted to GMD describes the impact of this new parametrization on distributed simulations with SVS2/Crocus. Section 4.2.3 of the Results section compares the simulation of snowmelt out date (SMOD) for several configurations of SVS2/Crocus. In particular, it compares the simulations *Def* and *Def_LAP*. The only difference between these two configurations is the snow albedo parametrization. *Def* uses the default snow albedo parametrization whereas *Def_LAP* uses the new parametrization. Our results show that SMOD simulation is greatly improved in *Def_LAP* compared to *Def* (Fig. 9 and 10 and Table 2 in the submitted manuscript) because the updated snow darkening coefficient in *Def_LAP* leads to slower rates of decrease of snow albedo in the visible range and slower melt rates. Therefore, we believe that our study demonstrates the impact of the new albedo parametrization across a large simulation domain and provides complementary results to the initial study of Gaillard et al. (2025)

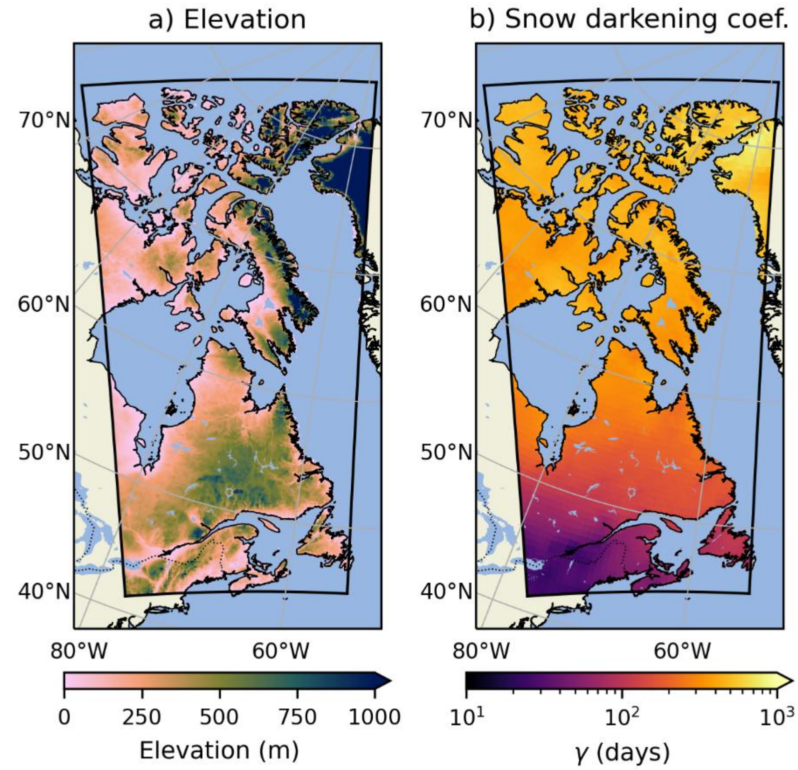
In the revised paper, we have added the following sentence when describing the albedo parameterization (Sect. 2.2.2, L 182-185):

This updated parameterization improved snow albedo simulations by 10% at the 10 experimental sites with the largest improvements found in the Arctic (more than 25\%) (Gaillard et al., 2025). ***The current study represents the first assessment of how this new albedo parameterization affects spatially distributed snowpack simulations (Sect. 4).***

We have also added a new paragraph at the beginning of Section 3 (L 465-480) to explain the context of the simulations carried out in this paper and explain our original contribution:

This section describes two simulation strategies used to evaluate SVS2/Crocus performance. First, point-scale simulations were performed to investigate the canopy module and its effects on simulated snowpack properties. These simulations also included comparisons with SVS1 to demonstrate model improvements. Second, spatially distributed simulations covering a domain spanning from southern Quebec to the Canadian Arctic were conducted to evaluate both the revised albedo parameterization in SVS2/Crocus and the Arctic snow parameterizations. Prior to this work, these modifications had been tested only at the point scale. The distributed simulations provided an opportunity to assess these parameterizations across large spatial scales and diverse snowpack types within the domain. These simulations enabled us to (i) quantify how the albedo parameterization of Gaillard et al. (2025) affects snow melt dynamics throughout the domain and (ii) evaluate the spatial applicability of both the default and Arctic configurations of SVS2/Crocus for estimating vertical profiles of snow properties (SSA and density). Results from the distributed simulations were also compared against reference snow products used as benchmarks.

Finally, we have added in the Supplementary material a map (see below and Fig. S6 in the revised Supplement) that shows the values of the snow darkening coefficient used across in the simulation domain in Eastern Canada.



Maps showing (a) the elevation and (b) the snow darkening coefficient across the simulation domain extending from Eastern Canada to the Canadian Arctic.

Answer to Reviewer 2

We thank Reviewer 2 for their comments. We provide here our responses to those comments and describe how we addressed them in the revised manuscript. The original reviewer comments are in normal black font while our answers appear in blue font. The line numbers mentioned below correspond to the line numbers in the manuscript in track-change mode.

The authors present an upgraded version of the Soil Vegetation and Snow (SVS), a land surface model employed for land surface climate and hydrological predictions. The model version presented here (SVS2) includes the snow scheme Crocus to improve the representation of snow processes, including snow microphysics and light absorbing particle deposition, a new canopy model to represent the effects of vegetation, and some improvements tailored to applications of the model to snow in arctic regions. In my opinion the paper is very well written and the model development presented here seems relevant. I believe the paper should be considered for publication once the authors address or respond to the reviewer's comments.

Comments

1) Since the abstract mentions explicitly the fact that one of the improvement is the addition of light absorbing particles effects to snow in SVS, some more detail on how this is implemented (e.g., how the spatial distribution of the snow aging time constant gamma was derived) would be very helpful to the reader. In section 2.2.2, it might also be worth reporting the albedo formulation used in SVS2, since this - and the value of its parameter gamma - are discussed in that paragraph. From the discussion it seems like using the radiative transfer model TARTES would improve on this parameterization - I wonder, is the 10x increased in computation cost mentioned in the paper for the entire land model, snow model, or only snow radiative transfer calculations?

The improvement of the default snow albedo parameterization in Crocus is described in detail in Gaillard et al. (2025). For this reason, we initially kept the description of this parametrization short in the submitted manuscript. Based on this comment of Reviewer 2, we have expanded the description of this parametrization in the revised manuscript by:

1. Adding a table (Table 1 in the revised manuscript) that describes the albedo formulation in Crocus:

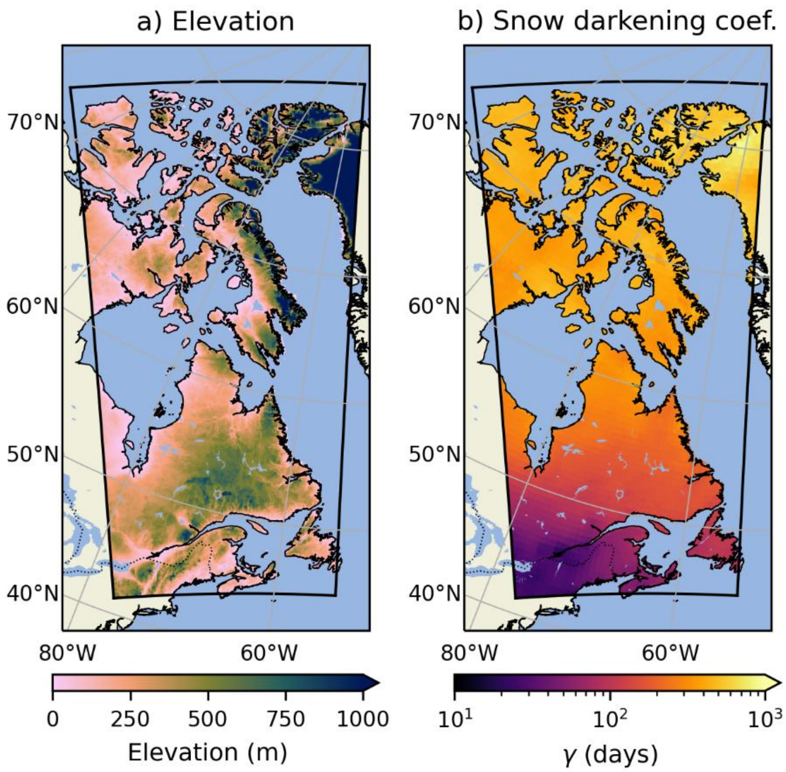
Table 1. Equations representing the snow albedo for the three spectral bands in the default albedo parameterization of Crocus used in SVS2. The parameters are as follows: d_{opt} (m) is the optical grain diameter of the snow, ρ is the snow density, A (days) is the age of the snow, and γ (days) is the snow darkening coefficient. Adapted from Table 4 in Vionnet et al. (2012). The pressure term present when computing $\Delta\alpha_{age}$ in SURFEX/Crocus (Vionnet et al., 2012) is not used in SVS2/Crocus as explained in (Gaillard et al., 2025).

Spectral band	Spectral albedo ($\alpha_{spectral\,band}$)
0.3—0.8 µm	$\alpha_{0.3-0.8\mu m} = \max(0.6, \alpha_i - \Delta\alpha_{age})$ where: $\alpha_i = \min(0.92, 0.96 - 1.58\sqrt{d_{opt}})$ and: $\Delta\alpha_{age} = 0.2\frac{A}{\gamma}$
0.8—1.5 µm	$\alpha_{0.8-1.5\mu m} = \max(0.3, 0.9 - 15.4\sqrt{d_{opt}})$
1.5—2.8 µm	$\alpha_{1.5-2.8\mu m} = 346.3d' - 32.31\sqrt{d'} + 0.88$ where: $d' = \min(d_{opt}, 0.0023)$

2. Adding some text (in bold below) to better explain how the spatial distribution of gamma was derived (L 175-185):

… To overcome this limitation, Gaillard et al. (2025) proposed a new approach for SVS2/Crocus where γ varies in space based on a global climatology of LAP deposition over snow ***that they developed. Optimized values of γ for multi-year snow albedo simulations with SVS2/Crocus were generated at 10 reference experimental sites spanning a large variety of climates across the world. A regression was then established between these optimal values and the climatological deposition of LAP on snow at the location of the experimental sites. This regression was finally combined with the global climatology to obtain a LAP-informed and spatially variable darkening coefficient for the Crocus albedo parameterization.*** *This methodology of intermediate complexity, implemented in SVS2, considers the spatial variability of LAP deposition in the default snow albedo parametrization without additional computational cost.* ***More details can be found in Gaillard et al. (2025)****. This updated parameterization improved snow albedo simulations by 10% at the 10 experimental sites with the largest improvements found in the Arctic (more than 25%) (Gaillard et al., 2025).* ***The current study represents the first assessment of how this new albedo parameterization affects spatially distributed snowpack simulations (Sect. 4).***

3. Adding in the Supplementary material a map (Fig. S6) that shows the values of gamma used across in the simulation domain in Eastern Canada. References to this map were also added to the main manuscript (L 734-735).



Maps showing (a) the elevation and (b) the snow darkening coefficient across the simulation domain extending from Eastern Canada to the Canadian Arctic.

We still encourage the reader to refer to Gaillard et al. (2025) to get more details about the revised snow albedo parameterization.

Concerning the radiative transfer model TARTES, Lafaysse et al (2025; Submitted to GMD) have recently shown that the cost of snow model increase approximately 20 times when activating TARTES (in a given configuration of SURFEX/Crocus: cost of the model without TARTES = 1450 cores x seconds; cost of the model with TARTES = 30038 cores x seconds). Therefore, the text of the revised manuscript has been changed as follows (L 189):

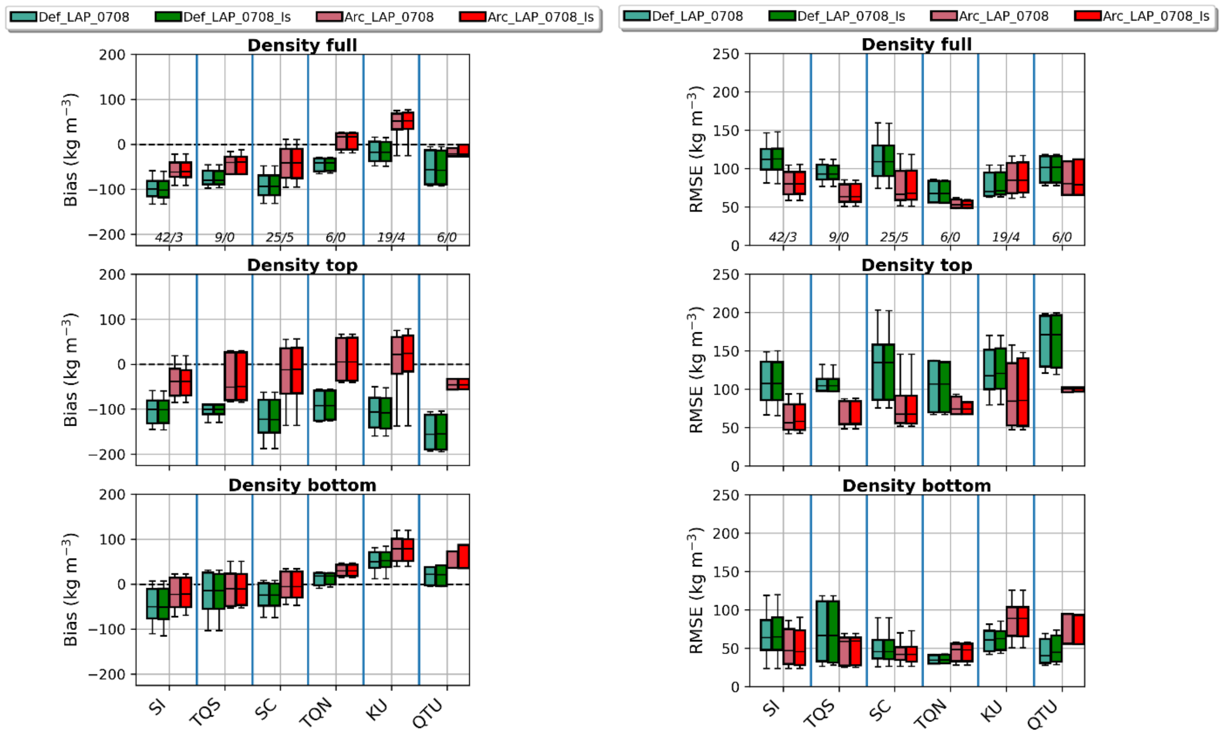
… *This second option is not yet activated in SVS2/Crocus due to a significant additional computational cost* ***(by a factor around 20 for the snow model)*** …

The reference to Lafaysse et al. (2025; Submitted to GMD) will be added if the paper becomes available when we submit the revised version of the paper.

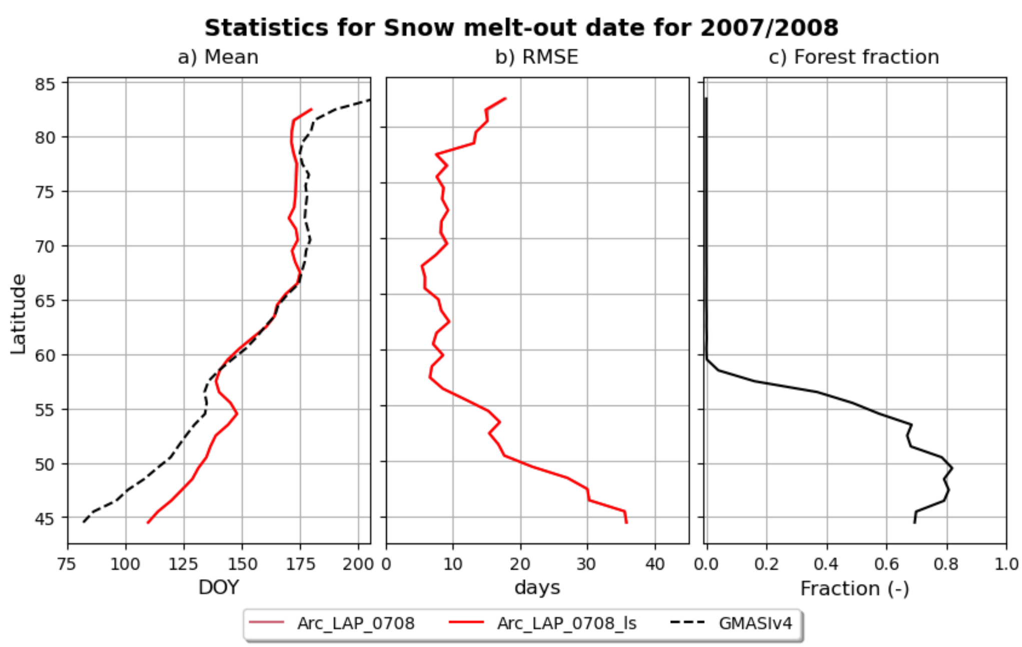
2) It seems the authors perform yearly simulations for each year starting in September 1st, where "The initial soil state on 1 September of each winter was taken from a 1-year spin-up of the land surface conditions." Is a 1-year model spin up enough to equilibrate the thermal regimes of soils or the ice content in the soil? Is it possible that this would affect the seasonal snow simulations given the high-latitude domain of this study?

Indeed, in the initial manuscript, we performed a 1-yr spin-up to provide initial land surface conditions for the different SVS2/Crocus simulations. We fully agree with Reviewer 2 that such spin-up period is not sufficient to balance the soil temperature and ice content over the full depth of the soil column, especially at high latitude. The importance of spin-up strategy is well documented for permafrost studies (e.g. Elshamy et al., 2020; Ji et al., 2022) that require long spin-up periods (e.g., hundreds of years) to capture well the soil thermal regime at high latitudes. Land surface models applied in this context use a deep total soil depth (for example: 15.2 m in Ji et al., 2022; 50 m in Elshamy et al., 2020) and either use a "no flux" thermal boundary condition at the bottom of the soil column (Elshamy et al., 2020) or a fixed temperature at a certain depth (for example 40 m in Ji et al., 2022). In the context of the SVS2 paper, we were focusing on the simulation of seasonal snow across a latitudinal gradient across Eastern Canada. For this reason, SVS2 was not applied in a configuration that was targeting the simulation of the thermal regime of the full soil column at high latitudes. Instead, we use the same soil column (total depth of 3 m) as the version of SVS1 applied for hydrometeorological forecasting across Canada (Durnford et al., 2021). A prescribed deep soil temperature at 5 m was used as described in the Supplementary material.

To better understand the impact of the spin-up duration on the simulated snowpack properties with SVS2/Crocus, additional simulations were carried out during the review of the paper. We focused on the snow season 2007/2008. A 5-yr spin-up of the land surface conditions (starting on 1 September 2002) was carried out using the configuration *Def* of the model. The outputs of this simulation were then used as initial land surface conditions for three simulations of the model using the same configurations as the simulations *Def, Def_LAP* and *Arc_LAP* of the submitted manuscript. The simulations with this 5-yr spin-up are identified with the suffix "*_ls*" in the rest of this paragraph. The two figures and the table below illustrate the impact of the duration of the spin-up period on the evaluation of the vertical profile of snowpack density and the Snow Melt-Out Date (SMOD). Error metrics for snow density remain unchanged when using a 5-yr spin-up compared to a 1-yr spin-up. The error metrics for SMOD are also consistent across different spin-up durations: (i) the latitudinal pattern of SMOD RMSE is the same for both spin-up periods (as illustrated below using the *Arc_LAP* configuration as an example), and (ii) the mean bias and RMSE values remain stable to two decimal places (see the table below).



Distributions of error metrics (Bias on the left and RMSE on the right) for the simulation of the vertical profile of snow density at different locations across Eastern Canada in February 2008. Error metrics are computed for the whole snowpack, the top 25% and the bottom 25%. For each SVS2/Crocus configuration, two durations of the spin-up period are considered (1 year and 5 years).



(a) Mean snow melt-out data as a function of latitude for the experiments *Arc_LAP* (1-year spinup) and *Arc_LAP_ls* (5-year spinup); (b) Mean RMSE as a function of latitude computed using GMASI as the

reference and (c) forest fraction as a function of latitude. The differences between the two experiments do not appear since the curves are superposed.

Error metrics (Bias and RMSE in days) compared to GMASI for the SMOD simulations above 55N for each SVS2/Crocus configuration with two different durations of the spin-up period (1 year and 5 years) for winter 2007/2008.

Experiment	Spin-up	Bias (days)	RMSE (days)
Def	1 yr	-18.38	21.46
Def_ls	5 yr	-18.39	21.49
Def_LAP	1 yr	-8.85	13.16
Def_LAP_ls	5 yr	-8.77	13.24
Arc_LAP	1 yr	-1.73	8.43
Arc_LAP_ls	5 yr	-1.75	8.46

Since the 5-yr spin-up does not change the results presented in the submitted manuscript, we have decided to keep the results from the 1-yr spin-up in the revised manuscript and to add comments in the text about the duration of the spin-up and the impact on the snowpack simulations. The following text has been added in Section 3.2.2 (L 523-527):

Such spin-up duration is short compared to typical spin-up durations (e.g., hundreds of years) used in studies focusing on the thermal regime of the permafrost at high-latitudes (Elshamy et al., 2020; Ji et al., 2022). In the context of this study, a sensitivity analysis showed that results for seasonal snow (snow physical properties and snow melt out date) remained unchanged when using a 5-year spin-up of the land surface condition.

When comparing the scores between the experiments with the 1-yr spin up and the 5-yr spin up, we have realized that the submitted version of the paper did not contain the latest scores for the experiments *Def* and *Def_LAP*. For this reason, we have updated Table 5 in the revised manuscript:

Table 4. Error metrics (Bias and RMSE in days) compared to GMASI for the SMOD simulations above 55°N for each SVS2/Crocus configuration and for two benchmarks products ($ERA5L$ and $ERA5\_CRO$) for winter 2007/2008 and winter 2015/2016.

	Def	Def_{LAP}	Arc_{LAP}	$ERA5L$	$ERA5\_CRO$
Bias (2007/2008)	~~-17~~ -18	~~-8~~ -9	-2	-4	-21
RMSE (2007/2008)	~~20~~ 21	~~12~~ 13	8	14	23
Bias (2015/2016)	-15	-7	-2	-2	-19
RMSE (2015/2016)	18	11	8	11	22

The conclusions of the paper remain the same. Changes in error metrics from one experiment to another have been adjusted to reflect the changes shown in Table 4 (L 723, L 732, L 733, L 742, L 743)

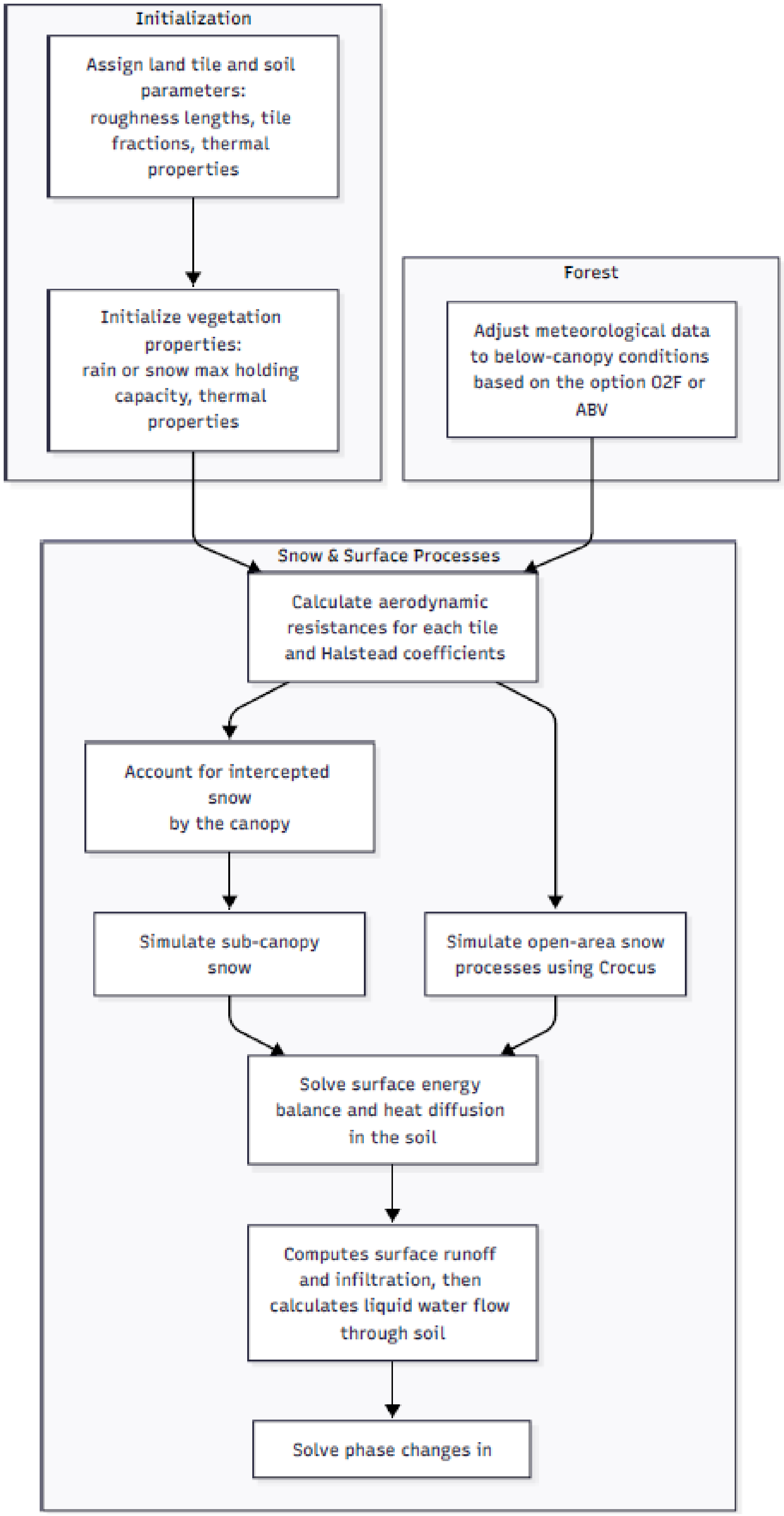
3) A large section of the paper focuses on the energy and mass balance of canopy and intercepted water. However, I did not find in the paper any discussion about the numerical scheme used, or order of operations in a model time step. Are there any particular strategies used for solving the

land surface energy balance which are relevant for the reader? Is it the same as in the previous version of the parent model (SVS / Crocus)? Since this model was developed for coupled runs for numerical weather predictions or earth system modeling, some detail on the solution of the energy and mass balance of the land surface / canopy / snowpack might be useful.

We thank Reviewer 2 for this comment. Details about the numerical schemes used in SVS2 are provided in Section S2 of the submitted Supplementary material, in particular Section S2.2 provides details about the numerical scheme used to solve the energy balance of high vegetation. More references to Section S2 have been added to the revised manuscript (L 273) to make it clear that the numerical schemes used in SVS2 are detailed in Section S2. In addition, a new figure (see below) has been created to show the order of operations within one time step of SVS2. This figure has been added to a new section of the revised Supplementary material that provides an overview of the model numerical implementations and corresponding orders of operations. The text of this section reads as follows:

Figure S2 presents a comprehensive overview of the sequential computational framework and order of operations that occur within a single model time step of SVS2. It is important to note that this computational structure and sequence of operations remain consistent with those originally established in SVS (Alavi et al., 2016; Husain et al., 2016), ensuring continuity and compatibility with previous modeling efforts.

SVS2 employs a sequential computational approach to calculate the energy and mass balance equations across the integrated soil-vegetation-snow column. To ensure numerical stability, the model utilizes implicit numerical schemes for (i) computing the energy balance of high vegetation, (ii) solving heat diffusion processes within the snowpack, (iii) determining heat diffusion through the soil column and (iv) modeling soil hydrology. Section S2.2 provides a description of the numerical techniques employed in SVS2 for solving heat diffusion in the soil column, while Section S2.3 presents the numerical implementation for computing the energy balance of high vegetation. The heat diffusion processes occurring within the stratified snowpack are solved using the implicit time integration scheme implemented in Crocus (Boone and Etchevers, 2001; Vionnet et al., 2012). Finally, the temporal evolution of soil moisture content throughout the various soil layers is computed numerically using the same fourth-order Runge-Kutta finite difference method that was implemented in SVS (Alavi et al., 2016). At the conclusion of each time step, after the new vertical soil temperature and liquid water content profiles have been determined, the model evaluates potential phase changes (freezing or thawing) that may have occurred in the soil. Following this evaluation, the temperature profile and soil liquid water and ice contents are updated accordingly, following the methodology described in Boone et al. (2000).



Flowchart showing the order of operations in SVS2 within a model time step.