

Bias-adjusted projections of snow cover over eastern Canada using an ensemble of regional climate models

Authors' response (RC1)

Bresson et al.

We thank the reviewer for reviewing the manuscript and their constructive comments. We will revise the manuscript to clarify the scientific context and the methodology for bias adjustment, add an assessment of ERA5-Land SWE performance against observations, and present bias adjustment effect on the ensembles. We address each specific comment in detail below.

General comments

1. The introduction of the paper is rather short and does not present well the scientific context of the study. It should give more details about the bias-adjusting methodologies that are widely used in climate services. These methods are not necessarily well known by non-experts in climate projections. In addition, the introduction could give more detail about the challenges associated with the debiasing of snow variables that present a strong seasonality. The authors mention L 44 that the only debiasing method for SWE has been proposed by Michel et al. (2023). They could explain briefly what the characteristics of this method are and why does it work for snow variables. At the end of the introduction, the readers need to understand why bias-adjusted variables are crucial for climate services and the associated challenges for snow variables.

The points mentioned above will be taken into consideration and the introduction will be amended accordingly.

Impact models can be sensitive to small systematic biases that are present in the global climate models or inherited by regional climate models from their driver (Muerth et al., 2013; Maraun et al., 2010). Bias adjustment helps reduce these biases, which also reduces the inter-model differences and eases their combination into multi-model ensembles. Currently, this is only applied to a subset of variables for which statistical adjustment has been more extensively studied, namely surface temperature (2-m temperature) and precipitation (e.g. Climate Portraits, climatedata.ca, Climate Atlas of Copernicus).

The standard bias adjustment techniques often rely on quantile mapping (QM). Declined in multiple variants (see Gutiérrez et al., 2019 for an exhaustive list), these methods generally divide the reference and the source into quantile-based bins and for each bin, find an adjustment factor that is applied either additively or multiplicatively, depending on the adjusted variable. Particularly, it is the zero-bounded aspect of surface snow that makes it more difficult as additive correction can create nonsensical negative values, and multiplicative correction is incapable of adjusting values that are zero in the source.

2. The authors use the SWE from ERA5-Land as the reference gridded product for debiasing. They only refer to performances reported in Kenda and Fletcher (2025) and Mudryk et al. (2024) to justify their choices. However, this justification remains vague. For example, they refer to the evaluation of ERA5-Land for different ranges of elevation detailed in Kenda and Fletcher (2025). However, this evaluation concerns Canada as a whole, including regions such as the Prairies or the Arctic where the snow conditions differ significantly from those found in Quebec. For this reason, I recommend the authors add an evaluation of the performances of ERA5-Land across Quebec using reference SWE measurements from the CanSWE dataset complemented by SWE data collected by the province of Quebec. Such rich dataset would allow a comprehensive evaluation of ERA5-Land in Quebec that would (i) strongly justify the choice of ERA5-Land as the reference product for debiasing and (ii) help identifying regions of lower performances for ERA5-Land where the result of the debiasing should be considered more carefully. In itself, a solid evaluation of ERA5-Land would be a very interesting outcome of this paper.

We performed an assessment of ERA5-Land against CanSWE (Vionnet et al., 2025) and SWE data collected by the province of Québec (GovQC hereafter; MELCC, 2020). Even if this work is not as thorough as, for example, Kouki et al. (2023) or Mudryk et al. (2015,2025), it helps justify the choice of ERA5-Land and identify regions with lower performance. These results will be added to the manuscript and will help weight the results.

We compared ERA5-Land against observations using the closest grid point of ERA5-Land, in a 3x3 boxes centered on the observation location following two criteria:

- Elevation difference between the grid point and the station is lower than 50 m;
- The grid point has more than 50% of land (lake/land ratio).

For every observation available in the reference period (August 1st, 1991, to July 31st, 2021), the difference between ERA5-Land and observation was computed. As observations are not always collected/recorded daily, indicators such as snow season duration/start/end or days without snow cover could not be obtained reliably. Bias between ERA5-Land and observed

SWEmax was evaluated, even if some limitations are also present here due to the observations' frequency. The focus here was on SWE evaluation.

First, no systematic bias shows between the two observation databases.

Second, the median bias between ERA5-Land and observations for all observations is presented in Figure 1. Median bias remained small in most of the domain (± 20 mm) with a predominance of a slight overestimation of ERA5-Land. The region near the Labrador/Québec border shows more stations with an underestimation of SWE in ERA5-Land than in the rest of the domain. A large underestimation is also noticeable in southeastern New Brunswick and relies on only three observations (Fig. 2).

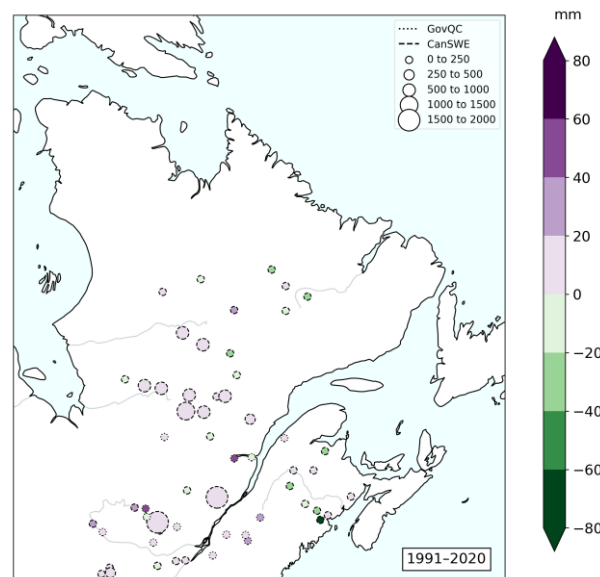


Figure 1. Median bias for ERA5-Land against observations (colors, mm) for the reference period 1991-2020. The size of the symbol represents the number of available observations per station. CanSWE and GovQC stations have dashed and dotted contours, respectively. © Gouvernement du Québec, ministère de l'Environnement et de la Lutte contre les changements climatiques, 2020.

When stations are sorted with respect to their elevation, some patterns are visible in the daily bias of ERA5-Land against observations during January and April (Fig. 2), some patterns are visible. When all observations are considered (no specific month), at elevation higher than 150 m, the overestimation of SWE in ERA5-Land is more systematic, and the range of positive bias is larger than the one for the negative bias (Fig. 2a). The seasonality of the snow cover is important, and the bias is not constant in time (Fig. 2b,c). Indeed, SWE is better estimated by ERA5-Land during January (Fig. 2b) and February, than in March (not shown) and April (Fig. 2c). April results show more variability in the bias of magnitude, leading to the hypothesis that ERA5-Land has more difficulty reproducing the end of the season accurately, and especially with the melting processes slower than observed.

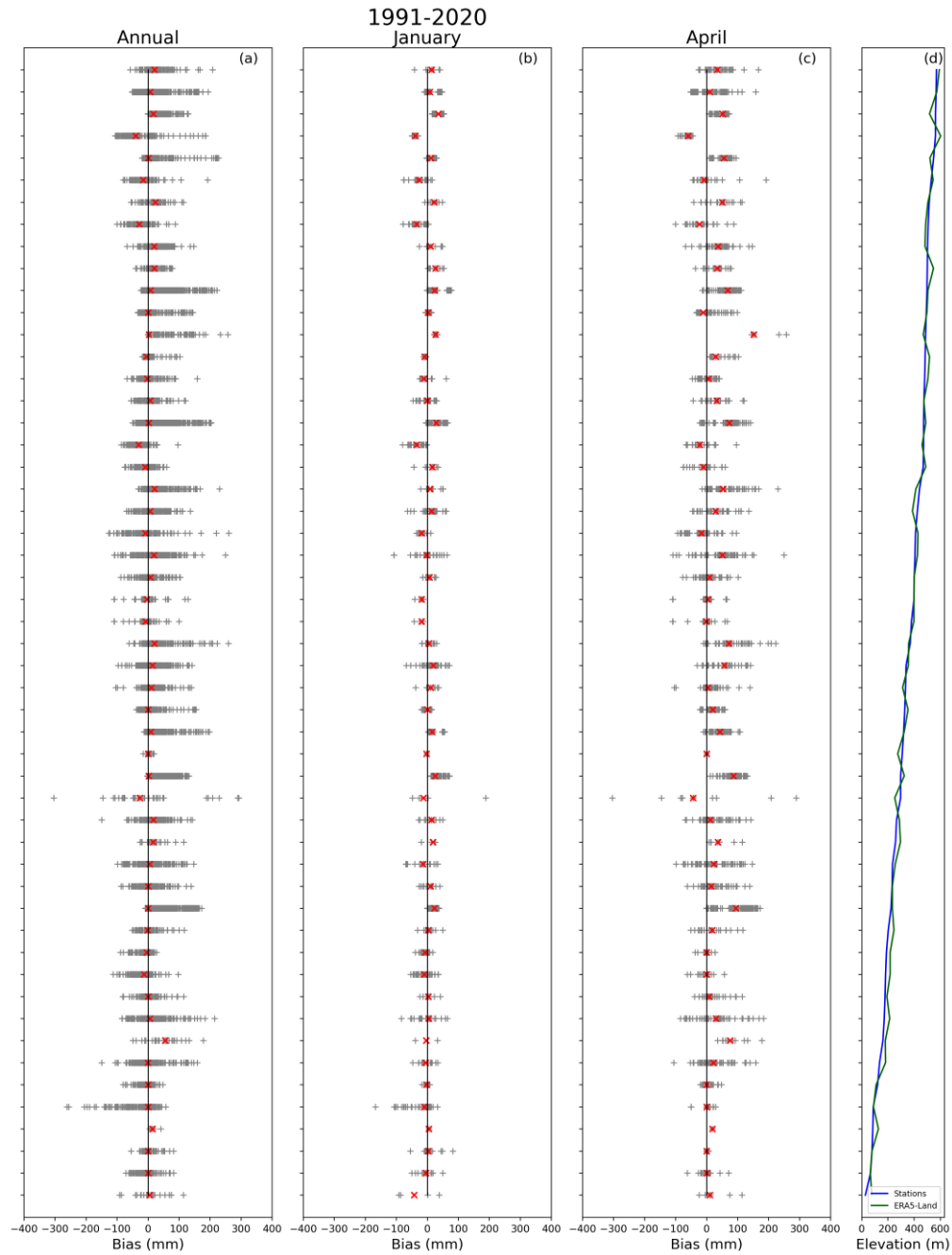


Figure 2. Daily bias (grey crosses) and median bias (red crosses) per station for the whole 1991-2020 period (a), for January (b) and April (c) months in the 1991-2020 period. Only the stations with observations during January and April are shown. Station's (blue) and ERA5-Land closest grid point's (green) elevation (d). © Gouvernement du Québec, ministère de l'Environnement et de la Lutte contre les changements climatiques, 2020.

3. A key component of this paper is the method used for the bias adjustment of SWE from regional climate models. In its present form, the paper does not explain well and

illustrate well why applying a bias adjustment is crucial before deriving relevant projections for different snow indices. Section 2.4 should be heavily revised to better explain the bias-adjustment method.

The following points should be considered:

- It is not clear how the method proposed by Michel et al (2023) addressed the issue associated with the seasonality of snow mentioned in the introduction as one of the main challenges for the bias adjustment of snow variables.
- It seems that the bias adjustment method allows for a downscaling from the native resolutions of the RCM (which are not mentioned in the paper) to the resolution of ERA5-Land. Can the author explain how such downscaling is possible?
- A pre-processing step is applied to the SWE time series during the melting season (P 6 L 135-142). It would be very valuable for the reader to have a figure that illustrates the impact of this pre-processing step. In addition, is this pre-processing applied to each of the grid cells?

The native resolution of the RCM will be added in Table 2. To provide a more complete and clearer description of the method for the bias adjustment and pre-processing of SWE, Section 2.4 “Statistical Downscaling and Bias-adjustment Method” will be modified as follows:

“The statistical downscaling of the simulations towards the resolution of the ERA5-Land reference is done in conjunction with the bias-adjustment, similarly to Lavoie et al. (2024): In a first step, the simulation cells were interpolated on the ERA5-Land grid using the bilinear method. In a second step, a bias-adjustment procedure is performed on each grid cell separately to correct the bias between the regridded simulations and ERA5-Land. This is similar to the Bias-Correction and Spatial Disaggregation approach (Wood, et al., b,a), with the important difference that the spatial interpolation precedes the bias adjustment which is performed on the finer grid. The period 1991-2020 was used for the training. Both the simulations and the ERA5-Land dataset were resampled to a daily frequency by taking the mean of sub-daily data. The quantile-based approach used for the bias-adjustment is described in what follows.

SWE time series were adjusted with the Empirical Quantile Mapping (QM) (Panofsky and Brier, 1968; Cannon et al., 2015). We used 48 quantiles, ranging from 0.05 to 0.99 with a 0.02 increment, with the stricter bound in the low tail chosen to ensure a better stability of the bias-adjustment procedure. Temporal grouping was performed for each day-of-year with a 15-day rolling window. We opted for QM for the following reason: As snow seasons are

expected to shorten in a warmer climate, the lower tail of the SWE distribution can become increasingly populated by near-zero values in certain periods of the year. That is, a given quantile in the training period that corresponds to a substantial SWE amount can be associated to a near-zero value in the future. When using QM, the value in the future is adjusted as near-zero values in the past. On the other hand, a method like Quantile Delta Mapping (QDM) will apply the same correction that was applied to the substantial SWE amount in the past. In other words, the QM method is less sensitive to a regime change from a period with snow-domination to a period with snow-scarcity.

[...]

To address these issues, we adapted the pre-processing method proposed in Michel et al. (2023) that precedes the quantile mapping adjustment of the SWE time series. This method specifically aims to improve bias adjustment during the end of snow seasons where the melting mechanism is at play. The idea is to artificially extend the melting period by replacing vanishing values of SWE with small non-zero values. These small values can then be adjusted with a multiplicative factor computed from the ratio of reference over the biased simulation values. When snow season ends occurs too early in a biased simulation, the algorithm inflates the small values in sim' to make them more similar to ref. In the opposite situation where the snow season end occurs too late, then adjustment factors of 0 are applied, returning those added non-zero values to 0.

This pre-processing is implemented by modeling the extended melting period with an exponential decay, as in Michel et al.(2023). The end of a snow season is mainly controlled by the melting mechanism, which is safer to extrapolate than the snowfall responsible for the start of the season. We first define a threshold of 0.001 mm below which SWE values are set to 0. Starting from first zero in a given season of this transformed series, the vanishing values are iteratively replaced by the preceding value divided by two. Once the proposed replacement falls below the threshold 0.001 mm, we stop the decay and keep the remaining zero values as-is. An example of this pre-processing is shown in Fig. 3.

Compared to the 0.5 mm threshold proposed in Michel et al. (2023), we use a smaller threshold 0.001 mm to increase the number non-zero SWE data reinserted by the decay process. On the other hand, we restrict the reinsertion of data points near the snow season end, defined as the start of 14 consecutive days below 1~mm threshold for this purpose. Hence, abnormal negligible snowfalls later in the year are not modified with new decaying values of SWE. The smaller threshold 1 mm instead of the 4~mm used for snow season indicators was chosen to apply a stronger filter on abnormal snowfalls.

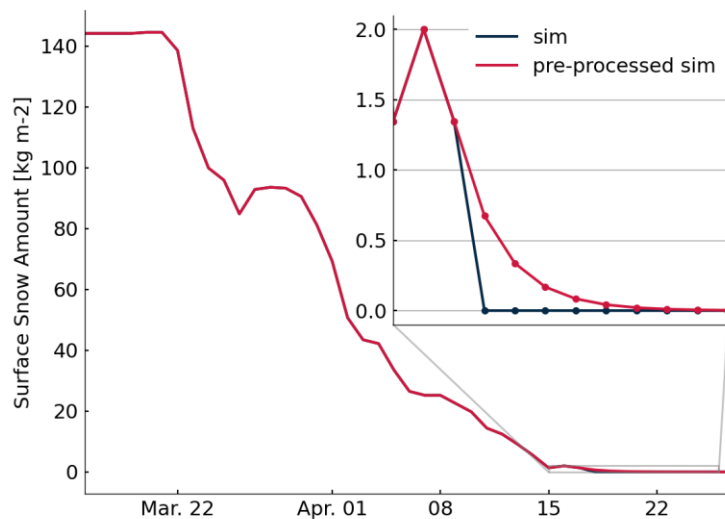


Figure 3. An example of the impact of the pre-processing on a simulation timeseries at the end of a season for a specific year. A sudden decay of SWE in the original simulation (sim) is smoothed with an exponential decay (pre-processed sim).

Following this pre-processing, we applied a regular frequency adaptation with a threshold of 0.0001 mm/day. Based on the idea of Themeßl et al. (2012), this process adds small randomized amount of snow to the simulations so that their frequency of days without snow ($SWE < 0.0001$ mm/day) is at least equal to the one of the reference. The adaptation is done on the same temporal groups as the quantile mapping (15 days windows centered on each day of year), only on the simulations for which the frequency of days without snow is lower than that of the reference.

4. I understand that the authors want to focus their analysis on the bias-adjusted projections as part of group that provides climate services to stakeholders. However, from a scientific point of view, I recommend the authors to quantify if the projections of the different snow indices would have been different without the bias adjustment. Such analysis would highlight the importances of carrying out such bias adjustment when considering snow variables. For climate service, it may be obvious for certain variables such as near surface temperature, but it seems that bias adjustment is less usual for snow variables due to methodological challenges. This analysis would be a solid contribution from this paper that would extend beyond stakeholders interested in the future of the snow cover in Quebec.

After the first selection of simulations, such inter-model differences still show, especially in the SWE amplitude. Figure 4 presents the differences between the climatology (1991-2020) of the annual cycle of SWE for raw (dotted line) and bias adjusted (solid line) simulations for the five subregions. The raw simulations were downscaled to ERA5-Land grid.

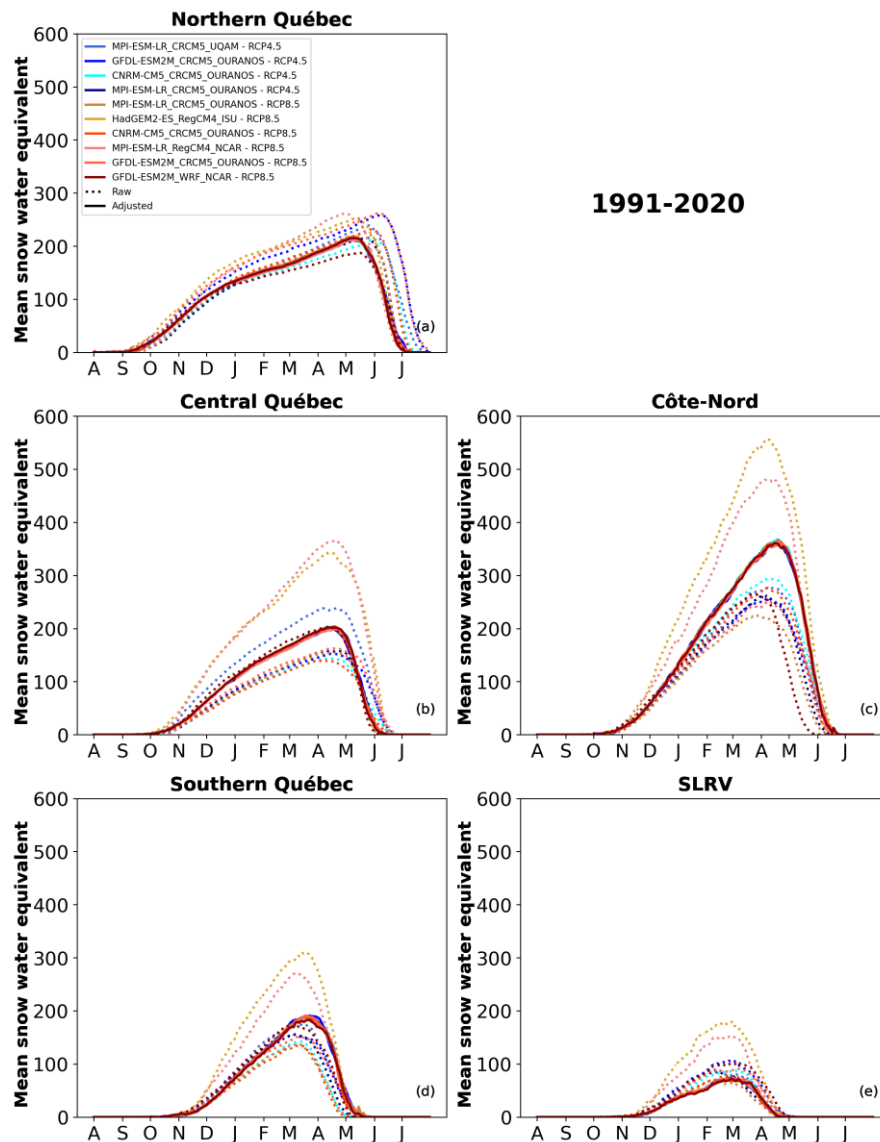


Figure 4. Mean annual cycle of SWE for the five subregions for 1991-2020. Raw simulations are represented with dotted lines, and adjusted ones with solid lines. Each color corresponds to a simulation.

The subregion with the larger discrepancies in raw simulations is Côte-Nord with maximum SWE from around 200 to 550 mm. The simulations produced with the RegCM4 model

present a larger amount of SWE than the other simulations, except for Northern Québec. This is coherent with McCrary et al. (2019) conclusions on the bias in RCM's SWE being mostly induced by the RCM, less by the GCMs.

As expected, bias adjustment mainly influences the SWE amplitude, and in a smaller part the SSS and SSE. The bias adjustment succeeds in reducing the small systematic bias from GCMs or inherited by RCMs from their drivers and helps reduce inter-model differences. This information will be added to the manuscript.

Specific Comments

P1 L 14: the terminology “the northern part of the northern hemisphere” is rather vague. Can the authors clarify? Maybe give a range of latitude.

The northern part of the northern hemisphere refers to the Arctic (66.6°N and up). Our sentence was unclear and will be modified for: “Changes in snow cover have significant feedback on climate. The Northern Hemisphere witnesses a decrease in snow cover extent, a shortening of the snow season (Derksen et al., 2019; McCrary et al., 2022; Mudryk et al., 2020; Fox-Kemper et al., 2021) and a greater warming than in the rest of the world for the Arctic part (e.g. Hoegh-Guldberg et al., 2018).”

P 1 L21: what do they authors mean by “best understood”?

By “best understood”, we meant the variables for which statistical adjustment has been more extensively studied, partially because temperature and precipitation have observations with the highest coverage and longest time span than the other variables. Some modifications will be applied to the text to clarify this point.

P1 L22: “surface temperature”: is it the actual surface temperature (“skin temperature”) or the screen-level temperature (taken for example at 2 m above the ground)?

The surface temperature described in this paper is the 2-m surface temperature, above the ground. Clarification will be added to the text.

P1 L24: it would be highly relevant for the readers to add here references that illustrate how challenging it is to adjust the bias of variables with rare occurrences or strong seasonality.

As presented in the first general comment, the standard bias adjustment techniques often rely on quantile mapping (QM). Declined in multiple variants (see Gutiérrez et al., 2019 for an exhaustive list), these methods generally divide the reference and the source into

quantile-based bins and for each bin, find an adjustment factor that is applied either additively or multiplicatively, depending on the adjusted variable. Particularly, it is the zero-bounded aspect of surface snow that makes it more difficult as additive correction can create nonsensical negative values, and multiplicative correction is incapable of adjusting values that are zero in the source.

P2 L 30-35: these sentences contain several statements that should be supported by appropriate references. For example, the statement “to better reproduce ... the processes such as sublimation or ablation” is really vague and must be supported by references.

This part of the introduction will be modified as follows :

“LSMs can also be used in an offline-mode, which presents some advantages, like allowing a higher resolution to have more accurate orography. For example, ERA5-Land is run off-line, forced by ERA5 atmospheric fields, has a finer resolution (9 km) than ERA5 (0.25°), uses a daily environmental lapse rate to adjust air temperature for the altitude differences, and has an overall better performance than ERA5 for SWE (Muñoz-Sabater et al., 2021). As bias adjustment of temperature and precipitation is better understood, it can also be performed on the drivers (GCMs or RCMs) of such offline LSMs (Luca et al., 2017; Morin et al., 2021). Using bias-adjusted inputs in offline LSMs adds a step in the simulation of snow at a high resolution. However, no feedback between the surface and the atmosphere are allowed when LSMs are used offline. “

P 2 L35: Offline simulations with snowpack schemes are often carried out at continental or global scales (such as the ERA5-Land product used in this study or the Crocus-ERA5 dataset (Ramos Buarque et al., 2025)). In this context, I recommend the authors to rephrase the sentence “Consequently, this method could be better adapted for specific purposes at a local scale”.

See previous answer.

P 2 L 43: the term “snow cover” used here is confusing since it is already widely used in the paper to refer to snow in general. Maybe use “snow cover fraction” since it is the variable of interest in the paper of Matiu and Hanzer (2022).

The term “snow cover” will be modified for “snow cover fraction”.

P 2L 48-49: can the authors explain briefly what are the problems that arise with snow simulations at high elevation?

At high elevation, the resolution used in the RCMs (12 to 45 km) can be too coarse to represent adequately the complex topography of mountains (orography is thus smoothed) and miss some of the orographic forcing on precipitation.

P 2 L59: It would be interesting to know the mean elevation of the different subregions considered for the analysis. In particular, it would illustrate well the contrast between Southern Quebec and SLRV.

We added information about mean elevation for each subregion in Section 2.1. The values are: 468 m for Northern Québec, 391 m for Central Québec, 356 m for Southern Québec, 59 m for SLRV and 390 m for Côte-Nord.

P3 L 71: what do the authors mean by “flexibility”? Would it be possible to reformulate to be clearer?

By flexibility we referred to a criterium that is not too strict. Indeed, with a 30-days threshold for example, some regions in southern Québec could have a no snow season at all due to the fragmentation of the snow cover by the end of the century. Considering more than two weeks for the SSS and SSE triggers can also limit the use of such indices for adaptation plan. The sentence will be modified.

P 4 L 89: what do the authors mean by “mismatch”? Between which datasets? What was the nature of this “mismatch”?

The term “mismatch” refers to differences between gridded datasets, such as Crocus, MERRA-2 or ERA5-Land. The sentence will be modified: “The databases show differences in the snow water mass, but also in their spatial distribution (e.g., Mudryk et al., 2015; Mudryk et al, 2025).”

P4 L 91-92: this sentence should be reformulated since Figure 3 in Kenda and Fletcher (2025) presents an evaluation of the SWE from ERA5-Land across Canada (including region below 50N). Kenda and Fletcher (2025) did not only evaluate ERA5-Land in northern Canada above 50N.

This mistake will be corrected and the sentence changed as follows: “. Kanda and Fletcher (2025) analyzed the bias of ERA5-Land SWE across Canada against Canadian Historical Snow Water Equivalent observations (CanSWE; Vionnet et al., 2021), for three ranges of elevation.”

P 5 L 103: how many simulations were considered in this first ensemble?

In the first ensemble, 26 simulations were considered (9 with RCP4.5 and 17 with RCP8.5).

P 5 L 117: Why are the authors using the argument about the availability of SWE observations to justify focusing on the region below 50 N in their selection criteria? Indeed, SWE observations are not used in this study to evaluate ERA5-Land (see my second general comment) and are not assimilated in ERA5-Land.

ERA5-Land has an atmospheric forcing based on ERA5 and does not assimilate observations (Muñoz-Sabater et al., 2021). On the other hand, ERA5 assimilate various variables including temperature and humidity that compel the near surface temperature field (Hersbach et al., 2020). ERA5 presents a better performance in the meridional regions with more instrumentation and consequently more observations to assimilate. In Eastern Canada, most of the observations are in the South. Another motivation to focus on this region (< 50N) was the population density, as one of the motivations to provide this dataset is to be used in an adaptation context.

P 5 L 119: how many candidates were present in the initial ensemble? Such information is interesting to better understand how strict the selection criteria were.

There were 26 candidates before the selection. We tested different thresholds (see Figure 5). This figure will be added to the text.

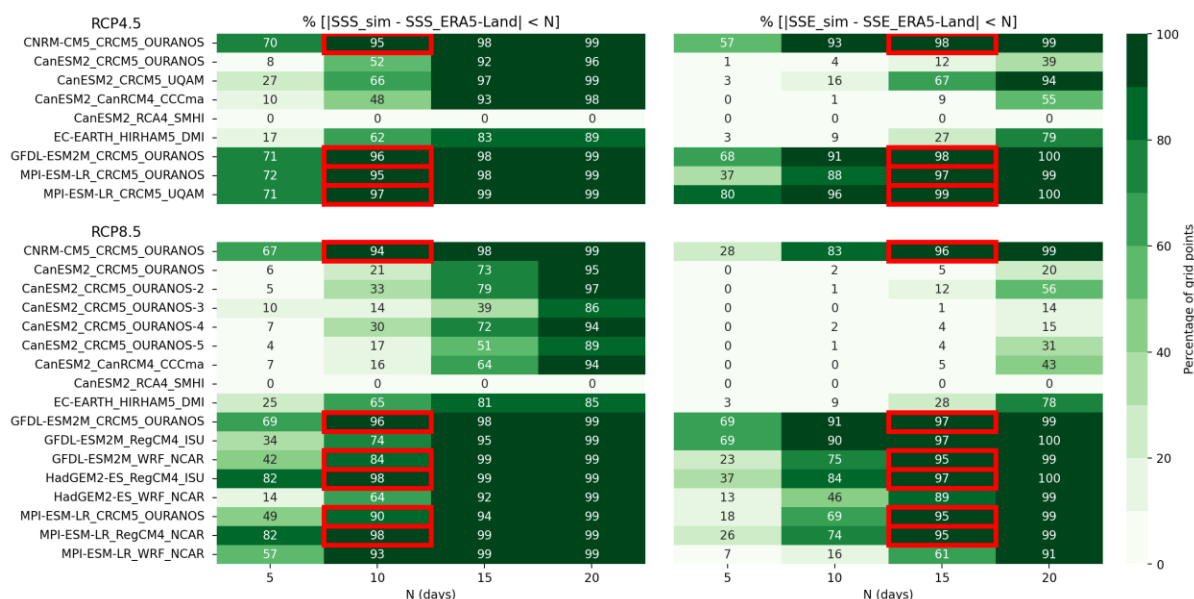


Figure 5. Percentage of grid points with a SSS bias (left) within a +/-10 days interval and a SSE bias (right) within a +/-15 days interval, below the 50° N for all RCP4.5 (top) and RCP8.5

(bottom) simulations. Red boxes present values for the selected simulations. Simulations names correspond to Driving-GCM_RCM_RCM-Institution.

P 5 L 119-120: it would be good to know what the selection criteria were in McCrary et al. (2022) to justify why it makes sense to compare the two ensembles.

McCrary et al. (2022) rejected RegCM4 simulations from the NA-CORDEX ensemble because of unbounded snow accumulation over some mountainous regions and the southern Baffin Island (see Figure S1 in their Supplemental Information). The comparison between their ensemble and ours was to confirm that our selected simulations were not flagged for some specific issue in our region of interest. This information will be better described in the reviewed manuscript.

P 6 L 147: does the value of 375 mm refer to ERA5-Land?

Yes, the value refers to ERA5-Land. A sentence will be added at the beginning of the section 3.1 for clarification: “The snow cover climatology of the historical period (1991 – 2020) was analyzed for ERA5-Land (Fig. 2a,d,g).”

P 7 L 157-159: Has the bias correction already been applied when presenting the results for the two ensembles?

Yes, all results were presented for the bias-adjusted indices in the first submitted article. In regards of reviewers’ comments, we will include more information about the ensembles before the bias adjustment, in the Discussion (see answer to reviewer 2 for more details).

P 12 Figure 9: The dots on the different subplots seem to be rather noisy, especially for the northern and central domain. Is it because of very few events (even only one) over the 30-yr period are considered when computing the mean duration of noSCseq? Showing results aggregated longer time periods can potentially reduce the noise and make the figure easier to read.

As we grouped noSCseq by the day of year on which they start and took the 30 years mean of their length, we can indeed have some noise specifically when only one sequence is registered. This happens rarely during the snow season and could be due to interannual variability. The issue with an aggregated version of Figure 9 is the smoothing of the results and potentially removal of the period without noSCseq during summer in the Northern Quebec region during 1991-2020.

Technical Comments

Text

P2 L 32: “CROCUS” is not acronym and can be written “Crocus”.

This mistake will be corrected.

P 2 L 46: “water content in the snowpack” could be confusing. Maybe use “total water content of the snowpack” to make sure that it does not only refer to liquid water content in the snowpack.

The term “water content in the snowpack” will be modified for “total water content in the snowpack” in the corresponding sentence.

P2 L 55: It could be worth mentioning the other Canadian provinces that are included in the simulation domain.

More details about the other provinces will be added to the description of the domain of interest. The missing provinces will also be added to Figure 1. The sentence will be: “The study domain encompassed the Canadian province of Québec and included New Brunswick and parts of Labrador, Newfoundland, Ontario, Nova Scotia and northeastern United States (Fig. 1)”.

P 5 L 104: the year is missing for the reference to Mearns et al.

This point will be corrected.

P 5 L105: Explain the meaning of the acronym “SM”. It should be changed throughout the document. I also recommend the authors to mention to which specific table or figure they are referring to in the Supplementary Material.

SM stands for Supplementary Material. The text will be modified in this way.

P 5 L 108: the term “melt” or “melting” is often preferred to “thaw” when referring to snow.

The word “thaw” will be replaced by “melting” in the sentence: “[...] a good synchronization in the timing of the melting and accumulation periods is needed”.

P 5 L 131: please double check to reference to (Thiemeßl et al., 2012). Is the family name written correctly?

After double checking, the name of the first author in this publication is correctly written.

P 6 L 144: this sentence can be included in the previous paragraph to avoid having a paragraph made of a single sentence.

The single sentence will be included in the previous paragraph.

P 6 L 148: explain that the names of the regions such as Charlevoix, ... are shown on Fig. 2.

This information will be added in the sentence: “[...] and particularly over mountainous regions like the Gaspesian peninsula, Charlevoix, or the Torngat Mountains (presented in Fig. 1) than the rest of the domain (e.g. 216 mm for central Québec) (Fig. 2a)”.

P 16 L 264: add the corresponding DOI.

The DOI will be added.

Figures

Figure 10: the different levels of transparency are not visible in this figure.

The figure will be modified and added in the text.

REFERENCES

- Gutiérrez, J. M., Maraun, D., Widmann, M., Huth, R., Hertig, E., Benestad, R., Roessler, O., Wibig, J., Wilcke, R., Kotlarski, S., San Martín, D., Herrera, S., Bedia, J., Casanueva, A., Manzanar, R., Iturbide, M., Vrac, M., Dubrovsky, M., Ribalaygua, J., Pórtol, J., Rätý, O., Räisänen, J., Hingray, B., Raynaud, D., Casado, M. J., Ramos, P., Zerenner, T., Turco, M., Bosshard, T., Štěpánek, P., Bartholy, J., Pongracz, R., Keller, D. E., Fischer, A. M., Cardoso, R. M., Soares, P. M. M., Czernecki, B., and Pagé, C.: An intercomparison of a large ensemble of statistical downscaling methods over Europe: Results from the VALUE perfect predictor cross-validation experiment, *International Journal of Climatology*, 39, <https://doi.org/10.1002/joc.5462>, 2019.
- Hersbach, H., Bell, B., Berrisford, P., et al. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, 146, 1999–2049.

Maraun, D., Wetterhall, F., Ireson, A. M., Chandler, R. E., Kendon, E. J., Widmann, M., Brieren, S., Rust, H. W., Sauter, T., Themeßl, M., Venema, V. K. C., Chun, K. P., Goodess, C. M., Jones, R. G., Onof, C., Vrac, M., and Thiele-Eich, I.: Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user, *Reviews of Geophysics*, 48, <https://doi.org/10.1029/2009RG000314>, 2010.

Ministère de l'Environnement et de la Lutte contre les changements climatiques, 2020. Données du Réseau de surveillance du climat du Québec, Direction de la qualité de l'air et du climat, Québec.

Mudryk, L., Mortimer, C., Derksen, C., Elias Chereque, A., and Kushner, P.: Benchmarking of snow water equivalent (SWE) products based on outcomes of the SnowPEX+ Intercomparison Project, *The Cryosphere*, 19, 201–218, <https://doi.org/10.5194/tc-19-201-2025>, 2025.

Muerth, M. J., Gauvin St-Denis, B., Ricard, S., Velázquez, J. A., Schmid, J., Minville, M., Caya, D., Chaumont, D., Ludwig, R., and Turcotte, R.: On the need for bias correction in regional climate scenarios to assess climate change impacts on river runoff, *Hydrology and Earth System Sciences*, 17, 1189–1204, <https://doi.org/10.5194/hess-17-1189-2013>, 2013.

Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., Boussetta, S., Choulga, M., Harrigan, S., Hersbach, H., Martens, B., Miralles, D. G., Piles, M., Rodríguez-Fernández, N. J., Zsoter, E., Buontempo, C., and Thépaut, J.-N.: ERA5-Land: a state-of-the-art global reanalysis dataset for land applications, *Earth Syst. Sci. Data*, 13, 4349–4383, <https://doi.org/10.5194/essd-13-4349-2021>, 2021.

Vionnet, V., Mortimer, C., Brady, M., Arnal, L., & Brown, R. (2025). Canadian historical Snow Water Equivalent dataset (CanSWE, 1928-2024) (Version v7) [Data set]. Zenodo. <https://doi.org/10.5281/zenodo.14901399>