Third Author Response for "Impact of Snow Thermal Conductivity Schemes on pan-Arctic Permafrost Dynamics in CLM5.0" by Damseaux et al.

Editor comment:

Dear Authors,

thank you very much for providing a revised version of your manuscript. I think that the inclusion and discussion of the sensitivity analysis concerning the likely overestimation of the snow densities addresses the remaining concerns adequately. However, since reviewer #2 chose not to review the manuscript again, I would have one final request. For the sensitivity range you investigated, I would agree with your conclusion that the relative benefits of the Sturm approach outweigh the drawbacks. But I could imagine that for an even lower af, e.g. 0.5, this is no longer the case, especially when looking at the near-surface temperatures. Would it be possible for you to justify your choice of the af-range investigated, possibly providing a rough estimate of the factor by which lsms tend to overestimate the snowpack density? If that is not possible, it may be quite informative to have one additional set of simulations with a lower af, in which the annually averaged RMSE in the 0-20cm layer is higher in the Sturm runs. In this way you could define the density(-error)-range for which the Sturm scheme should be the preferred choice.

I hope that the above is not an undue request and look forward to your answer.

Sincerely,

Philipp de Vrese

Authors answer:

Dear Editor,

Thank you for your thoughtful comment. We agree that it is appropriate to justify the choice of adjustment factors in our sensitivity analysis. The selection of adjustment factors (*af*) of 0.7 and 0.9 is based on observed snow density values in Arctic tundra regions. While CLM5.0 estimates an average bulk snow density of 311 kg/m³ over our study domain (Fig. A2 below), observational studies indicate that tundra snow densities should be lower. Zhao et al. (2023) reported an average tundra bulk snow density of 225 kg/m³ based on a large dataset of Arctic-wide snow sites, which aligns well with depth hoar density measurements from multi-site (Derksen et al. 2014) and single-site studies (Woolley et al. 2024), both of which report values around 228 kg/m³. In our sensitivity analysis, an *af* of 0.7 reduces the modeled bulk snow density to 217 kg/m³, aligning well with observed densities. Meanwhile, an *af* of 0.9 results in a bulk snow density of 279 kg/m³, representing an intermediate value between the typical

LSM-simulated densities and the observed tundra densities. We will update the manuscript as follows to include this justification:

“The choice of adjustment factors is based on observed snow density values in Arctic tundra regions. CLM5.0 simulates an average bulk snow density of 311 kg/m³ over our study domain (Fig. A2), whereas observational studies indicate that tundra snow densities should be significantly lower. Zhao et al. (2023) reported an average tundra bulk snow density of 225 kg/m³ using a large dataset of Arctic-wide snow sites, while depth hoar density measurements from multi-site (Derksen et al. 2014) and single-site studies (Woolley et al. 2024) both report values around 228 kg/m³. To align model outputs with these observations, an af of 0.7 was chosen to represent the lower range of observed densities, yielding a modeled bulk snow density of 217 kg/m³. Additionally, an af of 0.9 was selected as an intermediate value between CLM5.0 simulated densities and the observed tundra densities.”

Given this, we believe an af of 0.5 would lead to unrealistically low bulk densities, which are not representative of tundra snowpack conditions.

Appendix:

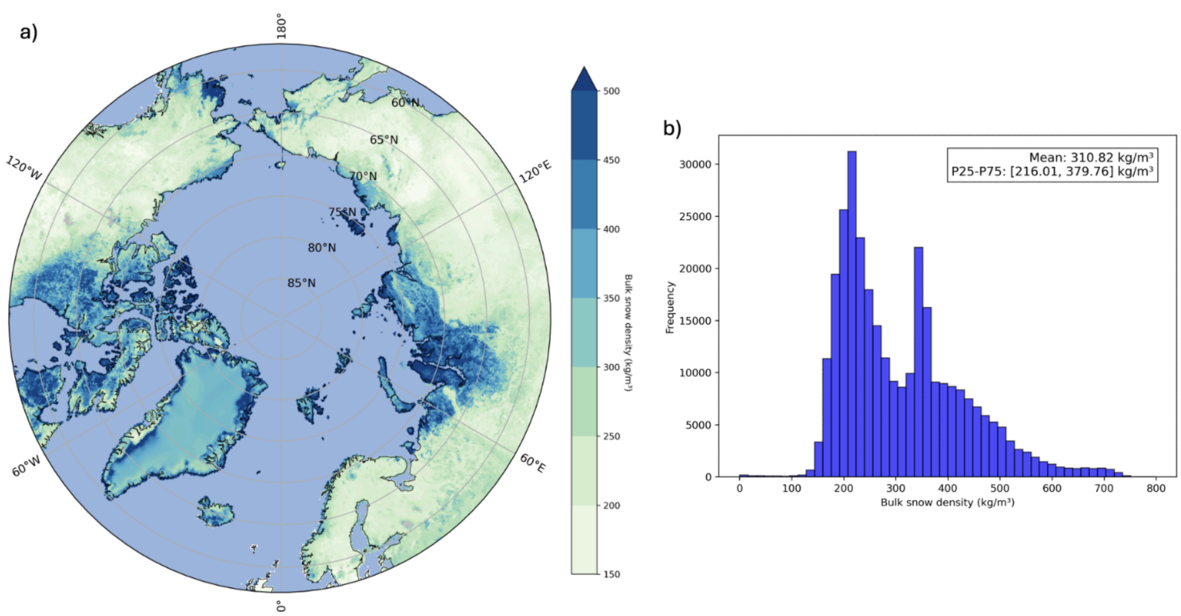

Figure A2. a) Period averaged (1980-2021) bulk snow density for the control run and b) its corresponding histogram.

“Figure A2 represents the spatial and statistical distribution of bulk snow density for the control run in our domain. The bulk snow density is calculated using the snow water equivalent (SWE) (m) and snow depth (m) through the following equation:

$$\rho_{sno} = \rho_w \frac{\mathrm{SWE}}{\mathrm{SD}}$$

where ρ_w is the density of liquid water (1000 kg/m³). The mean density is 311 kg/m³, with an interquartile range (P25–P75) of 216 to 380 kg/m³. The histogram reveals a multimodal distribution, indicative of different snowpack types (e.g. tundra, maritime, alpine)."

Additional literature:

Derksen, C., Lemmetyinen, J., Toose, P., Silis, A., Pulliainen, J., & Sturm, M. (2014). Physical properties of Arctic versus subarctic snow: Implications for high latitude passive microwave snow water equivalent retrievals*. Journal of Geophysical Research: Atmospheres, 119(12), 7254–7270.*

Woolley, G., Rutter, N., Wake, L., Vionnet, V., Derksen, C., Essery, R., Marsh, P., Tutton, R., Walker, B., Lafaysse, M., & Pritchard, D. (2024). Multi-physics ensemble modelling of Arctic tundra snowpack properties*. The Cryosphere, 18(12), 5685–5711.*

Zhao, W., Mu, C., Wu, X., Zhong, X., Peng, X., Liu, Y., Sun, Y., Liang, B., & Zhang, T. (2023). Spatio-Temporal Characteristics and Differences in Snow Density between the Tibet Plateau and the Arctic*. Remote Sensing, 15(16), 3976.*