Reviewer 2

This manuscript evaluated the performance of ELM in simulating snow-related properties across the Western United States. The authors conducted a 50-year offline regional land simulation and evaluated the modeled snow properties against various observational and reanalysis datasets. The experiment is well-designed, and the discussions are well-presented. Such comprehensive model evaluations are valuable for further studies on improving climate simulations, especially for studies based on E3SM.

Thank you very much for your helpful suggestions/comments!

General comments:

1. The authors should consider revising the title of this manuscript. Snow processes on land imply snow metamorphism, i.e., how snow changes over time. This manuscript focuses more on the accuracy of ELM-simulated snow properties rather than evaluating the ELM snow metamorphism schemes.

Considering this comment and the 1st comment from Reviewer 1, to avoid the misunderstanding, we have revised the title as "Evaluation of E3SM Land Model snow simulations over the Western United States" in the revised manuscript.

2. The authors gathered a lot of observational data to evaluate ELM model simulations. They presented many well-organized figures, including model-minus-observation and their temporal correlations for each snow property. Yet, they need to add more discussions on how these properties interact. For example, is the bias in snow grain size contributing to snow albedo and further influencing SWE and snow-covered fraction? Such discussions are crucial and will help the users to understand the snow simulations in ELM.

Good point! Systematic analysis of the propagation of uncertainty of different snow properties is crucial for better understanding the uncertainty source of snow simulations in ELM. Both snow grain size (S_{sno}) and snow albedo reduction (R_{sno}) are related to snow albedo (α_{sno}). α_{sur} is a combination of α_{sno} and the albedo of non-snow vegetation/soil. α_{sno} determines the energy absorbed by snow and thus affects the snowmelt process. Therefore, SWE and snow depth (D_{sno}) can be further affected by α_{sno} simulations. In ELM, snow cover fraction (f_{sno}) is modeled as a function of SWE. We have added such discussion on connecting different snow properties and the corresponding uncertainties as below in Line 519-530 of the revised manuscript.

The climatological aerosol deposition data used in the ELM simulations is too coarse to capture the fine-scale spatial variations of BC and dust, which limits the accuracy of simulated R_{sno} and thus α_{sno}. The model structures used in different LSMs have different complexities, assumptions and simplifications. In ELM, some snow processes are modelled empirically, and some parameters are set empirically or from the literature, which may contain large uncertainties. For instance, in the ELM snow albedo model, spherical snow grain shape, internal mixing of BC-snow and external mixing of dust-snow are the default settings, which can potentially affect the accuracy of R_{sno} and α_{sno}. The large uncertainty of S_{sno} is a factor responsible for the unrealistic snow aging representations in ELM (Qian et al., 2014), which can further affect α_{sno}. The bias in α_{sno} can further affect the accuracy of absorbed energy by snow and α_{sur} (contains the contributions from snow and non-snow vegetation/soil), and thus the change of SWE and D_{sno}. The uncertainties of SWE can further propagate to f_{sno}, because ELM uses SWE to estimate f_{sno} (Swenson and Lawrence, 2012). In the snow cover parameterization of ELM, snow accumulation ratio and snowmelt shape factor are empirically set as fixed values without spatio-temporal variations (Swenson and Lawrence, 2012), which can also affect the accuracy of f_{sno}. The snow cover over complex terrain is simply parameterized as a function of the standard deviation of elevation, which may explain the large biases of f_{sno} (Figure 3) over mountainous areas (Swenson and Lawrence, 2012). All of these contribute to the bias of snow phenology in ELM (Section 3.2).

3. Lastly, the authors conducted an offline ELM experiment, presumably for computational efficiency. Would the results differ with coupled simulations considering various snow-related feedbacks?

Yes, coupled simulations can consider the snow-related feedback between land and atmosphere, but can also have more uncertainties from the atmospheric forcing which is simulated. We conducted the offline land-only simulations for the following reasons:

1) Errors in both simulated temperature and precipitation have been recognized as the main drivers of snowpack errors in the coupled E3SM simulations (Brunke et al., 2021). To reduce the impacts of the uncertainties from atmospheric forcing, our study focused on evaluating the offline ELM simulations forced by data from the National Land Data Assimilation System phase 2 (NLDAS-2). However, snow-related land-atmosphere interactions were neglected in these land-only simulations. How well E3SM capture the impacts of snow on regional climate needs further investigations by performing coupled E3SM simulations with active land and atmosphere models. We added these discussions in Line 545-550 of the revised manuscript.

2) We conducted the ELM simulations over the WUS at 0.125° spatial resolution, which is higher than the typical 1° spatial resolution used in fully coupled E3SM simulations (Golaz et al., 2022). We expect that such high-resolution simulations can better capture the spatial heterogeneity of snowpack. Coupled simulations at such high resolution are more computationally demanding. We have added these discussions in Section 2.2 of the revised manuscript.

References

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