Response to Comments by Topical Editor Decision: Publish Subject to Minor Revisions (Review by Editor) for the Manuscript gmd-2021-333
"**Optimization of Snow-Related Parameters in Noah Land Surface Model (v3.4.1) Using Micro-Genetic Algorithm (v1.7a)**"
by Sujeong Lim, Hyeon-Ju Gim, Ebony Lee, Seungyeon Lee, Won Young Lee, Yong Hee Lee, Claudio Cassardo, and Seon Ki Park

We appreciate the valuable and constructive comments, which helped us improve the quality of the manuscript. An item-by-item response to the comments is provided below.

1. *Line 39-41: As a common knowledge, it is unnecessary to have this sentence "Here, the parameter is constant that makes up the equations, which is usually fixed during the simulation and differs from the variable representing the time-varying state of the model". Instead, I think that authors should make it clear in the text if the estimated parameters vary with space and time in this work. If yes, it would be nice to provide field plots of variables compared to observations (Currently, only plots with numbers are shown).*

   ⇒ Thank you for your comments. In this study, 'parameters' (i.e., P_s, $\alpha_{max,CofE}$, C, P_1, P_2, and W_{max}) are all constants while 'variables' (i.e., snow cover, snow albedo, and snow depth) vary with time and space. Therefore, we do not have any field plot showing temporal/spatial variations of parameters. Instead, we have added a statement in the revised manuscript, saying "These parameters are all constants and do not vary with time and space." (Line 231-232), and removed the statement in Line 39-41 as the Editor suggested.

2. *It should be said at the beginning of Line 83-86 that results are presented in Fig.1.*

   ⇒ Thank you for your comments. We have introduce the Fig. 1 in the revised manuscript (Line 86) at the beginning of original manuscript 83-86:

   "Figure 1 represents the responses of the snow variables to the variations in the snow-related parameters for given ranges."

3. *It would be good if authors can add a discussion on the current problems of old parameter estimation method at the end of 2.1 or at the beginning of 2.2.*

   ⇒ Thank you for your suggestion. We have included the old parameter estimation method at the end of 2.1 in the revised manuscript (Line 74-78).

   "The above-mentioned snow processes contain certain estimated coefficients or constants, known as *parameters*, which employ typical, empirical or a priori values. The parameters are provided as look-up tables based on their samples in the field or lab. Traditionally, they are tuned by trial and error to calibrate the model against historical observations in a specific location; however, a systematic and objective procedure is essentially required for a large number of stations (Duan et al., 2006; Rosolem et al., 2013). We explain below the details of the snow-related parameters to be optimized for various stations in SK."

4. *Would be better to move the last paragraph of section 5 to the section of conclusion as outlook? and change Section "Conclusions" to "Conclusion and outlook".*

   ⇒ We have rearranged the paragraph as your suggestion.

   5. Conclusions and Outlook

   "The Noah Land Surface Model (Noah LSM) generally underestimates snow amount during the peak winter and shows earlier snow melting in spring, whereas it overestimates snow albedo (SA) over Eurasia, mainly due to uncertain parameterzation processes (Saha et al., 2017). Our experiment with no optimization (CNTL) reveals underestimation of snow depth (SD) and fractional snow cover (FSC) and overestimation of SA compared to the in-situ or satellite observations. Therefore, we have developed a coupled system of micro-genetic algorithm (micro-GA) and Noah LSM to reduce the uncertainties in parameterized snow processes through optimization of parameter values. This parameter estimation is an effort to further improve the model performance by reducing uncertainty in pre-existing parameterization schemes by optimizing the parameter values inside the schemes based on the observational data that reflect local characteristics to improve snow simulation. If the employed parameterization scheme has less uncertainty, improvement by parameter estimation on that scheme may not be significant; if the scheme has large uncertainty in parameter values, parameter estimation may bring about prominent improvement in the scheme's performance.

   The coupling system of micro-GA and Noah LSM automatically estimates the optimal snow-related parameters by objectively comparing observations and model solutions through the fitness function. Instead of trial-and-error procedures, it has an advantage to reduce a substantial amount of computational time. The original micro-GA reduces the computational time using the elitism and re-initialization methods in the small number of individuals. However, we have developed a parallel system on the coupled system to further improve the computational efficiency in this study; it enables us to simultaneously execute multiple individuals in one generation and multiple Noah LSM runs in one individual.

   Six parameters included in the snow processes in Noah LSM have been optimized by using a micro-GA during the period 2009-2018 in South Korea (SK). The first parameter is the distribution shape parameter that participates in the FSC calculation and shows a positive correlation with the FSC: the optimized value is expected to increase the FSC, but it is not sufficient to alleviate its underestimation problems. The second parameter is snow water equivalent threshold value that implies 100 % snow cover and also is used in the FSC calculation depends on the land cover type: its optimized value improves the FSC in terms of RMSE and mean bias over some stations. The third parameter is the maximum SA coefficient: its optimized (decreased) value improves the RMSE by reducing the overestimation of SA. The fourth parameter is the coefficient in the maximum albedo of fresh snow, and its optimized value was similar to the default one. The other two parameters are related to the fresh snow density used for the SD calculation. In particular, the sixth parameter depends on air temperature and its optimization brings about the largest improvement in SD: the optimized (reduced) value remarkably reduces the RMSE, which ameliorates the underestimation problem of SD. This significant improvement of SD is due to the high spatial and temporal resolutions of observations.

The best combinations of snow parameters optimized for SK can be used to improve the snowfall prediction. Our results showed improvement in all snow variables in terms of RMSE by 3.3 %, 6.2 %, and 17.0 % for FSC, SA, and SD, respectively. Furthermore, SD increased after optimization, which lead to increases in both soil temperature and sensible heat flux via insulating response; soil moisture also increased due to increased SD in previous years. This implies that the optimized snow parameters not only let the model solutions close to the observations but also act in a physically consistent manner. Satellite observations proved to be effective in the optimization; however, their coarse resolution as well as insufficient number of stations used for optimization often restrict improvement of the snow variables, as shown in some discouraging statistics including the mean bias and the coefficient of determination (R^2).

Based on the encouraging optimization results in the off-line Noah LSM, we plan to optimize the Noah LSM in a coupled land-atmosphere prediction system. The online Noah LSM can produce a spatial distribution of model variables over the land surface, which allows a two-dimensional assessment of model performance and a three-dimensional extension through various interactions between the land surface and the atmosphere. We anticipate the optimized snow parameters can lead to positive effects on the atmospheric variables through the changes of heat fluxes as well as snow variables in Noah LSM. As a result, we can identify how optimal parameters are appreciated in SK in terms of both horizontal and vertical distributions. Furthermore, the micro-GA-Noah LSM coupled system can be utilized to optimize other parameters in Noah-LSM, including the ones that indirectly affect the snow processes."

References

[1] Rosolem, R., Gupta, H. V., Shuttleworth, W. J., de Gonçalves, L. G. G., and Zeng, X: Towards a Comprehensive Approach to Parameter Estimation in Land Surface Parameterization Schemes, Hydrol. Process., 27(14), 2075-2097, 2013.