Response to Comments on the Manuscript:

"Investigating the performance of Genetic Particle Filter in snow data assimilation across snow climates"

(HESS-2022-350)

May 17, 2023

The authors gratefully acknowledge the editors and the anonymous reviewers for their constructive comments. We have made a comprehensive revision of our previous manuscript. The main modifications have been highlighted in yellow color in order to highlight the issues raised by the editors and anonymous reviewers, and are summarized as follows:

For more details, please refer to the item-by-item response. Thank you for your time.

Response to comments by Reviewer #2：

We would like to take this opportunity to gratefully thank the reviewer for his/her constructive comments and recommendations for improving the paper. An item-by-item, point-by-point response to the interesting comments raised by the reviewer follows.

Main points:

1) The manuscript still needs a thorough copy editing. I have included suggestions on grammatical corrections below, but I have stopped at about page 6, since the text contained errors almost every other line. It can be cumbersome for foreign authors, like myself, but nowadays, several software packages assist the authors. In any case, a manuscript should appear written in proper English. Furthermore, it should be the task of a reviewer to correct the grammar of a manuscript, even less so when this is the second version.

Response: Thank you for your sincere and constructive suggestions. Despite our best efforts in revising this manuscript, it may still contain some errors. We would like to express our gratitude to the reviewer for correcting the grammar and syntax issues present in the manuscript. Additionally, we have thoroughly proofread the entire document and even utilized the services of a senior English writing expert to ensure that all language and grammar issues have been addressed.

2) As with the first version, the data assimilation's real purpose in the snow depth context

remains unclear. Usually, a model assimilates a set of limited observations but provides a much more complete output regarding variable and spatial coverage. For instance, a weather prediction model assimilates available station observations of some variables but produces a complete field of future predictions. Here, the hydrological model assimilates snow depth observations but estimates snow depth at the same location, and it does not even produce predictions of snow depth. So the utility of the whole set-up is unclear. Shouldn't the model be validated by comparing prediction versus observations? The conclusion of the study that the results of assimilation are closer to observations is to ma a tautology. Of course., the model results are corrected towards the observations. It is no surprise that those corrected values are closer to observations. A natural progress would be if the model *predictions* for a specific time step t are closer to observations when the observations prior to t are assimilated.

Response: Thank you for your sincere and constructive suggestions. We strongly endorse the reviewer's opinion that a set of limited observations assimilated by a model should lead to a comprehensive output. The original goal of this study was to investigate the performance of the Genetic Particle Filter as a snow data assimilation scheme across various snow climates. The model was driven by meteorological forcing data and halted when the observation occurred, then the observation data was assimilated into the model. Here, the observed snow depth at the point-scale was assimilated into Noah-MP model and the assimilation step was set to five days. Our findings demonstrate a noticeable improvement in the model results after each assimilation step. While we agree with the reviewer's suggestion of validating the model predictions against actual observations, it must be noted that in this study, historical data was used to perform experiments with assimilations being carried out every five days, resulting in only five-day-long "model predictions". Therefore, the effectiveness of the assimilation approach was evaluated by comparing the assimilation results, non-assimilated model simulations, and observations.

Particular points:

3) line 78 'and AMSR-E SWE into a hydrologic model to improve modeled SWE..' hydrological model.

Response: Thank you for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

4) line '81 assimilating ground-based snowfall and snowmelt rates, simultaneous assimilation of D-InSAR. The acronym has not been defined yet.

Response: Thank you for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

5) line 88 "dynamic system" usually has strong nonlinearity. change to "dynamical system".

Response: Thank you for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

6) line 95 "The greatest strength of PF technique is free from the constraints of model linearity and error following Gaussian distribution, this makes the PF technique succeed applied in nonlinear and non-Gaussian dynamic systems." change to "the greatest strength of PF technique is to be free from the constraints of model linearity and error following a Gaussian distribution. This allows the successful application of the PF technique to nonlinear dynamical systems with non-Gaussian errors".

Response: Thank you for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

7) line 97 "dynamic systems. Additionally, PF technique give weights" change to "dynamical systems. Additionally, the PH technique gives weights."

Response: Thank you for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

8) line 108 "snowpack runoff simulations (Magnusson et al., 2017). Above studies demonstrated that either assimilated the snow-related in-situ measurements or remotely sensed observation data through PF technique can successfully update the predictions of snowpack dynamics," change to "The studies indicated above demonstrated that the assimilated snow-related in-situ measurement or the remotely sensed observation data through PF technique can successfully update the predictions of snowpack dynamics."

Response: Thank you for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

9) line 112 "Nevertheless, particle degeneracy is still one potential limitation for PF technique, it occurs when most of particles have negligible weight and only few particles have significant weights, which makes the state probability distribution cannot be represented by the particles" to "Nevertheless, particle degeneracy is still one potential limitation of PF technique. It occurs when most particles have negligible weight, and only a few particles carry significant weights, which hinders a realistic sampling of the underlying probability distribution of the state."

Response: Thank you for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

10) line 116 "an efficient approach which can effectively mitigate the problem of particle degeneracy, however, may lead to the resulting sample will contain many repeated points a"

change to "An efficient approach that can effectively mitigate the problem of particle degeneracy. However, it may lead to the resulting sample containing many repeated points a."

Response: Thank you for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

11) line 147 is distributed at different latitudes in the "northern hemisphere" change to "Northern Hemisphere."

Response: Thank you for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

12) line 148 "located beside the Kitinen River in Finland and has a 2 m depths frost" change to "located beside the Kitinen River in Finland. The upper 2 meters are frozen."

Response: Thank you for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

13) line 164 It is noteworthy that "the spatial variance on the performance of the model" is negligible change to "the spatial variance of the performance of the model".

Response: Thank you for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

14) line 168 detailed information of snow climates, and dataset process introduction of the eight sites can be also referenced in You et al. (2020a). What is 'data process'. ....can also be found in You et al. (2020a).

Response: Thank you for your sincere and constructive suggestions. Regarding the dataset process, it involves the processing of original meteorological measurements from eight sites for the experiment. For instance, some subhourly measurements were converted to hourly at certain sites. You can find more information on the data processing method in You et al. (2020).

15) line 170 The snow partial within Noah-MP model. This is not proper English. It is unclear what snow partial is.

Response: Thanks for your sincere and constructive suggestions. Based on your feedback, we have revised 'snow partial' to 'snow partial module' in the manuscript and highlighted in yellow color. This term refers to the snow module within the Noah-MP model.

16) line 213 function p (zt xt i) , which measures the likelihood of a given model state concerning the observation z t. The notation could be clearer. Usually, I would interpret p (z_t) | x_ti) as the probability of z_t conditional on x_ti.

Response: Thanks for your sincere and constructive suggestions. Typically, the $p\left(x_t^i \middle| z_t\right)$ denotes the probability of x_t^i conditional on z_t, which is referred to as the posterior probability of x_t^i. Likewise, the $p\left(z_t \middle| x_t^i\right)$ denotes the probability of z_t conditional on x_t^i, known as the likelihood probability. However, if the reviewer feels that a clearer notation is necessary, we are happy to change it at any time.

17) line 215 "In general, a Gaussian distribution was assumed to perturb the observations and the likelihood function was defined to represent the errors." change to "The observation errors are generally assumed to follow a Gaussian distribution, and the chosen likelihood function represents this assumption."

Response: Thanks for your sincere and constructive suggestions. We have revised in the manuscript and highlighted in yellow color.

18) line 225 if the effective sample size. what is the effective sample size? Is it just the number of samples? The text does not mention autocorrelation at all, so the word 'effective' is unclear.

Response: Thanks for your sincere and constructive suggestions. As mentioned in the manuscript, particle filter schemes suffer from the degeneracy phenomenon. In fact, after several iterations, all but one particle will have negligible weight. To measure the degree of degeneracy, the effective ensemble size N_{eff} is a suitable metric. In our case, the estimation of N_{eff} can be calculated by $N_{eff} = 1 \Big/ \sum_{i=1}^{N} \left(w_t^i\right)^2$, and a small value indicates severe degeneracy (Mechri et al., 2014; Piazzi et al., 2018).

19) line 242 The role of the survival rate is unclear. It seems that the survival rate is just a measure of the distance between the particle and the observations. This distance is already considered when assimilating the observations with the weighted average over particles. So is this a double counting?

Response: Thanks for your sincere and constructive suggestions. The Genetic Algorithm could be defined as a stochastic searching algorithm (a function optimizer) ensuing from Darwin's evolution theory, simulating the well-known *survival of the fittest* evolution. In this study, the measurement of fitness was determined by the survival rate, which was calculated based on the distance between the particles and observations to select high-quality particles. Additionally, the distance was also considered when assimilating the observations, in order to update the weight of particles. Consequently, this does not constitute double counting, as noted by the reviewer.

20) line 268 All particles are disturbed with a gaussian error. Isnt is just the same as the mutation, only with a different type of error distribution? what is the role of the mutation?

Response: Thank you for your sincere and constructive suggestions. Our approach involves using a complete GA (genetic algorithm) that re-supplies or re-defines particles through the selection, crossover, and mutation operators. The mutation operator plays a crucial role in increasing particle diversity and avoiding particle impoverishment. In this study, we implemented the mutation process using equation (11) and assumed a random number from a uniform distribution. Since the particles represent the model variable 'snow depth' and must be greater than or equal to zero, introducing a random number from a Gaussian distribution may result in a negative particle value, which would cause the model to stop.

21) line 339 'Since the meteorological perturbations are unbiased, the nonlinearity of physical processes within the model is supposed to be the main reason for the uncertainty'. I may not understand this sentence. The magnitude of uncertainties is not related to the linear or nonlinear character of the model. A linear model would just rescale the spread in the forcing and nonlinear model would expand or shrink disproportionally the forcing uncertainties. So the nonlinear character itself cannot be the reason per se of.

Response: Thank you for your sincere and constructive suggestions. We greatly appreciate the reviewer's opinion that the magnitude of uncertainties is not solely dependent on the linear or nonlinear character of the model. In our view, the model structure is one of the main reasons for uncertainty, and it is influenced by the degree of complexity of physical processes with nonlinear characteristics. And we have revised in the manuscript and highlighted in yellow color.

22) Section 3.1 Open-loop ensemble simulations. The expression open loop-ensemble is used only once in the title of this section. What is its meaning? It is nowhere defined nor used again. This section is also tough to read. It contains just one very long paragraph without clear structure.

Response: Thank you for your sincere and constructive suggestions. The open-loop ensemble simulations mean the ensemble simulations forced by perturbed meteorological data and without data assimilation. With the aim of properly analyzing the skill of the data assimilation scheme, the assimilation results are evaluated through comparison with the control open-loop. We have revised the manuscript and presented a clear structure.

Mechri, R., Ottle, C., Pannekoucke, O., and Kallel, A.: Genetic particle filter application to land surface temperature downscaling, Journal of Geophysical Research-Atmospheres, 119, 2131-2146, 2014.

Piazzi, G., Thirel, G., Campo, L., and Gabellani, S.: A particle filter scheme for multivariate data assimilation into a point-scale snowpack model in an Alpine environment, Cryosphere, 12, 2287-

2306, 2018.

You, Y. H., Huang, C. L., Yang, Z. L., Zhang, Y., Bai, Y. L., and Gu, J.: Assessing Noah-MP parameterization sensitivity and uncertainty interval across snow climates, Journal of Geophysical Research-Atmospheres, 125, e2019JD030417, 2020.