Reply to comments from Anonymous Referee #2.

General Comments

This study investigates the temporal change of the uncertainty of initial condition in variably saturated flow model and assesses the impacts of several commonly-used initializing methods on results within various data assimilation frameworks. The topic is interesting and relevant to the topics of the Hydrology and Earth System Sciences. The manuscript is well-organized and easy to understand, although some of language, may be further refined and improved. The results and discussion are adequate to reach very instructive conclusions for variably saturated flow modeling. Several highlights for this manuscript: compared to previous researches on UIC issue, this study focuses on soil water modeling and makes a comparison between Monte Carlo (preferred by groundwater hydrologist) and Spinning up methods (preferred by surface water hydrologist). The investigation of warm-up time with different soil textures and depths is quite interesting. The study of UIC propagation with data-model interaction is another merit. Therefore, I recommend this paper for publication in the Hydrology and Earth System Sciences, with a few comments.

[Response]

Thank you for your positive comment!

Major comments:

1) Authors have compared the difference of model outputs with various data assimilation framework (i.e., EnKF and IES). As the authors correctly point out, the ensemble size is an important factor for these two algorithms, which need to be discussed further. I encourage the authors to explore the effects of ensemble size on EnKF and IES with multiple test so that a suitable ensemble size for these two assimilation framework can be determined.

[Response]

Thank you for your comment, according to the suggestions from you and another reviewer, we will add a new figure to explore the effects of ensemble size on the parameter estimations within EnKF and IES. The impact of ensemble size on UIC seems different for various data assimilation framework.

[Changes in the manuscript]

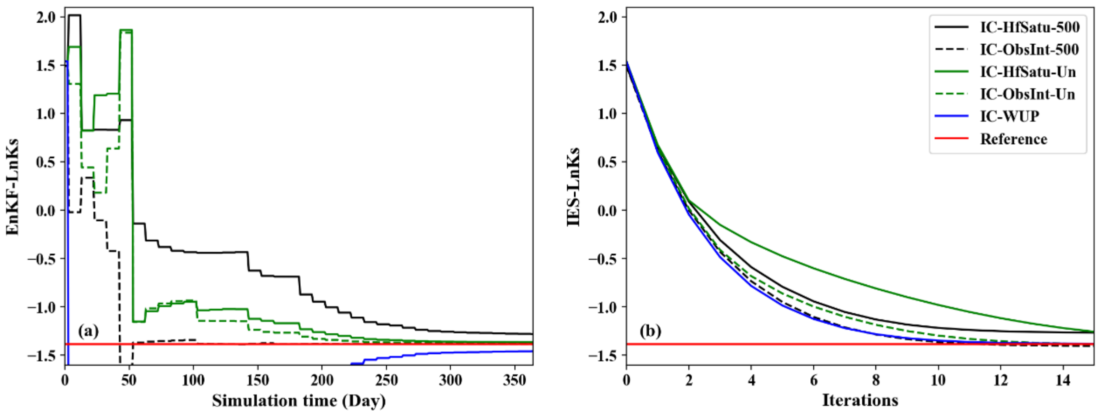

Figure 1. The impacts of ensemble size and the uncertainty of initial ensemble on the results of lnK_s estimations within EnKF and IES.

The effects of increasing ensemble size are totally different for EnKF and IES. In Figure 1(a), when the ensemble size grows to 500, the assimilation results of IC-HfSatu-500 are worse than that of IC-ObsInt-500, implying that the initialization methods still plays an important role in parameter revisions even with a larger number of ensemble size. Besides, compared with the IC-ObsInt and IC-HfSatu with the ensemble size of 300 (Fig. 6(a)), IC-ObsInt-500 and IC-HfSatu-500 both show better data assimilation results, indicating that the results of parameter estimations can be improved by increasing ensemble size for EnKF. The results are reasonable since the cross-correlation between model parameters and states can be better calculated with a large number of realizations. With the similar computational cost, the UIC of IC-ObsInt-500 stabilize the update steps, making the results better than IC-WUP. On the contrary, the impacts of improving ensemble size are slight for IES. As plotted in Figure 1(b), the data assimilation results of IC-HfSatu-500 and IC-ObsInt-500 are similar with that of 300. Since IES is a kind of iterative history-matching algorithm, the nonlinear relationship can be well calculated during the iterations, while the UIC is existed in the whole simulation. Therefore, warm-up methods show better data assimilation results within IES.

2) The synthetic case study present the proper warm-up time t_{wu} versus different soil texture, soil depth, and meteorological conditions. While the relationship between t_{wu} and meteorological conditions may be commonsense, the reveal of quantitative relationship between t_{wu} and soil texture and soil depth is surprising and interesting, due to the fact that t_{wu} changes abruptly from sand to finer texture, and it increases nonlinearly with the increase of soil depths. However, the soil is seldom homogeneous in natural conditions, especially for very long soil profile. The authors should at least present one simulating result of t_{wu} for layered soil, which is more applicable for real-world case. I believe this should take too much work since it is one-dimensional model.

[Response]

Thank you for your valuable comment. We have added a case to obtain the t_{wu} for layered soil in our manuscript. The layered soil is consistent of four kinds of soil types, including loam (0 to 75 cm), clay loam (75 to 150 cm), silt (150 to 225 cm) and sand (225 to 300 cm).

[Changes in the manuscript]

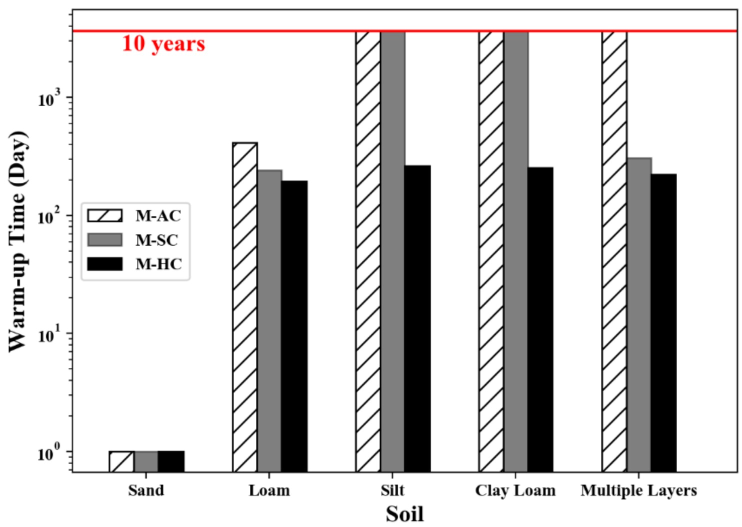

Fig. 4. The length of warm-up time t_{wu} with various soils and meteorological conditions. Note that t_{wu} of Silt and Clay loam with M-AC and M-SC exceed 10 years as well as the t_{wu} of multiple layers with M-AC. The consistent layers of heterogeneous soil are the loam (0-75 cm), clay loam (75-150 cm), silt (150-225 cm), and sand (225-300 cm).

In the revised manuscript, we expanded the results and demonstrate the difference of t_{wu} value in the layered soil.

Minor comments:

Line 12: various initial condition »> various initial conditions

Thank you. Revised

Line16: model initializing »> model initializing methods

Thank you. This has been revised.

Line 28: delete in

Thank you. Revised.

Line 48: a space between approaches and comma

Thanks. The error has been corrected.

Line 61: hereafter referred »> hereafter referred to

Thank you. It is revised

Line 77: delete the last the

Thank you. It is modified.

Line 81: initial ensemble are »> initial ensemble is

Thank you. It is rewritten.

Line83: Currenlty »> Currently

Thank you. Revised

Line 110: Richards's »> Richards'

Thanks. Revised

Lines 129-130: as state dependent, atmospherics boundary condition (try to be more concise here and some other statements)

Thanks. It is rewritten.

Line 135: detemined »> determined

Thanks. Revised

Line 141: use UIC instead Eqs. (9-10): try to use one equation instead and shorten the description of the equation.

Thank you. It is revised.

Line 172: assimilation + approach

Thanks. Revised

Line 210: which λ values you use in the simulations?

Thanks. λ is a dynamic stability multiplier during the iterations. The prior value of λ is 10, but the value can be adjusted adaptably according to the data assimilation results at every iteration.

Line 222: perscribe »> prescribe

Thank you. It is revised.

Line 223: availablitity »> availability

Thanks. Revised.

Line 256: be consistent using italic or not for PC.

Thank you. This has been revised.

Line 256: why 3%?

Thank you. The Gaussian noise is determined as 3% according to the observation error of soil moisture since the uncertainty of parameter is not taken into consideration in this part. We have added a sentence to explain it.

Line 335: warms »>warm

Thanks. Revised.

Line 356: delete both

Thanks. This has been revised.

Line 358-359: thus »> and thus

Thanks. Revised.

Line 372: multiple spaces between runs and are.

Thanks. Revised.

Change "than" to that

Thanks. This has been revised.

Line 405: Which evapotranspiration model are you using?

Thank you for your comment. The potential evaporation is calculated by Penman-Monteith's equation. We will add an explanation in the manuscript.

Line 427: needs a space after "part."

Thanks. Revised.

Lines 443-444: "soil moisture profile has large variation, e.g., discontinuous soil moisture in layered soils." — it would be interesting to see an additional case for heterogeneous soils, and this also leads to another interesting question — what will happen if pressure head profile, which is continuous in heterogeneous soil, is used as *initial condition. Please add some discussion on this topic.*

[Response]

Thank you for your valuable comments. We have added the case about t_{wu} of multiple layers in the manuscript, please see Fig. 4 above. Regarding the topic about using initial pressure head as initial condition, we are going to discuss it from three aspects:

(1) It is easier to collect the soil moisture data than pressure head in vadose zone, so that we only use soil moisture as observation in this study. In heterogeneous soil, the pressure head profile is more continuous than the soil moisture profile, which may contribute to better model outputs.

(2) With respect to t_{wu}, the conversion relationship between the spread of soil moisture and pressure head is deterministic (i.e., the spread as well as the t_{wu} value with pressure head profile can be derived from that with soil moisture profile). Thus, the effects of pressure head and soil moisture are slight on UIC.

(3) The impact of observation type (i.e., pressure head and soil moisture) on data assimilation results has been widely explored in previous studies (Shi et al. 2015), since they have various distributions, nonlinearity and observation errors. The deviation of data assimilation results between pressure head and soil moisture is less induced by UIC, so we are not going to discuss in detail here.

[Changes in the manuscript]

We will add some discussions about the effects of initial pressure head profile in heterogeneous soil in Section 5.

Line 452: atmospheric condition »> atmospheric boundary condition

Thanks. Revised.

Conclusion 2: Please include more details and add quantitative conclusions for this.

[Response]

Thank you. We have modified the conclusion 2 according to your suggestion.

[Changes in the manuscript]

Warm-up time varies nonlinearly with soil textures, meteorological conditions, and soil profile. A very long time is needed to warm up the model for the fine-textured soil with an arid meteorological condition and a thick vadose zone.

Errors in references: Line 566, Line 673, Line 610, Line 639.

Thanks. Revised.

Reference

Shi, L., Song, X., Tong, J., Zhu, Y. and Zhang, Q.: Impacts of different types of measurements on estimating unsaturated flow parameters, J. Hydrol., 524, 549–561, doi:10.1016/j.jhydrol.2015.01.078, 2015.