Reply to comments from Anonymous Referee #3

General Comments

This paper studies an important problem of soil water modeling: the uncertainty of initial condition (UIC) through analyzing the effects of different initial conditions on parameter estimation within two data assimilation frameworks. I believe this work provides useful insights to improve our understanding of uncertainty of initial conditions. I would be in favor of publication after the authors addressed the comments given below.

[Response]

Thank you for your positive comment! We have revised our manuscript according to your suggestions.

Comments:

1. The grammar of this paper needs some improvements, some small grammar errors can be found.

Thank you for your suggestion. We have invited a native English speaker to proofread our manuscript.

2. The quantification of initial condition uncertainty (UIC) is unclear, especially for the usage of data assimilation method. I don't follow how two methods combined.

[Response]

Thank you for your valuable comment. We are sorry that we did not explain it clearly. In data assimilation problems, the parameter uncertainty is considered to be major uncertainty source, while the effects of initial condition are often ignored. In this study, we take the uncertainty of both into the consideration. In order to gain a better understanding of the propagation of the UIC, we firstly assumed all the hydraulic parameters (i.e., K_s, α and n) to be deterministic and the UIC is the only uncertainty source (Section 3.2). By utilizing the PC and Spread index, the effects of UIC over time and the required warm-up time t_{wu} (minimum time required for the model to warm up to eliminate the UIC) can be calculated. Then, we take both the uncertainty of UIC and parameter into the consideration and compared several common initialization methods for variably saturated model. And we found that when we warm up model more than t_{wu}, better data assimilation results can be obtained. Our work can be a reference for the data assimilation problem.

[Changes in the manuscript]

We have added some explanations and modified our manuscript to make the description clearer.

3. The purposes of using data assimilation method and its relationships to results and conclusions are unclear.

[Response]

Thank you for your comment.

(1) Accurate characterization of soil properties is essential for the precise predictions of water movement and solute distributions in the vadose zone. However, obtaining detailed knowledge of soil parameters is challenging for its difficulty in direct measurement. Yet, hydrological data, such as soil moisture and pressure head, can be collected more conveniently and provide additional information. Incorporating these observations into stochastic models helps to reduce the uncertainty of the parameters and prediction which is known as “data assimilation”. In recent years, data assimilation has become a popular tool and been widely used in the field of vadose zone hydrology (Shi et al., 2015; Vereecken et al., 2010; Walker et al., 2001). Hence, it is necessary to fully investigate data assimilation problem. One of our purpose is to identify how exactly UIC affect the data assimilation results and propose a suitable initialization method for the model within various data assimilation framework.

(2) We drew two main conclusion about how UIC affects data assimilation results. First, by comparing sequential data assimilation (EnKF) and history-matching algorithm (IES), we found that the IES is affected less by the UIC if warm-up method is implemented at the beginning of the simulation for every iteration and with a long

period of observations, while regarding EnKF, data assimilation results can be improved by increasing ensemble size, but the effects of UIC should be paid more attention if a small ensemble size is employed. Second, by comparing data assimilation results, we propose a selection scheme for choosing a suitable approach of initializing variably saturated flow models within different data assimilation frameworks to minimize the influence of UIC.

[Changes in the manuscript]

We will improve our manuscript according to your suggestions. Some explanations will be added about our purposes of using data assimilation method and we will make its relationships to results and conclusions clearer.

4. Please be more specific about why using both experimental and field model, and how different their results are.

[Response]

Thank you for your comment. In this study, we used both synthetic and field observations. Synthetic data is generated by running the model, while the field data is collected in the experimental station. The true field observations may contain a lot of uncertainty such as artificial and natural error so that we cannot understand the reason which truly causes the change of observations. By utilizing the synthetic observations, we can obtain more accurate conclusions. Then, the field data can be used to validate these conclusions.

The conclusions are similar by using field or synthetic data, but the difference of results between various initialization methods are not so significant, since there are a lot of uncertainty in true observations.

[Changes in the manuscript]

We will add an explanation like "In order to examine the applicability of the conclusions drawn from synthetic case in the real-world, the true field observations are necessary to be incorporated into the model" in the manuscript.

5. Please describe more details about the novelty of this paper, it seems there is no new *method involved, and I am not sure how useful and novel the conclusions are.*

[Response]

Thank you for your comment. Indeed, we did not have any new method involved. However, to the best of our knowledge, we are the first to systematically analyze the effects of initial conditions and initialization methods on the various data assimilation frameworks to date. The specific novelties includes three aspects.

(1) Two common approaches for quantifying the temporal evolution of initial condition uncertainty are compared.

(2) The influences of soil texture, meteorological condition and soil profile length on initial condition uncertainty evolution are exploited.

(3) Different approaches to initialize unsaturated-saturated flow models within two data assimilation framework are assessed.

According to our results, Spin-up method and Monte-Carlo method can both quantify UIC and they agree well with each other after a sufficiently long simulation. And we recommend a threshold of 0.5% for percentage cutoff PC or ensemble spread S_p to balance the computation cost and the effects of UIC. Moreover, the relationship between warm-up time for variably saturated flow modeling and the model settings (soil textures, meteorological conditions and soil profile length) are quantitatively identified. In addition, UIC shows different impacts for IES and EnKF, and we propose a "warm-up" period before assimilating data in order to obtain a better performance for parameter and state estimation.

In conclusion, our work can be a reference for other study to choose a suitable approach of initializing variably saturated flow model within data assimilation framework to minimize the influence of UIC.

[Changes in the manuscript]

We will modify our manuscript according to the discussion above to make the novelties of the paper more apparent.

Reference

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