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Hydrology and Earth System Sciences Discussions

Interactive comment on "Improving soil moisture profile prediction from ground-penetrating radar data: a maximum likelihood ensemble filter approach" *by* A. P. Tran et al.

A. P. Tran et al.

phuong.tran@uclouvain.be

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The present work explores the potentials of a new sequential assimilation procedure to assess the accuracy of the soil moisture profile prediction using time-lapse GPR data. The authors develop a closed-loop data assimilation procedure based on the maximum likelihood ensemble filter algorithm (MLEF), developed by Zupanski (2005), to update the vertical soil moisture profile from time-lapse ground-penetrating radar (GPR) data.

The validation of the procedure was carried out using a numerical simulation generated by the Hydrus-1D model. The experiment was carried out on a synthetic soil column with a depth of 80 cm and analyzed the effects of the soil type on the data assimilation considering 3 different soil types: loamy sand, silt and clay.

The results show that the soil moisture profile obtained by assimilating the GPR data with a closed-loop is much better than that obtained with an open-loop. Results also reveal that the effectiveness of the GPR data assimilation depends on the hydraulic properties of the soil type.

Personally, I think the approach is interesting and can be useful for improving real-time prediction of the soil moisture profiles from time-lapse GPR measurements. The paper deserves to be published on HESS after revisions.

My major concern regards the fact that the methodology makes use only of synthetic data both for the soil moisture profile and also for the GPR data. These two are linked and representative of a virtual case that one will never be able to replicate in the real world, where soil will never be homogeneous and GPR data will be affected by noise due to the antenna or by the presence of stones or other elements. I understand that the scope of the paper is essentially to compare different algorithms, but as a reader I would like to see the real potential of the proposed approach using eventually measured data. Another aspect that deserves attention is the presentation of the methodology that needs a clear description not only of the mathematics, but also of the steps and interactions between different modules that construct the procedures (hydrodynamic model, the observation operator (electromagnetic model) and the MLEF data assimilation algorithm).

Reply: Yes, the main objective of this study is showing that accuracy of the soil moisture profile prediction can be much improved if the time-lapse GPR data are incorporated into the hydrodynamic model in an assimilation framework. In addition, the proposed approach permits to directly assimilate GPR data instead of the surface soil moisture

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only as we usually see in literature. This helps us to use all information of the soil moisture profile contained in GPR data, and therefore, take the advantage of deeper intrusion depth of GPR compared to the satellite remote sensing techniques.

For the homogeneity issue, in real application, we use the widely-used assumption that the soil is locally homogeneous under the antenna foot-print (around 1 m2) in horizontal plane. For the vertical direction, different types of soil can be applied for each soil layer.

The measurement errors were partly considered by the observation error covariance matrix R in the cost function (Equation 10). For more similar with the real application, in the revised manuscript, “observed” GPR data are modified by adding Gaussian noise to the synthetic GPR data. The mean of noise is equal to zero and its standard deviation is equal to the square the diagonal elements of the observation error covariance matrix R.

Each sub model is presented somewhat as independent from the others and it is not clear to me the full picture of the procedure proposed. For this specific point, I suggest to provide a preliminary overview of the procedure at the beginning of section 2, where the flow chart of figure 1 is introduced without an exhaustive description.

Reply: Figure 1 was modified so that the linkage between the sub-models appears more clearly. Some brief explanation was also added as below:

"Figure 1 shows the assimilation procedure that we used to update the state of the soil moisture profile using GPR data, which is interpreted as below to the revised version:

1. Specify the initial soil moisture state and its ensemble based on the priori knowledge on the moisture conditions. This values will work as the analysis state and analysis ensemble at time t=0.

2. Run the Hydrus-1D model to simulate the spatiotemporal dynamics of soil moisture and obtain the forecast state and forecast ensemble at time t+1.

3. Check whether the observation is available. If no, assign the forecast state and its

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ensemble to the analysis ones. If yes, apply the MLEF algorithm to estimate the analysis state variable and square-root analysis error covariance matrix. The observation operator which includes the petrophysical relationship and electromagnetic model is employed to transform the state variable to the observation.

4. Run the Hydrus-1D model for the next time with the initial state being the analysis state obtained from step 3. The ensemble for this step is calculated based on the analysis state and its square-root error covariance."

Minor points: - Pag. 14, line 25, should be: “Comparing Fig. 3a, c, e and 3c, d, f”.

Reply: This was corrected

-Pag. 16, line 5; in fig. 5 where a comparison between the open loop and data assimilation procedure with the synthetic soil moisture is reported, it is difficult to recognize in the same figure the different functions. Moreover it would be useful to increase the font size of the legend.

Reply: The figure was edited so that it appears more clearly.

- Pag. 16, line 15, the meaning of “updated soil moisture profile” should be clarified.

Reply: “updated soil moisture profile” is the predicted soil moisture profile that is updated by the GPR data assimilation. This will be clarified in the revised version.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 1581, 2013.

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