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State transformation to improve the Ensemble Kalman filter performance when using nonlinear unsaturated flow models

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Although it is commonly rather shallow, the unsaturated zone plays an important role in large scale coupled models as the division between rainfall into surface runoff, evapotransporation and groundwater recharge is strongly influenced by the flow processes in the unsaturated zone. In an integrated coupled data assimilation framework, the unsaturated zone could be included as a model compartment and states and parameters could be updated. One of the major problems with the commonly used equations describing flow in the unsaturated zone is that they are strongly nonlinear and that the relation between model states (pressure head) and observable quantities (here water content) can also be nonlinear. If the Ensemble Kalman filter is used as a data assimilation algorithm, these nonlinearities violate the linear assumptions of the filter and may cause problems.

In the presented study we show that extreme state values, as they may occur in an unsaturated zone model, causes skewed ensemble distributions and unrepresentative ensemble means. Ultimately, this can destroy the update and the ability of the filter to correctly estimate model state and parameters. Two type of transformations, the Normal Score Transform and a transformation of the state variable into the observed quantity, are discussed as means to mitigate the problem. It is shown that both transforms improve the estimation of the model states and parameters.