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How useful are head observations for constraining vadose zone models?

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The application of numerical models simulating both groundwater flow and vadose zone processes such as evapotranspiration is becoming more and more common in hydrological sciences. Along with the increase of model complexity, the amount of parameters required is rising: For example, pedo- transfer functions or parameters such as root - or extinction depth of evaporation are often required , but in most cases these parameters cannot be measured and thus are calibrated. However, more often than not, unsaturated models are calibrated based on head observations only, even though it is so far not explored to what extent parameters describing vadose zone processes can be constrained with head observations only.
We aim to close this gap and systematically quantify to what extent vadose zone parameters can be constrained with water table observations, and further quantify the associated predictive uncertainty. In a second step, we explore how additional observation data such soil moisture measurements at the top of the soil, observations of evapotranspiration, transpiration or evaporation allow to further constrain the estimated parameters. We have chosen these kind of data as they can be obtained through remote sensing techniques. Our analysis is based on the simulation of infiltration events through partially unsaturated 1d columns. Unsaturated flow and evapotranspiration are simulated for different hydrological conditions. We apply two methods to explore predictive uncertainty: The linear method which has been discussed in the literature, as well as the new pareto method of PEST. Both methods can be used in conjunction with any model, but so far they have not been applied to a highly non-linear unsaturated model.

The main conclusions of our work are:
• The linear method is generally applicable, even in the context of highly non linear models simulating unsaturated flow and evapotranspiration. The linear analysis provides a useful suite of information that would be otherwise impossible to obtain using nonlinear methods. The Pareto method too, provides a useful method for uncertainty analysis and is extremely efficient if only the uncertainty associated with one or two predictions is required.
• Our results show that measurements of the water table provide reasonable predictive ability under similar hydrological conditions as were used to generate the observation data. However, the linear analysis illustrates that this it is not because any one parameter is well estimated. Rather, it is acquired knowledge that is applicable to combinations of parameters that contributes to a significant reduction of predictive uncertainty.
• Observations of soil moisture, evapotranspiration, transpiration or evaporation used in combination with water table measurements allow for a further reduction of the individual parameter uncertainty, but only if they can be measured with relatively high accuracy.
Our findings have considerable implications for recharge estimates obtained on the basis of vadose zone models, as well as on regional scale groundwater models that simulate saturated and unsaturated flow as well as evapotranspiration processes.