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State and bias estimation for soil moisture profiles by an ensemble Kalman filter

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A number of assumptions and simplifications have hampered successful assimilation of real data by optimal techniques, like the Kalman filter, to estimate the three-dimensional (3D) state of soil moisture. In this study, the presence of bias in a complex nonlinear land surface model, inaccurate knowledge of error covariances, and the computational load of the filtering algorithm for full 3D soil moisture state estimation are discussed. A parallel implementation of the ensemble Kalman filter (EnKF) for state estimation was extended with bias estimation to estimate soil moisture profiles in a small corn field with the CLM2.0, through the assimilation of real profile measurements from capacitance probes. With inclusion of bias estimation, the results were improved. Based on the distribution of the innovations, it was concluded that the filter worked better within its underlying statistical assumptions. Accurate estimation of the bias error covariance, the choice of the bias model and a good initialization of the bias in all other layers were found to be difficult requirements to obtain improved results in all layers of a profile, since it is impossible to estimate the bias in layers for which no observations are available. Several scenarios were analyzed to study the effect of the assimilation frequency, the assimilation depth, and the number of observations assimilated per profile, on the root mean square error ($RMSE$) for the complete profile and the individual soil layers. It was found to be best to spread assimilations of a given number of observations in time to compensate for error in the forecasts mainly due to model error, as assurance of a good analysis (and initial state for further forecasts) by intensive assimilations of the same number of observations during a short time pe-

riod did not guarantee good predictions later in time. In case of assimilation in 1 soil layer only, the optimal assimilation depth was found to be partially dependent of the calibration results: deeper layers are more biased and benefit more from assimilation, with as well as without bias estimation. The effect of assimilation in the upper layers is less persisting due to the atmospheric forcings. When all available observed profile information was intensively assimilated during a very short period, the results were generally better than for the same amount of assimilation events of a single observation in one layer spread in time. The optimal frequency for assimilation of complete profiles is about 1 to 2 weeks: more intensive assimilation does not help to further improve the profile-integrated $RMSE$.