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Genetic algorithm applied to a Soil-Vegetation-Atmosphere system: Sensitivity and uncertainty analysis

Sébastien Schneider, Diederik Jacques, and Dirk Mallants
SCK•CEN, EHS, Mol, Belgium (sschneid@sckcen.be)

Numerical models are of precious help for predicting water fluxes in the vadose zone and more specifically in Soil-Vegetation-Atmosphere (SVA) systems. For such simulations, robust models and representative soil hydraulic parameters are required. Calibration of unsaturated hydraulic properties is known to be a difficult optimization problem due to the high non-linearity of the water flow equations. Therefore, robust methods are needed to avoid the optimization process to lead to non-optimal parameters. Evolutionary algorithms and specifically genetic algorithms (GAs) are very well suited for those complex parameter optimization problems. Additionally, GAs offer the opportunity to assess the confidence in the hydraulic parameter estimations, because of the large number of model realizations.
The SVA system in this study concerns a pine stand on a heterogeneous sandy soil (podzol) in the Campine region in the north of Belgium. Throughfall and other meteorological data and water contents at different soil depths have been recorded during one year at a daily time step in two lysimeters. The water table level, which is varying between 95 and 170 cm, has been recorded with intervals of 0.5 hour. The leaf area index was measured as well at some selected time moments during the year in order to evaluate the energy which reaches the soil and to deduce the potential evaporation. Water contents at several depths have been recorded. Based on the profile description, five soil layers have been distinguished in the podzol. Two models have been used for simulating water fluxes: (i) a mechanistic model, the HYDRUS-1D model, which solves the Richards' equation, and (ii) a compartmental model, which treats the soil profile as a bucket into which water flows until its maximum capacity is reached.
A global sensitivity analysis (Morris' one-at-a-time sensitivity analysis) was run previously to the calibration, in order to check the sensitivity in the chosen parameter search space. For the inversion procedure a genetical algorithm (GA) was used. Specific features such as elitism, roulette-wheel process for selection operator and island theory were implemented. Optimization was based on the water content measurements recorded at several depths. Ten scenarios have been elaborated and applied on the two lysimeters in order to investigate the impact of the conceptual model in terms of processes description (mechanistic or compartmental) and geometry (number of horizons in the profile description) on the calibration accuracy.
Calibration leads to a good agreement with the measured water contents. The most critical parameters for improving the goodness of fit are the number of horizons and the type of process description. Best fit are found for a mechanistic model with 5 horizons resulting in absolute differences between observed and simulated water contents less than 0.02 cm3cm-3 in average. Parameter estimate analysis shows that layers thicknesses are poorly constrained whereas hydraulic parameters are much well defined.