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Comparing the performance of coupled soil-vegetation-atmosphere models at two contrasting field sites in South-West Germany

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The soil moisture, the energy balance at the land surface and the state of the lower atmosphere are closely linked by complex feedback processes. The vegetation acts as the interface between soil and atmosphere and plays an important role in this coupled system. Consequently, a consistent description of the fluxes of water, energy and carbon is a prerequisite for analyzing many problems in soil-, plant- and atmospheric research. To better understand the complex interplay of the involved processes, many numerical and physics-based soil-plant-atmosphere simulation models were developed during the last decades. As these models have been developed for different purposes, the degree of complexity in describing individual feedback processes can vary considerably. In models designed to predict soil moisture, for example, plants are often sufficiently represented by a simple sink term. If these models are calibrated, sometimes only one state variable and the corresponding calibration data type is used, e.g. soil water contents or pressure heads. In this case, vegetation properties and feedbacks between soil moisture, plant growth and stomatal conductivity are neglected to a large extent. Some crop models, in turn, pay little attention to modeling soil water transport. In a coupled soil-vegetation-atmosphere model, however, the interface between soil and atmosphere has to be consistent in all directions. As different data types such as soil moisture, leaf area development and evapotranspiration may contain contrasting information about the system under consideration, the fitting of such a model to a single data type may result in a poor agreement to another data type. The trade-off between the fittings to different data types can thereby be caused by structural inadequacies in the model or by errors in input and calibration data.
In our study, we compare the Community Land Model CLM (version 3.5, offline mode) with different agricultural crop models to analyze the adequacy of their structural complexity on two winter wheat research fields under different climate in South-West Germany. We investigate the ability of the models to simultaneously fit measured soil water contents, leaf area development and actual evapotranspiration rates from eddy-covariance measurements. The calibration of the models is performed in a multi-criteria context using three objective functions, which describe the discrepancy between measurements and simulations of the three data types. We use the AMALGAM evolutionary search algorithm to simultaneously estimate the most important plant and soil hydraulic parameters. The results show that the trade-off in fitting soil moisture, leaf area development and evapotranspiration can be quite large for those models that represent plant processes by simple concepts. However, these trade-offs are smaller for the more mechanistic plant growth models, so that it can be expected that these optimized mechanistic models will provide the basis for improved simulations of land-surface-atmosphere feedback processes.