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Implementation of a mechanistic model of soil water and heat flows in a context of minimal soil characterization: impact on the soil moisture prediction.

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Introduction

At present time we can say that a robust physical background exists to describe diffusive soil water transport and soil water status in soil, dynamically. Good results could be obtained once the soil hydraulic properties, the upper and lower boundary conditions and the initial conditions are characterized [1]. However, such a characterization effort is generally out of proportion with respect to the applications. So there is a need to examine how soil water transport model can be implemented in a context where only little information is available on soil properties and soil state. We assume here a common context where available data are limited to the soil texture, dry bulk density and the climatic conditions. To implement a soil water transport model, we need to address three questions that are the characterization of the soil hydraulic properties, the estimation of the lower boundaries conditions as well as the soil state variable initialisation. For the soil hydraulic properties, many studies were done on pedotransfer functions [2-6]. Many intercomparisons exist, based in general, on an accuracy assessment of the retention curve or the hydraulic conductivity [7-9]. The impact of implementing soil water transfer models with pedotransfer functions is also addressed in several papers [10-13]. Most of them underlined the strong impact of hydraulic properties inaccuracies obtained with such functions and the need to introduce external measurements. But the performances given by the different pedotransfer functions were not compared and the other aspects of water transport models implementation, as initialisation or lower boundaries conditions were seldom analysed.

In this presentation we propose to analyse the performance we can expect when a mechanistic model of soil heat and mass flow is implemented in the context of little information as described before. This study belongs to a more general program dedicated to the determination of soil workability, i.e. the available days for tillage operations. So we will focus the study to the soil moisture in the top layers and to autumn and spring periods when such determination is critical. These periods are characterised by a medium climatic demand and frequent wet and dry cycles. The evaluation exercise will consider an intercomparison of different pedotransfer functions and the impact of different assumptions on the initialization and lower boundary conditions.

Materials and methods

We used the TEC model described in [1]. It accounts for the coupling of heat and mass flows. The model is driven at the surface by the heat and mass flows derived from the surface energy balance computations. So, standard climatic data can be used for the upper boundaries conditions. In this study we assume that the albedo, the surface emissivity and the surface roughness and the dry bulk density are known. Such assumptions are justified by a low sensitivity of the moisture simulated by TEC to these variables and/or by the fact that we can access to these variables at a reasonable cost. For instance, the albedo could be derived with good confidence from remote sensing information. The thermal and hydraulic parameters were derived from the measurement of the soil texture. De Vries model was taken to estimate thermal conductivity [14], whereas the pedotransfer functions of Wösten [15], Rawls and Brackensiek [3], Vereeken et al [4, 5] and Cosby et al [2] to estimate soil hydraulic properties are compared. For initialisation we assume that after a rainfall, the soil moisture profile is homogenised and the resulting water potential ranges between -1 m and -10 m. At the bottom we either used a gravitational flow or a prescribed flow ranging between -1 and -10 m.

To make the error assessment, we used both simulation and experimental approaches. With the simulation approach, we chose 6 soils covering a wide range of soil conditions (from sandy soils to clayey soils). For each of these soils, hydraulic properties were already measured and calibrated in previous studies. Reference simulations were done using such properties under two climatic sequences representative of the spring and the autumn periods. Then simulations were done with the different pedotransfer functions and assumptions on the boundary conditions. Model performances were evaluated by comparing the moisture and water potential profiles in the upper 30 cm given by these simulations to the references ones. The errors quantified by the simulations exercise will be compared to that obtained with experimental data sets. Two experiments were done on a silty clay loam at Avignon (France) and a loam at Mons en Chaussées (France). As for simulations, the TEC model was implemented with the pedotransfer functions and the different assumption for soil moisture and results were compared to soil moisture provided by capacitance probes and water potential measured by automatic tensiometers. With the Mons experiment, two plots with different structural conditions obtained on a same soils (same texture, same pedological unit) were monitored concurrently. This was a way to introduce the variability of soil properties, which moves very quickly in the ploughed layer thanks to tillage operations and climatic influence.

Results

Simulations results lead to the following conclusions:

- considering the six soils, pedotransfer function leads to similar range of error with the exception of Rawls and Brackensiek functions which leads to higher errors in most cases.

- The RMSE for the average soil moisture in the top 0-30 cm ranges between 0.02 and 0.08 m3/m3. In the top five centimetres the error can raise up to 0.12 m3/m3 in some cases.

- There not clear rules relating the errors to the soil texture. However, the worst results were obtained with tilled situation.

- The water potential appears to be much easier to estimate than the soil water content.

- The initialisation has a strong impact on the water content simulation. The error fall within the same range of magnitude as that induced by the use of pedotransfer functions (0.04 to 0.11 m3/m3). However, the impact of the initialisation decrease with time, especially when the soils are watered by rainfall. So, a "warming period" is requested to minimize the impact of initialisation. We propose a relationship that determine this warming period in relation to cumulative rainfall.

- The errors induced by the assumption for the bottom boundary conditions are significantly lower than the other source of error (lower than 0.03 m3/m3). However, an exception occurred with the soil having the highest hydraulic conductivity showing that in given cases, coupling between the surface and the bottom can have a strong impact. So, in such cases, a good determination of boundary condition at the bottom is crucial.

- Temperature initialisation and heat lower boundaries conditions have a negligible impact on the soil moisture simulations.

The fact of using simulations allows highlighting the errors which are specific of the soil hydraulic properties determination or of the assumption made for the boundaries conditions. With experimental data sets, other source of information could come from the error of measurements as well as the model structure errors. However our experimental cases confirmed that the range of error characterized in the simulation exercise is comparable to that obtained with the actual observations. In any case, results obtained in a context of little information showed that accuracies are unacceptable for most applications. The use of other sources of information are necessary. Therefore, we will test in a future endeavour how simplified soil hydraulic characterization or some soil moisture measurements can be used to improve the model accuracy.

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