Time-dependent sensitivity and uncertainty analyses of an agro-climatic model for the water status management of vineyard

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This work describes the global sensitivity analysis (SA) of an agro-climatic model embedded in a decision support system (DSS) for the water status management of vineyard in the Languedoc-Roussillon region, France. The DSS is used in real time to recommend irrigation amounts in order to maintain optimal vine water stress dynamics, based on the quality objective targeted by the winegrower (table wine, aging or laying-down wine, etc.). A major characteristic of agro-climatic models is the difficulty of estimating the numerous input parameters because field measurements are both costly and tedious. This is particularly true when soil-related parameters are involved - which is the case here - because their estimation requires subsoil measurements. The operational use of the model thus requires finding the right balance between data-friendliness and precision: the less input parameters asked to the end-user, the better. In this context, in addition to the obvious interest for the modeller in gaining insight into the model behaviour, the practical use of the SA is twofold. It is first to identify the most influent parameters in order either to concentrate experimental efforts on their field measurement when possible, or to calibrate them otherwise. It is then to measure the ouputs uncertainty – computed along with the sensitivity indices – to parameters estimation in order to provide the end-user with confidence indices on the DSS irrigation recommendations. After a preliminary screening of the less influential parameters via Morris method [1], the SA is achieved with Sobol method [2]. The model includes a temporal output and correlated temporal inputs, so the study addresses some issues arising from these two aspects when met in a practical context.

Several model outputs are analyzed. The first one is a discrete-time (daily) output called the predawn leaf water potential (PLWP) that measures in MPa the water status in vine leaves. It is the reference indicator of vine water status, which describes the physiological state that vine experiences under water deficit. It is estimated based on a discrete-time mechanistic soil-vegetation-atmosphere-transfer model [4], i.e. through the combination of models describing the dynamics of soil water balance, vine canopy growth and solar radiation absorbed by the vegetation. The soil water balance model is itself the combination of sub-models describing the various soil water transfer processes: rain and irrigation infiltration, bare soil evaporation, vine root absorption, runoff and drainage. The soil water balance model runs daily starting January 1st, and the PLWP is computed daily during the vine vegetative cycle, i.e. when leaves are present, typically from April till October. The other outputs of interest are scalar outputs related to the DSS irrigation recommandations: triggering date and amount. They are computed when the PLWP falls below an optimal range, defined by the winegrower and varying over time. For a practical use of the model in a DSS, these are the outputs whose uncertainty and sensitivity to inputs variability is the most critical to assess. The model requires the definition of 4 temporal and 22 scalar inputs. The 4 temporal inputs are to some extend correlated. They represent the weather data necessary for driving the model: daily precipitations, solar radiation, mean air temperature and potential evapotranspiration, and are in practice measured by a weather station.

Firstly, the SA was achieved at the Languedoc-Roussillon scale on the temporal PLWP output only, in order to gain a general insight into the model behaviour. The distributions of all scalar parameters were set rather easily from literature or field expertise in order to scan their whole variation range at the regional scale. The case of the weather data was more an issue, since to the authors' knowledge, the introduction of correlated functional inputs in a SA is still under research. The solution chosen was to use an equivalent of the map-labeling method develop for spatial inputs [4]. It consists in grouping the 4 temporal inputs into a single one, defining a weather scenario. The weather scenarios are then equiprobably drawn among 22 sets of data (i.e. scenarios) collected in various spots of the Languedoc-Roussilon in the past 40 years, and representative of dry, medium-dry and humid years. A preliminary screening via Morris method allowed to identify 6 parameters as being negligible, and consequently to fix them to nominal values. These are the soil albedo, which depicts the radiation reflecting power of the soil surface, and the 5 cumulative thermal times defining the transition between phenological stages (leaf appearance, flowering, etc.). A Sobol SA was then achieved, and the first order and total sensitivity indices were computed sequentially at each simulation step, which enables to follow the variation of parameters influence over time. Results showed the predominant influence of the weather data and of the total transpirable soil water (TTSW) parameter controlling the maximum amount of soil-water available to the vine, which confirms the empirical knowledge of the modelers. Yet one drawback of the method is that it does not allow to quantify the individual influence of the weather components, and especially of precipitations that are empirically known to be the most influent one.

The second step was to quantify at the vine plot scale the sensitivity to inputs estimation error of the PLWP, and most importantly of the irrigation amount and triggering date. Since simulations are rather time-consuming, the regional-scale results were used to help defining 12 vine plots representative of the Languedoc-Roussillon variability and restrict the analysis to them. 3 independent SA (i.e. 36 in total) were then realized for each vine plot for 3 fixed weather scenarios representative of dry, medium-dry and humid years. The aim was thus to test the model sensitivity to the scalar inputs in various fixed pedo-climatic contexts. In all SA, the temporal evolution of the PLWP uncertainty and of the sensitivity indices strongly related to the precipitations histogram, which confirms the critical influence of this weather component. In order to compare the various SA, synthetic sensitivity indices were defined based on previous works [5] to rank parameters according to their global influence on the whole time-dependent simulations. In all cases, the same 3 parameters predominate, even if their relative influence varies from one vine plot to another. These are the TTSW parameter, the soil-water content at January 1st and a soil-water content threshold controlling root absorption. The same 3 parameters have the highest influence on the irrigation recommendations variability, along with the vegetation maximum width. These 3 soil-related parameters, especially the TTSW, are hard to measure and thus hard to directly ask to the end-user. So the suitability of calibrating one or all of them is currently under discussion.

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