European Geosciences Union

Sensitivity Analysis to Uncertain Parameters of TopModel in Tropical Regions with Application to the Middle Magdalena Valley (Colombia)

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EGU General Assembly, Vienna-Austria, 8-13 April 2018

EGU2018-8474

Introduction

Management of uncertainty in hydrologic modeling is related to our ability to (a) select appropriate values for model parameters and (b) assess the extent to which their variation affects a simulated response. We focus on the application of sensitivity and uncertainty analyses to assess the influence of main parameters associated with the widely used semi-distributed watershed model TopModel in estimating surface runoff in the area of the Middle Magdalena Valley, Colombia. We ground our study on the GLUE methodology, as included in the MCAT Toolbox. This methodology is conducive to a Regional Sensitivity Analysis (RSA), rendering global information about the relative importance of given model parameters through an a-posteriori probability function. GLUE is viewed as a first step to undertake a comprehensive global sensitivity analysis based on the statistical moments characterizing the outputs of the simulations.

Research Objective

The aim of this research was to assess the influence of main parameter and determine the uncertainty that they produce on model results

Study Area

The basin of the Middle Magdalena Valley (Fig 1) is located geomorphologically along the central part of the valley. The Magdalena river runs between the Eastern and Central mountain ranges of the Colombian Andes, covering an area of 32.000 km^2.

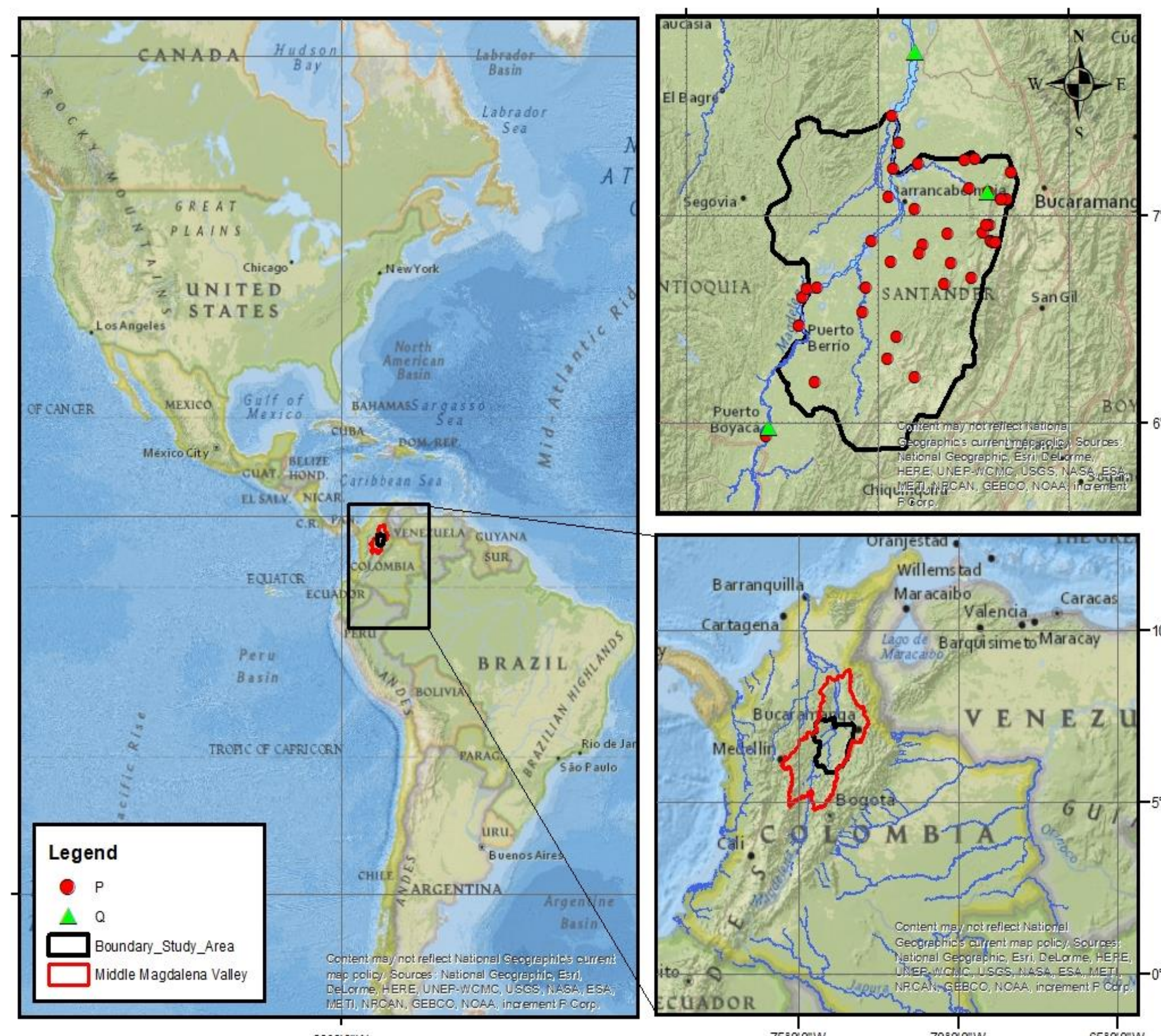

Fig. 1. Location Study Area in Magdalena-Cauca Basin and Middle Magdalena Valley.

Model Formulation

TopModel is defined as a variable contributing area model in which the dynamics of surface and subsurface saturated areas is estimated on the basis of storage-discharge relationships established from a simplified steady state theory for downslope saturated zone flows (Fig. 2) (Beven, 1997).

Model Formulation

Parameters	Description
Qs0	Initial subsurface flow per unit area
LnTe	Log of the areal average of Transmissivity
M	Model parameter controlling the rate of decline of transmissivity in the soil profile
Sr0	Initial root zone storage deficit
Srmax	Maximum root zone storage deficit
Td	Unsaturated time zone delay per unit storage deficit
Vch	Channel flow outside the catchment
Vr	Channel flow inside catchment
K0	Surface hydraulic conductivity
CD	Capillary drive
Dt	Time step

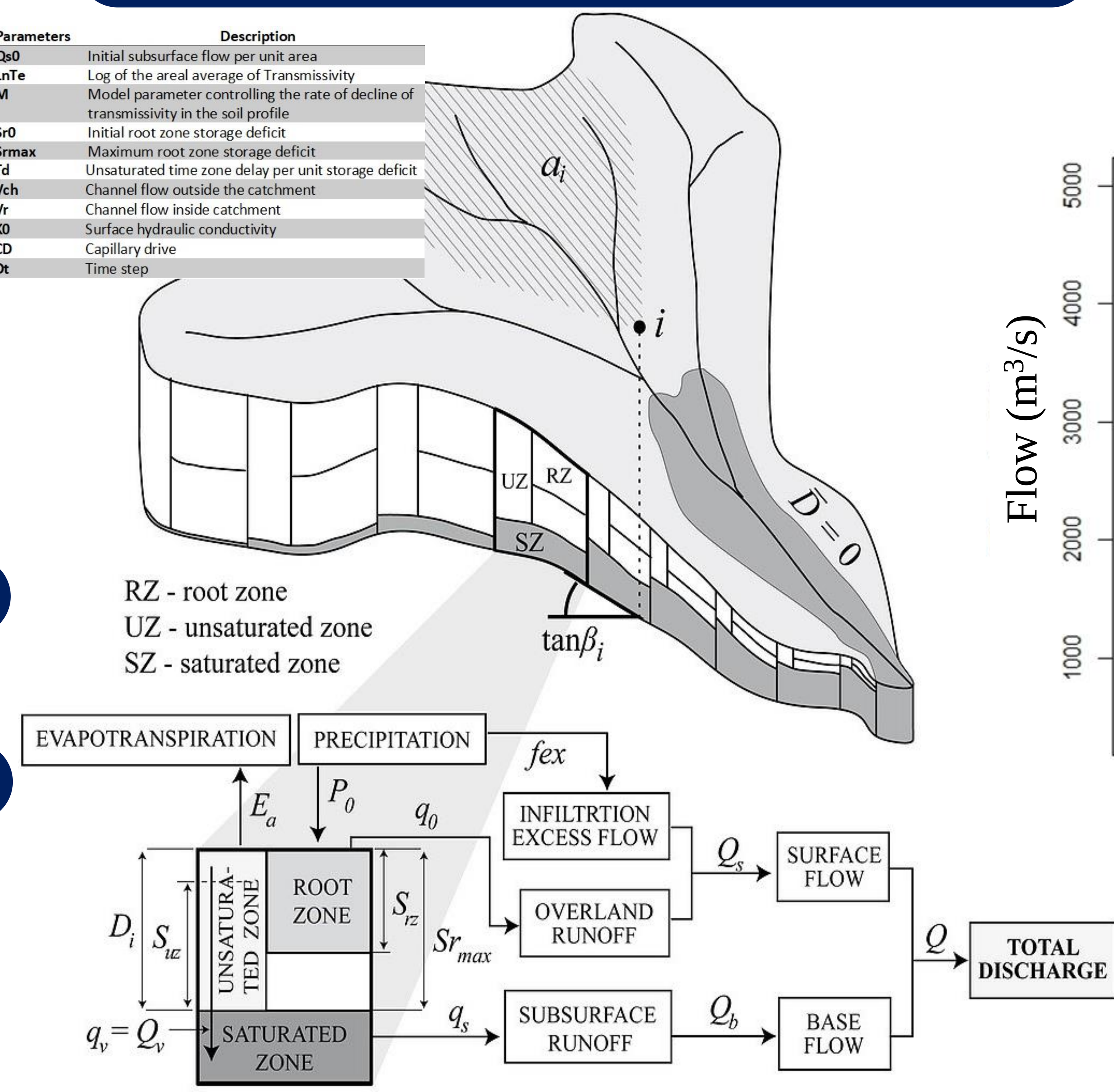

Fig. 2. TopModel model description. Source: (Jeziorska and Niedzielski, 2015)

Our analyses are grounded on a collection of 150.000 model simulations, each spanning a 12-year temporal window. These are constructed by assuming those model parameters are random and associated with a uniform distribution.

Sensitivity Analysis (SA) - MCAT

SA is the study of how the variation (uncertainty) in the output of a model can be qualitatively or quantitatively, to different sources of variation in the parameters of the model (Fig 3) (Saltelli, et., al. 2000; Borgonovo et., al. 2017)

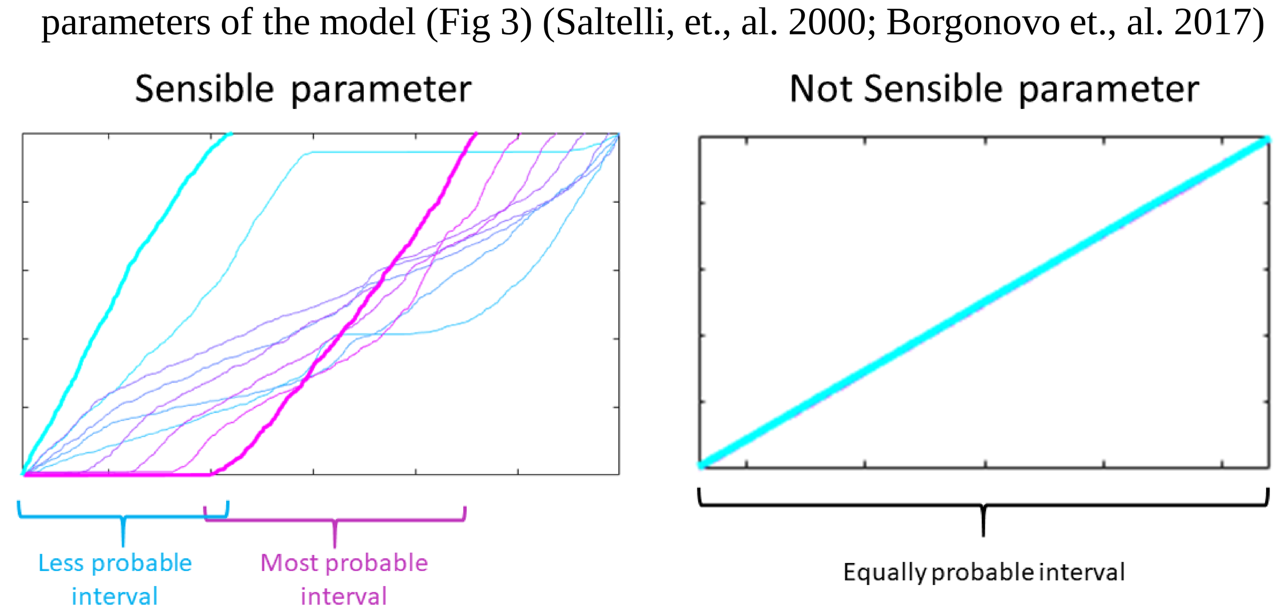

Fig. 3. Diagram of sensitivity analysis

MCAT is a library developed in Matlab that contains the methodology known as GLUE, Generalized Likelihood Uncertainty Estimation (Freer et al., 1996); which works under the assumption that there is not a single optimal parameter that is identified, but instead, a set of parameters are identified where each model has a certainty probability of correctly representing the system.

Results

The set of parameters inside in fig. 4, was used to calculate the simulated flows by TopModel during the period studied, presenting an under estimation of the maximum flows. The results of the validation process of the model results generated from the calibrated parameters, the values of efficiency were near to 0.74 and its simulated flows are shown in the figure 4.

Parameters	Value
Nash	0.7415
Bias	2.6
Qs0	0.0001234649
LnTe	1.1.54715
m	0.2166118
Sr0	0.01572018
Srmax	0.2277885
Td	61.5606
Vch	2256.519
Vr	1088.248
K0	7.104976
cd	4.37078

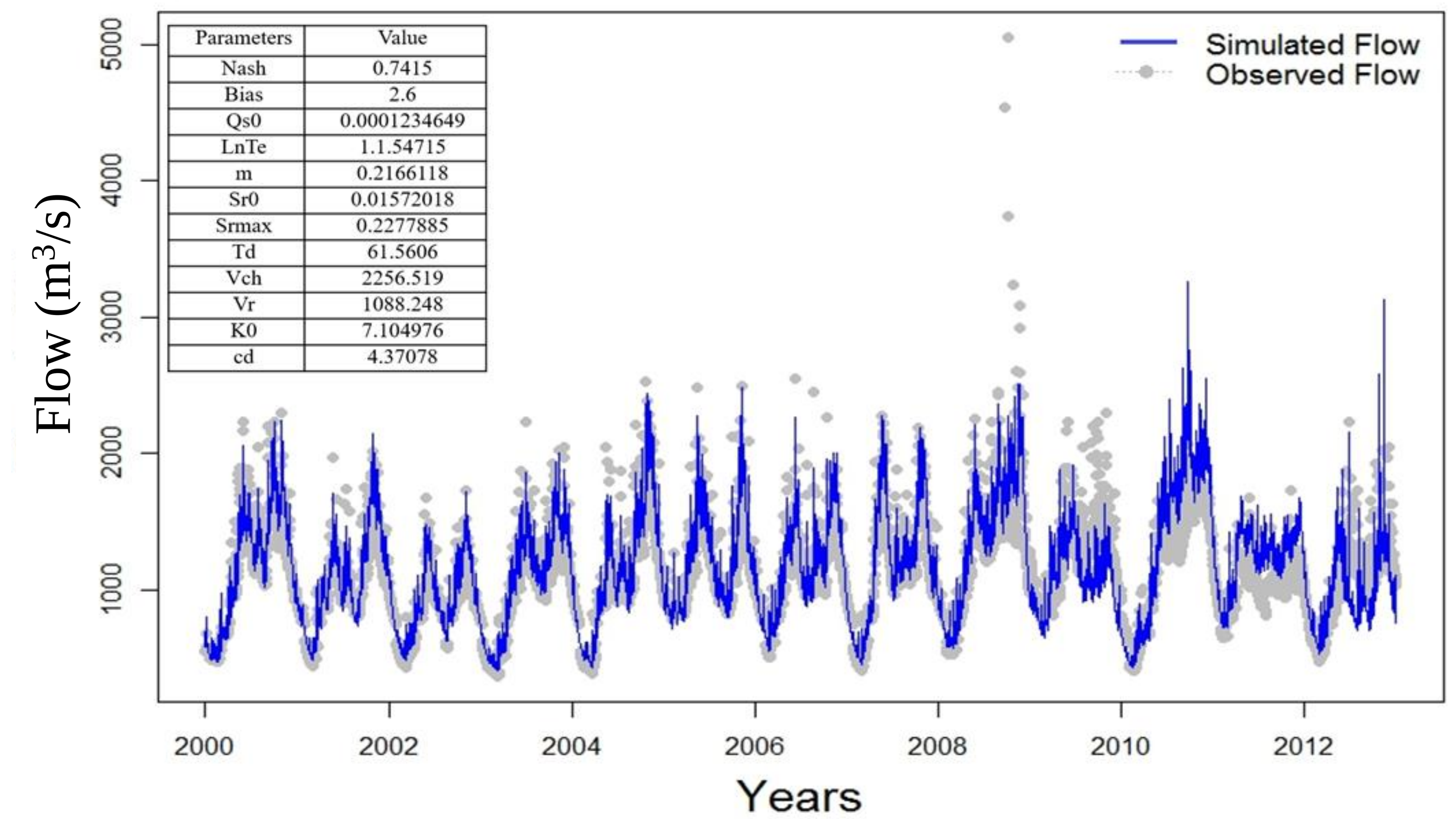

Fig. 4. Observed (grey points) and simulated flows (blue lines) for the area in MMV.

The initial determination of the dominant and sensitive parameters was performed with MCAT through the cumulative distribution curves which were created from the division of the Monte Carlo sampling results of into the ten groups equally sized, showing that the parameters LnTe, m, qso and srmax present a greater slope of the distribution curve (Figure 5).

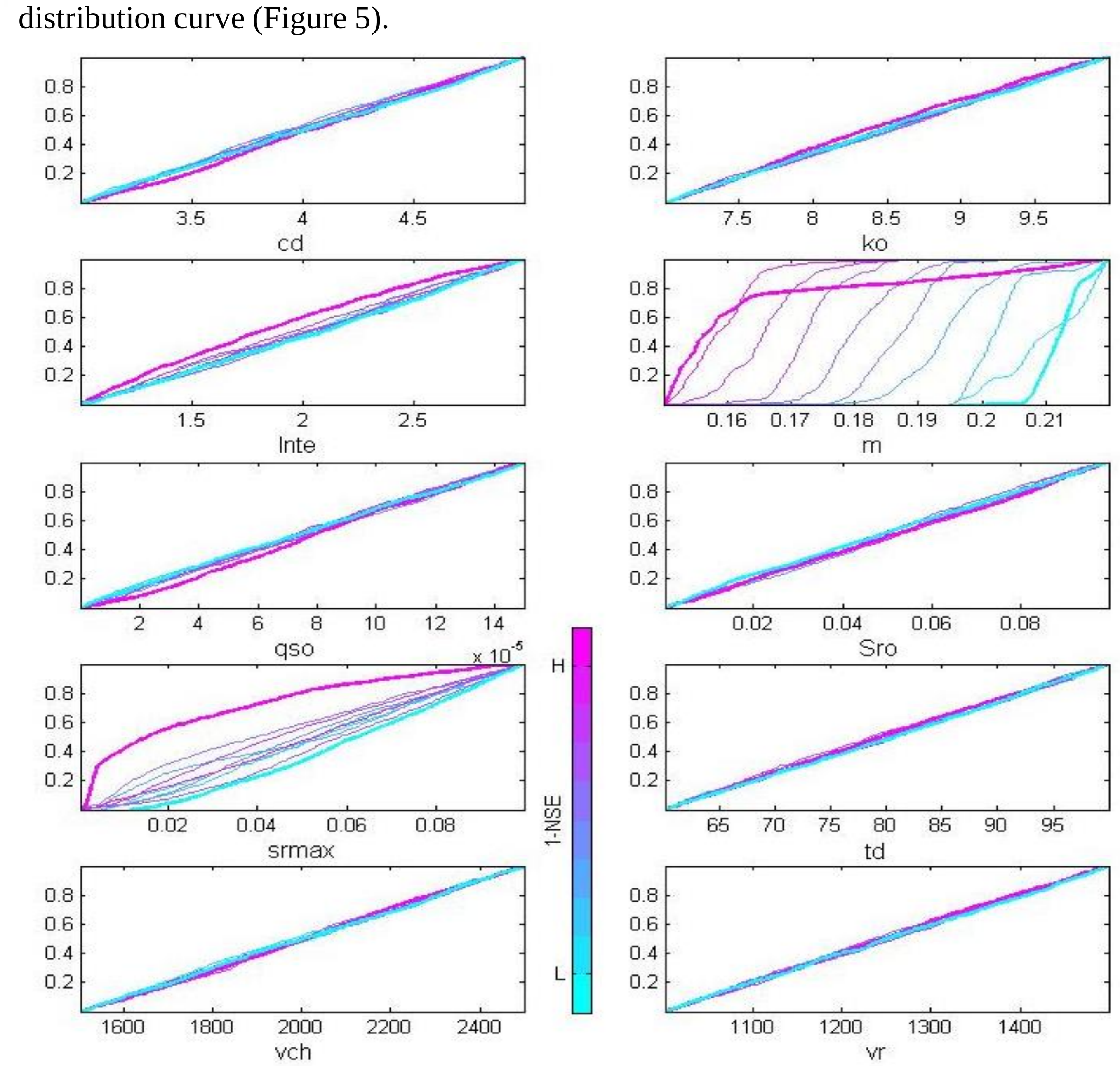

Fig. 5. Cumulative distribution function plot of the model parameters according to the simulations performed for the 12 years of analysis.

Conclusions

- ✓ The sensitivity analysis allowed to establish the intervals of the parameters that offer a better response of the model. Additionally, it allowed identifying which of these parameters govern the behavior of the model
- ✓ The calculated sensitivity of model output, with respect to a parameter depends on the selected global sensitivity index, i.e., variability of a model parameter affects statistical moments of model in different ways and with different relative importance depending on the statistical moment considered.
- ✓ Results of the global sensitivity analysis enable identifying a reduced set of model parameter values, showing that the parameter driving the transmissivity recession curve (associated with an exponential decrease of saturated hydraulic conductivity with depth), the maximum root zone storage deficit, and the initial subsurface flow can be considered as the most sensitive ones.

Future Work

Comparing Global Sensitivity Analysis approaches based on the Sobol' indices, associated with a classical decomposition of variance with recently developed AMA indices, which quantifying the relative contribution of each uncertain model parameter to the (ensemble) mean, variance, skewness and kurtosis of the model output.

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