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Sensitivity Analysis of a process based erosion model using FAST

(Fourier Amplitude Sensitivity Test)

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Introduction and Objectives

Erosion, sediment redistribution and related particulate transport are severe problems in agro-ecosystems with highly erodible loess soils. They are controlled by various factors. The interplay between those factors is not well understood. A number of models were developed to indicate those complex interactions and to estimate the amount of sediment which will be removed, transported and accumulated. In order to make use of physical-based models to provide insight on the physical system under study it is necessary to understand the interactions of parameters and processes in the model domain. Sensitivity analyses give insight in the relative importance of model parameters, which in addition is useful for judging where the greatest efforts have to be spent in acquiring or calibrating input parameters.

The objective of this study was to determine the sensitivity of the erosion-related parameters in the CATFLOW model.

Methods

The sensitivity analysis was performed based on virtual hillslopes (Figure 1). We applied the FAST-method (Fourier Amplitude Sensitivity Test)[1][2][3], which provides a global sensitivity analysis with comparably few model runs. We varied model parameters concerning erosion in predefined and physically meaningful parameter ranges (Figure 1). These parameters and their ranges are listed in Table 1.

Table 1: Ranges for creating parameters using FAST

Parameter	Range
Percentage clay content [%]	5 – 40
Strickler value, k_{st} [-]	15 – 50
Erosion resistance of soil, f_{crit} [N/m²]	0.1 – 2
Ground cover BBG	0 – 0.95
Slope, I [°]	3 – 30
Max. rainfall intensity [mm/h]	8.4 - 76

The ranges of the rainfall intensities were derived from preliminary studies where we searched for the lowest rainfall intensity which produces erosion.

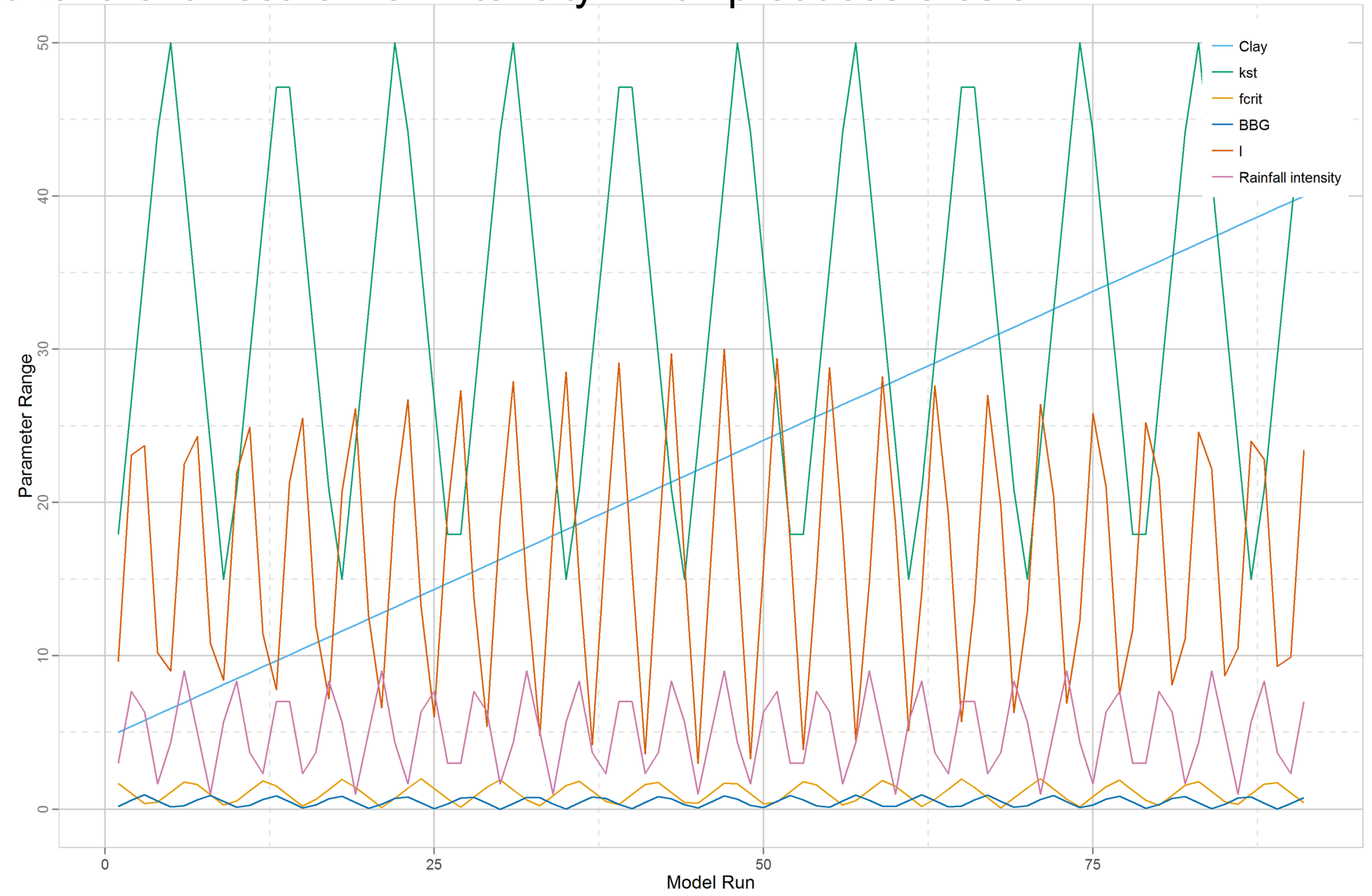

Figure 2: Parameter variations of the model runs using FAST.

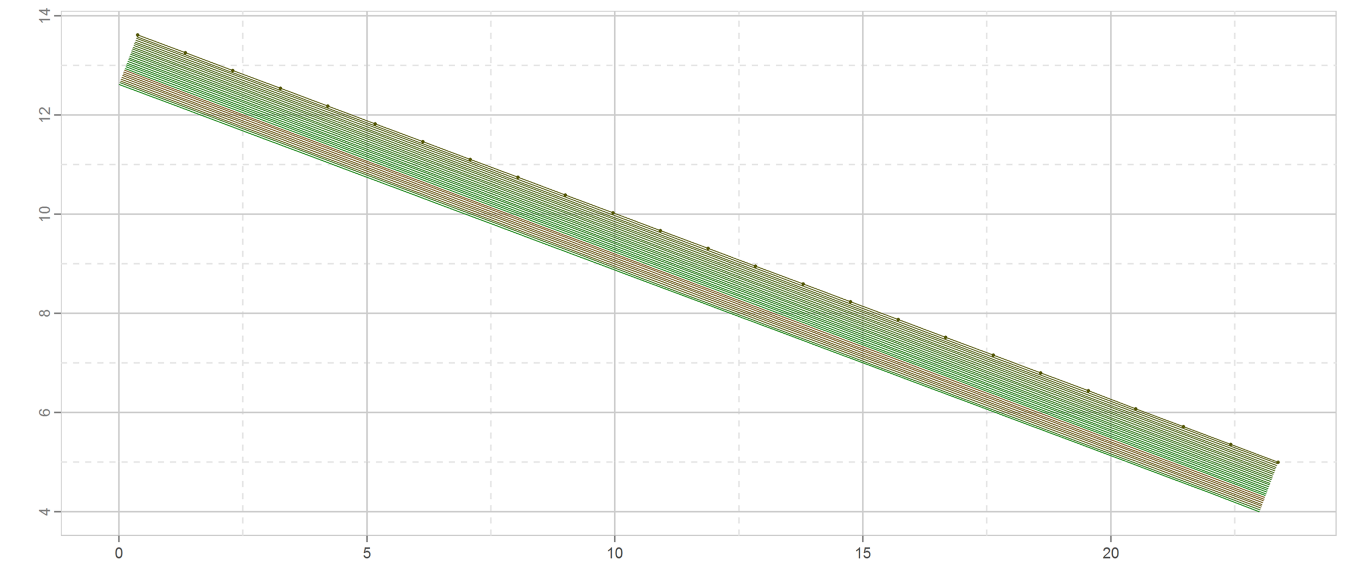

Figure 1: Model of a virtual hillslope.

Catflow

CATFLOW is a process-based hydrology and erosion model that can operate on catchment and hillslope scales. Soil water dynamics are described by the Richards' equation including effective approaches for preferential flow. Evapotranspiration is simulated using an approach based on the Penman-Monteith equation. The model simulates overland flow using the diffusion wave equation. Soil detachment is related to the attacking forces of rainfall and overland flow, and the erosion resistance of the soil. Sediment transport capacity and sediment deposition are related to overland flow velocity using the equation of Engelund and Hansen[4] and the sinking velocity of grain sizes, respectively.

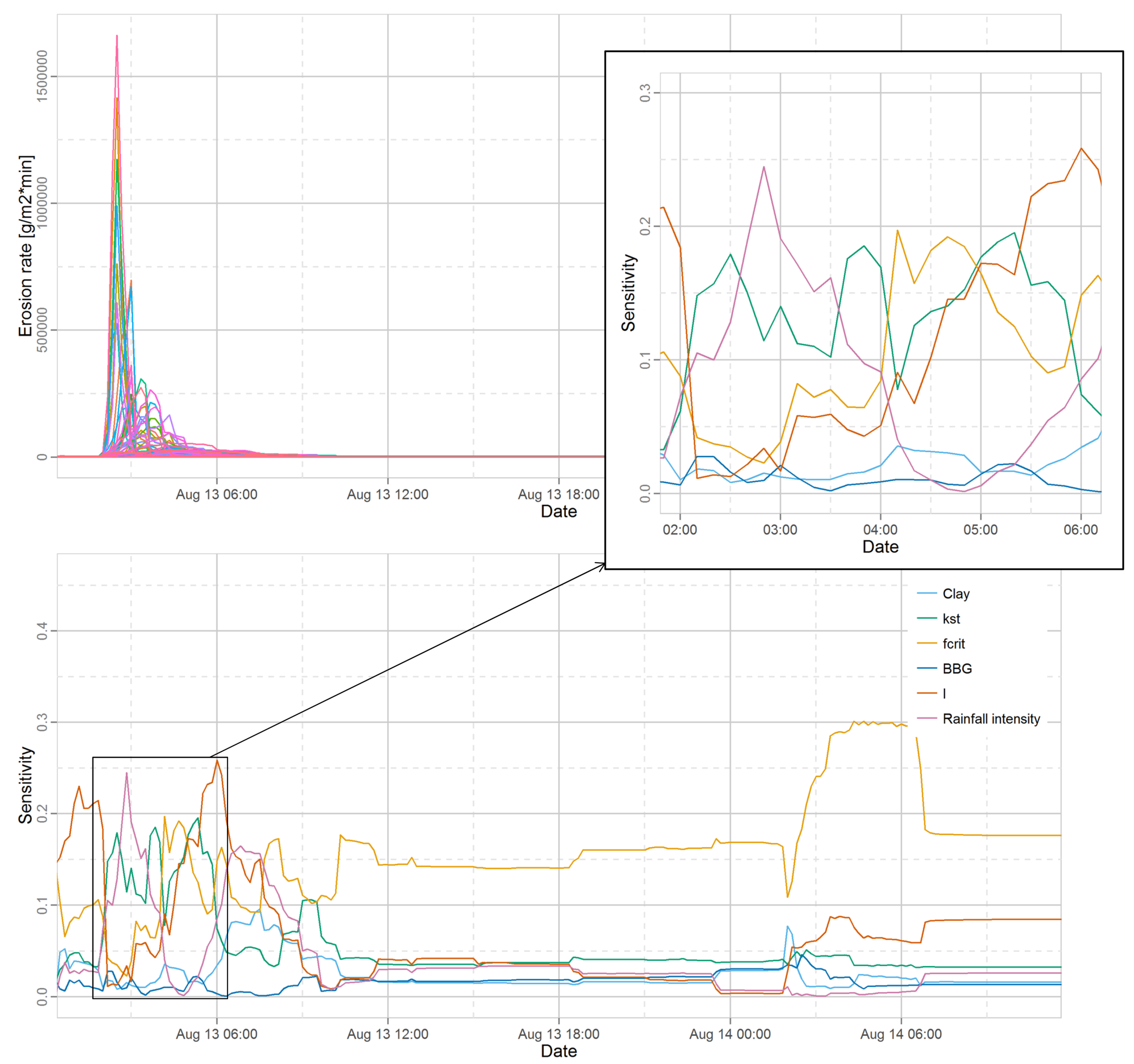

Figure 3: Erosion rate and sensitivity of the model runs.

Results

For our analysis we were looking at three different model outputs. The first one include the final amount of the erosion after all model runs (Table 2). The second one the temporal progress of the erosion rate (Figure 3). Furthermore, we analysed the change in the sensitivity of the parameters concerning the full amount of erosion of each segment downslope (Figure 4).

Figure 3 displays the erosion rate of the 91 model runs (above) after the beginning of rainfall events and the sensitivities of the different parameters for these runs (below). At first the slope (I) and the erosion resistance of soil (f_{crit}) are the most sensitive parameters. After the start of the rainfall the strickler value (k_{st}) and the rainfall intensity become more prominent.

The sensitivities of the parameters for each segment of the slopes are shown in Figure 4. The sensitivities of the strickler value and the rainfall intensity are increasing downwards. Downslope the erosion resistance of soil and the slope are the most sensitive parameter.

At the last segment the slope (I) is the most sensitive parameter, followed by the erosion resistance of soil, the rainfall intensity, the strickler value, the clay content and ground cover (BBG).

Table 2: Sensitivities for the erosion

Parameter	Sensitivity
I	0.277
f_{crit}	0.271
Max. rainfall intensity	0.230
k_{st}	0.182
Clay content	0.036
BBG	0.003

Our sensitivity analysis for the full amount of erosion on the hillslope is similar to those results. Table 2 lists the sensitivities of the parameters concerning the full amount of erosion on the hillslope.

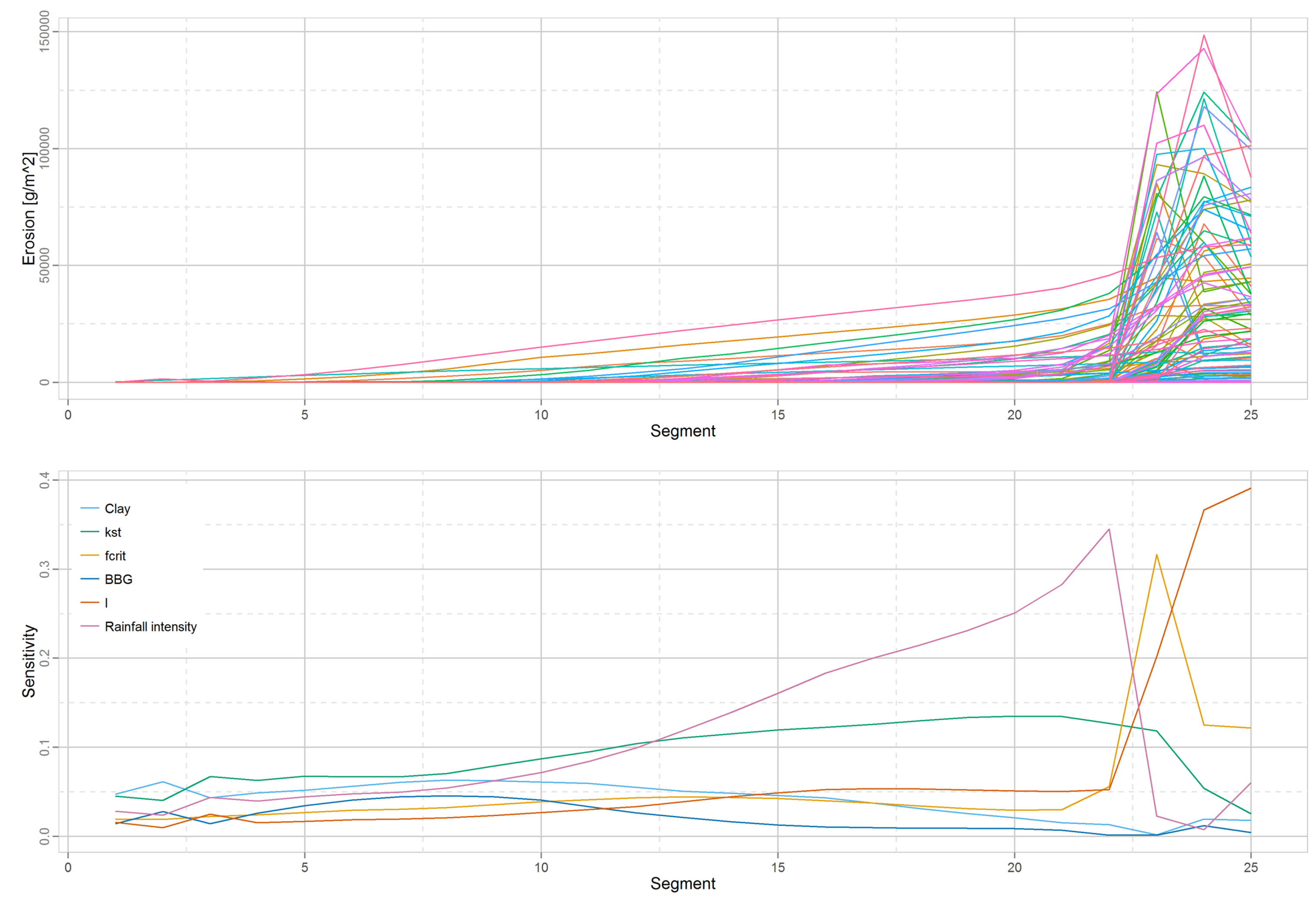

Figure 4: Final amount of erosion of the different slope segments and sensitivities.

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References:
[1] Cukier et al (1975): "Study of the sensitivity of coupled reaction systems to uncertainties in rate coefficients. III. Analysis of the approximations" The Journal of Chemical Physics
[2] Reusser, D. (2011): "Inferring model structural deficits by analyzing temporal dynamics of model performance and parameter sensitivity"
[3] Reusser, D. (2007): "Implementation of the Fourier Amplitude Sensitivity Test (FAST) in R"
[4] Engelund, F., Hansen, E. (1967): "A monograph on sediment transport in alluvial streams", Teknisk Forlag

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