IMPACT OF MODEL STRUCTURE SIMPLIFICATIONS ON THE PERFORMANCE OF A DISTRIBUTED PHYSICALLY-BASED SOIL EROSION MODEL AT THE HILLSLOPE SCALE

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CONTEXT AND OBJECTIVES

Soil erosion and subsequent sediment delivery to river systems are increasingly studied as a consequence of both on-site and off-site impacts such as net soil and nutrient losses (Pimentel, 2006), turbidity increase in rivers and reservoir filling (Owens et al., 2005). Several physically based formulations representing the processes involved in soil erosion and sediment transport have been proposed at small scales in the last decades and implemented in distributed soil erosion models. All these formulations require a detailed definition of parameters that are difficult to measure. At the same time, the calibration of distributed soil erosion models with field data is complex for several reasons as the large number of parameters that need to be estimated, the high non-linearity of the equations, the interaction between input parameters, the scarcity of comprehensive field data available for calibration and the uncertainty in the experimental measurements. In order to make affordable the use of physically based models in meso-scale watershed studies it is often necessary to reduce the number of parameters or adapt the calibration method to the available data sets. The objective of this study was to analyze how the performance and calibration of a distributed event-based soil erosion model at the hillslope scale are affected by different simplifications on the parameterizations used to compute the production of suspended sediment by rainfall and runoff (Cea et al., 2016).

FIELD DATA

- Data from the Hydrometeorologic Cévennes Vivarais observatory (Nord et al., 2015).
- Hillslope plots : 60m * 2m.
- Brown calcareous clayey soil.
- Continuous measurements :
  - ✓ rainfall : intensity (*R*) + drop sizes,
  - ✓ water heights.
- Measurement on water samples:
  - ✓ concentrations,
  - ✓ effective and absolute particle sizes.

- 5 rainfall runoff events:

Event	Start	Rain before runoff starts (mm)	Time before runoff starts (h)	Rain since runoff starts (mm)	Max. 1 min rain intensity (mm/h)	Runoff duration (h)	Runoff depth (mm)	Q_{max} (l/s)
R1	09/11/2012 22:00	43	14.3	22	24	10.0	12	0.30
R2	04/11/2011 12:00	113	45.0	16	79	3.9	17	0.98
R3	18/05/2013 08:00	19	7.0	27	80	5.0	29	1.73
R4	07/09/2010 19:00	91	24.6	61	92	2.7	12	1.12
R5	20/10/2013 06:00	20	5.0	44	92	2.6	29	1.35

Data available at http://mistrals.sedoo.fr/?editDatsId=1347

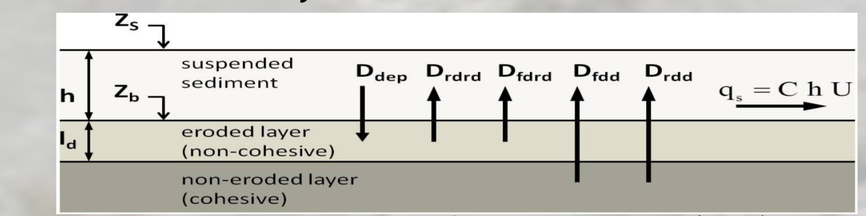
MODELING

Hydraulics

- 2D shallow water equations including rainfall and infiltration terms (Cea et al., 2014).
- Infiltration is modeled by an initial loss (I_a) followed by constant infiltration (k_s).
- Coefficients I_a, k_s and *n* (Manning) were visually calibrated.

Erosion

$$\frac{\partial hC}{\partial t}+\frac{\partial qxC}{\partial x}+\frac{\partial qyC}{\partial y}=D_{rdrd}+D_{fdrd}+Df_{dd}+Dr_{dd}+D_{dep}$$



Adapted from Nord et Esteves (2005)

$$D_{rdd}=\alpha_d\,R\,(1\text{-}\varepsilon) \qquad D_{rdrd}=\alpha_{rd}\,R\varepsilon$$

$$\varepsilon=\min\left[\frac{Ms}{Ms_{cr}},1\right]$$

$$D_{fdd}=\frac{F}{J}\Omega(1-\varepsilon) \qquad D_{fdrd}=\frac{\rho_s\,rf}{(\rho_s-\rho)g}F\frac{\Omega}{h}$$

$$D_{dep}=-\rho_s\,ws\,C$$

- 5 five model structure scenarios were compared:

Modelling scenario	Rainfall production	Runoff production	Number of layers	Model parameters	Monte Carlo runs for calibration
MS1	Yes	No	1	α_{rd}	100
MS2	No	Yes	1	F	100
MS3	Yes	Yes	1	α_{rd}, F	250
MS4	Yes	No	2	α_{rd}, α_d, $M_{s,cr}$	1000
MS5	No	Yes	2	F, J, $M_{s,cr}$	1000
MS6	Yes	Yes	2	α_{rd}, α_d, F, J, $M_{s,cr}$	5000

Cea et al. (2016)

- Erosion parameters were calibrated:
  - ✓ with the standard GLUE methodology (Beven and Binley, 1992),
  - ✓ on measured sediment fluxes,
  - ✓ with the following prior parameter distribution for calibration:

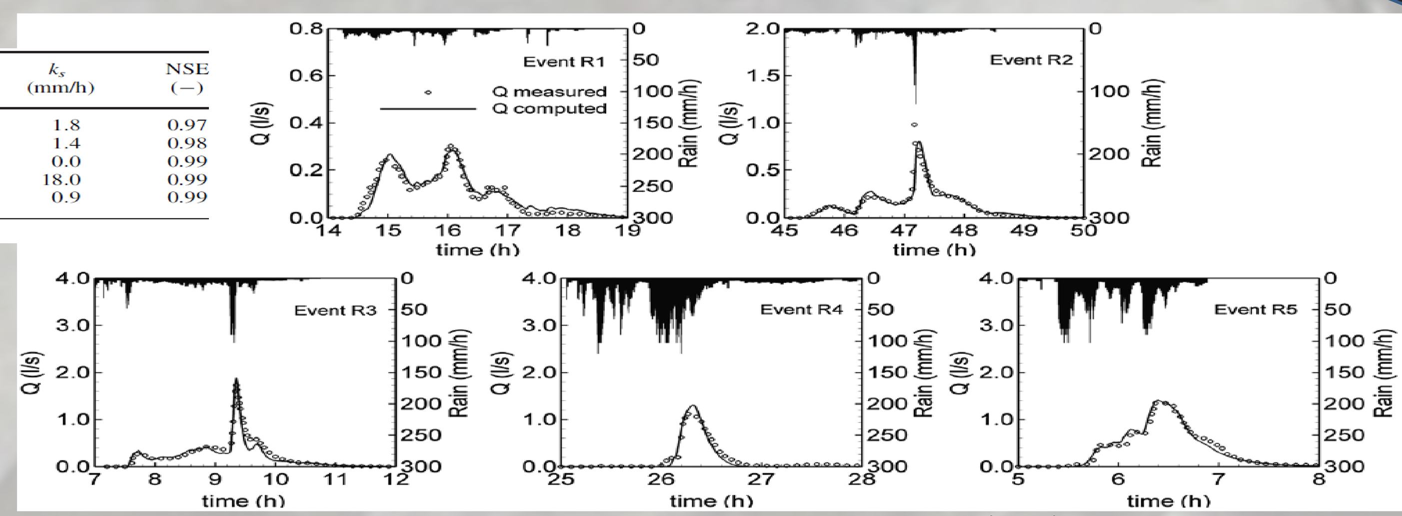
$0<\alpha<50$ kg m^{-3} $\quad 0<F<1.10^{-3}$ $\quad 1<J<10$ J kg^{-1} $\quad 0<M_s<2.8$ kg m^{-2}

RESULTS

Hydraulics

Rainfall event	n ($sm^{-1/3}$)	I_a (mm)	k_s (mm/h)	NSE (−)
R1	0.60	43	1.8	0.97
R2	0.30	113	1.4	0.98
R3	0.20	19	0.0	0.99
R4	0.40	91	18.0	0.99
R5	0.80	20	0.9	0.99

NSE, Nash–Sutcliffe efficiency.

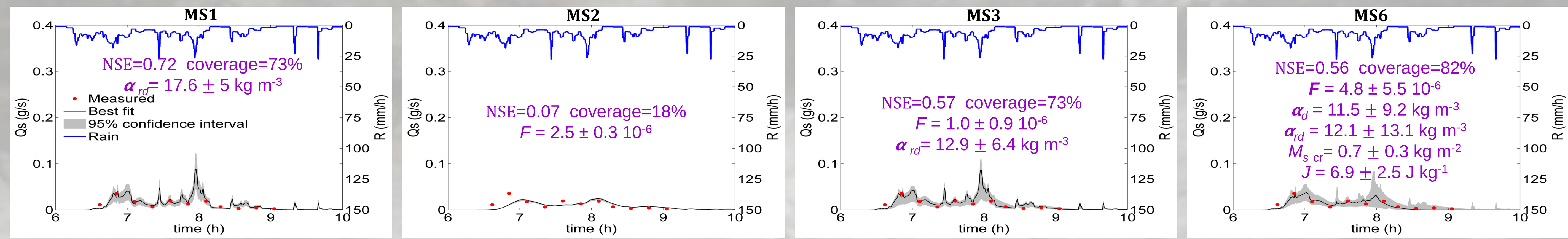


Cea et al. (2016)

- Measured hydrographs are well captured by the model.
- I_a values show a high influence of the antecedent soil moisture conditions.

Erosion

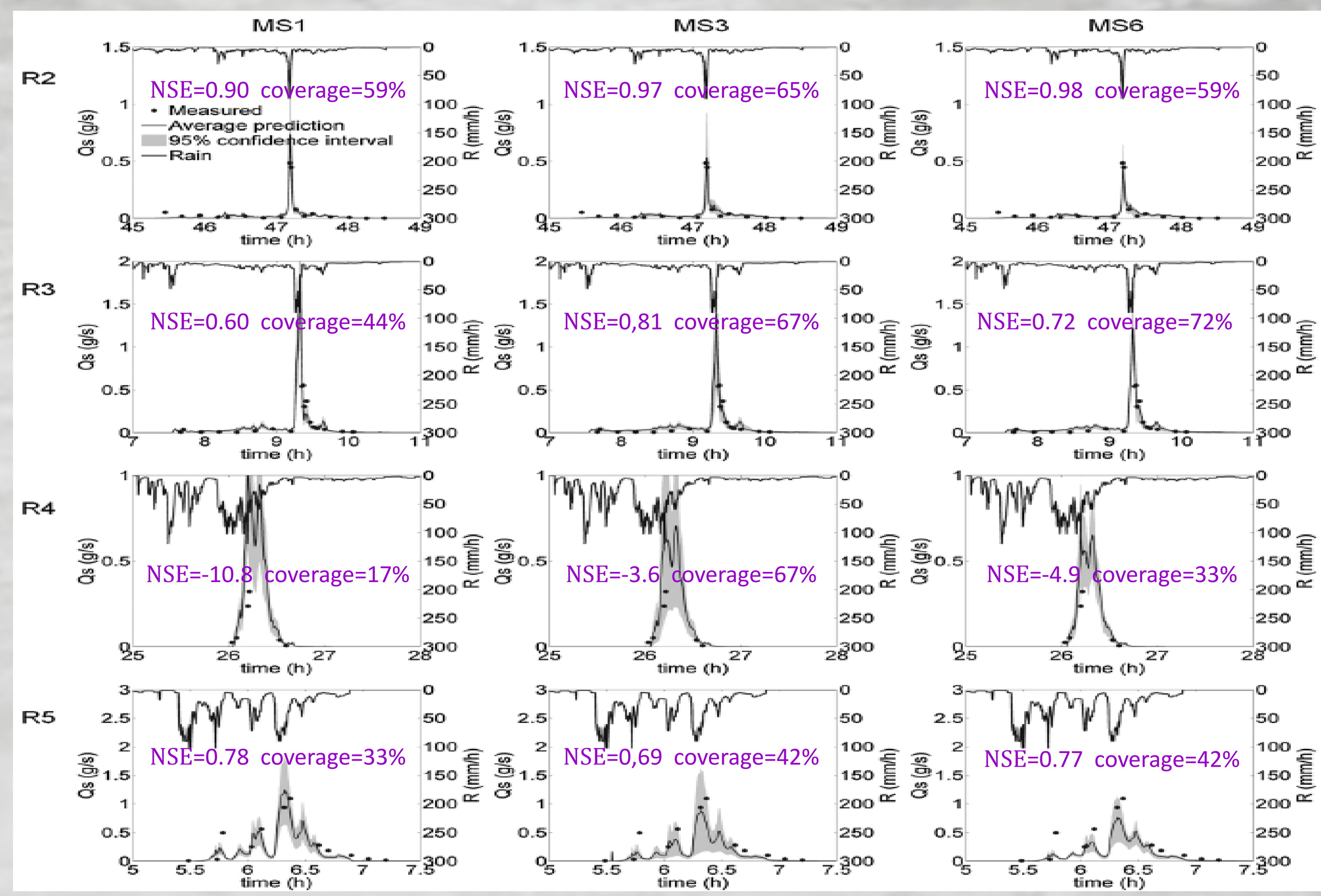
- Calibration on event R1 : results for various modelling scenarios



Cea et al. (2016)

- Scenarios considering rainfall and runoff production (MS3 and MS6) are able to reproduce the measured sediment fluxes.
- Scenarios considering only rainfall production (MS1 and MS4) also give good results.
- The two scenarios with the worst performance are those that only consider detachment by runoff (MS2 and MS5).

- Validation on events R2, R3, R4, R5 :



Cea et al. (2016)

- The model structure with the best predictive capabilities is MS3.
- The scenarios MS1 and MS6 also produce satisfactory predictions.
- A model structure considering a single soil layer with just two erodibility parameters accounting for the production of suspended sediment due to rainfall impacts and runoff shear offers a good compromise between calibration efforts and model performance.
- A two-layer soil structure makes the calibration process more complex without improving significantly model performance, while it might be a constraint in the application of these types of models at meso-scales.

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