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Representation of subgrid-scale variability in large-scale hydrological models using hydromorphological units

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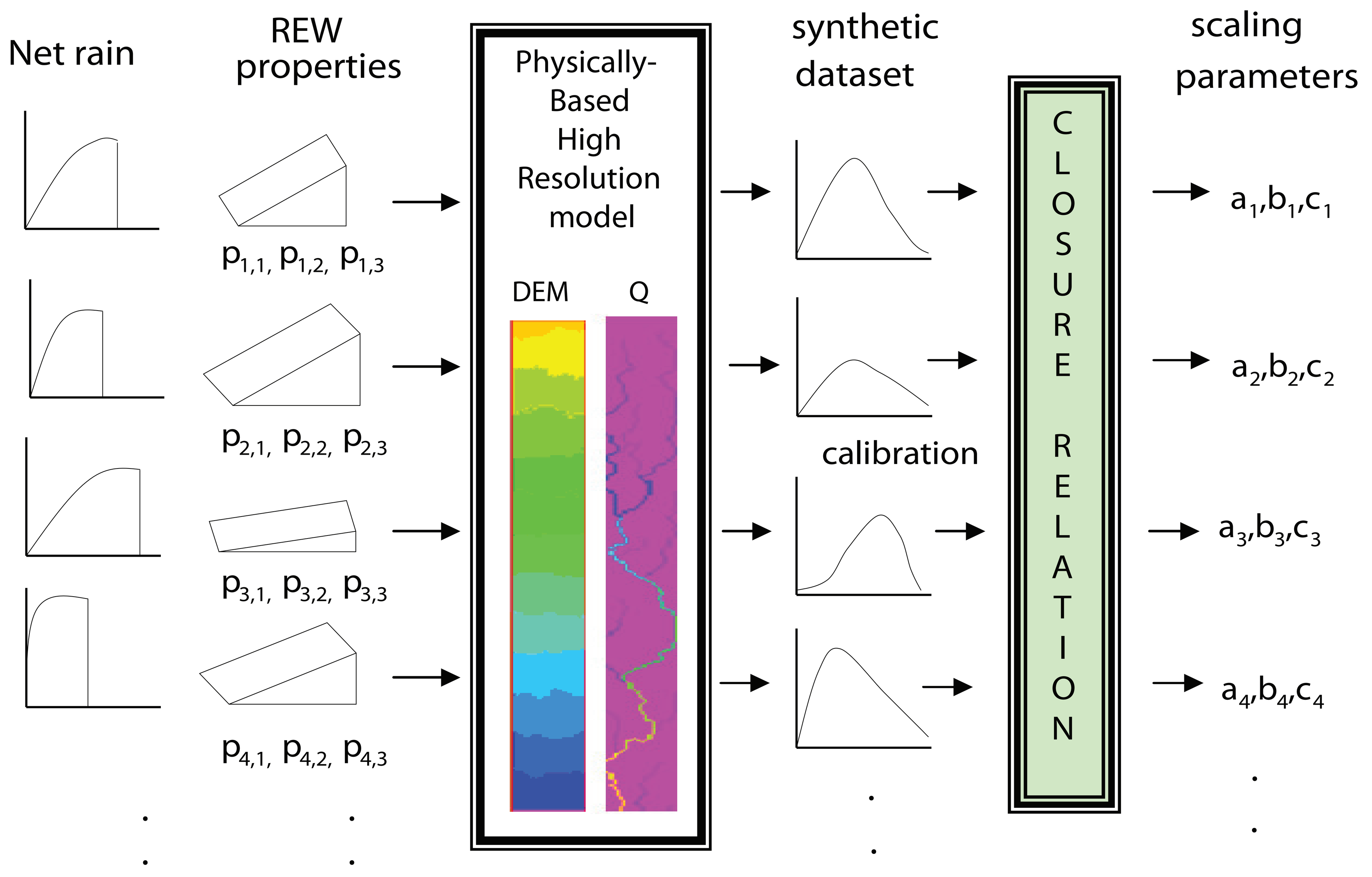
Introduction

Performance of large-scale (10^4-10^6 km^2) hydrological models using a coarse grid resolution (i.e. >10 km^2) can be improved by incorporating subgrid variability of hydrological processes and model forcing. Modeling subgrid processes is traditionally done using simple distribution functions based on digital elevation data. We propose a physically-based representation of subgrid variability using Representative Elementary Watershed (REW) approach [1]. A grid cell is disaggregated into a set of REWs corresponding to the geomorphology. An individual subgrid unit is divided into sub-zones to characterize the dominant hydrological processes. Mass exchange flux across these sub-zones within a REW and among other REWs in the subgrid can be modeled using a physically-based lumped equation (i.e. the closure relation). We focus on the quantification of concentrated overland flow (i.e. Hortonain runoff) flux exchange between the sub-zones within REW and in subgrid REWs.

Development of a closure relation for Hortonain runoff



The closure relation is developed as a lumped conceptual model with two key processes; infiltration and Hortonian runoff. The closure relation C is formulated as:

$$e_t = C(\mathbf{i}_t, \mathbf{s}_t, \mathbf{u})$$

$$\mathbf{u} = u(\mathbf{p}, \mathbf{i}_t, \mathbf{g})$$

- e_t trans-boundary flux at time t
- $\mathbf{i}_t$ input at time t
- $\mathbf{s}_t$ storage at time t
- $\mathbf{u}$ scale-transfer parameters
- u scale-transfer parameters function
- $\mathbf{p}$ measurable REW physical properties
- $\mathbf{g}$ REW geometry

Calibration of the closure relation against the synthetic discharge data set of approximately 65,000 scenarios results in a lookup table containing the scale-transfer parameters **u** for an extensive range of REW geometry and rainstorms.

Evaluation of performance of the closure relation with the synthetic data

- Simulate the discharge using the developed closure relation for an independent set of REWs and rainstorms (i.e. 256 scenarios)
- Evaluate the simulated discharge against the results from the high-resolution model

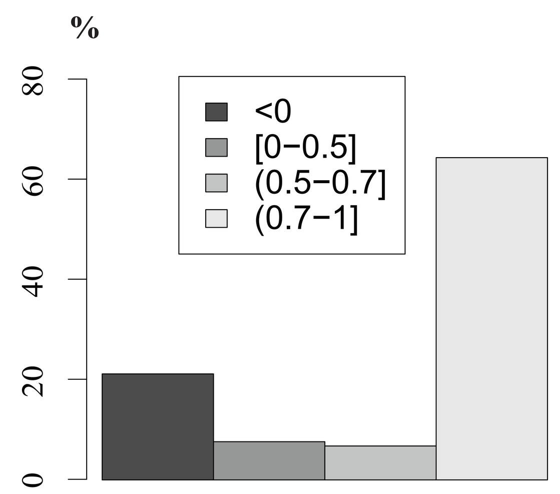
The scale-transfer parameters **u** in the closure relation are estimated using the information from the look-up table as:

$$\mathbf{u} = f(\mathbf{g}, \mathbf{i}_t, \mathbf{p})$$

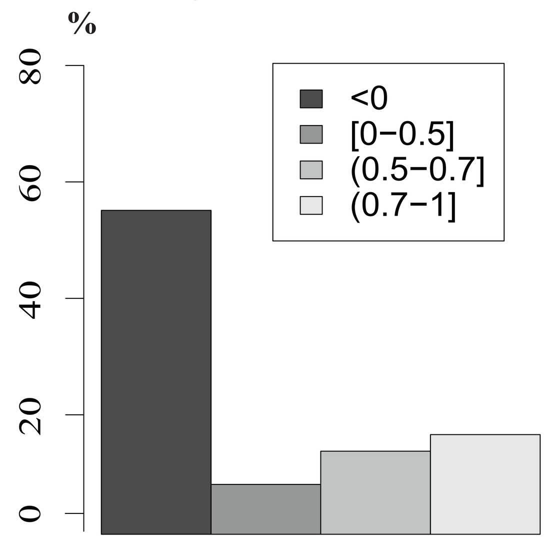
- f inverse-weighted distance interpolation
- $\mathbf{g}$ REW geometry
- $\mathbf{i}_t$ input at time t
- $\mathbf{p}$ measurable REW physical properties

Results

Nash-sutcliffe index (E)



high-runoff scenarios



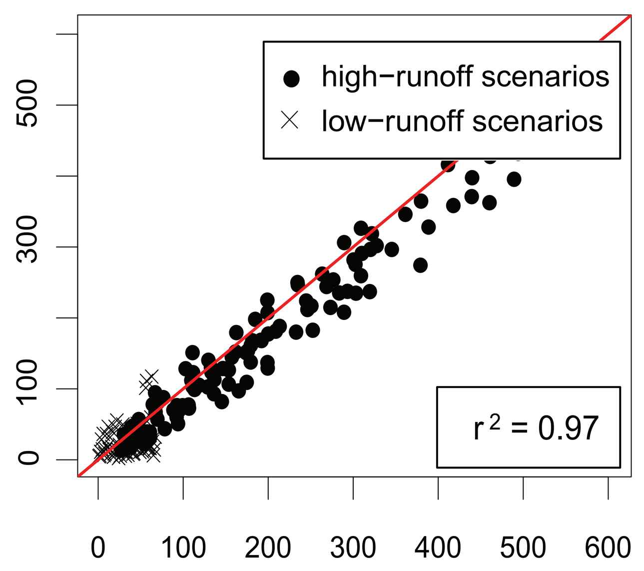
low-runoff scenarios

Key findings

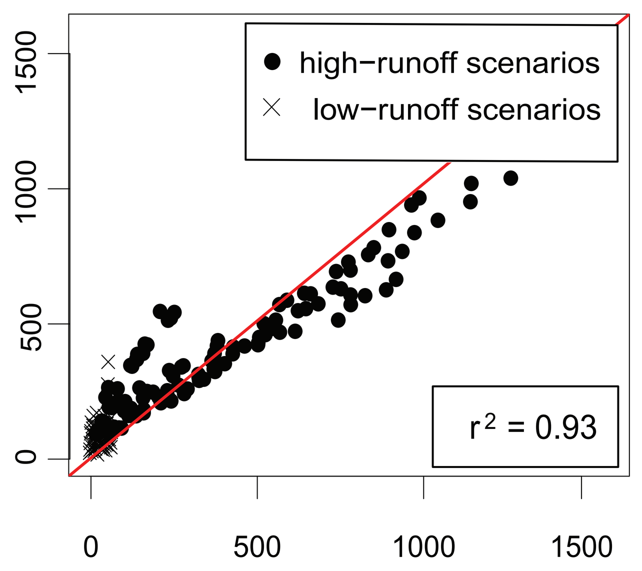
Performance of the closure relation is high with:
- Large amount of runoff
- Fast hydrologic response

This is because for these events:
- Small estimation errors in scale-transfer parameters **u**
- Spatial process in infiltration and runoff generation is less important

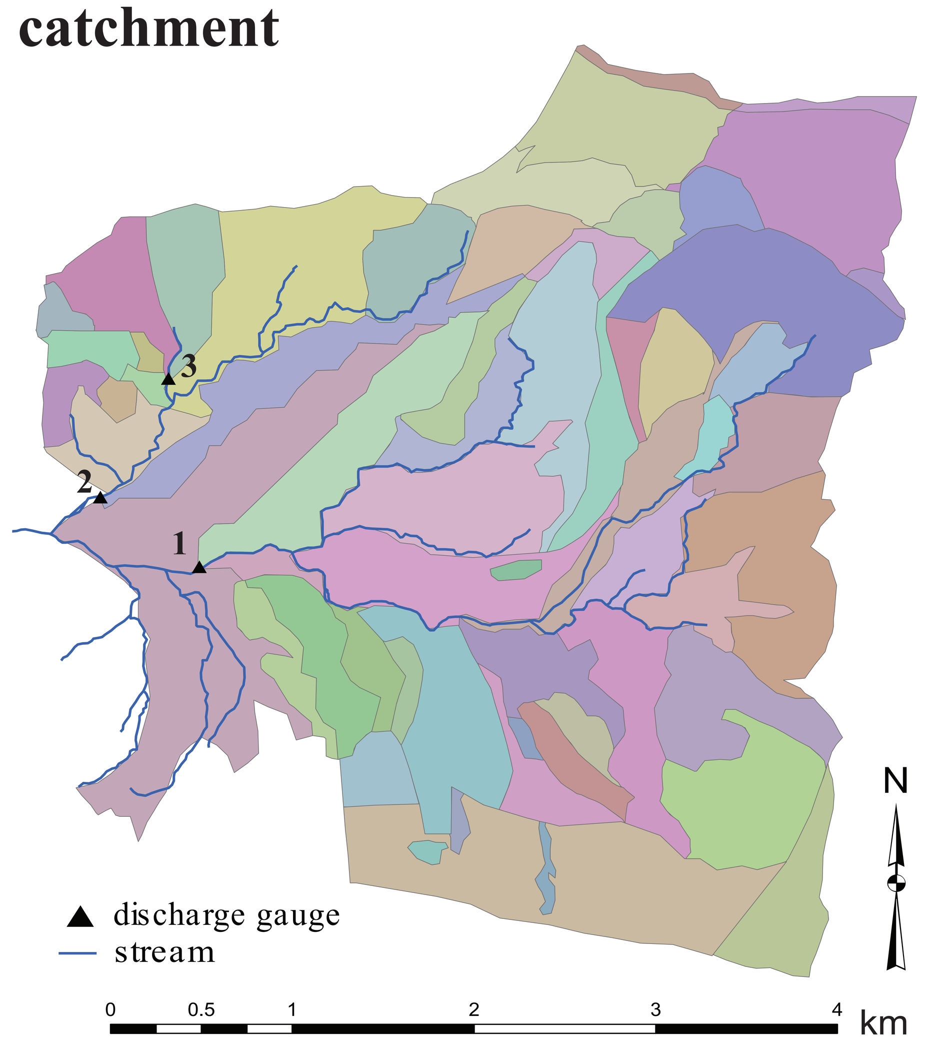
Qcum



Qmax



Application of the closure relation to the subgrid REWs in a real-world catchment

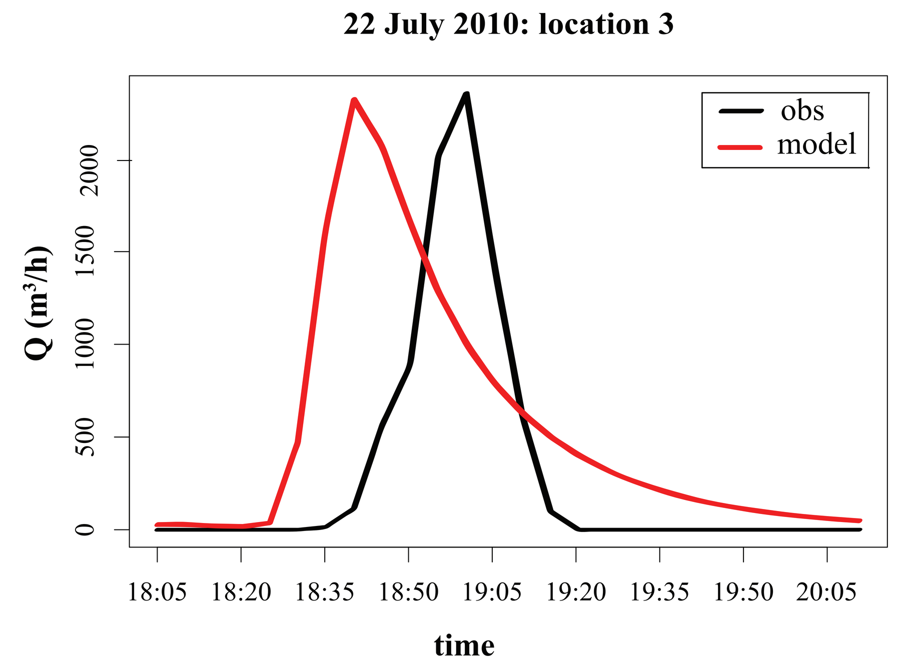


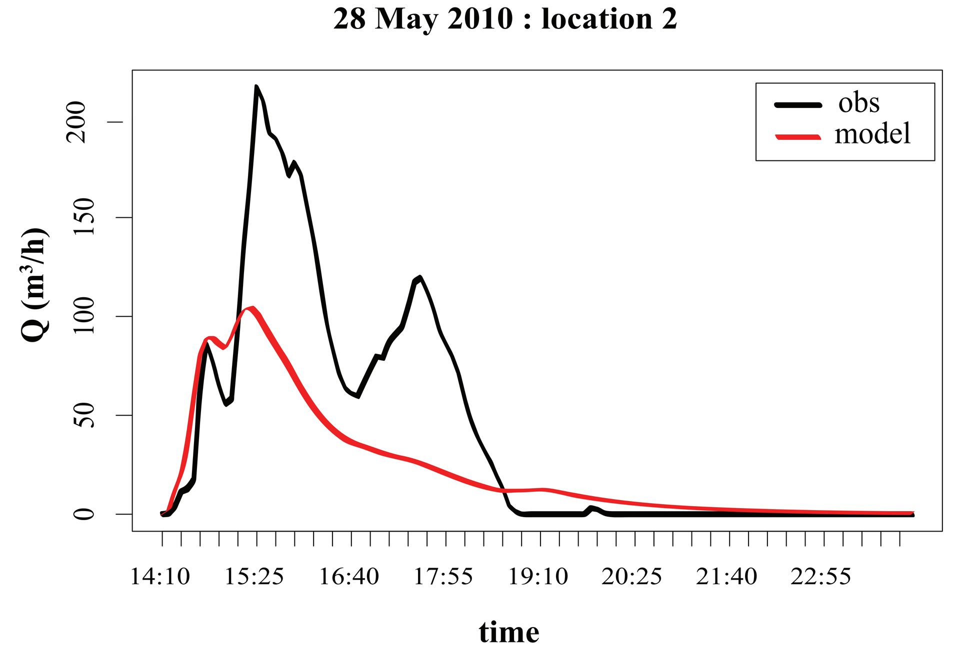
Study area
- 15 km^2 catchment in French Alps (a gridcell)
- 60 REWs with size up to 1 km^2 (polygons in the map)

Data
- 12 rain gauges
- 3 discharge gauges (for validation)
- 1 meteostation
- Soil hydraulic properties and vegetation parameters from observations and literature

Modeling appoarch
- Event-based runs
- Calculate discharge for each REW
- Accumulate discharge from individual REWs to obtain the total hydrograph for the catchment

Preliminary results





Future work
- Include the delay of hydrologic response at the subgrid level
- Better estimation of the REW properties and initial conditions
- Calibration of the closure relation with the field data
- Continuous model runs including dry periods

Reference

[1] Reggiani P, Sivapalan M, Hassanizadeh M. S. A., Unifying Framework for Watershed Thermodynamics: Balance Equations for Mass, Momentum, Energy and Entropy, and the Second Law of Thermodynamics. Advances in Water Resources Research 1998;22(4):367–98.