Multifractal analysis of the output of a fully distributed model for two case studies in urban hydrology

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Introduction

- Hydrological fields are extremely variable over a wide range of spatio-temporal scales
- These features are studied in the specific context of urban hydrology where there are greater coeff. of imp. and shorter response time.

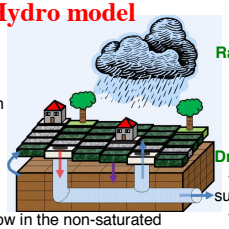
Introduction

Universal multifractals are used to quantify the variability of the various fields. The basic features are:
- Rely on the concept of multiplicative cascades

$$\left\langle \varepsilon_\lambda{}^q \right\rangle \approx \lambda^{K(q)}$$ (Scaling moment function) $$\lambda = \frac{L}{l}$$ (Resolution)

- Only two relevant parameters (C_1 the mean intermittency and α the multifractality), with straightforward consequences (great parameters→ strong extremes)

Multi-Hydro model



Surface module
- Runoffs
- Infiltration

Rainfall module
- Spatio-temporal rainfall

Drainage module
- Sewer flow (free surface, loaded)
- Overflow

Soil module
- Vertical flow in the non-saturated area
- Saturation during a rainfall event

Giangola-Murzyn et al., 2012

Conclusion

Quantifying the uncertainty associated with unmeasured small scale rainfall variability :

- It cannot be neglected (*CV*' reaches 30% for up-stream links and 7.5% for the outlet, and power law fall-off for probability distribution for both discharge and rainfall). Furthermore much more uncertainty is unveiled with the fully distributed and even moderate rainfalls are affected.
- A need to implement X band-radars (which provide an hectometric resolution) in urban area

The use of fractal and multifractal tools should be developed in urban hydrology

- Catchment data (land use, network, rainfall data, discharge…) exhibit fractal and multifractal features
- A way to better take into account small scale phenomenon in urban hydrology

References

Giangola-Murzyn A., et al. (2012). Multi-Hydro: physically based modelling to assess flood resilience across scales, case studies in Paris region. Proceedings of 10th Urban Dranaige conference, Belgrade 3-7 Sept. 2012, Serbia.

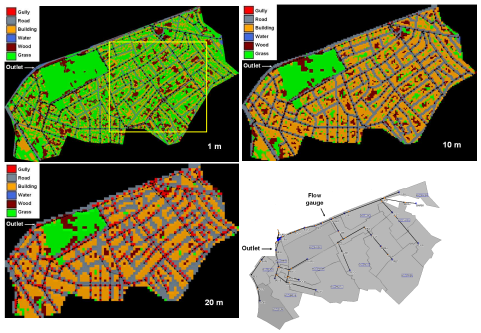
Gires A., et al. (2012), Multifractal analysis of an urban hydrological model on a Seine-Saint-Denis study case. *Urban Water Journal*.

Schertzer, D. and S. Lovejoy (2011), Multifractals, generalized scale invariance and complexity in geophysics. *International Journal of Bifurcation and Chaos*, 21 p. 3417-3456.

Case study and fractal analysis of the input

Kodak catchment (Seine-Saint-Denis, France)

- 1.47 km²
- Known for regular overflow
- Project to build a storm water storage basin



Percentage of impervious area

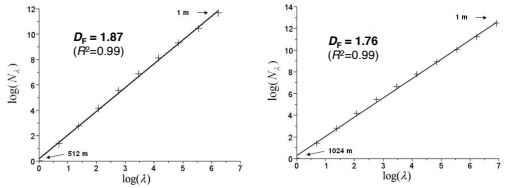
Size of pixel (m)	Kodak	Jouy-en-Josas
20	87	57
15	83	52
10	77	44
5	63	34
1	40	23

Notion of fractal dimension of a set *A*:

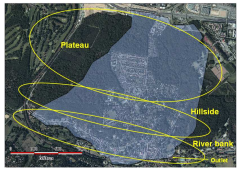
$N_\lambda \approx \lambda^{D_F}$

N_λ = number of boxes of size l needed to cover the set A of outer scale L

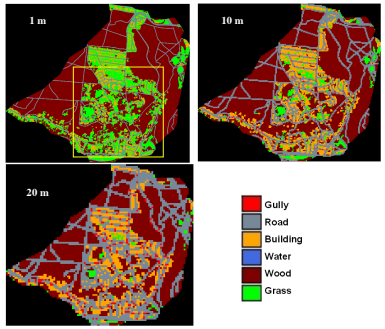
Resolution = $\lambda = \frac{L}{l}$



Jouy en Josas (Yvelines, France)



- 2.5 km²
- Steep area
- Possible flash-flood events with rapid surface runoff



Uncertainty associated with small scale unmeasured rainfall variability

Methodology

(See Gires et al. 2012)

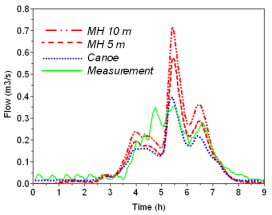
(i) Generation of an ensemble of realistic downscaled rainfall fields :
- Multifractal analysis of rainfall data
- Spatio-temporal (Marsan et al., 1996; Gires et al., 2011) downscaling with the help of discrete universal multifractals cascades

(ii) Simulation of the corresponding ensembles of hydrographs :
- Use of operational hydrological/hydraulic urban models

(iii) Analysis of the ensembles :

Variability among the 100 samples ⟺ Uncertainty due to the unknown high resolution rainfall variability

Comparison of the simulated flows at the outlet

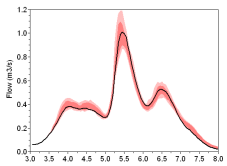


- Similar pattern
- Peak flow underestimated with 1D model

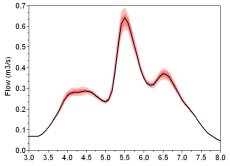
Results: quantification of the uncertainty

For the outlet

Fully distributed MH



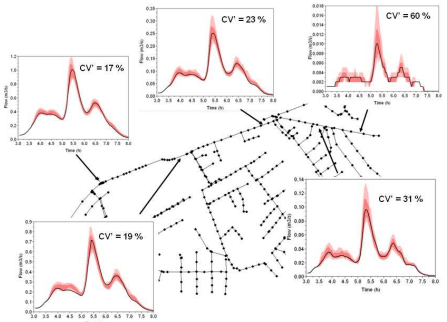
1D model



CV' = 7 % for MH and 6% for 1D model

- MH (10m) unveils much more uncertainty
- Even moderate rainfalls are affected with MH

For the whole network



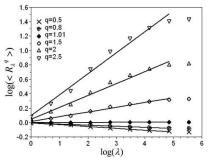
Multifractal analysis of simulated flow

Methodology

(i) UM Generation of 100 high resolution (111 m x 111 m x 1 min) 256 min realistic rainfall event
(ii) Simulation of the corresponding hydrographs
(iii) Performing a multifractal analysis on the ensemble of 100 hydrographs..

→ Implemented on a 3400 ha area in Seine-Saint-Denis represented with the help of a semi-distributed model

Results



Scaling features retrieved on the range 5-256 min