Impacts of small scale rainfall variability in urban areas: a case study with 2D/1D hydrological model in a multifractal framework

A. Gires, A. Giangola-Murzyn, I. Tchiguirinskaia, D. Schertzer, S. Lovejoy

auguste.gires@leesu.enpc.fr

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Introduction

Basic features of hydrological processes at stake in urban hydrology flooding (rainfall, surface runoff, sewer flow, and sub-surface flow):

- **Non linear**
- **Different characteristic spatial and temporal scales**

Numerous studies suggest that rainfall variability, which is extreme over wide ranges of spatial and temporal scales, has a significant impact in hydrology and moreover in urban hydrology (greater coeff. of imper. And shorter response time)

→ What is the impact of small scale (< 1 km x 5 min, usually unmeasured) rainfall variability in urban hydrology ?

→ What should be the spatial resolution of the model used to take it into account ?

A case study :

- **Kodak Catchment (1.44 km^2 urban near Paris)**
- **Two models : a fully distributed one and a semi distributed one**
- **One rainfall event : 9th February, 2009**

The Multi-Hydro model

Overall description:

- Multi-hydro is a numerical platform developed at LEESU (v1, El Tabach et al, 2008, v2, A. Giangola-Murzyn et al., 2012) in the framework of SMARTesT. It is currently in a validation and demonstration (Heywood site, Manchester; Villecresnes site, Val-de-Marne) phase.

- It a is core that makes interact different modules, each representing a portion of the water cycle in urban hydrology.

(see Giangola-Murzyn et al. paper at this conference)

Main goals:

- taking into account small scales → fully distributed model

- physically based model (no calibration)

- easily transportable → a conversion module to generate inputs from available GIS data

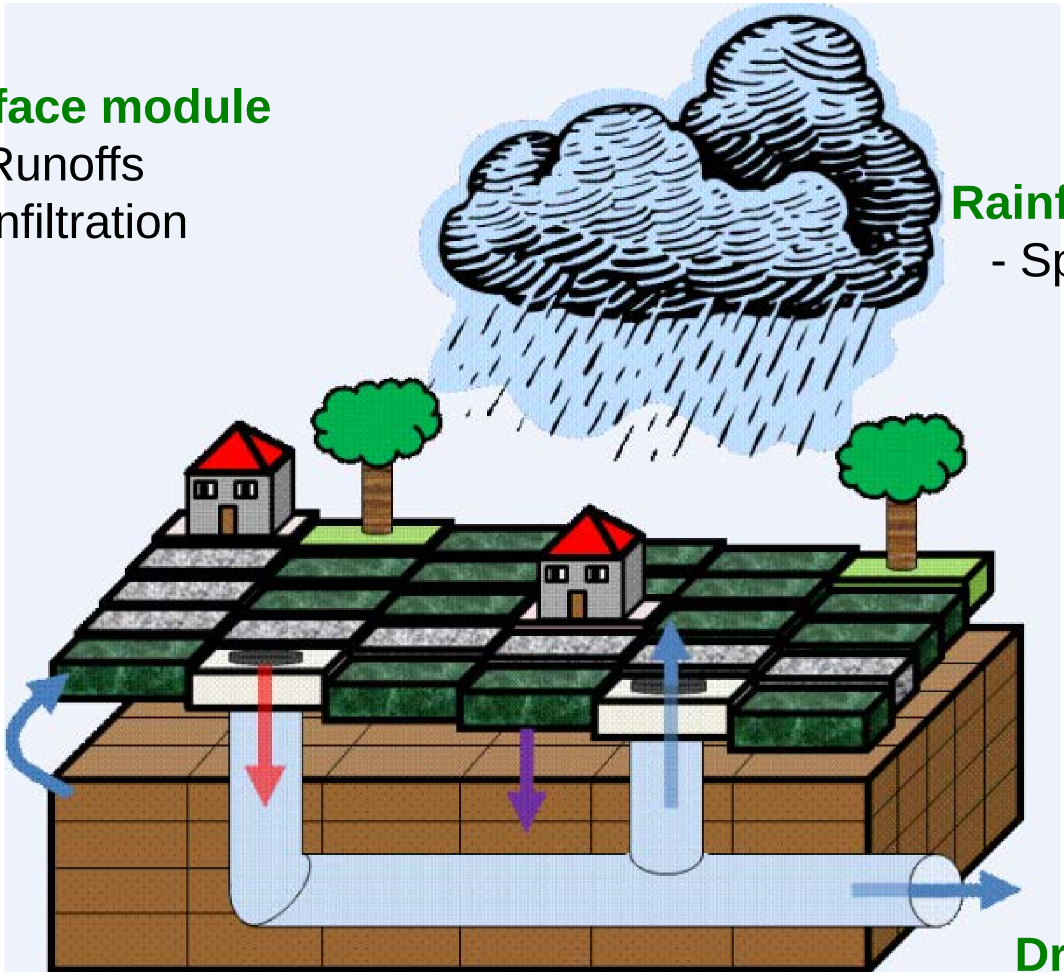
- open access software packages to benefit from the feedback of a large community and frequent update.

The Multi-Hydro model

Urban area physical processes modeled in Multi-Hydro

Surface module
- Runoffs
- Infiltration

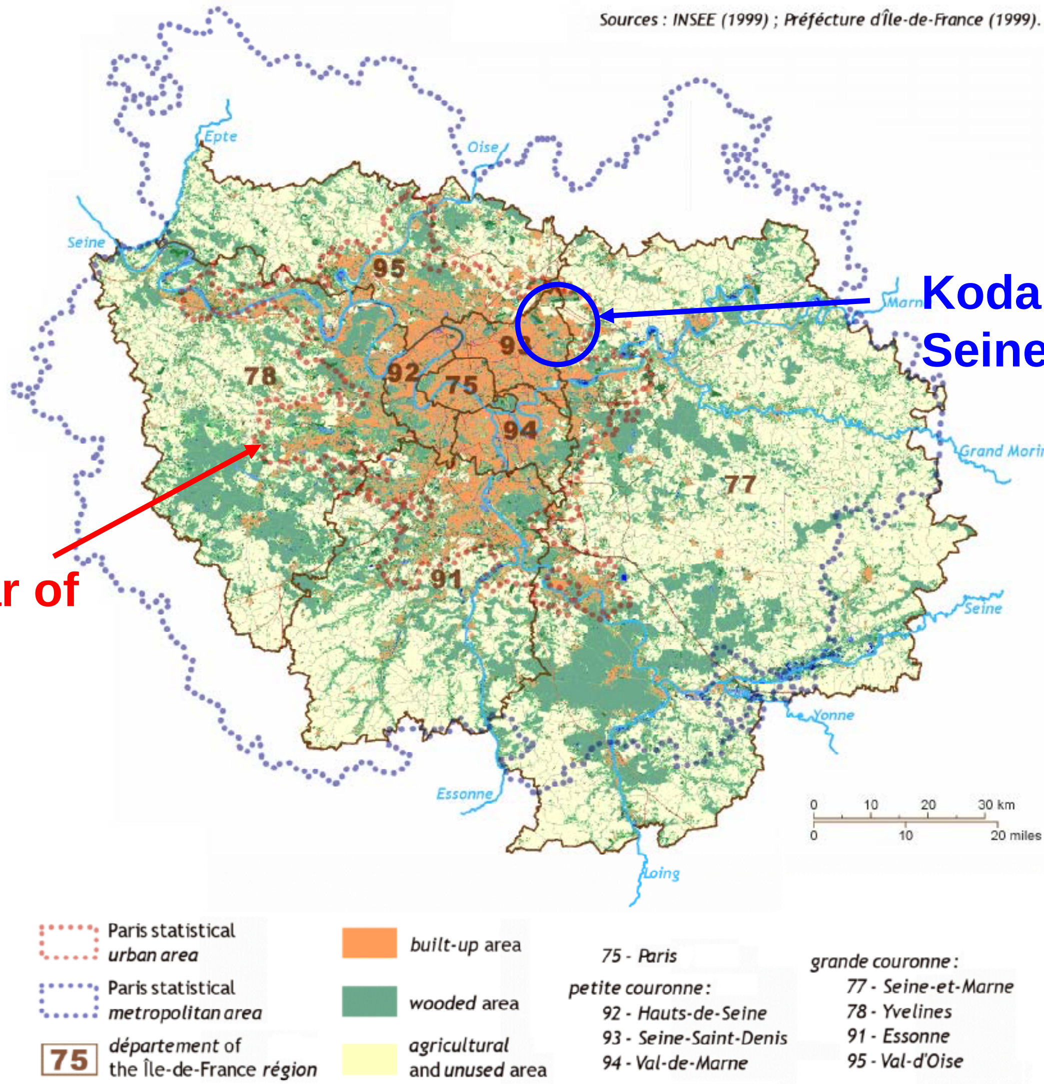
Rainfall module
- Spatio-temporal rainfall



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

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

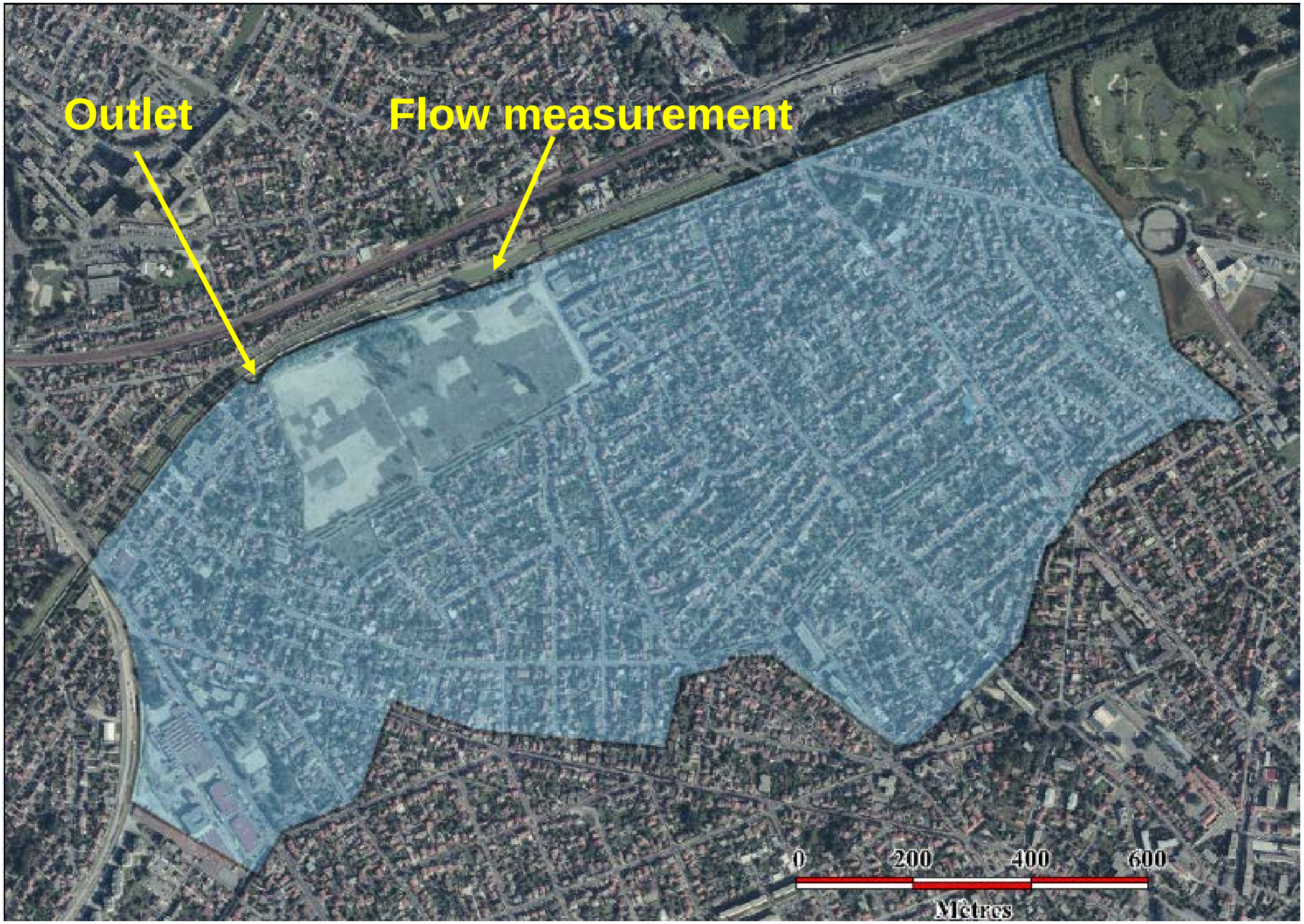
Kodak catchment



Kodak catchment, in Seine-Saint-Denis

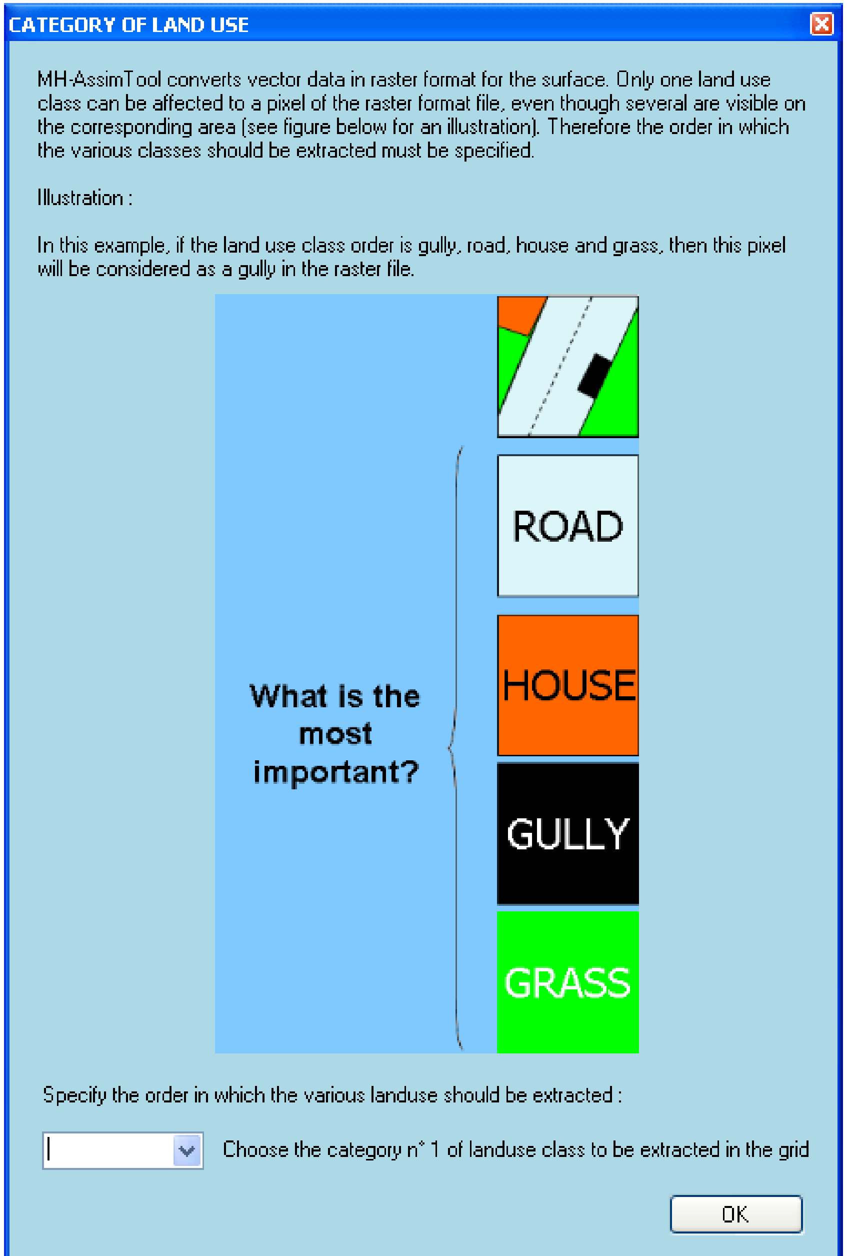
C band radar of Trappes

Kodak catchment



- $1.44\ km^2$
- Known for regular overflow
- Project to build a storm water storage basin

Multi-Hydro resolution



Snapshot of MH AssimTool

Raster data

→ Only one land use class per pixel …

Multi-Hydro resolution

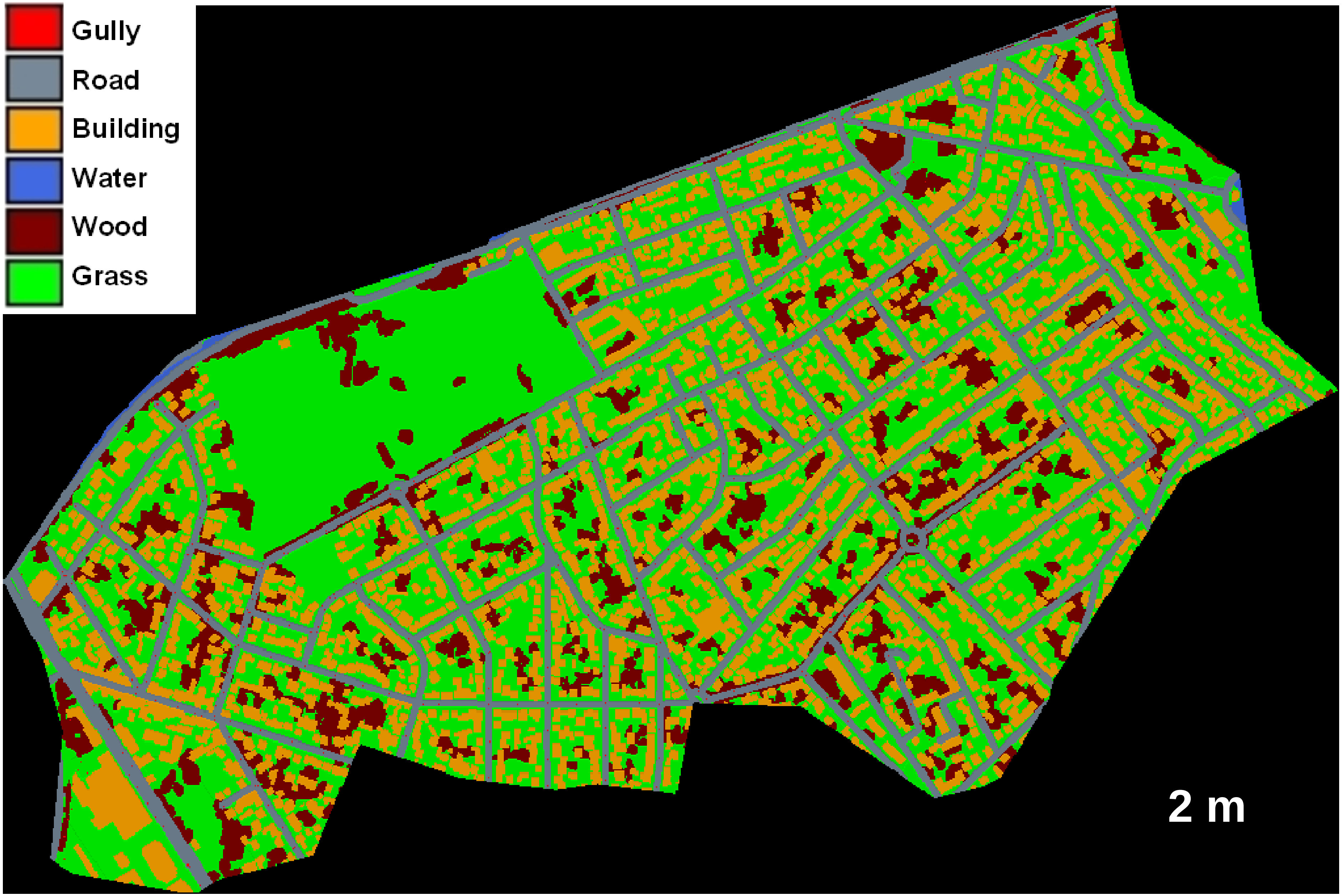
Multi-Hydro resolution

Multi-Hydro resolution

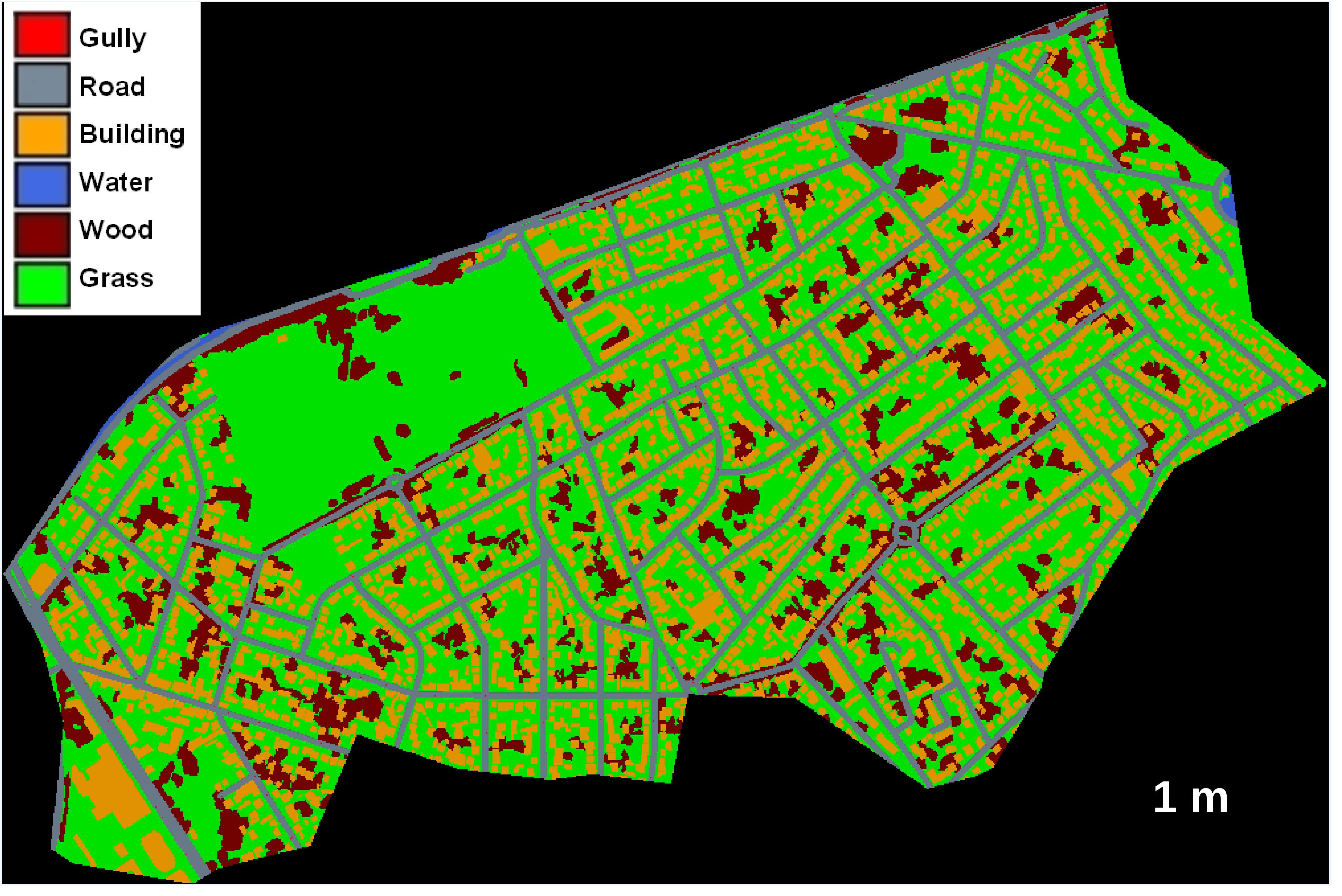
Multi-Hydro resolution

Multi-Hydro resolution

Multi-Hydro resolution



Multi-Hydro resolution



Multi-Hydro resolution

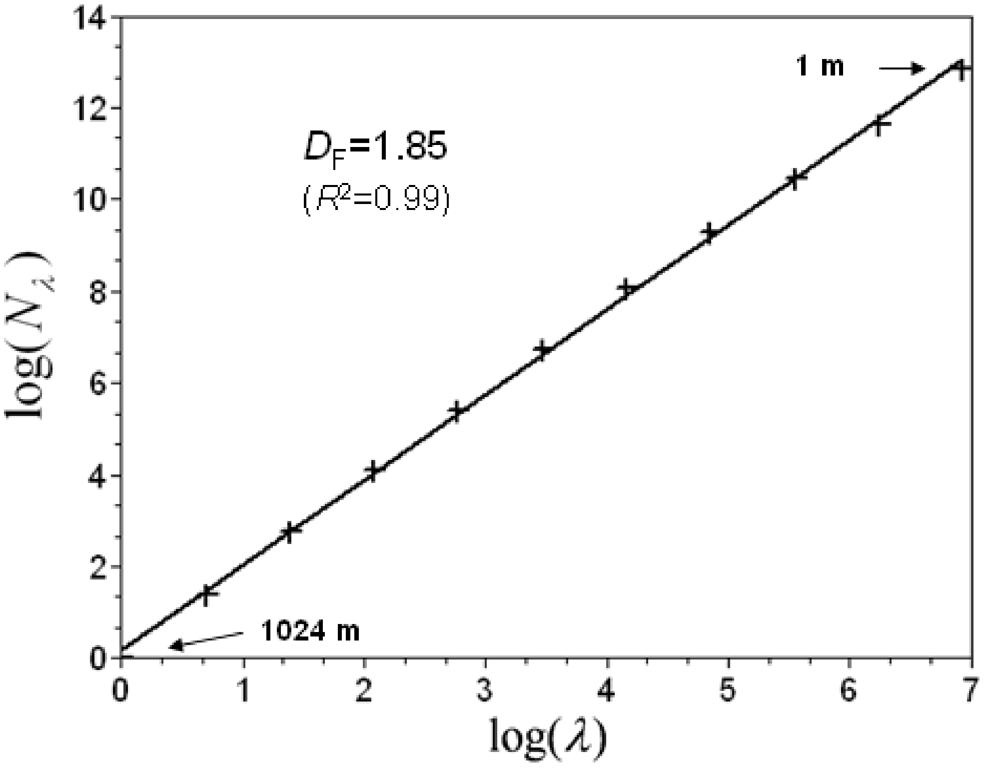
Example of hydrological consequences:

Size of pixel (m)	% of impervious area
20	87
15	83
10	77
5	63
3	53
2	47
1	40

How to explain these figures with a unique notion ?

Multi-Hydro resolution

Fractal dimension of the impervious area :



Notion of fractal dimension of a set *A*:

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

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

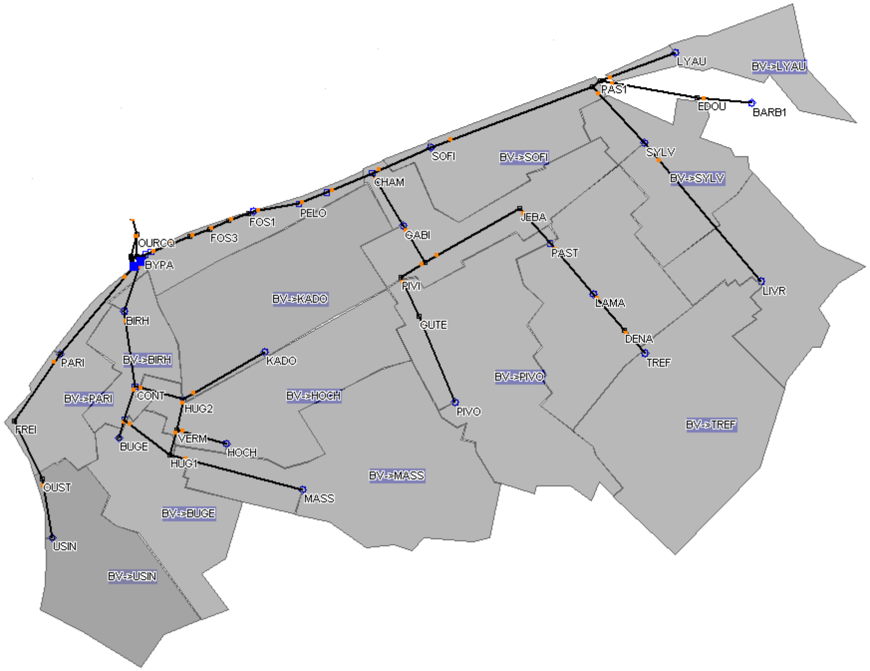
Resolution = $\lambda = \dfrac{L}{l}$

Fractal tools which are commonly used in geophysics can also be helpful in urban environment.

Kodak catchment

Multi-Hydro : 10 m resolution

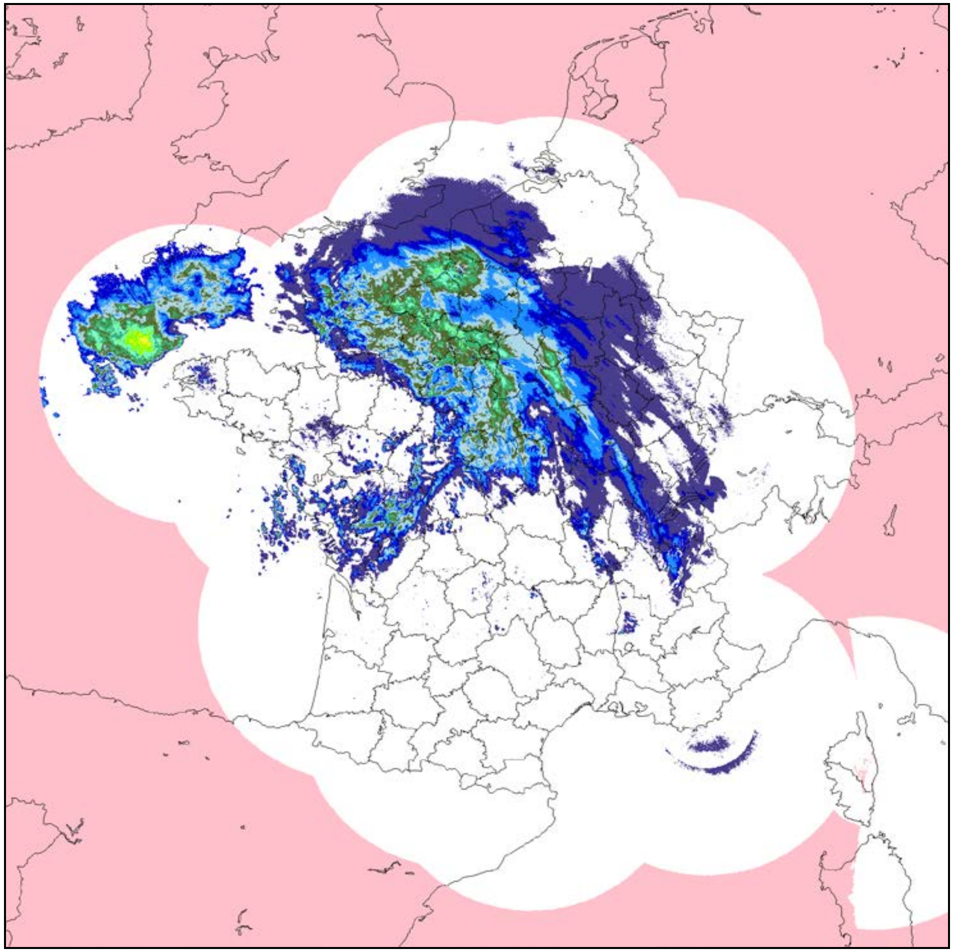
Semi-distributed 1D model



- Modelled with semi-distributed 1D model Canoe (lumped model for each sub-catchment and Saint-Venant equations in the links)
- 16 sub-catchments (considered homogeneous) with size ranging from 4 to 14.5 ha
- Calibrated by DEA 93

Rainfall event of February 9th 2009

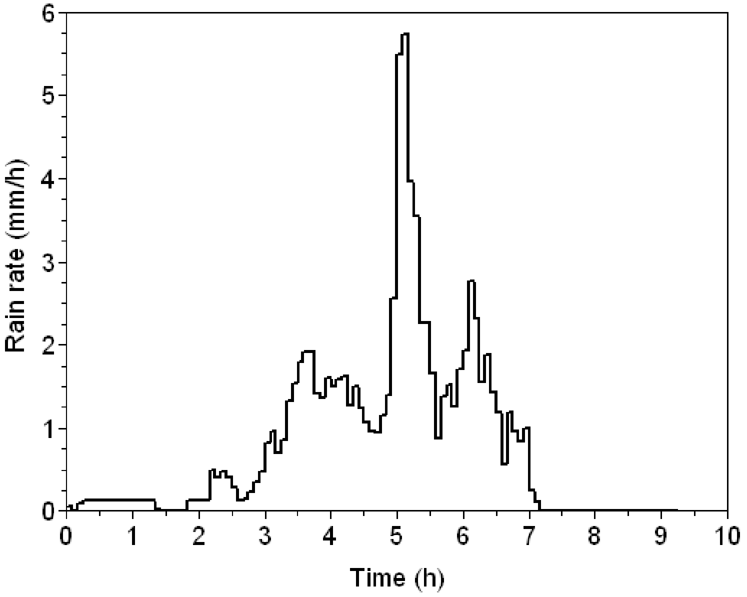
Data : Météo-France radar mosaic



Météo-France radar mosaic, provided by Méteo-France

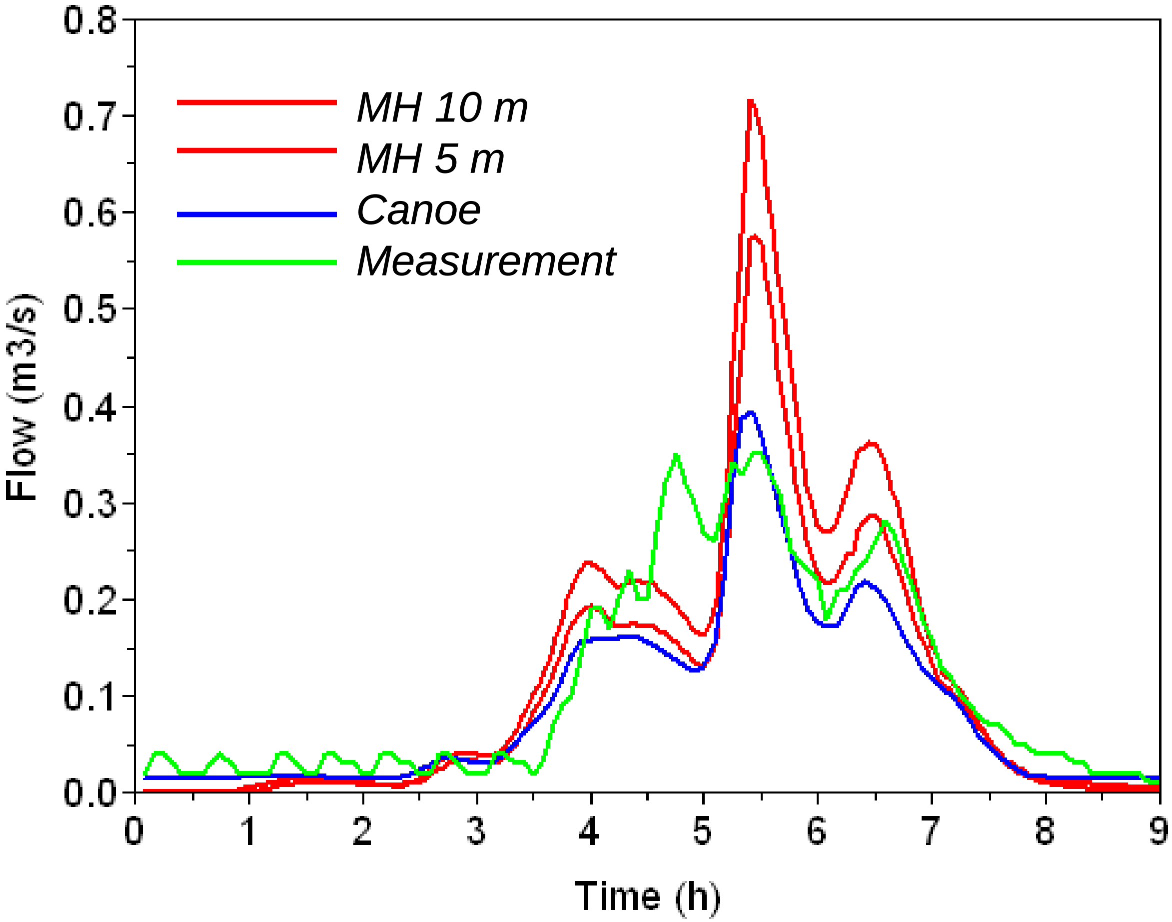
Resolution :
1 km * 1 km * 5 min

Time evolution of the rain rate for the studied catchment



Comparison of the simulated flow with raw radar data

For the measurement point :



Nash-Sutcliff
- *MH 10 m : 0.40*
- *MH 5m : 0.68*
- *Canoe : 0.78*

- Rather similar patterns

- Significant differences in the peak flow

- Data quality ?

Quantifying the uncertainty associated with small scale rainfall variability

Methodology : stochastic ensemble approach

(i) Generation of an ensemble of realistic downscaled rainfall fields :

- Multifractal analysis of rainfall data
- Downscaling with the help of discrete universal multifractals cascades

(ii) Simulation of the corresponding ensembles of hydrographs :

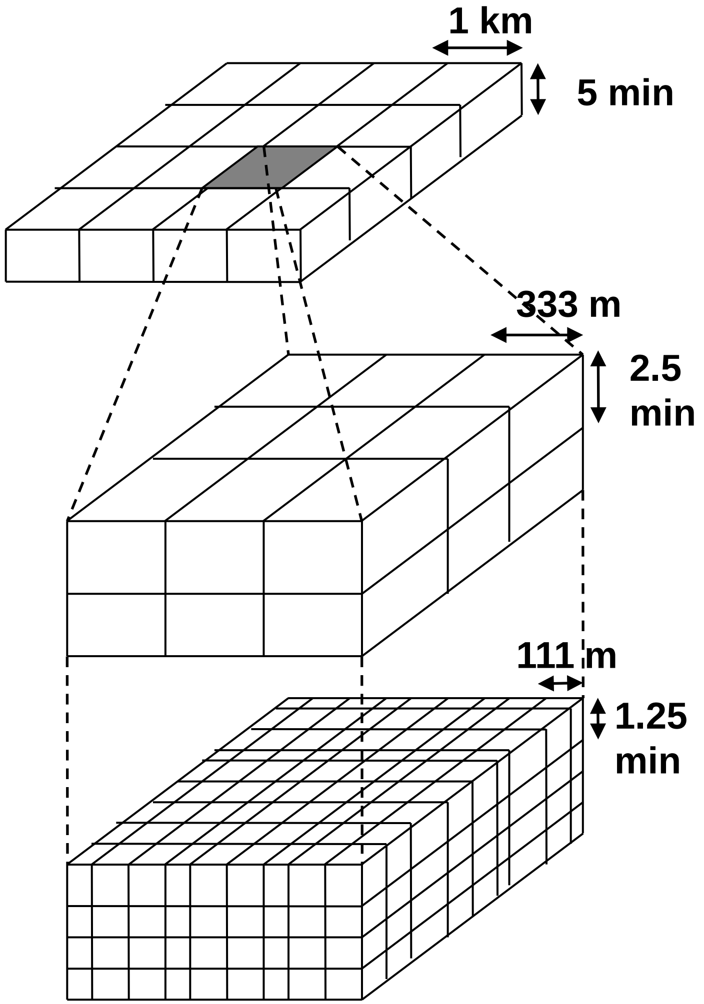
- Use of operational hydrological/hydraulic urban models

(iii) Analysis of the ensembles :

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

Quantifying the uncertainty associated with small scale rainfall variability

Rainfall downscaling technique



Measured or deterministically nowcasted

Multifractal analysis → two relevant parameters of the cascade process

Stochastic spatio-temporal downscaling for each pixel

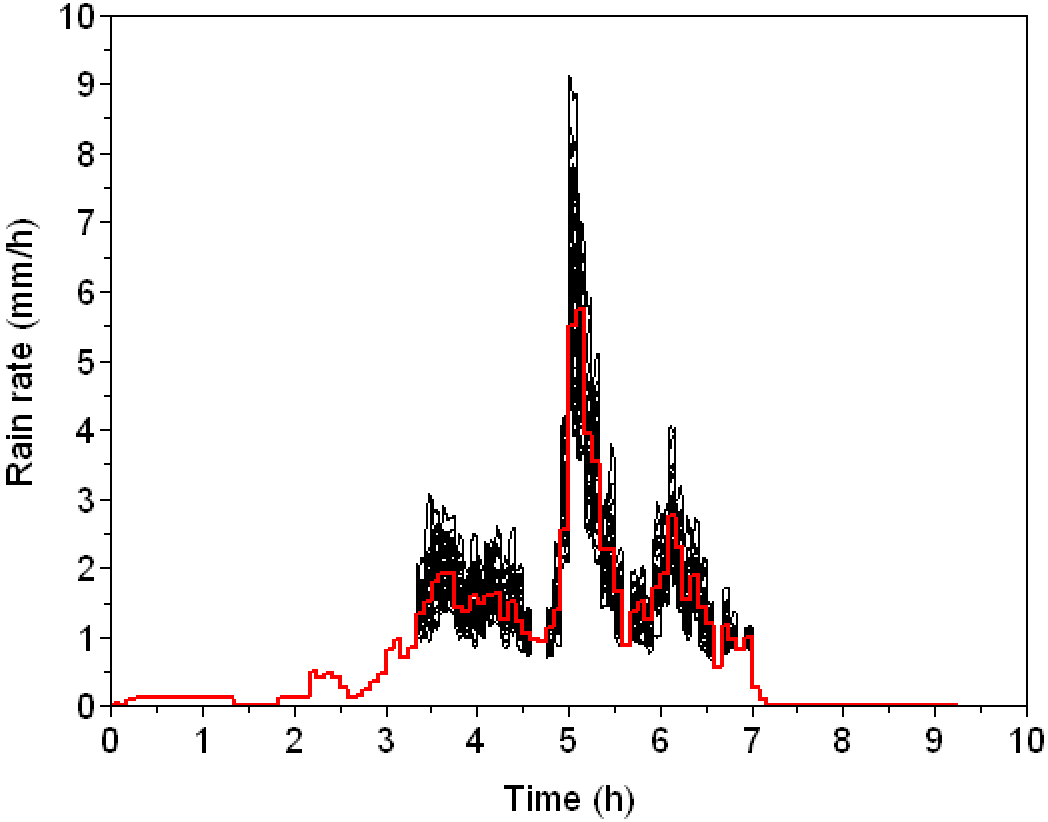
Performed with the help of discrete Universal Multifractal cascades

Two more cascade steps… → 11 m x 19 s

Quantifying the uncertainty associated with small scale rainfall variability

Rainfall downscaling technique

Temporal evolution of the avg rain rate over the studied area



Total rainfall amount :

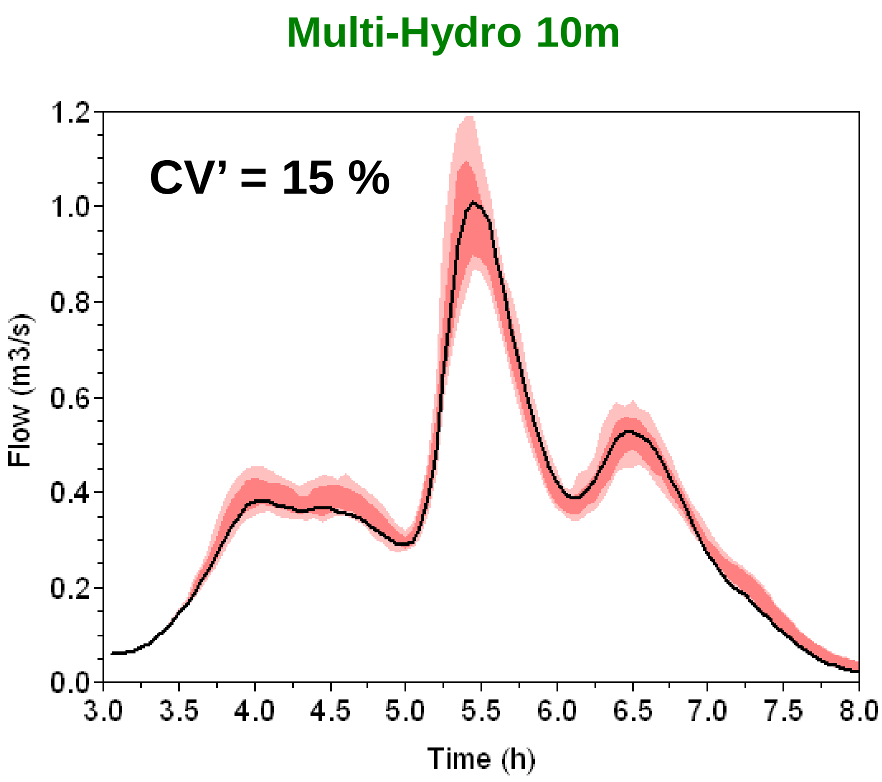
- Raw radar : 7.34 mm

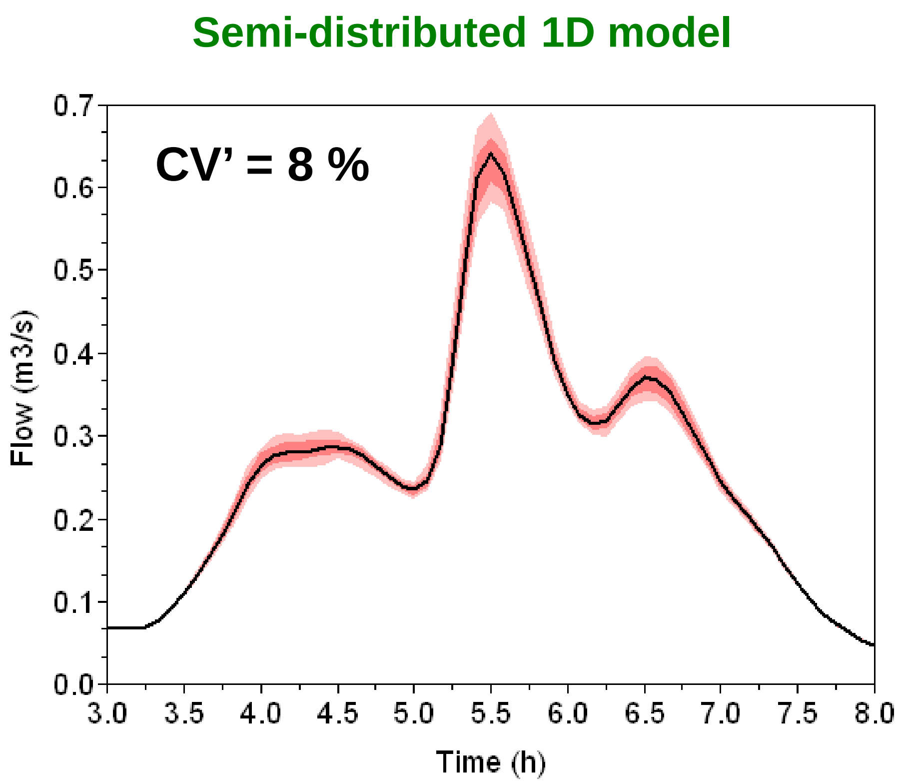
- Simulated ensemble : 7.37 ± 0.21 mm (CV=2.9%)

Potential hydrological effects are due to disparities of spatio-temporal distribution, not total amount.

Quantifying the uncertainty associated with small scale rainfall variability

Uncertainty on the simulated flow for the outlet

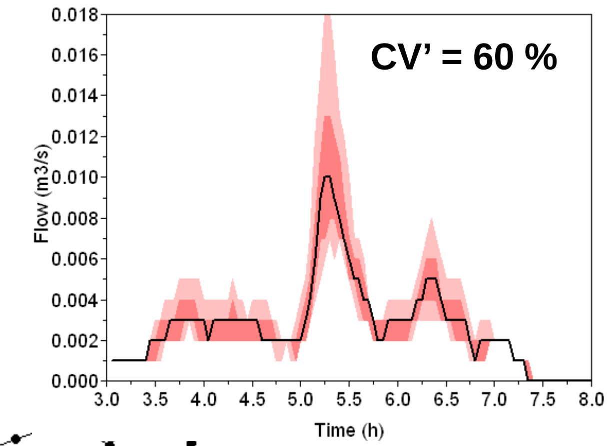


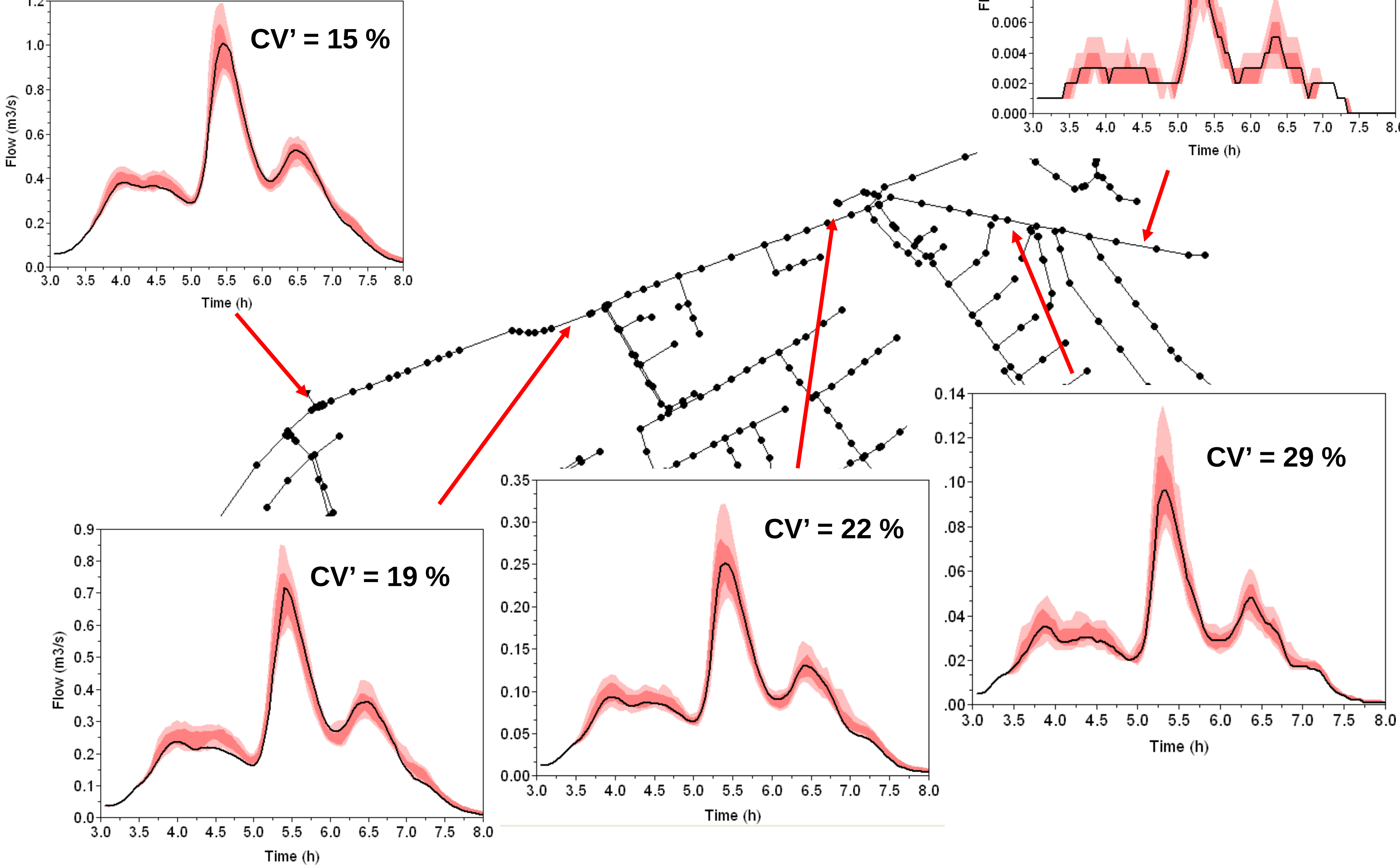


$$CV' = \frac{Q_{0.9}(t_{PF,radar}) - Q_{0.1}(t_{PF,radar})}{2 * PF_{radar}}$$

Quantifying the uncertainty associated with small scale rainfall variability

Upstream / downstream influence





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Conclusion

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Quantifying the uncertainty associated with unmeasured small scale rainfall variability :

- It cannot be neglected (*CV'* reaches 60% for up-stream links and 15% for the outlet, and power law fall-off for probability distribution for both discharge and rainfall).
- A need to implement X band-radars (which provide an hectometric resolution) in urban area

Comparison of a fully distributed model (10 m resolution) with semi-distributed one (300 m resolution)

- Much more uncertainty is unveiled with the fully distributed / Even moderate rainfalls are affected.
- Semi-distributed models would be unable to take advantage of an improved data resolution.

→ Small scale phenomenon must be taken into account in urban hydrology

Limits / further investigations :

- Perform similar study with other inputs
- More heaviest rainfall, actually generating floods should be tested

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