École des Ponts
ParisTech

leesu
laboratoire eau environnement systemes urbains

1) Impacts of small scale rainfall variability in urban areas: a case study with 2D/1D hydrological model in a multifractal framework (presentation from UDM 2012 Conference)

2) Comparison between radar and rain gauge estimates (preliminary results)

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

auguste.gires@leesu.enpc.fr

UNIVERSITÉ PARIS-EST

École des Ponts ParisTech

laboratoire eau environnement systemes urbains

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

Chair "Hydrology for Resilient Cities" (*sponsored by Véolia*)

SMARTeST (*EU FP 7*)

RainGain (*EU INTER-REG NEW*)

UNIVERSITÉ PARIS-EST

EGU General Assembly, Vienna, 22-27 April 2012

Introduction

École des Ponts ParisTech

UNIVERSITÉ PARIS-EST

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)

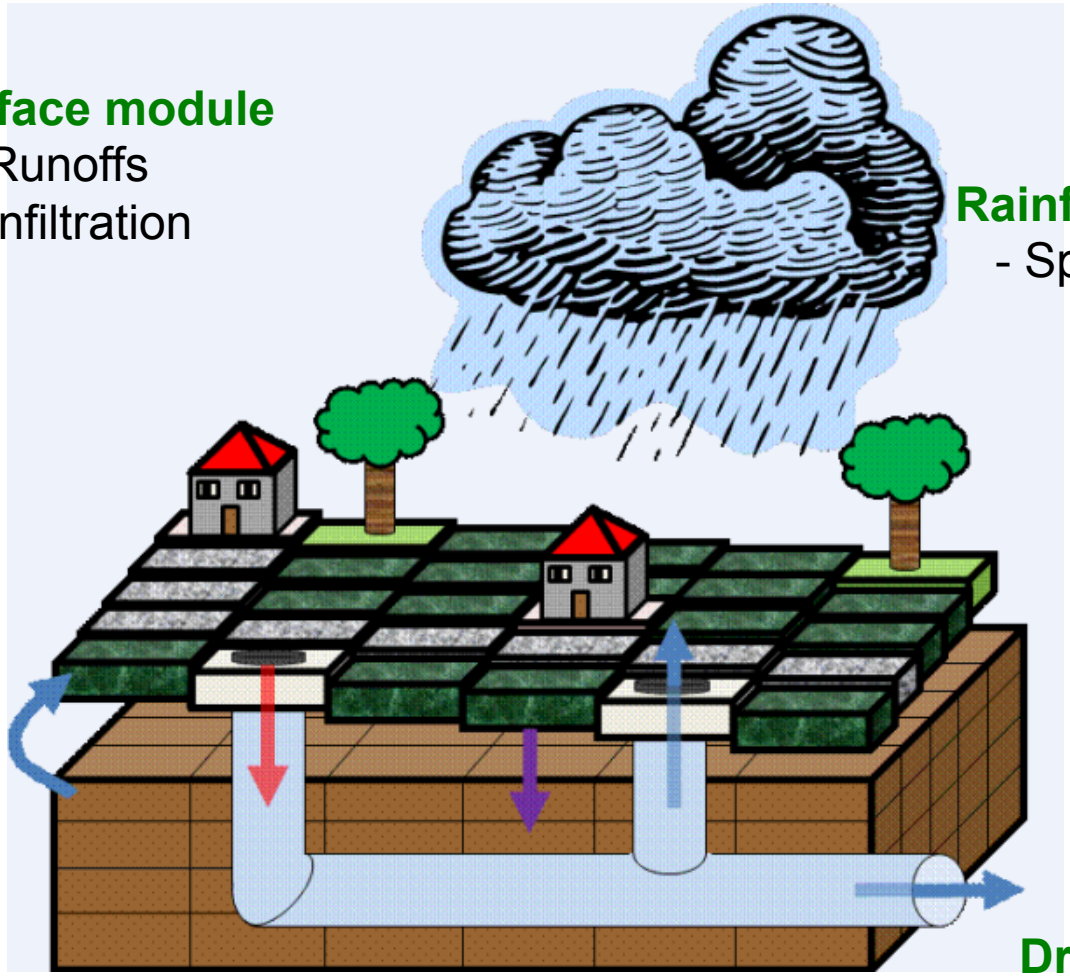
- easily transportable → a conversion module to generate inputs from available GIS data

- 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

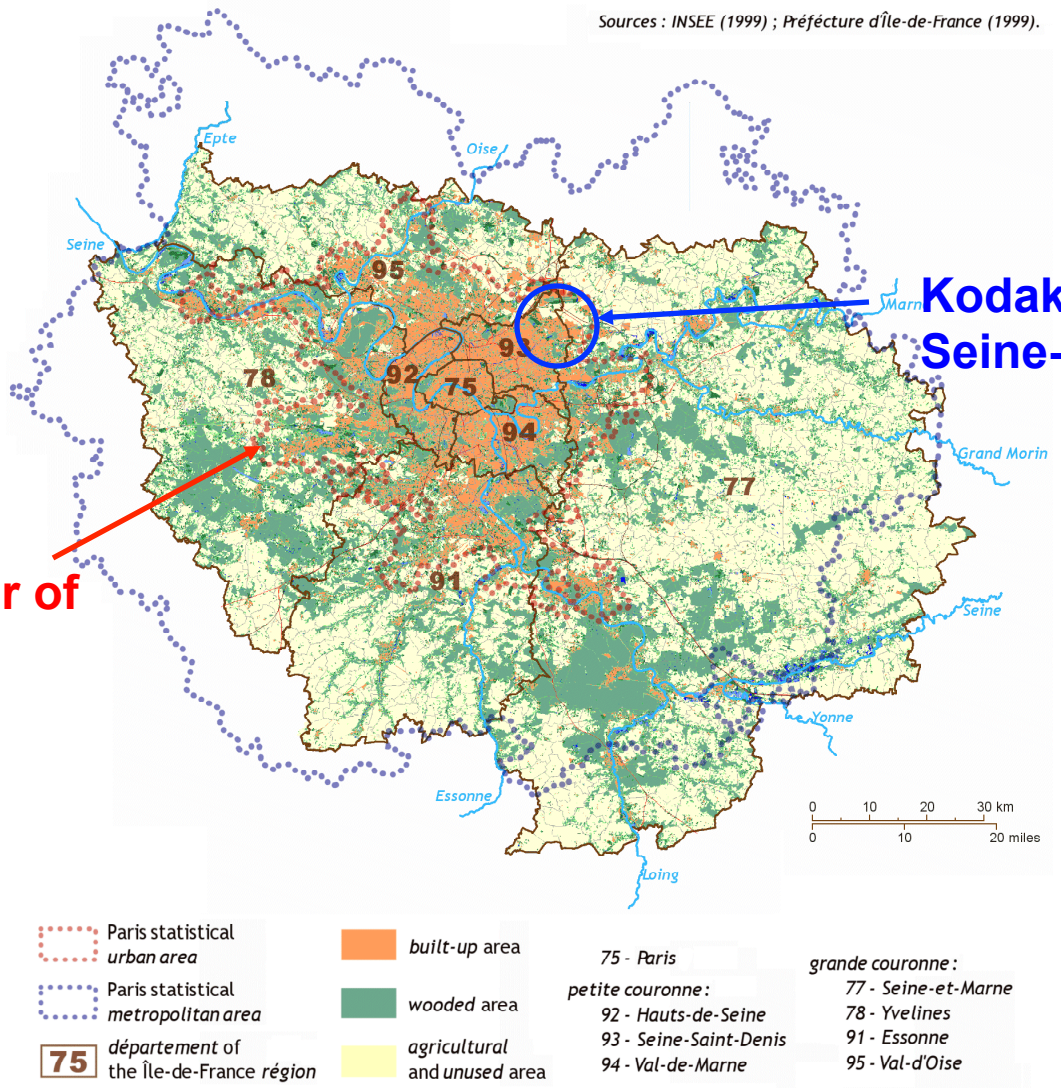


Rainfall module
- Spatio-temporal rainfall

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

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

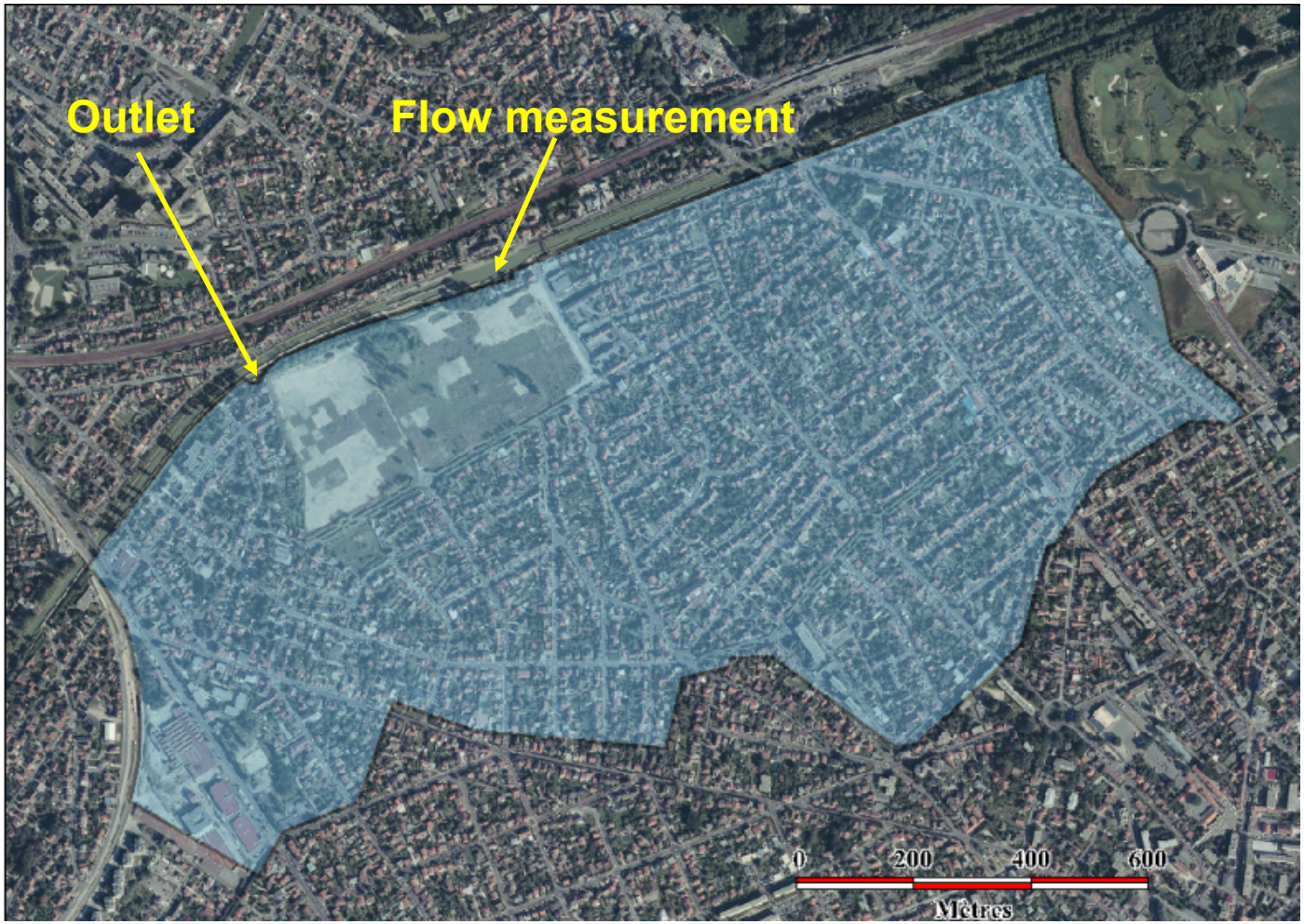
Kodak catchment



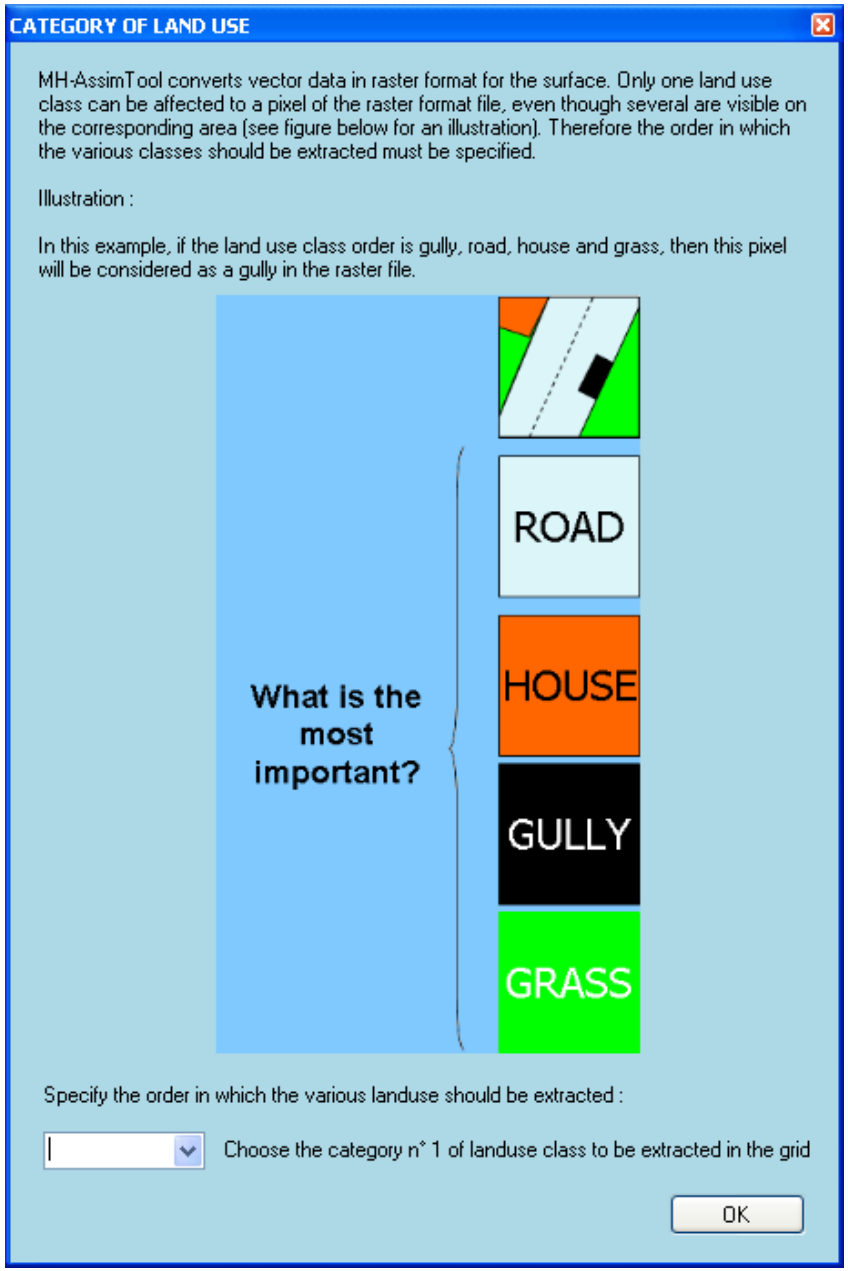
Kodak catchment, in Seine-Saint-Denis

C band radar of Trappes

Kodak catchment



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



Snapshot of MH AssimTool

Multi-Hydro resolution

Raster data

→ Only one land use class per pixel …

Multi-Hydro resolution

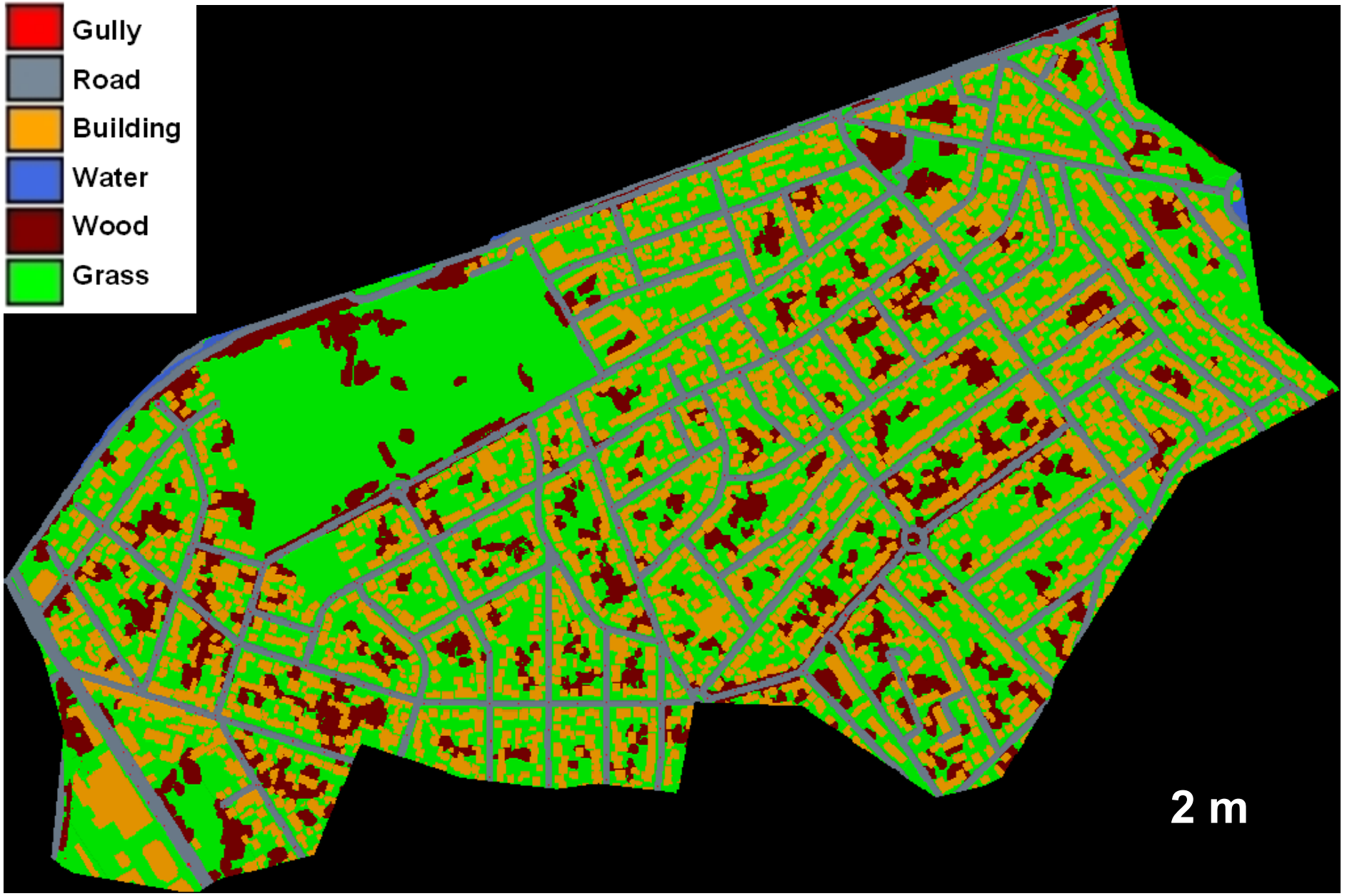
Multi-Hydro resolution

Multi-Hydro resolution

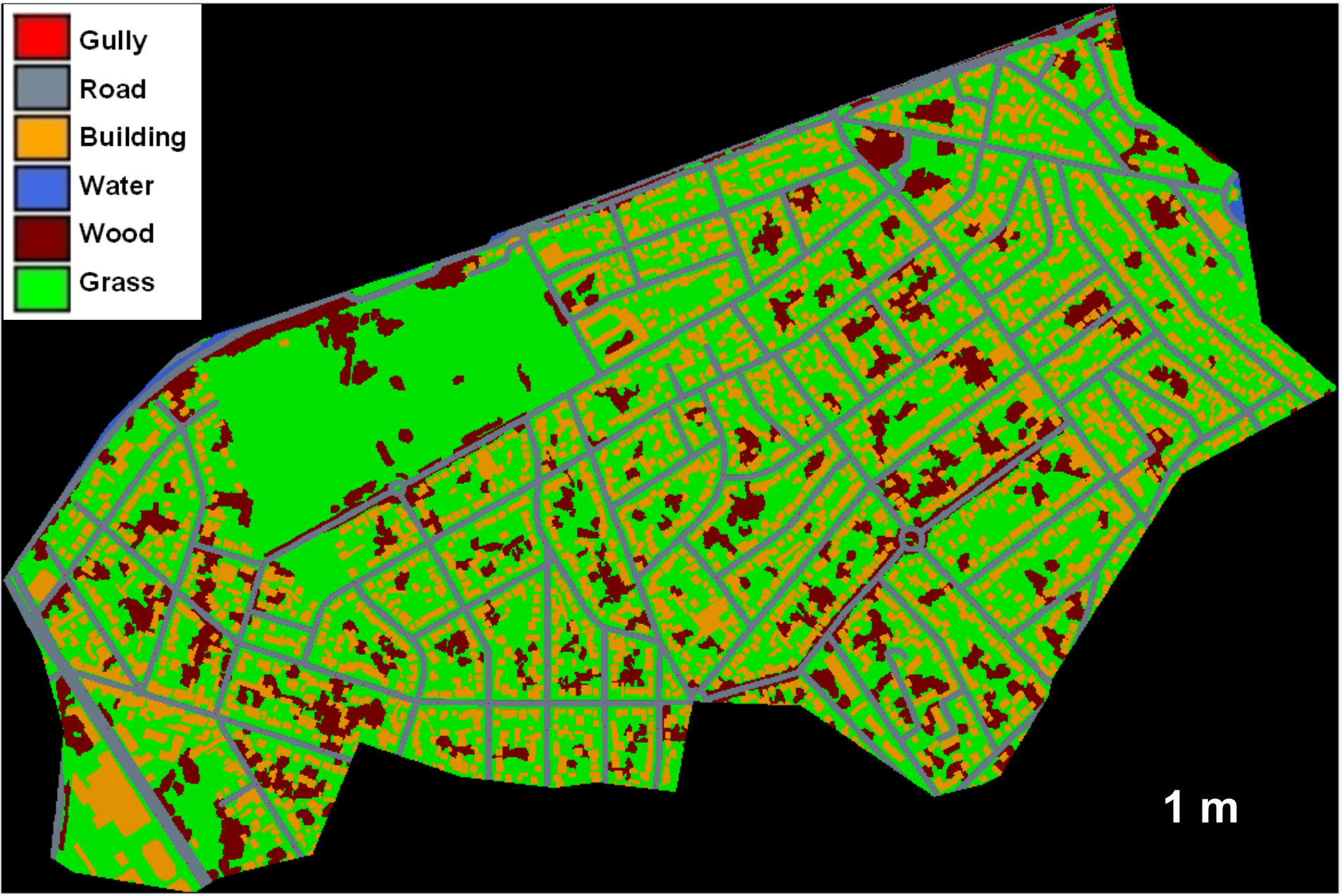
Multi-Hydro resolution

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

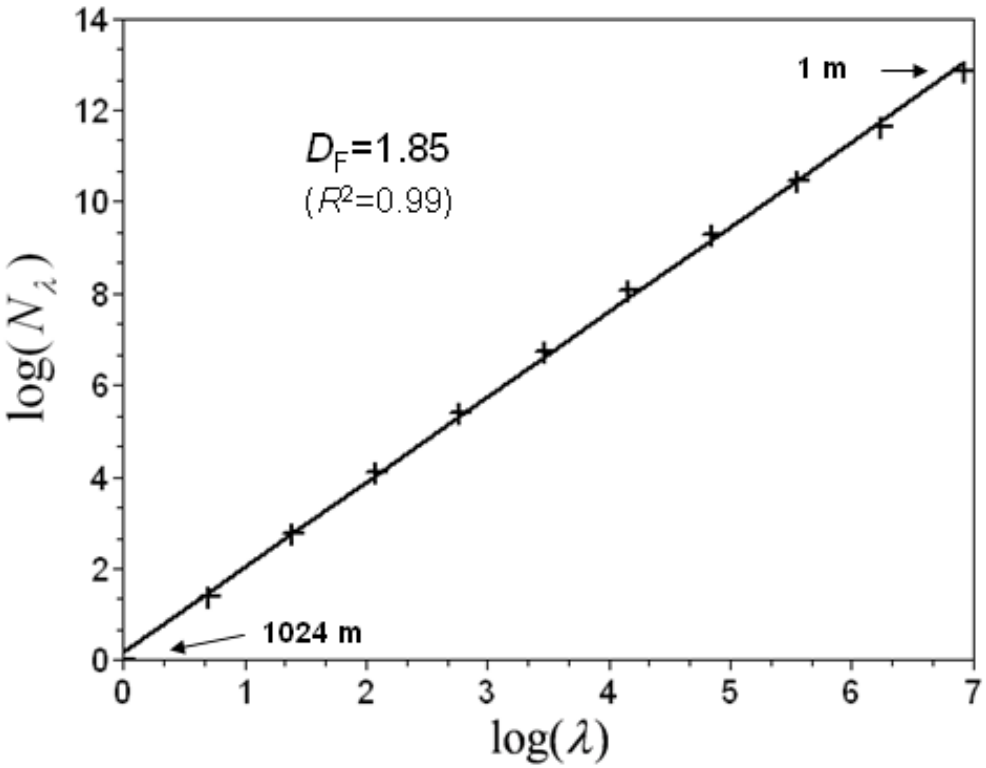
Notion of fractal dimension of a set *A*:

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

Fractal dimension of the impervious area :

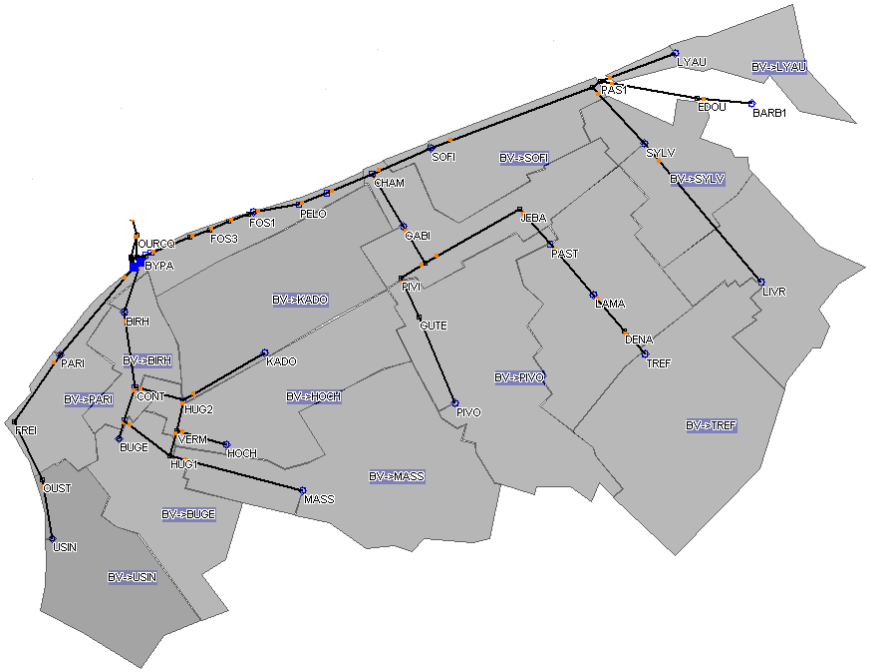


Fractal tools which are commonly used in geophysics can also be helpful in urban environment.

Kodak catchment

Multi-Hydro : 10 m resolution

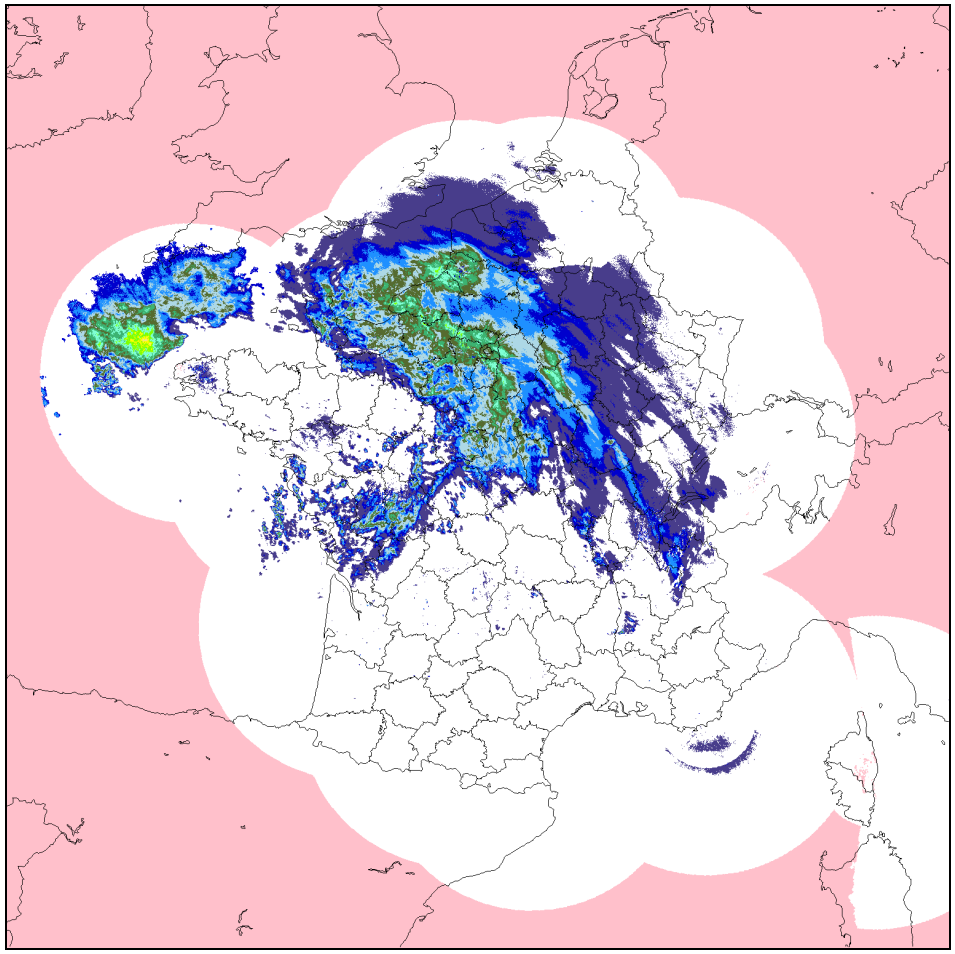
Semi-distributed 1D model



- 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

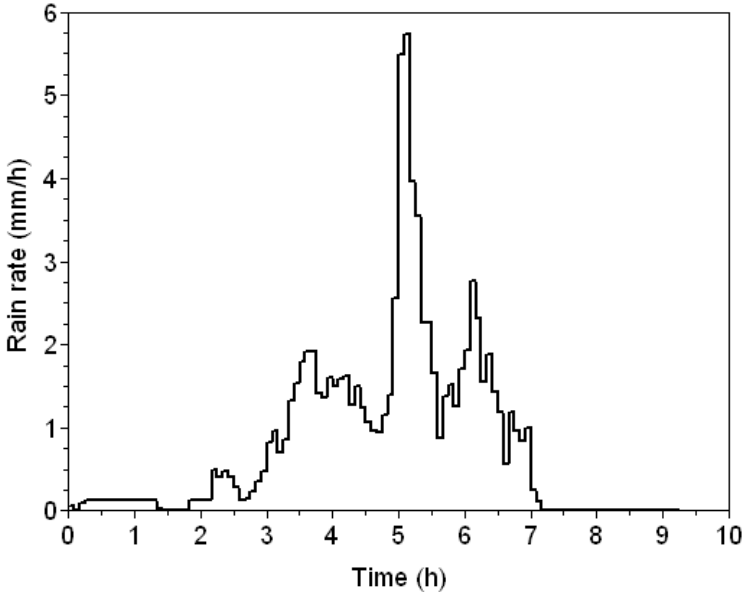
Data : Météo-France radar mosaic



Météo-France radar mosaic, provided by Météo-France

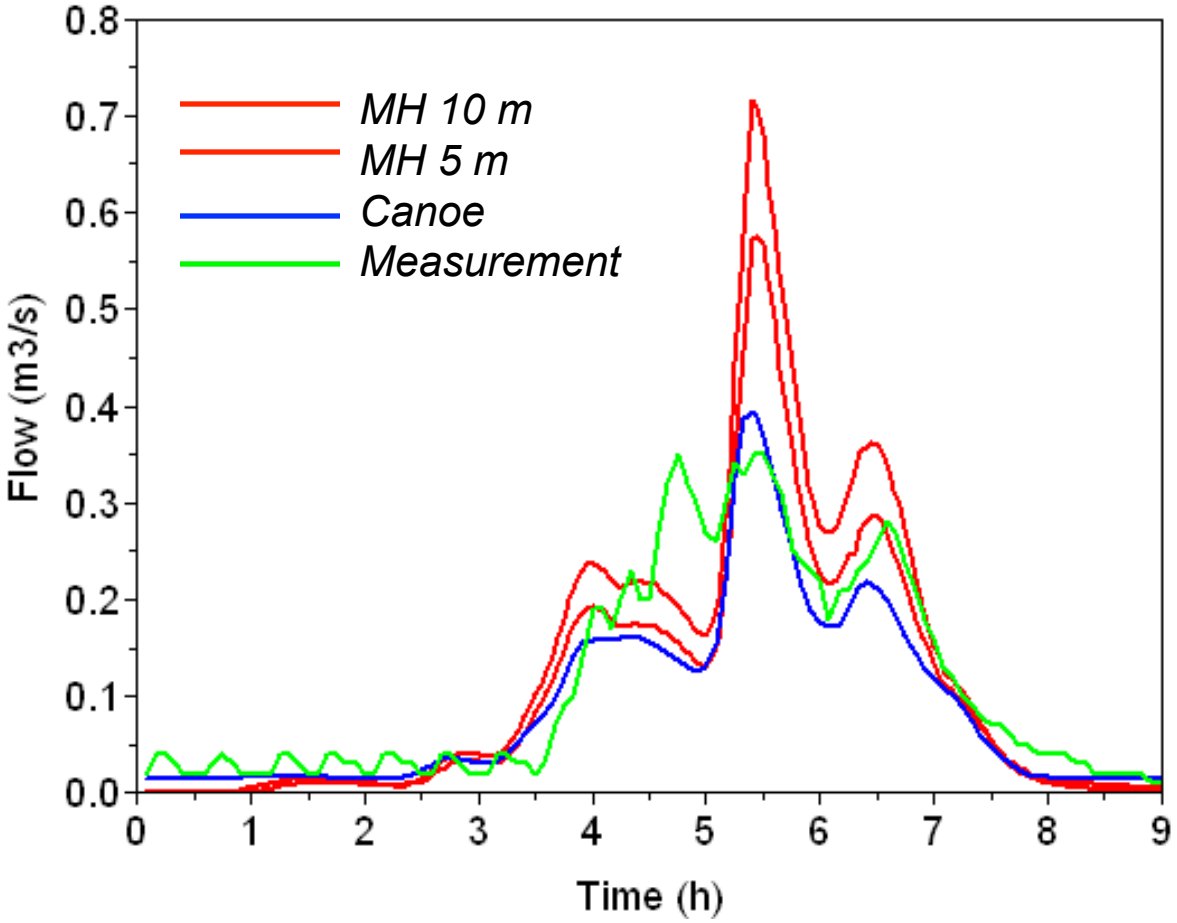
Resolution :
1 km * 1 km * 5 min

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**

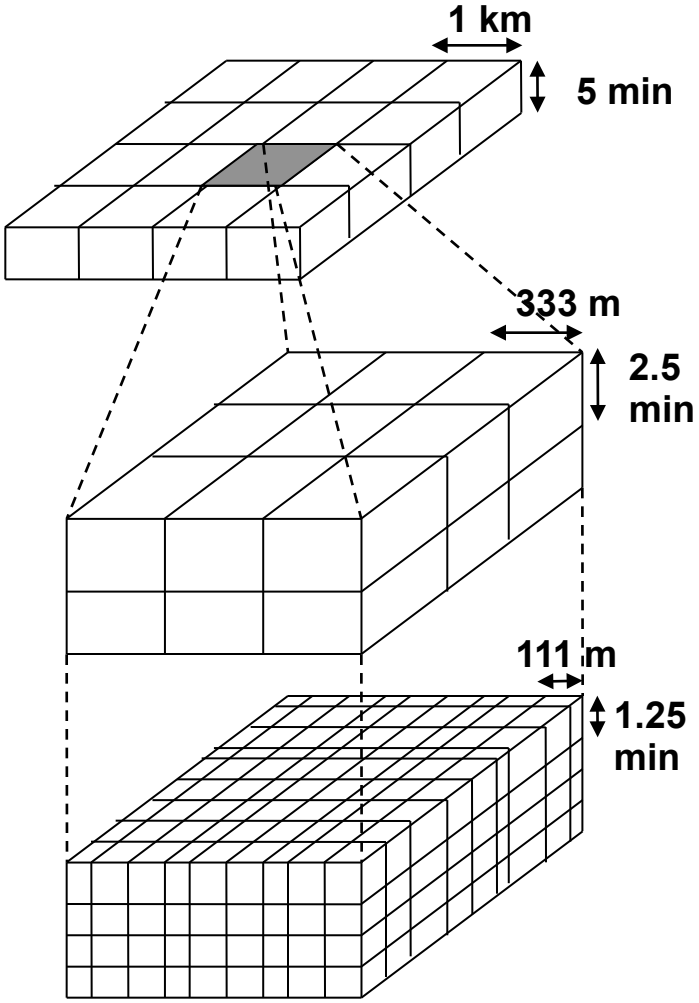
(iii) Analysis of the ensembles :

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

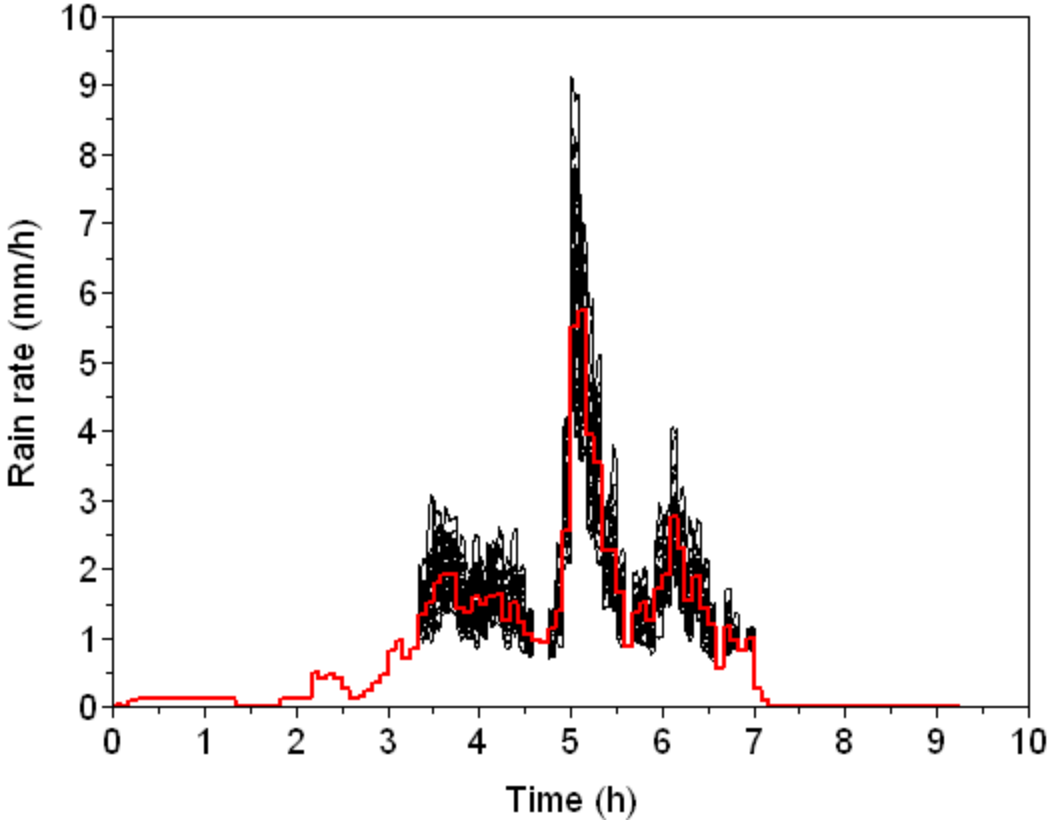
Performed with the help of discrete Universal Multifractal cascades

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

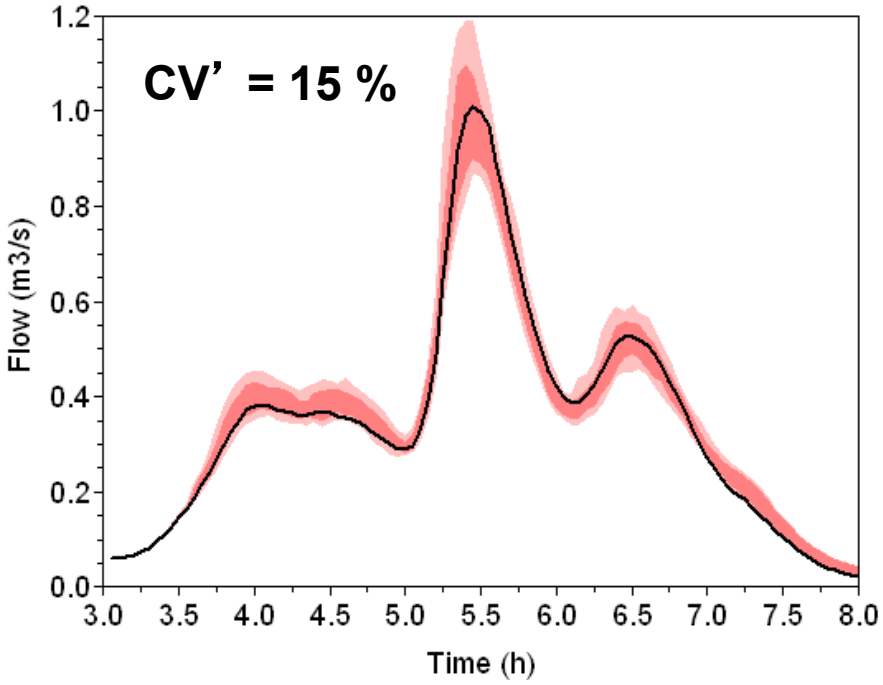
- Simulated ensemble : 7.37 ± 0.21 mm (CV=2.9%)

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

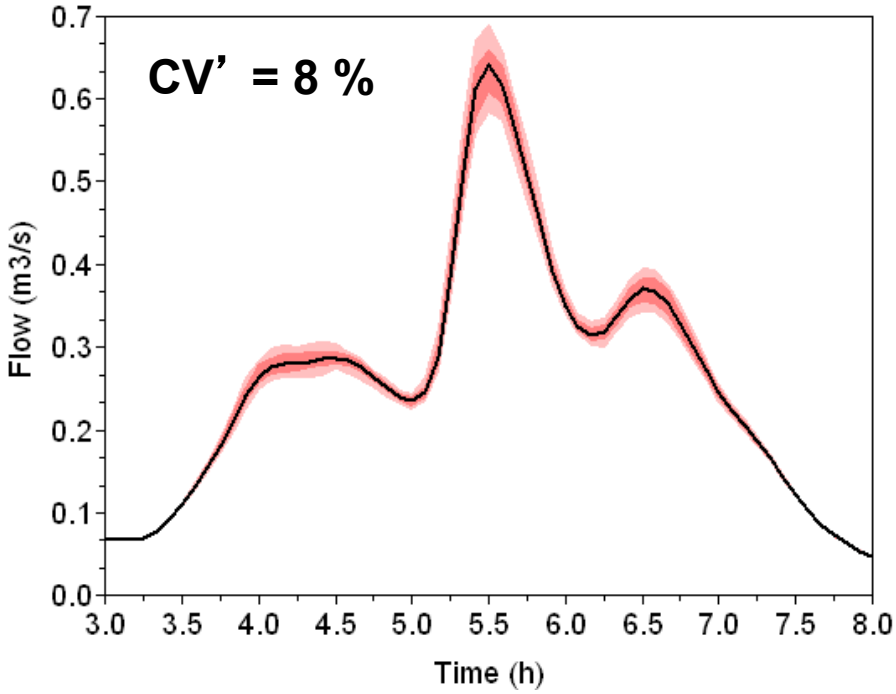
Quantifying the uncertainty associated with small scale rainfall variability

Uncertainty on the simulated flow for the outlet

Multi-Hydro 10m



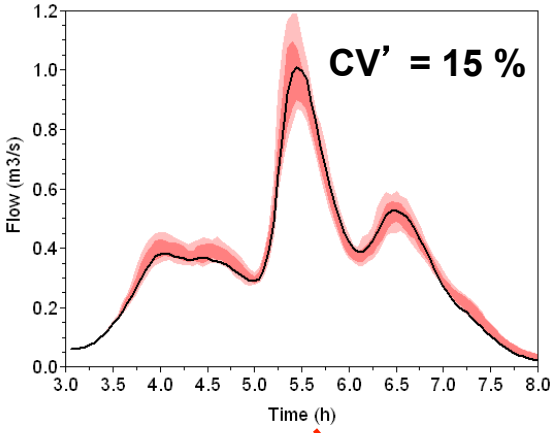
Semi-distributed 1D model

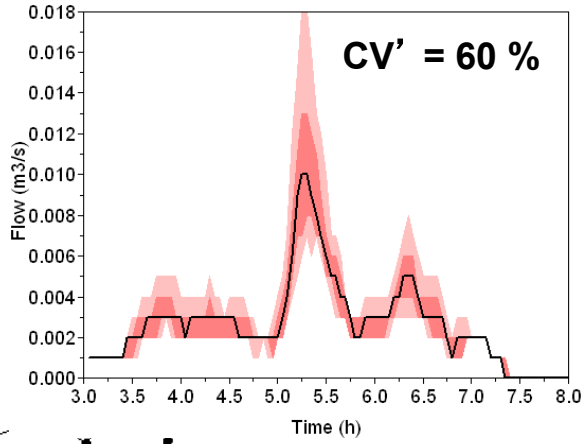


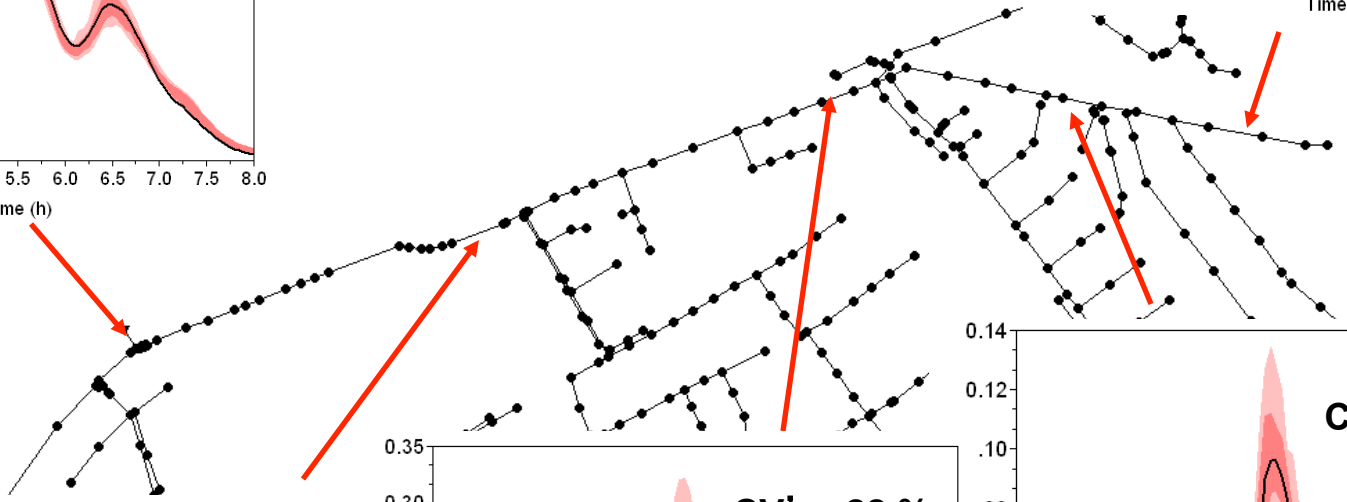
$$CV' = \frac{Q_{0.9}(t_{PF,radar}) - Q_{0.1}(t_{PF,radar})}{2 * PF_{radar}}$$

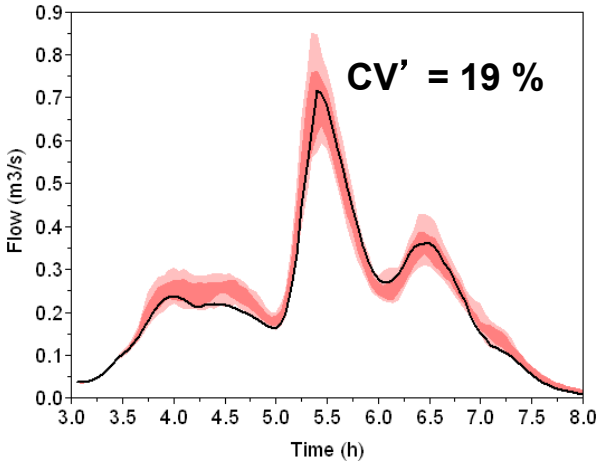
Quantifying the uncertainty associated with small scale rainfall variability

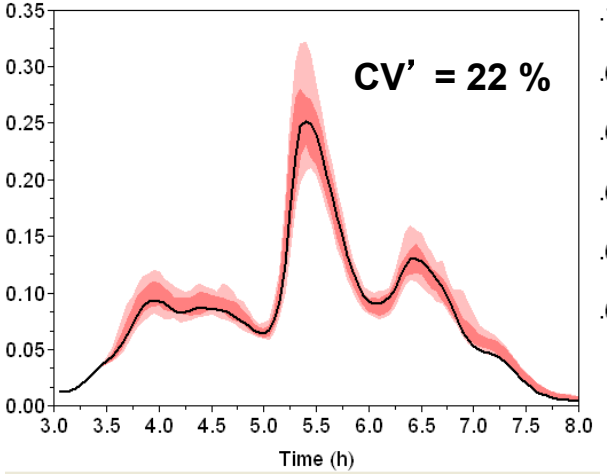
Upstream / downstream influence

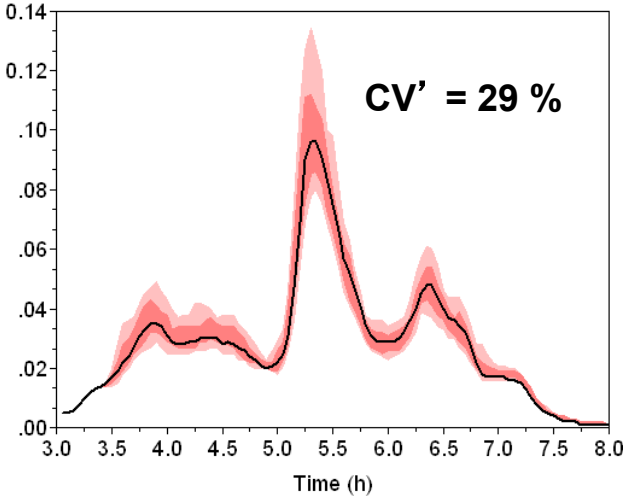












Conclusion

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.

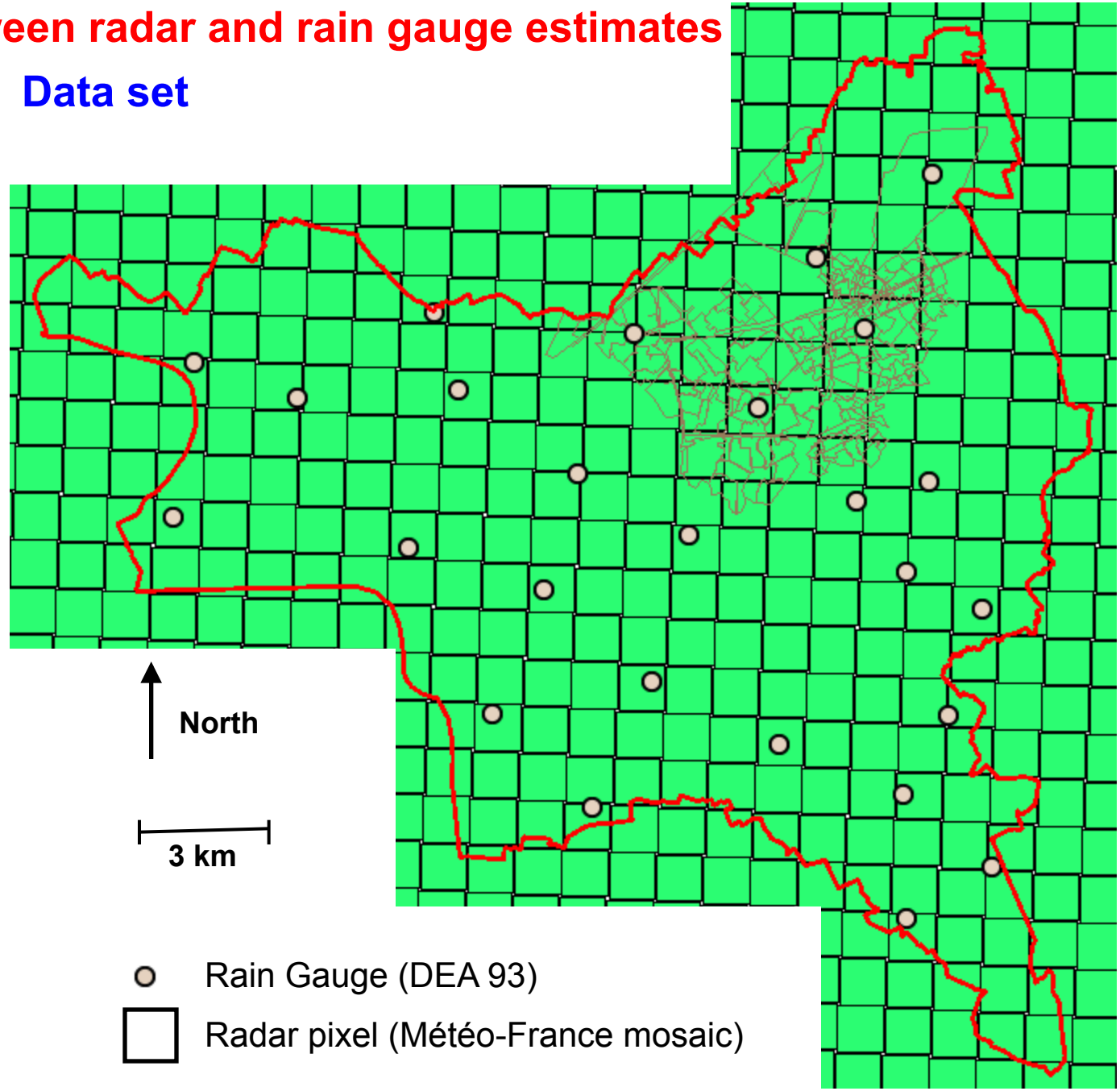
→ Small scale phenomenon must be taken into account in urban hydrology

Limits / further investigations :

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

Comparison between radar and rain gauge estimates

Data set



Comparison between radar and rain gauge estimates

- 7 steps of spatio-temporal downscaling : 1km x 5 min → 46 cm x 2.3 s

- $3^7 x 3^7$ virtual rain gauges → 10, 25, 75 and 90 % quantile