Generation of 2D rain maps with realistic properties: methodology and results

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Context

- Rainfall is a very complex naturally occurring phenomenon.
- It is highly variable in time and space especially for high resolutions
- Variability relies on some characteristics namely intermittency, rain extremes, high rain rate variability and multiple scaling regimes
- Multiple domains are concerned by rainfall maps modeling (hydrology, meteorology, Impact studies ...)

Objective

- generating five minutes water sheet maps with 1Km spatial resolution
- Realistic statistical properties :
  - Rain support:
    - ✓Intermittency (rain/no rain occurrence frequency)
    - ✓Spatial structure (Variogram)
  - Water sheet :
    - ✓Scale invariance properties (Power spectrum)
    - ✓Non-Gaussian heavy tail distribution (Extreme rain) (Realistic CDF).

Plan

- ***Rain maps data set***
  - Data set properties

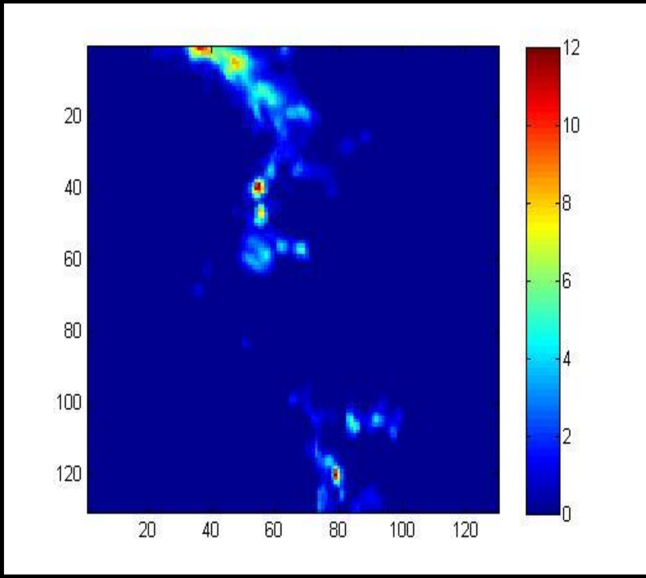
- ***Rain maps modeling (generator)***

  - Step1: Generate rain supports
  - Stet 2: Generate normalize water sheet (using multifractal model)
  - Step 3: Re-normalization of water sheet
  - Step 4: rain /no rain transition

- ***Validation***
- ***Conclusion and perspectives***

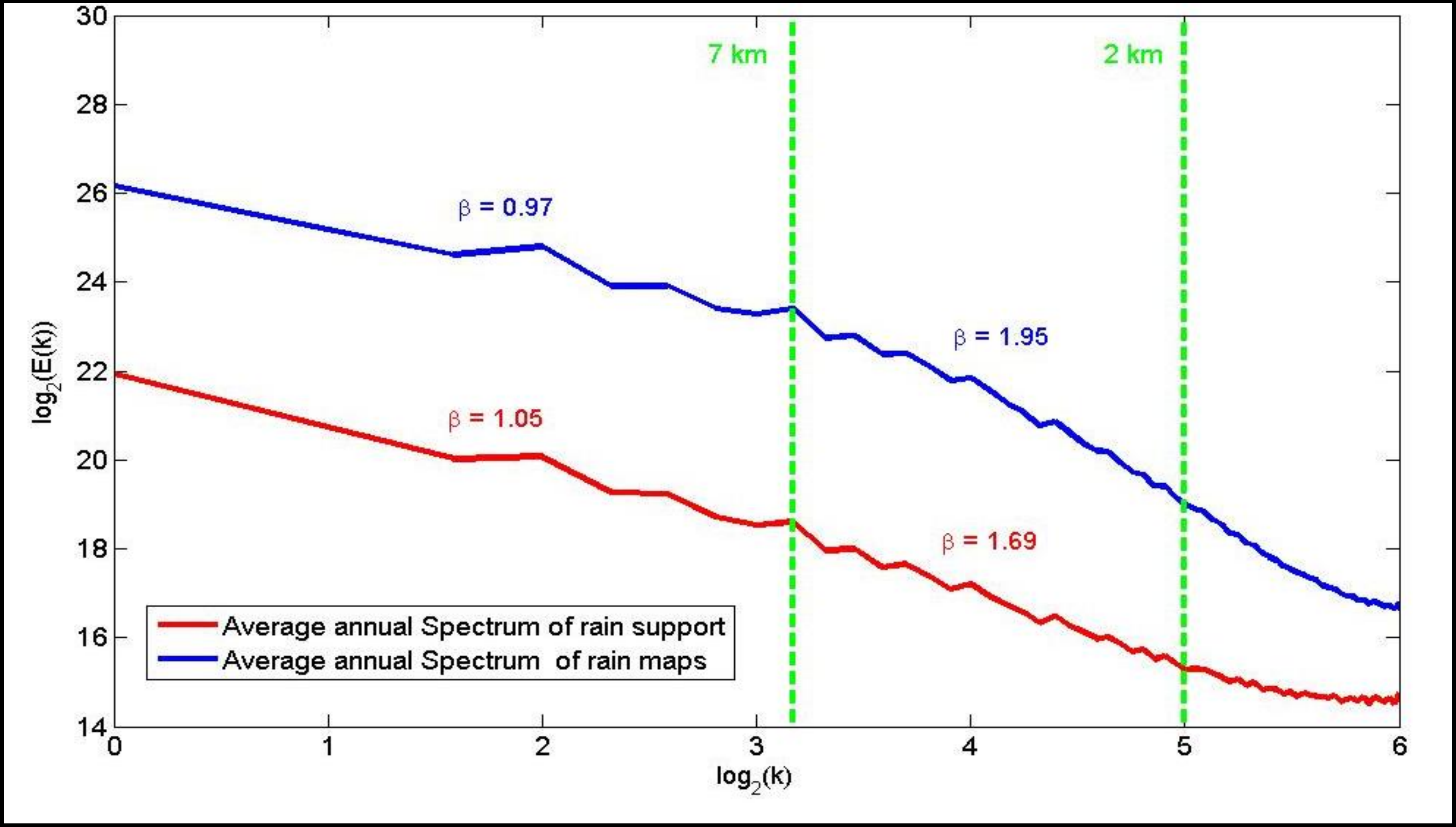
Data set (What are we trying to model?)

- METEO FRANCE data set is used
  - 100 000 radar maps collected for 1 year (2012) : 5 minute water sheet
  - spatial resolution : 1km×1km
  - Location: Trappes
  - 42 000 rain maps having percentage of rain occurrence exceeding 15% are used in our study.
  - Radar maps size : 130*130 km2



Rain Support = $\begin{cases} 0 & if\ water\ sheet < 0{,}48mm \\ 1 & else \end{cases}$

Data set properties: Multiple scaling regime



Power spectrum (scale invariance properties)

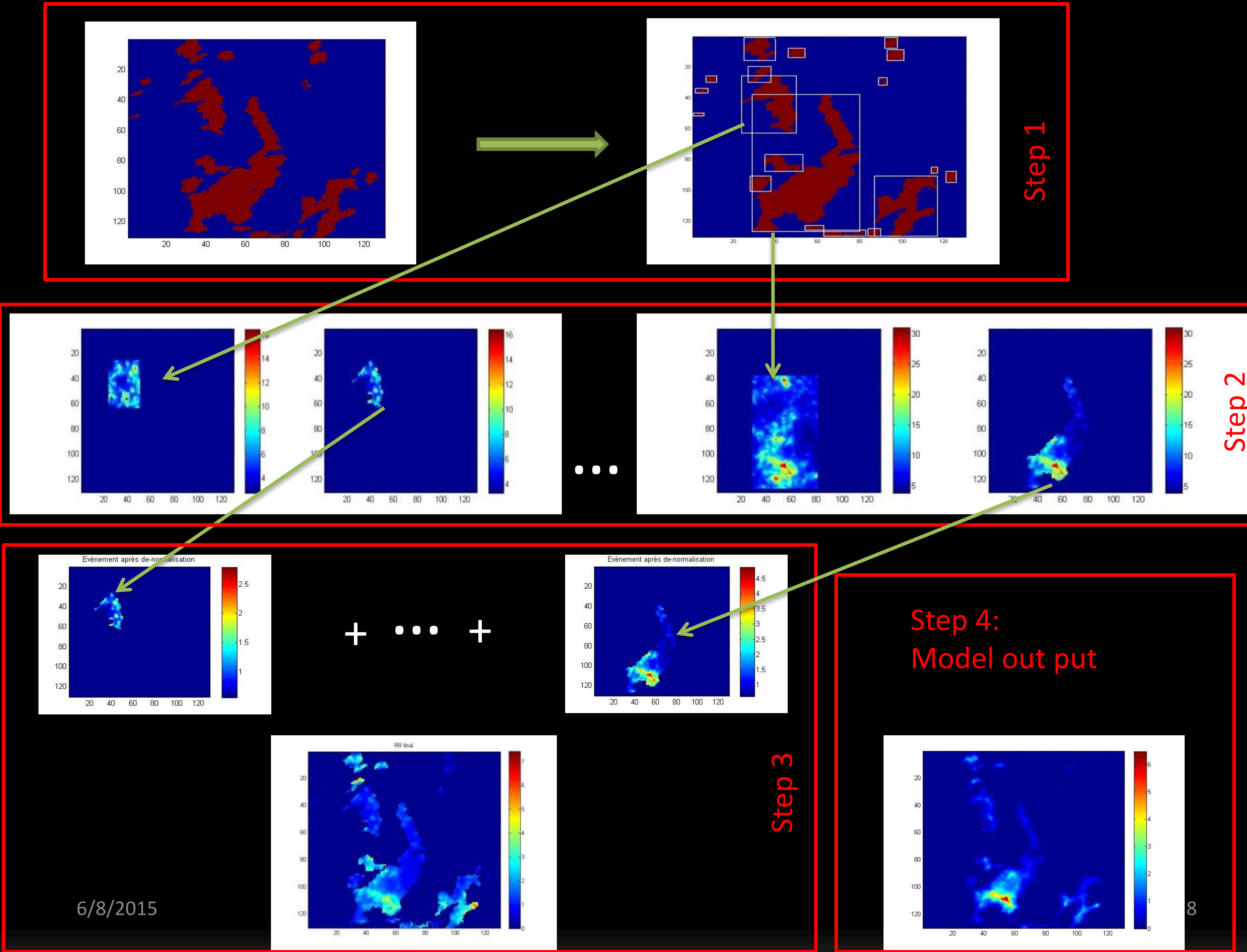
Methodology :

step1 → rain support generation (using SIS method)

step2 → generate rain events using FIF model

Step3 → Re-normalization per rain cell (Mean water sheet/areas relationship)

Step4 → Rain/no rain transition


Step 1
Step 2
Evènement après de-normalisation
Evènement après de-normalisation
RR final
Step 3
Step 4:
Model out put

Rain support generation (Step1) :

Rain support is simulated map by map using a Sequential Indicator Simulation (SIS) algorithm (Ripley 1987).

Assumptions : isotropy and stationnarity

Variogram (spherical model : 3 parameters)

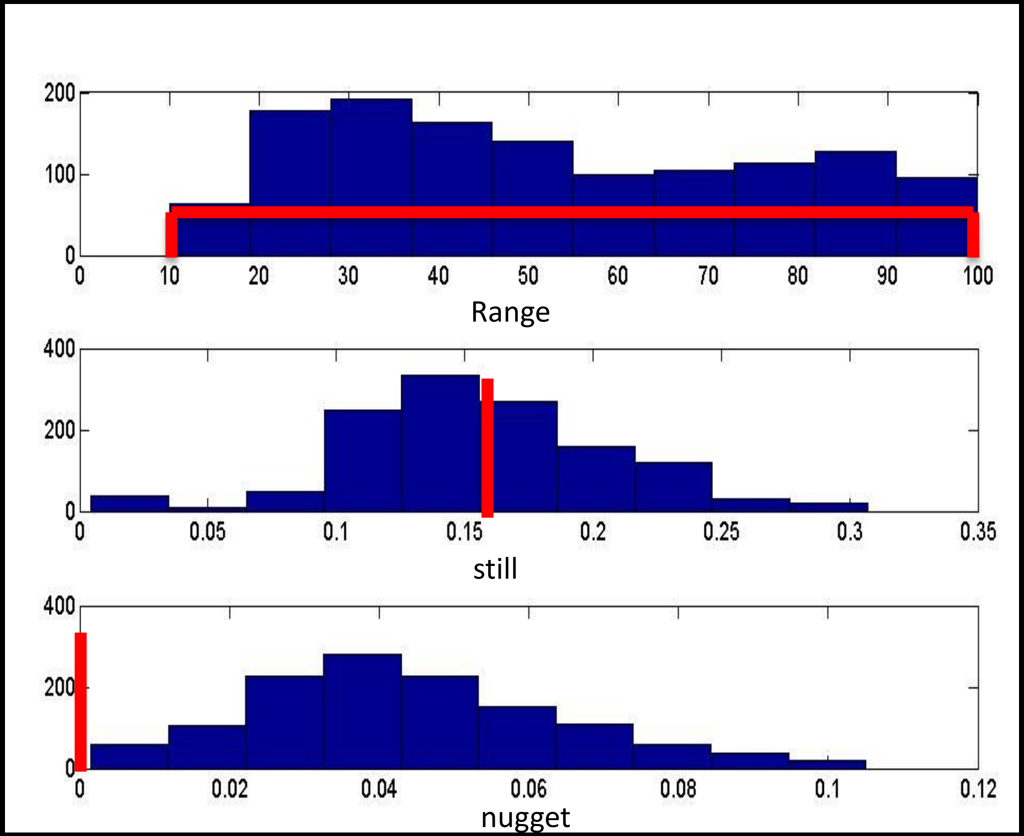
Occurrence probability drawn uniformly between [0.15 1].

Principle :

- Point by point sequential simulation
- Sequentially draw the support (Bernoulli law)
- Parameter of the Bernoulli law conditioned by neighboring values (calculated by kriging)

Rain support (Step1) :

Variogram analysis of MF maps: → Strong variability



Estimated variogram parameters

Spherical variogram model :

- Range drawn uniformly between [10 100] km
- Still = mean (estimated stills)= 0.17
- Nugget = 0 (theorique value)

→ 1 parameter

Normalized rain events generation (Step2) :

Multifractal (FIF) model is used (Schertzer et al. 1987)

✓ Multiplicative cascades

✓Scale invariance properties.

✓Non- conservativity

- moment scaling function : $K(q) = \frac{C_1}{\alpha-1}(q^{\alpha} - q)$
- Structure function : $\langle|R_{\lambda}(\Delta t)|\rangle \sim \lambda^{H}$

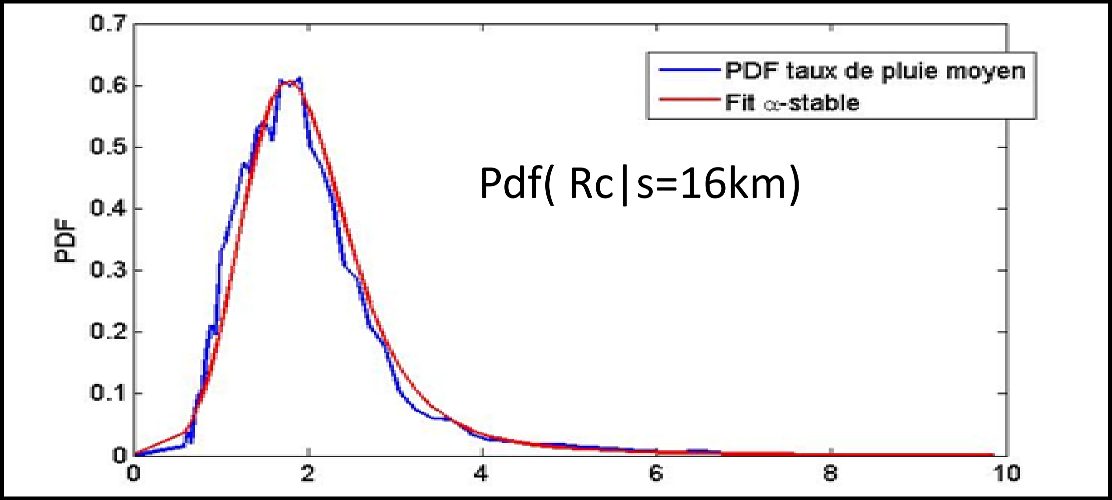
➔3 parameters: α=1.6 C1=0.10 H=0.4

Re-normalization per rain cell (Step3): Mean water sheet/areas relationship:

The average water sheet for a rain cell is conditionned by its size s: <Rc|s>

s = square root of the rain cell area

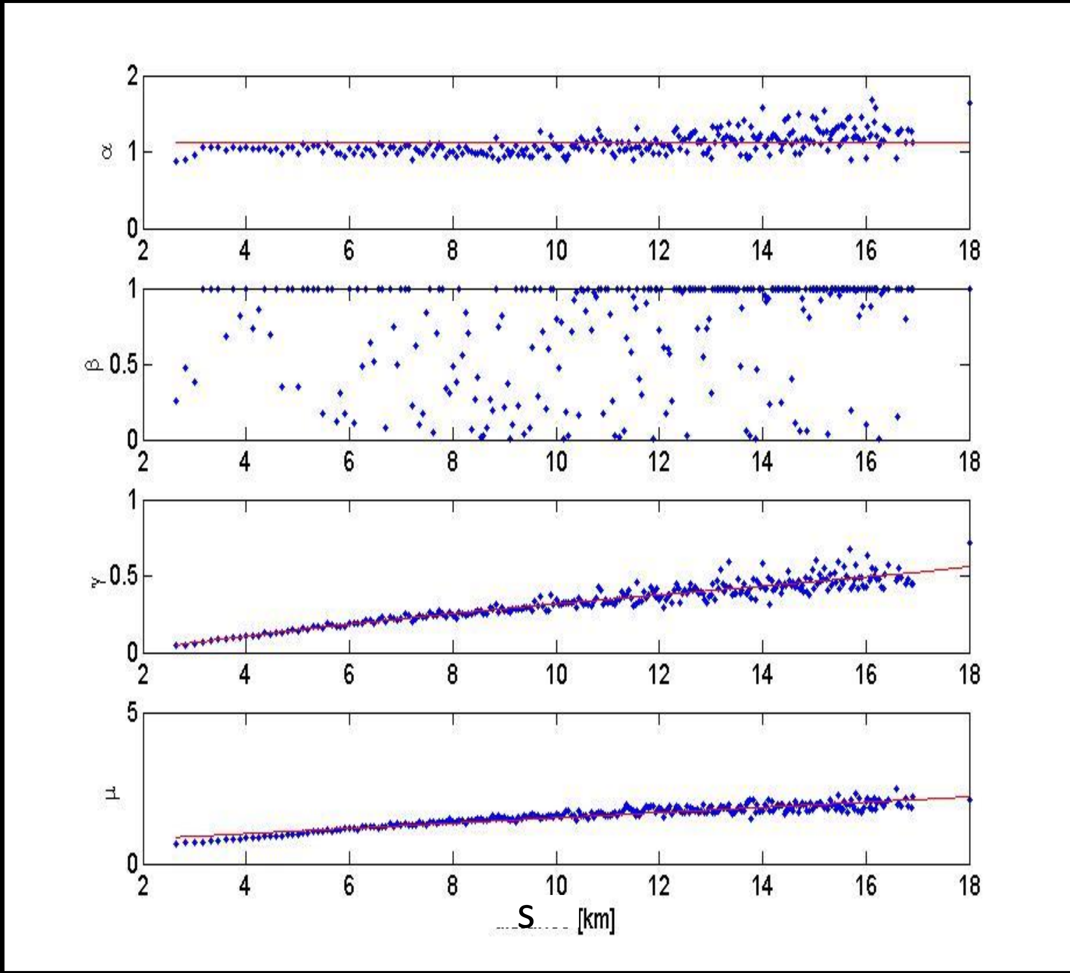
➔ each <Rc|s> has a distribution : Pdf(<Rc|s>)



- α-stable distributions are used to model mean water sheet

Renormalization : Events mean rain rate/rain cell areas relationship(Step3) :

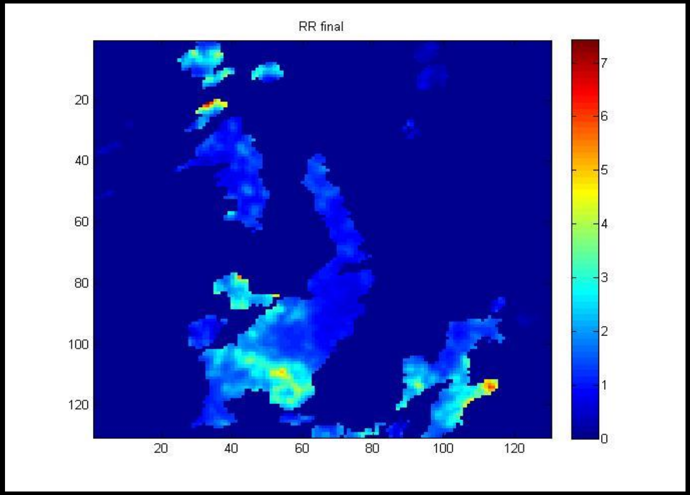
- Pdf(<Rc>|s) : α-stable distribution parameters :
  - Stability parameter: $\alpha = 1{,}18$
  - Asymmetry Parameter: $\beta = 1$
  - Scale parameter : $\gamma = 0.03 \times s$
  - Location parameter: $\mu = 0.09 \times s + 0.65$



➔ 5 parameters

Rain/no rain transition (step 4) :

Step 3 output water shet



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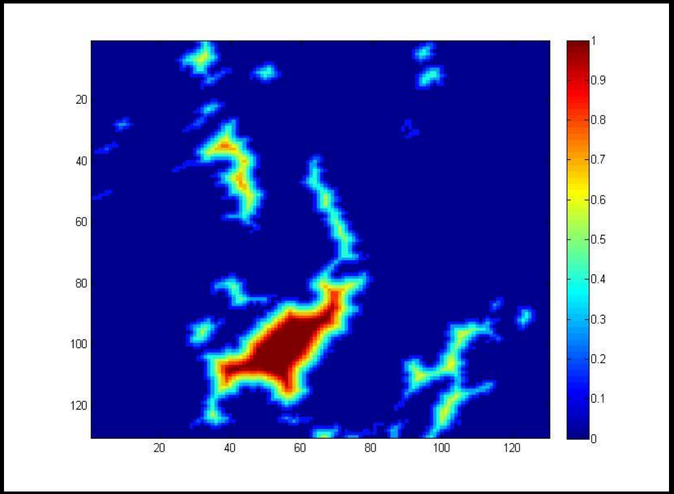
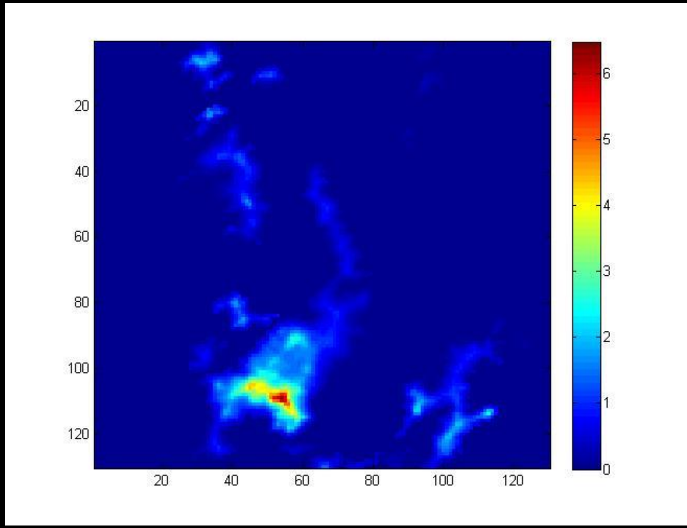
Transition map d(z)





Generator output water sheet map

$$d(z) = \begin{cases} \min \ f(\|z-y\|) \\ 10 \ if \ (\|z-y\|) > 10 \end{cases}$$

$d(z)$ is normalized between 0 and 1

$z \in \{x, \ I(x) = 1\}$
et $y \in \{x, \ I(x) = 0\}$

Inspired from [Schliess et al, 2014]

Validation :

Observed data : 42 000 radar maps

Simulated data 4 years dataset :

→ 42 000 * 4 water sheet maps

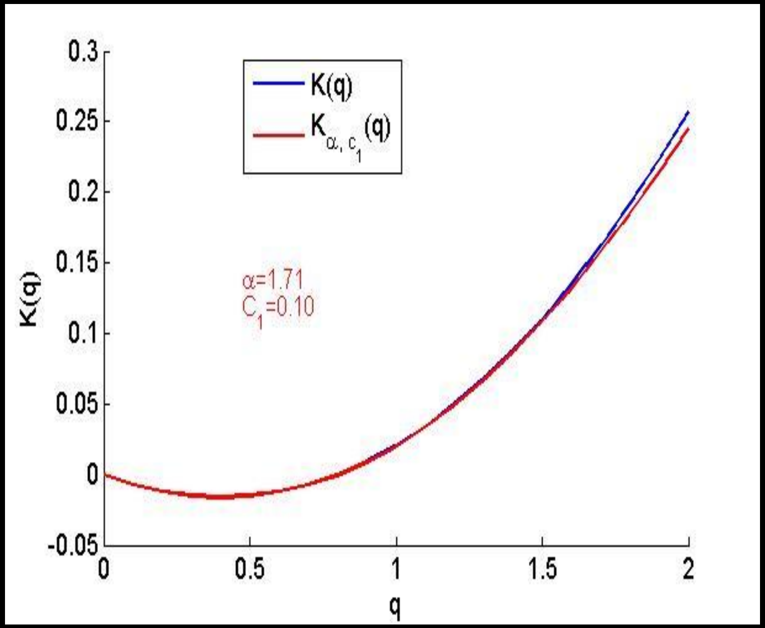
It remains to verify the global properties of the simulated rain maps:

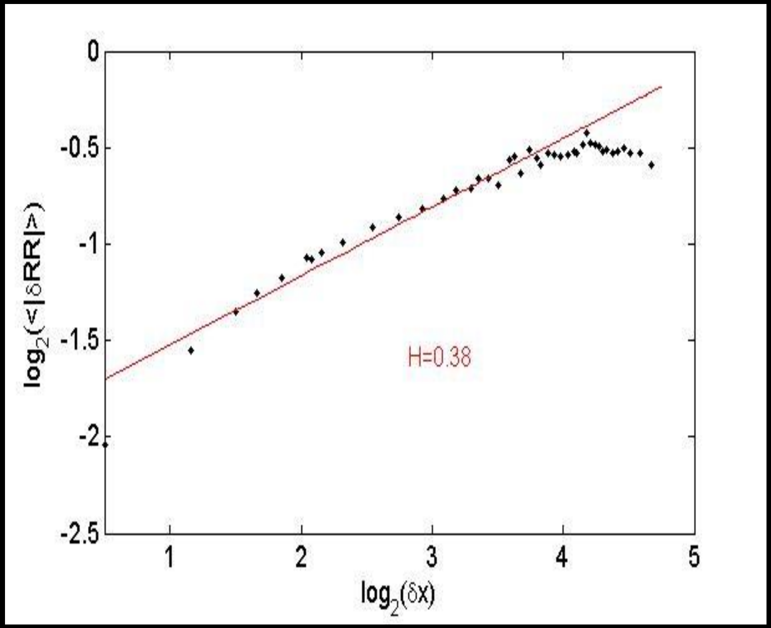
- multifractal anaysis
- Power spectrum
- Water sheet distribution.

Multifractal analysis :

- Selected simulated sub maps with 100% of rain having size equal to 40 Km * 40 Km

➔ Model parameters: $\alpha=1.6$ C1=0.10 H=0.4

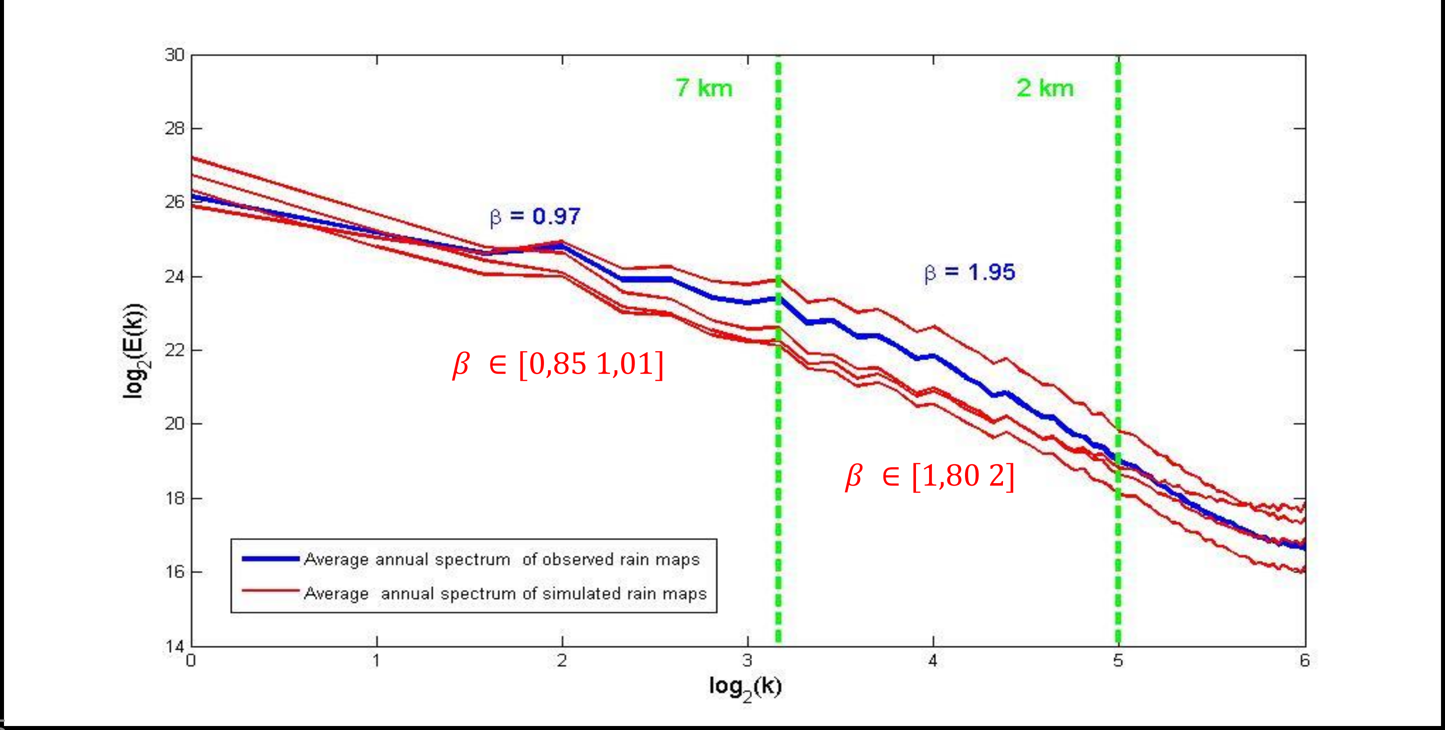




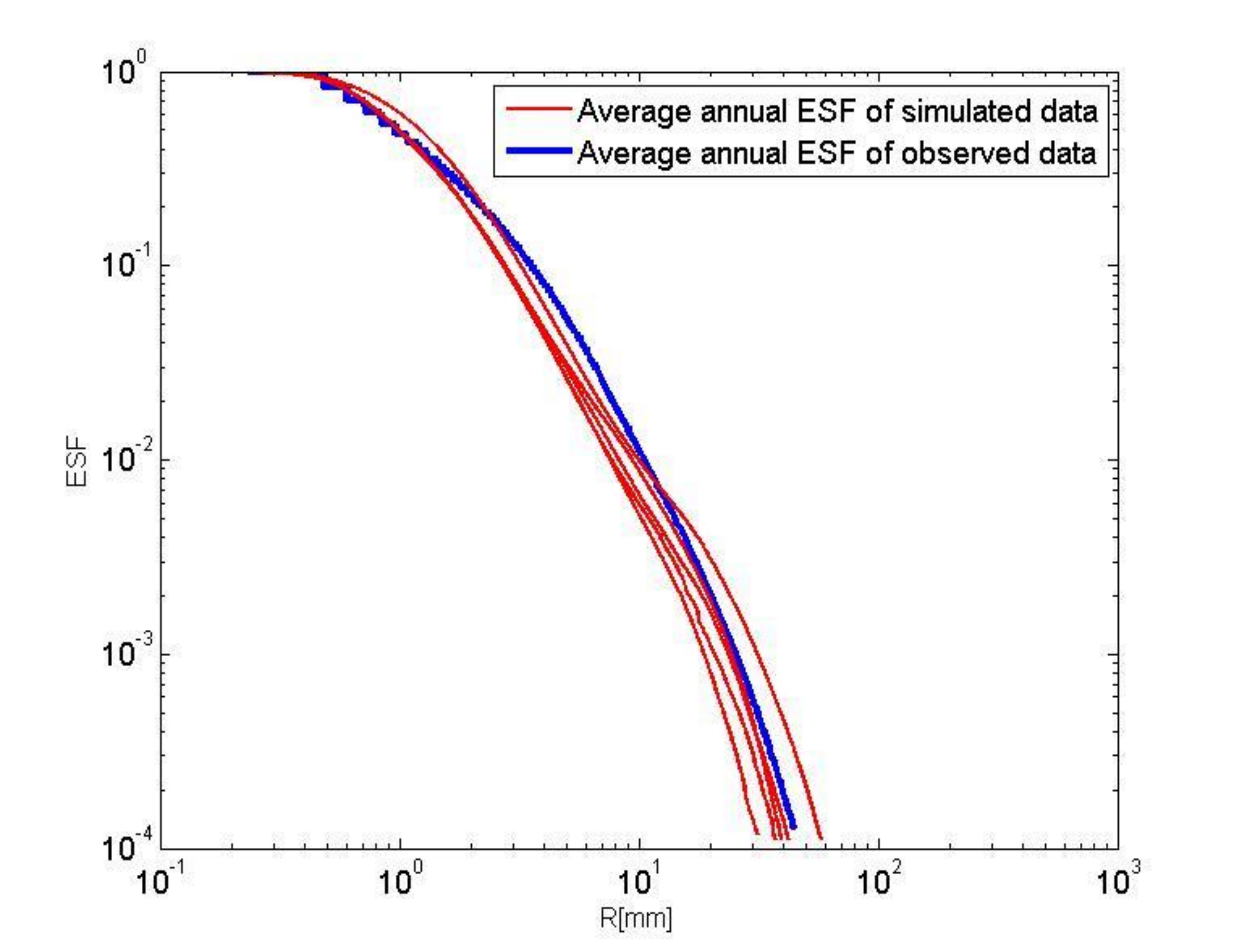
➔ Average estimated parameters: $\alpha=1.71$ C1=0.10 H=0.38

Rain rate power spectrum:

- Red curve: average spectrum of 42000 simulated water sheet maps.
- Bleu curve : average annual spectrum of observed data (42000 rain maps)



Survival function (ESF) of water sheet:



Conclusion:

- Our model simulates

in agreement with the collected data , and it is able to restore various aspect (intensity, support, variability …) :

- Simulate water sheet maps of 250*250 km with 1km resolution

Rain support properties (1 parameter)

+

Intra events

Scale invariance properties + water sheet distribution (8 parameters)

Global properties

✓Simulated & observed power spectrum show the same regime of scaling.

✓Simulated & observed rain rate distribution are coherent

Perspectives:

- The break in the rain scaling properties are well reproduced via support model:
  - ➔Improvement of rain support mode needs the use of finer spatial resolution observations (250 m)

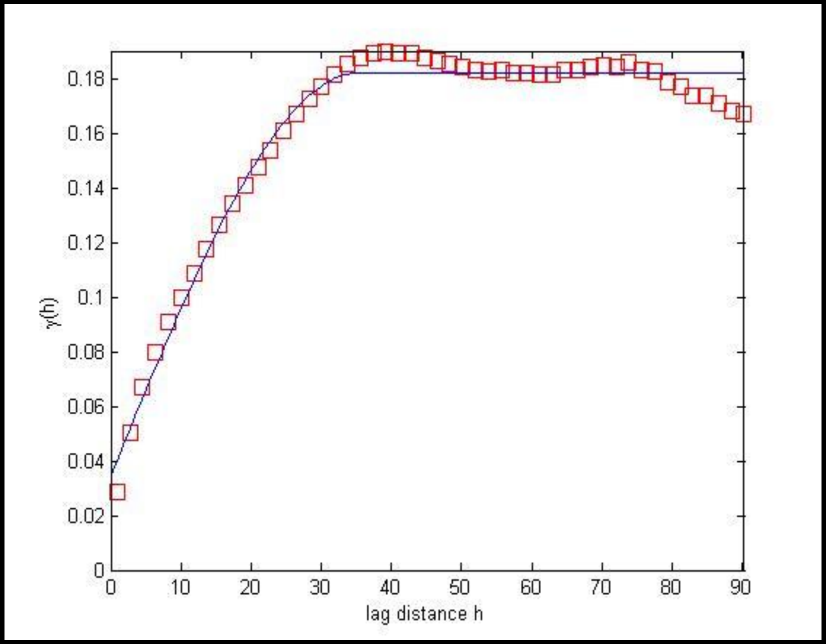
- The rain properties and structure observed in a particular location are well reproduced using 9 parameters model
  - ➔ observations performed in other climate area has to be analysis
  - ➔ A generator able to simulate different climatic area has to be developped
  - ➔ Study about what are the global parameters (properties) and what is specific to local rain properties.

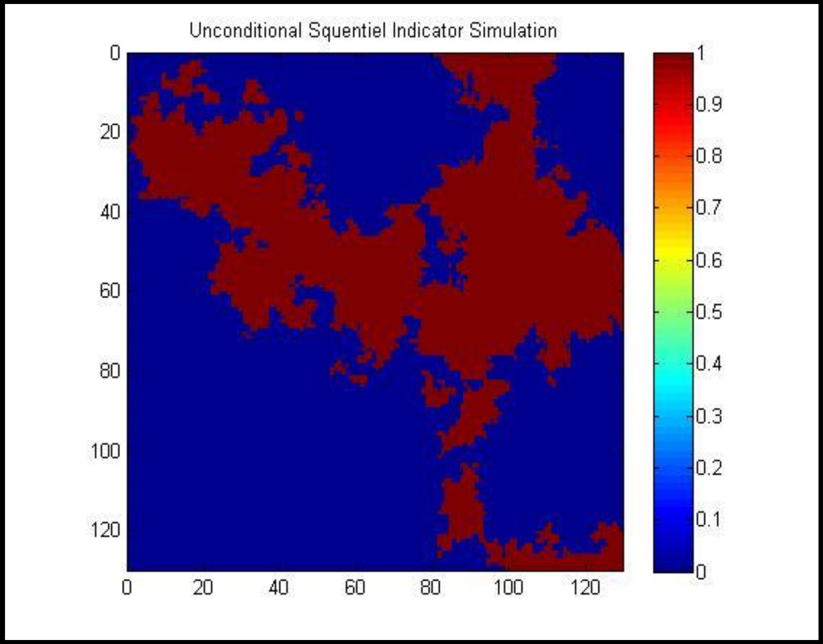
Thank you for your attention

generate rain support (Step1) :

Example of simulated support :

Occurrence probability =0,25   Range = 31.44 , Still = 0.17, Nugget= 0





Occurrence probability =0.29, Range =30.02, Still =0.16 et Nugget=0.02