Generation of mono-site Rainfall time series from micro to large scale

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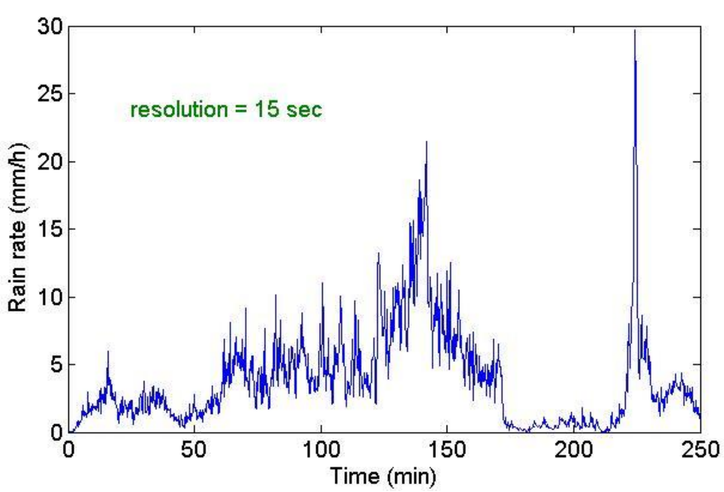
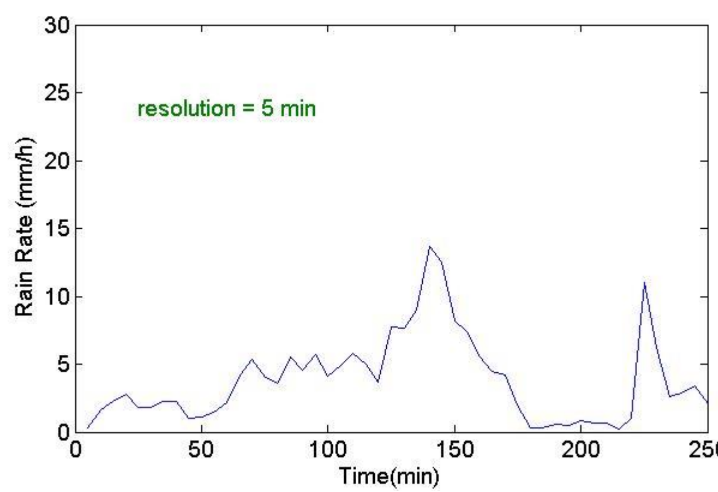
Context

- Rainfall is a very complex naturally occurring phenomenon.
- It is highly variable in time and space especially for high resolutions
- Complexity of the modelling of rainfall is related on some characteristics namely intermittency, rain extremes, high rain rate variability and multiple scaling regimes
- Modeling rainfall at high resolution influence number of areas(hydrology, meteorology, …)
- It is important to have high resolution data.





Context

Two approaches are used to model precipitations

Top-down:

- availability of data at coarse resolution
- Simulate data at coarse resolution
- Downscaling

Bottom-up:

- Lack of data
- Generate data at high resolution (at least 5 minutes in existing models)
- Aggregation

Our work

- Generate intra rain events (parameters observed at high scale)

+

Generate rain support and restore its caracteristic at high resolution

Simulate high resolution long time-series of rainfall

Objective 1/2 : The basic idea

- generating rainfall time-series with a very high temporal resolution:
  - mono-site (Palaiseau France)
  - Spatial resolution (sensor capture : 100cm2) .
  - temporal resolution (15 seconds)

- Rain properties are checked from small to large scales (for several weeks / months).

Objective 2/2 : more specifically

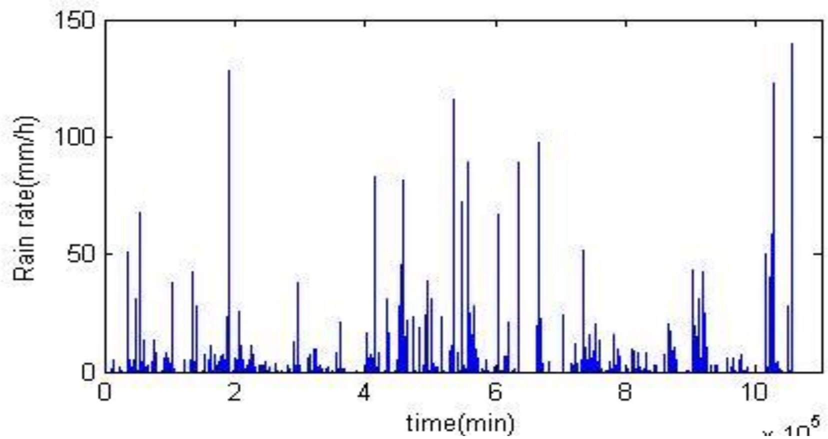
- Realistic statistical properties of rainfall and support:
  - ✓Occurrence frequency rain/no rain durations (intermittency)
  - ✓Fractal dimension of rain support
  - ✓power spectrum,
  - ✓ (rain rate)scale invariance properties
  - ✓(Extreme rain) Non-Gaussian tail distribution
- Realistic CDF of rain rate and rain durations at different resolution (15 sec, 5 min, 1 hour)

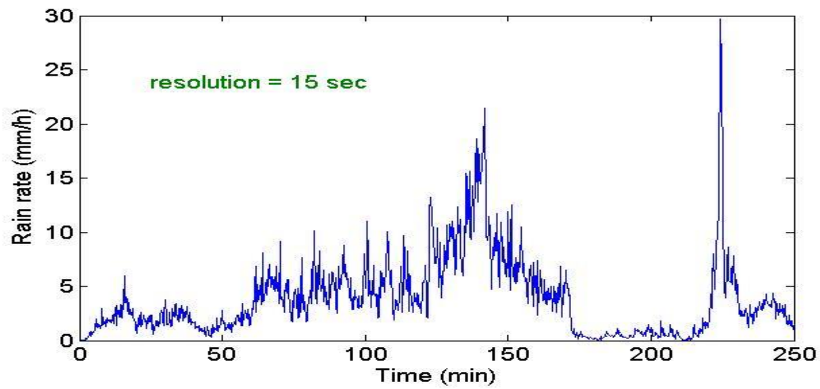
Plan

- ***Data set***
  - Data set properties
- ***Modeling (generator)***
  - Step1: Generate rain support
  - Step 2: Generate rain rate (using multifractal model)
  - Step 3: Calibrate/forcing rain rate
- ***Validation***
- ***Conclusion and perspectives***

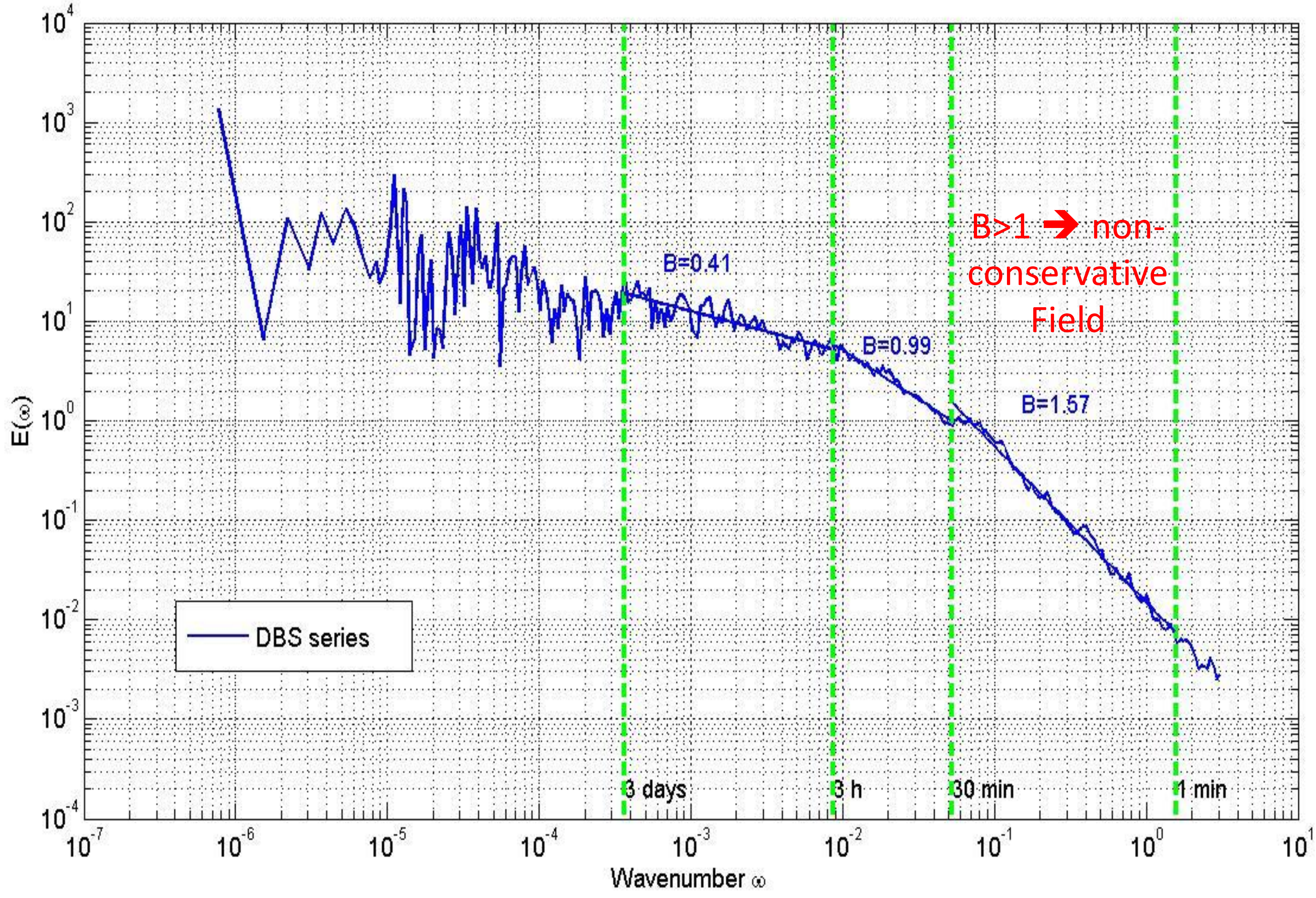
Data set (What are we trying to model?)

- Dual-Beam Spectropluviometer (DBS)
  - Time series resolution is 15s
  - The existing literature does not provide a model for this order of scale
- Rain rate measurements in Palaiseau (France) from 01 July 2008 to 31 December 2009.





Data set properties: Power spectrum (scale invariance properties)

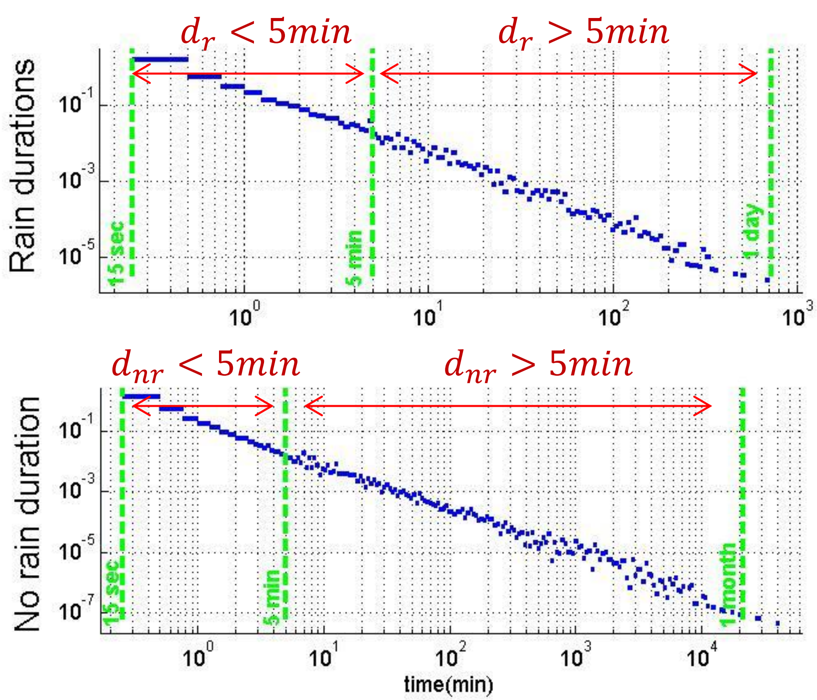


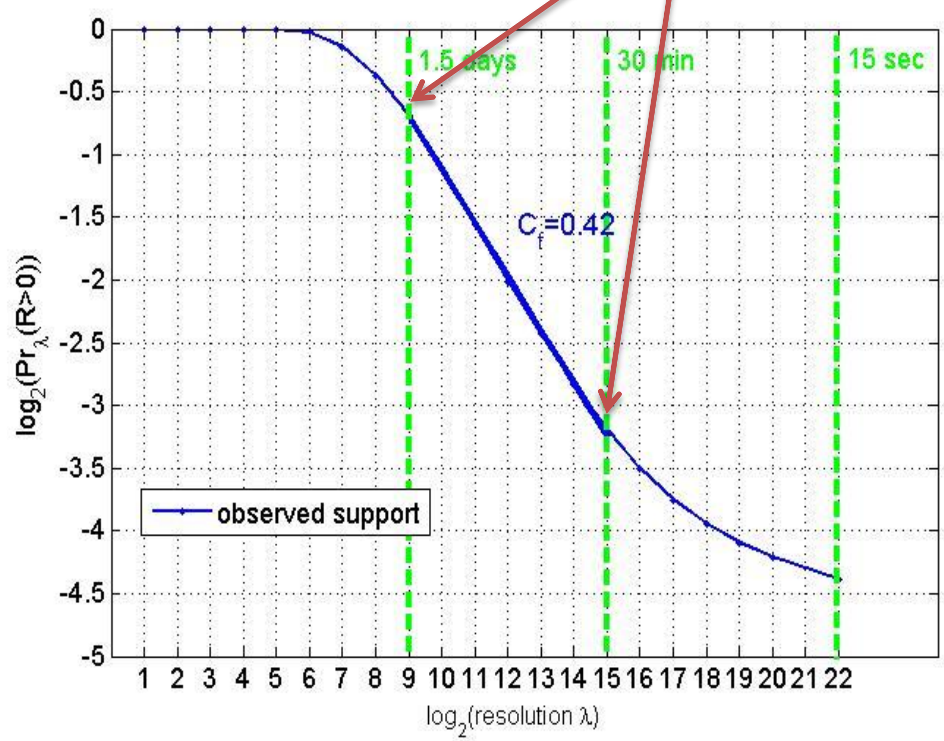
Data set properties: Observed rain support (precipitation occurrence)

- Intermittence rain/no rain (rain support) at resolution λ

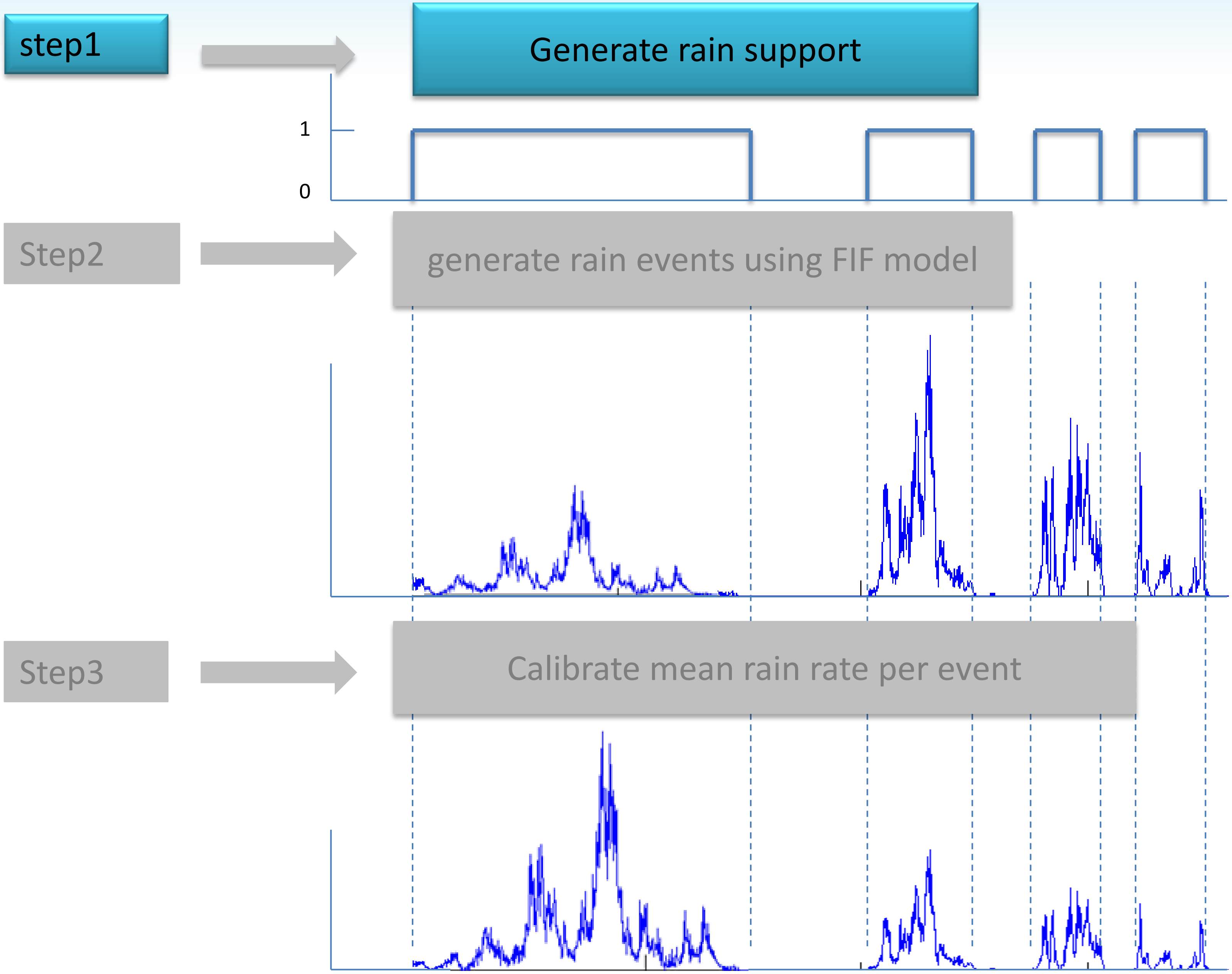
$$I_\lambda(x) = \begin{cases} 0 & si \quad R_\lambda(x) = 0 \\ 1 & si \quad R_\lambda(x) > 0 \end{cases}$$

- Support properties: Support is fractal if : $\Pr\left(I(x)=1\right) \propto \lambda^{-Cf}$ is satisfied.



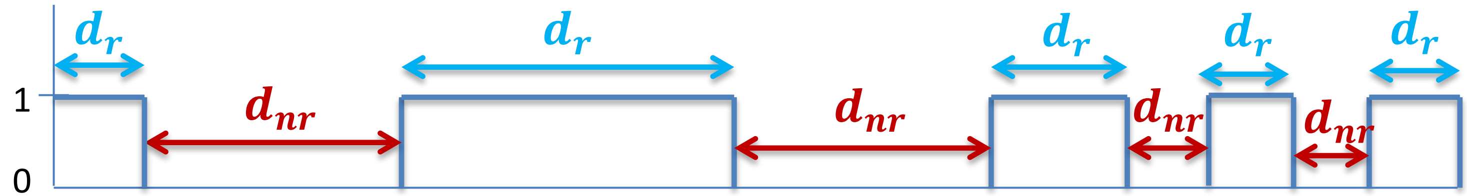


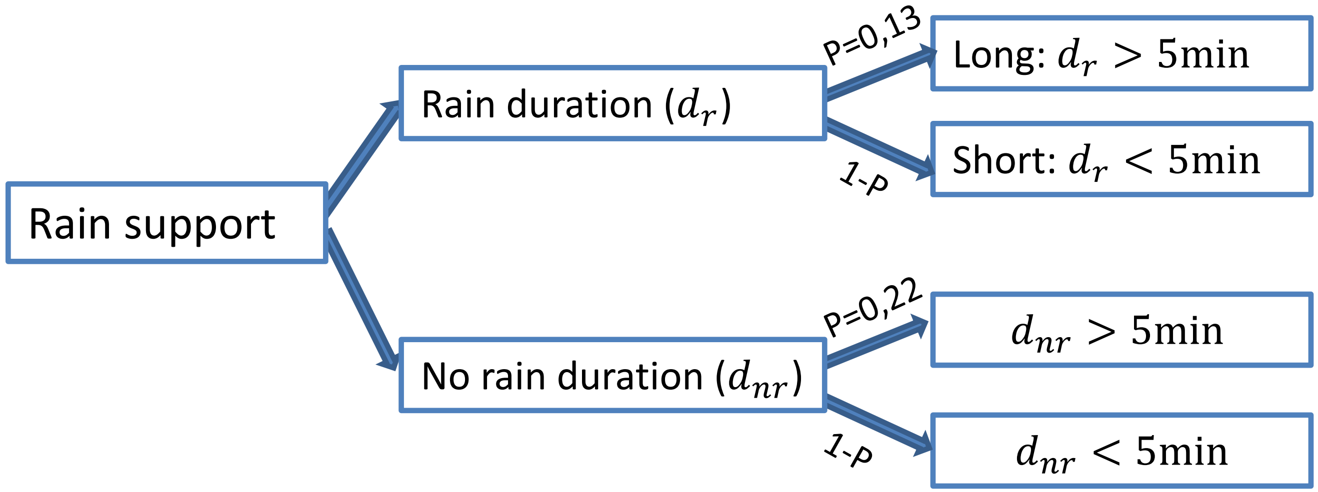
Rainfall generator



Step1: generate rain support

- Alternating rain (d_r)/no rain (d_{nr}) duration



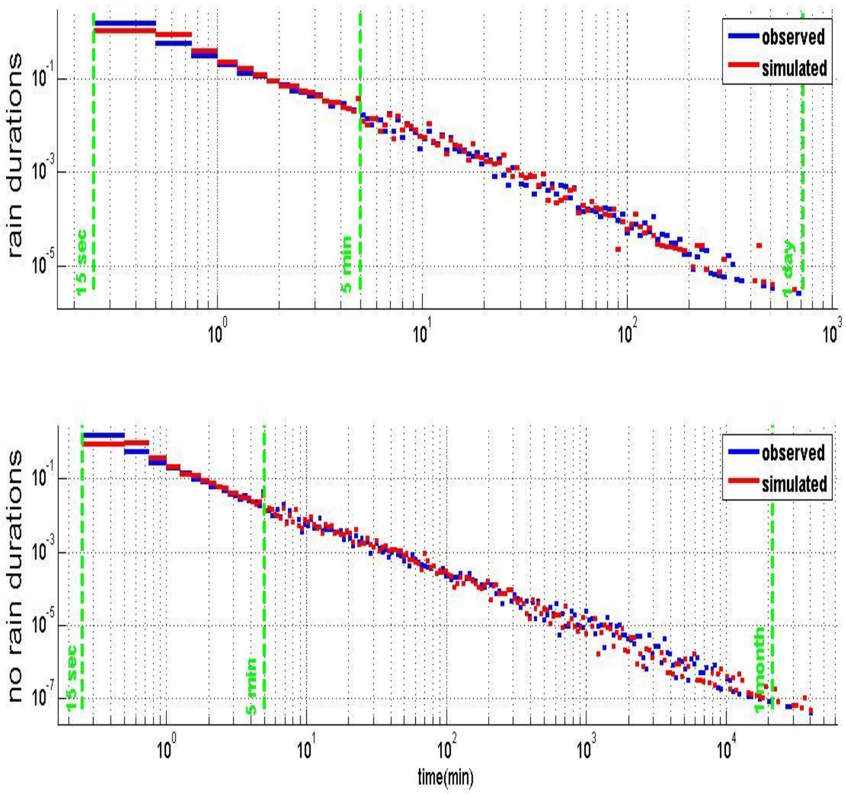


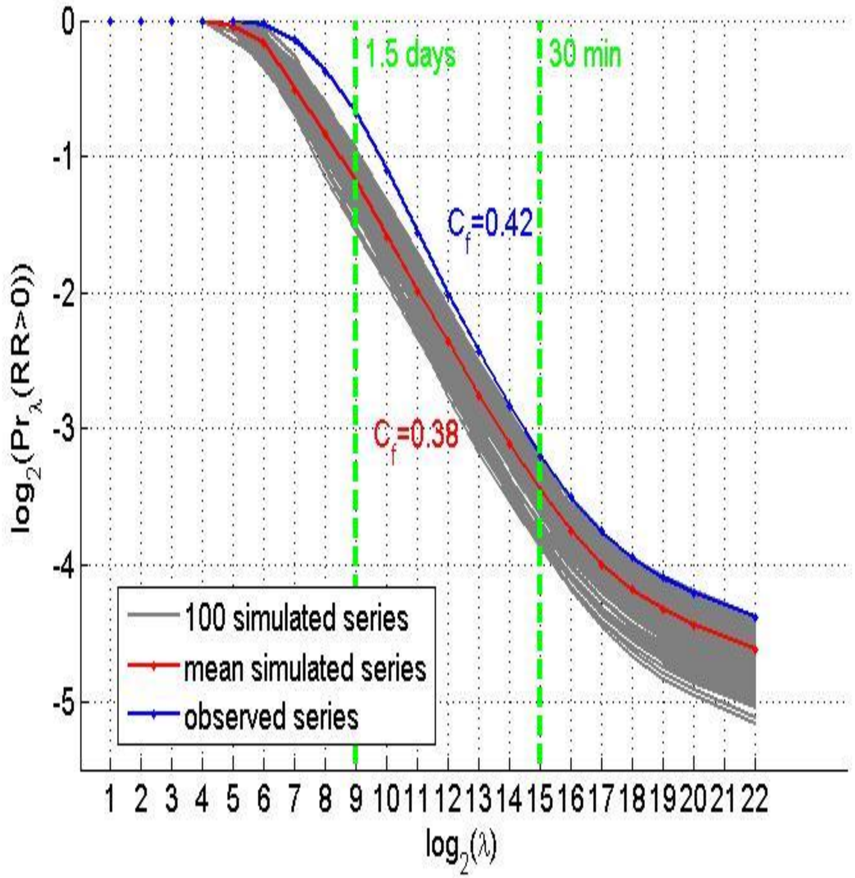
- Generalized pareto distribution is used to model duration short/long rain/no rain durations:

$$f(d/k,\sigma,\theta) = \left(\frac{1}{\sigma}\right)\left(1 + k\frac{(d-\theta)}{\sigma}\right)^{-1-\frac{1}{k}}$$

- Three parameters are estimated on each short/long rain/no rain durations ➔ 12 parameters

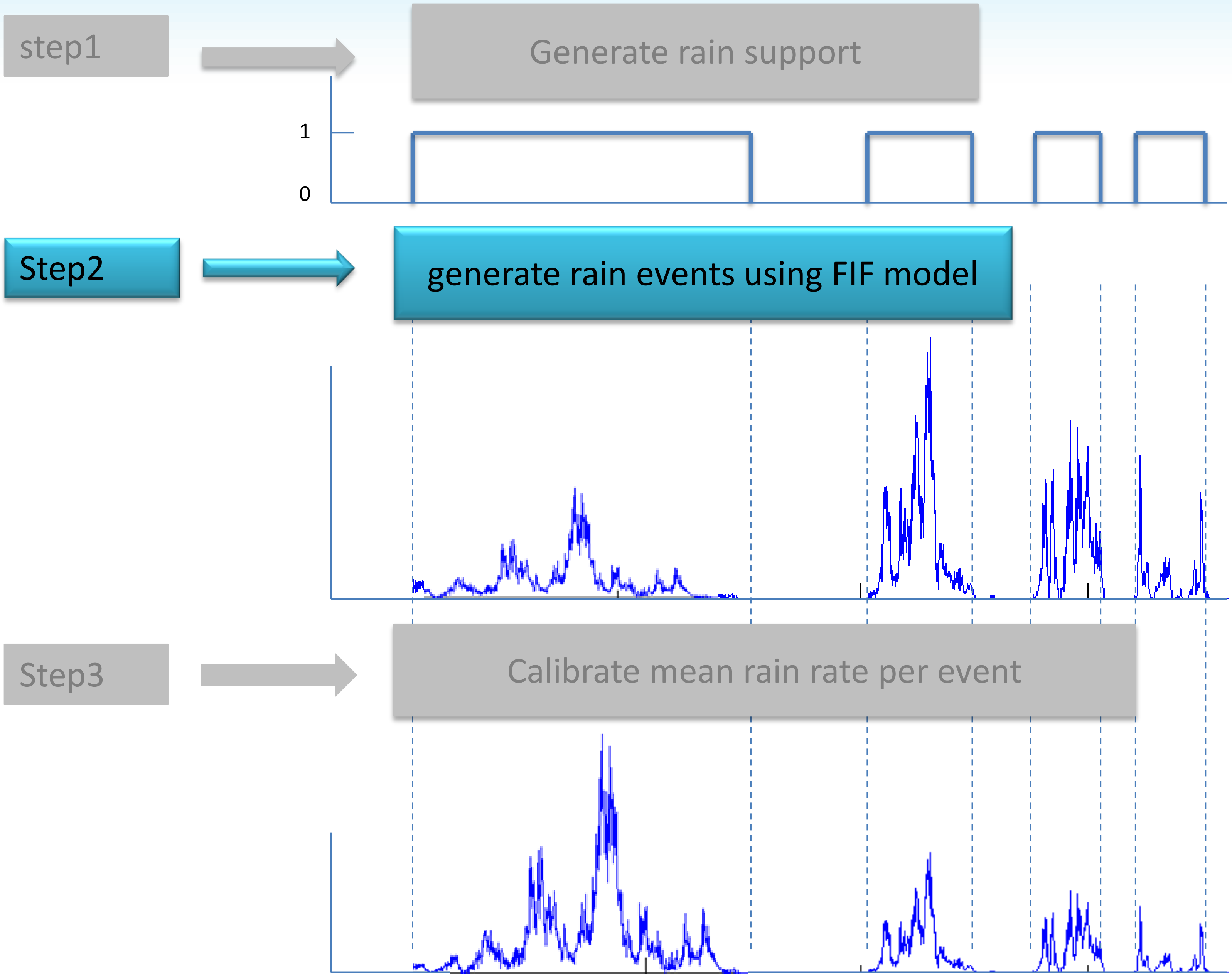
Step1: generate rain support





- Percentage of rain in observed time series : 4,46%
- Mean percentage of rain in 100 simulated series: 4,11%

Rainfall generator



Step2: Generate rain events

- Models and techniques for simulation
  - Poisson processes…
  - Geostatistique techniques…
  - Multifractal techniques …

➔Multifractal

- ✓ Multiplicative cascades
- ✓Scale invariance properties.
- ✓Non- conservativity

Theory: Multifractal field: properties 1/2

- Multifractifal field ϕ is characterized by a fractal co-dimension function $c(\gamma)$ which extends the usual notion of topological dimension for non-integer values

Threshold

Codimension function

$$\Pr\left(\phi_\lambda > \lambda^\gamma\right) \propto \lambda^{-c(\gamma)}$$

Resolution

Multifractal field
at resolution λ

- Moment scaling function caracterises the statistical properties at differents resolutions

Moment scaling function

Order moment

$$E(\phi_\lambda^q) \propto \lambda^{K(q)}$$

Resolution

moments

Theory: Multifractal field 2/2 :Multiplicative cascades

- Construction of multifractal fields by a self-similar , stochastique, iterative procedure

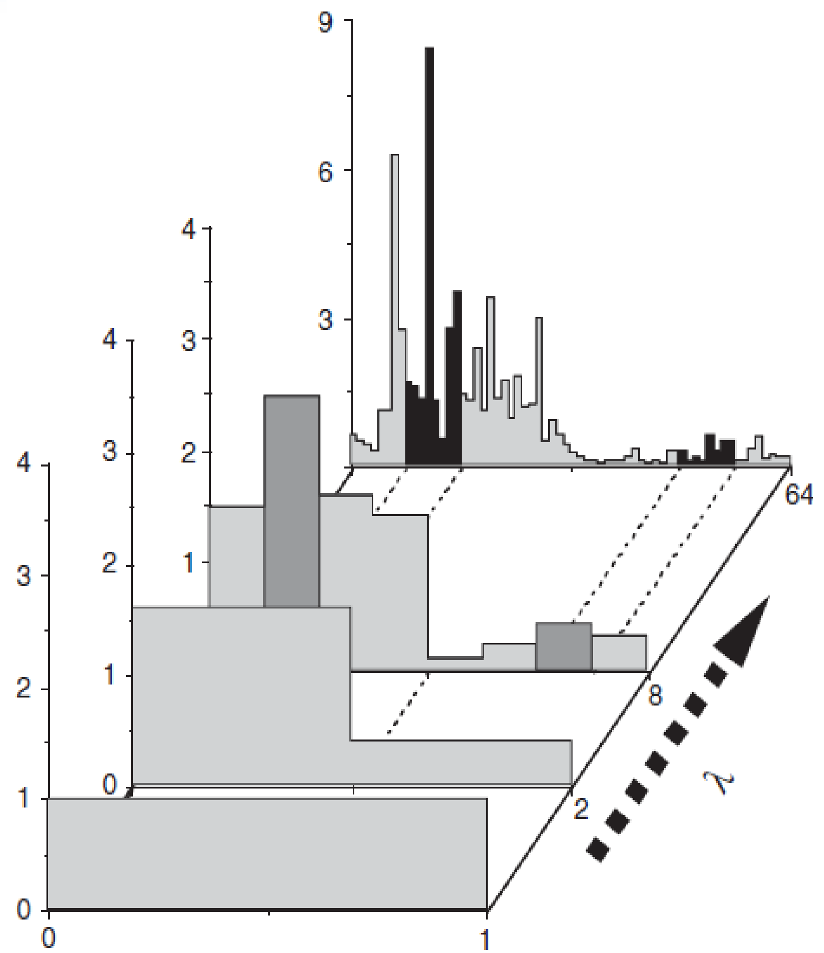
$$\Phi_{\lambda_n} = \Phi_{\lambda_{n0}} \cdot \prod_{i=1}^{n} \mu\Phi$$

→ *Convergence to multifractal fields*

→ *scale invariance properties*

- Universal multifractal (UM) parameters:
  - α (multifractality, < 2)
  - C_1 (homogeneity)

- ***FIF (integrated UM model) parameters :***
  - ***α & C_1***
  - ***H (no conservative field)***



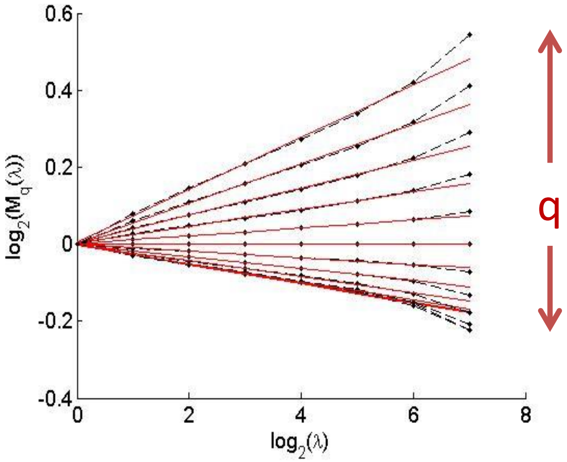
Graph from Schertzer & Lovejoy (2002)

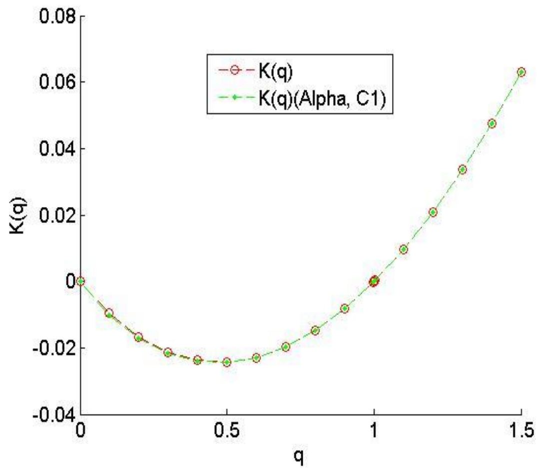
Step2: Multifractal analysis of observed data

Estimation of parameters 1/2:

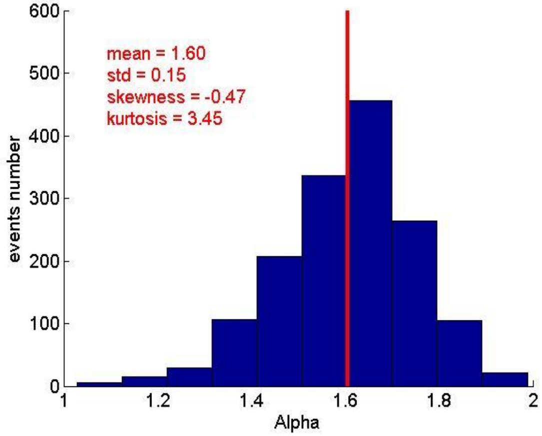
- moment scaling function : $K(q) = \frac{C_1}{\alpha - 1}(q^{\alpha} - q)$

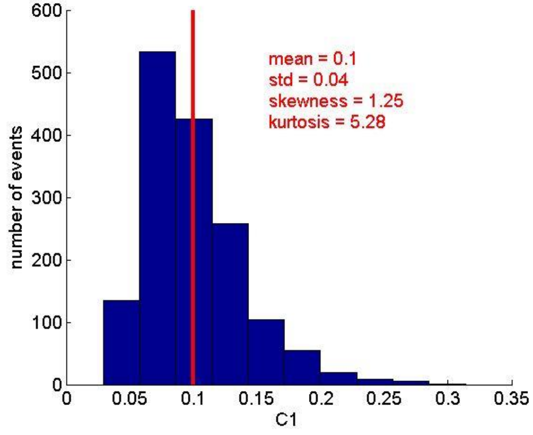
For each event:





Histogram of 1200 events extracted from observed data





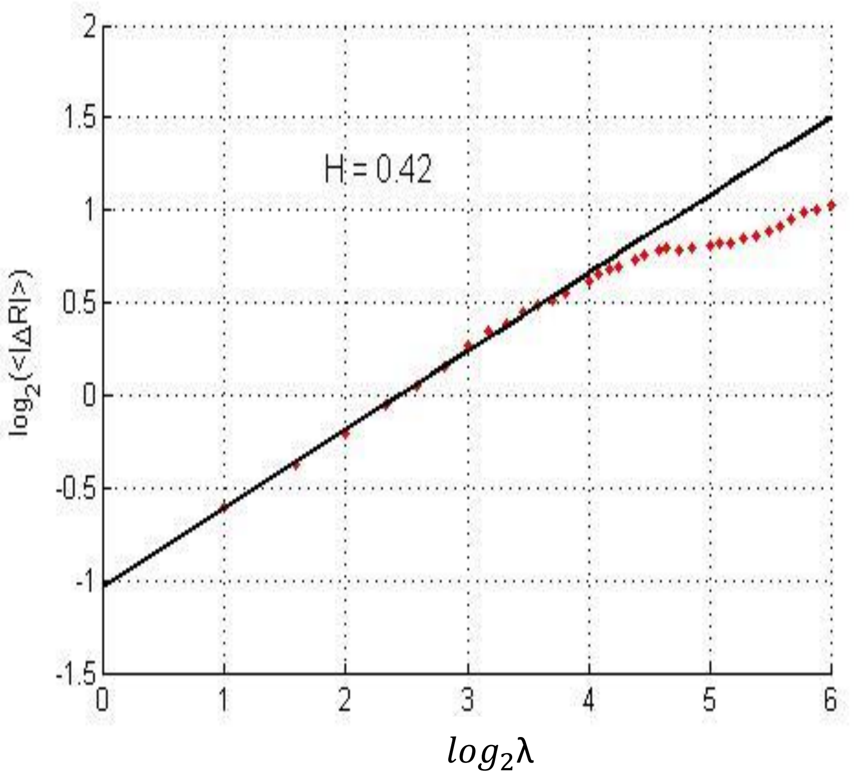
➔Retained FIF parameters: α=1,6   C1=0.10

Step2: Multifractal analysis of observed data
Estimation of parameters 2/2:

- Structure function

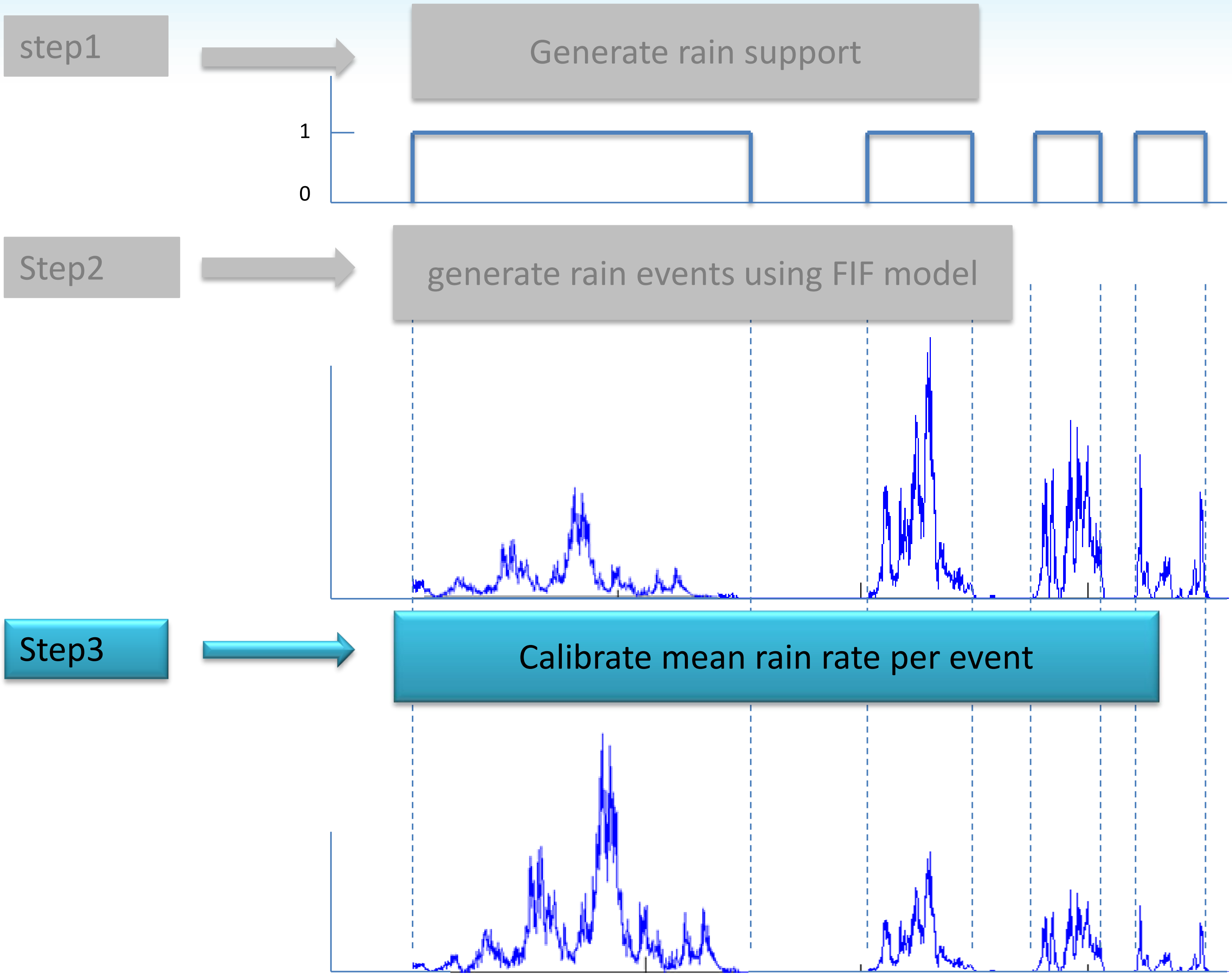
$$\langle |R_\lambda(\Delta t)| \rangle \sim \lambda^H$$

- *H* parameter is estimated on all observed events



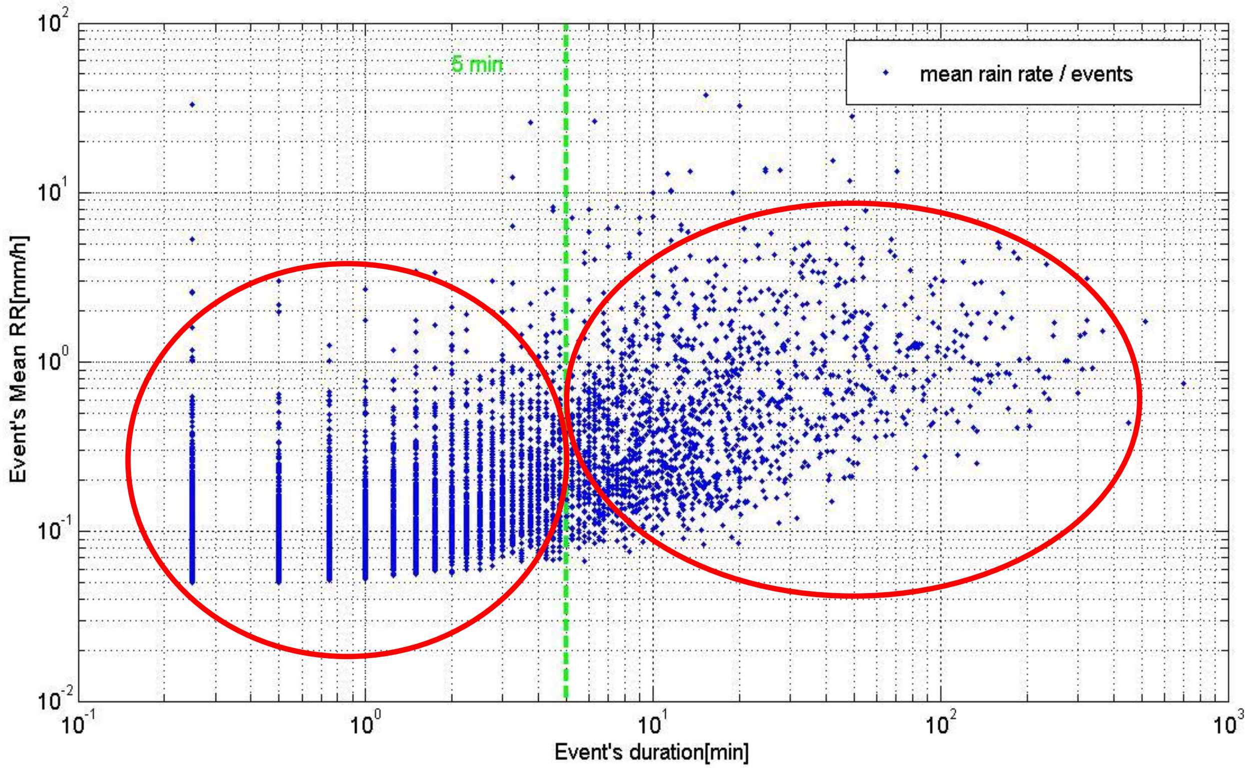
➔Retained FIF parameter H=0.42

Rainfall generator



Step3: calibration

Events mean rain rate/duration relationship 1/2



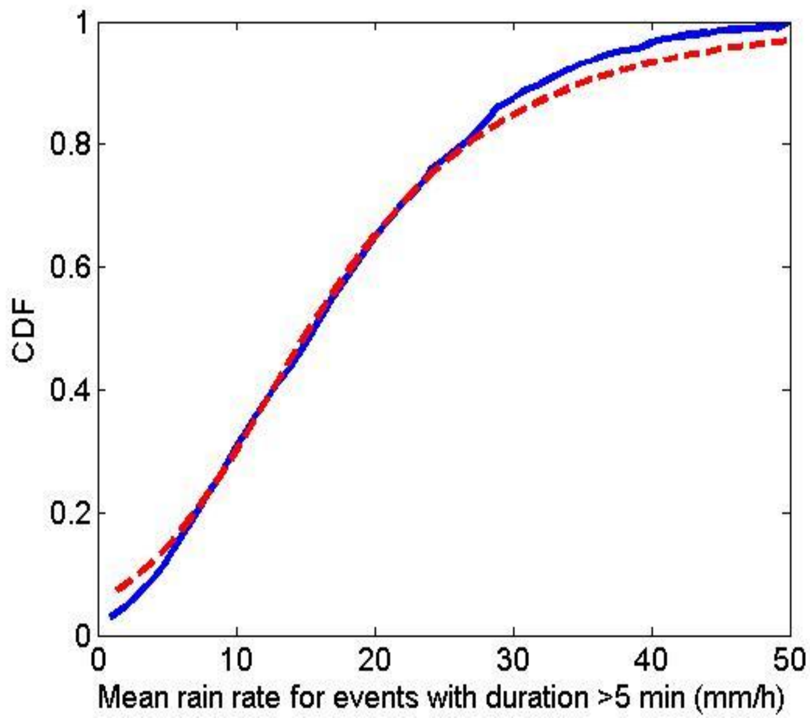
- Two classes are considered (less or more than 5 minutes)
- α-stable distributions are used to model mean rain rates corresponding to both short and long durations.

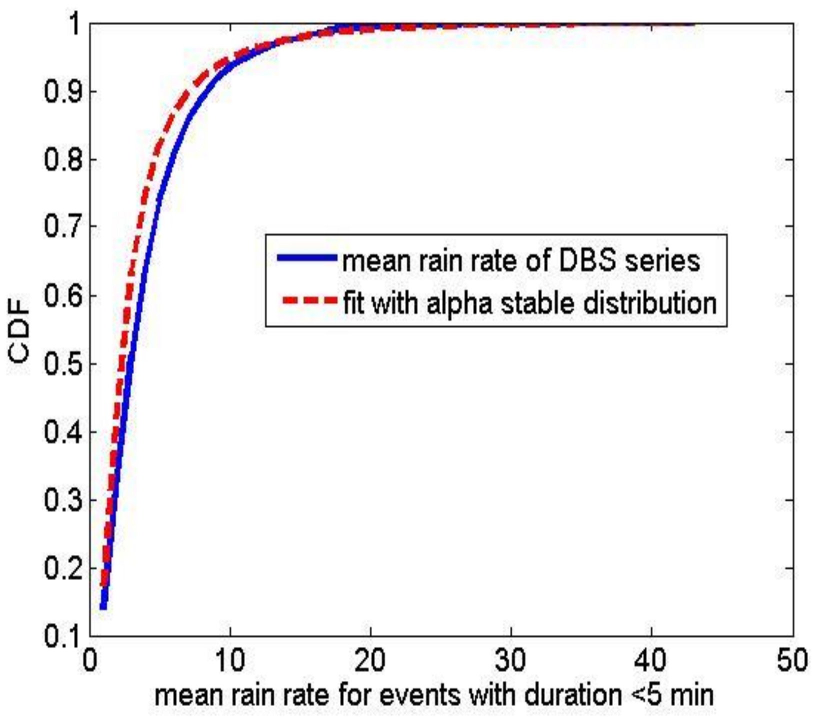
  ➔ 4 parameters.

Step3: calibration

Events rain rate/duration relationship 2/2

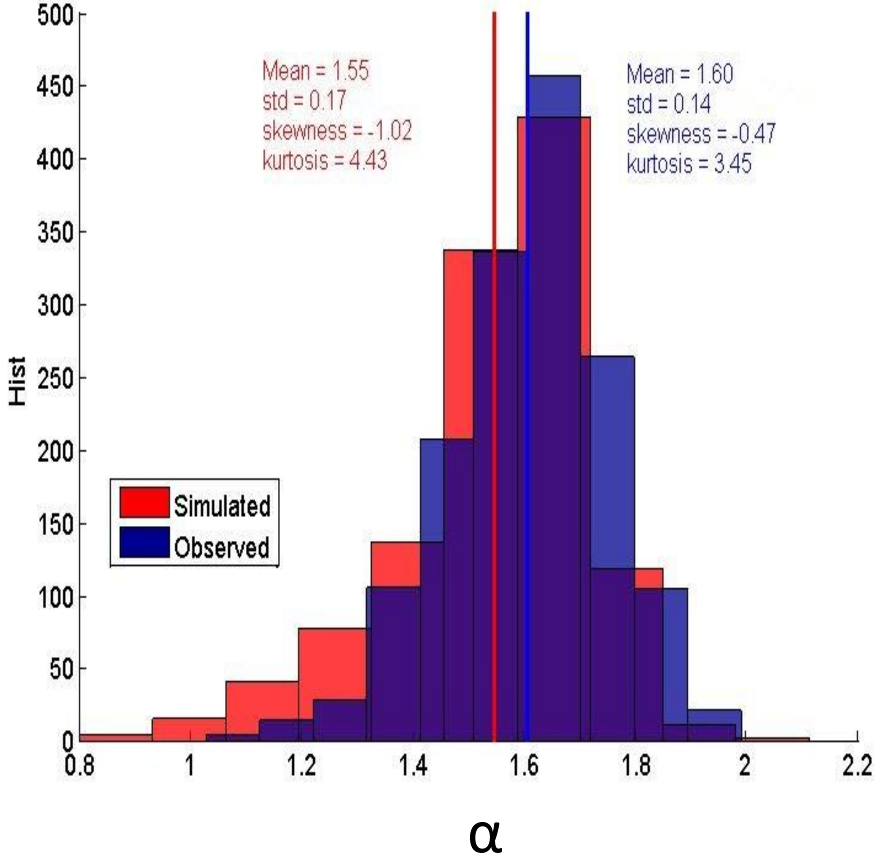
- α-stable distribution parameters
  - •Location parameter (fixed) $\delta = 0$
  - •Asymmetry Parameter (fixed) $\beta = 1$
  - •Stability and scale parameters $\alpha_r = 0.78$, $\gamma = 0.17$ long events
  - •and $\alpha_r = 0.91$, $\gamma = 0.01$ are estimated from short events

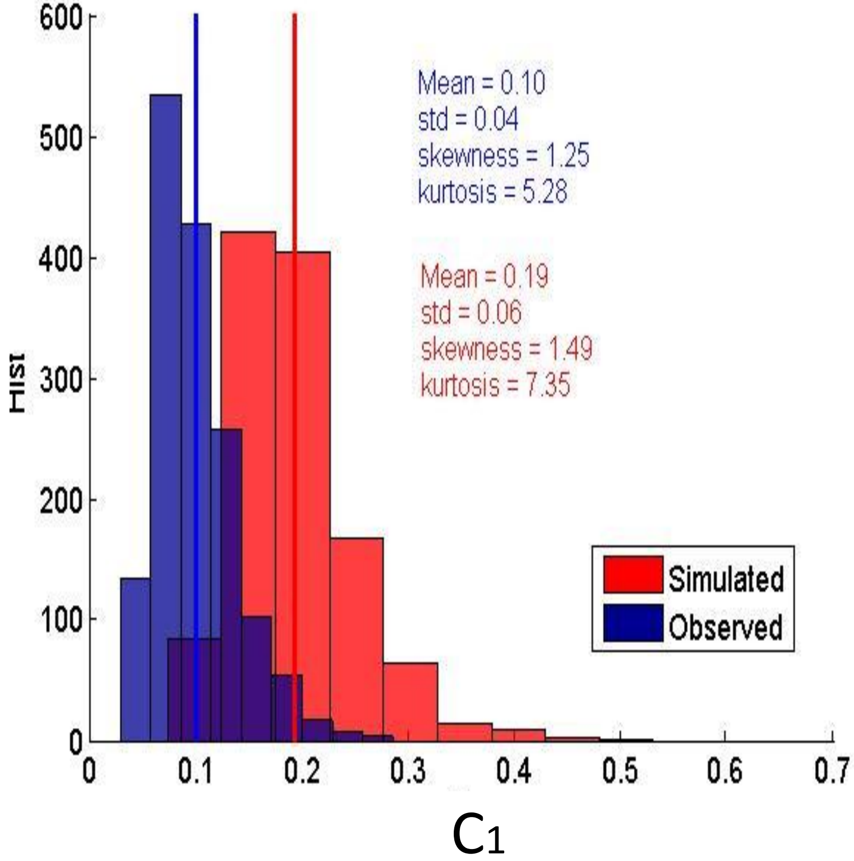




Step3: calibration

Multifractal analysis (exemple of 2 years simulated series)





Rainfall generator

step1 → Generate rain support using Generalized Pareto distribution

- ✓ Intermittency
- ✓ rain/no rain durations probability distribution
- ✓ Support co-dimenion

Step2 → generate rain events using FIF model

- ✓ Scale invariance properties

Step3 → Calibrate mean rain rate per event using α-stable distribution

- ✓ Mean rain rate distribution

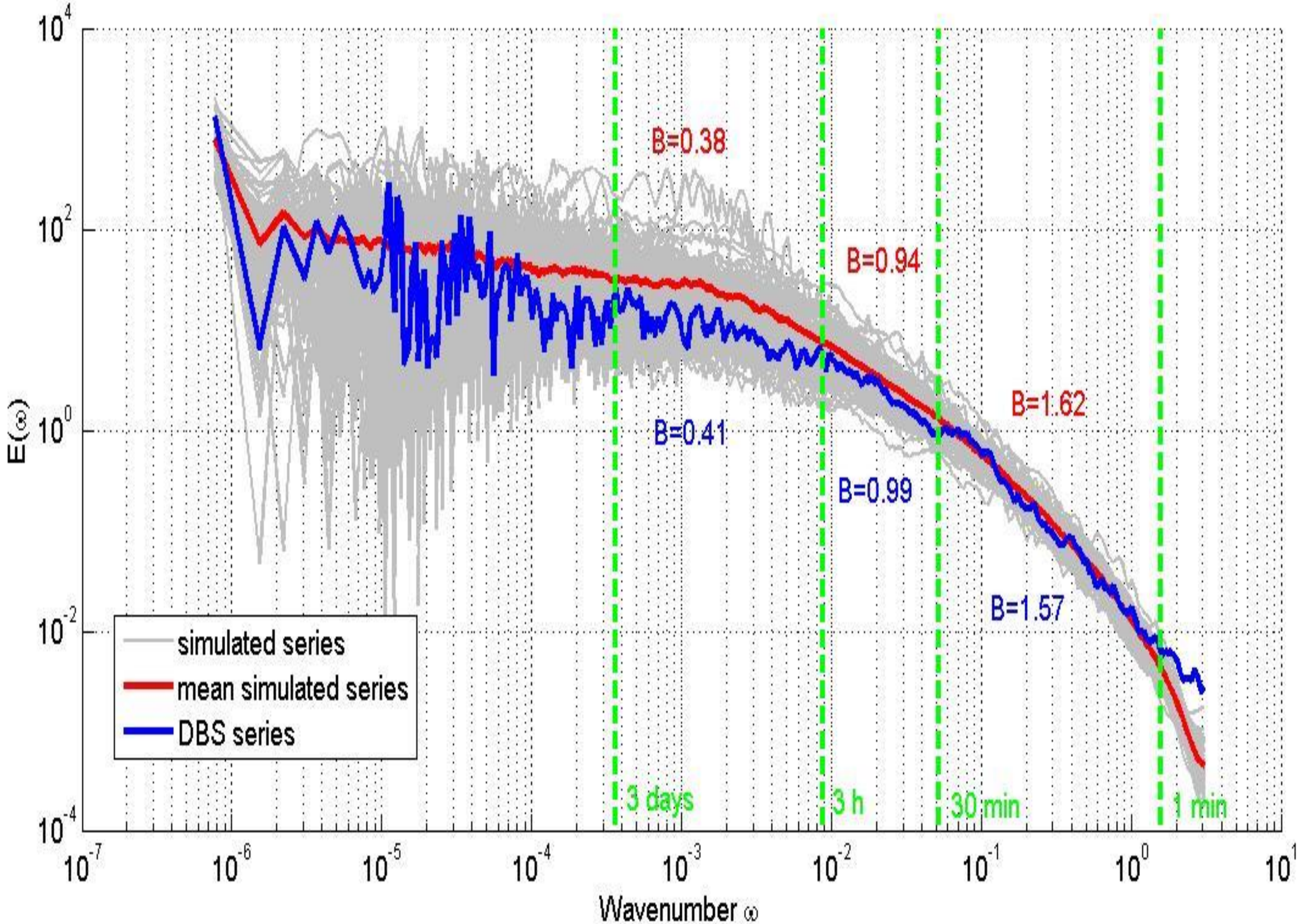
Simulate 100 two-year time series at 15s resolution

validated properties

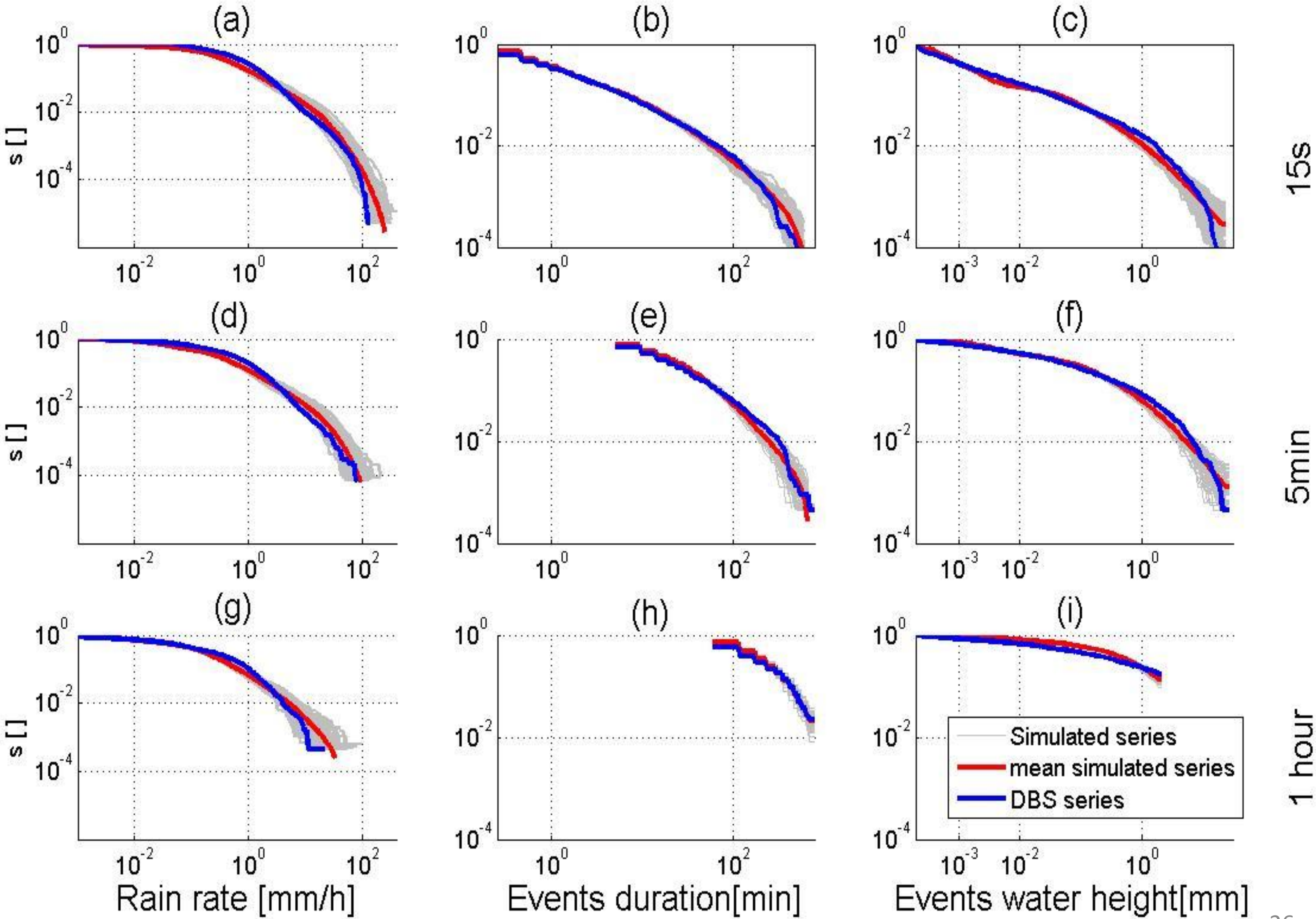
➔ It remains to verify the global properties of the complete series:

- Power spectrum
- Rain rate distribution checked from small to large scales.

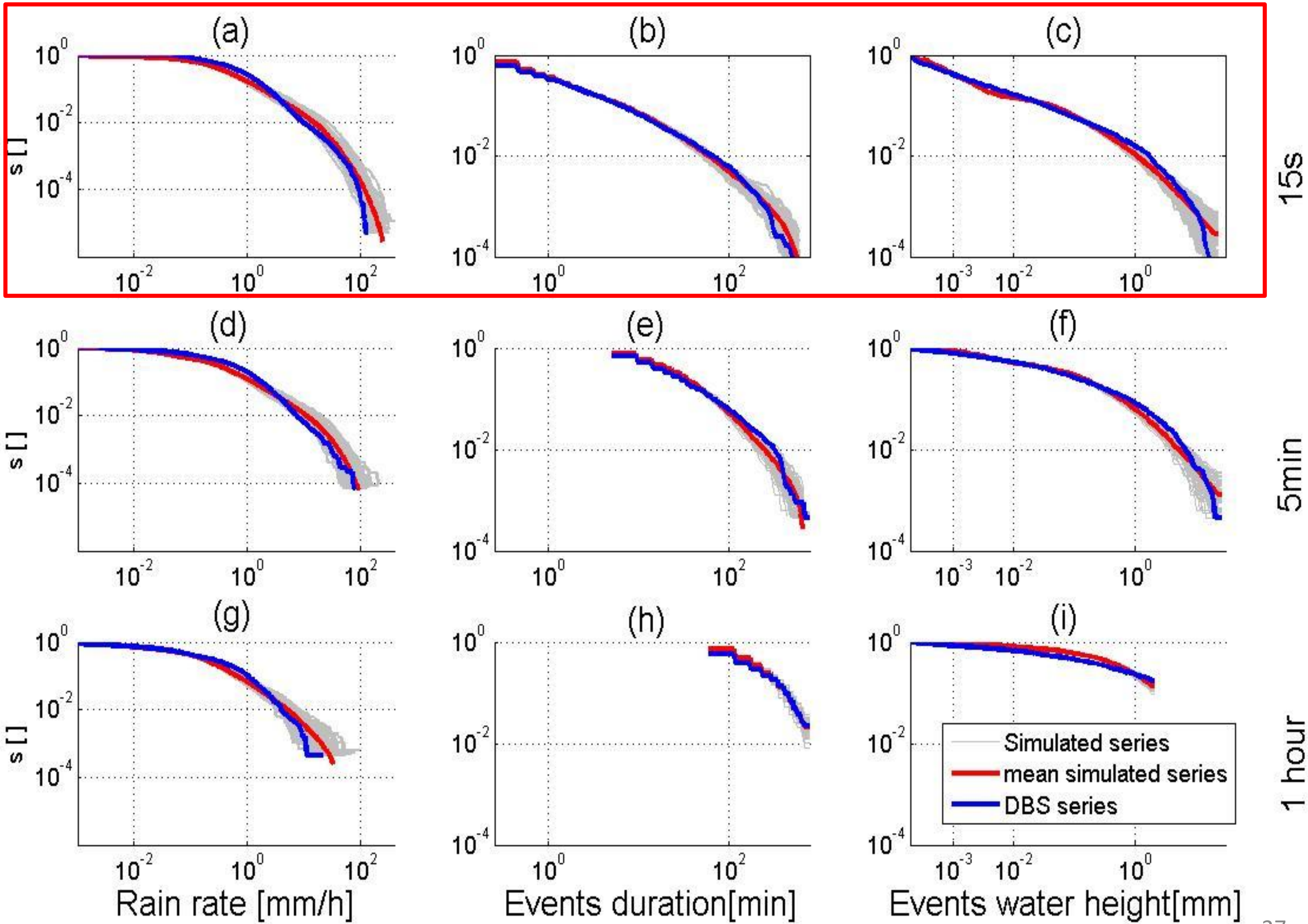
Rain rate power spectrum (100 simulated series)



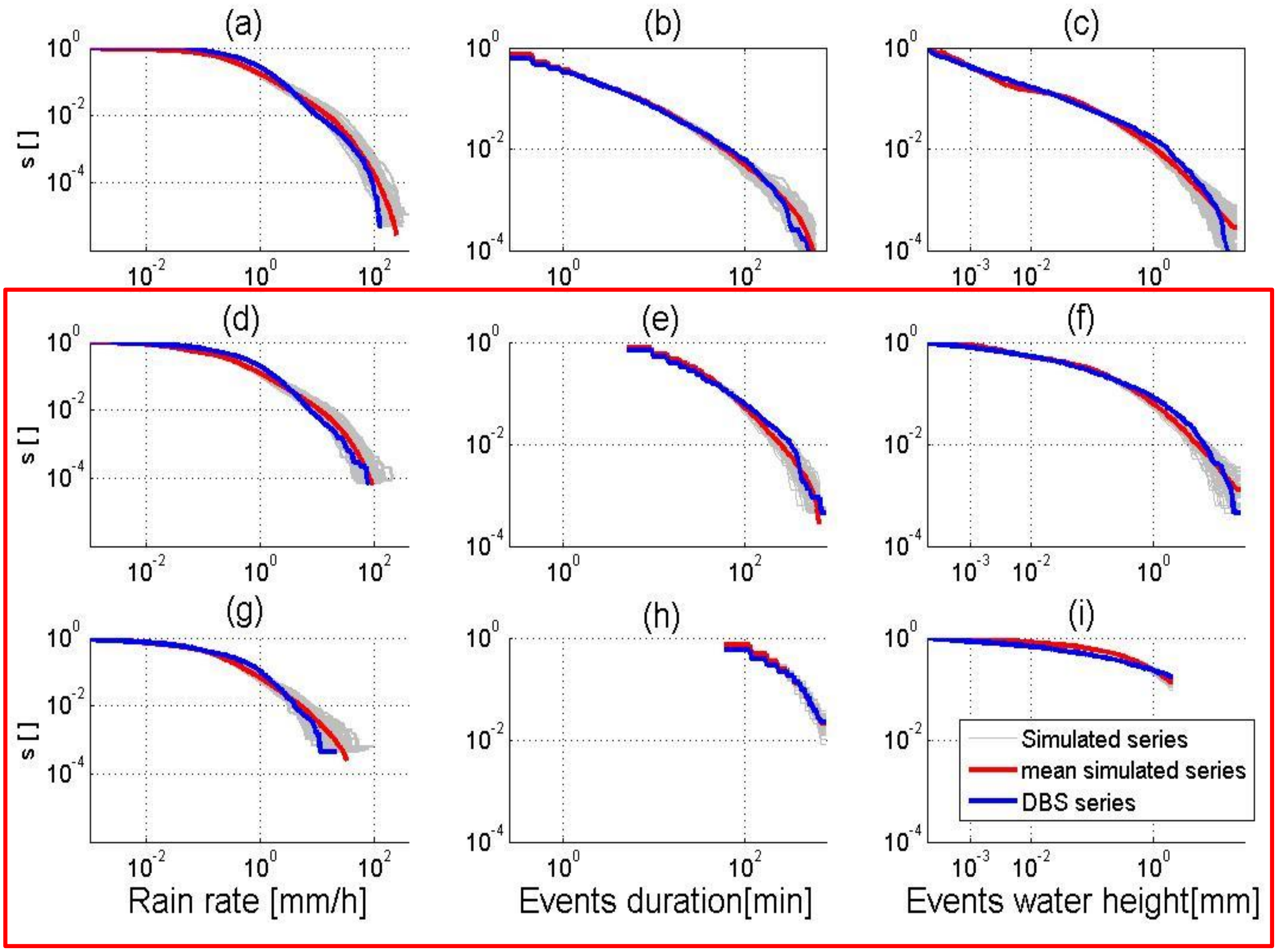
Survival function (100 simulated series)



Survival function (100 simulated series)



Survival function (100 simulated series)



Conclusion :

- Our model simulates yearly time series with a 15s resolution in agreement with the observed data , and it is able to restore various aspect (intensity, support, variability …) :

Support properties

+

Events

Scale invariance properties
+ mean rain rate

Global properties

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

✓From small to large scale:

- ✓Simulated & observed rain rate distribution are coherent
- ✓Simulated & observed rain durations distribution are coherent

 =

Perspectives

- Generalization to other climatic area

    ➔ Study the variability of mean rain rate / duration relationship parameters on other data sets.

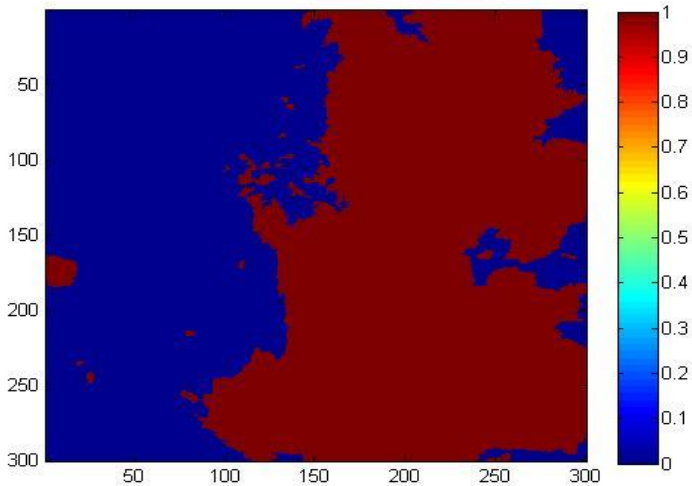
    ➔10 parameters are needed to adapt the simulator to a particular climatic area.

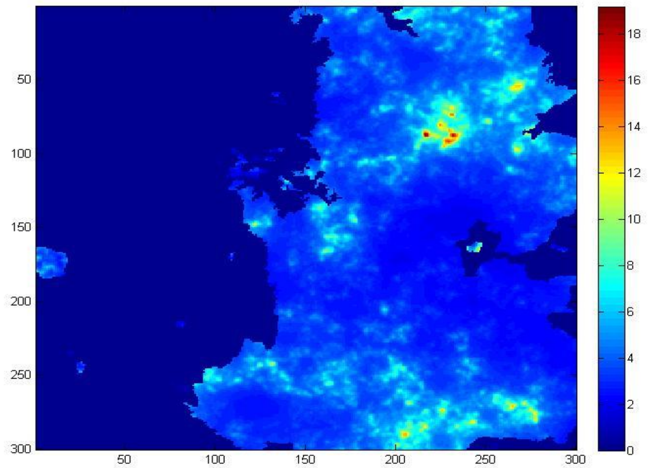
    ➔Improve the modeling (parametric method)

- Include the concept of seasonality in the simulation process

    ➔Require longer observed time series.

- Extension to 2D rain maps (work in progress)





Thank you for your attention

Extension to 2D: work in progress

- The used dataset are collected for 6 years with a 5 minutes temporal resolution and 1km×1km spatial resolution
- Rain support is simulated using a Sequential Indicator Simulation (SIS) algorithm.
- Calibration of rain rate events is based on the relationship between the mean rain rate of events and theirs surfaces