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

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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)**
  • Step 1: Generate rain supports
  • Step 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 = \[
\begin{cases} 
0 & \text{if water sheet} < 0.48 \text{mm} \\
1 & \text{else}
\end{cases}
\]
Data set properties: Multiple scaling regime

Power spectrum (scale invariance properties)
Methodology:

Step 1: Rain support generation (using SIS method)

Step 2: Generate rain events using FIF model

Step 3: Re-normalization per rain cell (Mean water sheet/areas relationship)

Step 4: Rain/no rain transition
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

Spherical variogram model:

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

Estimate variogram parameters

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

$\Rightarrow$ 3 parameters: $\alpha=1.6$  $C_1=0.10$  $H=0.4$
Re-normalization per rain cell (Step3):
Mean water sheet/areas relationship:

The average water sheet for a rain cell is conditioned by its size \( s \): \( <R_c|s> \)

\( s = \) square root of the rain cell area

\( \Rightarrow \) each \( <R_c|s> \) has a distribution: \( \text{Pdf}( <R_c|s> ) \)

• \( \alpha \)-stable distributions are used to model mean water sheet
• *Pdf*<sub>*</sub> *(<Rc>|s)* : \( \alpha \)-stable distribution parameters:

  - Stability parameter: \( \alpha = 1.18 \)
  - Asymmetry Parameter: \( \beta = 1 \)
  - Scale parameter: \( \gamma = 0.03 \times s \)
  - Location parameter: \( \mu = 0.09 \times s + 0.65 \)

\( \Rightarrow \) 5 parameters
Rain/no rain transition (step 4):

Step 3 output water sheet

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

\( d(z) \) 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:

\[ \Rightarrow 42,000 \times 4 \text{ water sheet maps} \]

It remains to verify the global properties of the simulated rain maps:
- Multifractal analysis
- 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: $\alpha=1.6$  \hspace{1cm} C1=0.10  \hspace{1cm} H=0.4

⇒ Average estimated parameters: $\alpha=1.71$  \hspace{1cm} C1=0.10  \hspace{1cm} 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)

\[
\beta \in [0.85, 1.01]
\]

\[
\beta = 0.97
\]

\[
\beta = 1.95
\]

\[
\beta \in [1.80, 2]
\]
Survival function (ESF) of water sheet:
Conclusion:

Our model simulates in agreement with the collected data, and it is able to restore various aspects (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

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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 developed
  ➔ 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