Space-time characterization of heavy rainfall events: Application to the Cévennes-Vivarais region

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OUTLINE OF THE PRESENTATION

- Introduction
- Methodological development
- Application: Severity Diagrams
- Conclusions

PART I

INTRODUCTION

General overview

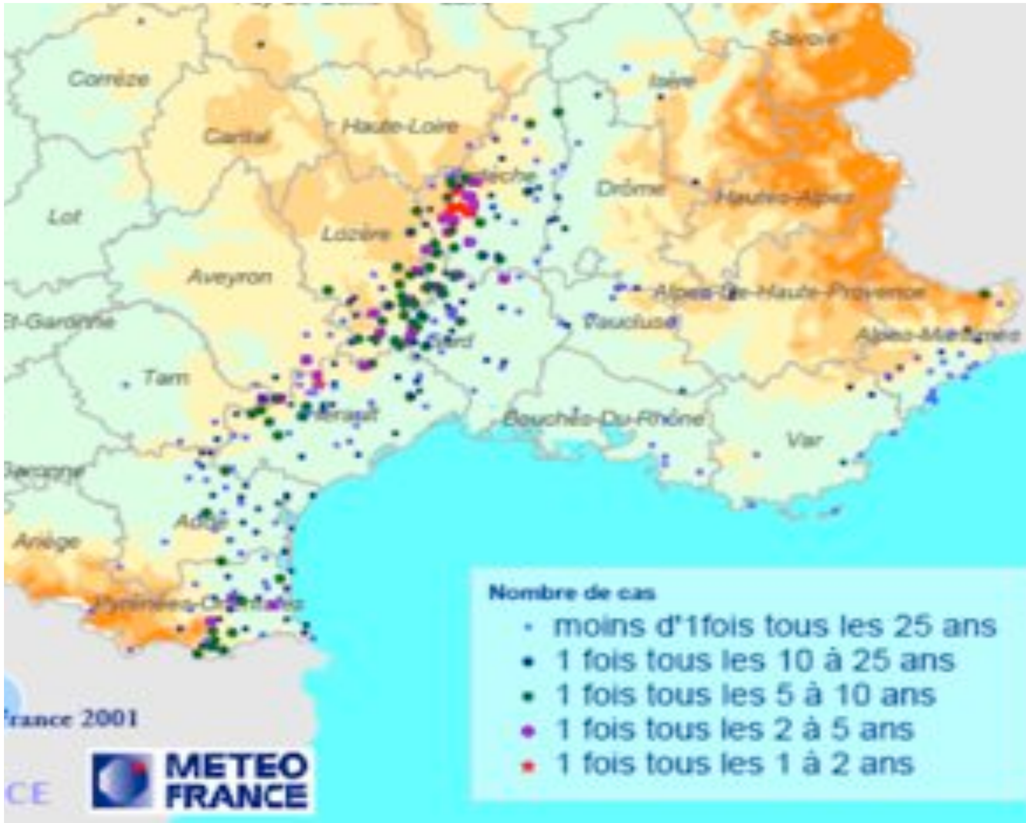
Context:

Extreme rainfall in a Mediterranean Mountainous Region

1958-1994:

Daily amount > 190 mm

Total: 144 events



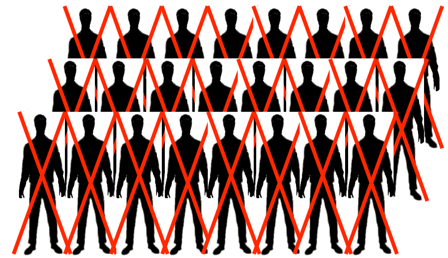
Warm humid air from Mediterranean Sea + Orography = Storms

Jacq (1994)

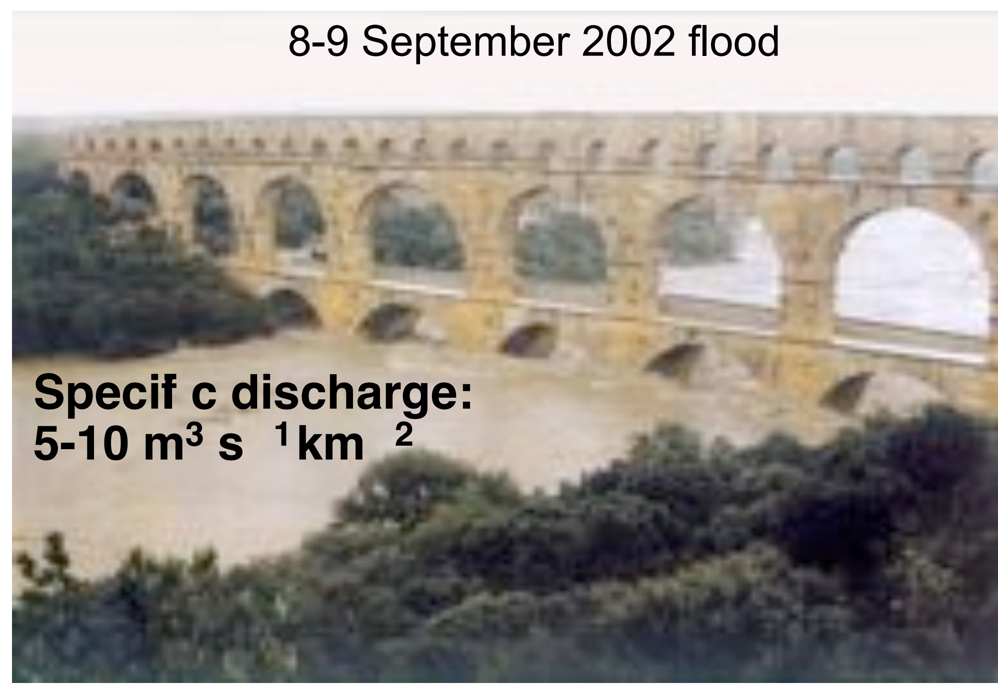
General overview

Cévennes-Vivarais: region prone to catastrophic flash-floods

Social and economic impact (human lives, damages,...)



1600 M€



General overview

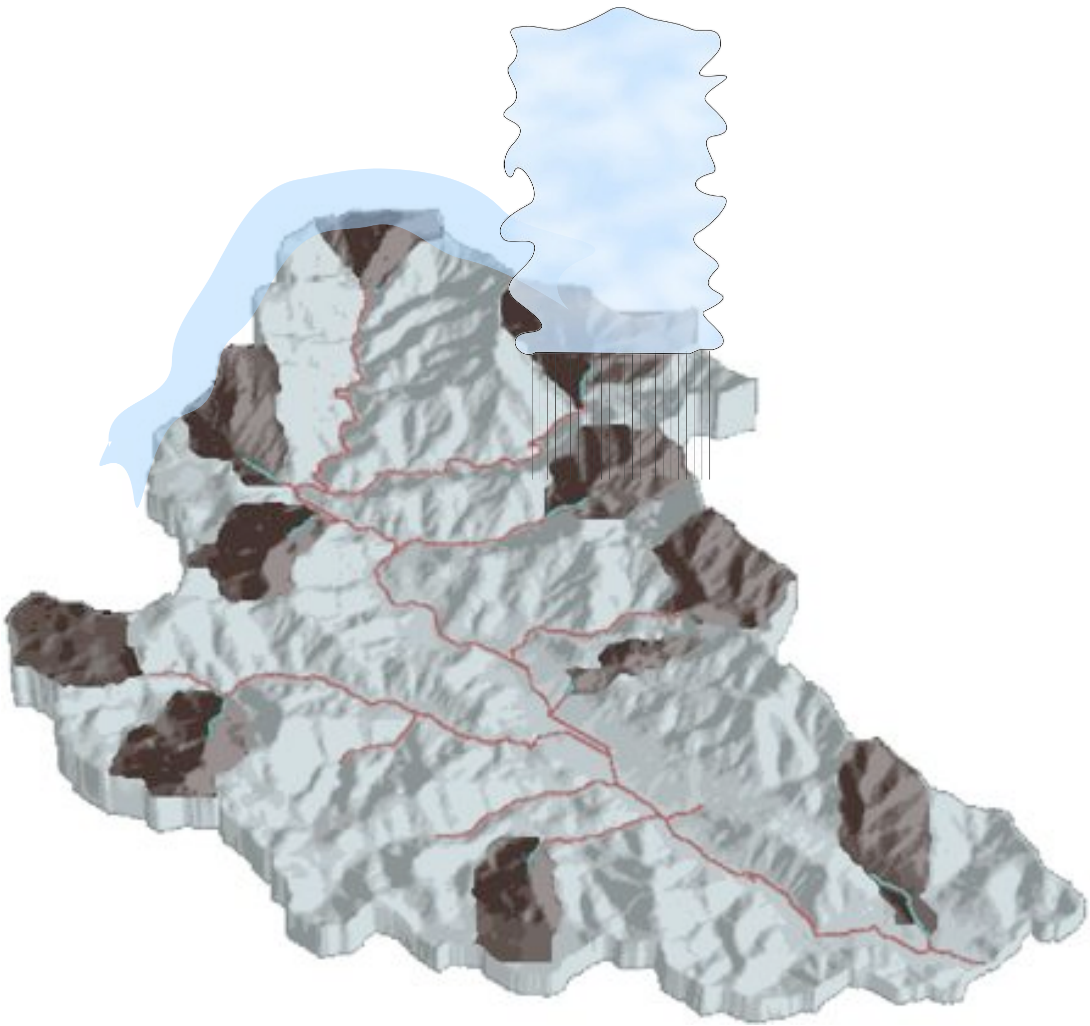
Is it a « hydrological monster » or a regular event?

8-9 September 2002 flood

How can we measure the magnitude of extremes?

Impact of storms at various durations

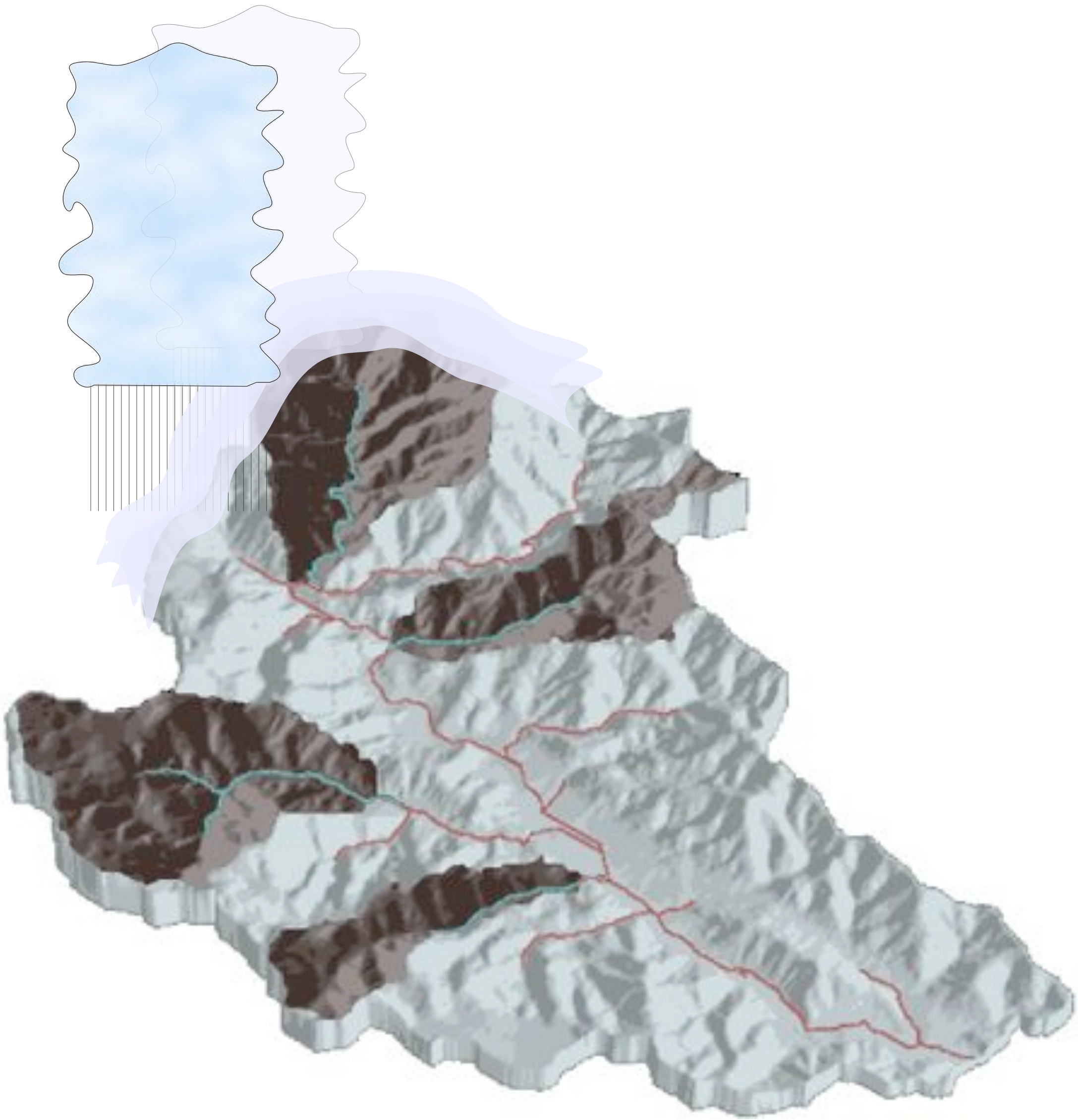
Spatial and temporal scales are related



D= 2 h

Impact of storms at various durations

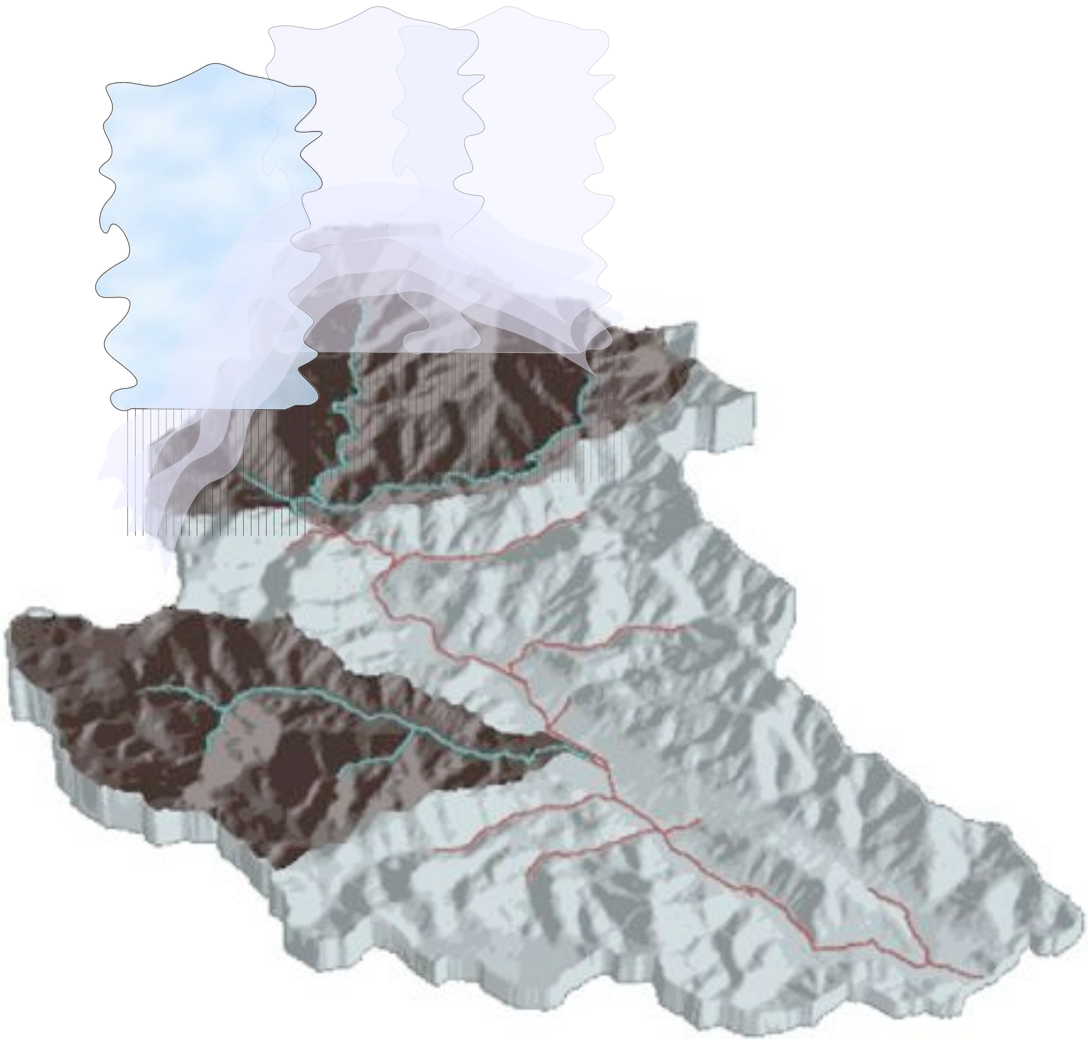
Spatial and temporal scales are related



D= 4 h

Impact of storms at various durations

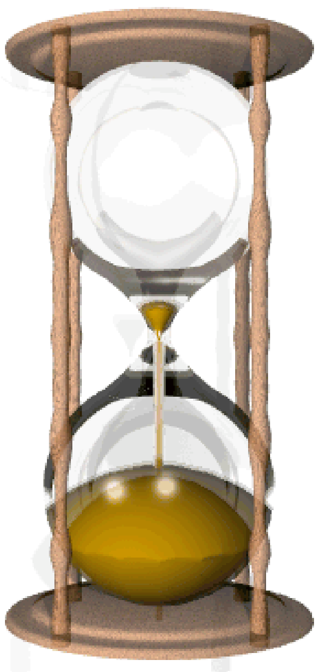
Spatial and temporal scales are related



D= 8 h

Impact of storms at various durations

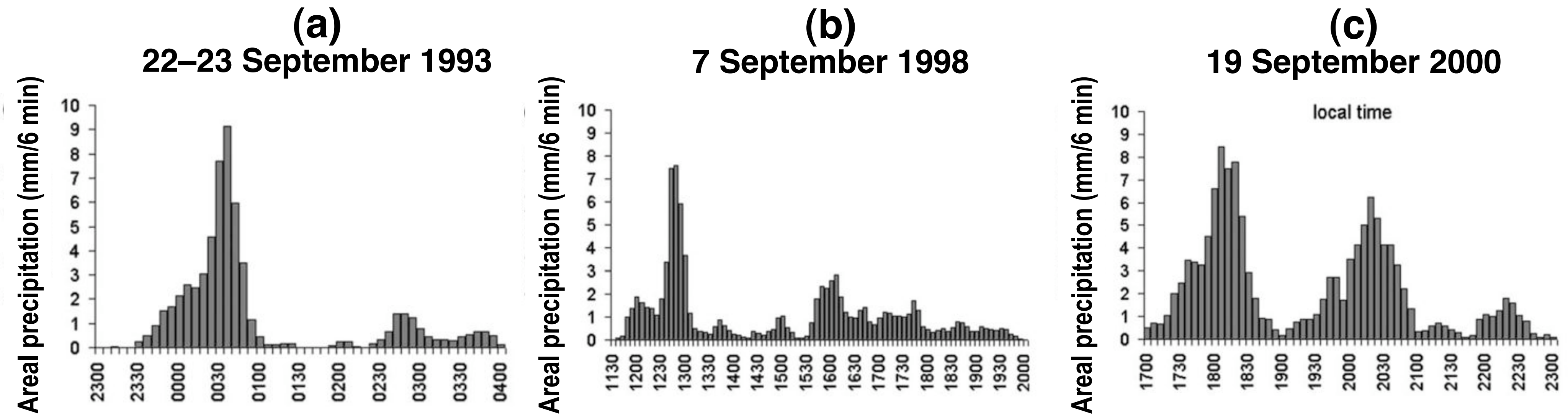
Spatial and temporal scales are related



D= 16 h

Aim of the study

HOW TO ESTIMATE THE MAGNITUDE OF RAINFALL EVENTS?



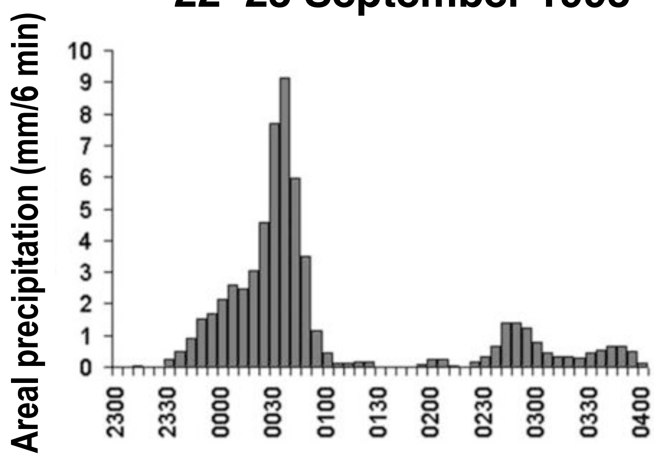
Storms over Marseille

EVENT	a	b	c
Event duration (h)	5	8.5	6
Total areal rain depth (mm)	59.2	92.4	130.8
Max point rainfall (mm)	151	116	210
Max hourly intensity (mm/h)	125	62	88

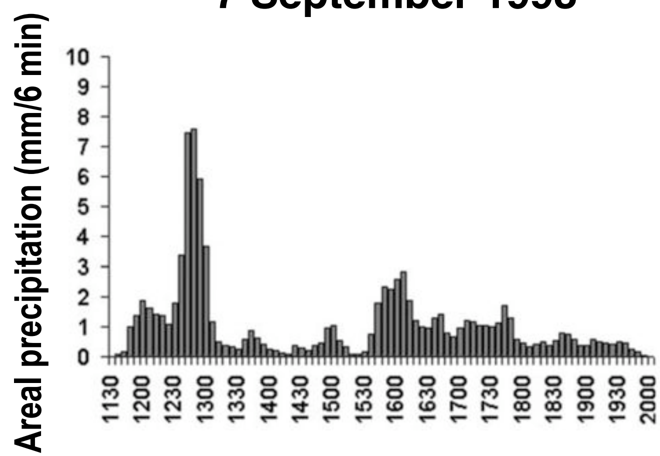
Aim of the study

HOW TO ESTIMATE THE MAGNITUDE OF RAINFALL EVENTS?

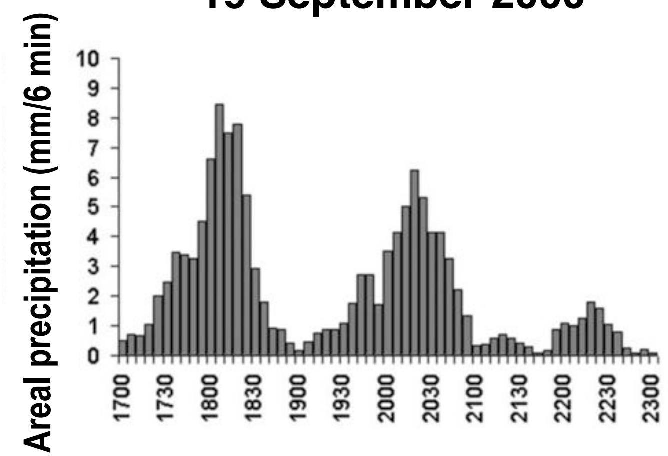
(a)
22–23 September 1993



(b)
7 September 1998



(c)
19 September 2000



NO DAMAGES

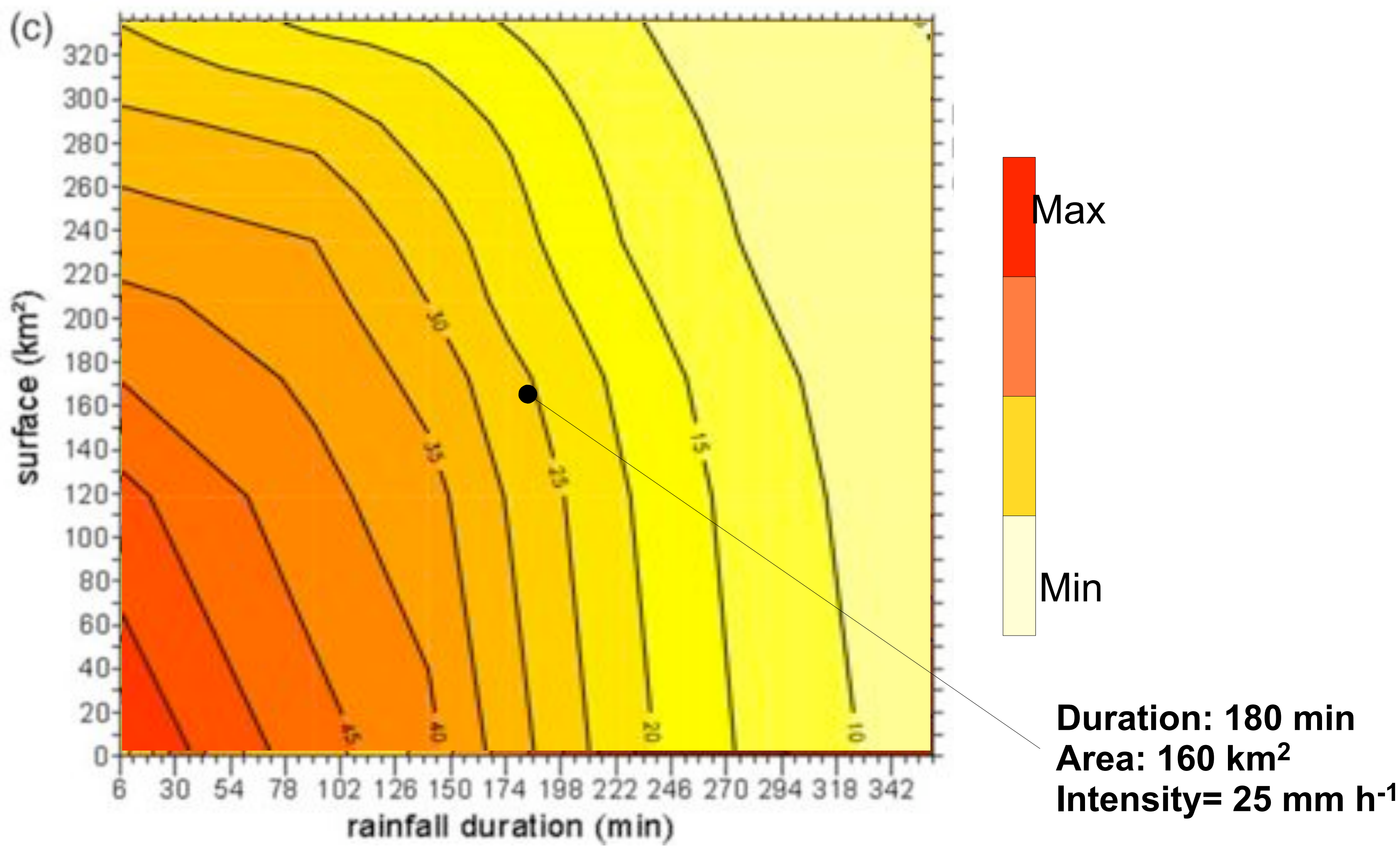
NO DAMAGES

60 M€

Classic statistics are unable to detect the more dangerous event

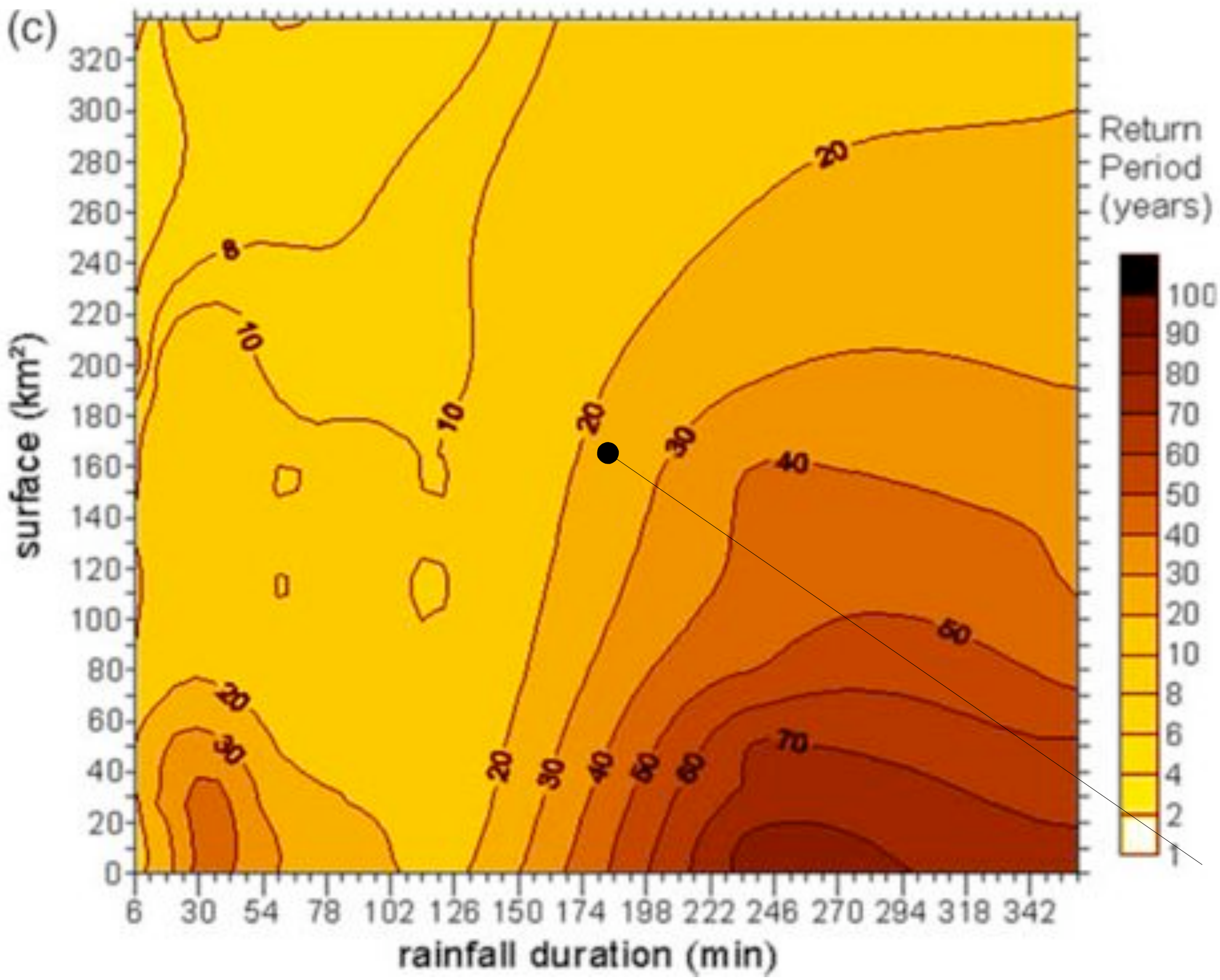
Need of a multi-scale descriptor of storms

Maximum rainfall intensity



Integration Smoothing **Trivial scale pattern**

Proposition: transform max intensity into FREQUENCY

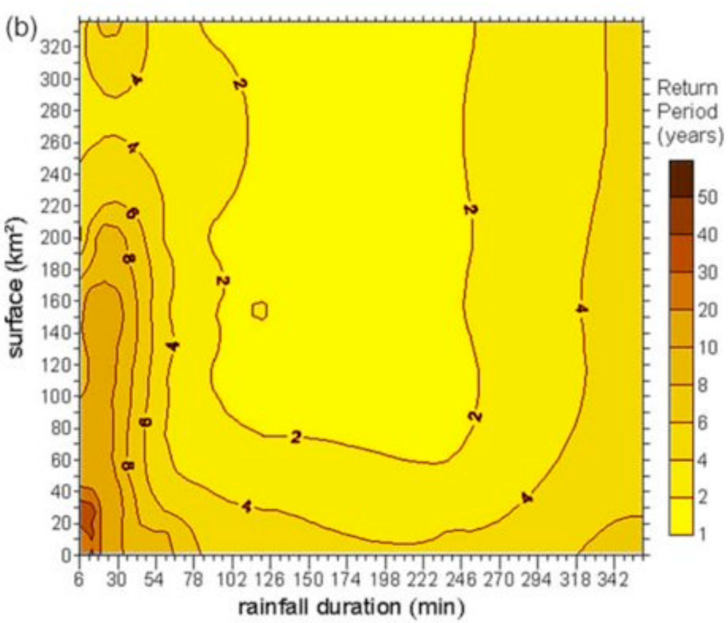


Duration: 180 min
Area: 160 km2
Intensity= 25 mm h^{-1}

SEVERITY DIAGRAMS: Event magnitude at all scales

Severity diagrams: a storm comparison tool

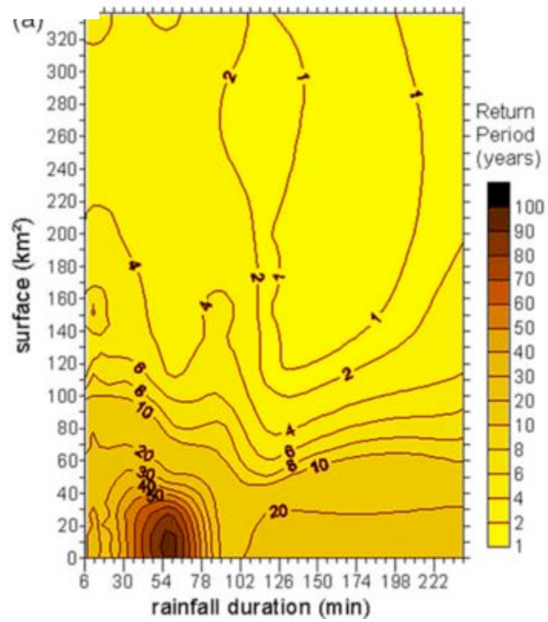
(a)
22–23 September 1993



Weak event

NO DANGER

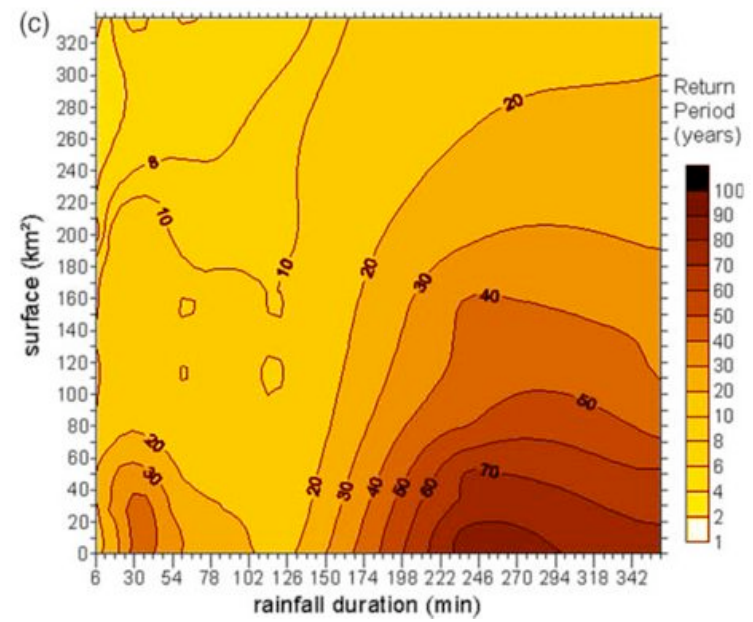
(b)
7 September 1998



Local event

LIMITED DANGER

(c)
19 September 2000



Heavy and extended event

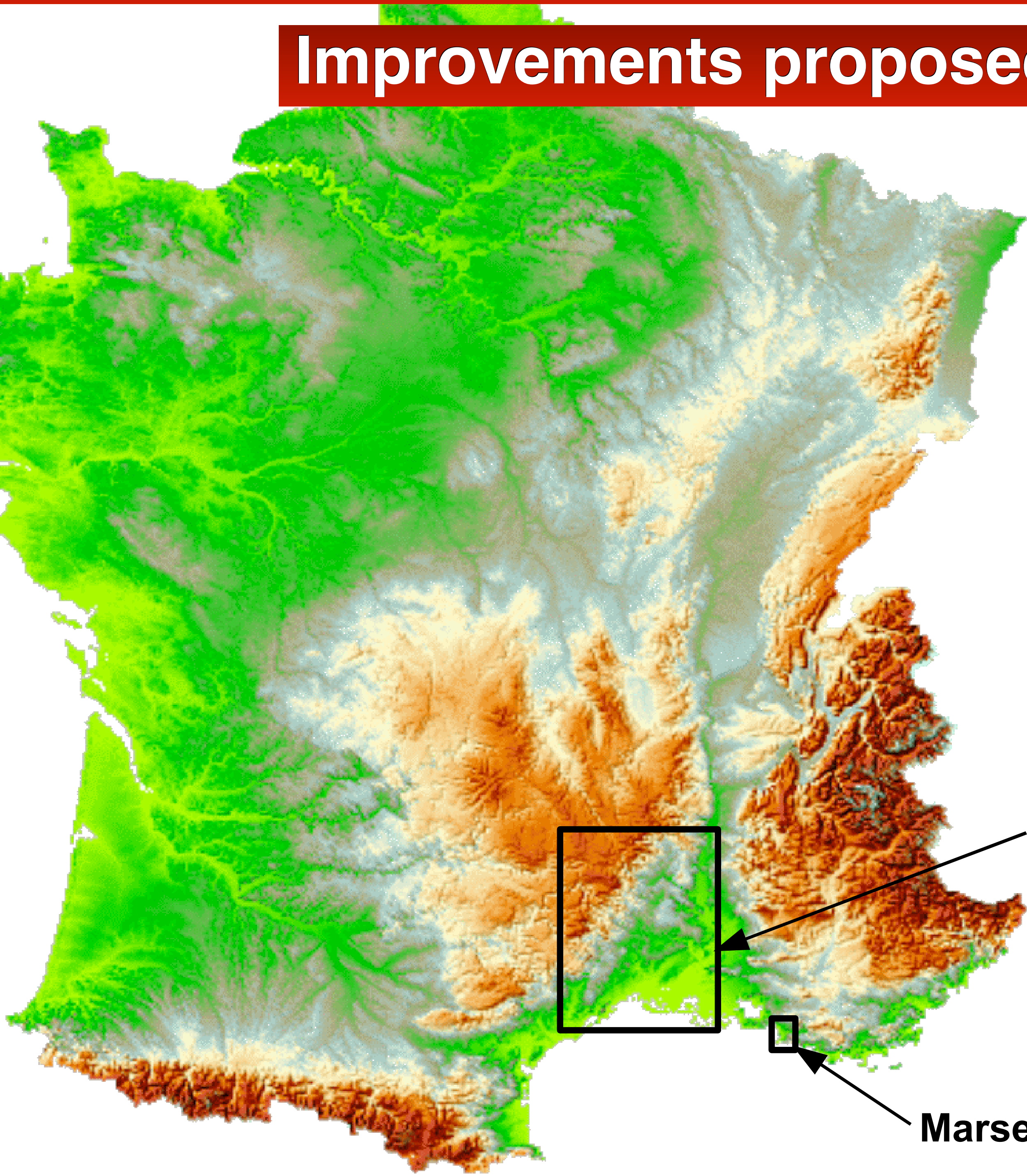
DANGER

Ramos et al., 2005

Improvements proposed in the thesis

	BEFORE	AFTER
Size of the region	250 km^2	32000 km^2
Involved events	Urban f oods	Flash-f oods
Regional model	✗	✓
Point rainfall extremes	EMPIRICAL	SCALE-INVARIANT MODEL
Spatial rainfall extremes	EMPIRICAL	SPACE-TIME MODEL

Improvements proposed in the thesis



A larger region

↓

Take into account spatial heterogeneity

Cévennes-Vivarais Hydro-Météorological Observatory
Area: 32000 km^2

Marseille area: 250 km^2

Geographical context

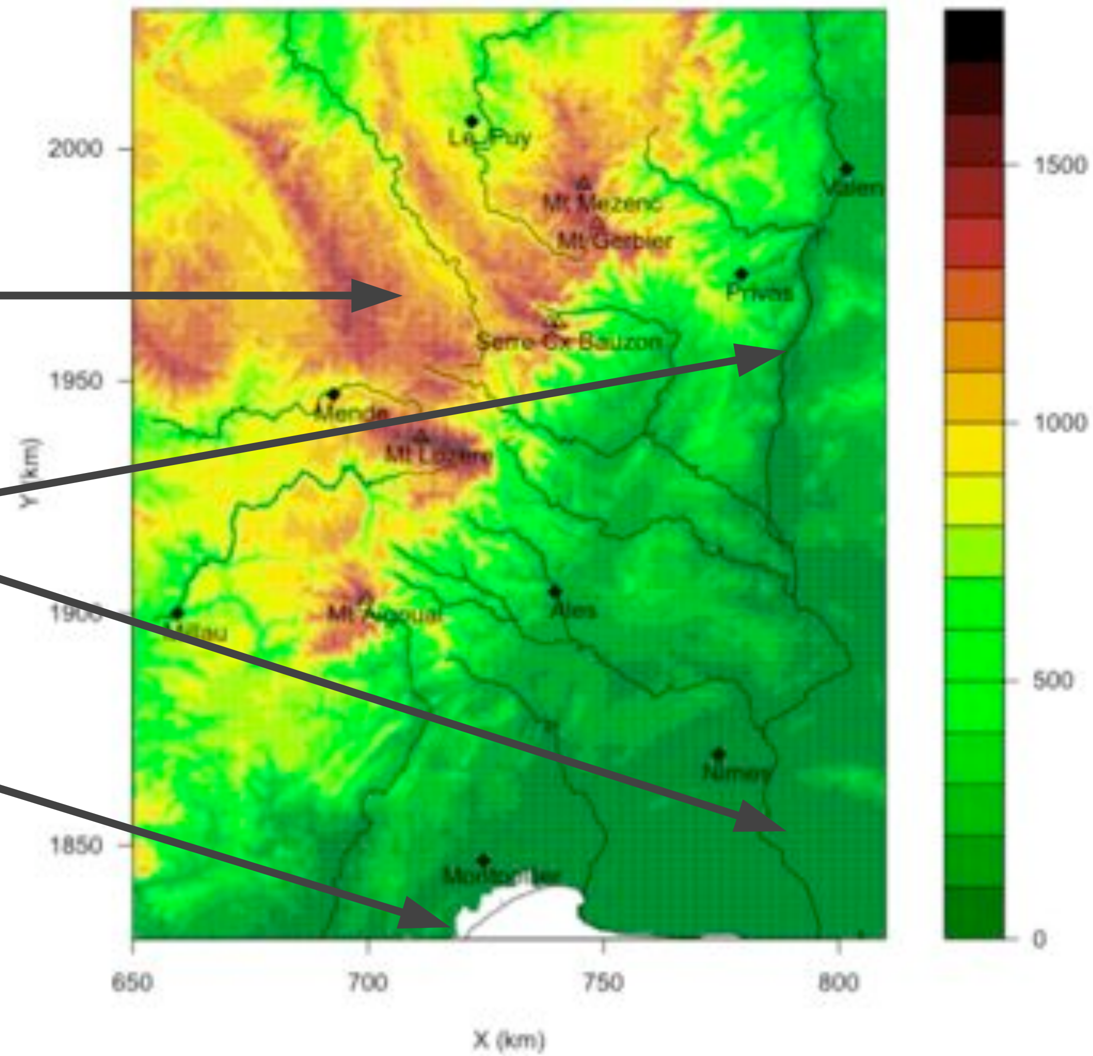
Cévennes-Vivarais région

Size	160 x 200 km²
Elevation	0 – 1950 m

Cévennes Massif

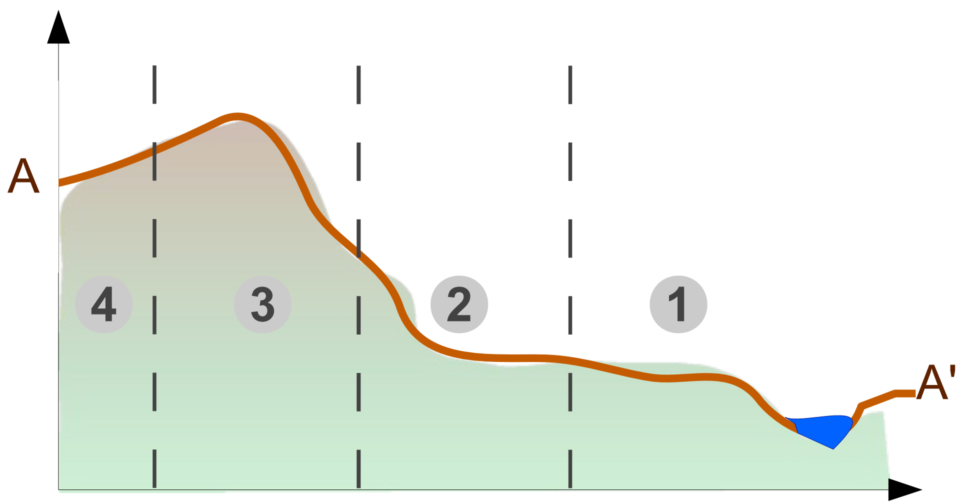
Rhône River

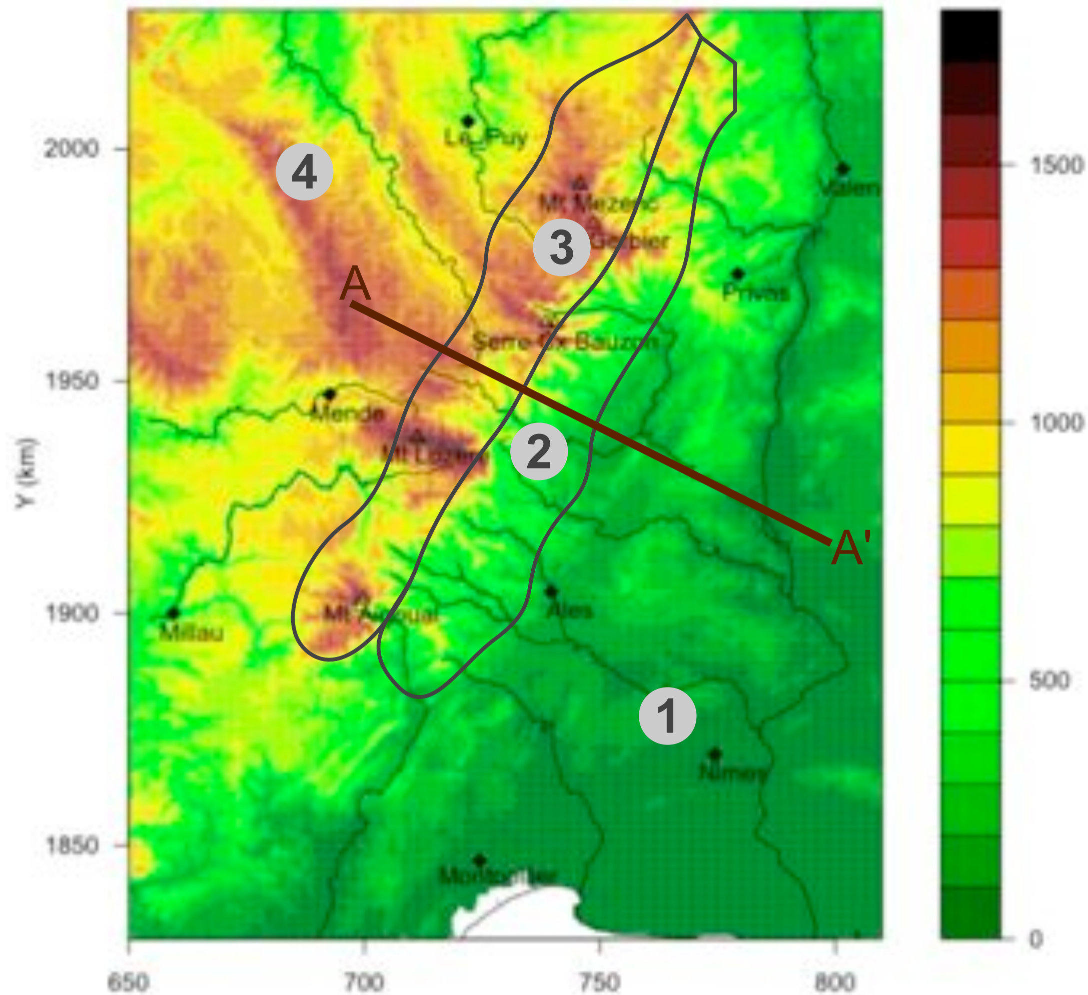
Mediterranean Sea



Geographical context

Cévennes-Vivarais région



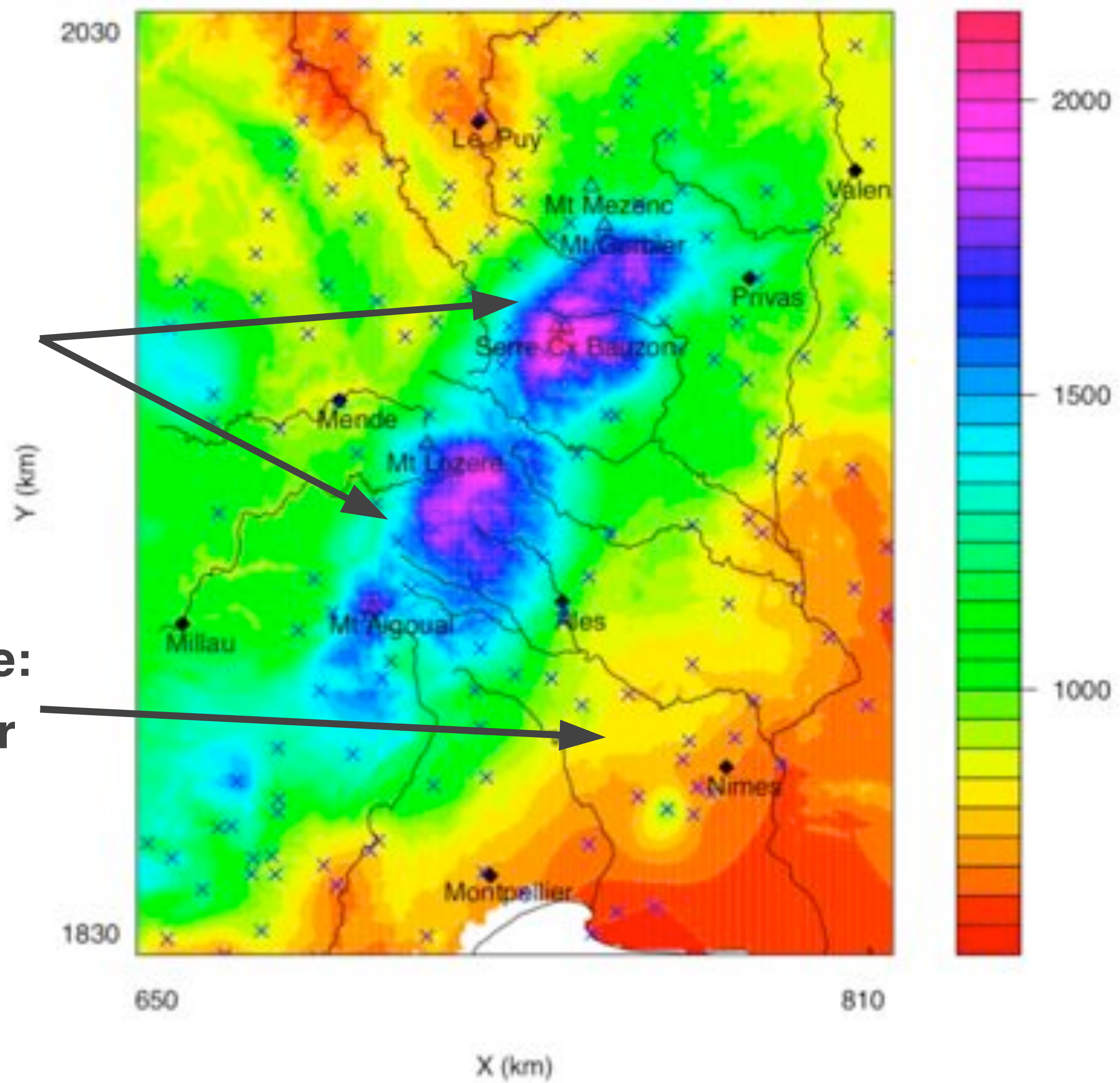


The region gathers f at lands 1, a SE oriented foothill 2, a mountain ridge 3 and a plateau 4 .

Climatic features: average annual rainfall (mm)

Mountain ridge:
Over 2000 mm / year

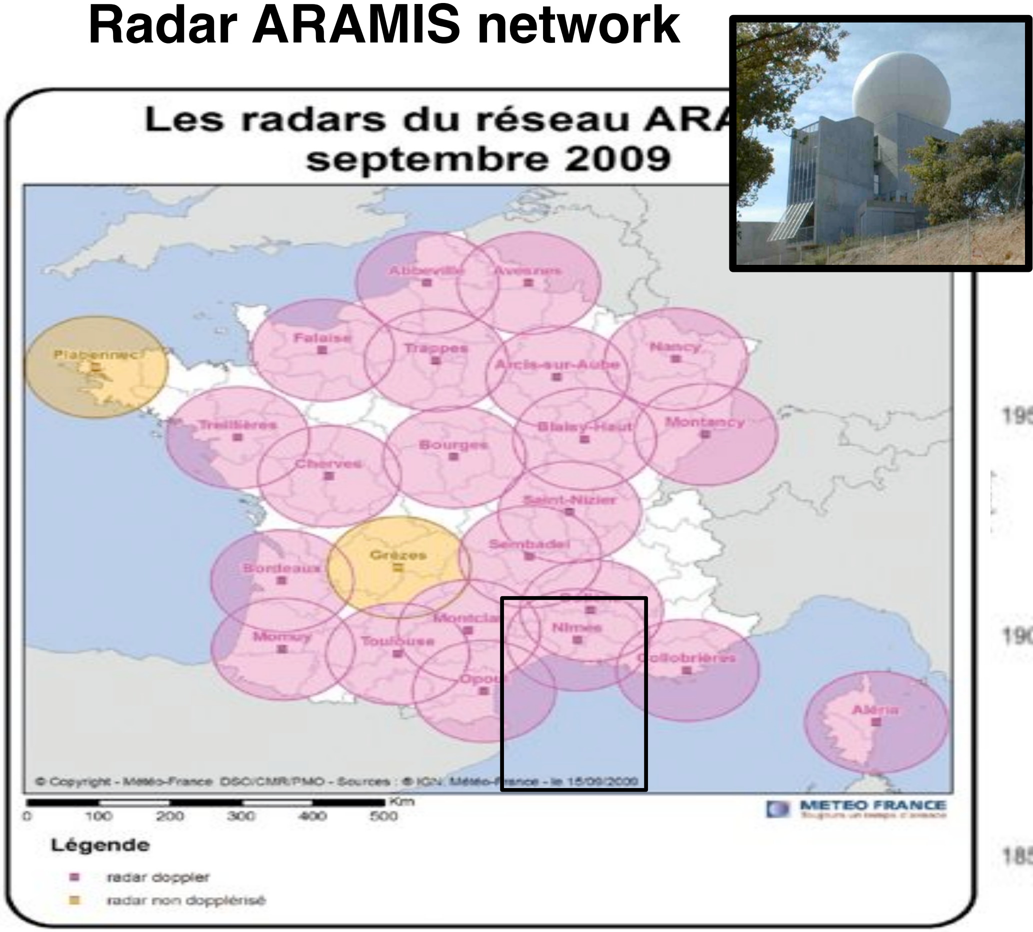
Mediterranean sea shore:
less than 1000 mm / year



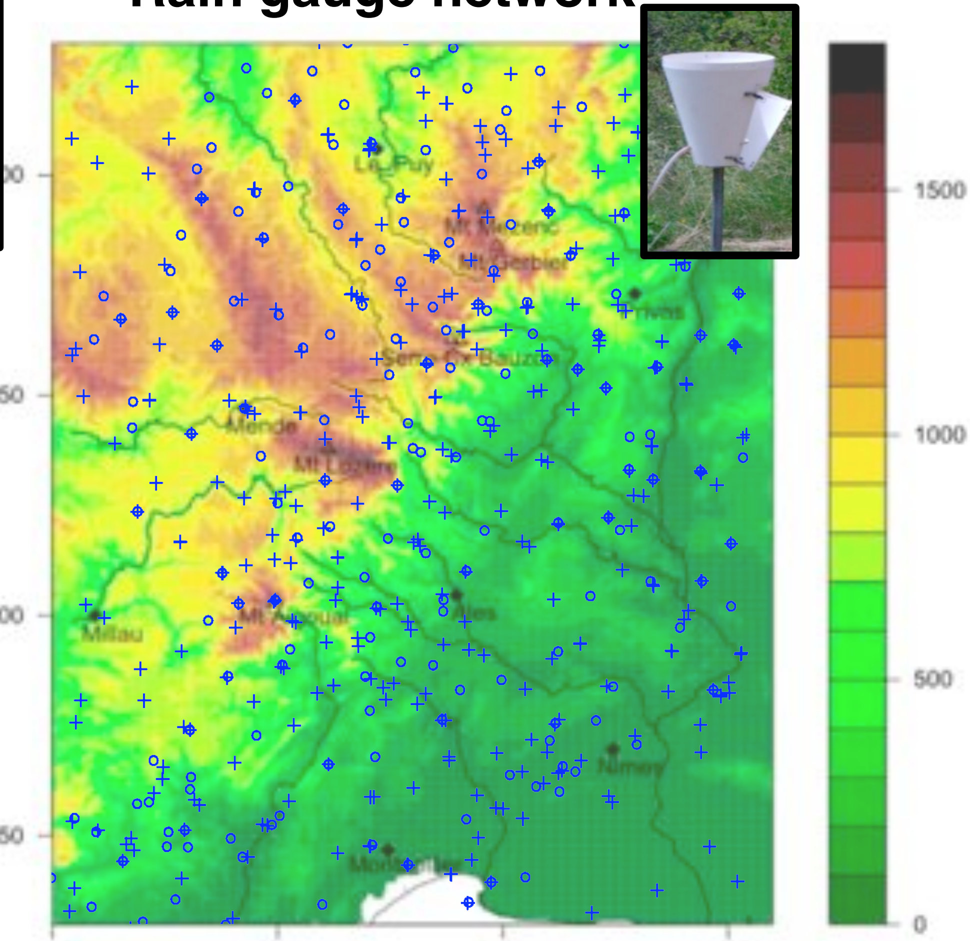
Measurement network

OHM-CV: Cévennes- Vivarais Hydro-Meteorological Observatory

Radar ARAMIS network



Rain gauge network



Hourly (150 gauges, 1993-2008) +

Daily (225 gages, 1958-2000) ○

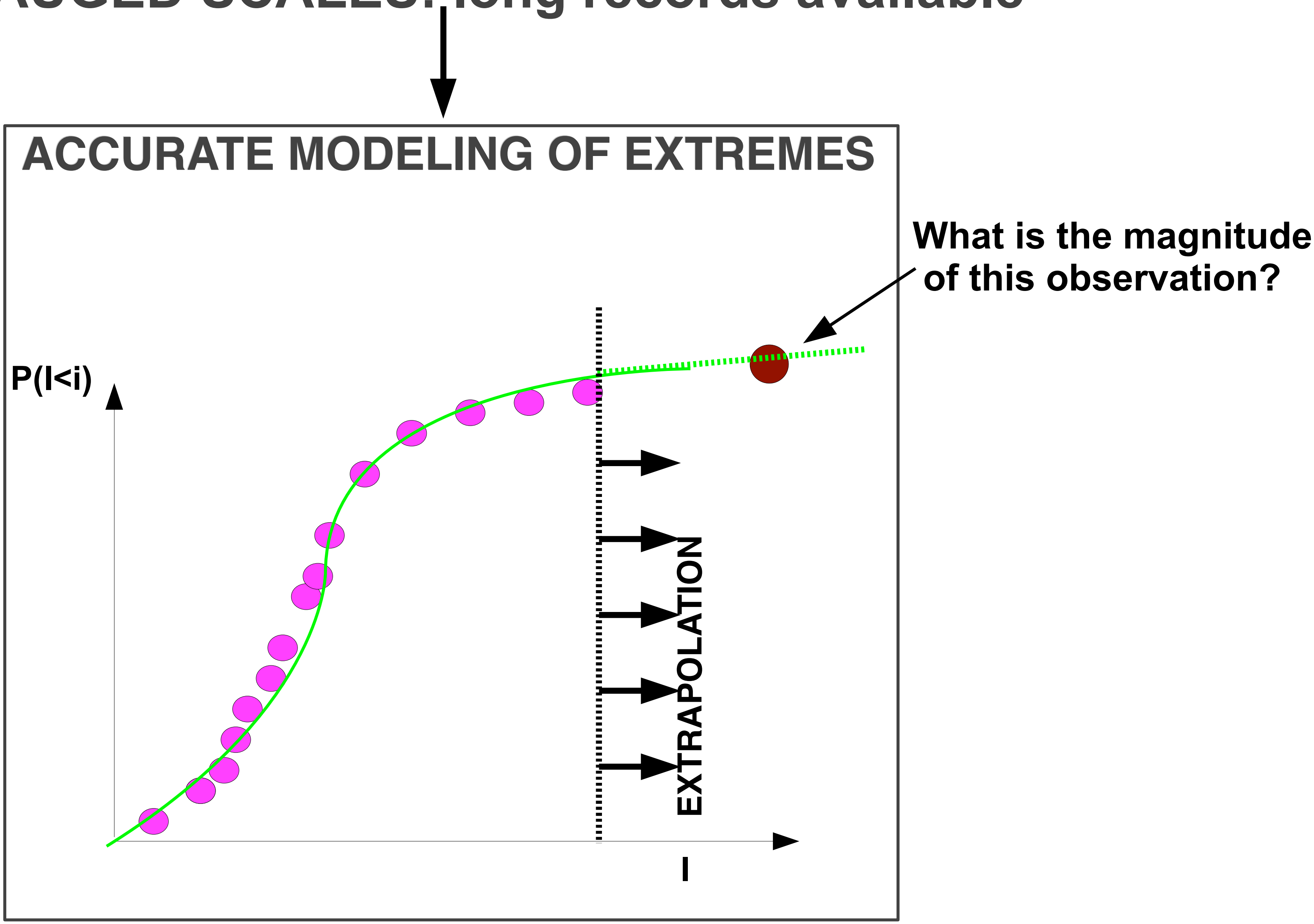
OHM-CV: one of the Europe densest rain gauge networks (1/50 km^2)

PART II

METHODOLOGICAL DEVELOPMENT

For a reliable magnitude estimation

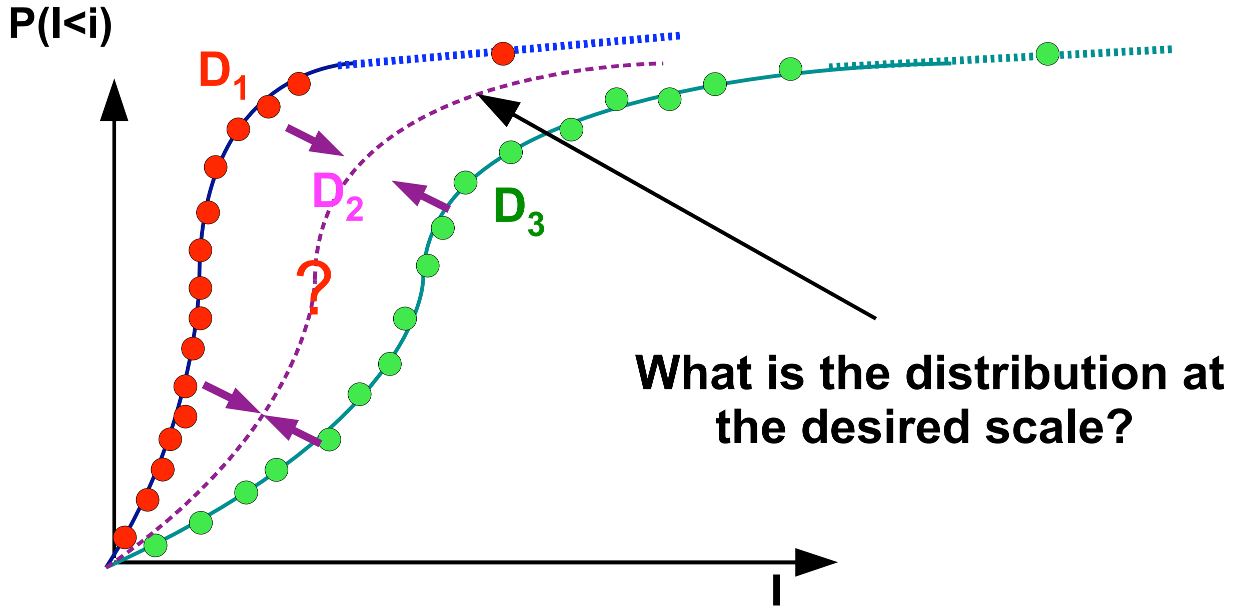
GAUGED SCALES: long records available



For a reliable magnitude estimation

UNGAUGED SCALES: no measurements at the desired scale

SERIES RECONSTRUCTION THROUGH SCALE-INVARIANCE METHODS

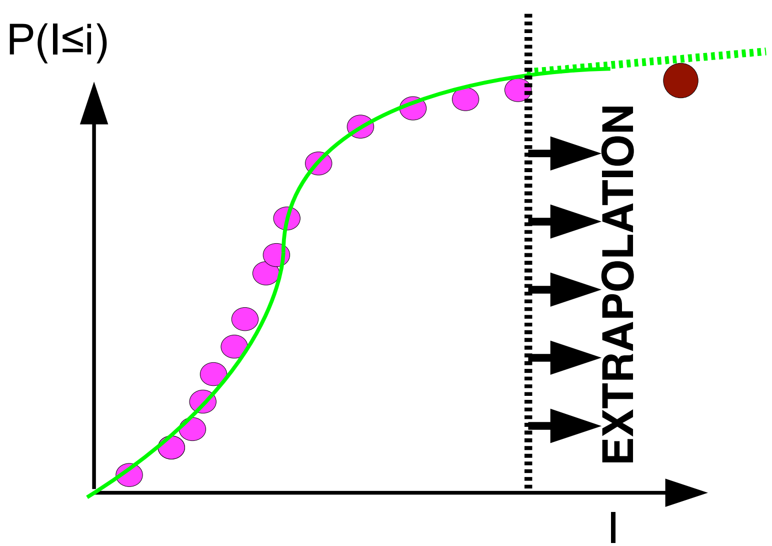


For a reliable magnitude estimation

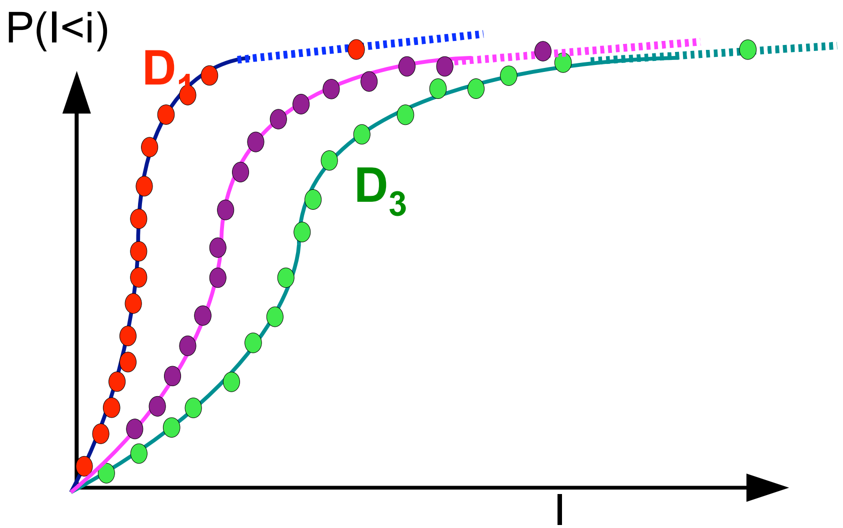
GAGED SCALES

UNGAGED SCALES

ACCURATE MODELING OF EXTREMES



SERIES RECONSTRUCTION THROUGH SCALE-INVARIANCE METHODS

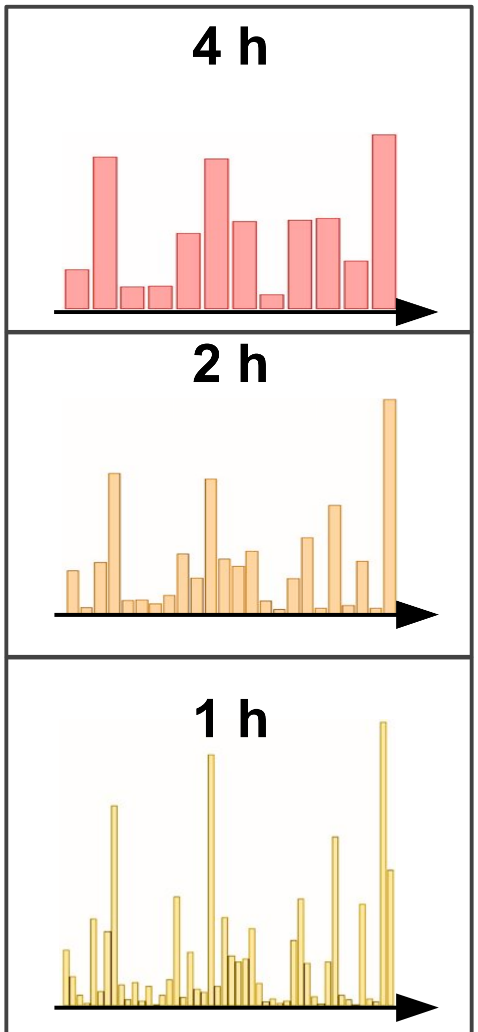


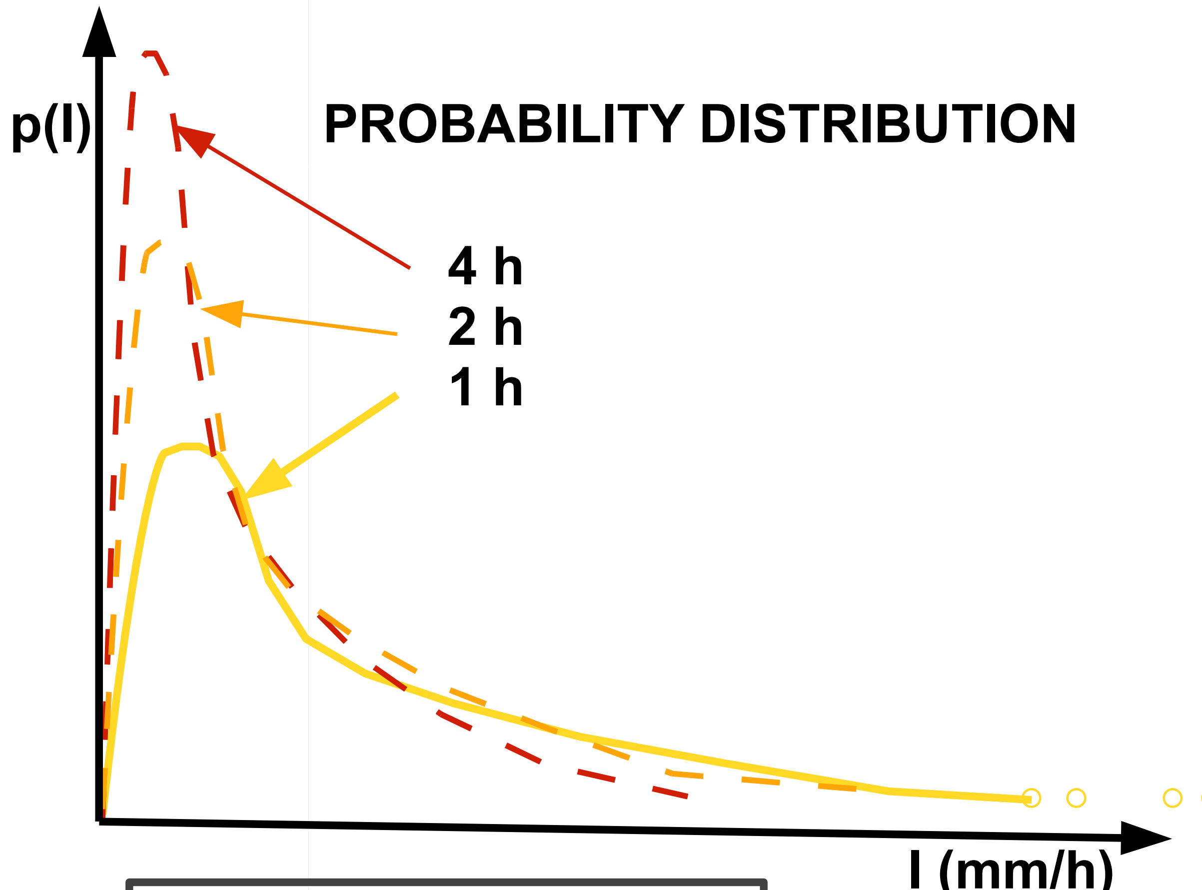
ROBUST MODELING OF EXTREMES AT VARIOUS SCALES

Dealing with ungauged scales: SCALING

SCALING OF A PROCESS

relation between probability distributions of a process at different scales

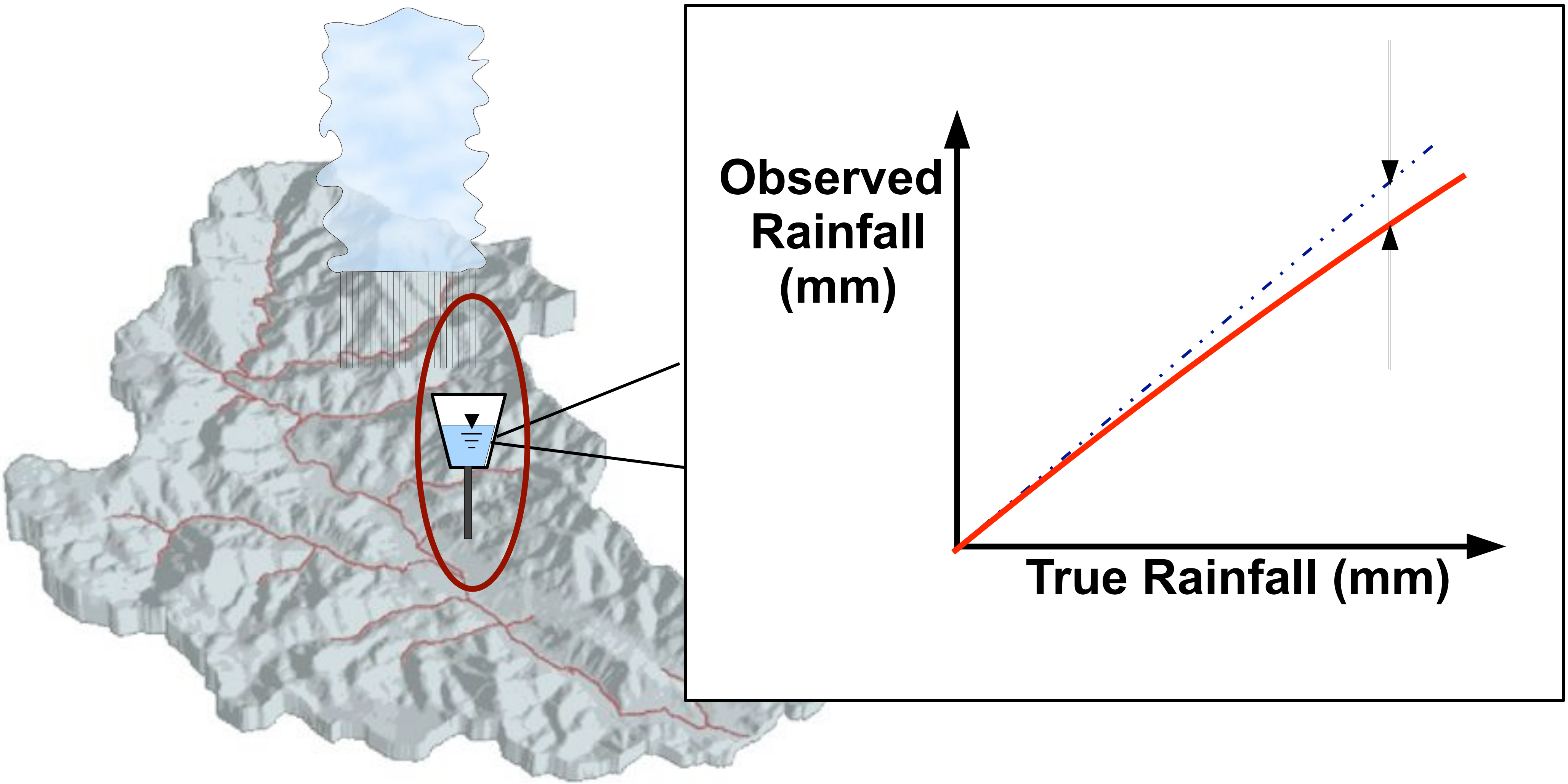




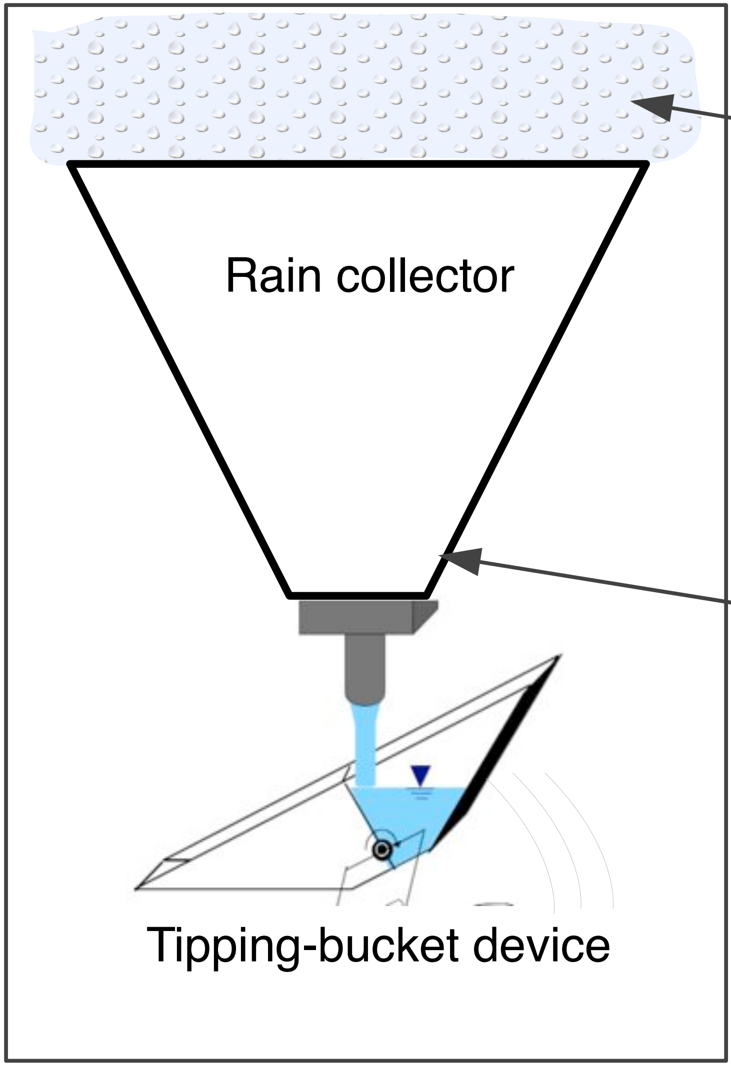
$$P(I_\lambda) \overset{d}{=} \lambda^c P(I_1)$$

Scale invariance of pdfs

Prerequisite: Evaluation of rain gauge uncertainties



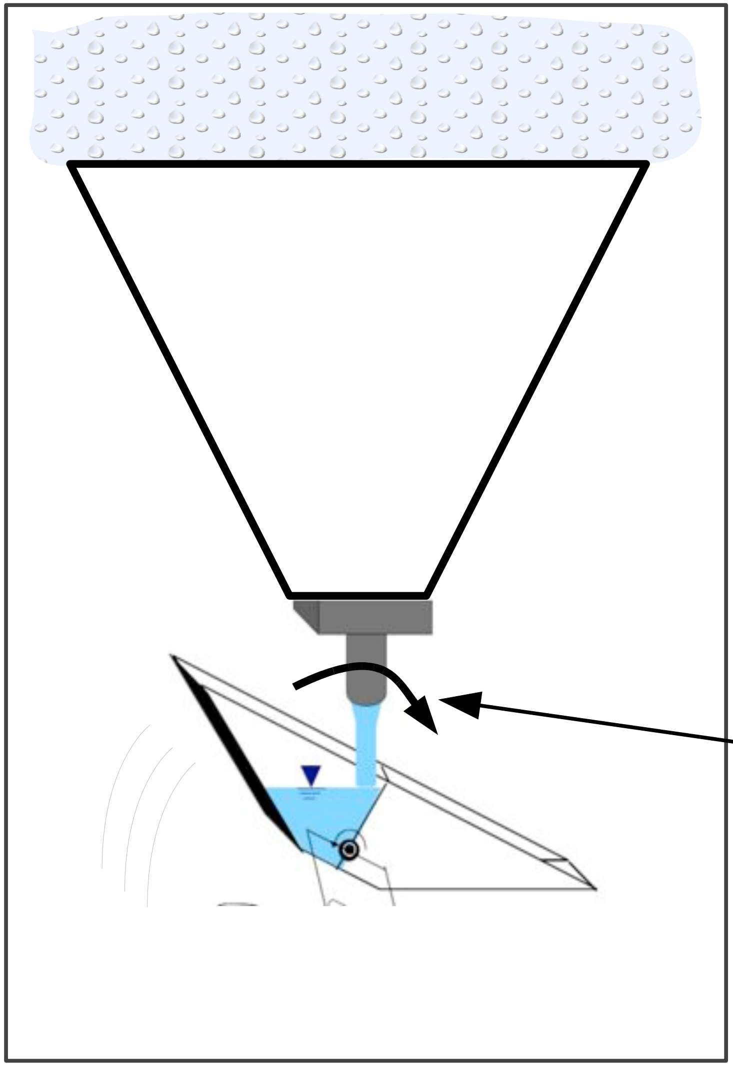
Evaluation of rain gauge uncertainties



Wind effect — Neglectable for high intensities

Bottom hole lamination underestimation in case of very high intensities

Evaluation of rain gauge uncertainties

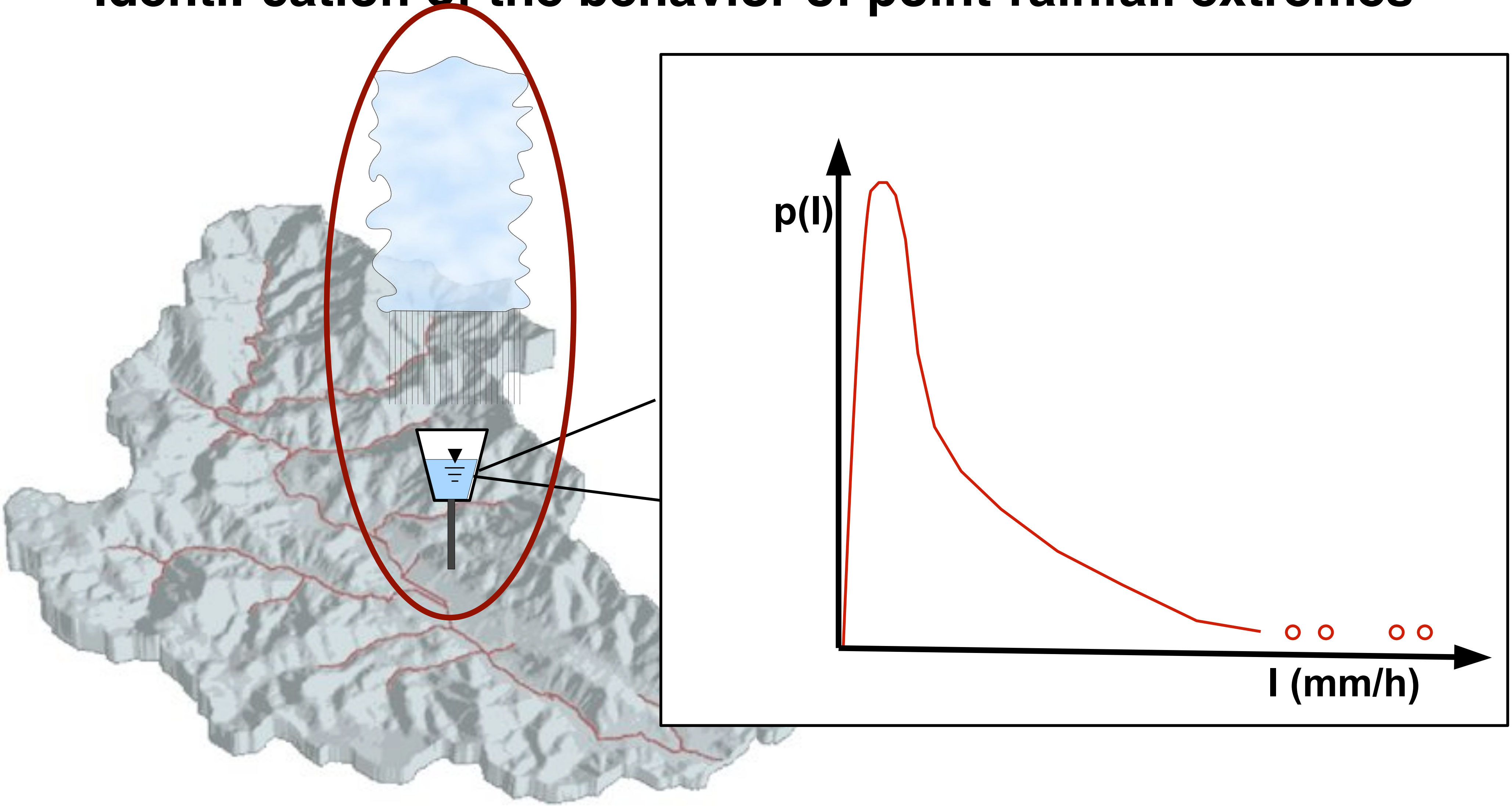


Reversal time:
~ 0.2 s in which no water is stored

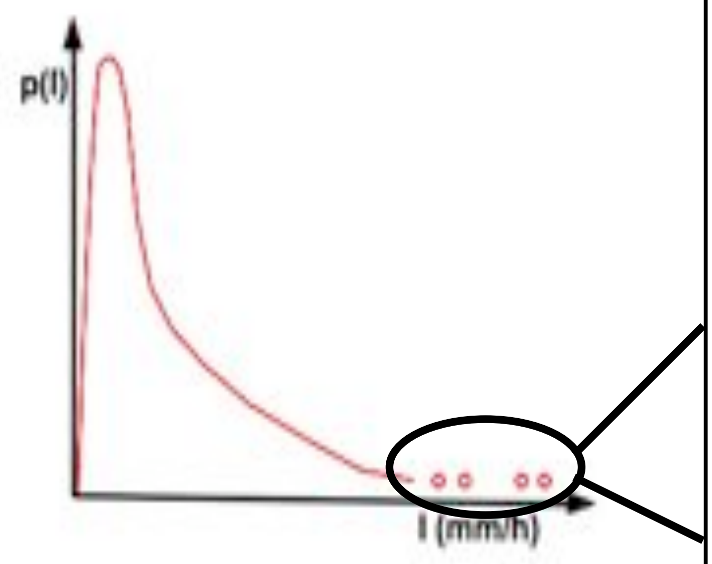
- **Experimental calibration**
- **Numerical Simulation**

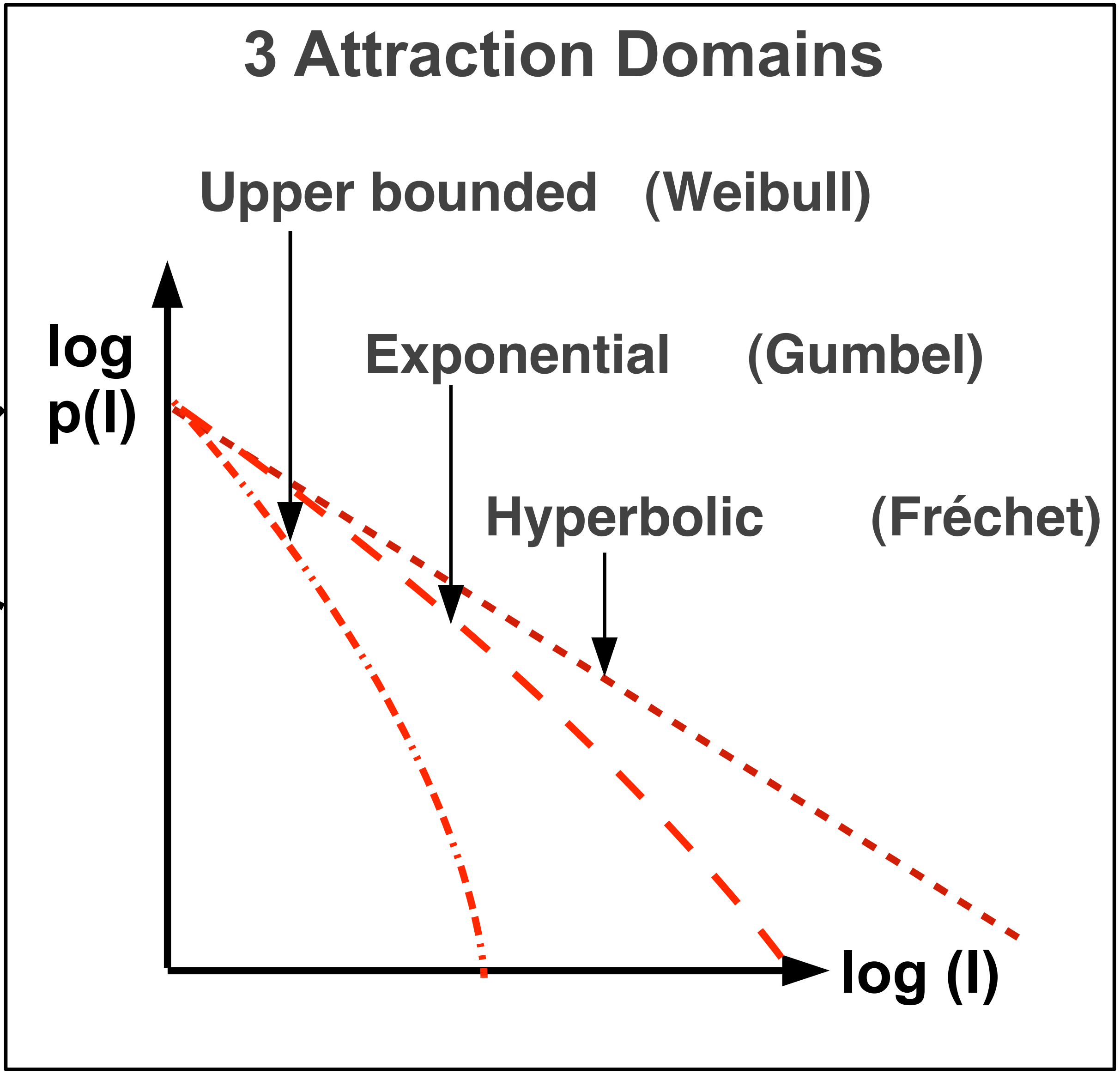
Heavy rainfall Underestimation: 5-10% 5-min rainfall
2-5 % hourly rainfall

Identif cation of the behavior of point-rainfall extremes



Open question: how are the distribution tails of rainfall?



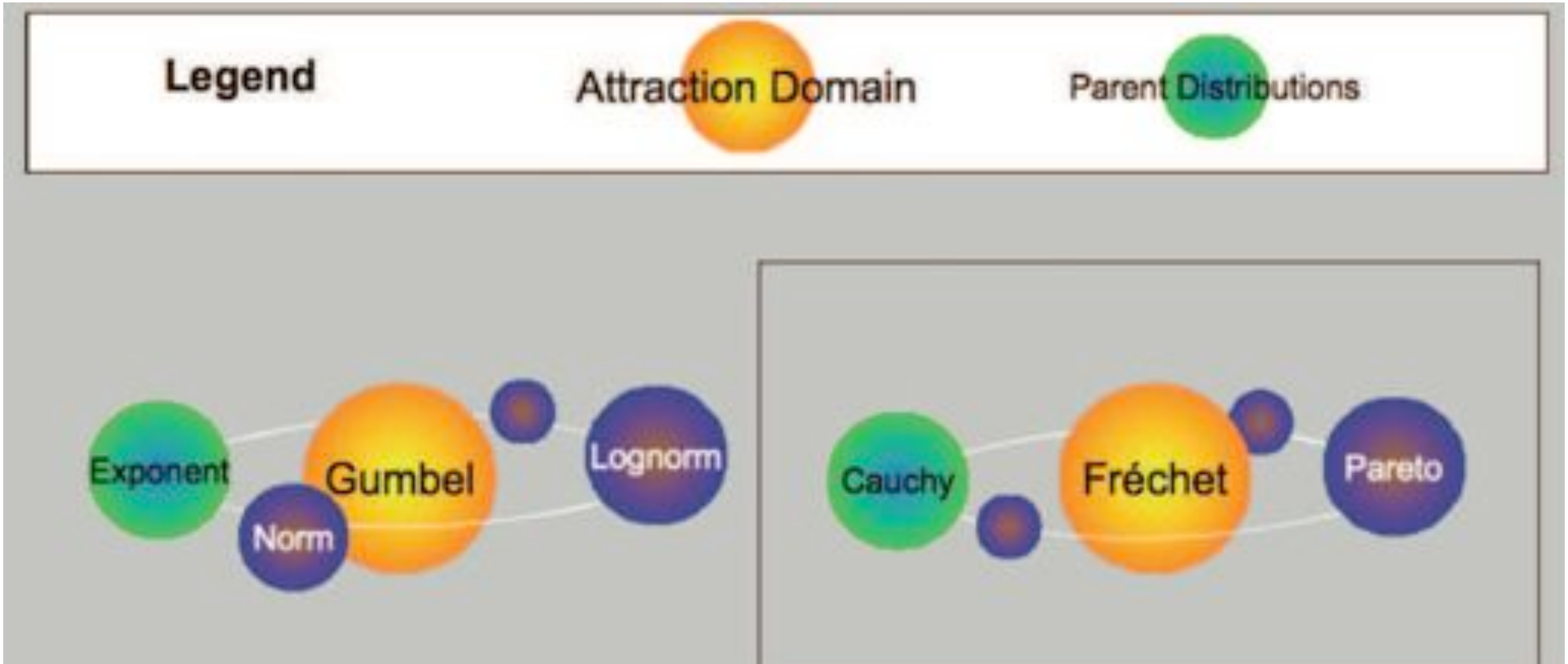


Tails behavior — Point rainfall model — Spatial rainfall model

One has 3 possibilities:

1) Extract Maxima
2) Peaks over Threshold
3) **Work on distributions**

(1 and 2: Reduce sample size)



taken from Mestre, 2008

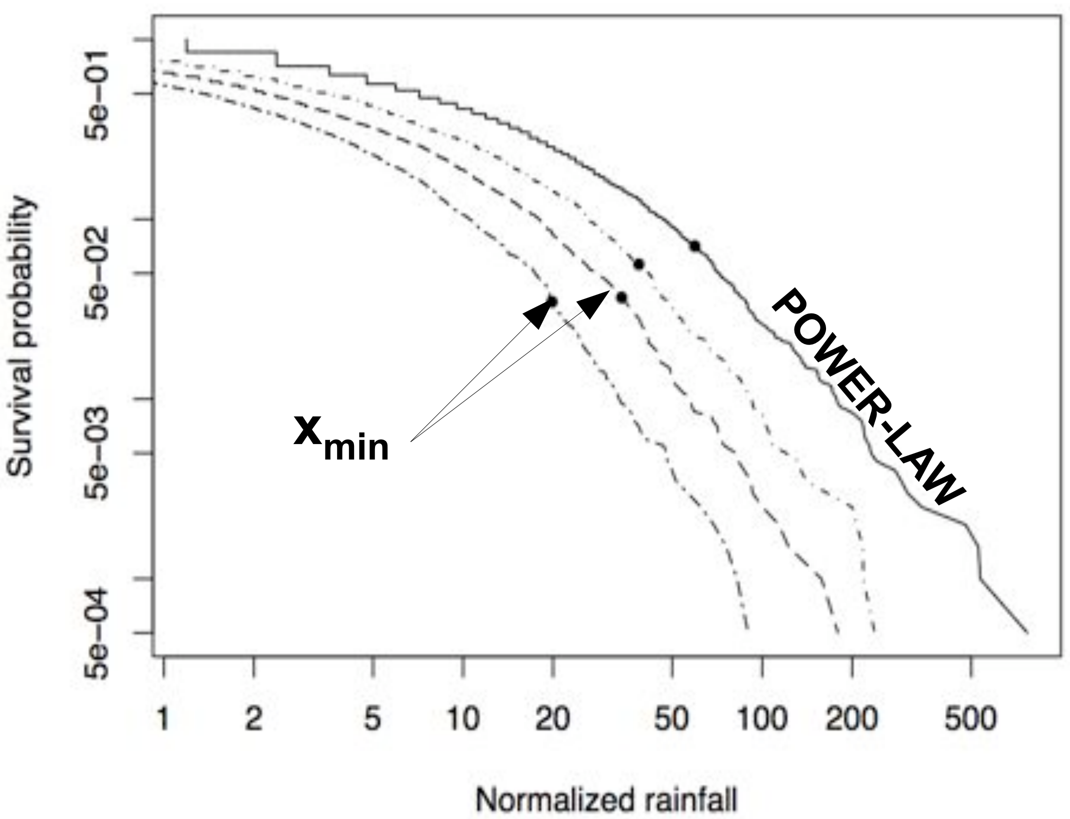
Tails behavior — Point rainfall model — Spatial rainfall model

At various duration --> tail behavior of point rainfall series

Rigorous method

- K-S test for lower bound x_{min}
- Estimator for power-law slope

Goldstein et al, 2004, Clauset et al., 2007



Straight line in log-log — Power-law — Fréchet distribution

Ceresetti et al, 2010, WRR

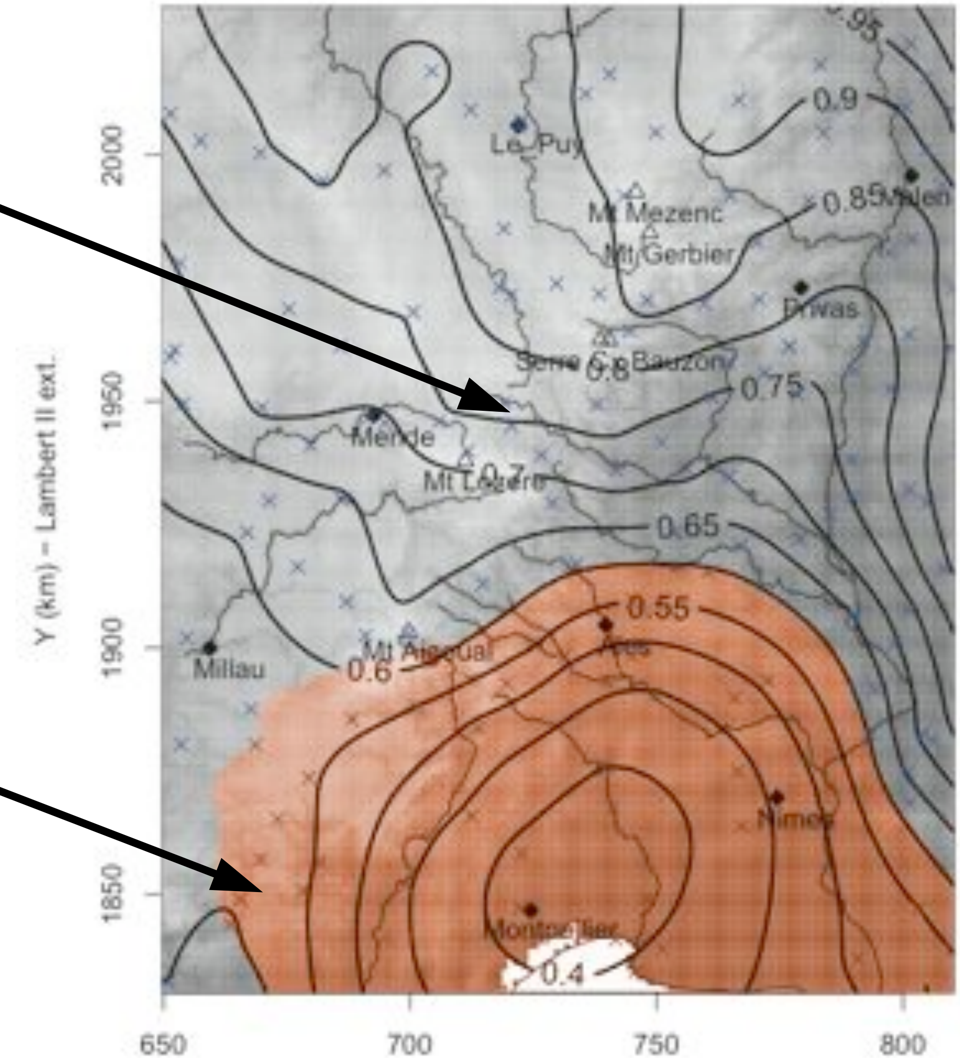
Tails behavior — Point rainfall model — Spatial rainfall model

Mountainous region

Gumbel

Flat lands

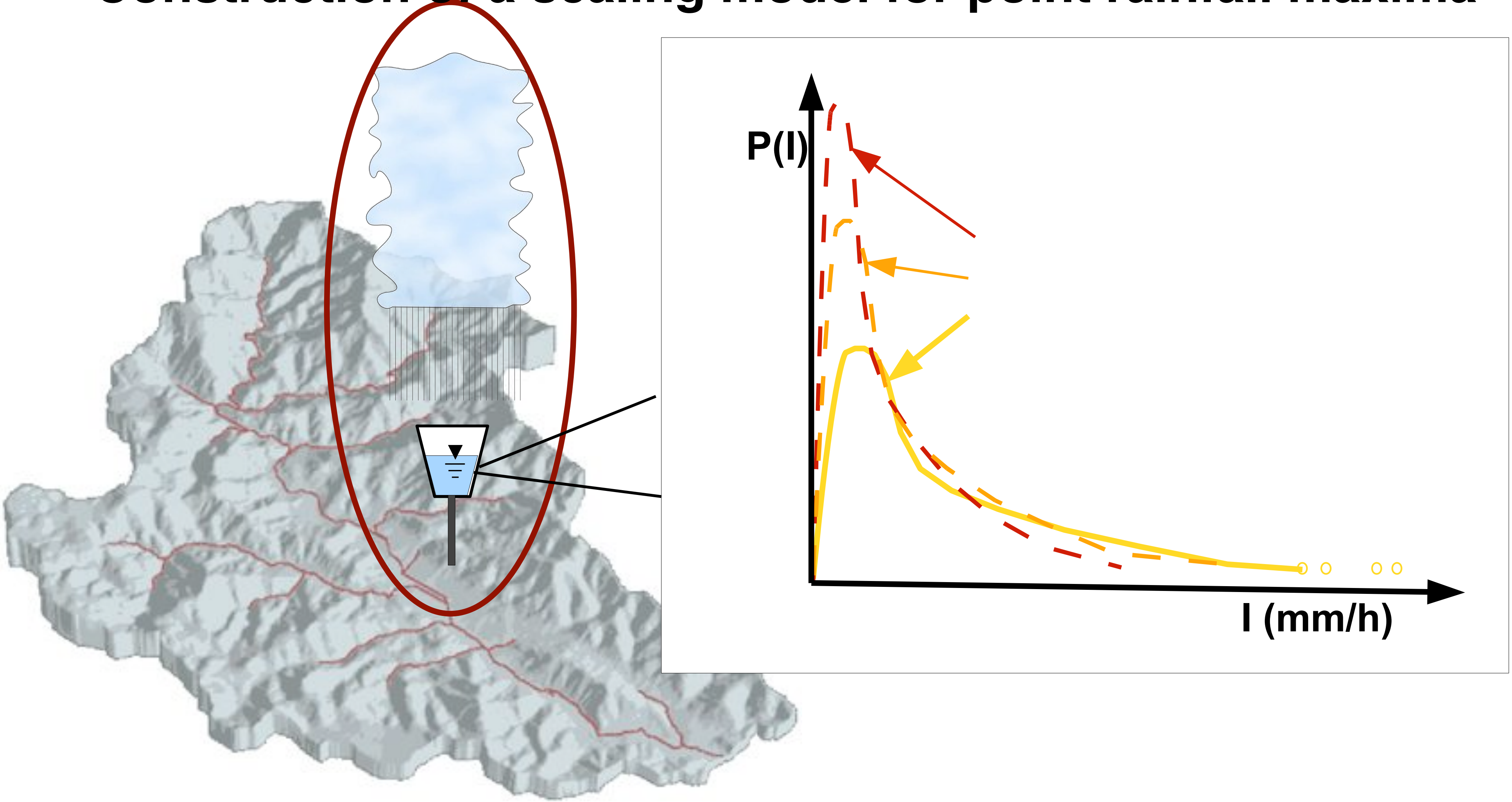
Fréchet



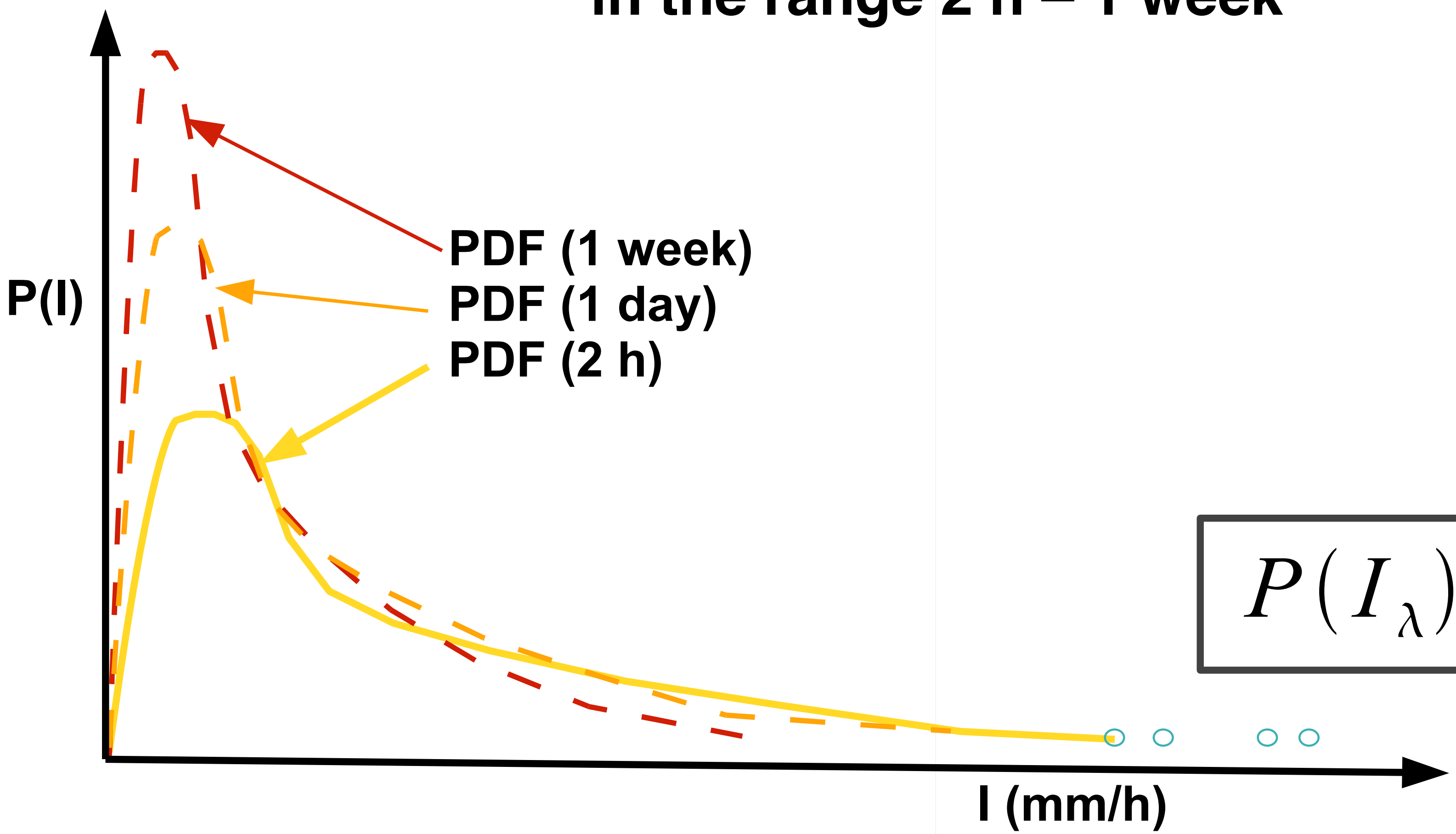
DUAL BEHAVIOR: Need of a GENERALIZED model for EXTREMES

Ceresetti et al, 2010, WRR

Construction of a scaling model for point rainfall maxima



Annual Maxima Distribution is scale-invariant in the range 2 h – 1 week



$$P(I_\lambda) \stackrel{d}{=} \lambda^c P(I_1)$$

Menabde et al, 1999
Veneziano et Furcolo, 2002

Tails behavior — **Point rainfall model** — Spatial rainfall model

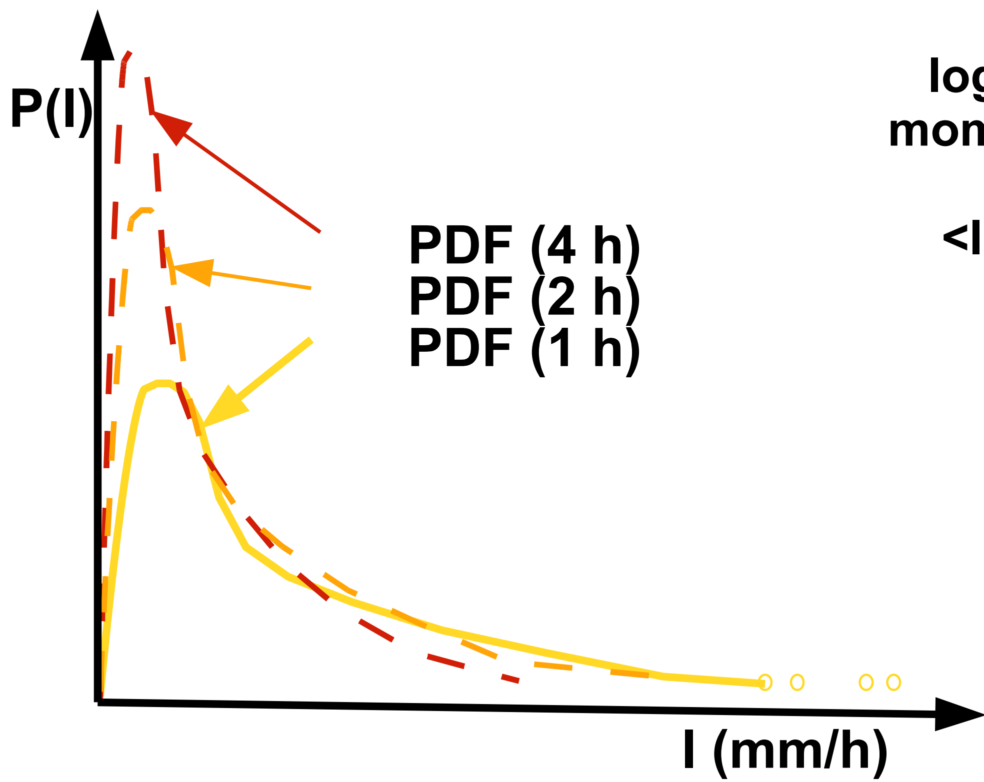
PROBABILITY DISTRIBUTION

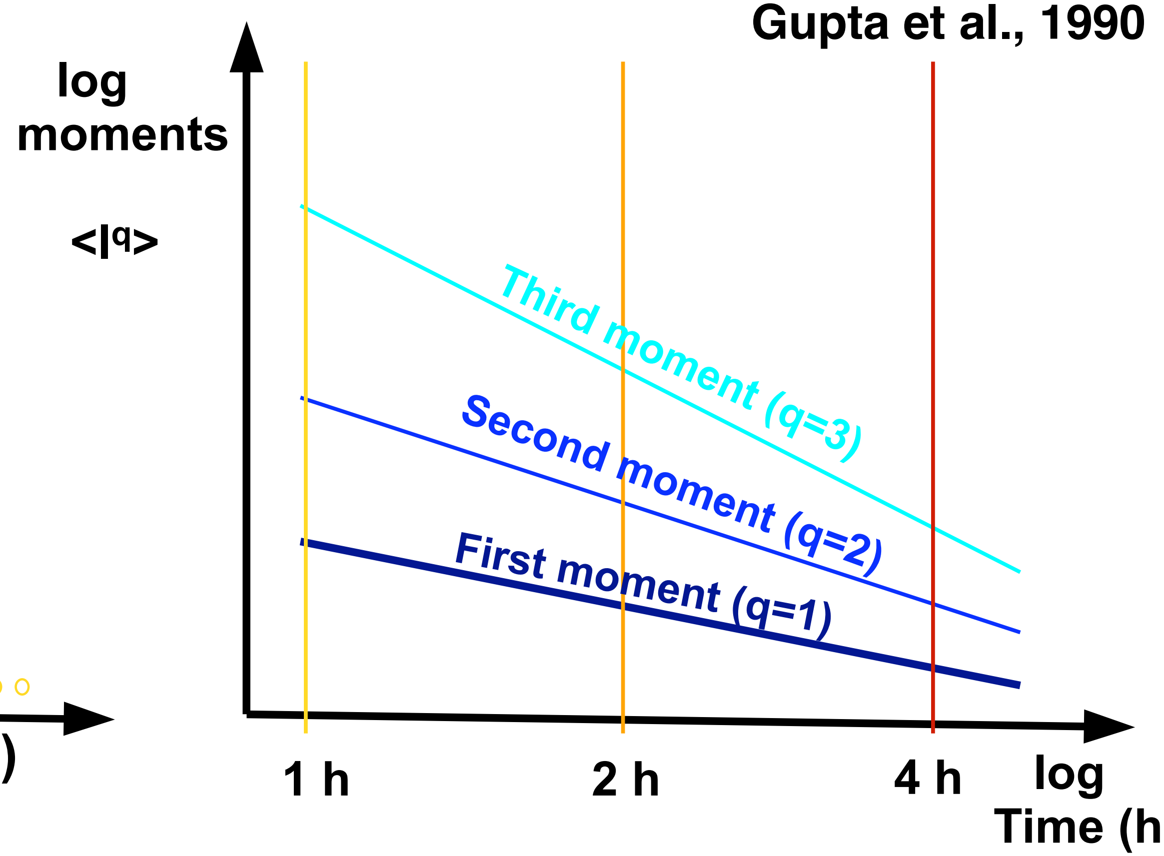
$$P(I_\lambda) \overset{d}{=} \lambda^c P(I_1)$$

STATISTICAL MOMENTS

$$< I_\lambda^q > = \lambda^\gamma < I_1^q >$$

Gupta et al., 1990





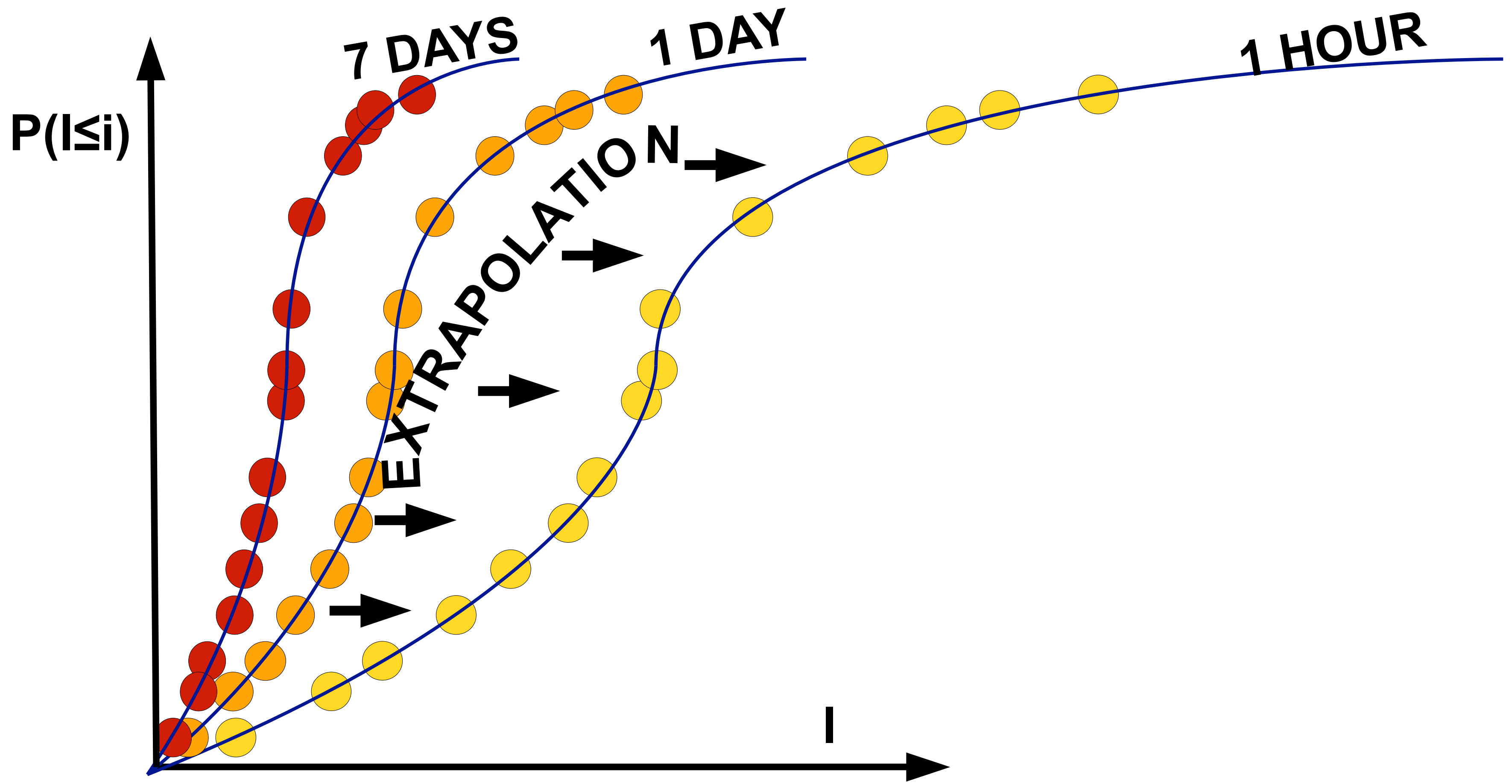
Scaling moment linearity in log-log vs scale

Tails behavior — **Point rainfall model** — Spatial rainfall model

Extreme distribution def ned through moments

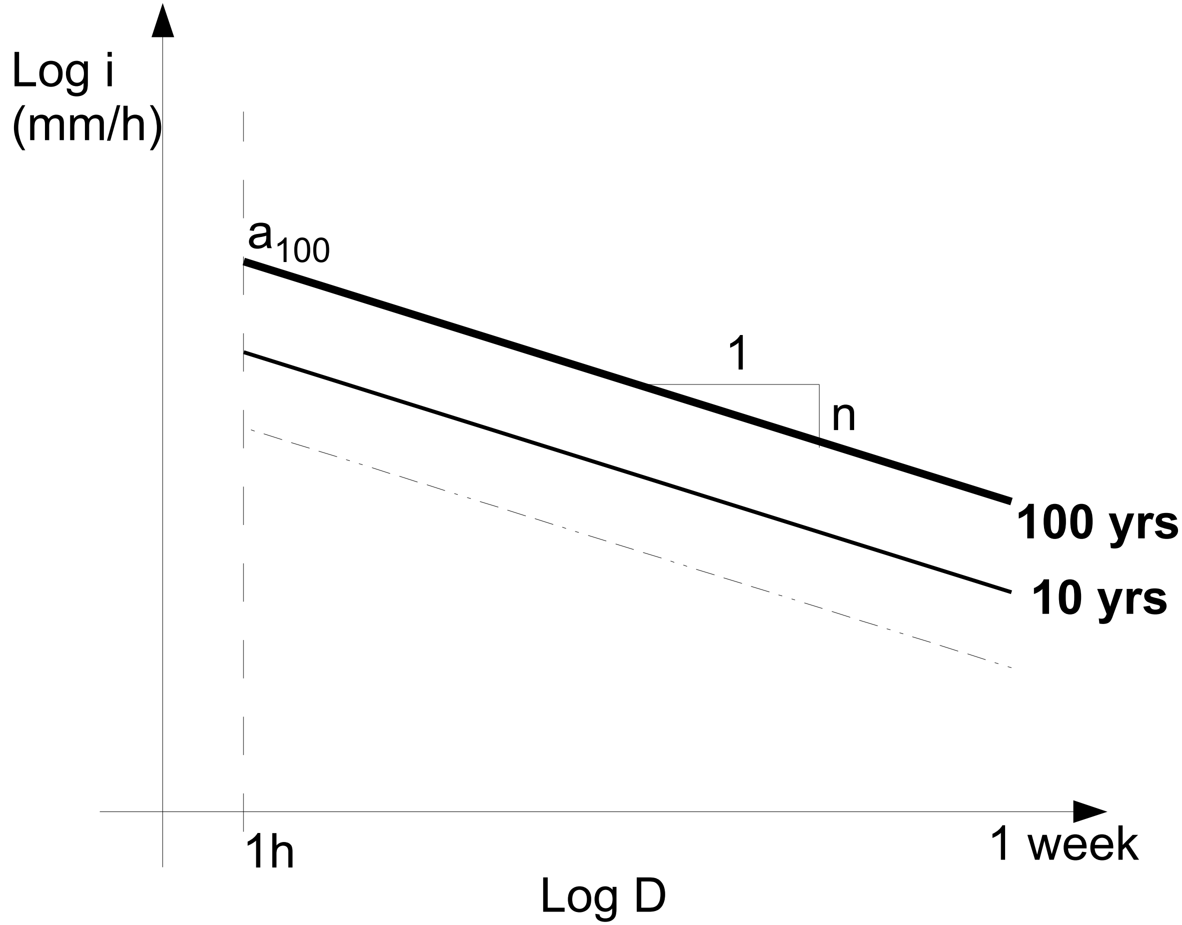
THUS

Moments scaling Extreme distribution scaling



IDF: Intensity – Duration – Frequency curves

IDF $i_{D,T_R} = a(T_R)\,D^{-n(T_R)}$

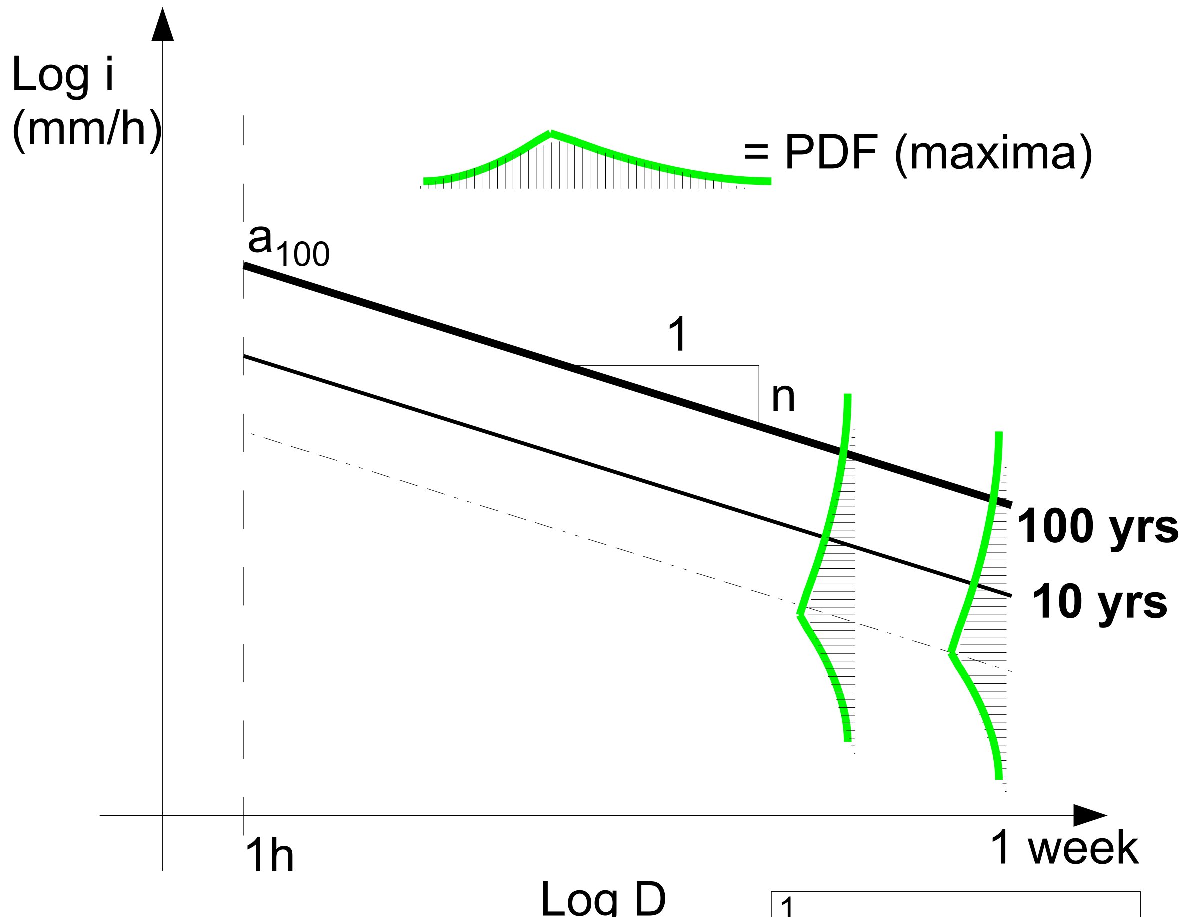


IDF: implicit scale-invariance relations for one T_R

IDF: Intensity – Duration – Frequency + GEV Extremes

IDF $i_{D,T_R} = a(T_R)\, D^{-n(T_R)}$

GEV $i(\mu,\sigma,T_R,\xi) = \mu + \sigma \dfrac{1-(\varepsilon)^{-\xi}}{-\xi}$



[1] $\varepsilon = -log(1 - \frac{1}{T_R})$

IDF + GEV Model for all scales and all T_R

Tails behavior — **Point rainfall model** — Spatial rainfall model

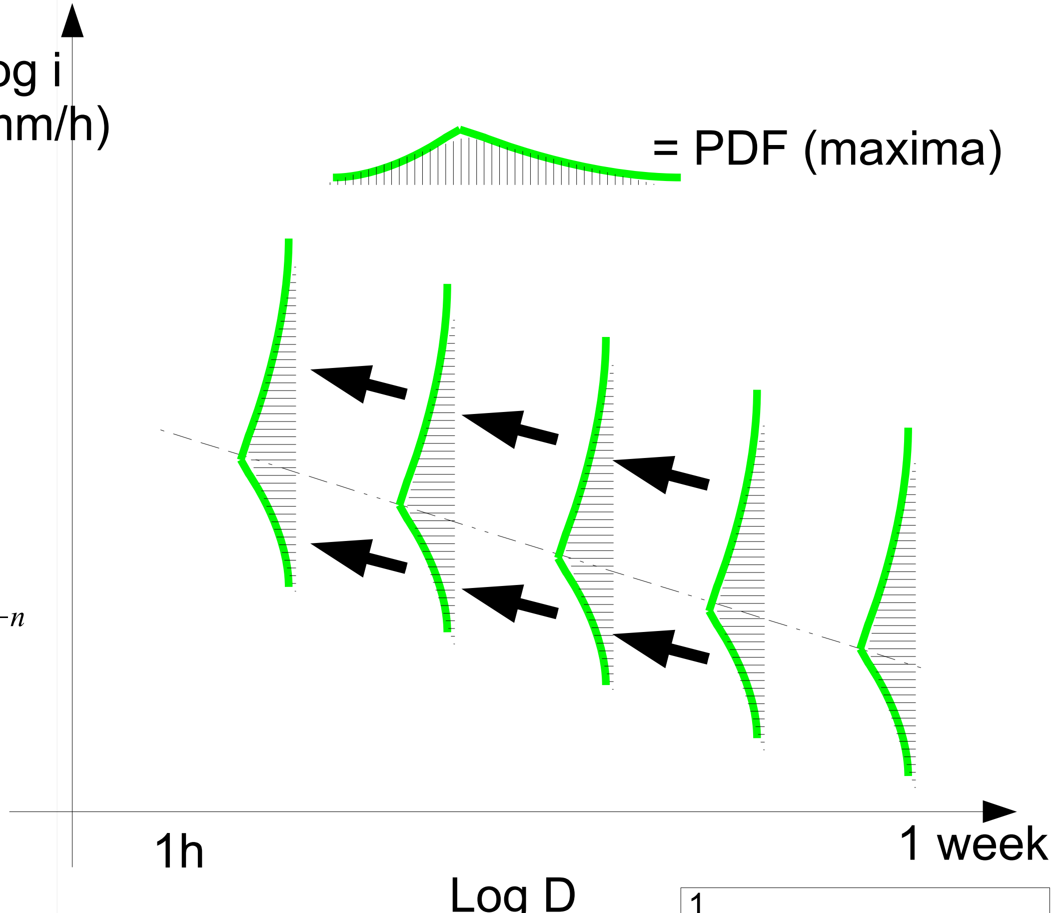
GEV simple-scaling IDF model

IDF $i_{D,T_R} = a(T_R)\, D^{-n(T_R)}$

GEV $i(\mu,\sigma,T_R,\xi) = \mu + \sigma \dfrac{1-(\varepsilon)^{-\xi}}{-\xi}$

Moments scaling

$$\begin{cases} \mu_D = \left[m_{Dref}(x) + \dfrac{\sigma_{Dref}}{\xi} - \dfrac{\sigma_{Dref}}{\xi}\Gamma(1-\xi)\right] \left(\dfrac{D}{D_{ref}}\right)^{-n} \\ \sigma_D^2 = \dfrac{s_{Dref}^2(x)\,\xi^2}{\Gamma(1-2\xi) - \Gamma(1-\xi)^2} \left(\dfrac{D}{D_{ref}}\right)^{-n} \\ \xi_D = \xi_{Dref} \end{cases}$$



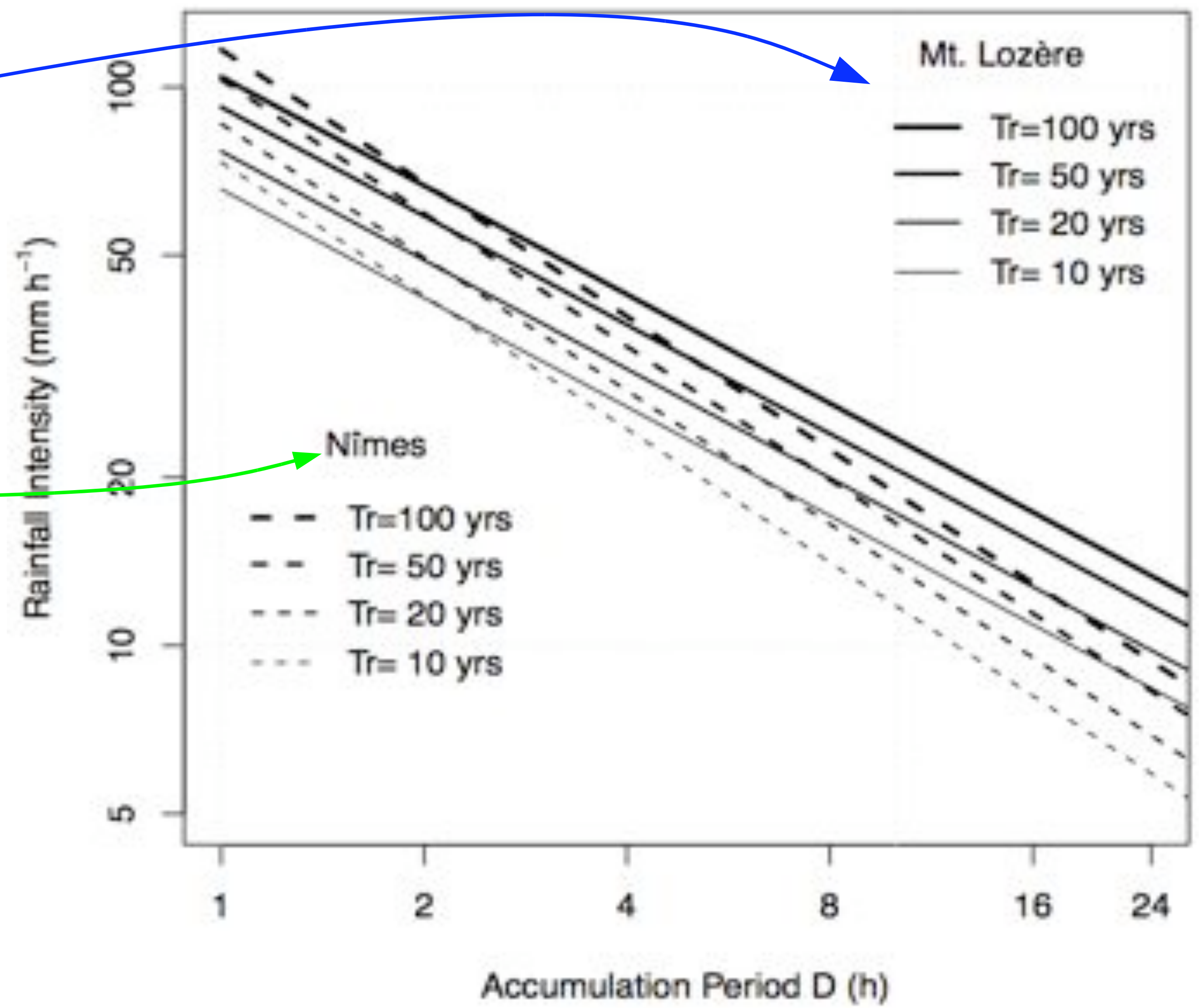
[1] $\varepsilon = -log(1 - \dfrac{1}{T_R})$

Use of daily series to estimate extreme rainfall down to 1 hour

Tails behavior — **Point rainfall model** — Spatial rainfall model

Mountainous region

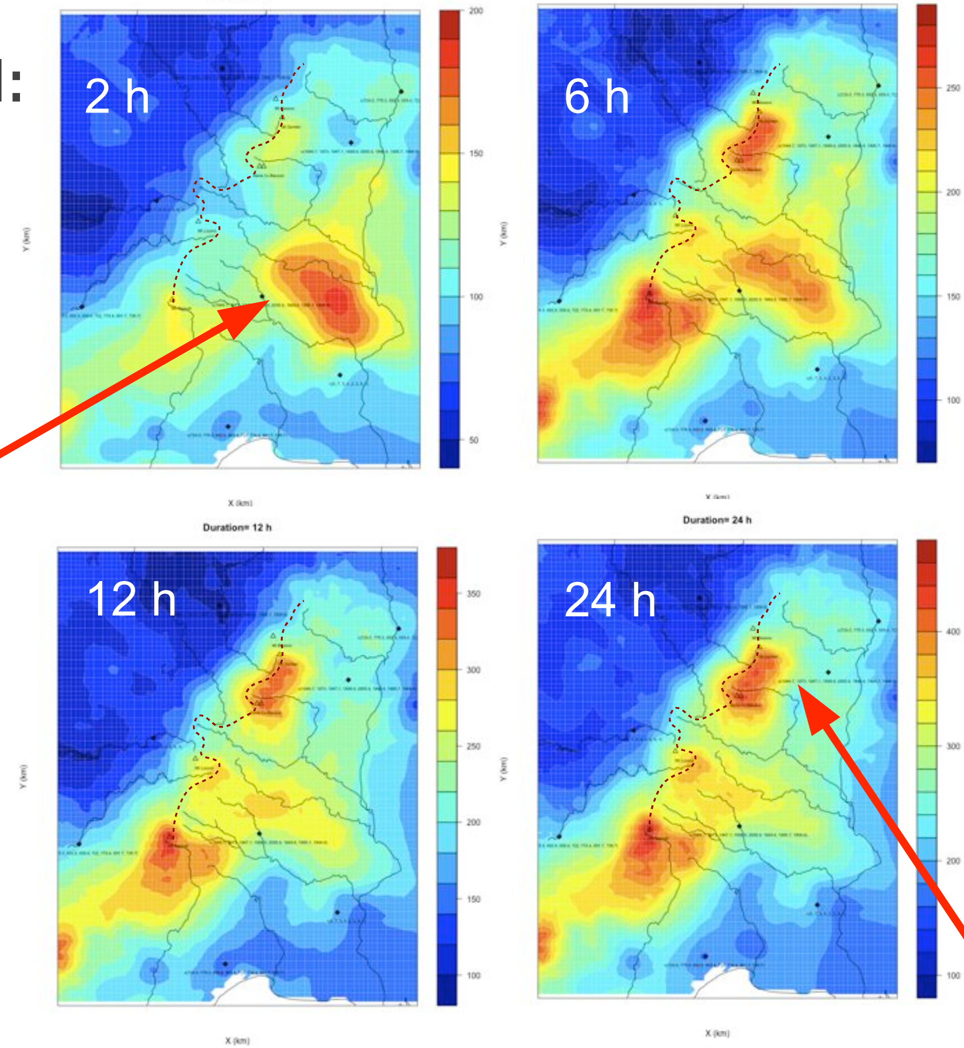
Flat lands



Need of a regional model for IDF relations

Tails behavior — **Point rainfall model** — Spatial rainfall model

GEV simple-scaling IDF model:
Rainfall Tr=100 years



Maximum: Flat land

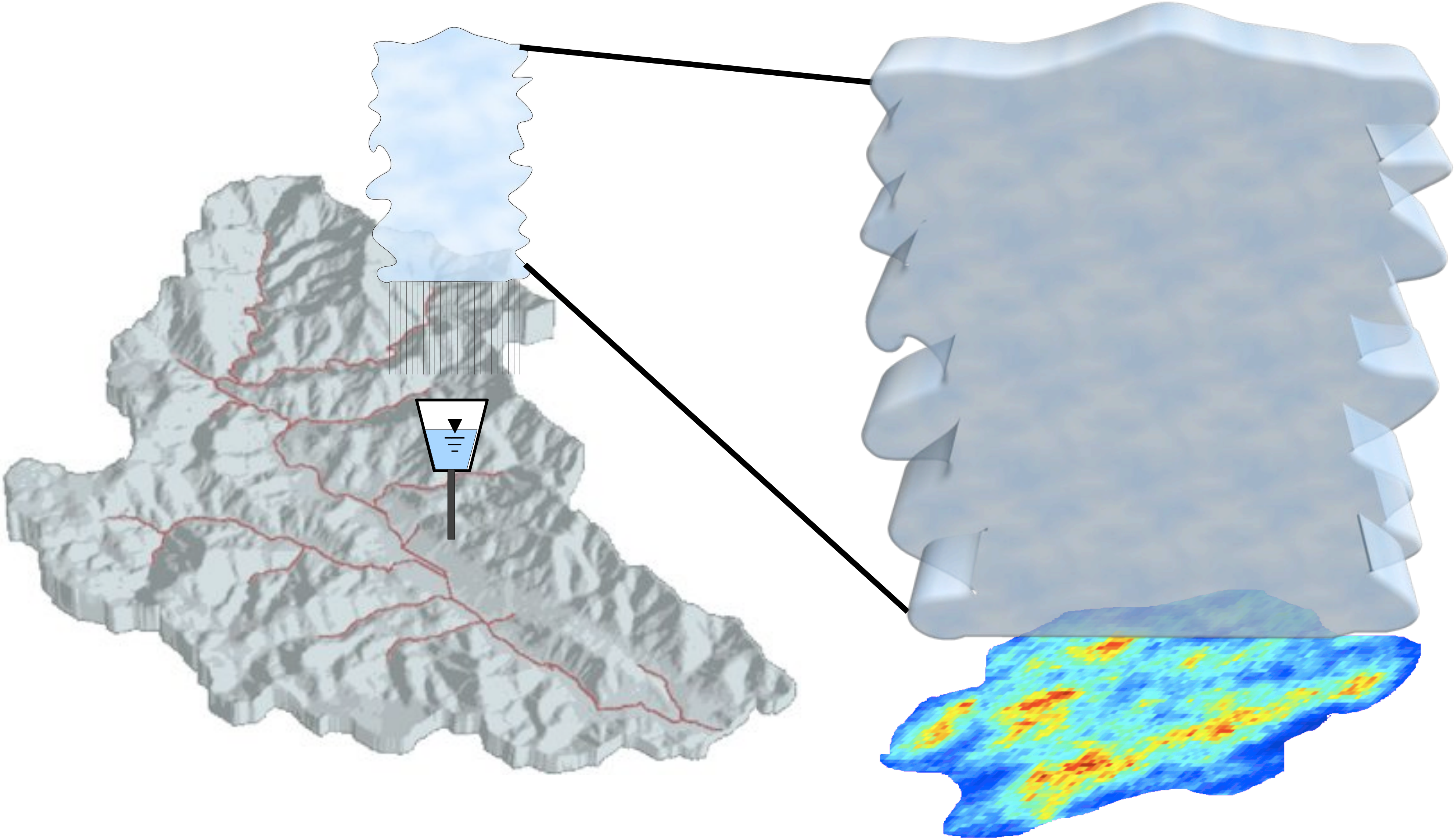
ROBUST:
Obtained using daily data
(> 50 years of data at 225 gages)

Daily data hides information on infra-daily scale

Maximum: mountain ridge

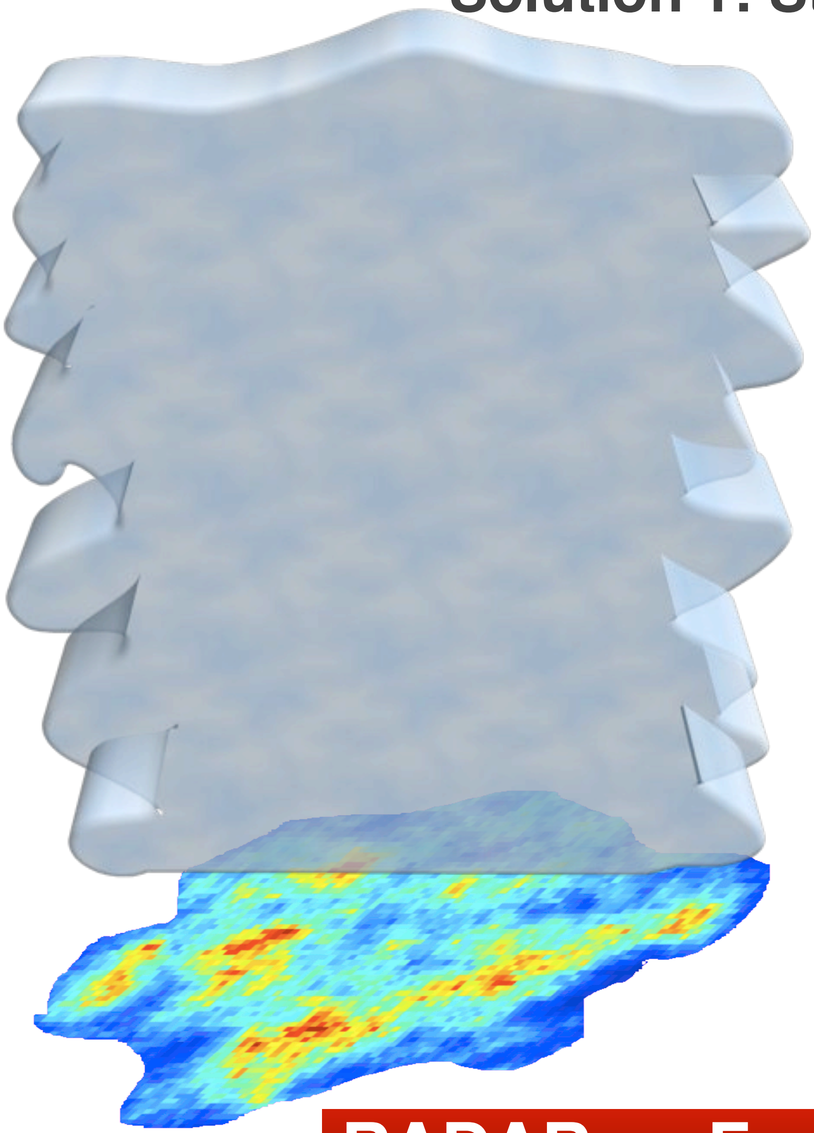
Ceresetti et al, 2011, Submitted to WRR

Tails behavior — Point rainfall model — **Spatial rainfall model**

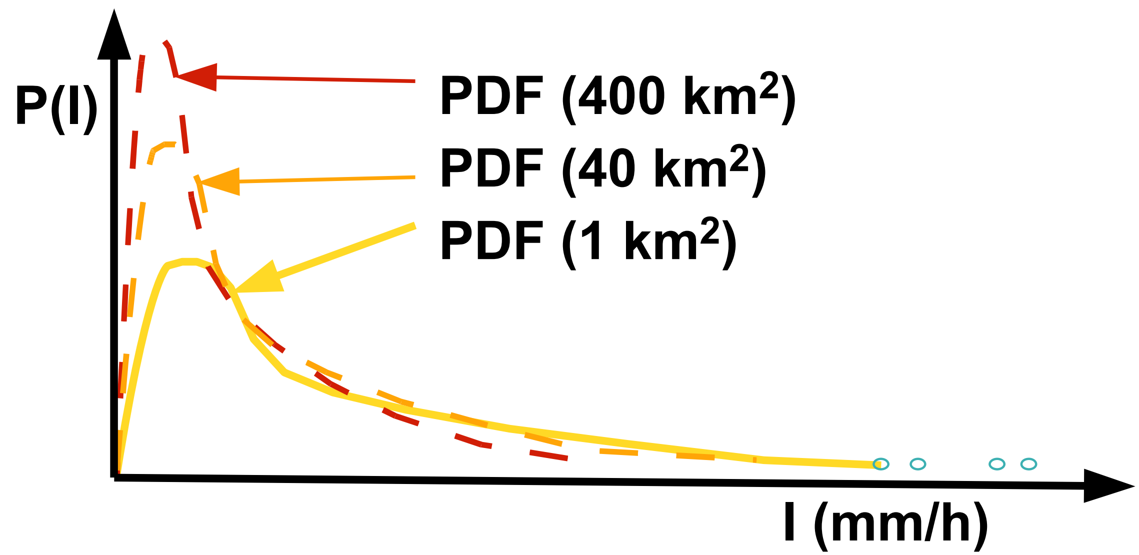


Need to model extremes in space

Solution 1: Statistics on radar data



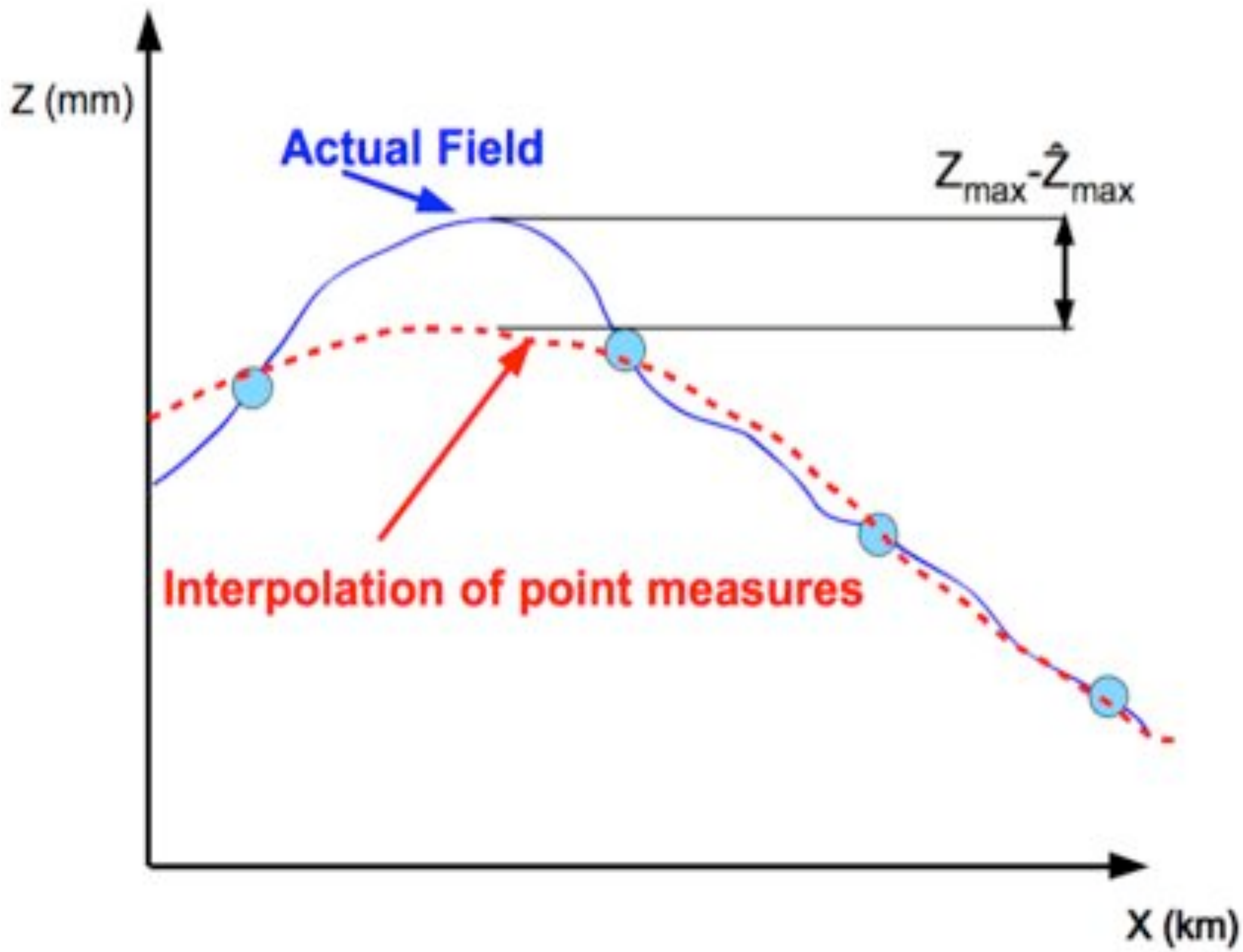
RADAR IMAGERY
spatial scale-invariance
detected in the range 1-400 km^2



$$P(I_\lambda) \overset{d}{=} \lambda^c P(I_1)$$

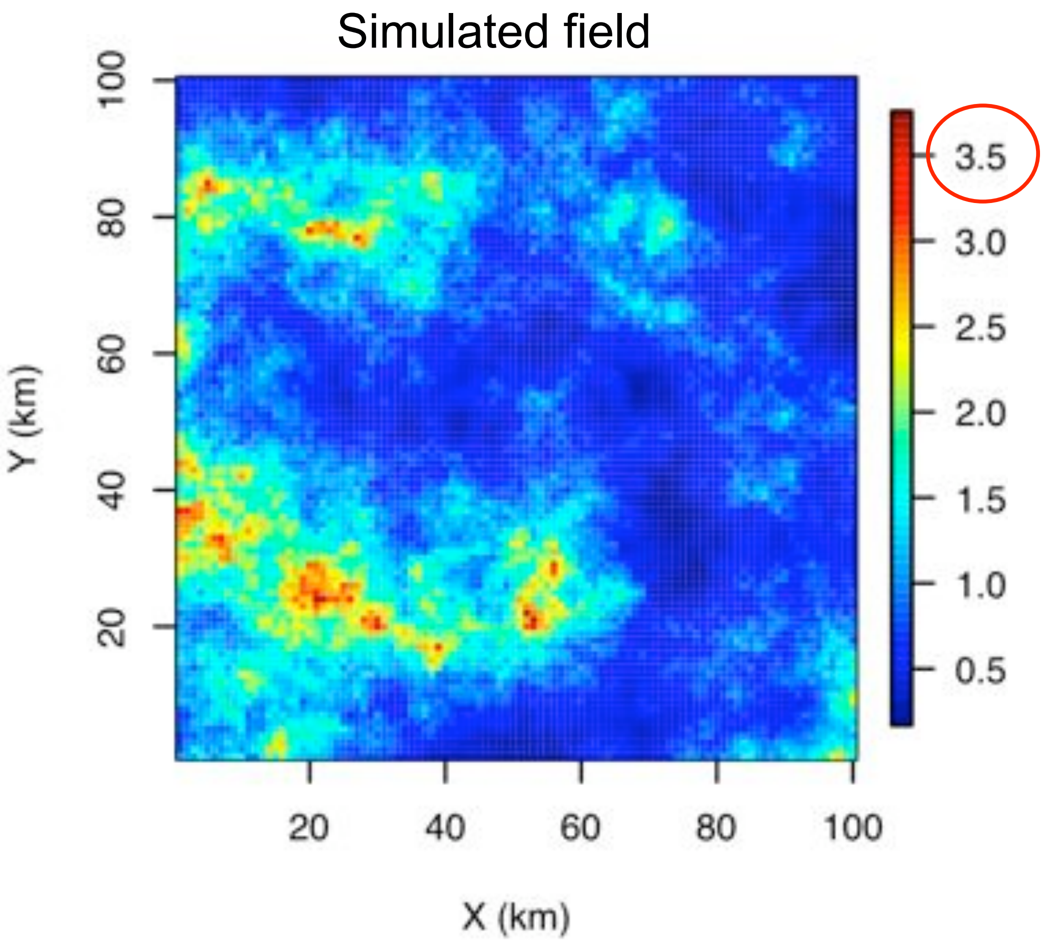
RADAR Few events, not enough data

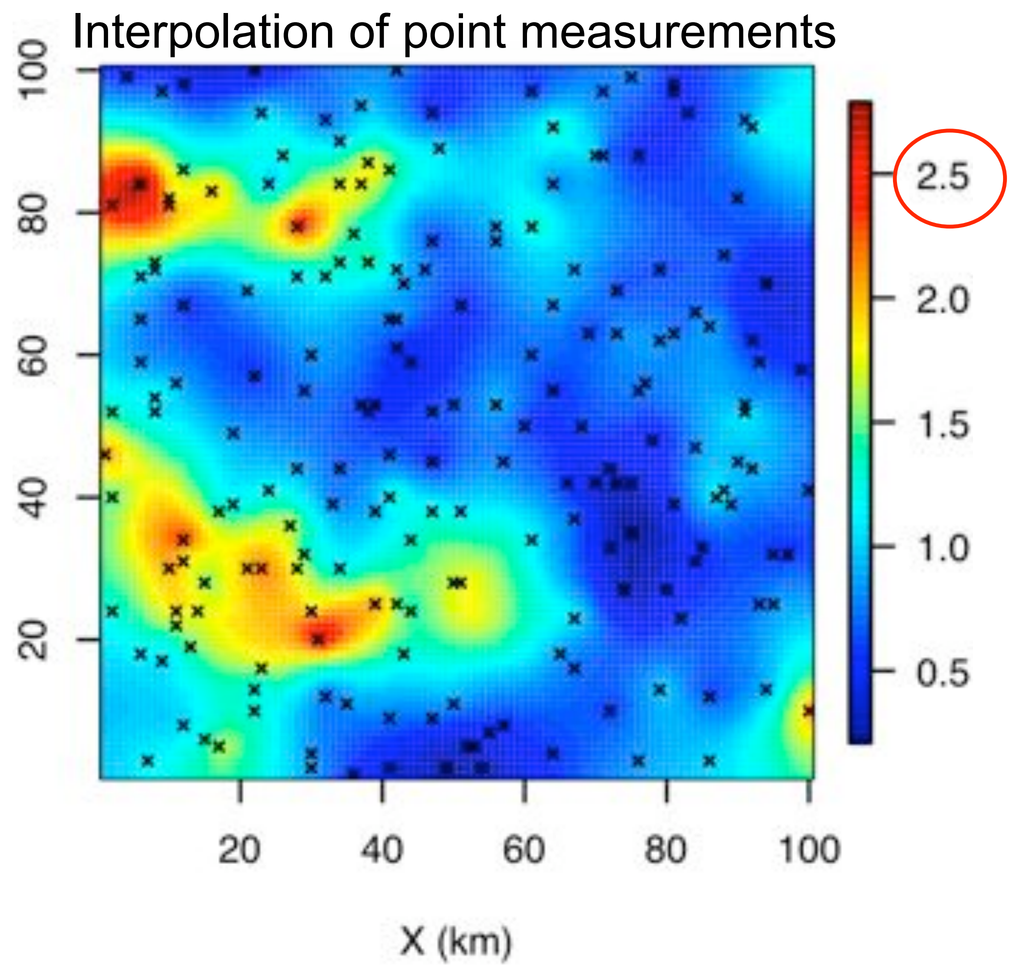
Solution 2: Interpolation of point data



Signif cant underestimation of maxima in coarse networks

Solution 2: Interpolation of point data



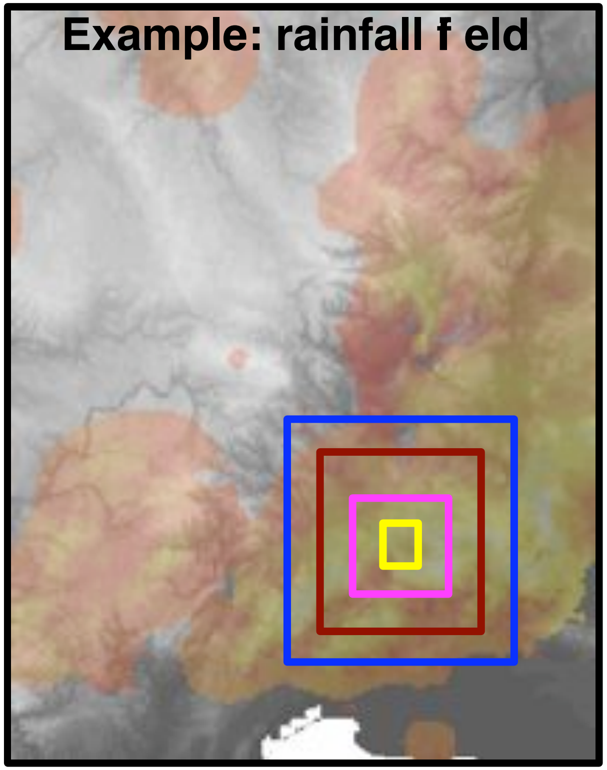


Spatial undersampling → Underestimation maxima 20-50%

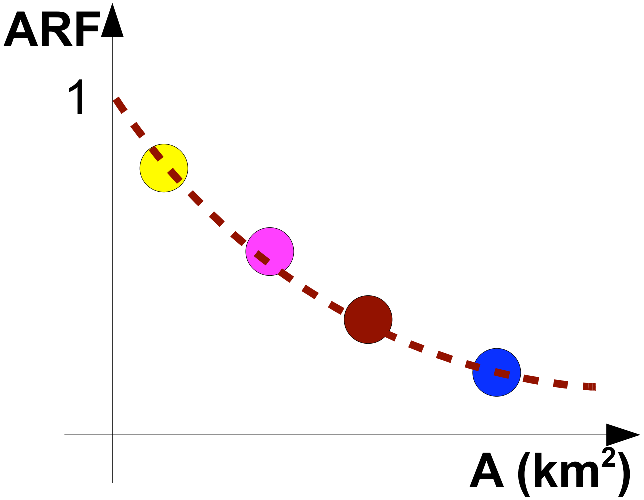
Solution 3: Semi-empirical model based on gages

ARF: Areal Reduction Factor

$$I_{Tr}(A,T) = I_{Tr}(0,T) \cdot ARF_{Tr}(A,T)$$



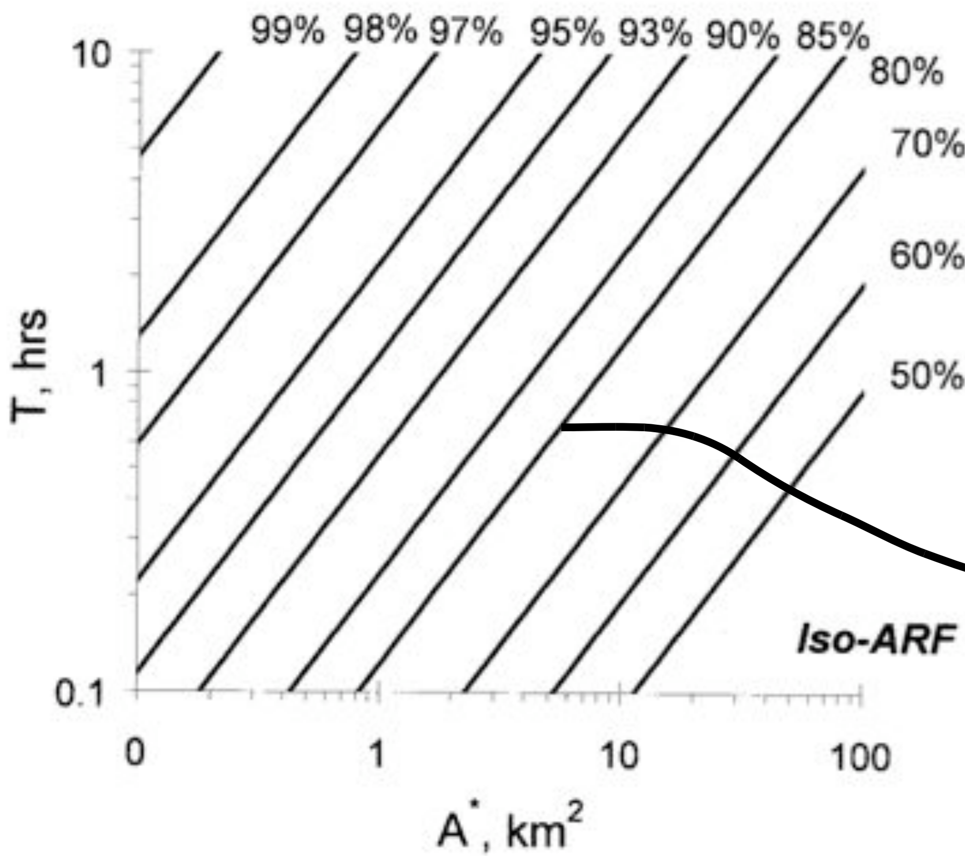
$$ARF = \frac{I_A}{I_0} \leq 1$$



ARF computed from historical series 1993-2008

Solution 3: Semi-empirical model based on gages

Dynamic scaling model for ARF



Dynamic scaling ratio

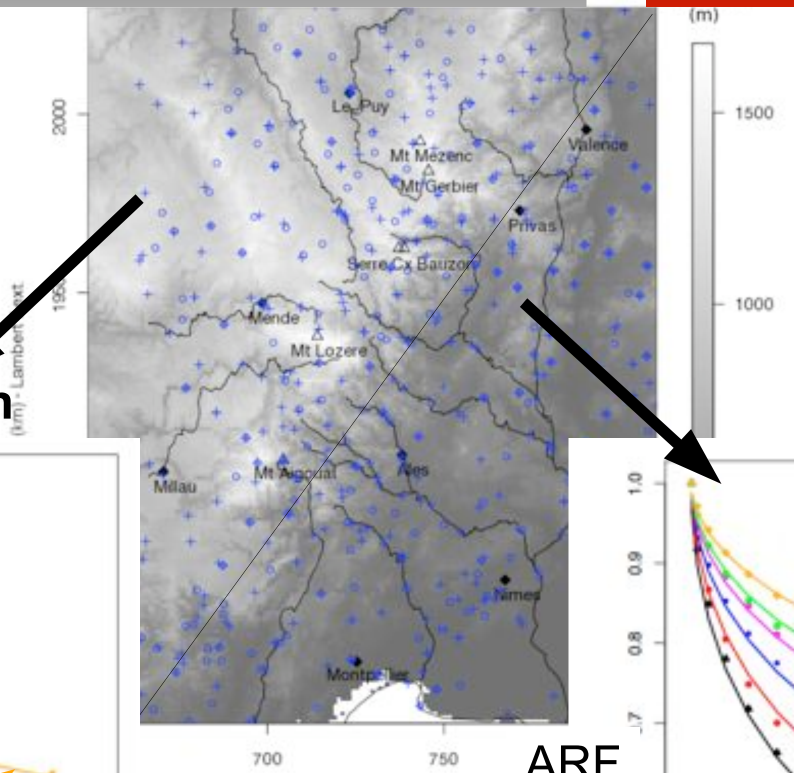
$$\frac{T}{A^z} = const$$

De Michele et al., 2001

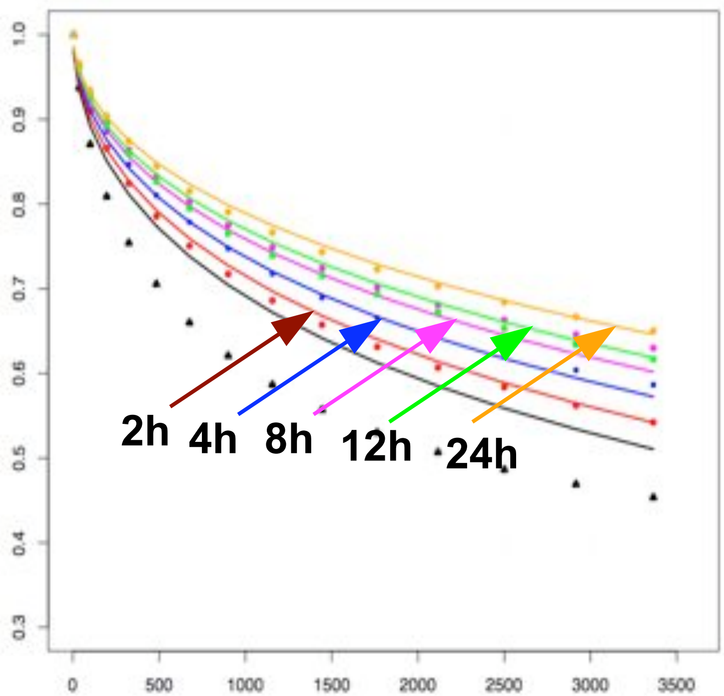
We can build AREAL REDUCTION FACTOR

Tails behavior — Point rainfall model — **Spatial rainfall model**

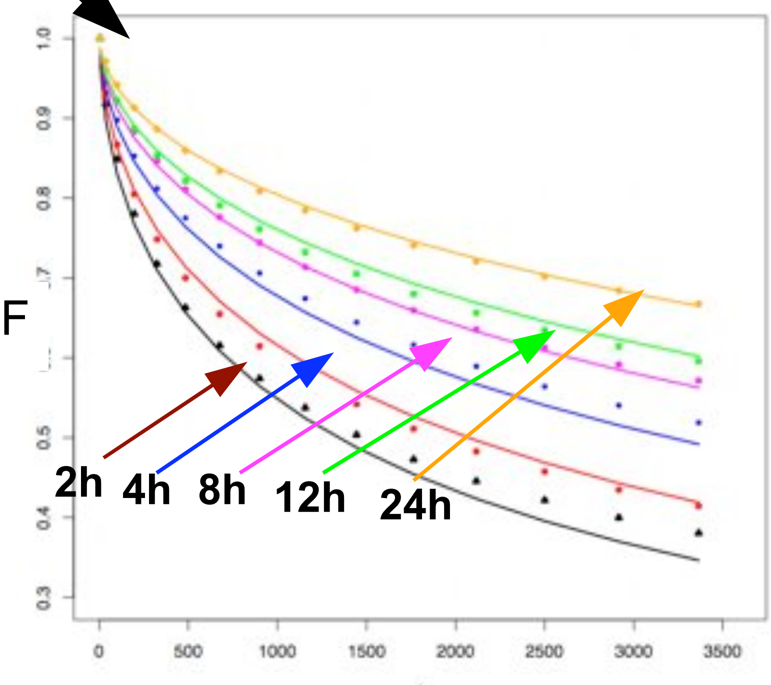
ARF in Cévennes-Vivarais region



Mountainous region

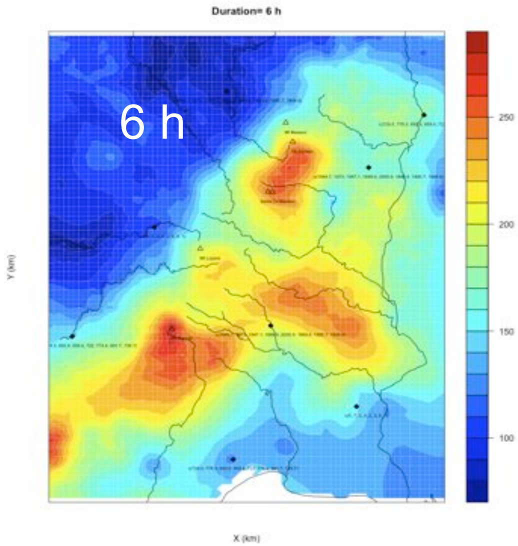


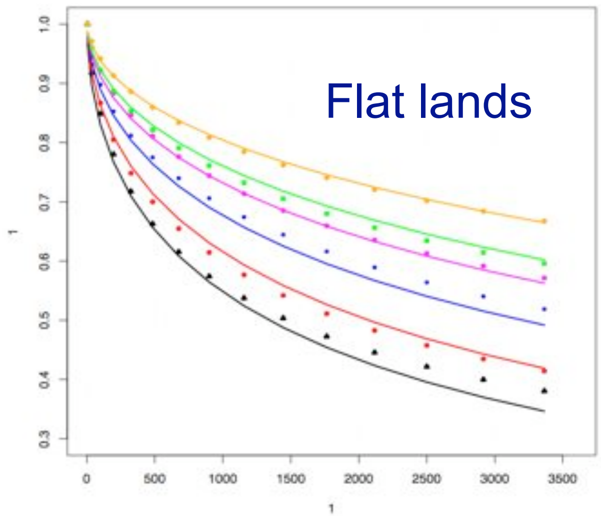
Flat Lands



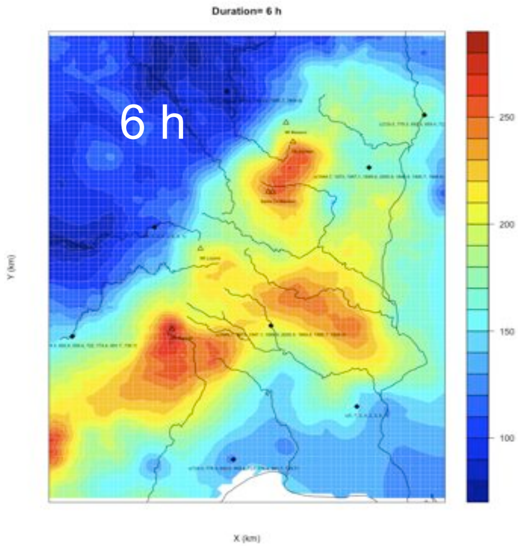
Duration has lower inf uence in mountain

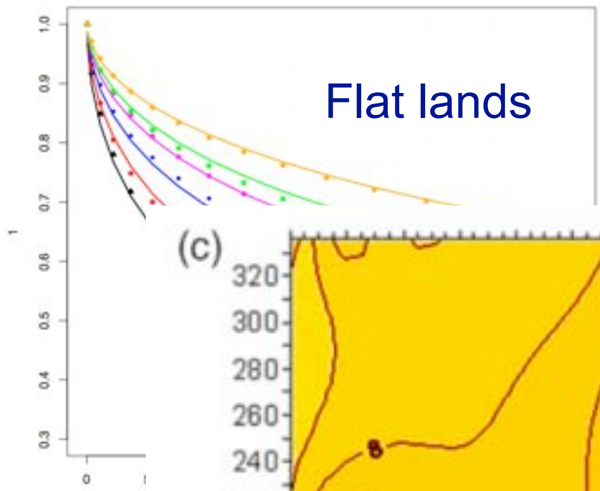
Point rainfall model + Spatial rainfall model

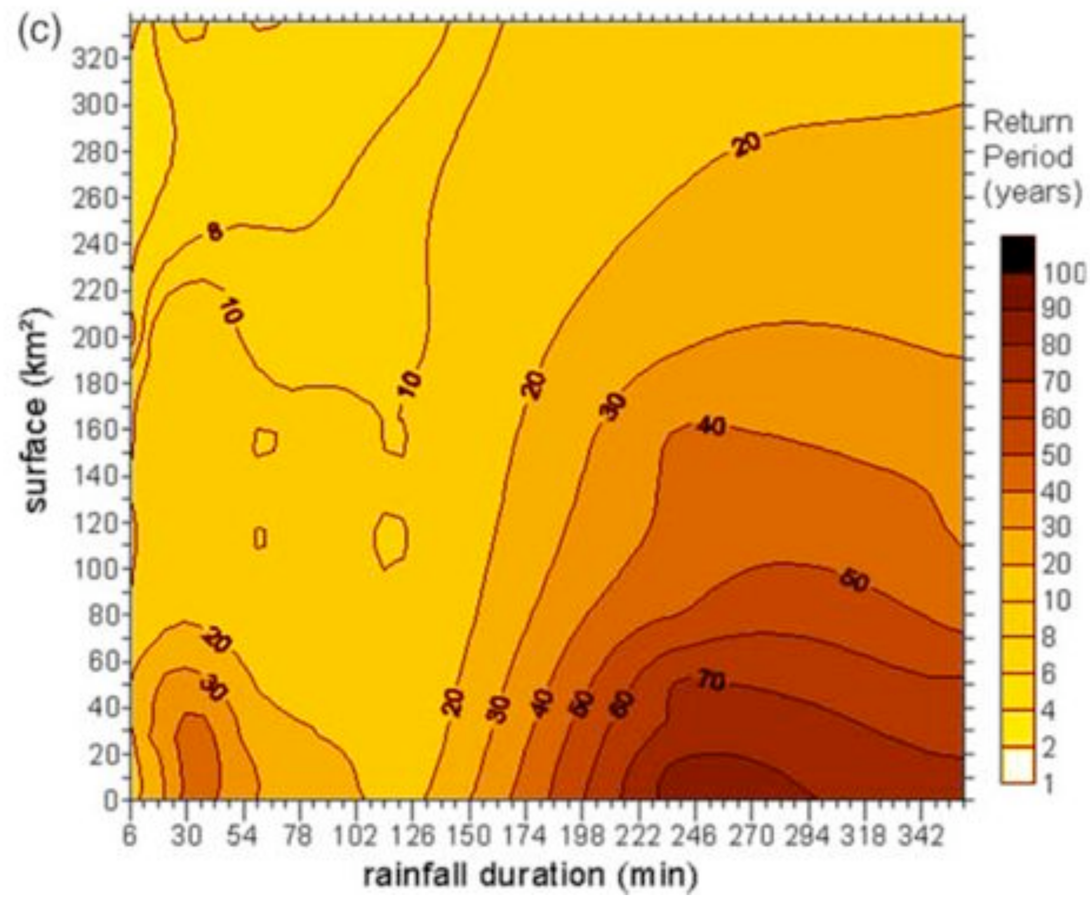




Point rainfall model + **Spatial rainfall model**







→ **Severity Diagrams**

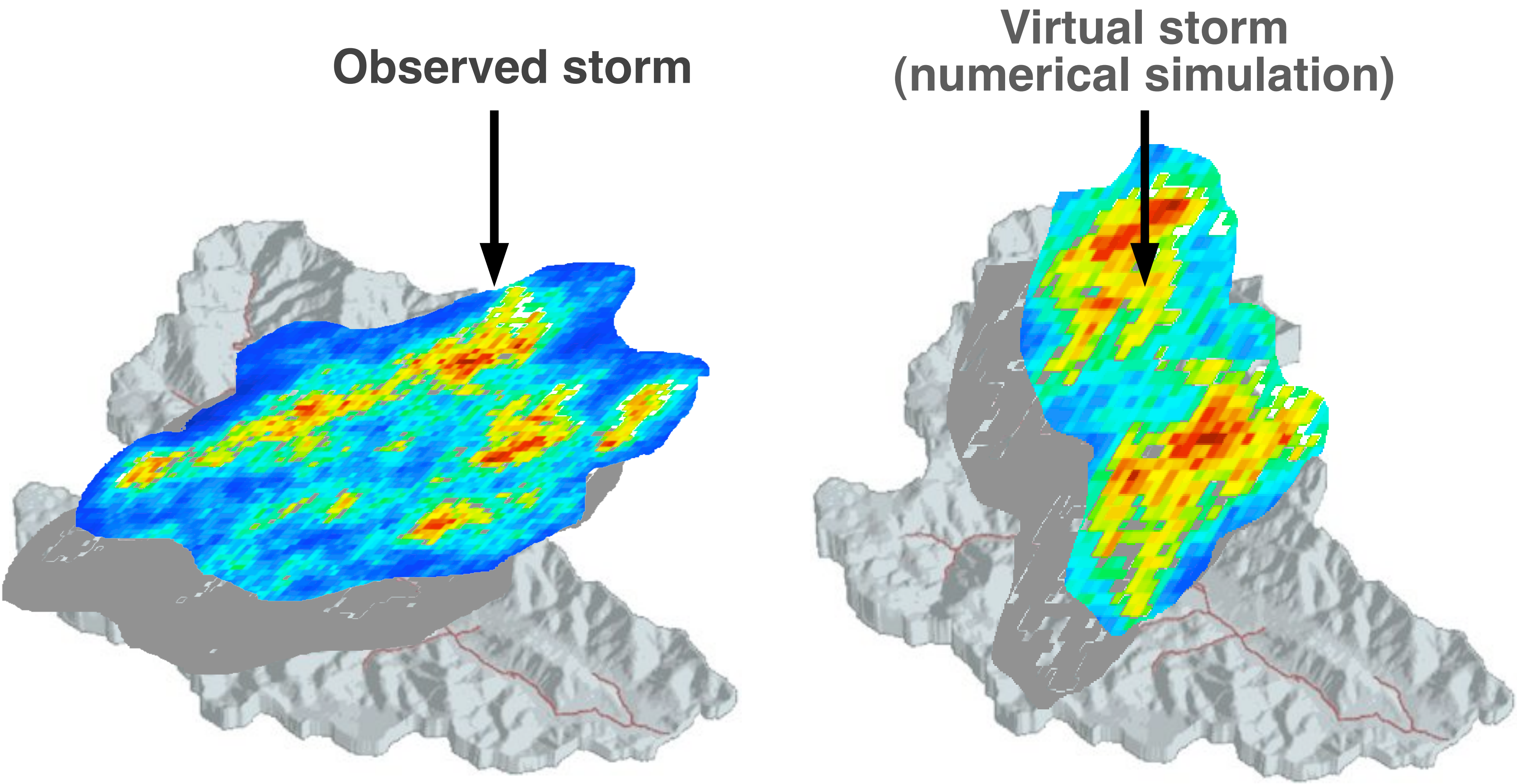
Regional model for assessing the magnitude of extremes

PART III

APPLICATION:
SEVERITY DIAGRAMS

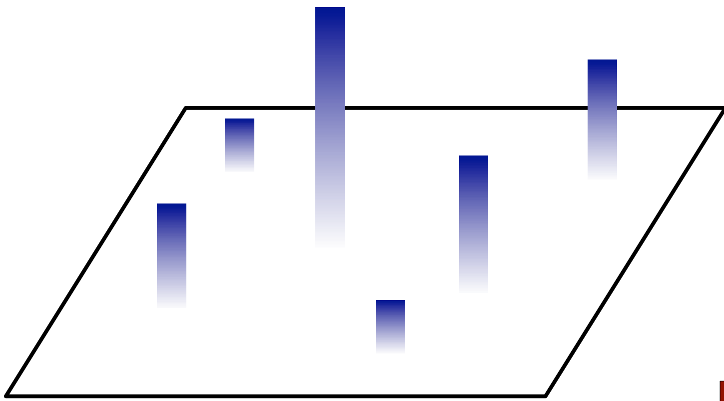
Use of Severity Diagrams

Storm comparison

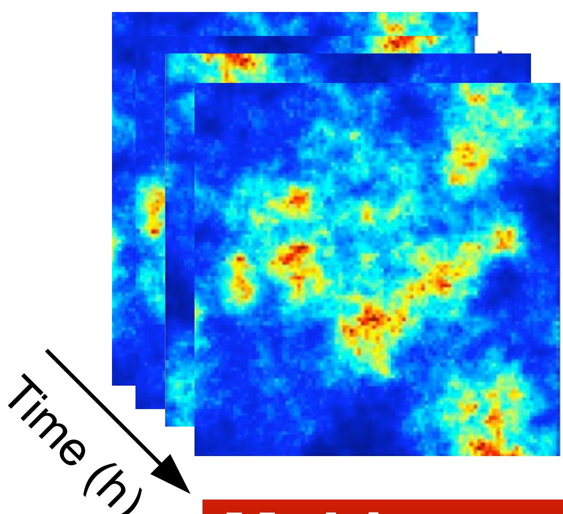


From rainfall f elds to severity diagrams

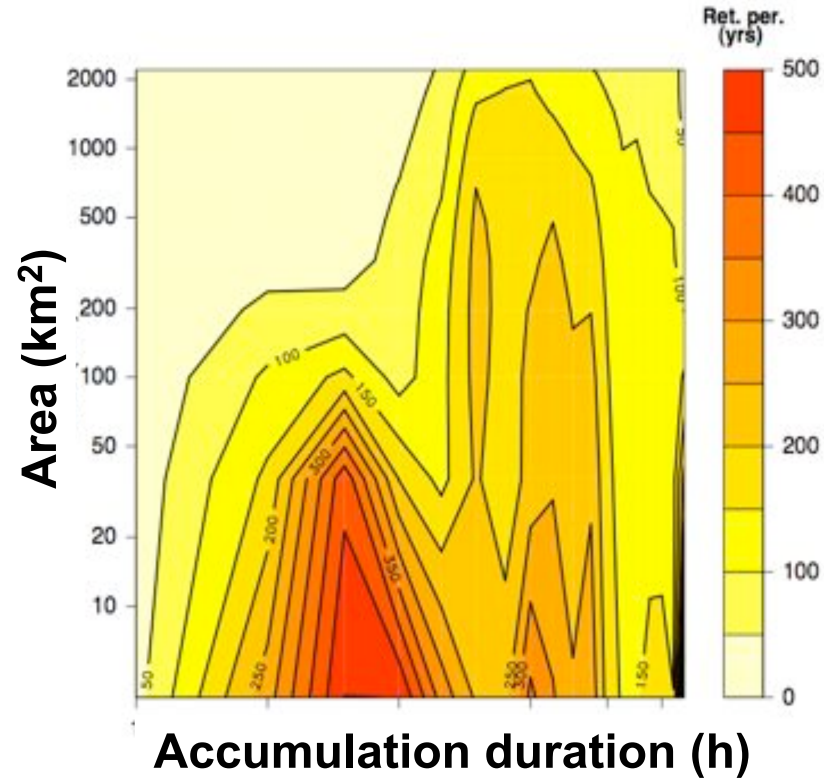
Rain gauge data



Radar data or simulated model



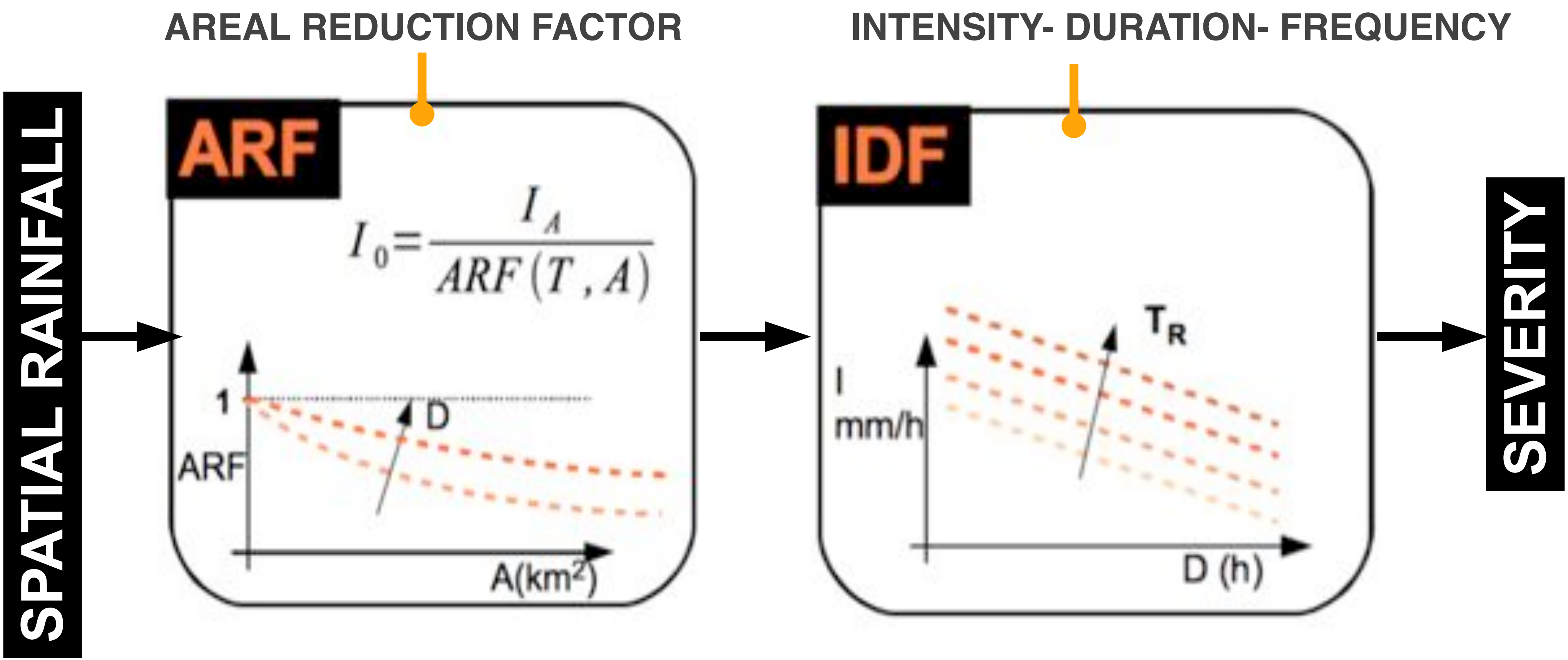
Severity Diagram (yrs)



- Storm comparison
- Model evaluation
- Real-time monitoring

Multi-step process involving historical series

Severity Diagrams computation



Assign to each spatial rainfall observation a frequency value (severity)

Application of severity diagrams

Respect to Ramos --> larger domain with

- Heterogeneity of rainfall extreme behavior (flat lands, mountain..)
- Coarser rainfall network

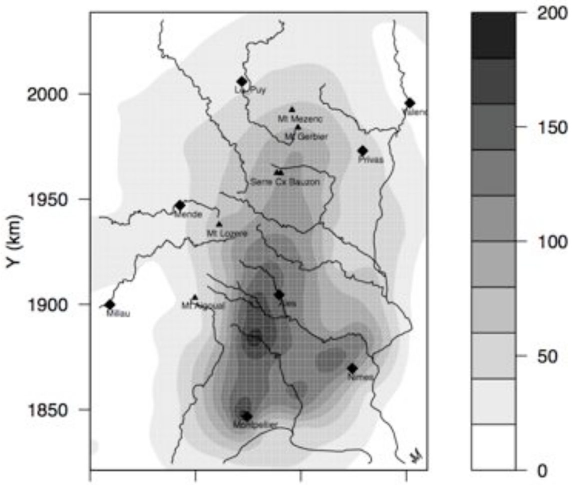
We can use our space-time model to compute SEVERITY DIAGRAMS for any storm occurring in the Cévennes

Applications:

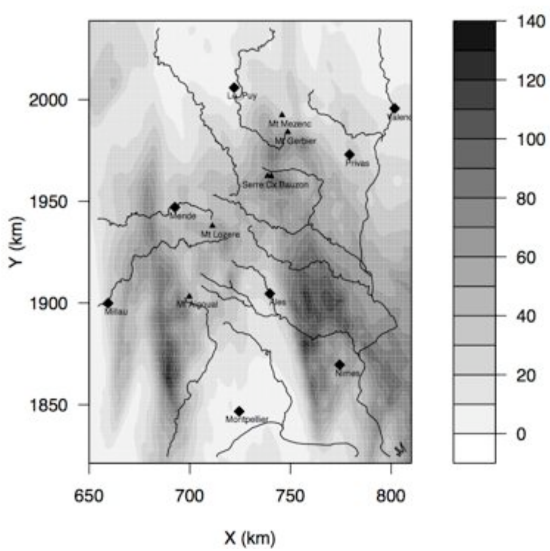
1. Evaluation of meso-scale deterministic simulations (MesoNH)
2. Evaluation of the variability of Ensemble simulations (AROME)

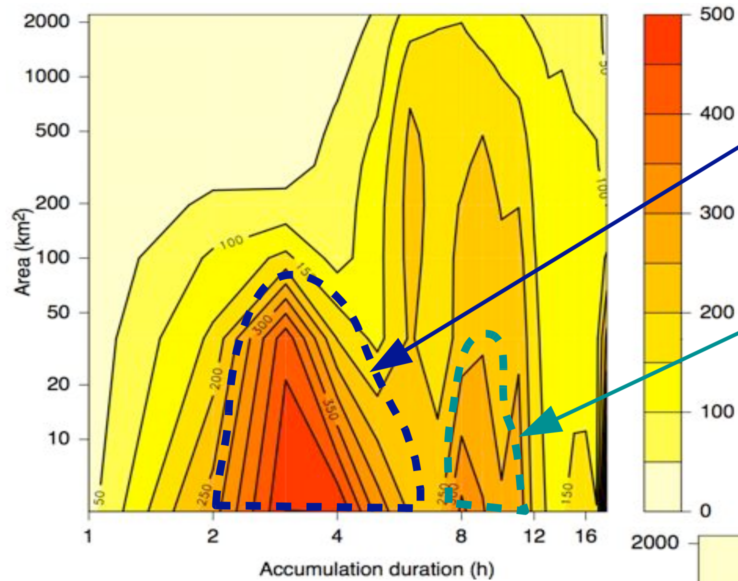
Evaluation of deterministic simulations performance: 2005, Sep 06

Observed rainfall



MesoNH rainfall





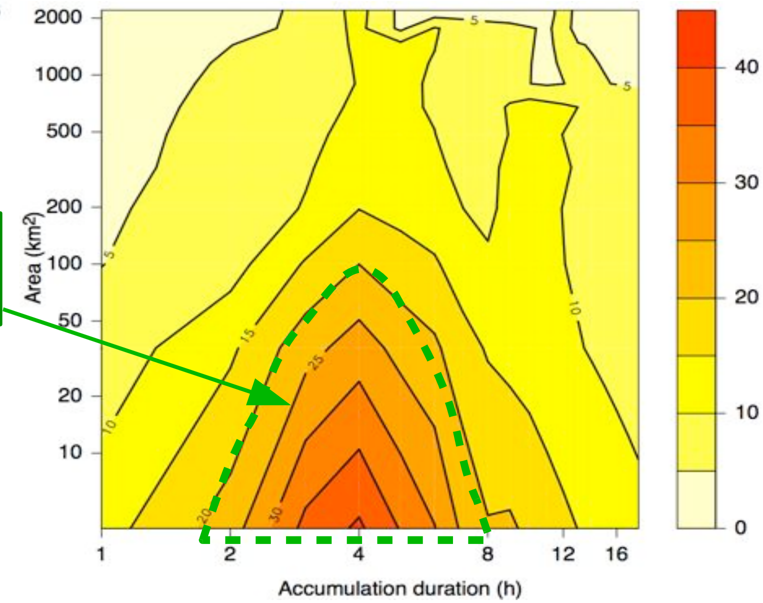
Observed severity

Small scale max ~ 500 yrs
3-4 hours / 0-100 km²

Large scale max ~ 300 yrs
7-10 hours / 0-30 km²

Simulated severity

Small scale max ~ 50 yrs
3-6 hours / 0-50 km²

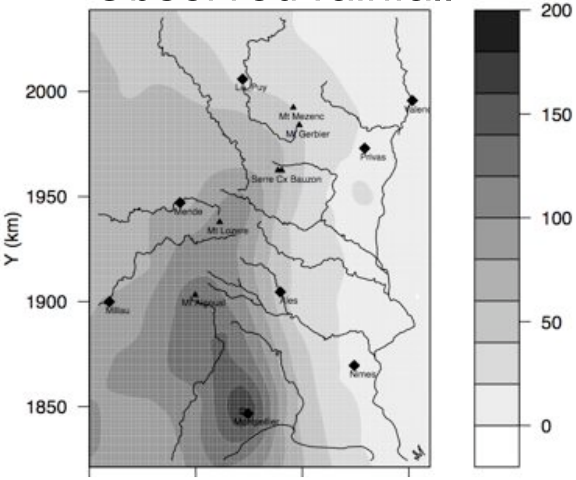


Wrong Maximum Location - Rainfall Underestimation – Different space-time scales

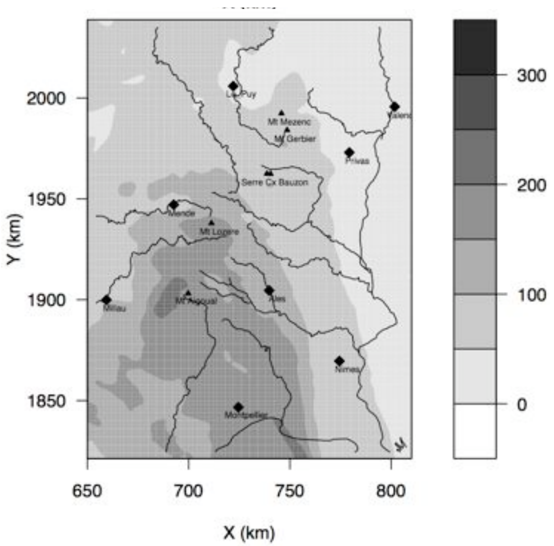
Ceresetti et al, 2011, submitted to WAF

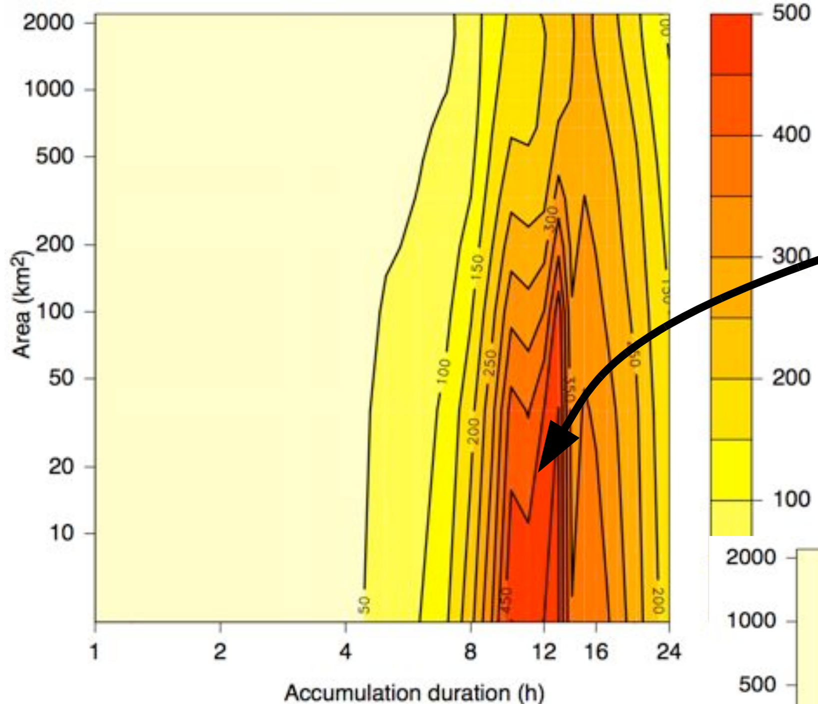
Deterministic simulation performance: 2003, Dec 03

Observed rainfall



MesoNH rainfall





Observed severity

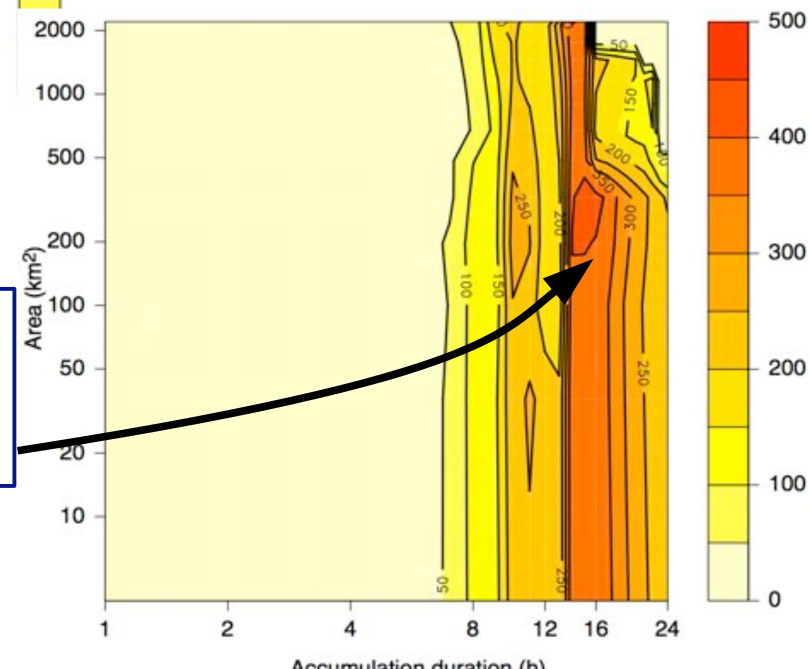
Maximum Severity: ~500 yrs

Time scale: 9-14 h
Spatial scale: 0-200 km^2

Simulated severity

Maximum Severity: ~500 yrs

Time scale: 14-18 h
Spatial scale: 200-500 km^2



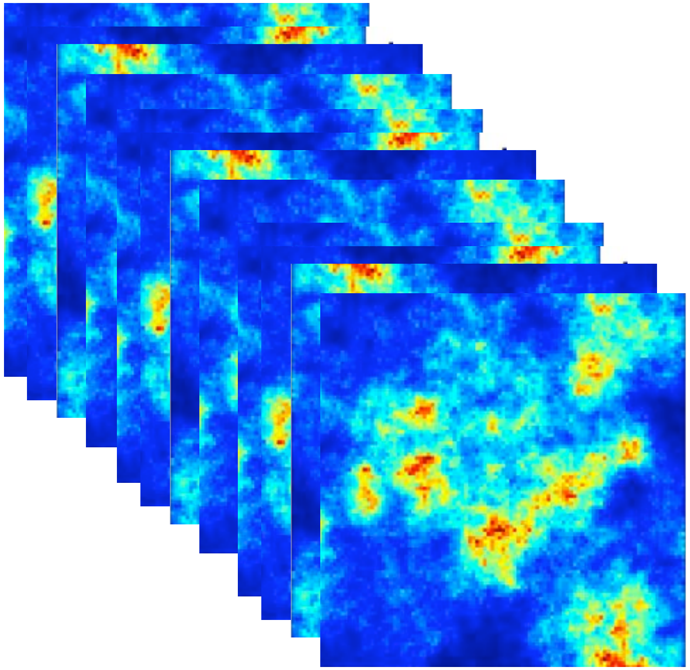
Severity: an effective multiscale diagnostic

Ceresetti et al, 2011, submitted to WaF

Evaluation of ensemble simulations variability

Model: AROME Operational Model (Météo-France)

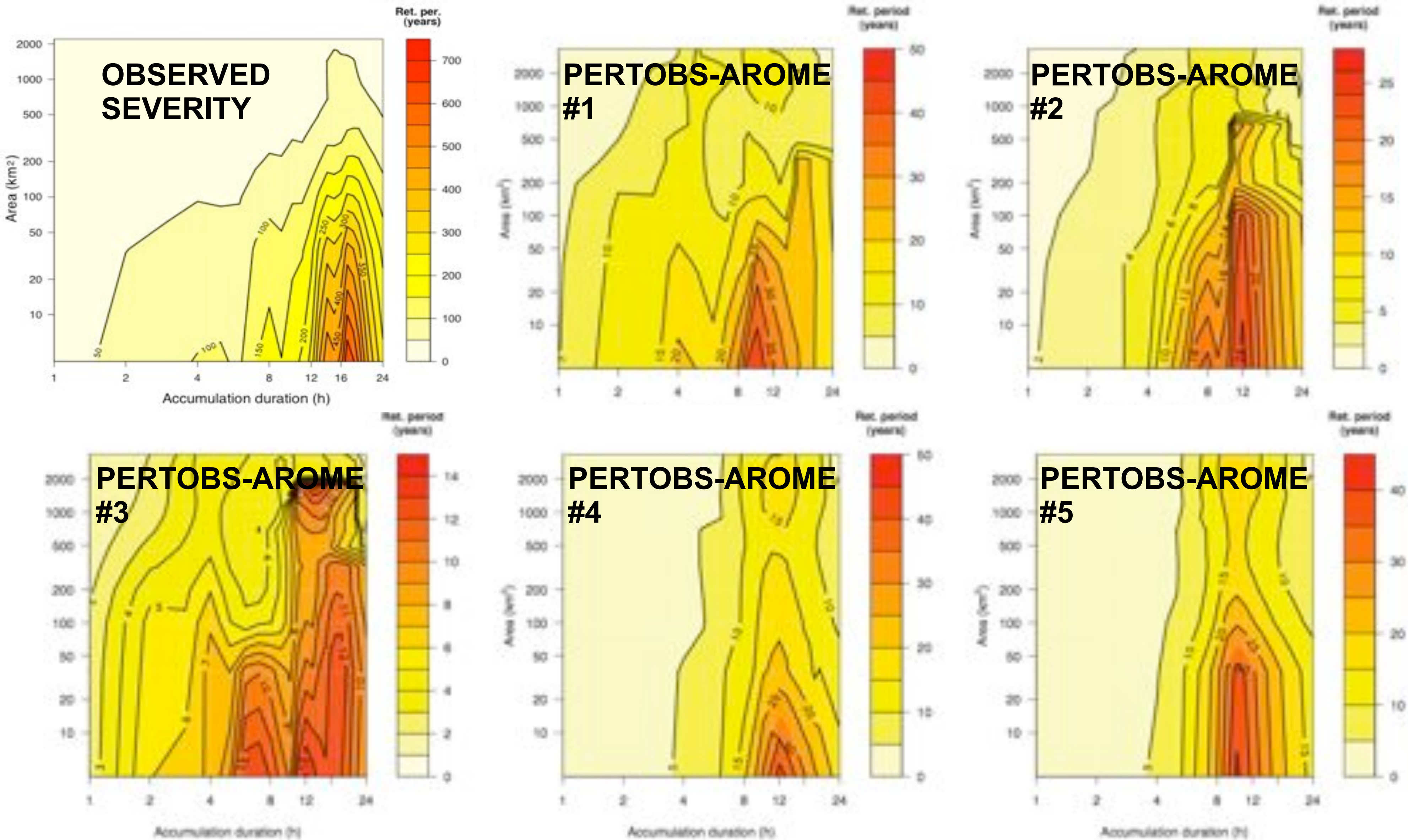
Probabilistic ensemble: group of simulations obtained perturbing
- Initial Conditions
- Boundary Conditions



2008, November 01 Storm

Determine the variability of the members

Application: effect of initial conditions



Space-time scales OK, LOW magnitude

CONCLUSION AND PERSPECTIVES

Conclusion

MAIN RESULTS:

- **Quantification of the error committed by rain gauge devices**
- **Quantification of the underestimation due to spatial undersampling**
- **Assessment of the tail behavior of rainfall extremes**
- **Regionalization of point/spatial rainfall extremes (IDF+ARF curves)**
- **Detection of the spatial and temporal scale-invariance ranges**
- **Estimate the magnitude of heavy rainfall events in the Cévennes region**
- **Evaluation of performance of meteorological models**

Perspectives

- Rain gauge uncertainties: design of a new rain gauge network (HyMeX project)
- Regional IDF+ARF curves: severity characterization of future events
- Severity diagrams of ensemble simulations: improvement of ensemble simulations

Dissemination of a rigorous framework in which precipitation is seen as a continuum of scales

Can we apply this framework to other variables?

THANK YOU!

Dissemination of a rigorous framework in which rainfall is seen as a continuum of scales

Dissemination of a rigorous framework in which rainfall is seen as a continuum of scales