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A REGIONAL SCALE INVARIANT DEPTH – DURATION-FREQUENCY MODEL FOR SUB-HOURLY EXTREME RAINFALL ESTIMATES IN SICILY

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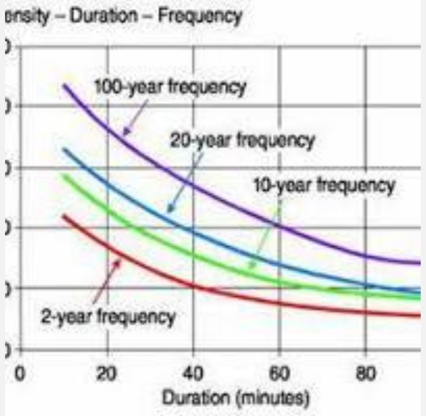
Key challenges in short term heavy rainfall analysis

Why are so important

Design of urban drainage systems or flood risk assessment in fast-responding catchments

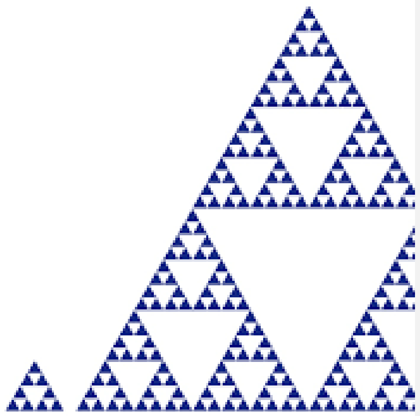


Main statistical tool

Depth (or intensity)-duration-frequency (DDF or IDF) curves to derive storms of fixed duration and return period

Obstacle

Data are usually unavailable or too scarce for estimating reliable DDF or IDF curves



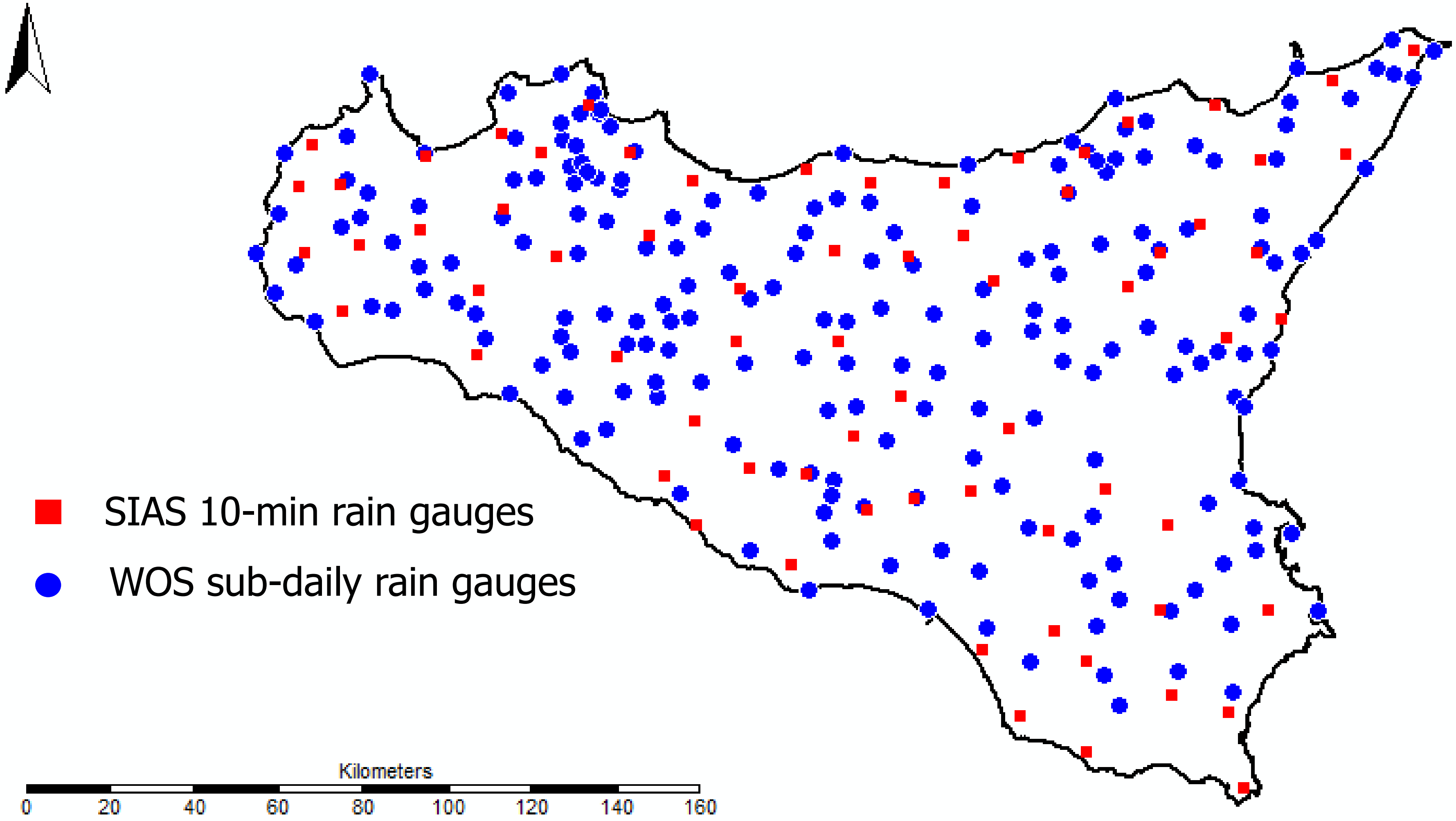
Inherent features

Regularities in the temporal pattern are usually exhibited by storm records, known as scaling properties

Solution

Scaling properties could help in characterizing extreme storms at partially gauged sites better than the application of traditional statistical techniques

Case study



SIAS 10-min rain gauges
WOS sub-daily rain gauges
Kilometers
0 20 40 60 80 100 120 140 160

Aim of the study

To **develop a scaling approach** for estimating the distribution of **sub-hourly extreme rainfall** by taking advantage both from 10-min rain gauges with short functioning period and low spatial density and from hourly rain gauges with higher density and longer records

Hypothesis testing

Simple VS multiple scaling assumption is verified for AMR data from 10 min to 24 h duration recorded by the Sicilian Agro-meteorological Service gauge network

Regional DDF curves derivation

Regional DDF curves under a scale-invariant framework are developed to estimate T-year sub-hourly extreme rainfalls at sites where rainfall data at duration ≥ 1h are available

Model validation

Validation of sub-hourly estimates with respect to historical observations are carried out

Scaling properties of short term heavy rainfall

Let H_d and $H_{\lambda d}$ be the annual maximum rainfall (AMR) of duration d and λd

Strict sense scaling property

$$H_{\lambda d} \overset{dist}{=} \lambda^n \cdot H_d$$

$$h_{\lambda d,T} = \lambda^n \cdot h_{d,T}$$

$$E[H_{\lambda d}^r] = \lambda^{n_r} \cdot E[H_d^r]$$

n scaling exponent

n_r scaling exponent of order *r*

λ^n scaling factor

Wide sense scaling property

$$E[H_{\lambda d}^r] = \lambda^{n_r} \cdot E[H_d^r]$$

- *Simple scaling* holds if $n_r = r \cdot n_1$
  - where n_1 is the scaling exponent of order 1
- *Multiple scaling* holds if $n_r = r \cdot n_1 \cdot \phi_r$
  - where ϕ_r is a dissipation function of r

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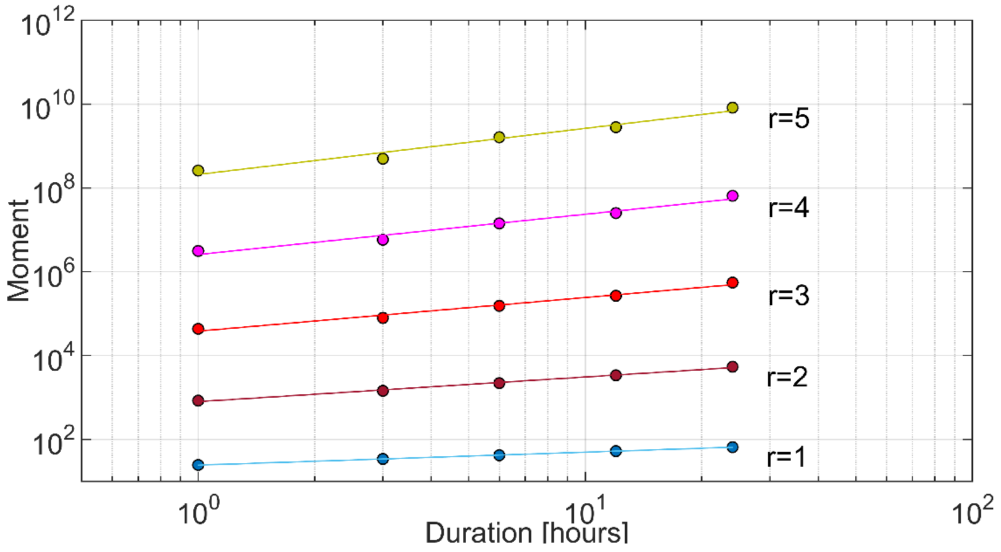

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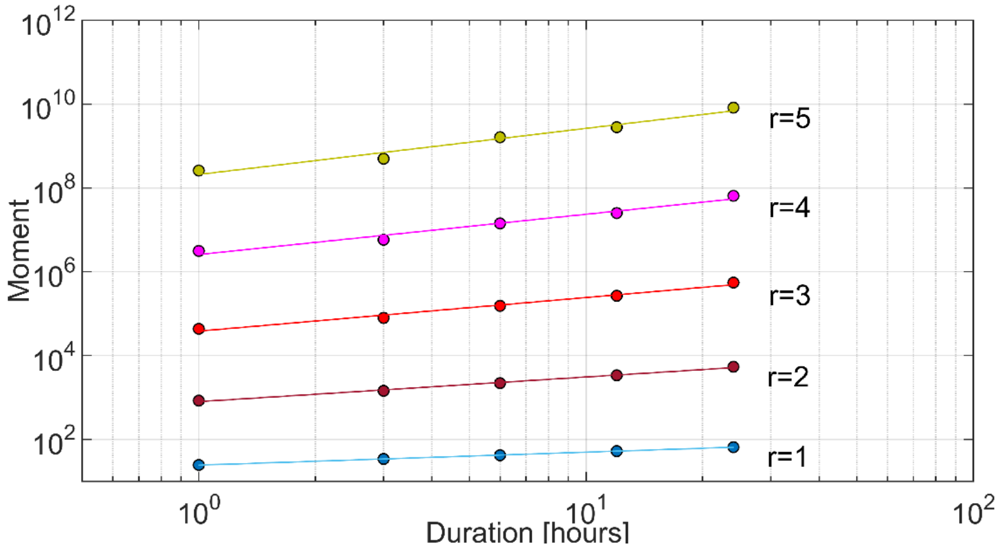
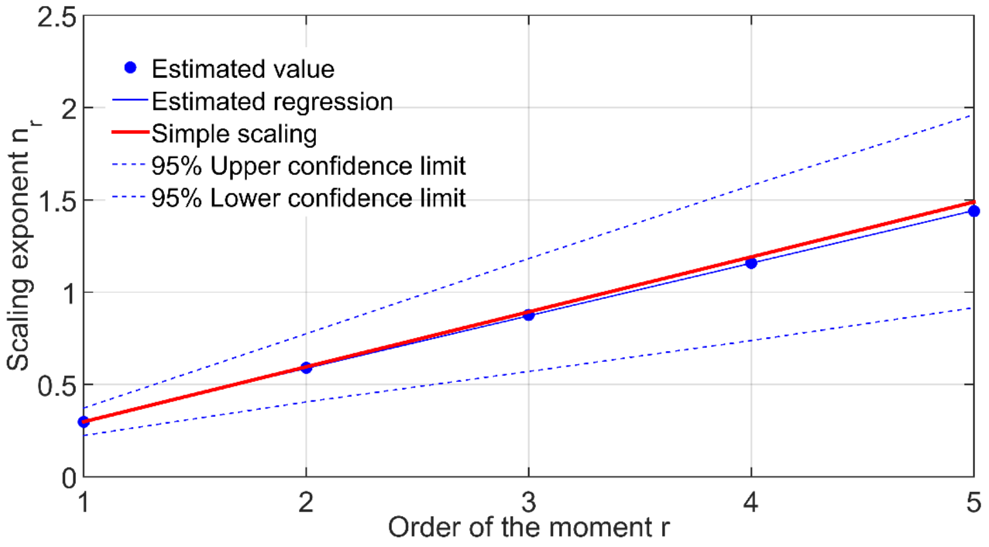


Wide sense **simple** scaling

$$E[H_{\lambda d}^r] = \lambda^{r \cdot n_1} \cdot E[H_d^r]$$



Scaling properties of short term heavy rainfall

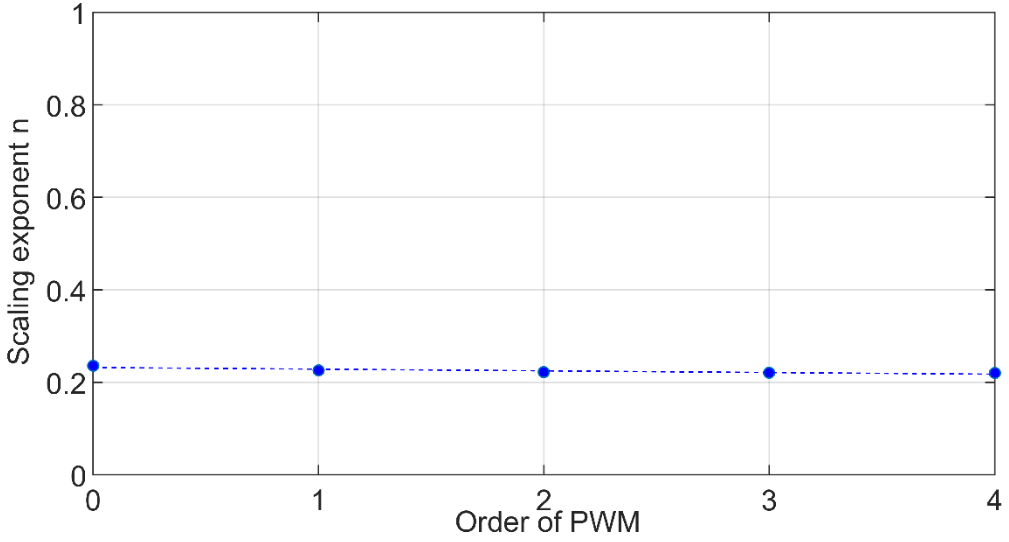
Let H_d and $H_{\lambda d}$ annual maximum rainfall (AMR) of duration d and λd

Wide sense scaling of PWMs

$$M_d = M_d^{1,r,0} = E\left[H_d \cdot F(H_d)^r\right] = \int_0^1 h_d(u) \cdot u^r \cdot du$$

$$with \qquad u = F(H_d)$$

$$\Rightarrow M_{\lambda d}^r = \lambda^n \cdot M_d^r$$



Simple scaling DDF of short term heavy rainfall

Assumption: **Wide sense simple scaling** implies strict sense simple scaling

Under the assumption of scale invariance, DDF curves can be formulated as:

$$h(d,T) = \left(\frac{d}{D_0}\right)^n \cdot \left(\mu_{D_0} + K_T \sigma_{D_0}\right)$$

where

$D_0 = \lambda d$

$$\mu_{D_0} = E\left[H_{D_0}\right]$$

$$\sigma_{D_0} = \sqrt{Var\left[H_{D_0}\right]}$$

K_T=frequency factor

In the present study a GEV scaling model is assumed for sub-hourly AMR series

$$h(d,T) = \left(\frac{d}{D_0}\right)^n \cdot \left\{\mu_{D_0} - \frac{\sigma_{D_0}}{\xi_{D_0}} \cdot \left[1 - \left(-\ln\left(1 - \frac{1}{T}\right)\right)^{-\xi_{D_0}}\right]\right\}$$

whose location, scale and shape parameters are functions of the GEV parameters of AMR series at a reference duration $D_0 = \lambda \cdot d$

$$\mu_d = \mu_{D_0} \cdot \left(\frac{d}{D_0}\right)^n \quad \sigma_d = \sigma_{D_0} \cdot \left(\frac{d}{D_0}\right)^n \quad \text{and} \quad \xi_d = \xi_{D_0}$$

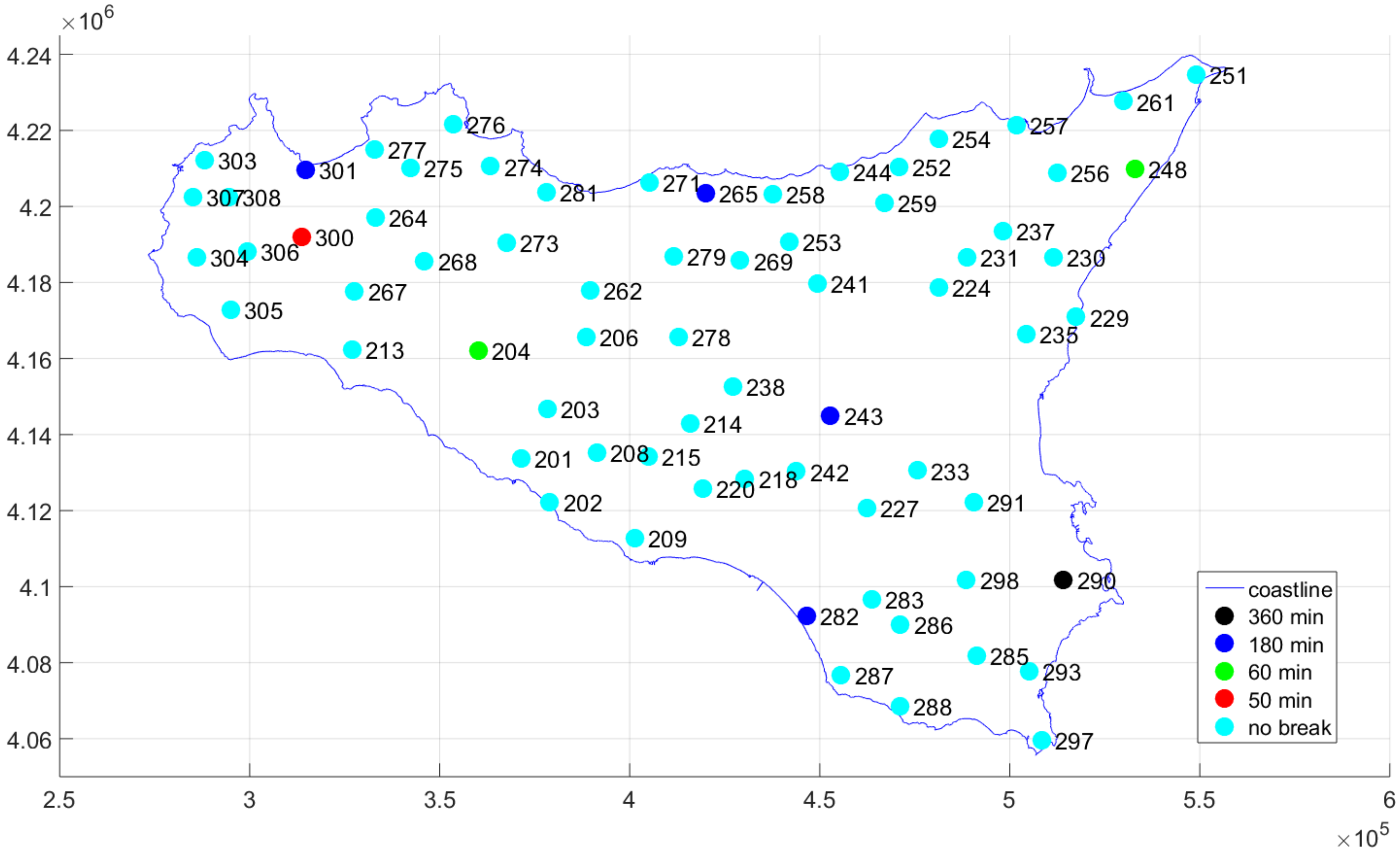
Wide sense simple scaling test results

Mann Kendall test for trend detection in relationships between scaling exponents and various orders of PWMs reveals that:

- Trend hypothesis is rejected at α=5% for 14 out of 69 stations
- Trend hypothesis is rejected for all the stations with a minimum p value equal to 2.75%

Chow test for the presence of structural break in linear regressions reveals that the simple scaling regime holds from 20 to 60 minutes for 68 stations out of 69

→ Sicily scaling homogeneous region with respect to sub-hourly data



Chow test results for the presence of structural break in linear regressions

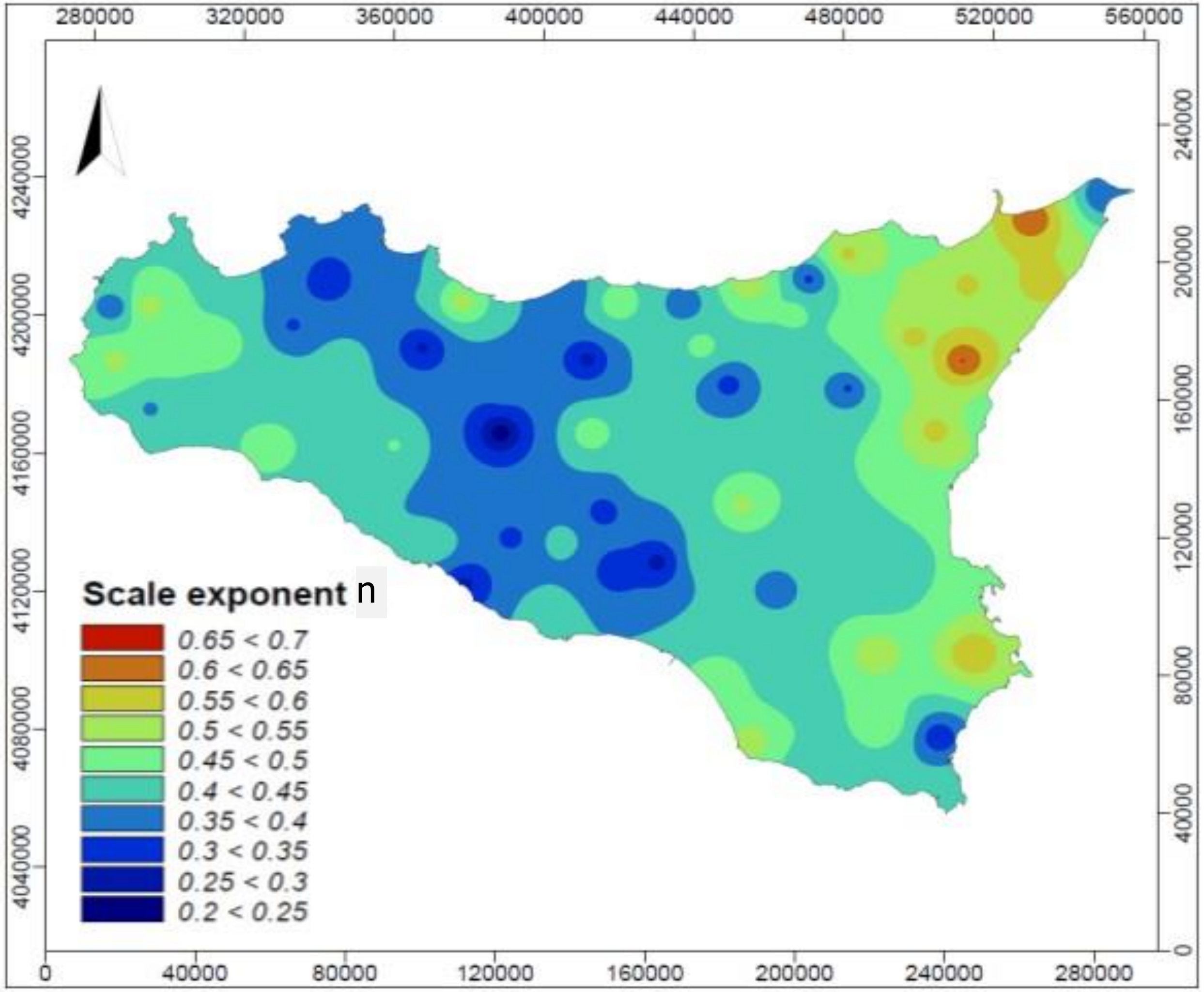
Regional DDF curves derivation

The scaling exponent spatially interpolated by IDW method to allow assessment also for ungauged or partially gauged sites

3 main subregions arise:

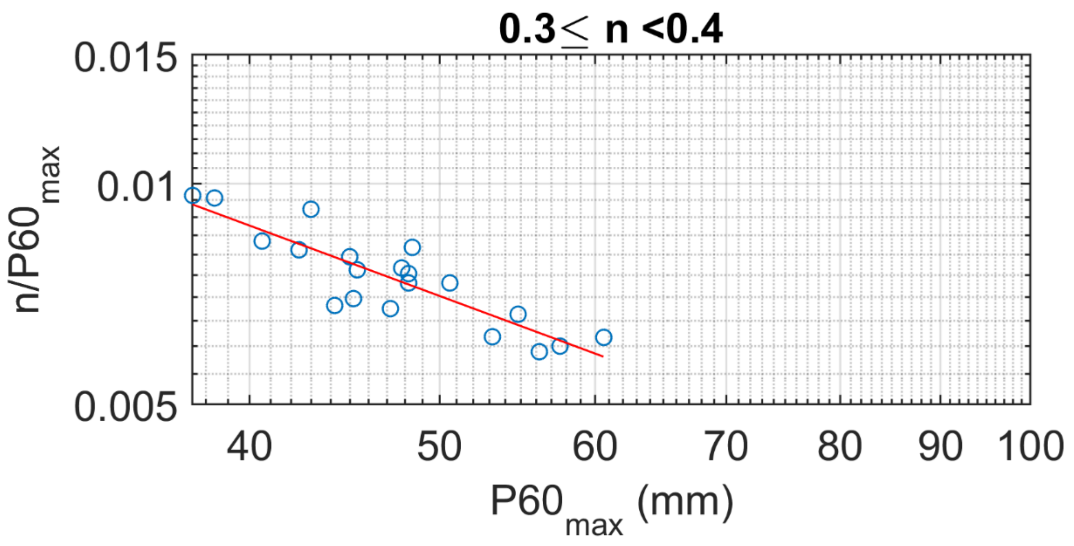
- Eastern (0.5<n<0.6)
- Central-Eastern and Western (0.4<n<0.5)
- Central-Western (0.3<n<0.4)

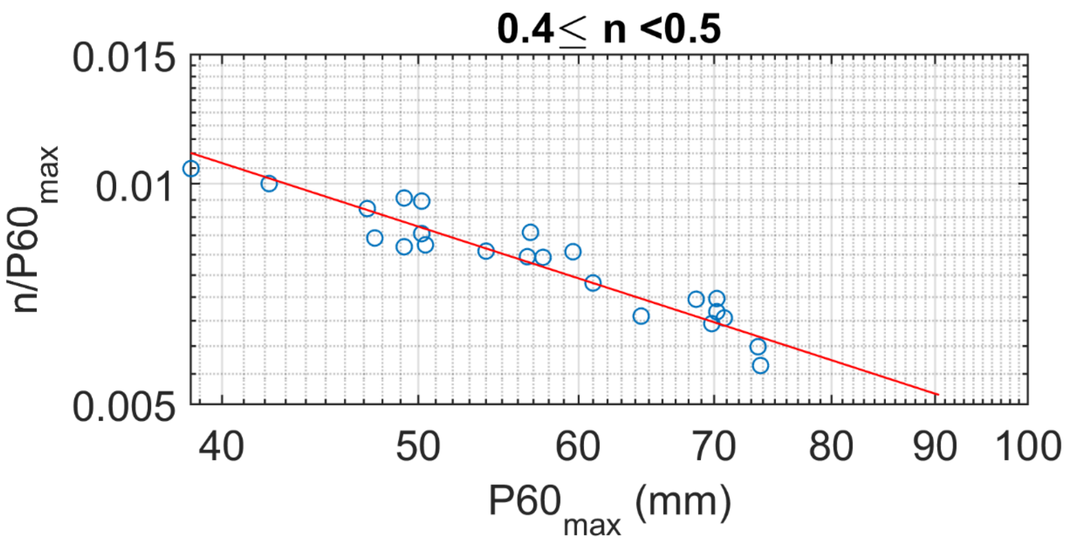
Some spots show n<0.3 (dark blue) or n>0.6 (orange to red)

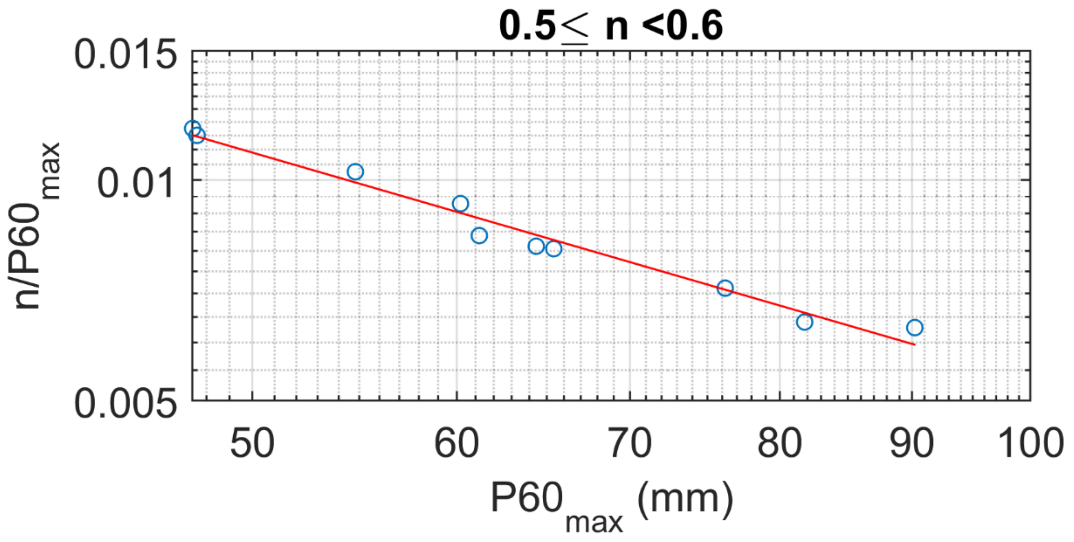


Regional spatial distribution of the scaling exponent n

Regional DDF curves derivation

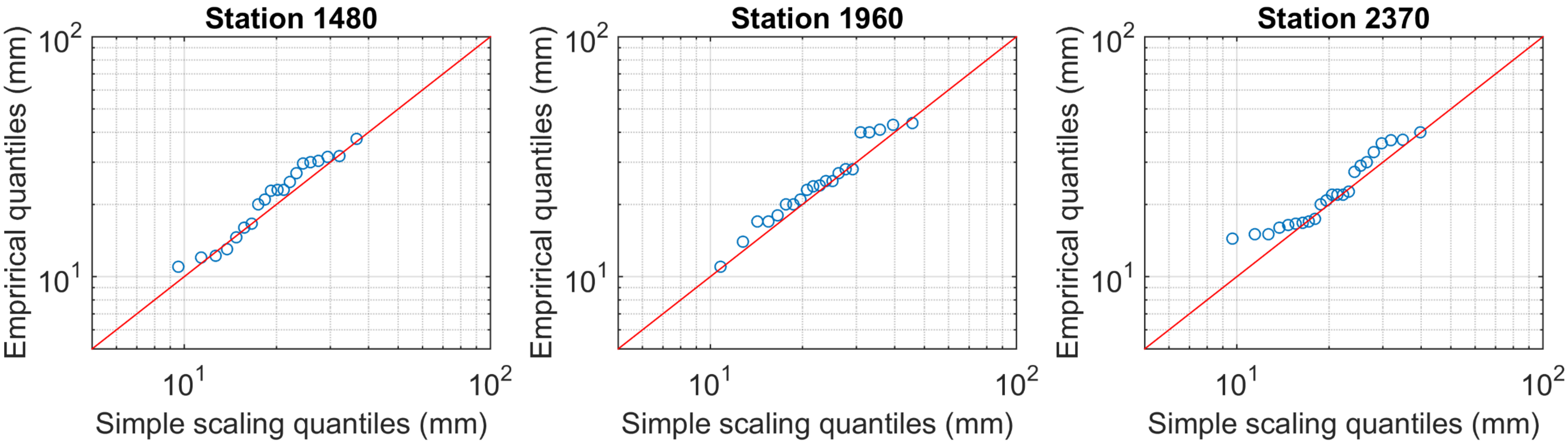


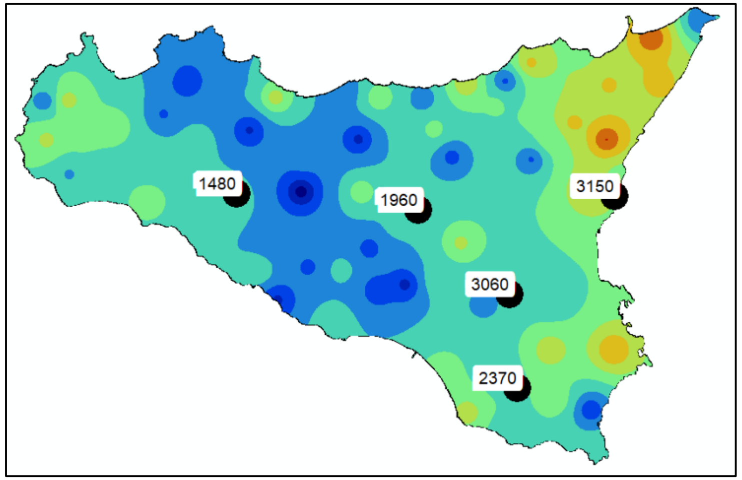


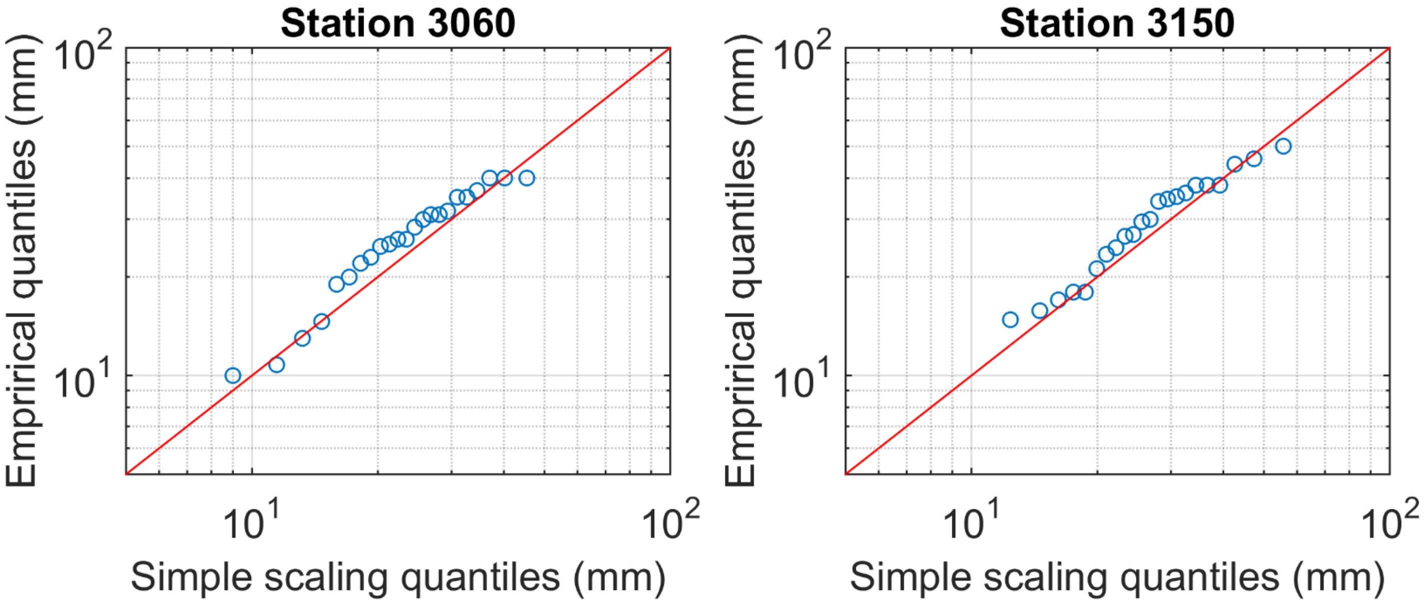


n	slope	intercept	r^2	Relations
n<0.3	-1.6675	1.2032	0.961	$n=3.331 * P60_{max}^{-0.667}$
0.3<n<0.4	-0.9917	-1.0789	0.765	$n=0.340 * P60_{max}^{0.008}$
0.4<n<0.5	-0.8939	-1.2431	0.909	$n=0.288 * P60_{max}^{0.106}$
0.5<n<0.6	-1.0231	-0.5168	0.975	$n=0.596 * P60_{max}^{-0.023}$

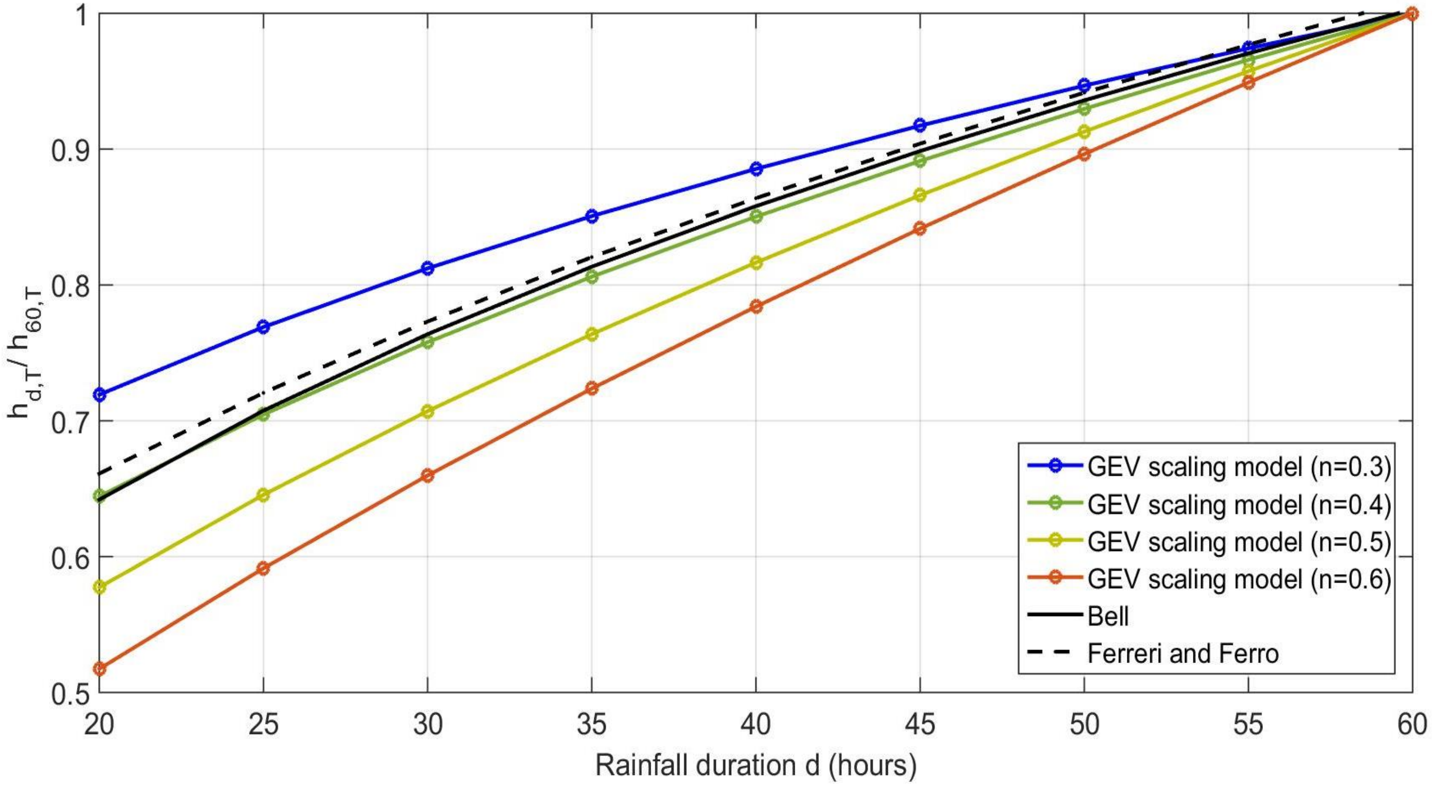
Validation of GEV simple scaling model







Comparison with previous empirical approaches

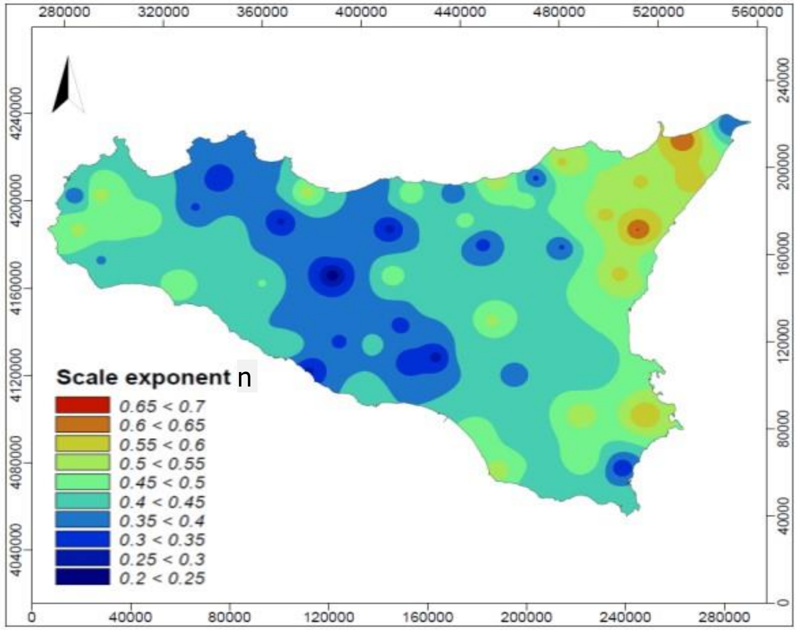


$$\frac{h_{t,T}\left(t<1\,ora\right)}{h_{t,T}\left(1\,ora\right)}=0.54t^{0.25}-0.50$$

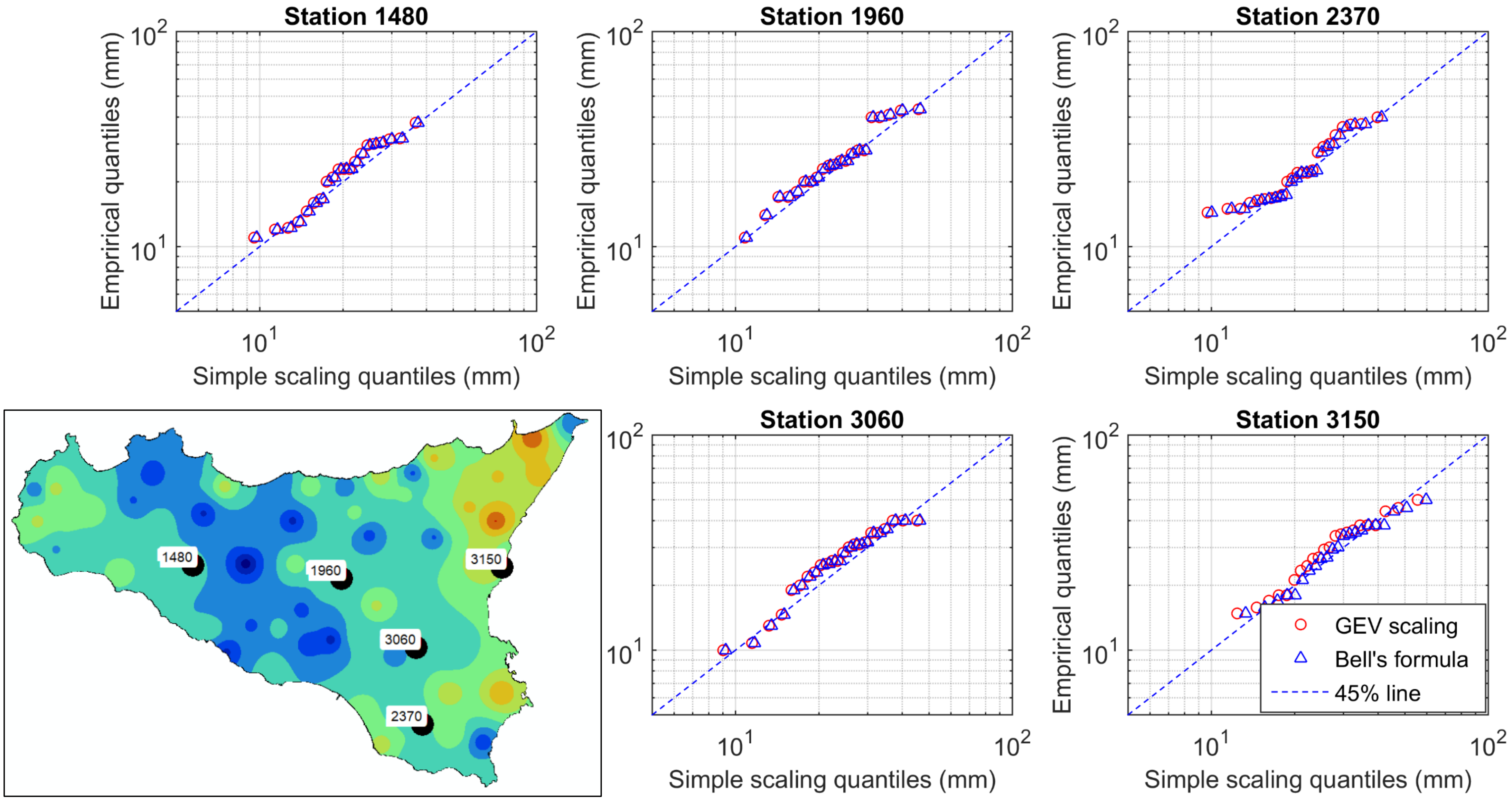
Bell (1969)
5 ≤t≤ 120 min

$$\frac{h_{t,Tr}\left(t<1\,ora\right)}{h_{t,Tr}\left(1\,ora\right)}=0.208t^{0.386}$$

Ferreri & Ferro (1990)
30 ≤t≤ 55 min



Comparison with Bell’s formula



- The proposed regional DDF scaling approach for estimating sub-hourly AMRs could help to obtain more spatial information on design rainfall
- The scaling properties of sub-hourly rainfall data at 69 rain gauges in Sicily was analyzed. Wide sense simple scaling property from 20 to 60 min duration largely holds for all of them
- The distribution of n reveals 3 main clusters. Regional relationship between n and $P60_{max}$ for each cluster was calculated to formulate regional DDF formulas in each homogeneous region
- Validation results by using 30-min AMR data for a few rain gauges, show that the regional DDF scaling formulas proposed have good performances

Conclusions

Looking forward to answering your questions

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