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Performance comparison of temporal precipitation downscaling methods

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Outline

◆ Introduction

- The impacts of climate change related urban flooding in China cities
- Motivation and objectives of the research

◆ Temporal precipitation downscaling method

- Foundation of mathematics
- Calculation procedures
- Performance evaluation based on the statistical indicators

◆ Case study: three cities in China

- The selection of distribution forms
- The determination of scale invariance options
- Performance evaluation

◆ Conclusion

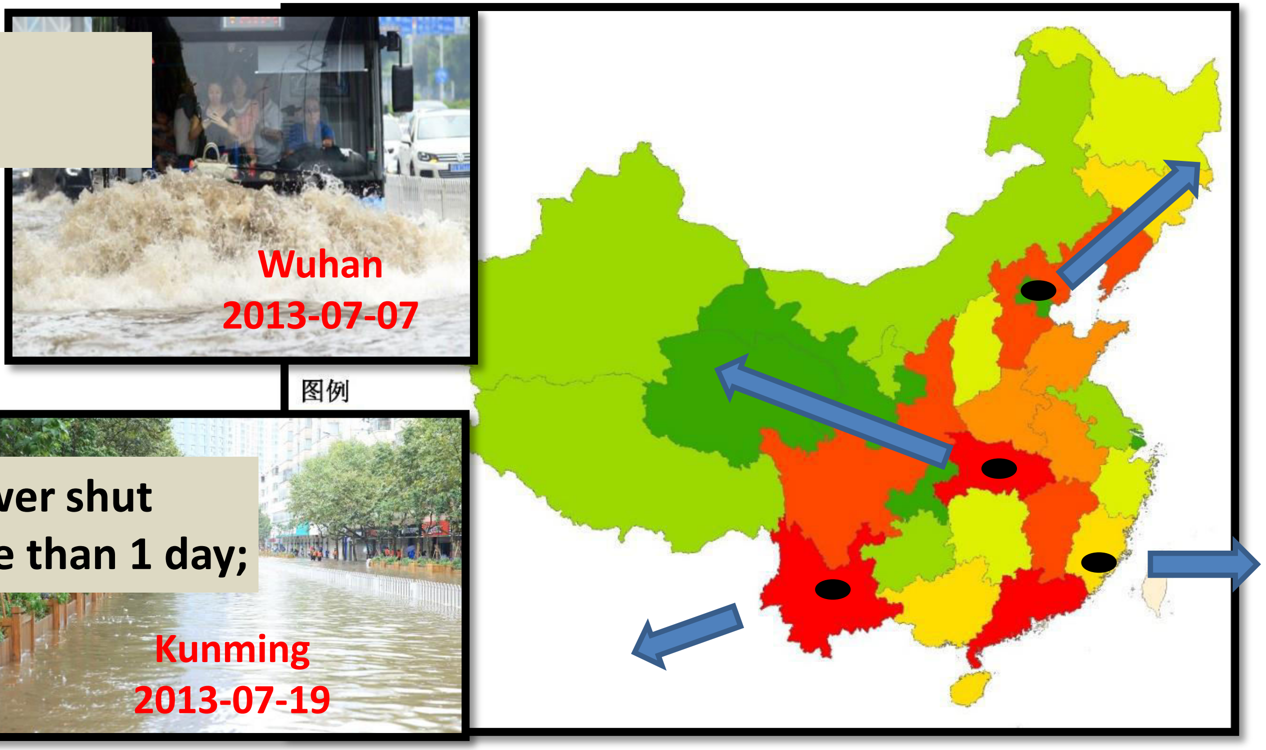
Introduction— The issue of urban inundation in China

According to a survey executed by the Ministry of Housing and Urban-Rural Development (MOHURD) in China :

- Investigated period: 2008~2010
- 289 / 349 cities (83%)
- Varying degrees of urban inundation issues

- 79 death;
- 1.6 mil. people;
- 11.6 bill. RMB

- ~250mil. RMB
- 250K people



- Traffic and power shut down for more than 1 day;

- 5 death;
- >1000 vehicles;

Introduction — Accountable reasons

Drainage Infrastructure
- Stormwater Drainage: 50 km per city
- Buffers: scarce detention and infiltration devices

Inadequate Capacity for urban runoff disposal and absorption;

Land-use Change
- Urban Sprawl
- Increasing percentage of impervious pavement

Changed hydrological processes;

Planning Policy
- System designed in a empirical way
- Insufficient criteria: 1-3 design rainfall return period

Not flexible enough;
Not efficient enough;

Climate Change
- Extreme rainfall: more frequently
- High magnitude still there, low occurrence no longer exist

Much stronger input

Introduction— Climate related precipitation changes

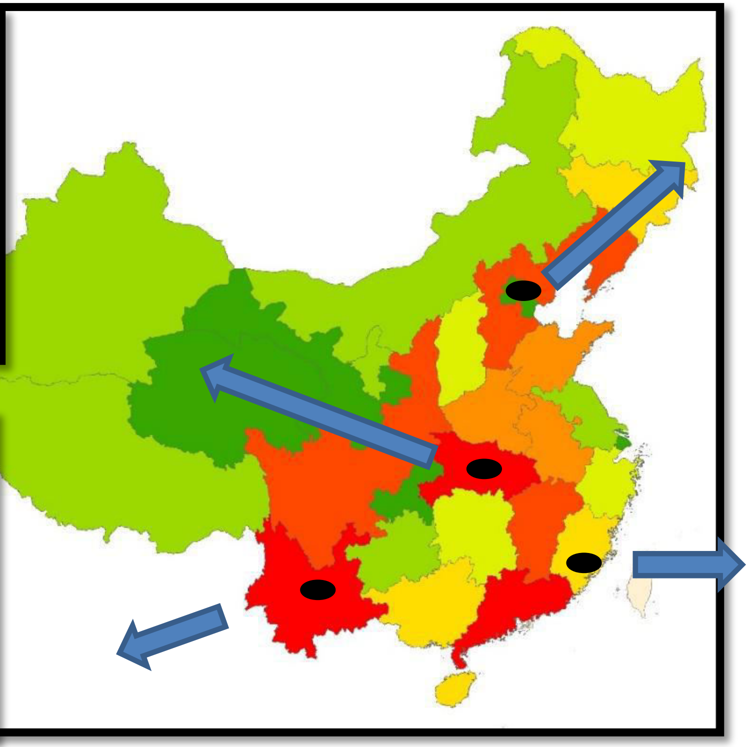
Legend:

Rainfall amount/ duration

Annual rainfall amount

215mm/16h
~620mm

334mm/17h
~1200mm



190mm/12h
~980mm

141mm/8h
~1100mm

Climate change impacts assessment in urban drainage system: Temporal downscaling is needed.

Global/regional climate models provide predicted future precipitation information for possible impact assessments, such as:

Annual or seasonal

- Investigating the future precipitation regimes and hydrological cycle changes in a specific area, annual and seasonal results has the advantages of emphasizing the distinctions in a macroscopic perspective

Seasonal or monthly

- As to the water resource assessment and planning, seasonal or monthly rainfall perdition would be highly valuable and likely adequate

Max daily

- Downscaled maximum daily precipitation as the input for the extreme events modeling could provide appropriate recommendations and potential measurements for impact adaptation

Climate change impacts assessment in urban drainage system: Temporal downscaling is needed.

These data is not working in urban drainage system!

In the planning and operation of urban drainage system, the rainfall information (intensity / duration) at sub-daily scale (hourly or even minute-based) plays an important role, which usually summarize into the form of intensity-duration-frequency (IDF) relationship.

For the urban drainage system impact assessment in a changing climate, The climate model outcomes needs both spatial and temporal downscaling procedures.

However, in contrast to spatial downscaling methods applications, the performance of temporal downscaling has attracted little attentions.

Motivations of the research

There are two important steps in this temporal precipitation downscaling:

the selection of distribution forms of annual maximum precipitation (AMD) series

- Generalized Extreme Value
- Gamma distribution
- Log-Normal distribution

the determination of scale invariance options

- simple scaling
- two-stage scaling

This paper aims to identify the appropriate combination to apply the downscaling processes, by the way of comparing their corresponding performances based on quantitative evaluations.

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Foundation of mathematics

◆ The method is based on the scaling invariance property of precipitation

$$f(x) = C(\lambda) * f(\lambda x)$$

Possibility distribution

Scaling option

◆ Burlando and Rosso (1996) demonstrated a power law form of IDF relationship can be derived from the scale invariance concept

$$P_d = \lambda^{\beta} \times P_{sd}$$

- where $\lambda \in [0,1]$, indicates the scale parameter. P_d and P_{sd} represents the series of annual maximum rainfall intensity at daily scale and sub-daily scale, respectively. And β represents the scaling exponent.
- IDF is the Intensity-Duration-Frequency

Calculation procedures

- the scale invariance of the distributions results in the equality of their moments of order *q*

$$\langle P_d^q \rangle = \lambda^{K(q)} \times \langle P_{sd}^q \rangle$$

- In order to calculate the value of *β*, we can simply take the logarithm of both sides of above equation, which transforms it into following:

$$log\left(P_d^q\right) = \mathrm{K(q)log\lambda} \times \log\left(P_{sd}^q\right)$$

- If the scale function is linear, K(q)= βq, the process is a simple scaling; otherwise the process is multi-scale.
- In this form, the function of scaling exponent, is regarded as the slope of the relationship between the log-transformed values of annual maximum series and the scale parameter, and could be obtained from the log-log plot.

Calculation procedures

- Once β is determined, the hourly rainfall intensity of various durations (1, 3, 6, 12, 18 and 24 hours) could be calculated by the values of daily precipitation with the corresponding λ (1/24, 1/8, 1/4, 1/2, and 1).
- Repeat this process for different return periods (1, 2, 3, 5, 10, 15, 20, 25 years), the required IDF curve could be drawn.
- On the other hand, the local existing IDF relationship obtained by the storm intensity formula:

Four statistical indicators for performance evaluation

- mean bias error (MBE)

$$\text{MBE} = \frac{1}{n}\sum_{i=1}^{n=40}(y_i' - y_i)$$

- root mean square error (RMSE)

$$\text{RMSE} = \left[\frac{1}{n}\sum_{i=1}^{n=40}(y_i' - y_i)^2\right]^{0.5}$$

- index of agreement (d)

$$d = 1 - \frac{\sum_{i=1}^{n=40}(y_i' - y_i)^2}{\sum_{i=1}^{n=40}\left(|y_i - y_{avg}| + |y_i' - y_{avg}|\right)^2}$$

- coefficient of determination (R^2)

$$R^2 = 1 - \frac{\sum_{i=1}^{n=40}(y_i' - y_i)^2}{\sum_{i=1}^{n=40}\left(y_i - y_{avg}\right)^2}$$

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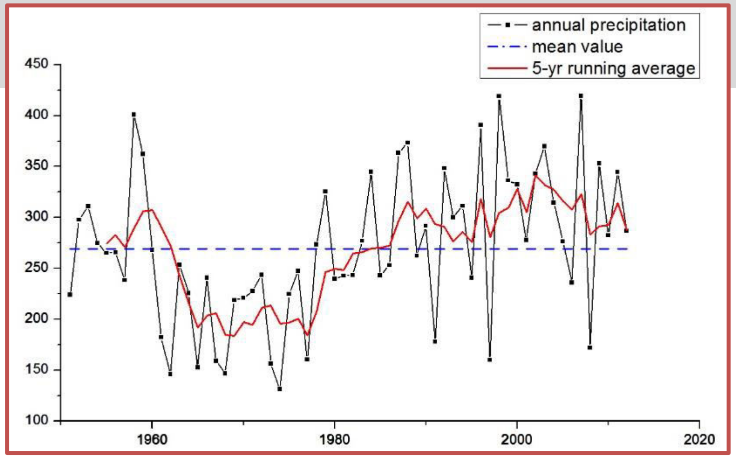
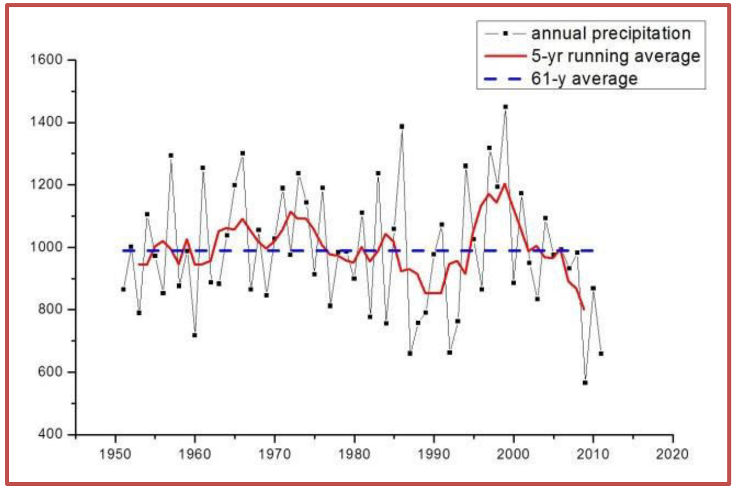
Case study cities:

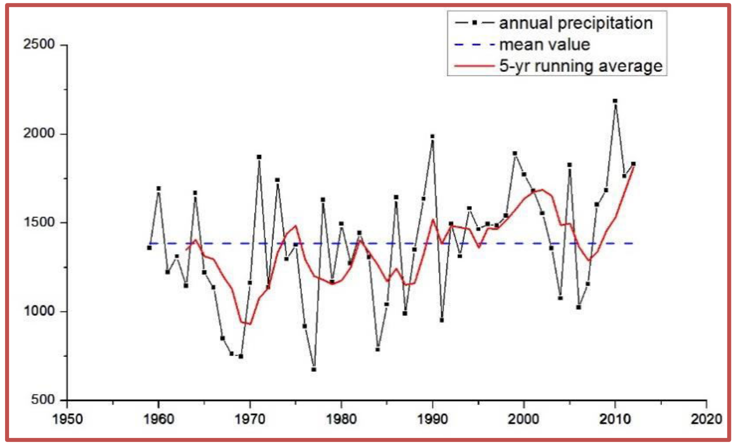
located in disparate climate areas



UC
269 mm

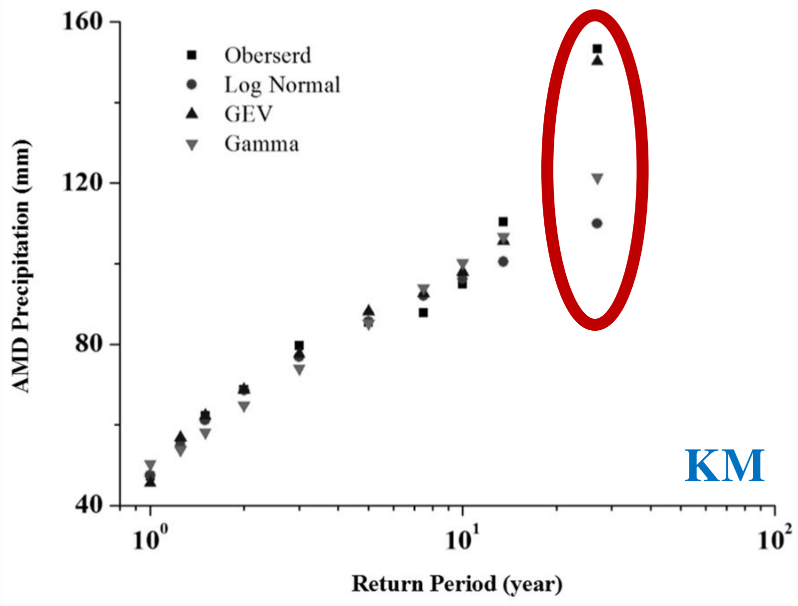


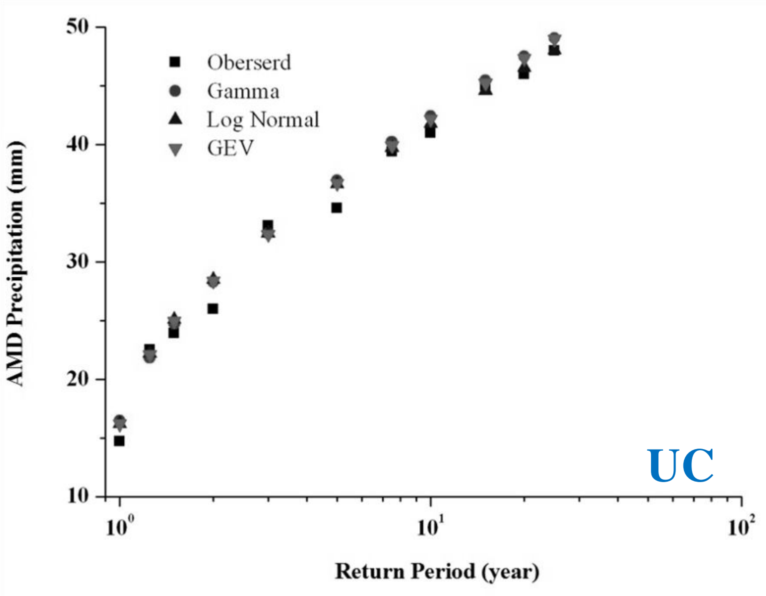
KM
984 mm

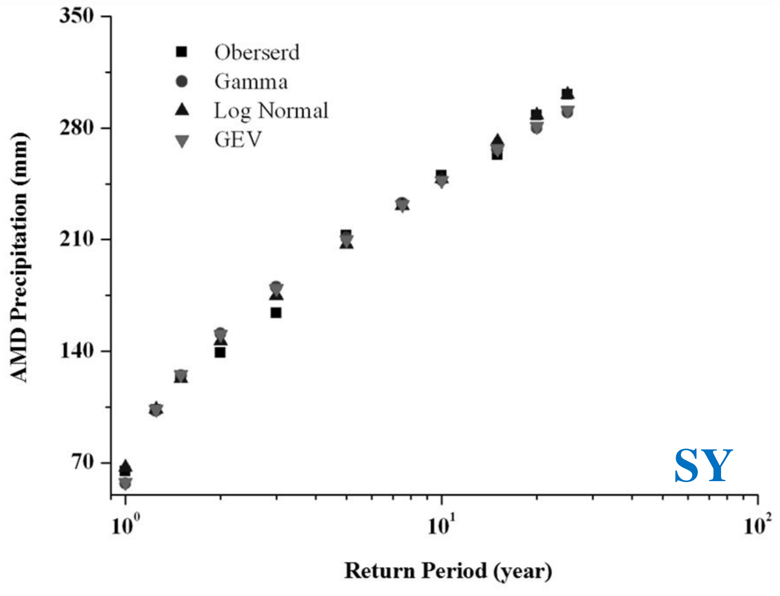


SY
1385 mm

Fitted AMD precipitations and observations







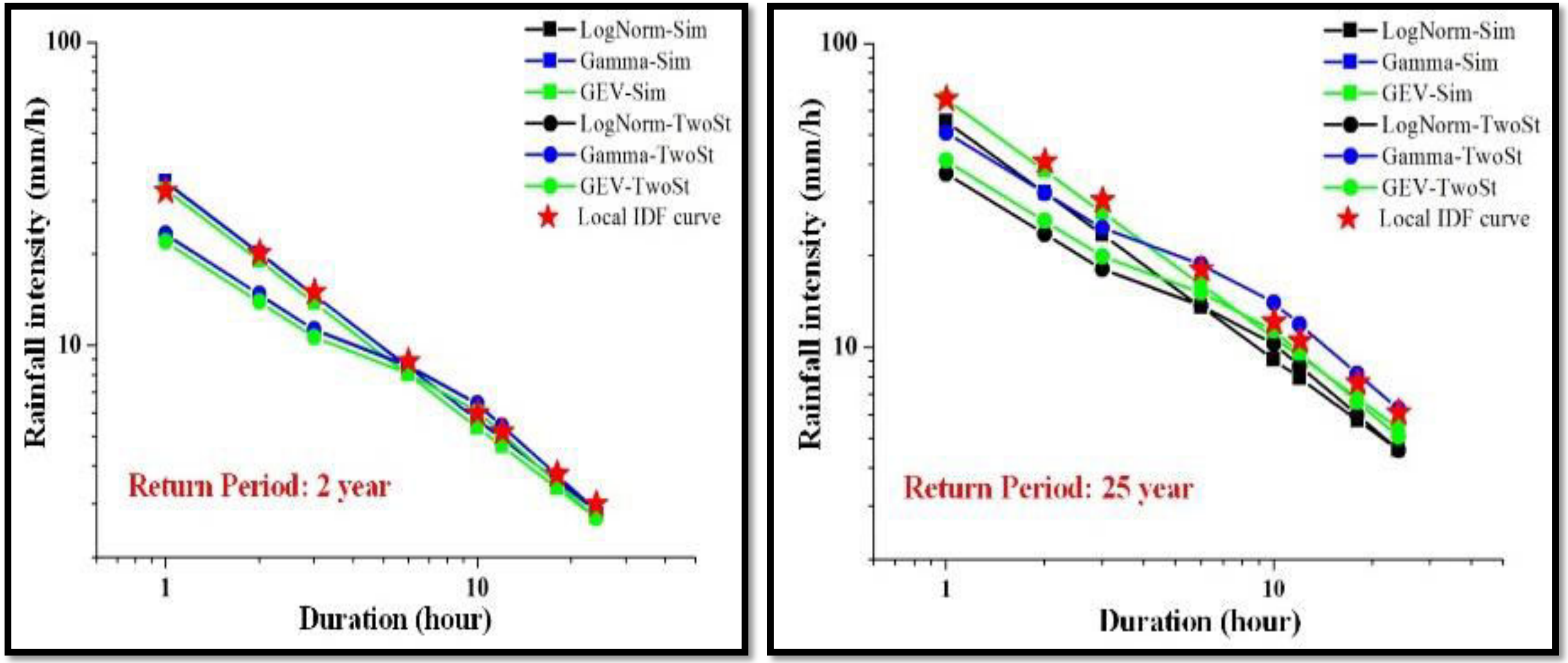
- Negative

5%
21%
28%

- For low return periods, relative error controlled within 3%;
- Condition varies for the extreme values among different cities

IDF curves comparison with different return periods

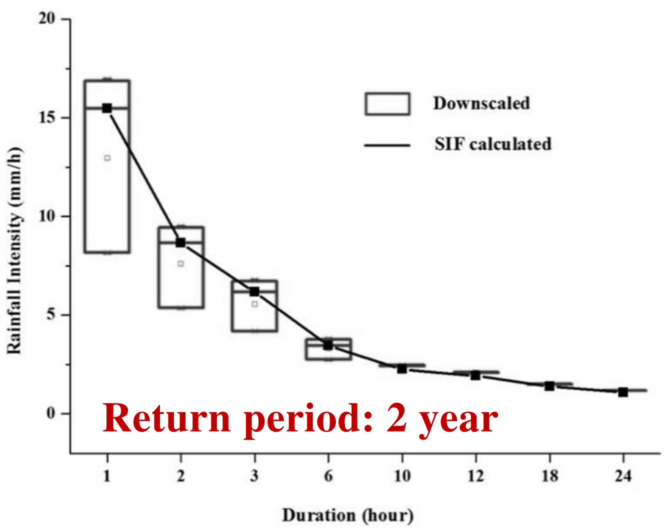
KM case

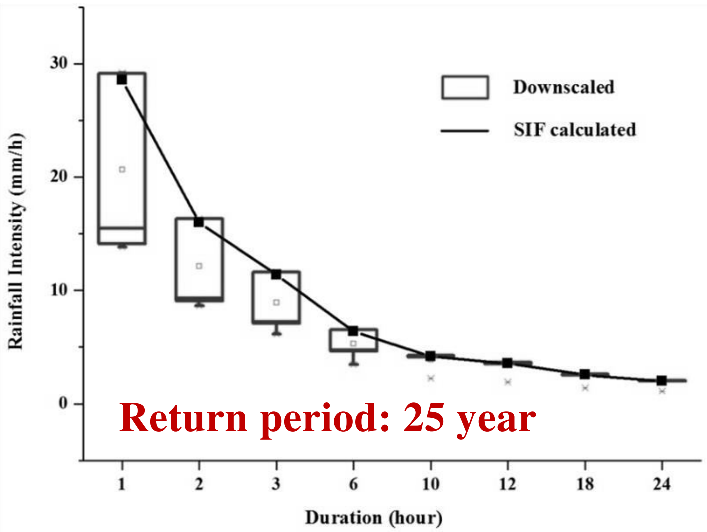


- Simple scaling is better ;
- 5% ;
- Multiple scaling match well when duration bigger than 6 hr.

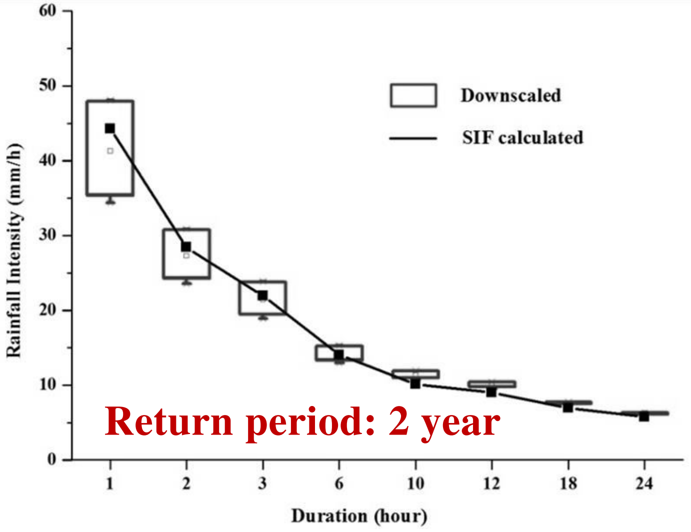
- a much less concise and explicit image ;
- the different scale invariance options still exist ;
- also the disparities of various fitted distributions shown up.

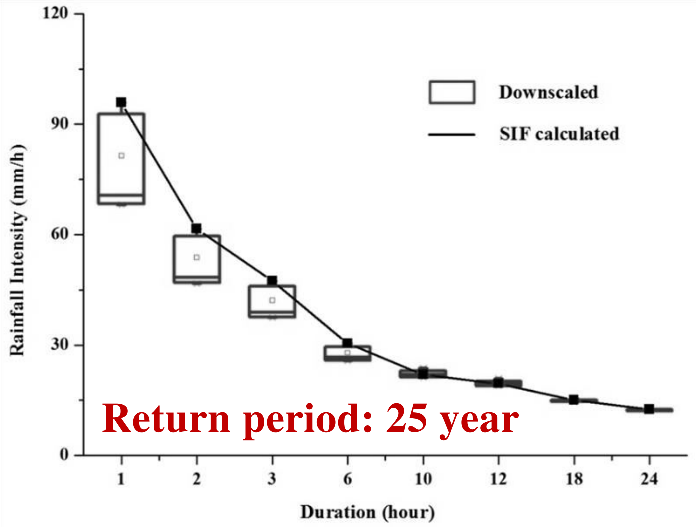
IDF curves comparison with different return periods





UC case





SY case

- Differences for the shorter duration is much bigger than the ones with the longer duration;
- Since the AMD-distribution-fitting performed similar in the UC and SY cases, so these differences are caused by the variance options selection;
- In other words, the scale variance options in the proposed temporal downscaling play a significant role in the process of deriving the rainfall intensities with shorter durations.

Performance comparison of different combination

Case	Items	MBE	RMSE	d	R^2
KM	LogNorm-Simple	-1.86	3.13	0.9890	0.9599
	GEV-Simple	-0.59	1.42	0.9980	0.9917
	Gamma-Simple	-1.18	1.66	0.9971	0.9887
	LogNorm-TwoStage	-4.98	8.46	0.8865	0.7073
	GEV-TwoStage	-3.03	5.86	0.9531	0.8597
	Gamma-TwoStage	-4.44	7.52	0.9145	0.7687
UC	LogNorm-Simple	0.21	0.40	0.9992	0.9968
	GEV-Simple	0.27	0.41	0.9991	0.9967
	Gamma-Simple	0.30	0.45	0.9990	0.9960
	LogNorm-TwoStage	-2.39	4.47	0.8163	-0.2510
	GEV-TwoStage	-2.35	4.42	0.8217	-0.2135
	Gamma-TwoStage	-2.33	4.40	0.8236	-0.2035
SY	LogNorm-Simple	0.24	0.82	0.9997	0.9986
	GEV-Simple	-0.14	1.11	0.9994	0.9974
	Gamma-Simple	-0.14	1.17	0.9993	0.9972
	LogNorm-TwoStage	-3.82	7.65	0.9601	0.7823
	GEV-TwoStage	-4.14	7.98	0.9562	0.7608
	Gamma-TwoStage	-4.14	7.99	0.9561	0.7599

- simple scaling is better than multiple scaling in all the cases;
- Based on the MBE evaluation, multiple scaling undervalued the results to some extent;
- “GEV-Simple”, “LogNorm-Simple”, and “LogNorm -Simple” showed more suitable than others for the KM, UC, and SY cases.

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- The aim of this study was to compare the performances of different temporal downscaling methods for deriving the IDF relationships from the AMD rainfall data.
- The results indicated that, selecting an appropriate distribution form is important in this process, and it is a more wise way to test several candidates rather than using one directly.
- As to the scale invariance options, the simple scaling appeared to be more reliable in all the cases, and multiple scaling mainly underestimated the precipitation intensities with shorter durations.

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Thank you !

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