Establishing Rainfall Depth-Duration-Frequency Relationships at Daily Raingauge Stations in Hong Kong

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Abstract: Rainfall intensity (depth)-duration-frequency (IDF/DDF) relationships provide essential information in urban stormwater drainage system design and other hydrosystem infrastructures. For catchments where drainage areas are small, rainfall DDF relationships with short duration can be established based on rainfall records from automatic raingauges. Due to the progression of technology development, wide spread installation of automatic raingauges does not happen until 2~3 decades ago. Therefore, record lengths at majority of automatic raingauges are relative short and the derived rainfall DDF relationships on the basis of at-site frequency analysis are potentially subject to significant sampling error. On the other hand, many conventional raingauges exist long before automatic raingauges were used. However, daily rainfall data with long records at conventional raingauges are of limited use to establish rainfall DDF relationships in areas like Hong Kong where storm duration significantly shorter than 24-hr are needed. This study presents a practical method to derive rainfall DDF relationships with short duration at conventional raingauge locations. The core components of the method include scaling model of rainfalls of different durations, establishment of relationship between annual maximum daily rainfall and rolling-time 1440min rainfall, quantification of statistical features of estimated annual maximum 1440min rainfalls, and assessment of uncertainty of derived rainfall DDF relationships at conventional raingauges.

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Introduction

- Design of stormwater drainage systems and other hydrosystem infrastructures

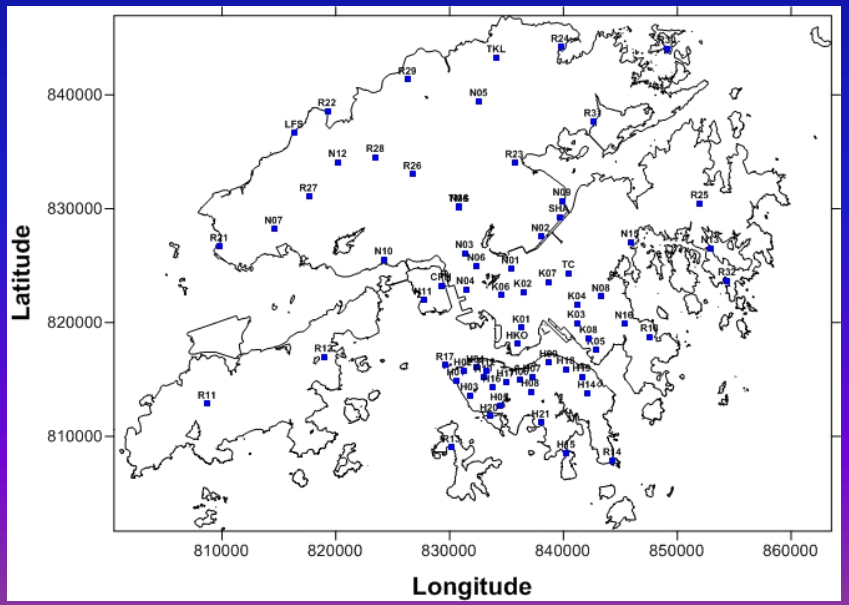
- *Rainfall intensity (depth)-duration-frequency (IDF/DDF)*

1997/98 Flooding in Mong Kok & Kowloon

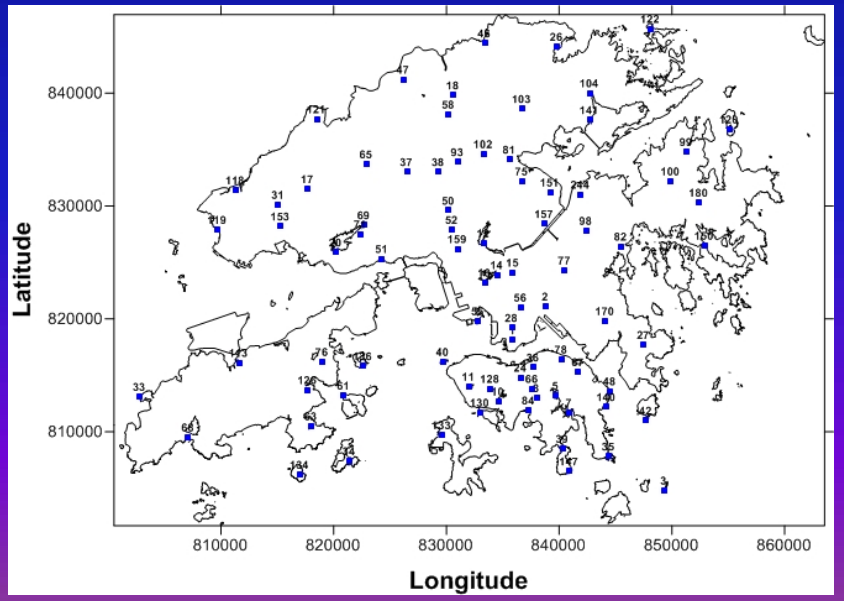
Flooding in Northern New Territory HK

Rainfall Data in HK

- Automatic stations
  - *Rainfall with fine time resolution*
  - *Short record length (<26yr)*



- Conventional stations
  - *Daily rainfall (3pm-3pm)*
  - *Longer record length (up to 57yr)*
  - How to utilize the data?



Rainfall Scaling Model (1)

- Scaling model

$$\frac{D_{t,T}}{D_{t_b,T}} = e^{c_0(t)}\left(\frac{t}{t_b}\right)^{c_1(t)}$$

where t = rainfall duration of interest

t_b = selected reference rainfall duration

T = return period

c_0, c_1 = scaling model parameters

$D_{t,T}$ = t-min, T-yr rainfall depth

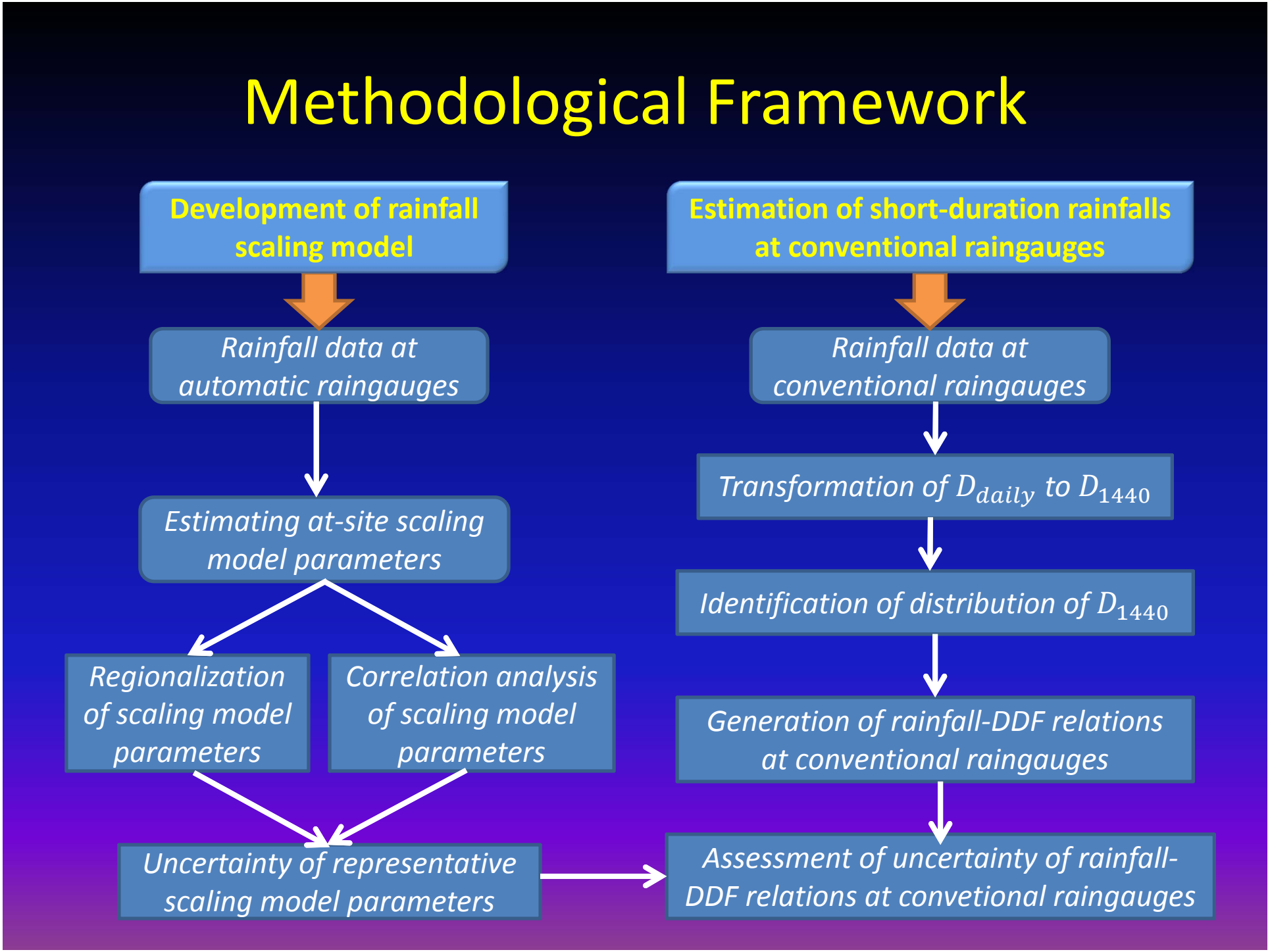
Rainfall Scaling Model (2)

- Scaling-invariant property

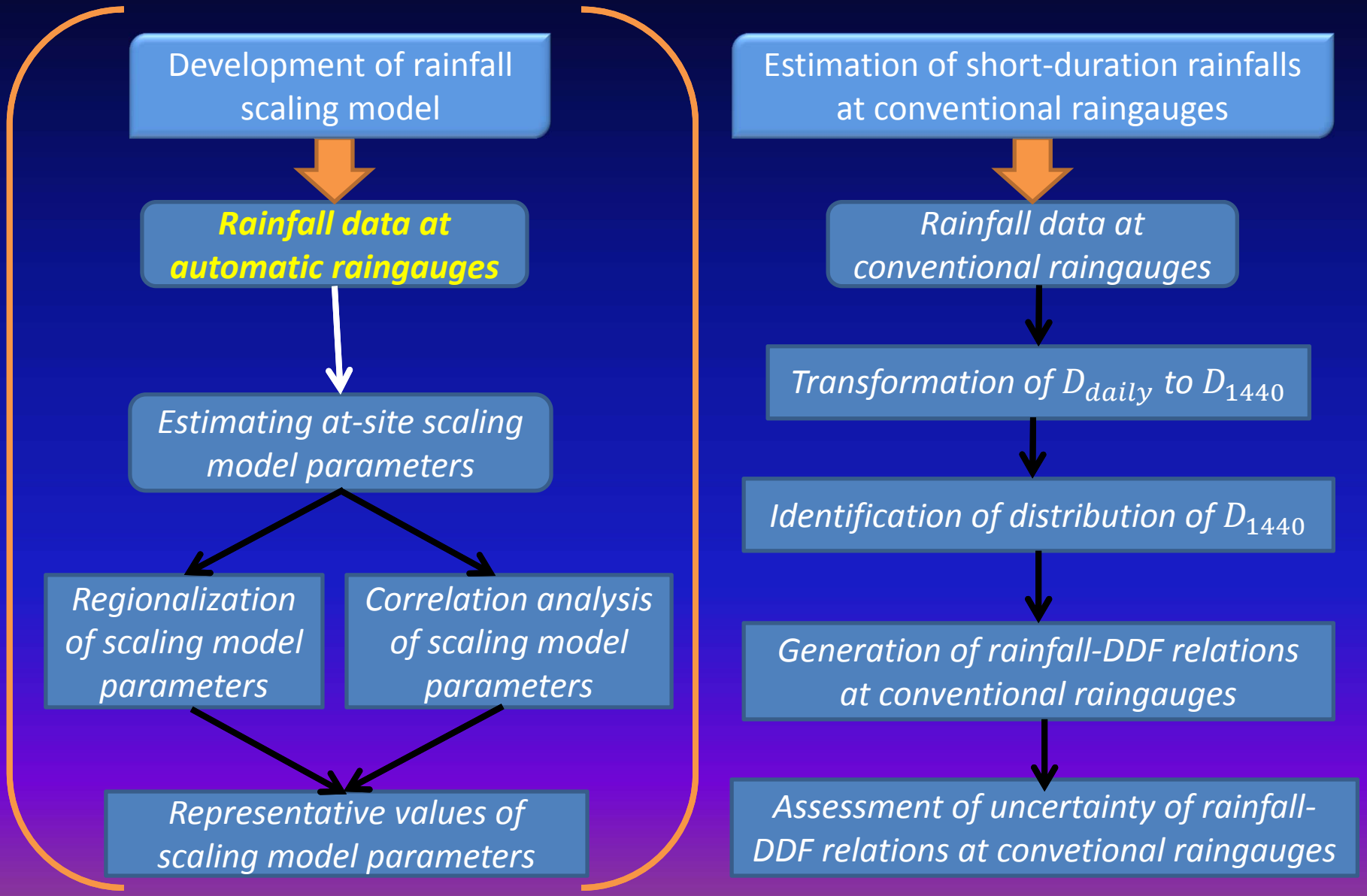
$$\frac{D_{t,T}}{D_{t_b,T}} = \left(\frac{t}{t_b}\right)^{\beta}$$

where β = scaling model parameter independent of rainstorm duration t

Methodological Framework

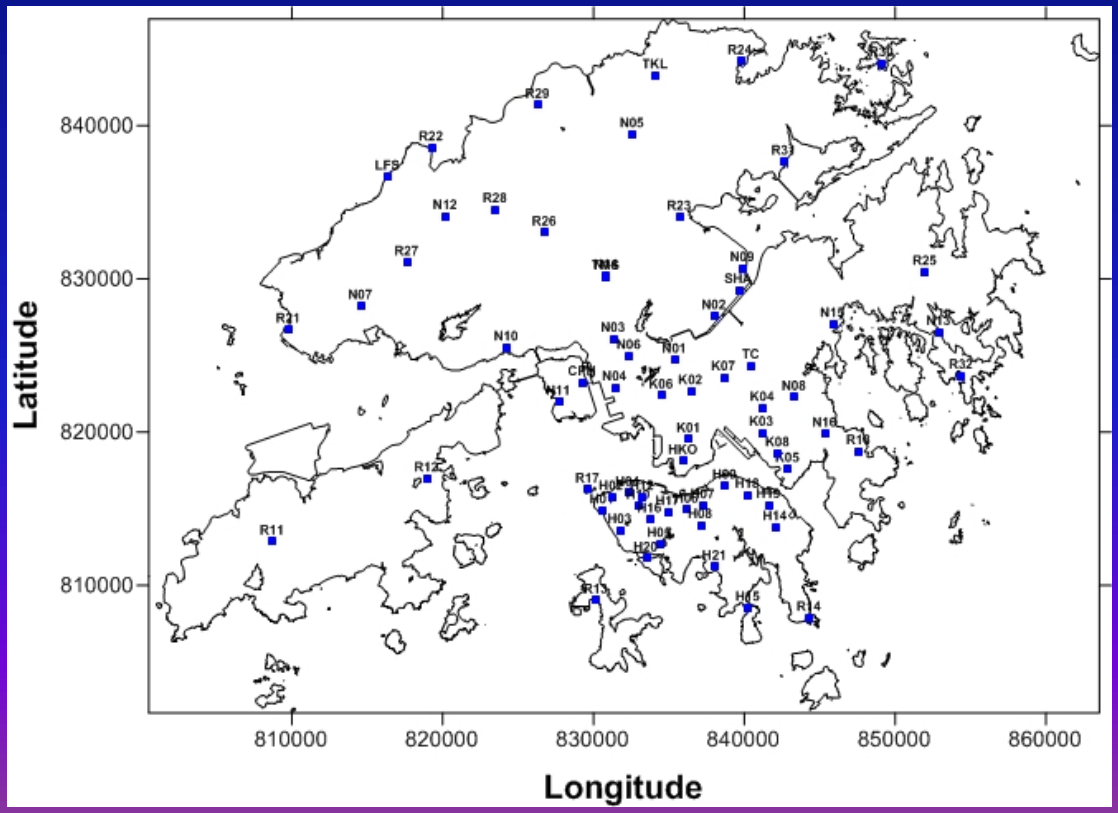


Methodological Framework



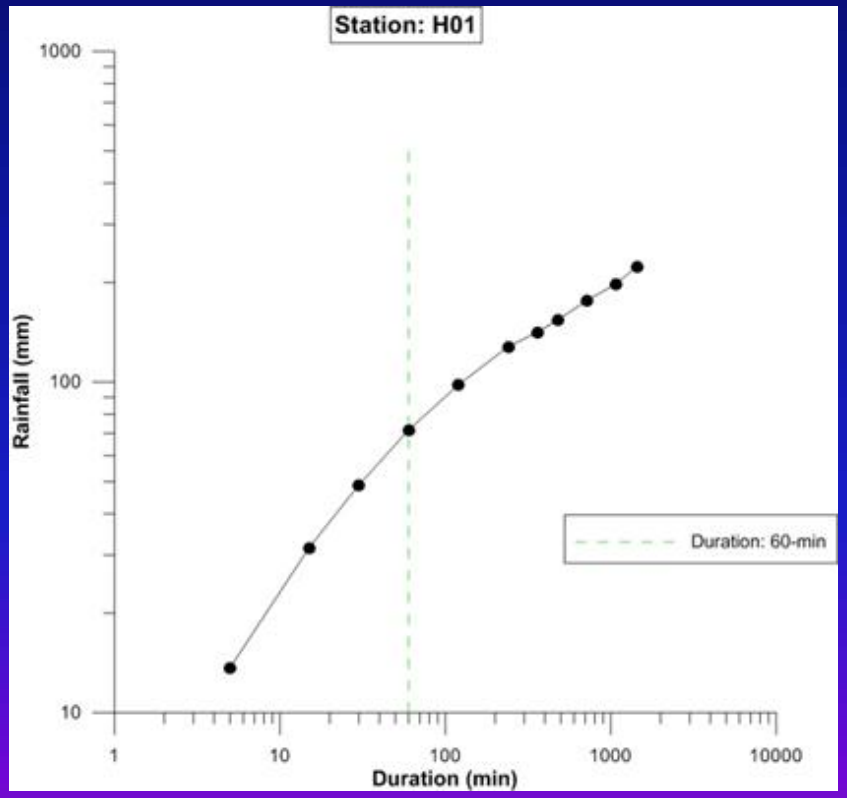
Raingauge Stations in HK (1)

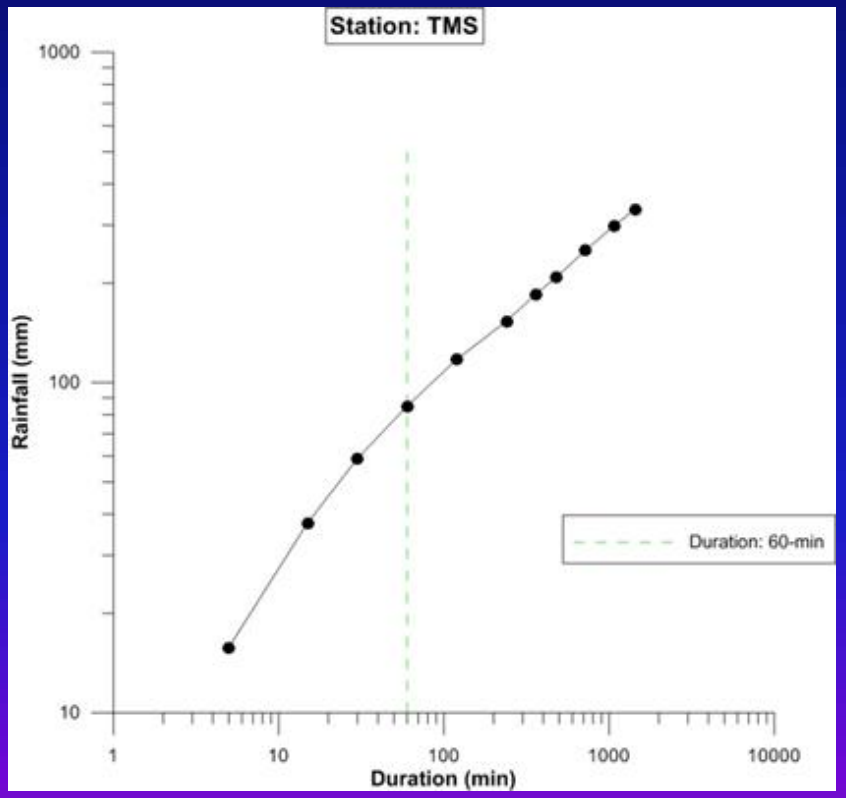
- Automatic raingauges (5min) in HK
  - *Total: 150*
  - *Selected: 68 (Record length 20~26 yr)*



Mean Annual Maximum Rainfall vs. Duration

- *Two slopes: 0~60min 60~1440min.*





Rainfall Scaling Model for Hong Kong

- *5min < t < 60min*

$$\frac{D_{t,T}}{D_{t_b,T}} = e^{a_0}\left(\frac{t}{t_b}\right)^{a_1}$$

- *60min < t < 1440min*

$$\frac{D_{t,T}}{D_{t_b,T}} = e^{b_0}\left(\frac{t}{t_b}\right)^{b_1}$$

where (a_0, a_1) and (b_0, b_1) = scaling model parameters in the two duration segments

Scaling-invariant of Property of GEV

- Scaling-invariant property of GEV:

- If

$$\alpha(t) = \alpha(t'), for\ t \neq t'$$

- Then

$$\frac{D_{t,T}}{D_{t_b,T}} = (\frac{t}{t_b})^{\beta}$$

where β = scaling model parameter independent of rainstorm duration t

α = shape parameter of GEV distribution

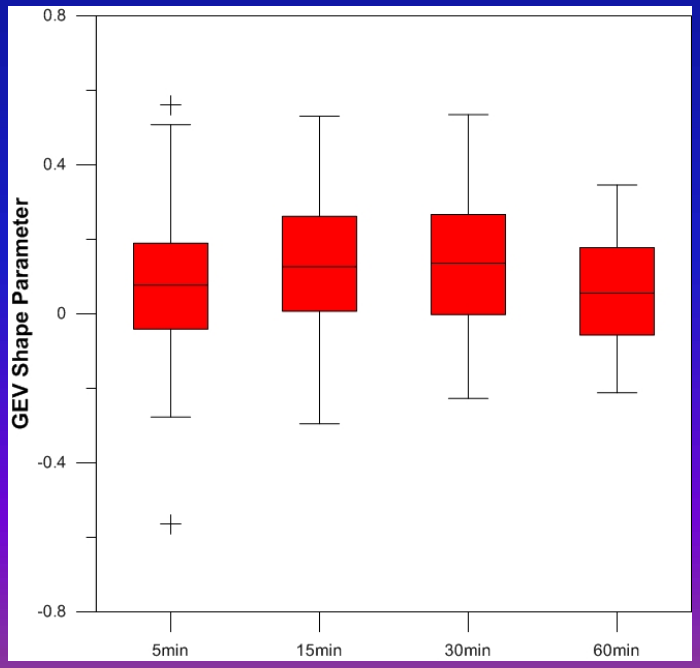
Scaling-invariant Property of GEV at Automatic Raingauges

- Scaling-invariant property of GEV

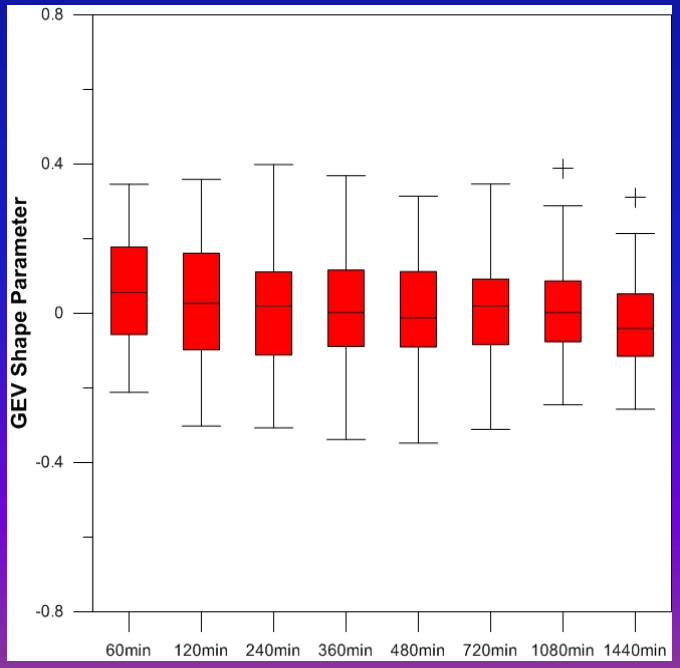
$$\alpha(t) = \alpha(t'), for\ t \neq t'$$

Box plots of GEV shape parameter value by duration.

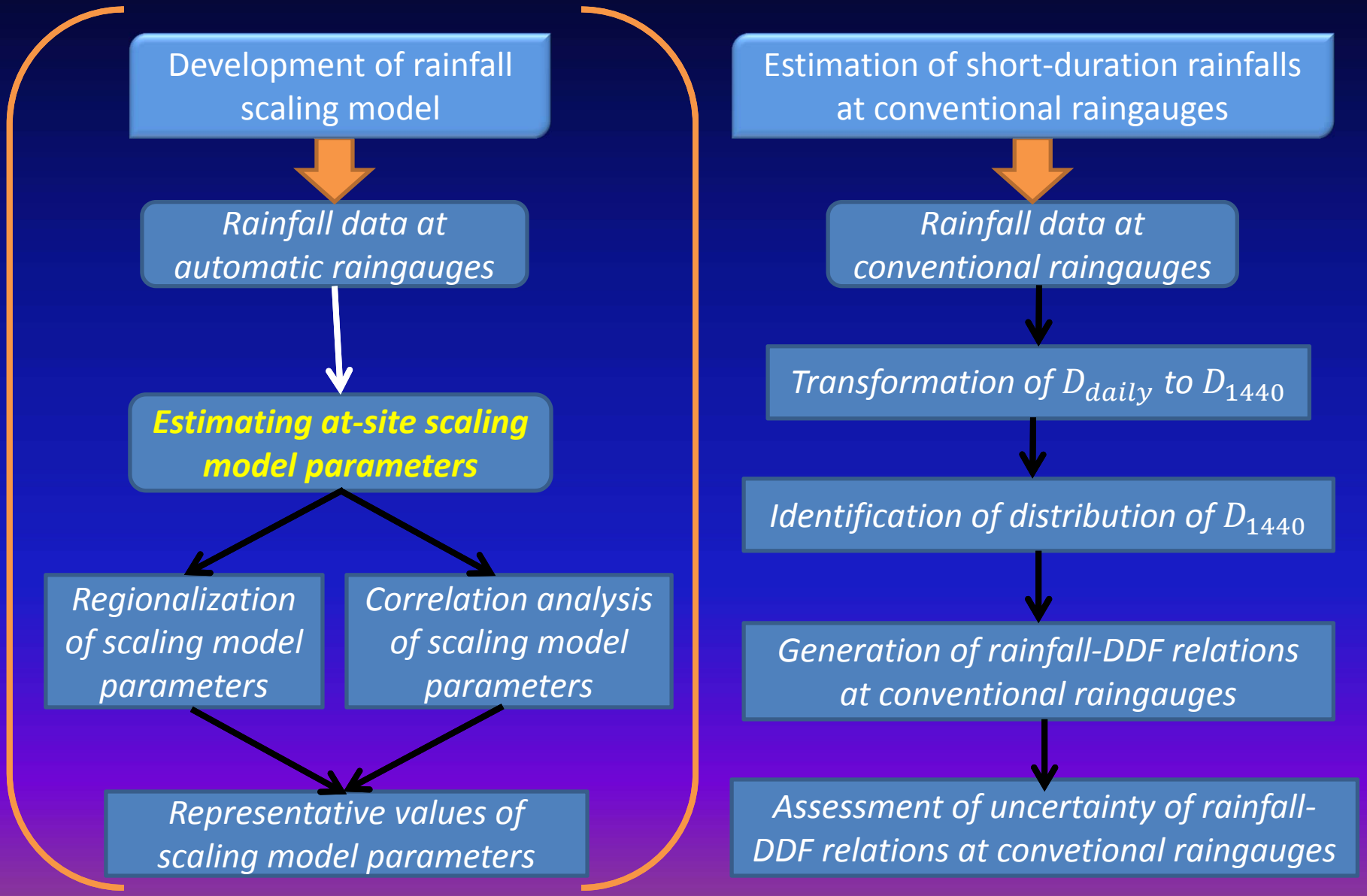
5min<t<60min



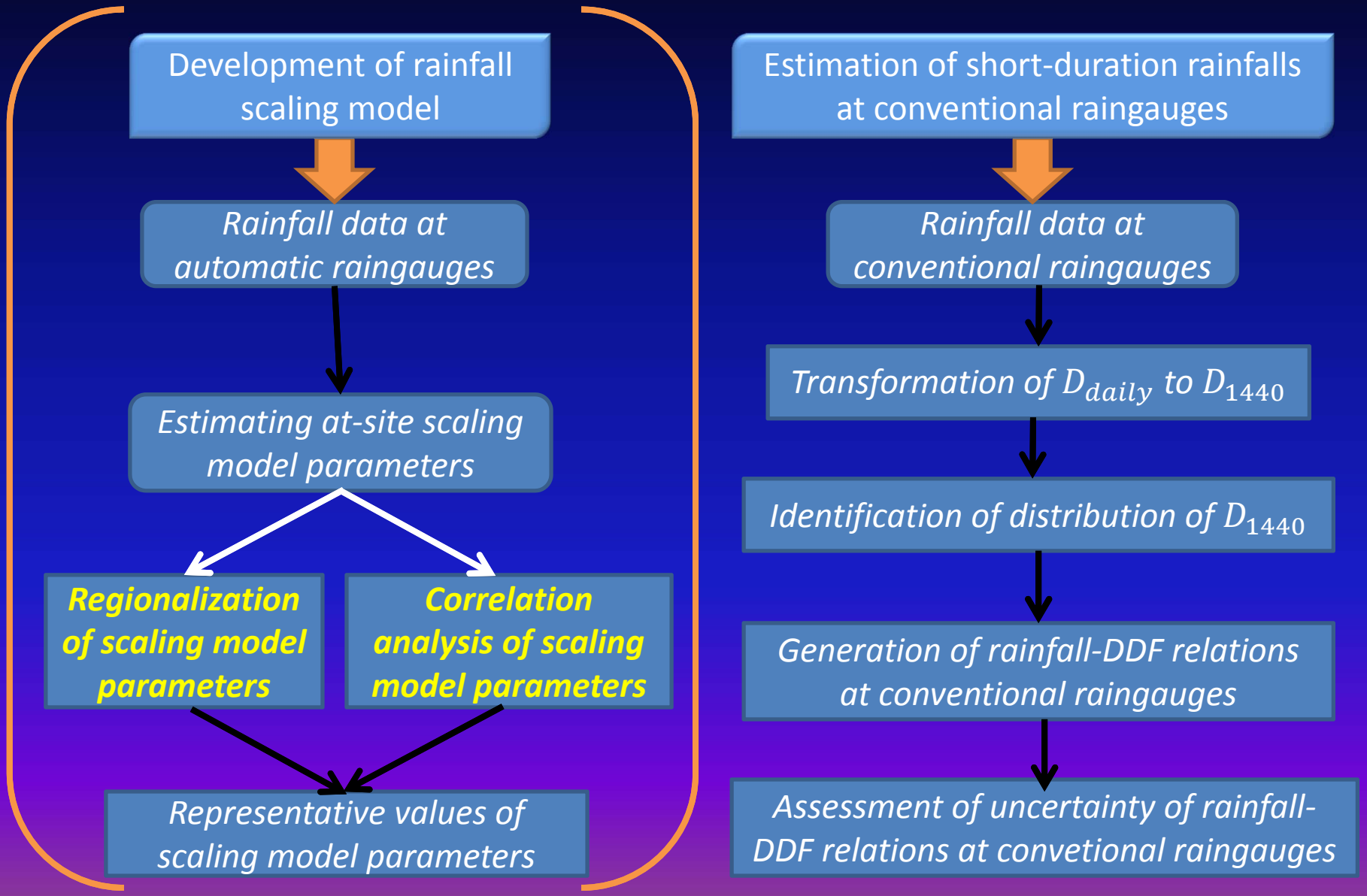
60min<t<1440min



Methodological Framework



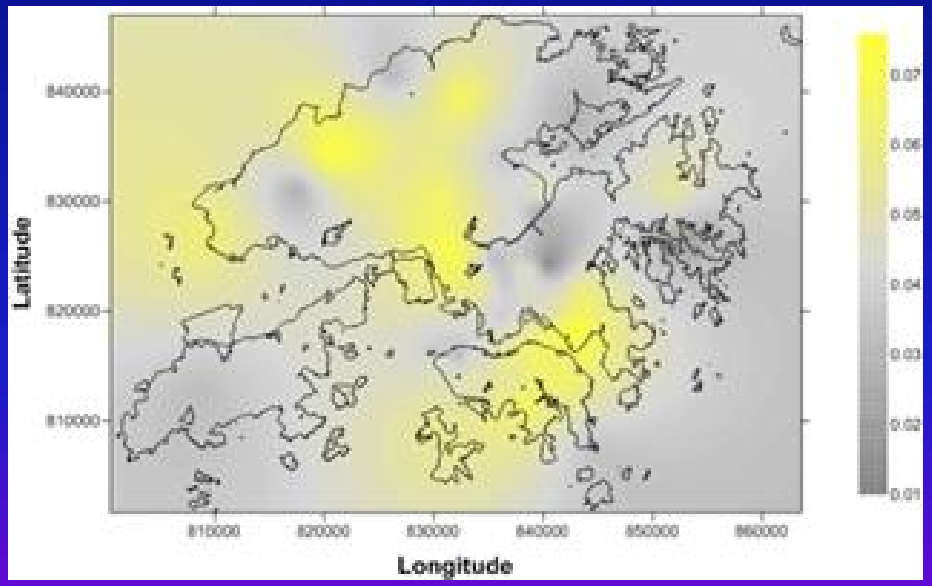
Methodological Framework



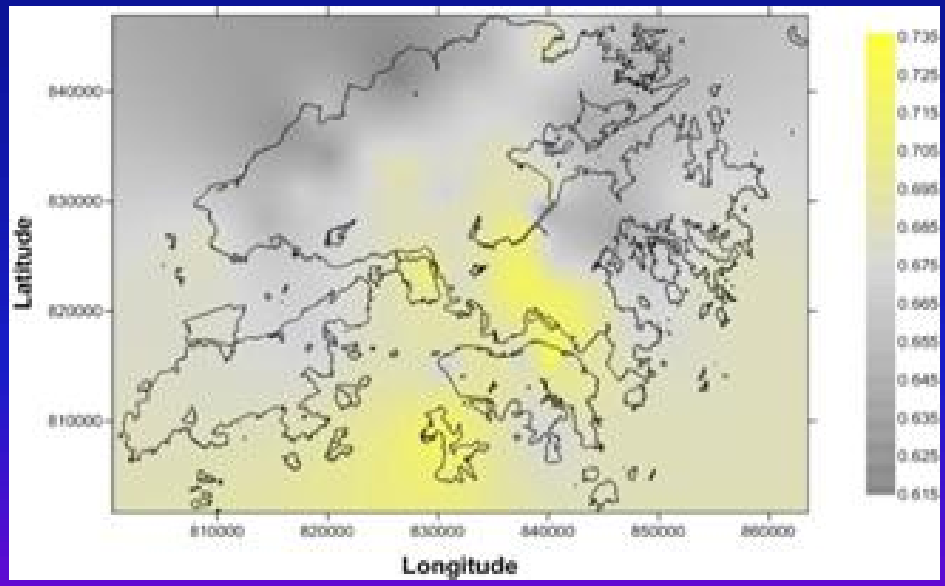
Contours of Scaling Model Parameters (1)

- *Duration: 5min< t<60min*

Parameter a_0



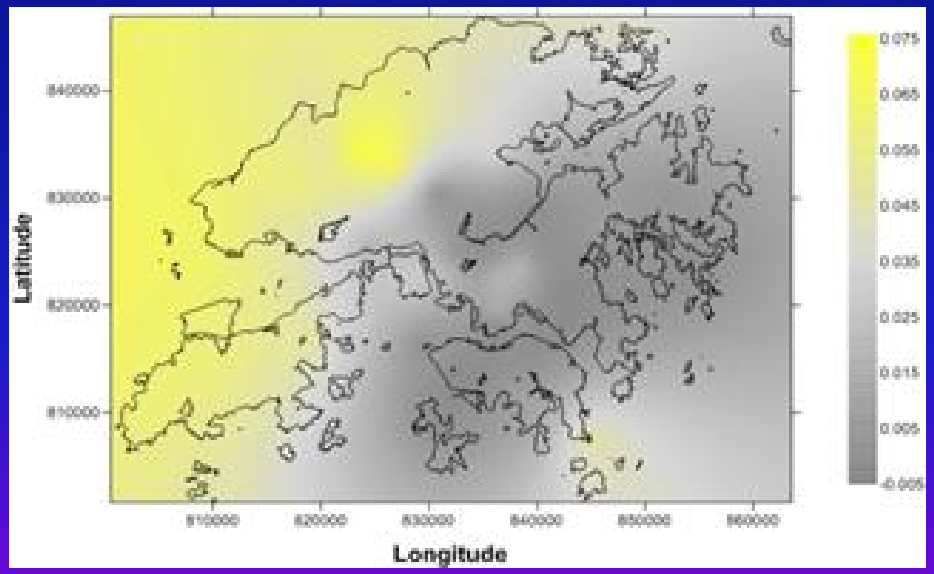
Parameter a_1



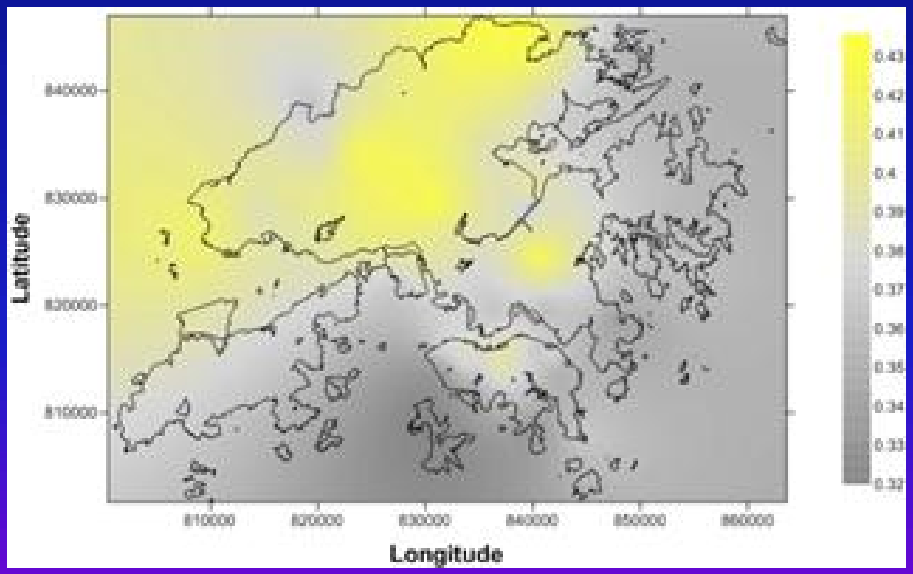
Contours of Scaling Model Parameters (2)

- *Duration: 60min< t<1440min*

Parameter b_0



Parameter b_1



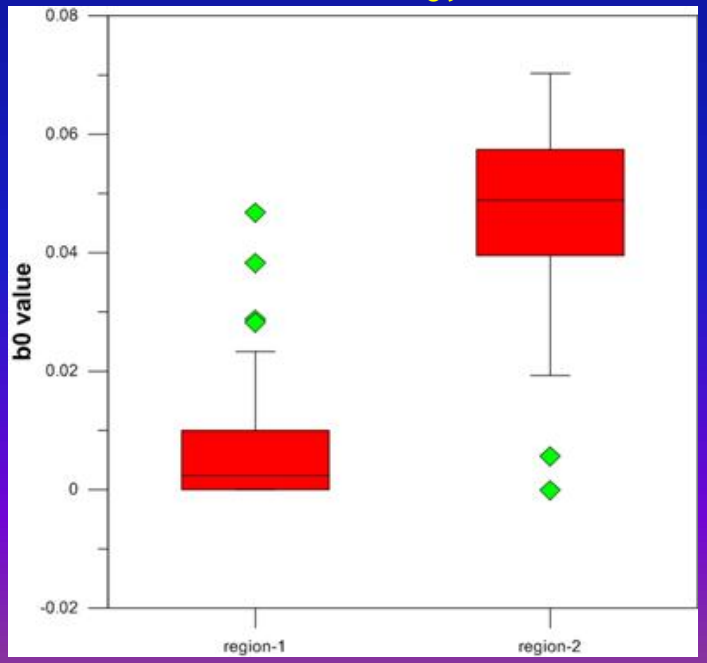
Regionalization of Scaling Model Parameters

- K-means cluster analysis:

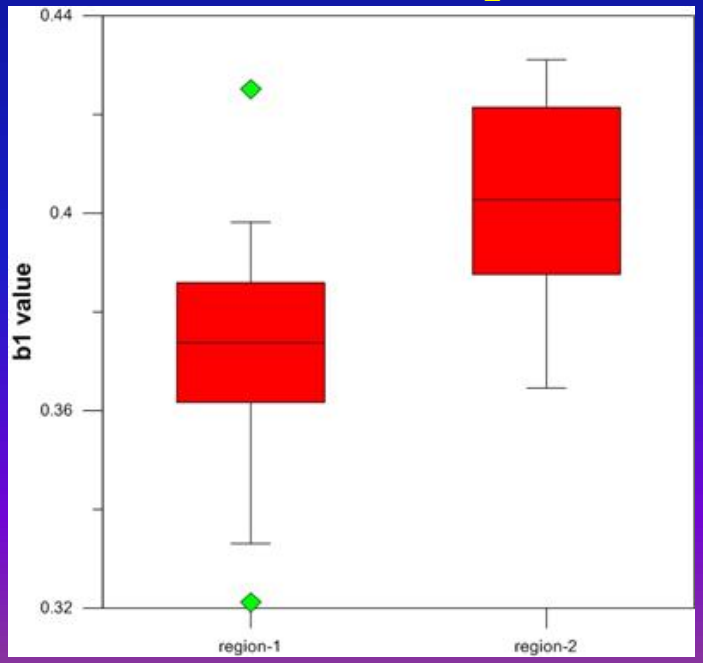
❑ *Parameter pairwise* (a_0, a_1) : one region (the whole HK)

❑ *Parameter pairwise* (b_0, b_1) : two regions

Box plot (b_0)



Box plot (b_1)

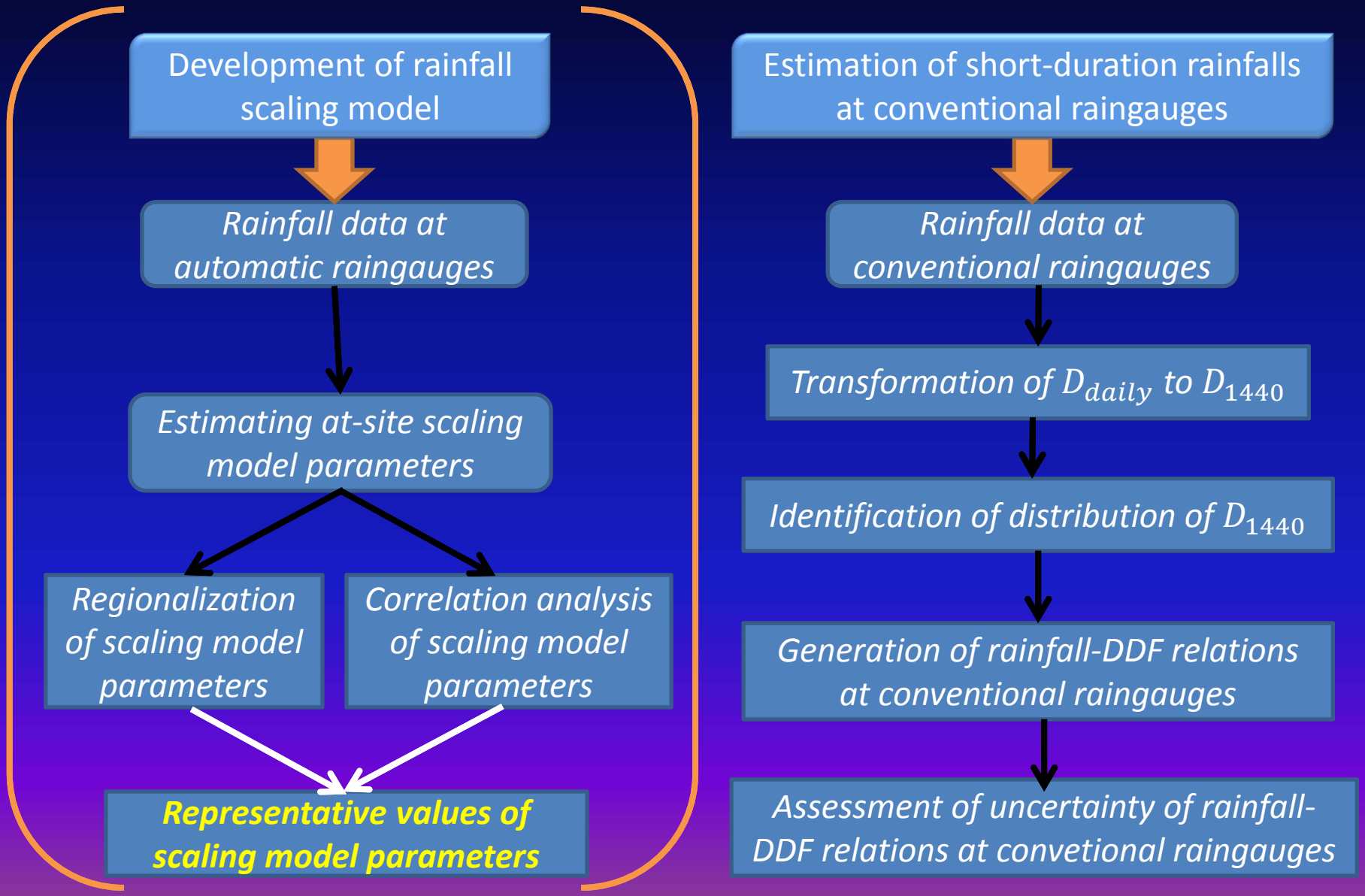


Correlation of Scaling Model Parameters

	(a_0, a_1)	(b_0, b_1)	
	Entire Hong Kong	Homog. Region 1*	Homog. Region 2*
ρ	0.202	0.032	-0.276
p-value	0.099	0.826	0.268

where $\rho =$ correlation coefficients

Methodological Framework



Representative Values for Scaling Model Parameters (1)

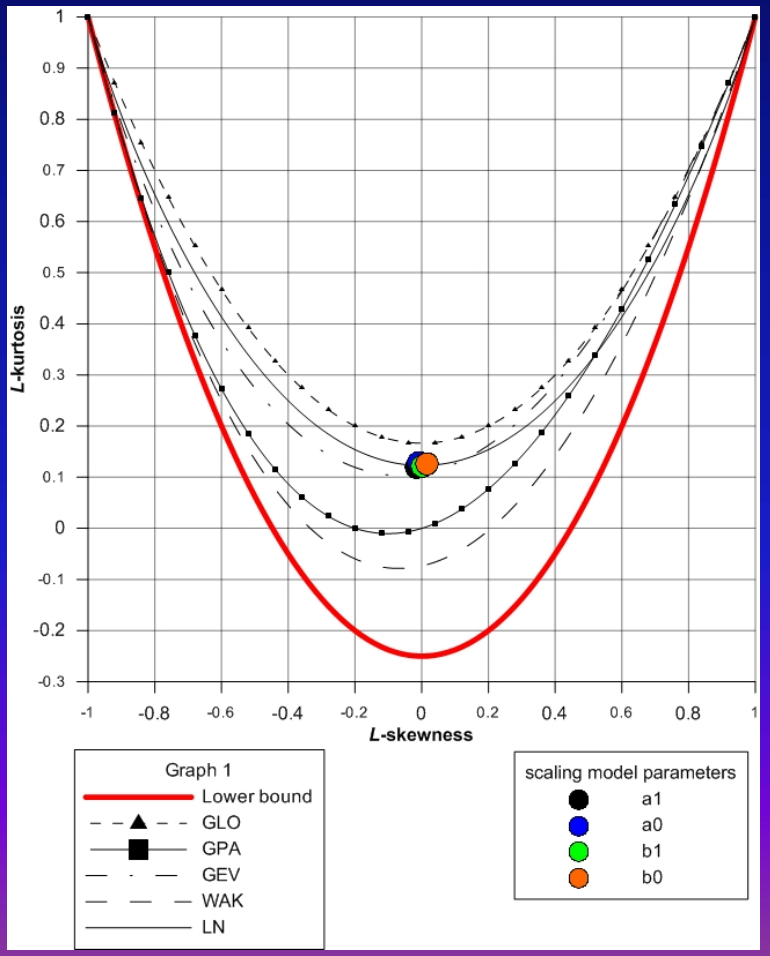
- Representative values
  - *The mean values of at-site scaling model parameters within a homogeneous region*

- Uncertainty
  - *Bootstrap method (5000 repetitions)*
  - *LMR diagram is used to determine the distributions*

Representative Values for Scaling Model Parameters (2)

- L-moment ratio diagrams of the representative scaling model parameters

- *Normal distribution*



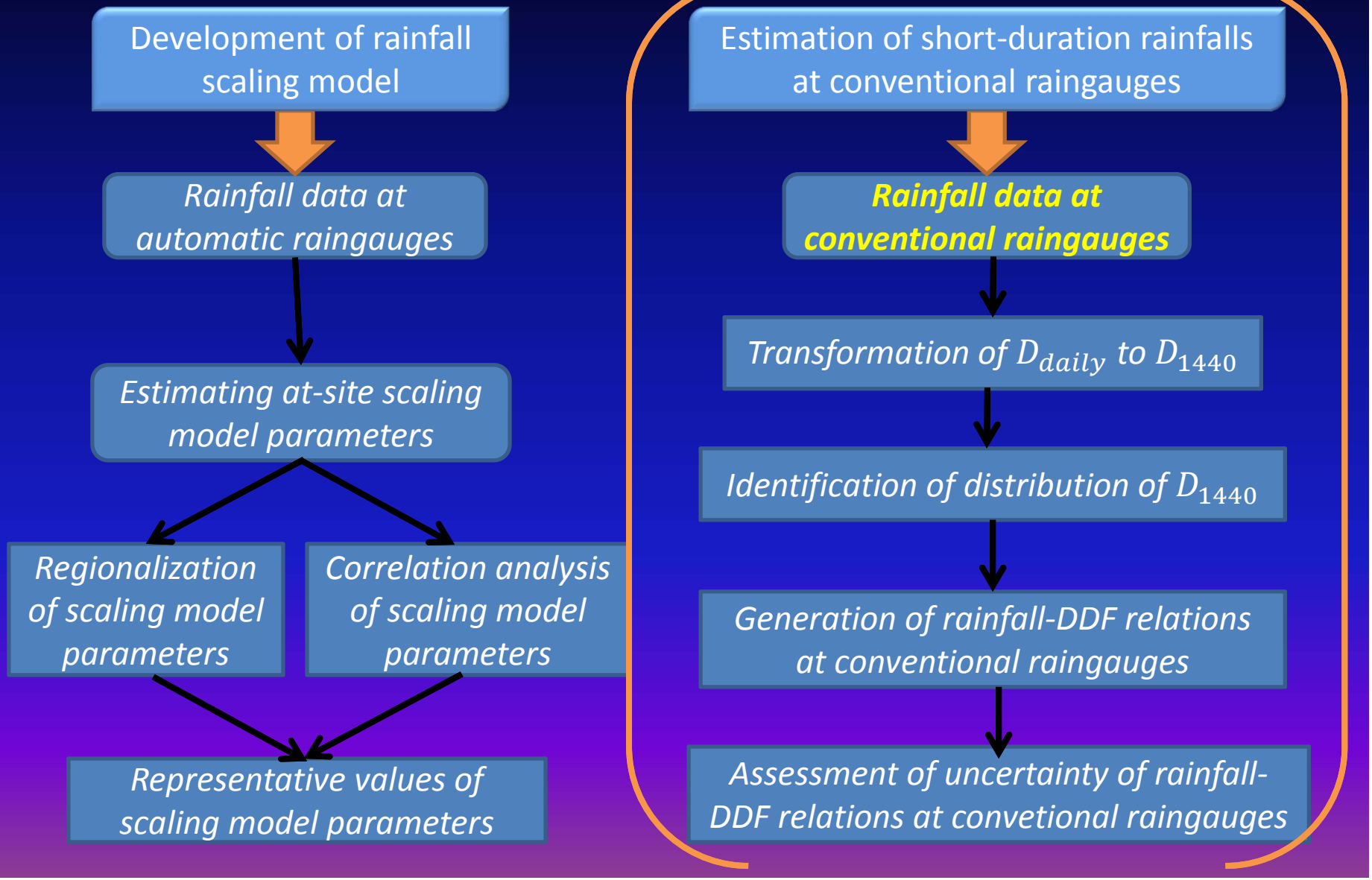
Representative Values for Scaling Model Parameters (3)

- Statistical properties

Parameter	a_0	b_0	
Region	Entire Hong Kong	Homog. Region 1	Homog. Region 2
Mean	0.053	0.007	0.044
Stdev	0.002	0.002	0.004

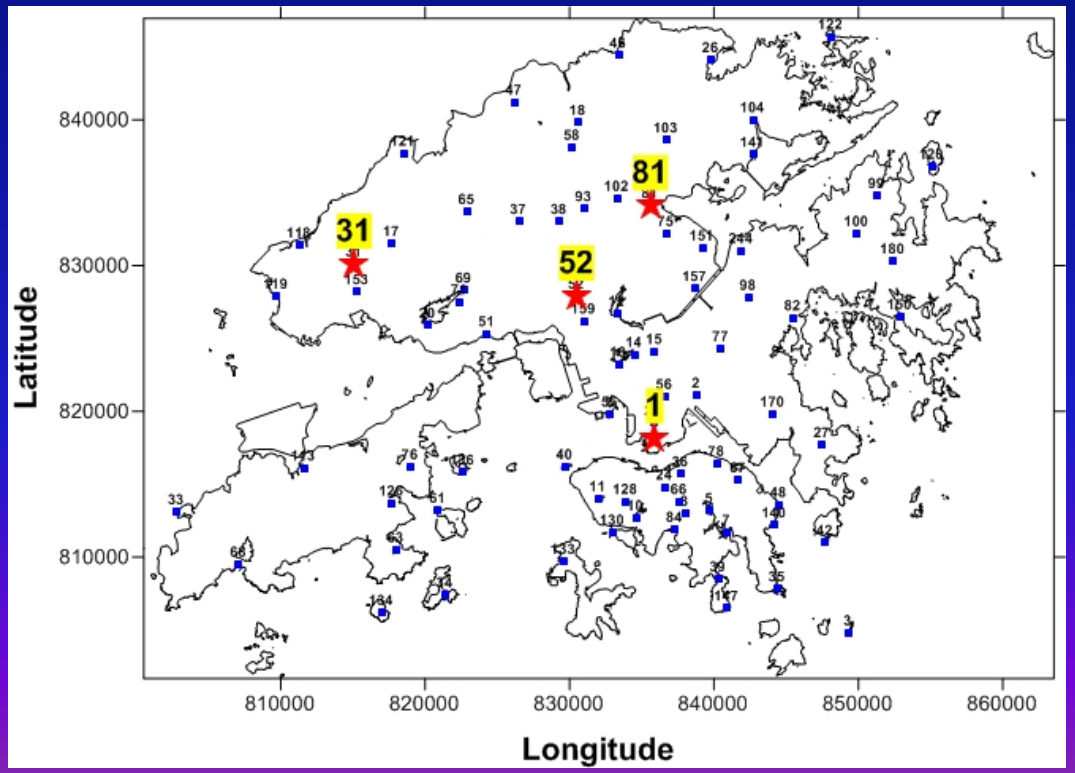
Parameter	a_1	b_1	
Region	Entire Hong Kong	Homog. Region 1	Homog. Region 2
Mean	0.684	0.372	0.402
Stdev	0.003	0.003	0.005

Methodological Framework



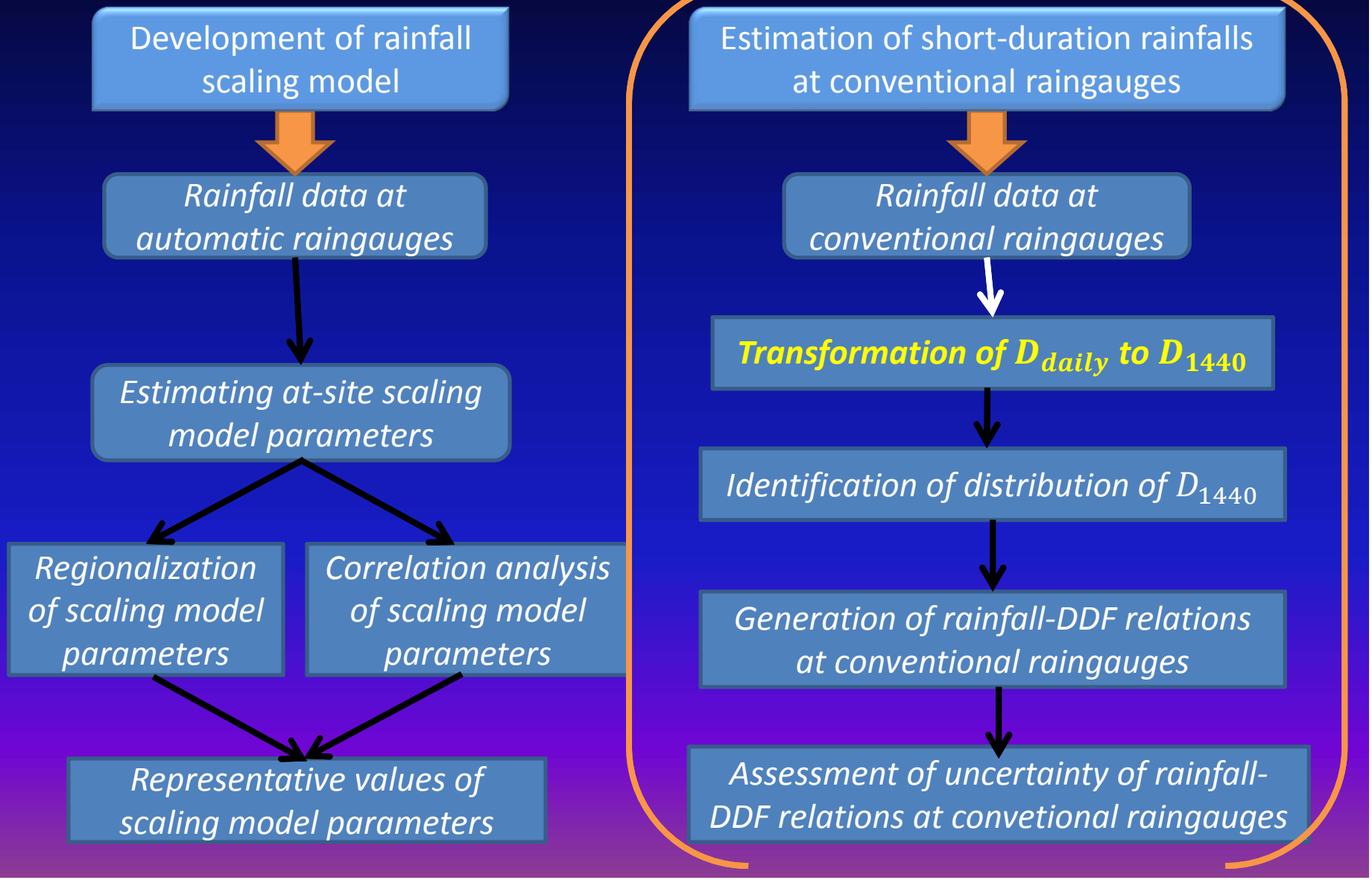
Raingauge Stations in HK (2)

- Conventional raingauges in HK
  - *Total: 250*
  - *Selected: 122 (Record length 20~57 yr)*



Note: starred stations are utilized for the presentation purpose

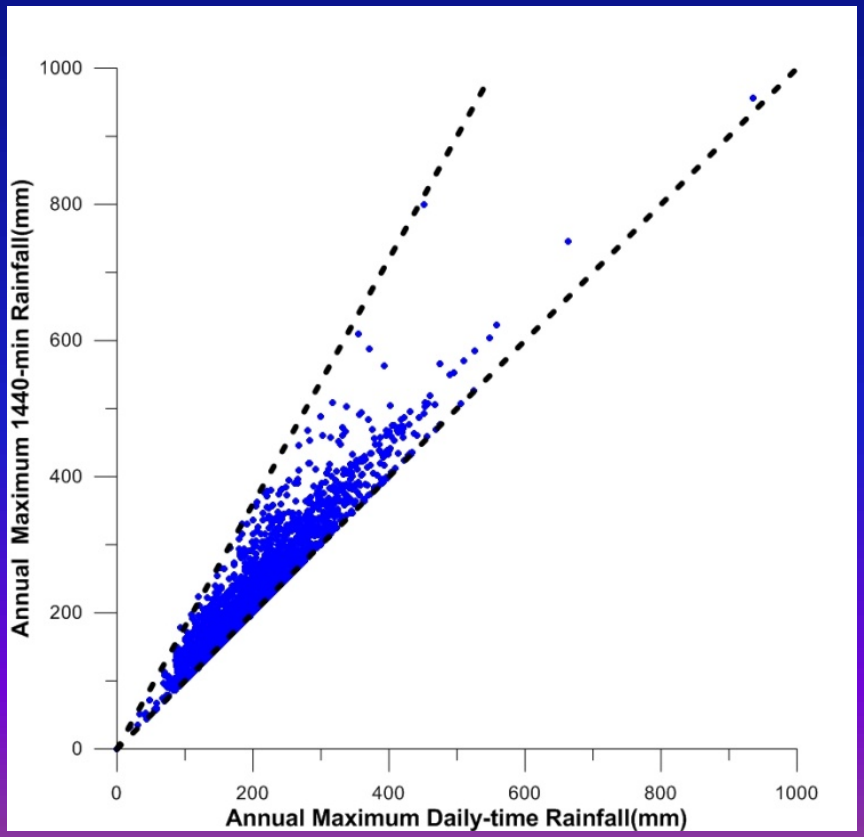
Methodological Framework



Transformation of D_{daily} to D_{1440} (1)

- $D_{1440} = f D_{daily} + e$

D_{1440} vs. D_{daily} at selected automatic raingauges in Hong Kong.



Transformation of D_{daily} to D_{1440} (2)

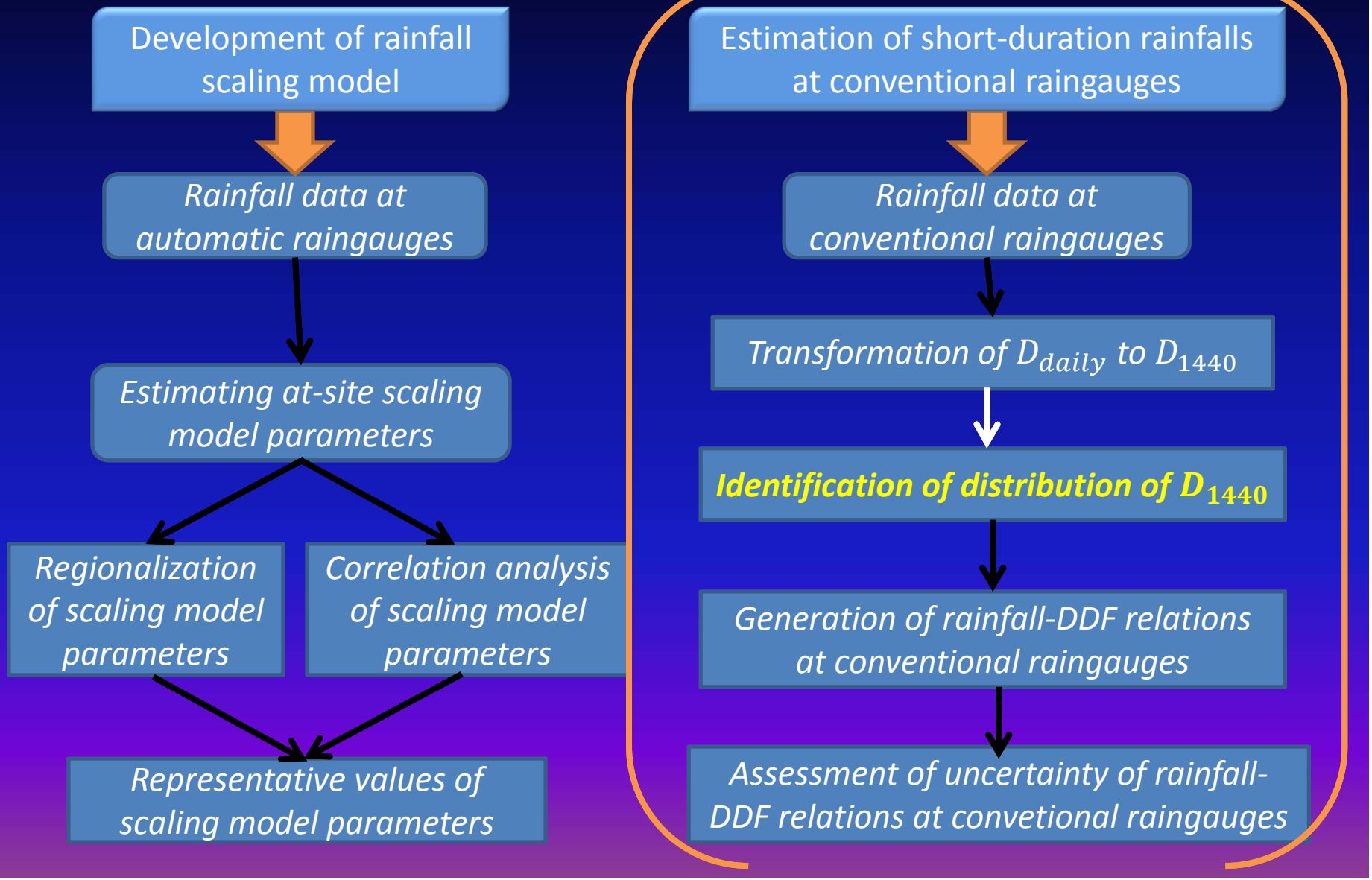
- *Weighted least square method*
- $D_{1440} = f\,D_{daily} + e$

Statistical properties of the estimated coefficients.

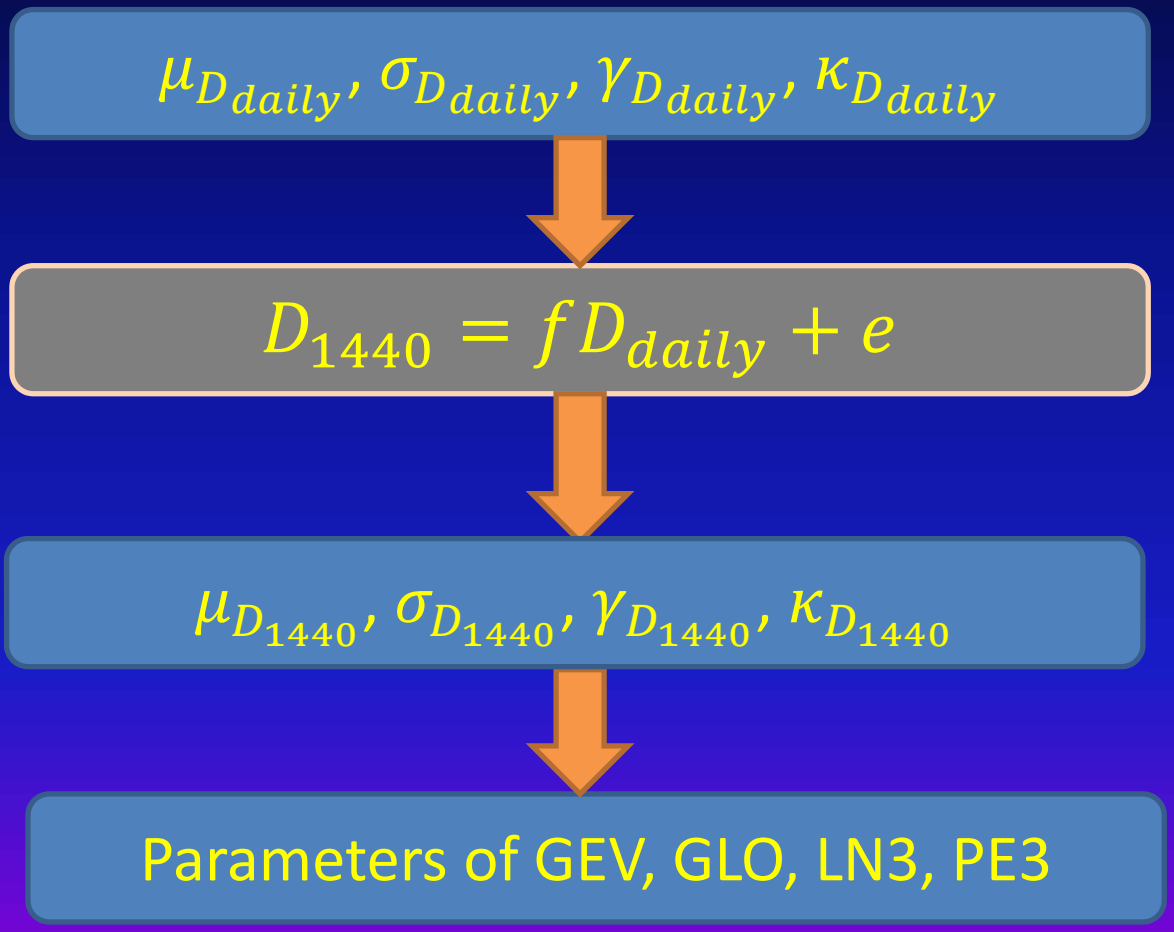
	Coefficient	Standard Error	t-value	p-value
f	1.145	0.00312	367.10	0.000
e	0.000	28.8774		

- f: $a\ constant$
- $e \sim N(0,\ 28.88^2)$

Methodological Framework

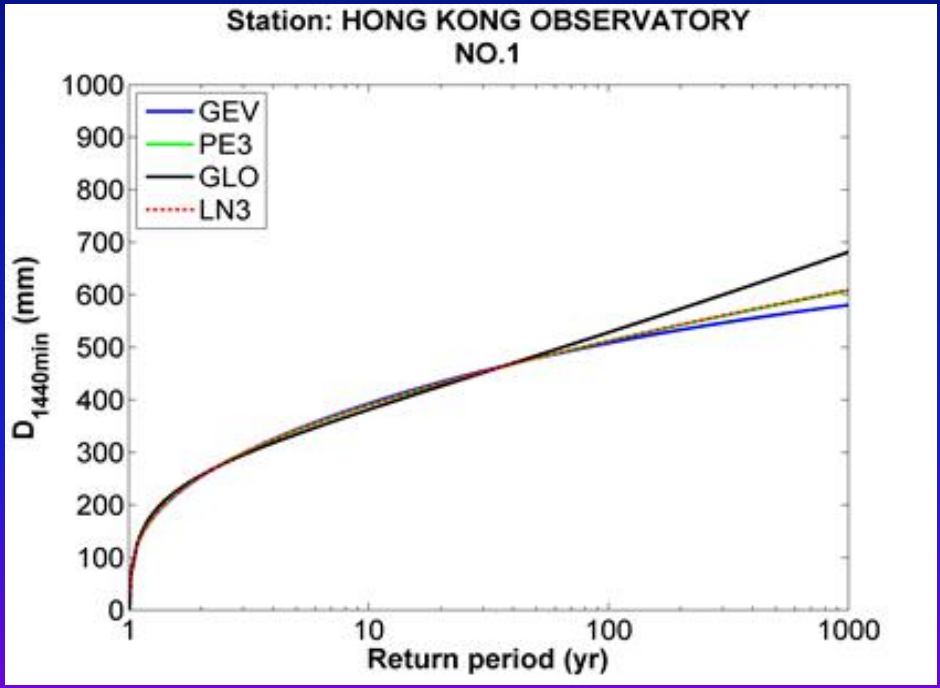


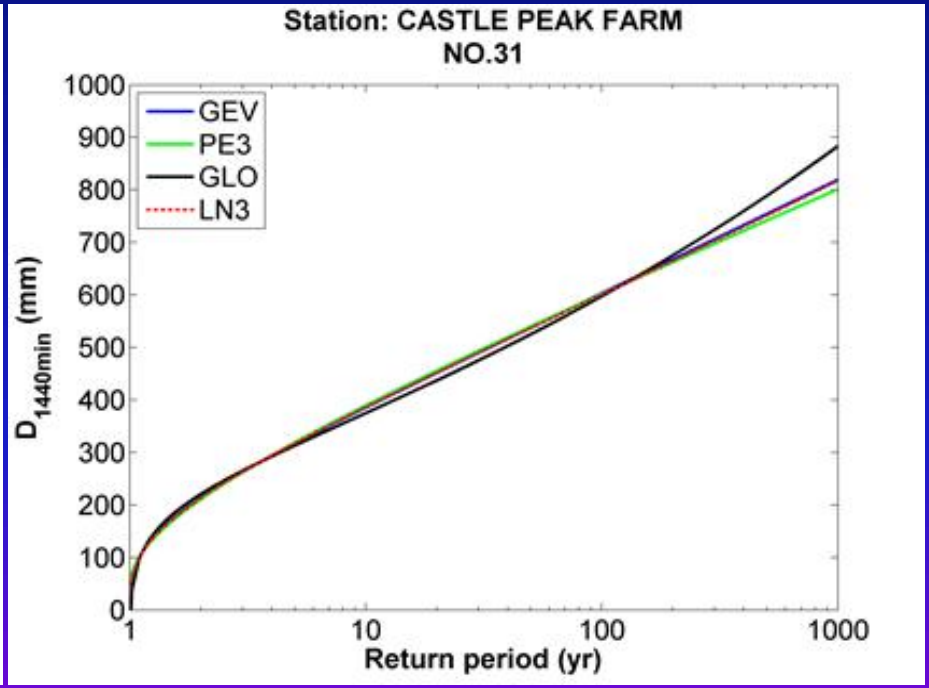
Identifying Distribution of D_{1440} at Conventional Raingauges (1)



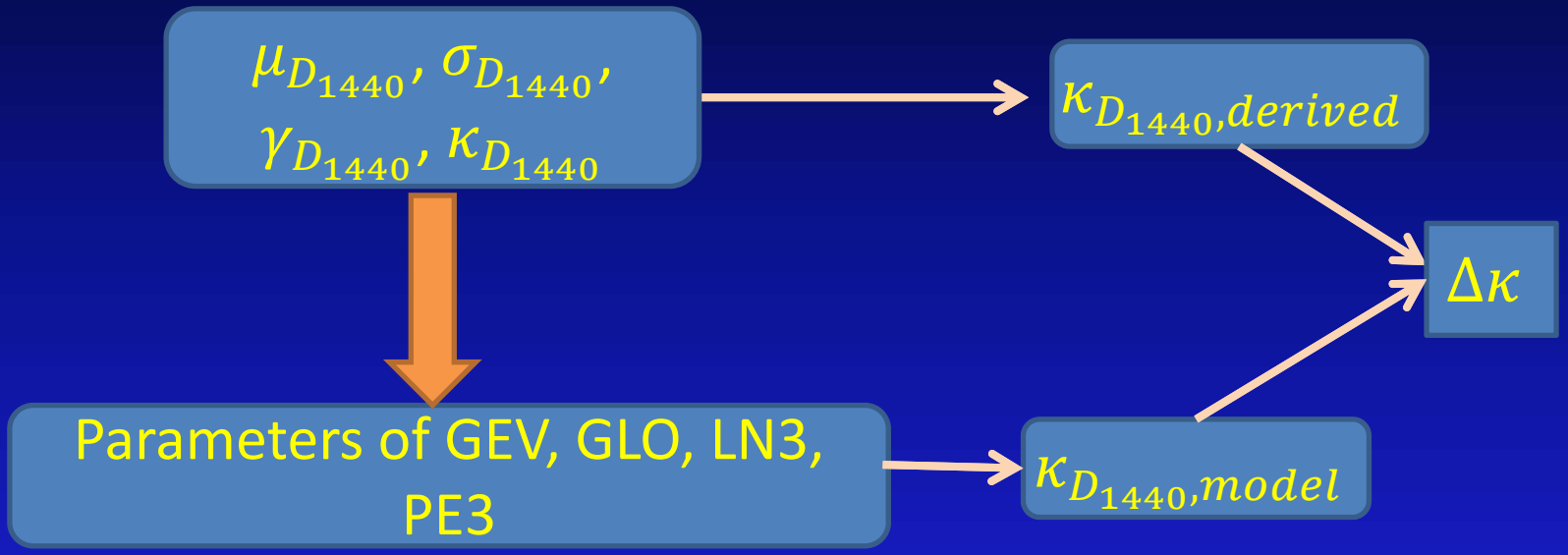
Identifying Distribution of D_{1440} at Conventional Raingauges (2)

- Fitted to different distributions
  - *GEV, GLO, PE3, LN3*





Identifying Distribution of D_{1440} at Conventional Raingauges (3)

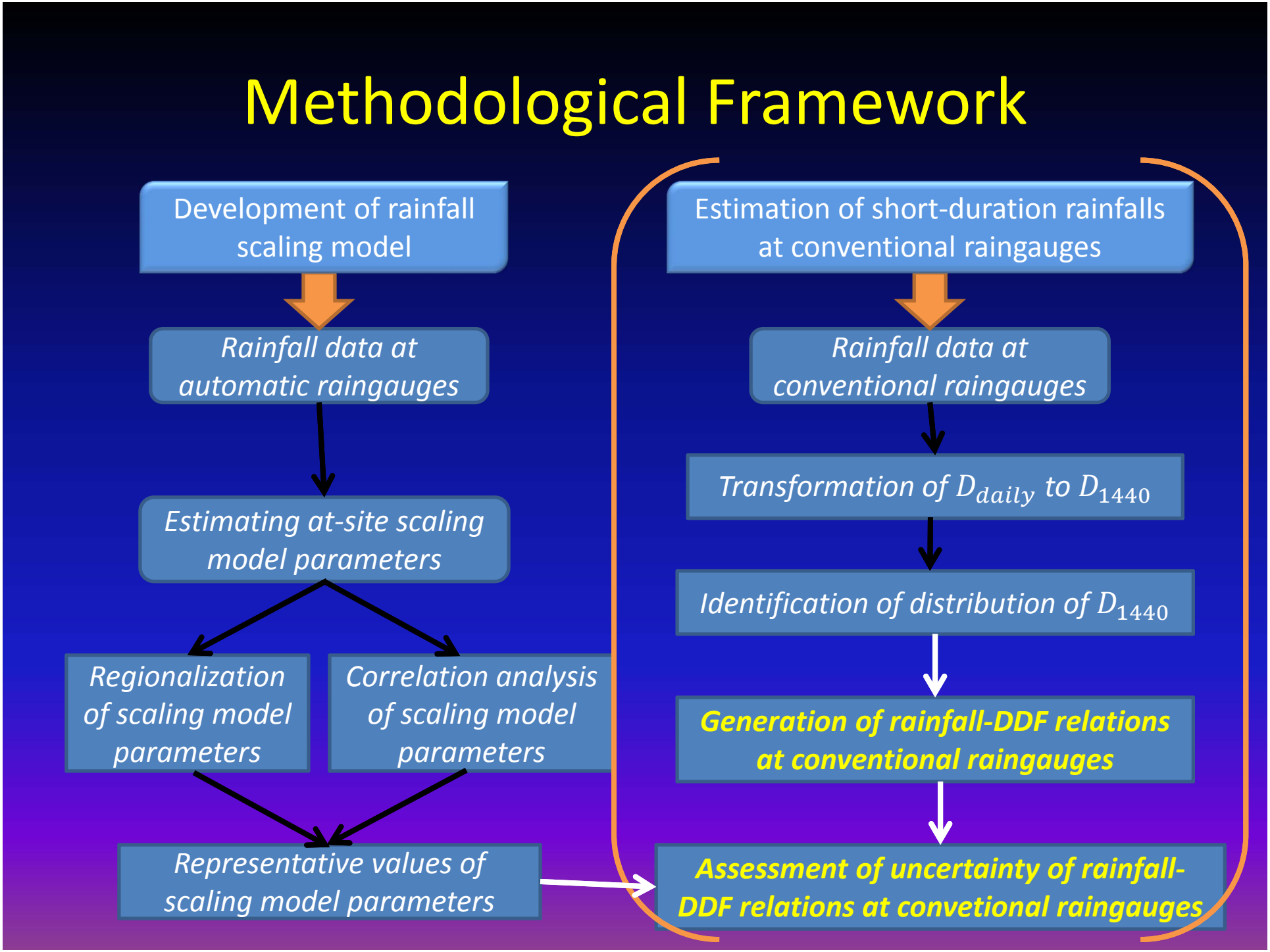


$$\Delta\kappa = \left|\kappa_{D_{1440},model} - \kappa_{D_{1440},derived}\right|$$

No. of conventional raingauges whose best-fit distribution model for D_{1440}

GEV	PE3	LN3
92	17	13

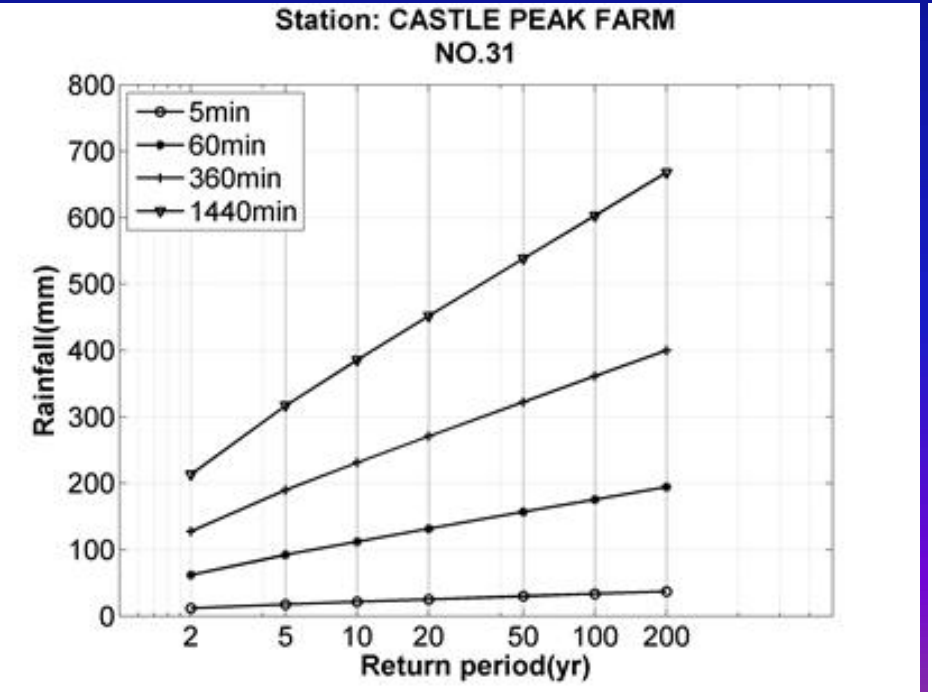
Methodological Framework



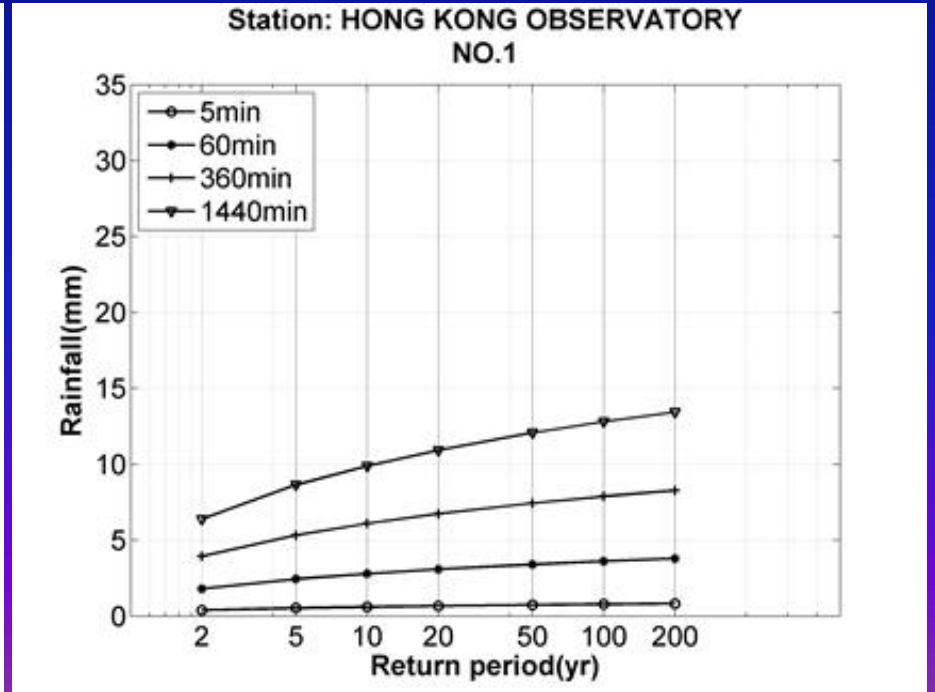
Uncertainty of Rainfall DDF at Conventional Raingauges

- Scaling models are subject to uncertainties
- $\ln\left(D_{t,T}\right)$: *Normal*

Mean



Standard Deviation



Conclusions

- Scaling-invariant property of GEV is applicable in Hong Kong in two duration segments.

- Scaling model parameters can be regionalized for enhancing estimation accuracy:

  5min< t<60min (a_0, a_1) *one region;*

  60min< t<1440min (b_0, b_1) *two regions.*

- GEV is a suitable distribution for D_{1440} at conventional stations.

- Provision of uncertainty features of estimated rainfall DDF relationships allows more prudent engineering design.

Thank You!