Computation of Spatially Distributed Rainfall by Merging the Raingauge Data and the Satellite-Based Data: A Case of "Beijing 7·21 Rainstorm" in 2012 in China

Hai-Yun SHI [a,b], *Dr. Ji CHEN* [b]

[a] State Key Laboratory of Hydroscience and Engineering, Tsinghua University, Beijing, China

[b] Department of Civil Engineering, The University of Hong Kong, HKSAR, China

Abstract: This study develops a method to compute spatially distributed rainfall by merging the raingauge data and the satellite-based data. Taking "Beijing 7•21 rainstorm" in 2012 in China as an example, first, three types of the satellite-based data (i.e., TMPA 3B41RT, 3B42RT, and CMORPH, which are all near real-time) were compared against the observed data recorded at the raingauges. It revealed that the CMORPH data matched the raingauge data best and it was selected for data merging in this study. Second, the original grid size of the CMORPH data (8 km) was too large so that each grid was dispersed into smaller grids (e.g., 1 km) by using the Digital Elevation Model data, considering the topography influence. Third, for any interest point in the study area, raingauge stations within a calculated effective influence radius were used and differences between the raingauge data at those stations and the corresponding dispersed CMORPH data were calculated. Finally, the raingauge data and the CMORPH data were merged as a linear combination of the dispersed CMORPH data at that interest point and the weighted differences at those adjacent raingauge stations, and then the spatially distributed rainfall were obtained. Comparing with the information from the Beijing Water Authority, it indicated that the merged rainfall data can properly reflect the spatial distribution of rainfall. Moreover, the comparisons of hydrological processes simulation by using the Tsinghua University Digital Basin Model show that better performance can be obtained by using the merged data than by using the raingauge data or the satellite-based data only. The new method for merging the two rainfall data developed in this study would be useful to provide the inputs for distributed hydrological models.

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Computation of spatially distributed rainfall by merging the raingauge data and the satellite-based data: A case of "Beijing 7•21 rainstorm" in China

Supervisor: Ji CHEN

Haiyun SHI

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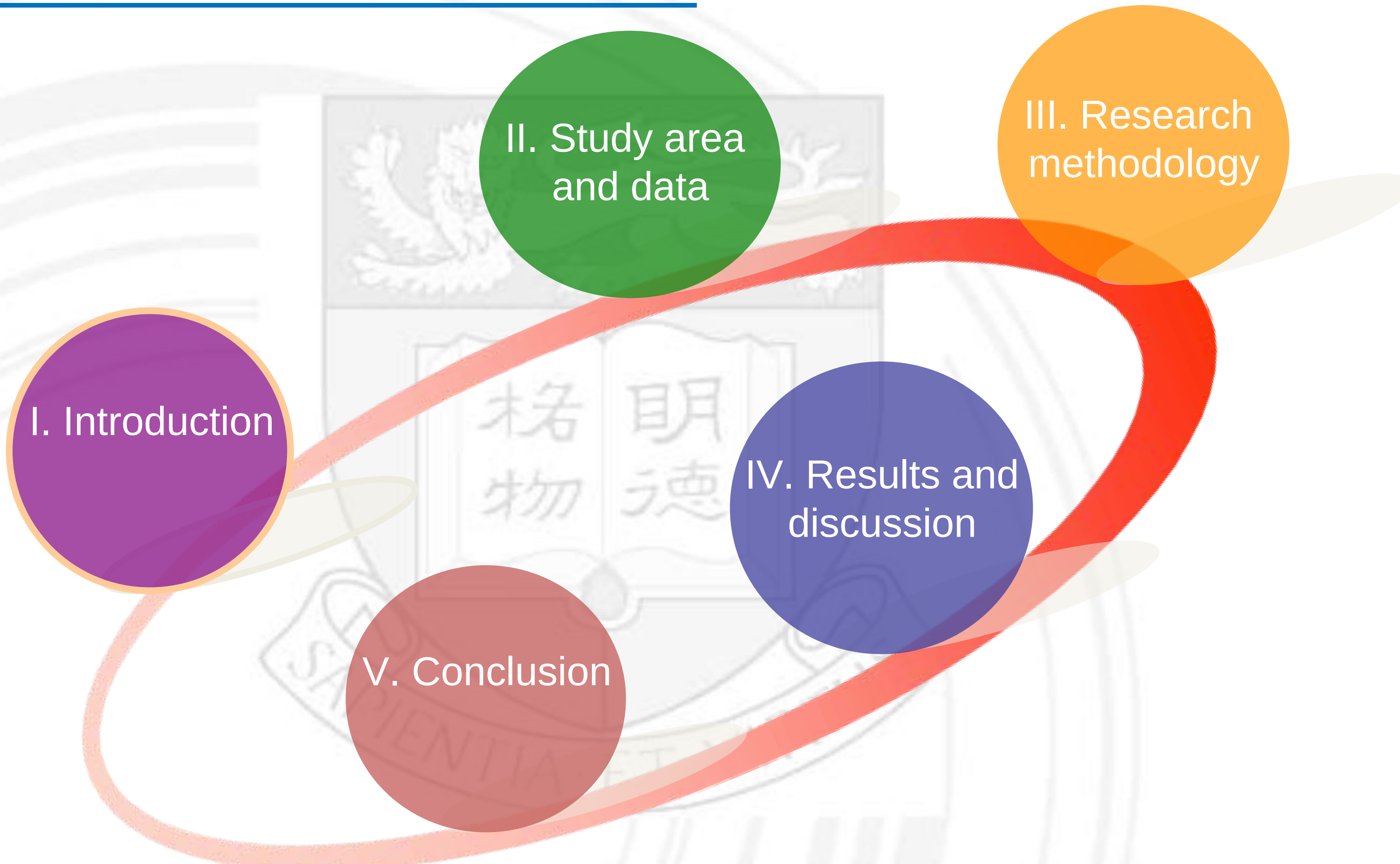
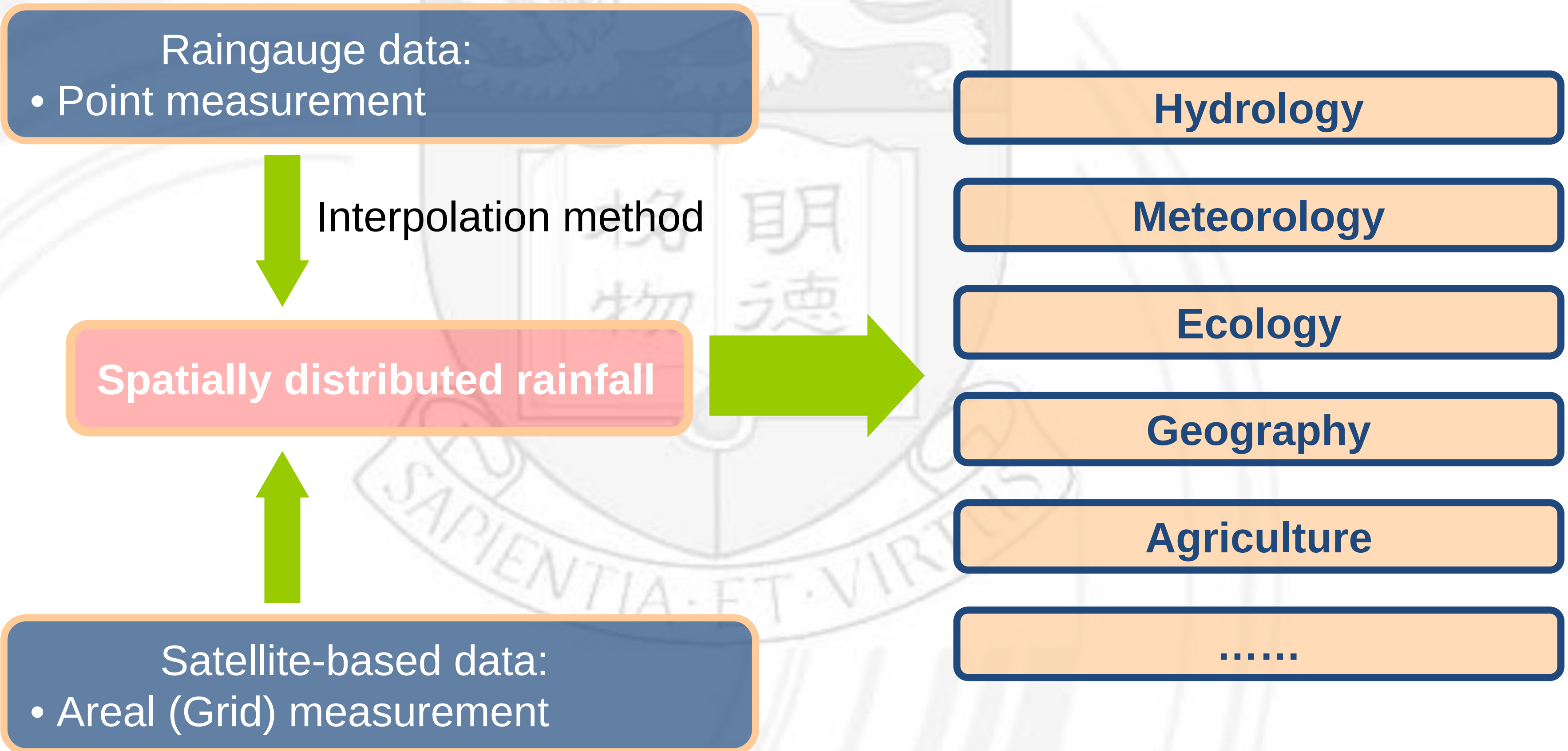
Presentation Outline



I. Introduction

1. Background

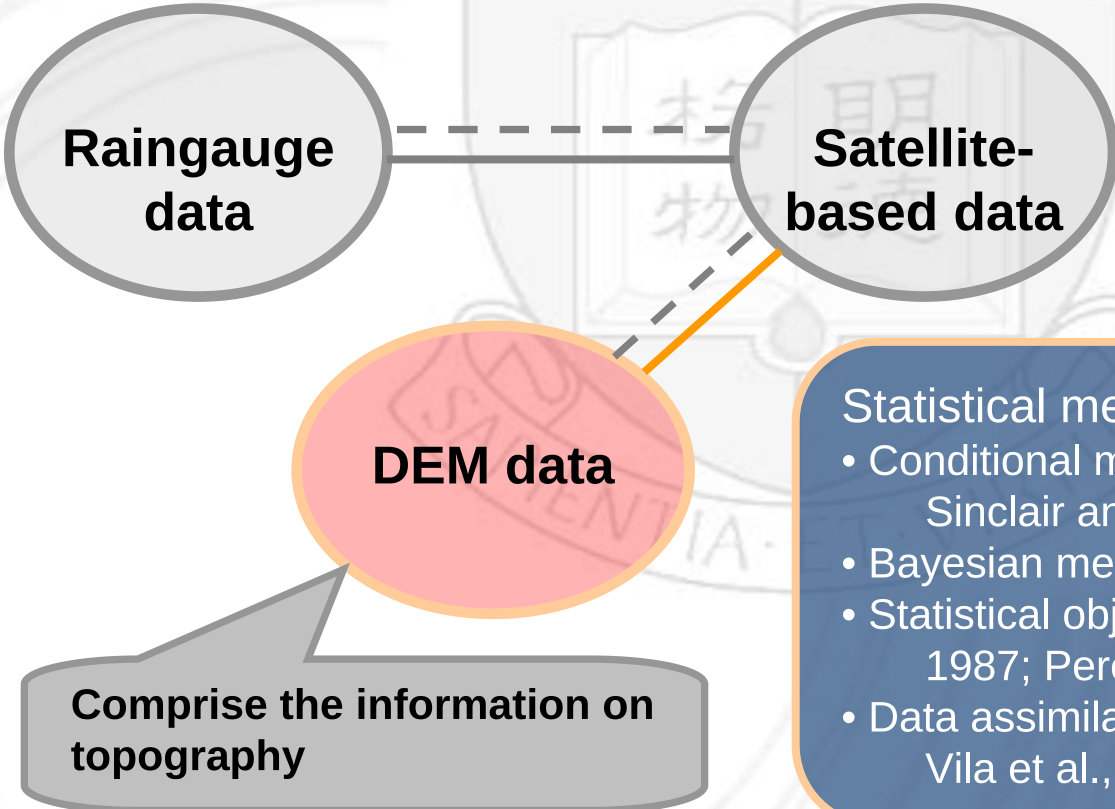
Rainfall ---- a basic hydrological variable



I. Introduction

2. Objective

To develop a method to compute spatially distributed rainfall by merging the raingauge data and the satellite-based data, considering the impact of topography on rainfall



Statistical methods

- Conditional merging (Ehret, 2002; Sinclair and Pegram, 2005)
- Bayesian merging (Todini, 2001)
- Statistical objective analysis (Krajewski, 1987; Pereira Filho, 1998)
- Data assimilation (Huffman et al., 2007; Vila et al., 2009)

II. Study area and data

1. Study area

To develop and verify the data merging method

- **The whole city of Beijing**

To verify the method by using hydrological simulation

- **The Dashi River basin, a small basin in the southwest of Beijing (115° 33' - 116° 01' E, 39° 41' - 39° 55' N), with a drainage area of 513 km^2**

Study period

- **The event duration, from July 21 to July 22, 2012**

II. Study area and data

2. Data

Raingauge data

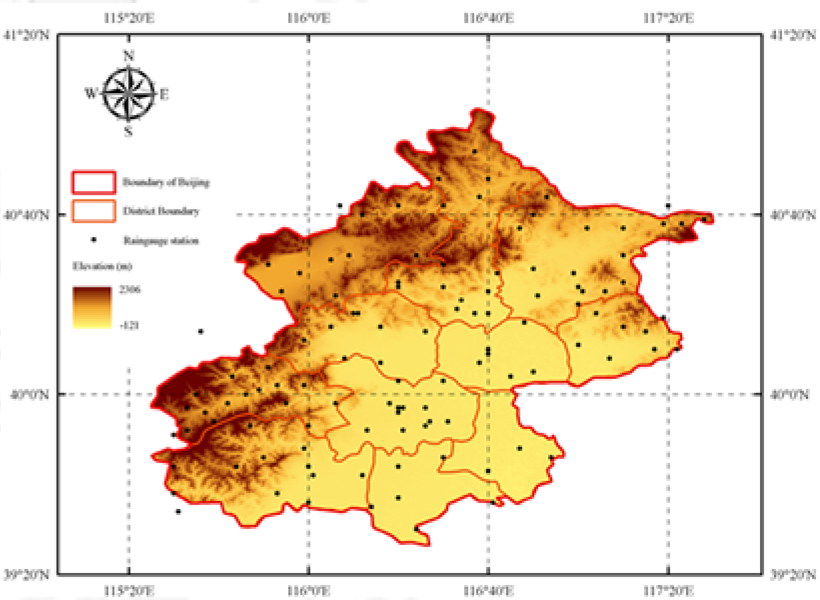
- From the Beijing Water Authority (BWA)
- Including 115 stations inside or around Beijing
- At hourly time scale

Satellite-based data ---- CMORPH

- From NOAA
- Highest resolution: 8 km, 30 min
- Near real time
- Near global

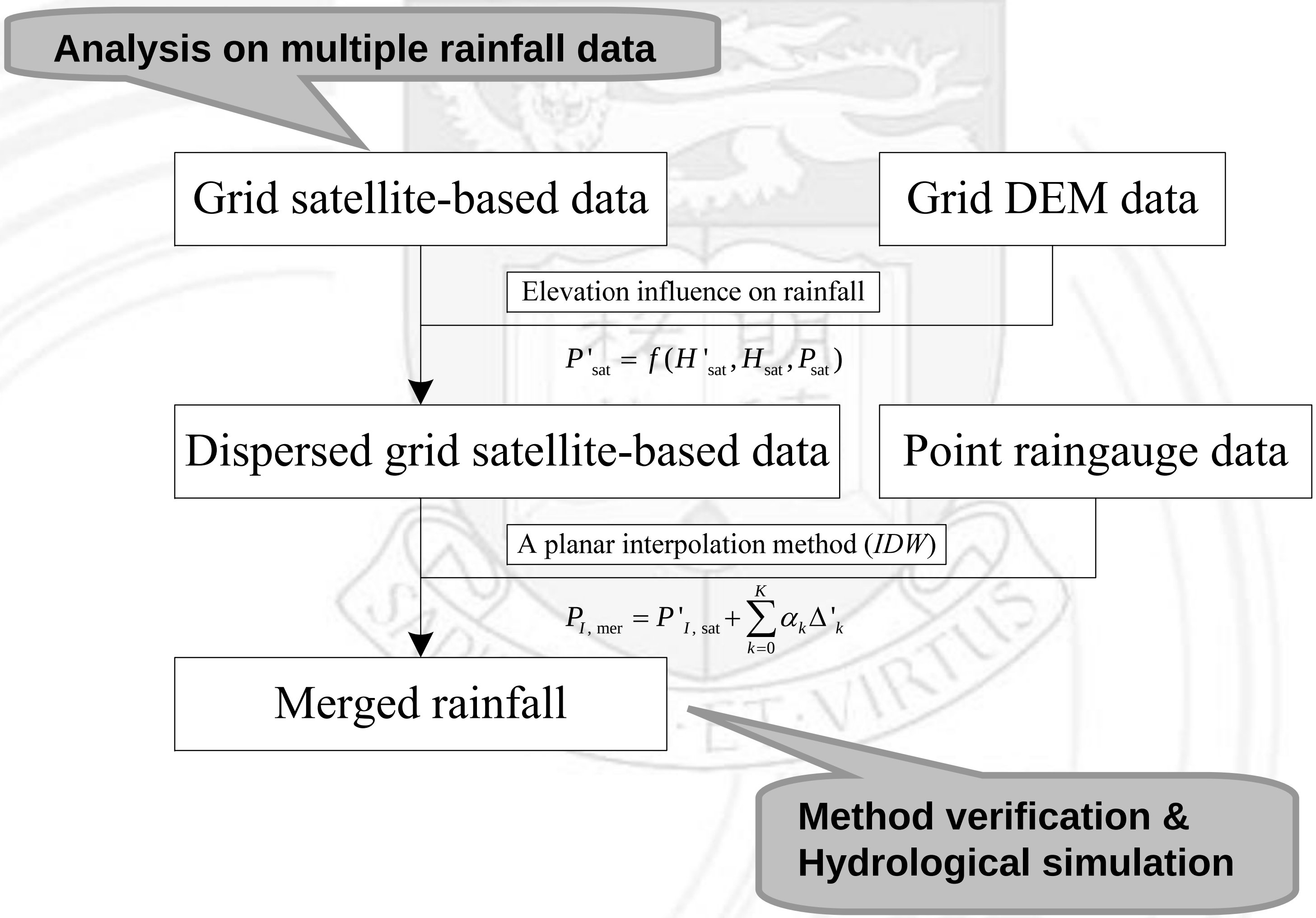
DEM data ---- ASTER GDEM

- From NASA and METI of Japan
- Grid size: 30 m



III. Research methodology

Data merging method



III. Research methodology

Data merging method

- The raingauge data: $P_{gau} = P_{true} + \varepsilon_{gau}$
- The satellite-based data: $P_{sat} = P_{true} + \varepsilon_{sat}$

At the same location, the difference between the two rainfall data Δ can be expressed as follows: $\Delta = P_{gau} - P_{sat} = \varepsilon_{gau} - \varepsilon_{sat}$

Three assumptions

- 1) Every rain has an effective influence radius (EIR), which is no more than a certain distance (e.g., 10~50 km. Qian, 2004).

Mean distance between stations: $L = \sqrt{\dfrac{S}{N}}$, If L<50, EIR=L; else EIR=50.

- 2) The rainfall has a relationship with the elevation.
- 3) The errors of the two rainfall data are independent.

III. Research methodology

Data merging method

Downscaling the satellite-based data by using DEM data

- To disperse the original grid into a number of smaller ones

$$P'_{sat} = f(H'_{sat}, H_{sat}, P_{sat})$$

P'_{sat} : the rainfall of each dispersed grid of the satellite-based data;

P_{sat} : the rainfall of an original grid of the satellite-based data;

H'_{sat} : the average elevation within the range of the dispersed grid;

H_{sat} : the average elevation within the range of an original grid.

- The observed rainfall data and the DEM data can be used to determine the best form of the function for the designated region
- In this study, it is the exponential function.

III. Research methodology

Data merging method

Merge the raingauge data and the dispersed satellite-based data

- **A linear combination of the dispersed satellite-based data and the weighted differences between the two rainfall data**

$$P_{I,\,\mathrm{mer}} = P'_{I,\,\mathrm{sat}} + \sum_{k=0}^{K} \alpha_k \Delta'_k$$

$P_{I,\,\mathrm{mer}}$: the merged rainfall at the interest point *I*;

$P'_{I,\,\mathrm{sat}}$: the dispersed satellite-based data at the interest point *I*;

K : the number of raingauge stations found within the EIR of the interest point *I*;

α_k : the weight of the *k*-th used raingauge station, computed by using the inverse distance weighting (IDW) method:

$$\alpha_k = \frac{\dfrac{1}{D_k^{\beta}}}{\sum_{k=1}^{K} \dfrac{1}{D_k^{\beta}}}$$

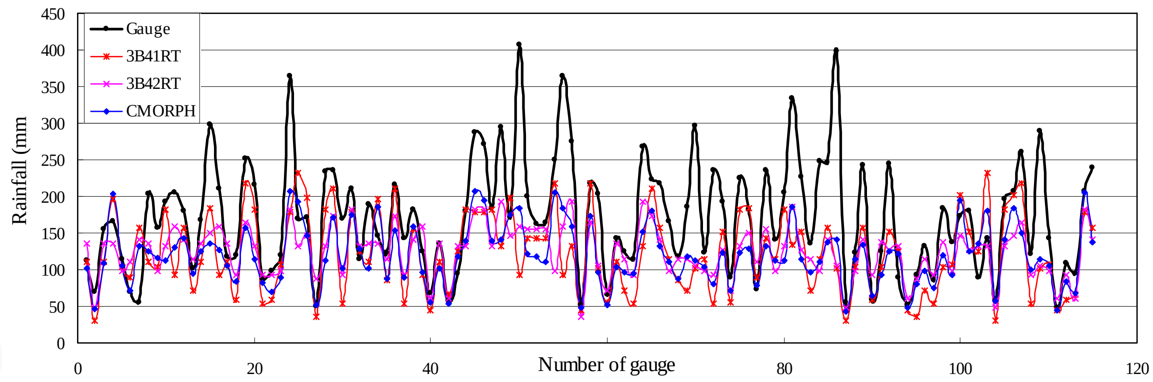
IV. Results and discussion

Select the suitable satellite-based data

- Three satellite-based data (CMORPH, TMPA 3B41RT and 3B42RT)
- The rainfall totals during the study period

The CMORPH data matches the raingauge data best

- **The highest *r* (Correlation Coefficient)**
- **The smallest range of *RE* (Relative Error)**
- **The second smallest *RMSE* (Root Mean Square Error)**
- **Also, the highest temporal and spatial resolution**



Data	*r*	Range of *RE*	*RMSE* (mm)
CMORPH	0.70	-0.66~1.41	77.20
3B41RT	0.52	-0.77~1.87	83.65
3B42RT	0.65	-0.74~1.56	77.09

IV. Results and discussion

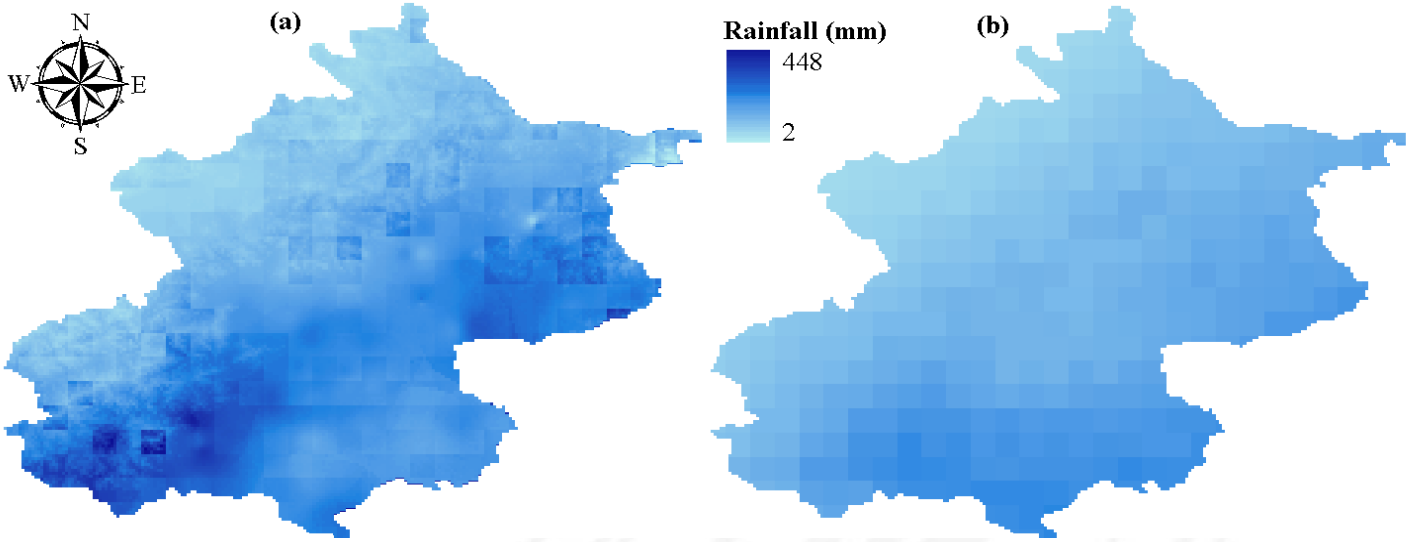
Merge the two rainfall data

Disperse the CMORPH data

- 8 km ➔ 1 km, one grid ➔ 8×8 smaller ones
- 20,817 smaller grids in total for the whole city of Beijing

Merge the dispersed CMORPH data and the raingauge data

- Spatial distribution of:
  (a) the merged rainfall; (b) the original CMORPH data



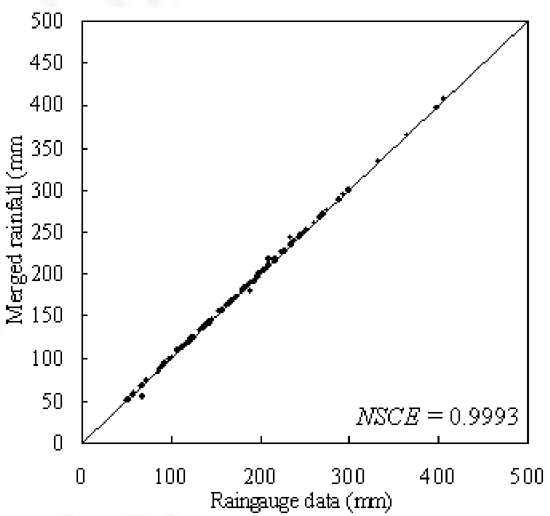
IV. Results and discussion

Verification

Evaluate the performance of the merged rainfall

- Table: (a) for the merged data, comparing with
  (b) the original CMORPH data
  (c) the information from BWA
- Figure: compare with the raingauge data

Data	The whole city	Fangshan	Pinggu	Shunyi	Urban	Daxing
(a)	164.92 (-2.99%)	271.14 (-9.92%)	231.13 (0.49%)	217.16 (-2.62%)	219.37 (-2.03%)	187.06 (-0.50%)
(b)	119.41 (-29.76%)	157.20 (-47.77%)	155.46 (-32.41%)	125.64 (-43.66%)	135.18 (-37.13%)	191.02 (1.61%)
(c)	170	301	230	223	215	188
Data	Tongzhou	Mentougou	Miyun	Changping	Huairou	Yanqing
(a)	176.75 (-1.00%)	140.06 (-2.05%)	150.96 (6.31%)	145.71 (5.59%)	103.05 (-15.53%)	69.03 (0.04%)
(b)	171.77 (-1.85%)	102.15 (-28.57%)	115.80 (-18.45%)	100.63 (-27.08%)	82.82 (-32.11%)	58.60 (-15.07%)
(c)	175	143	142	138	122	69



IV. Results and discussion

Hydrological simulation

Hydrological model

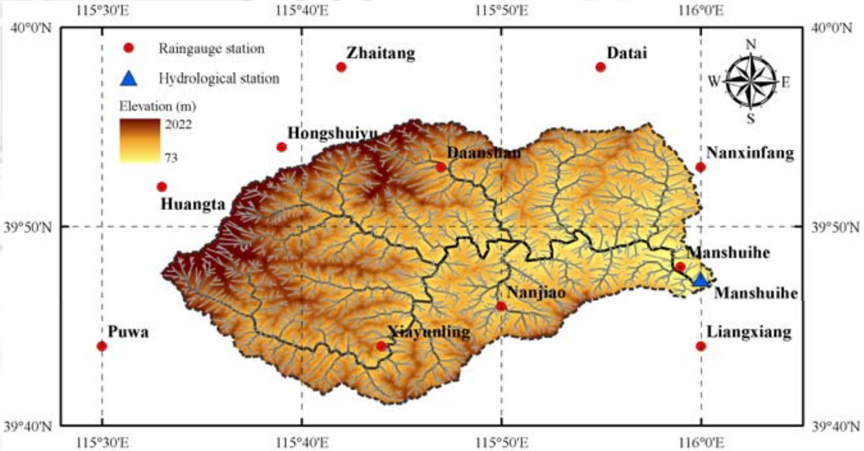
- Tsinghua University Digital Basin Model (TUD-Basin)

Digital drainage network extracting

- The CSA (i.e., critical source area) is 4 ha
- The MSCL (i.e., minimum source channel length) is 200 m
- 3,304 river reaches and nearly 8,260 hillslopes in total

Raingauge station

- Eleven stations inside or around the Dashi River basin
- At hourly time scale

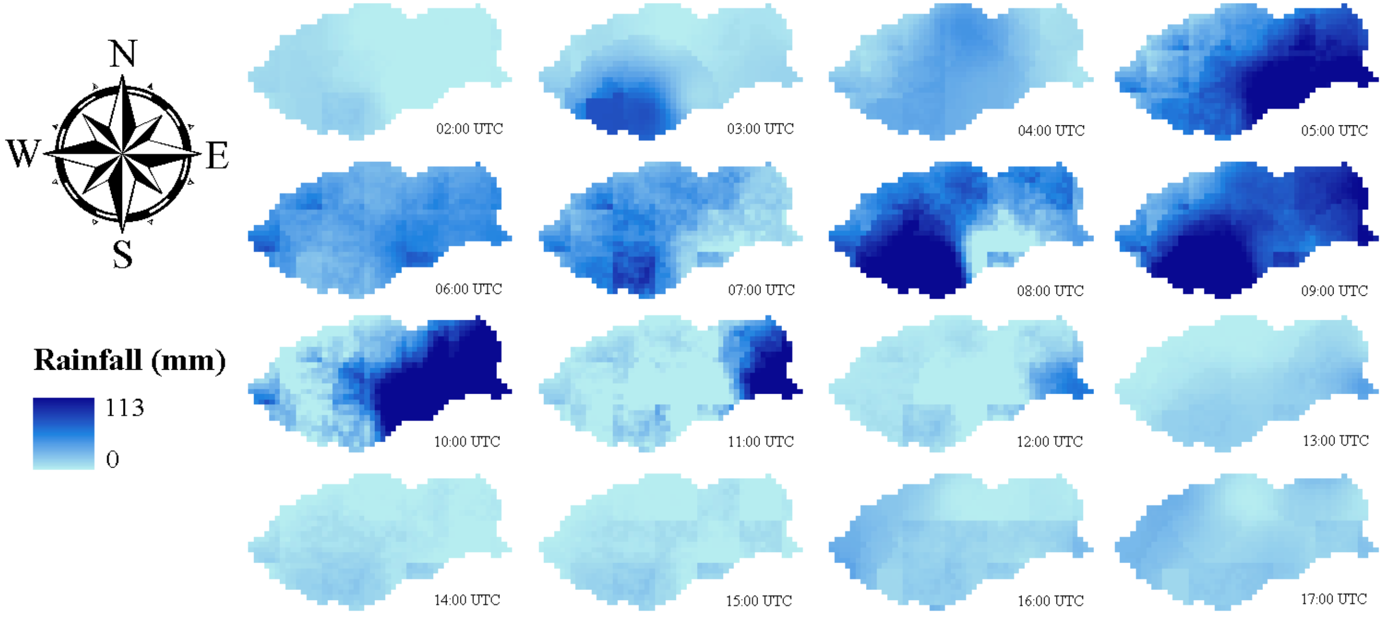


IV. Results and discussion

Hydrological simulation

Compute the merged rainfall

- Two heavy rains: 05:00 UTC & 08:00 UTC
- The maximum hourly rainfall: 113 mm, 08:00 UTC
- No more heavy rain occurred after 12:00 UTC



IV. Results and discussion

Hydrological simulation

Model parameters

- The invariant parameters: describing the properties of land use and soil type, influenced by climate, topography and other basic features of the river basin

Parameter	Field capacity of top soil layer	Free water content of top soil layer	Field capacity of deep soil layer	Free water content of deep soil layer	Depth of top soil layer (m)	water capacity of unit LAI (m)
Value	0.265	0.31	0.22	0.32	0.3	0.0036

IV. Results and discussion

Hydrological simulation

Model parameters

- **The adjustable parameters are determined in three scenarios: for each scenario, the parameters are calibrated by one of the three data; and then, the model is run again to simulate the runoff process by using the other two rainfall data with the calibrated parameters**

Scenario	Infiltration rate of ground surface (mm/hr)	Vertical infiltration rate from top soil layer to deep soil layer (mm/hr)	Horizontal infiltration rate of top soil layer (mm/hr)	Horizontal infiltration rate of deep soil layer (mm/hr)
(a) Raingauge	15.0	180.0	18.0	72.0
(b) CMORPH	2.0	100.0	18.0	72.0
(c) Merged	10.0	100.0	18.0	72.0

IV. Results and discussion

Hydrological simulation

Runoff simulation

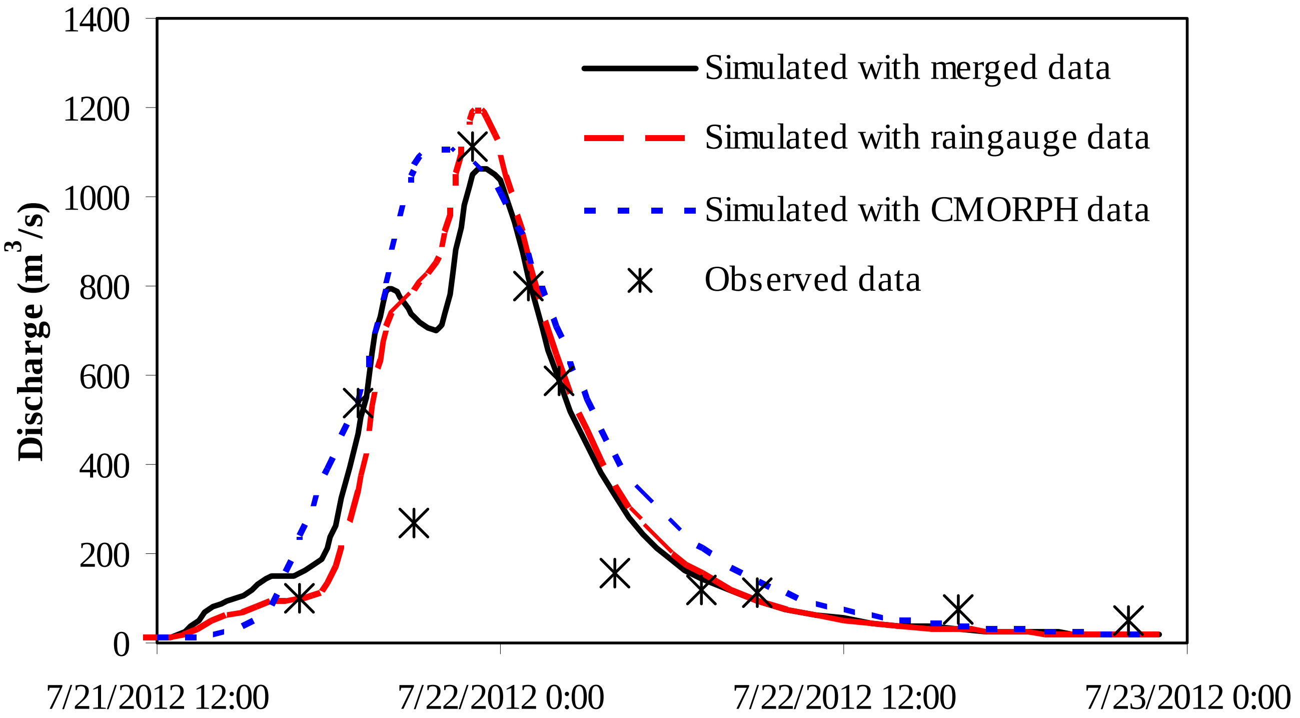
Scenario	Data type	Peak flow (m^3/s)	*RE*	Flood volume (10^6 m^3)	*RE*	*NSCE*
(a)	Raingauge	1188	7%	32	13%	0.71
	CMORPH	14	-99%	1	-95%	-1
	Merged	562	-49%	18	-38%	0.15
(b)	Raingauge	4783	331%	102	262%	-25
	CMORPH	1076	-3%	38	33%	0.39
	Merged	3742	237%	86	204%	-14
(c)	Raingauge	1852	40%	46	61%	-0.64
	CMORPH	36	-97%	2	-93%	-0.97
	Merged	1051	-5%	31	10%	0.79
	Observed data	**1110**	/	**28**	/	/

IV. Results and discussion

Hydrological simulation

Runoff simulation

- The discharges are also calculated by using the three rainfall data with their own optimal parameters, comparing with the observed data



V. Conclusion

1. **A method of merging the raingauge data with the satellite-based data was proposed.**
2. **The DEM data, reflecting the impact of topography on rainfall, was also considered, and the function for describing the relationship between elevation and rainfall was established.**
3. **The spatially distributed rainfall over the whole city of Beijing during the rainstorm event was obtained.**

This method would be valuable in providing the basic input for distributed hydrological models.

Thank you!