天津大学
Tianjin University

Emerging technologies and their applications in hydrological research

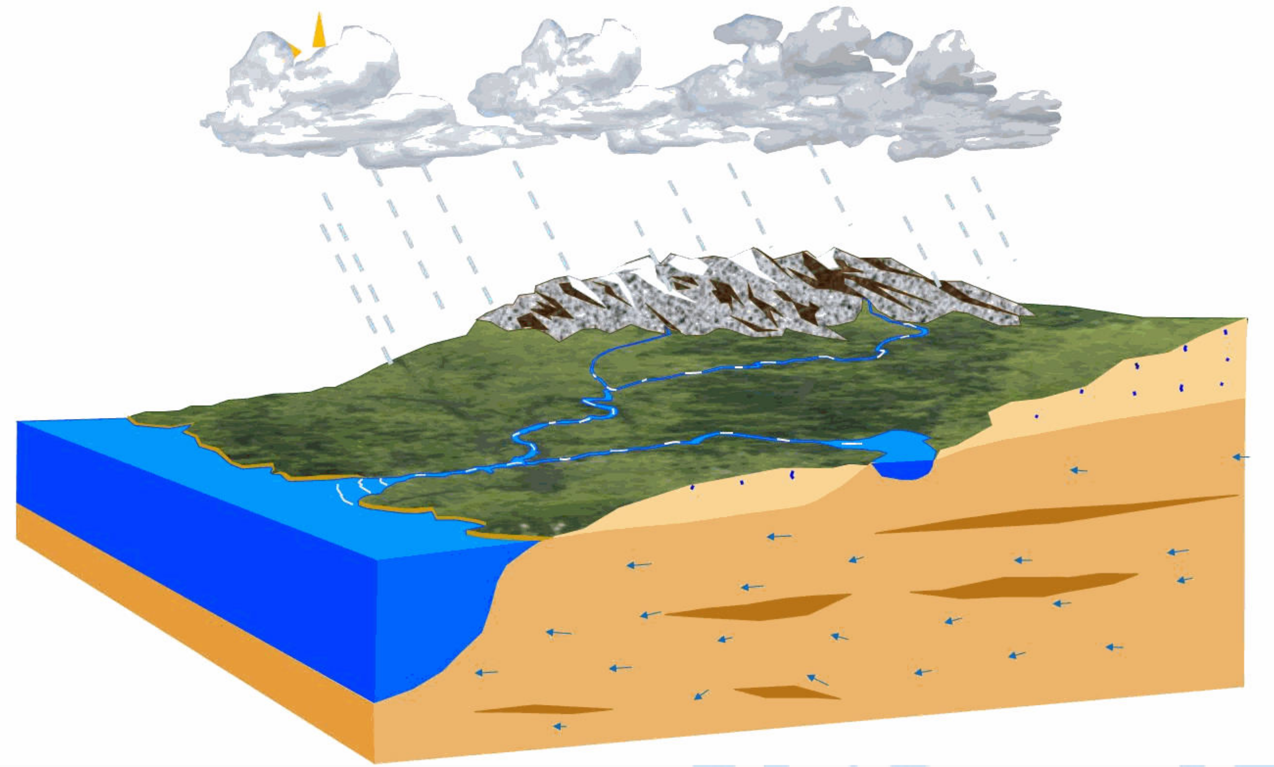
Mingna Wang, Manuel Fiallos, Jia Wang
School of civil Engineering, School of environment science and Engineering
Tianjin University, Tianjin, China

CONTENTS

01

Traditional hydrological research

- Meteorological Data
- hydrological data
- Human activity data
- Underlying surface factor
- Water quality data, etc



Complex hydrological processes require a large amount of data support

3154 national basic hydrological stations

3043km^2/station

2421 national meteorological stations

3965km^2/station

The hydrological stations recommended by the World Meteorological Organization have a control area of **1000-2500** square kilometers per station

There are many local meteorological stations, but data acquisition is difficult

Insufficient data is an important factor limiting the development of hydrological technology

02

What we are having nowadays

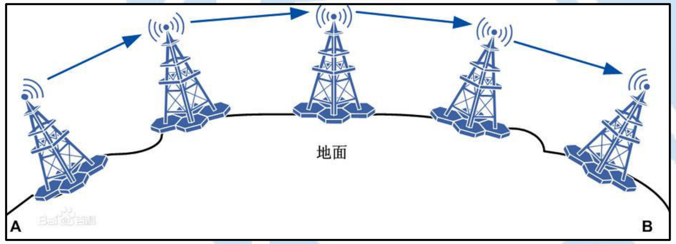
Remote sense

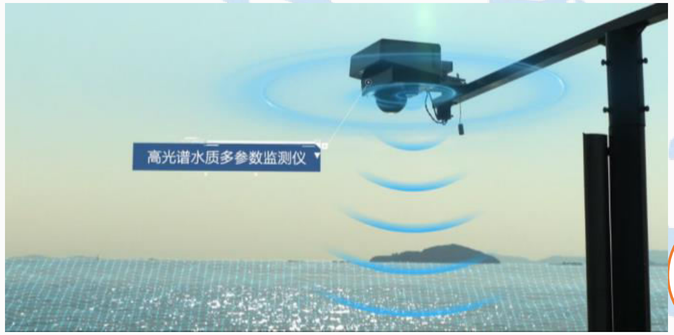
Hyperspectral analysis

New method

Video/Image analysis

Microwave link

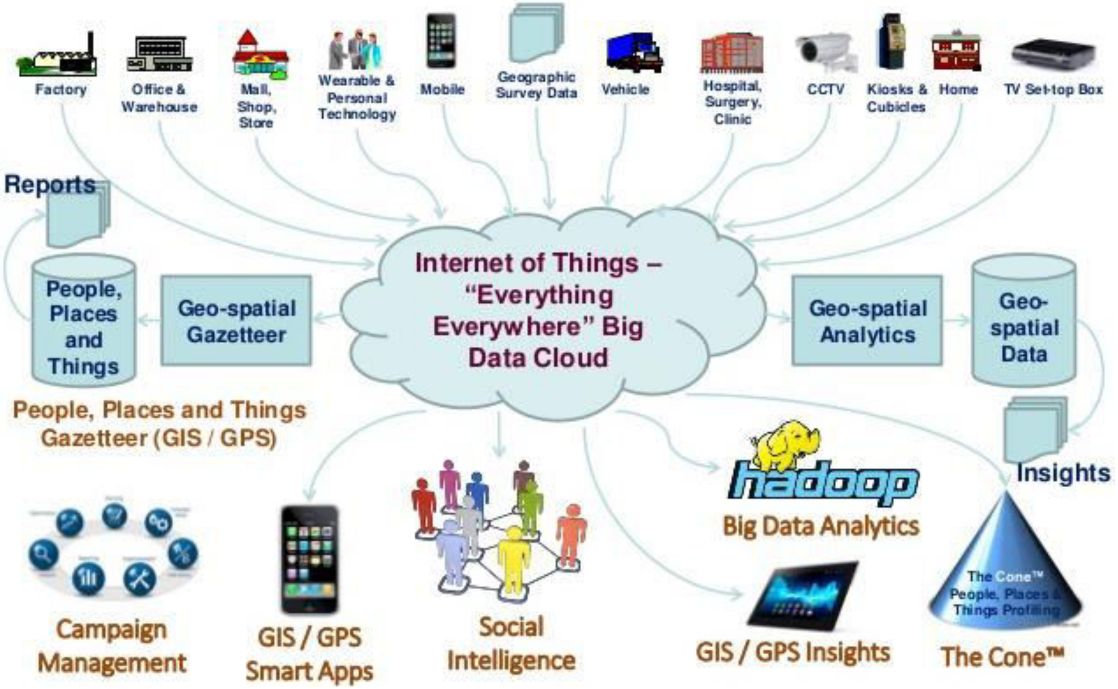




ANYWHERE，ANYTIME, BY ANYONE AND ANYTHING

- The term “**ubiquitous**” is derived from the Latin word ubique meaning “**everywhere**”.
- The definition is based on **socio-economic**, rather than ***geographicalines***, and describes a technology which can be available “**anywhere**”, rather than “everywhere”.
- It is wider than just a geographical measure, and the expression **anywhere, anytime, by anyone and anything** could help modelling to support planning for resilience in changing world.

ubiquitous sensing



Calm technology: embedded, invisible, seamlessly, unobtrusive, intelligent.

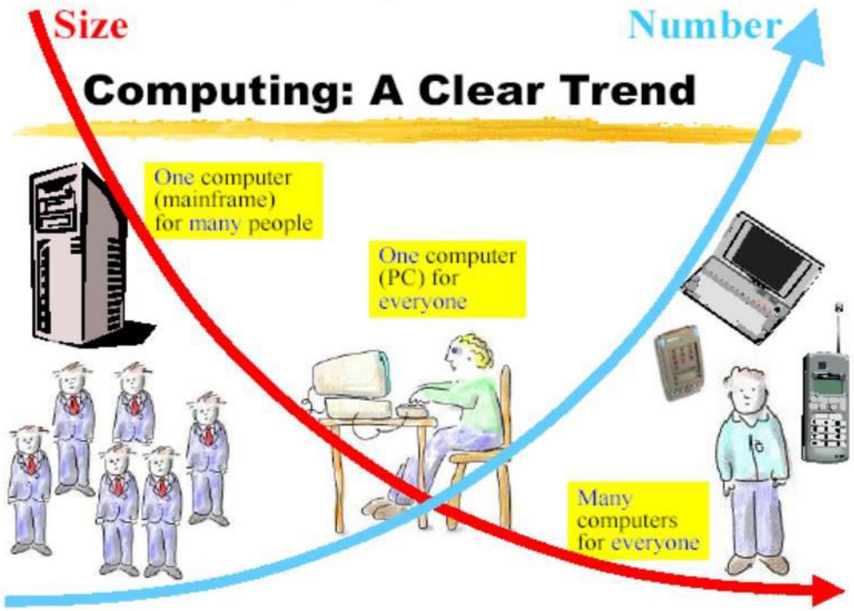
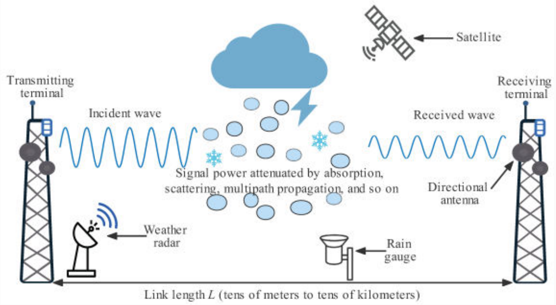


Image source:
Friedemann Mattern
(ETH Zürich)

Types of Smart Water Big Data



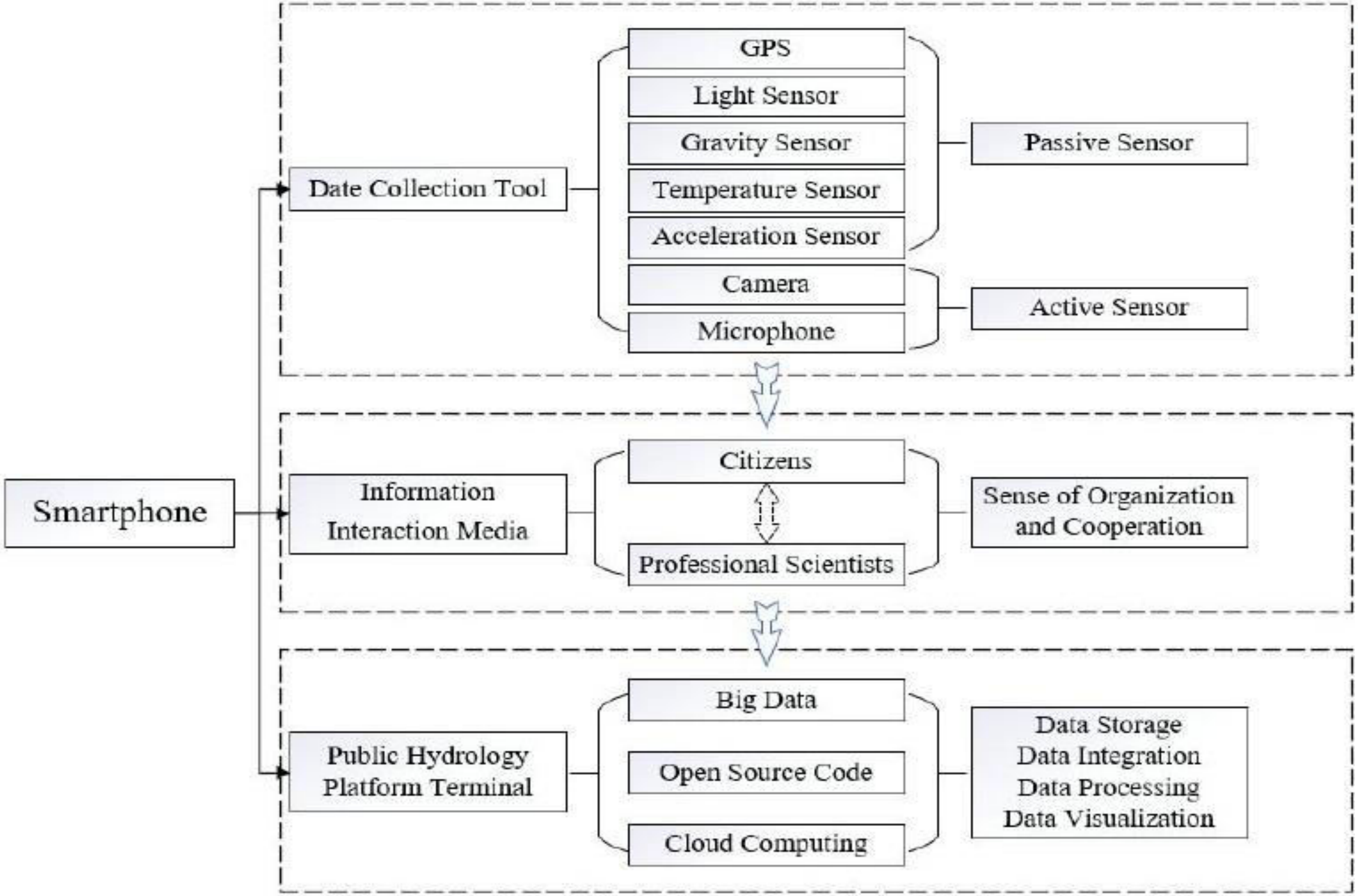
ubiquitous sensing

Error range of rainfall measure using different sensing techniques

Techniques	Error range	Evaluating indicator
Pictures	±25%	Mean Absolute Percentage Error： MAPE
Surveillance c		MAPE
Moving car	±30%	Mean Absolute Percentage Error： MAPE
Microwave link network	±3.10%~±9.70%	Mean Absolute Percentage Error： MAPE

Limited accuracy and lack of application in practice!

Types of Smart Water Big Data



Smartphone

Date Collection Tool

GPS

Light Sensor

Gravity Sensor

Temperature Sensor

Acceleration Sensor

Camera

Microphone

Passive Sensor

Active Sensor

Information Interaction Media

Citizens

Professional Scientists

Sense of Organization and Cooperation

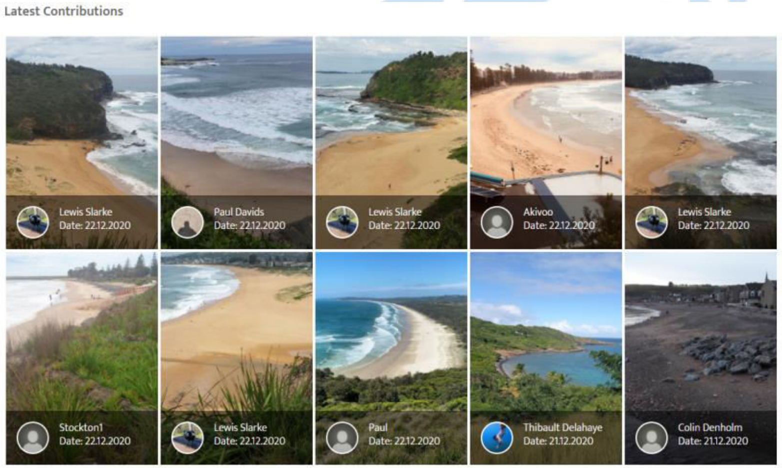
Public Hydrology Platform Terminal

Big Data

Open Source Code

Cloud Computing

Data Storage
Data Integration
Data Processing
Data Visualization



03

Case Studies

Case Studies-Rainfall monitoring from videos captured by CCTV cameras and smartphones.

METHOD

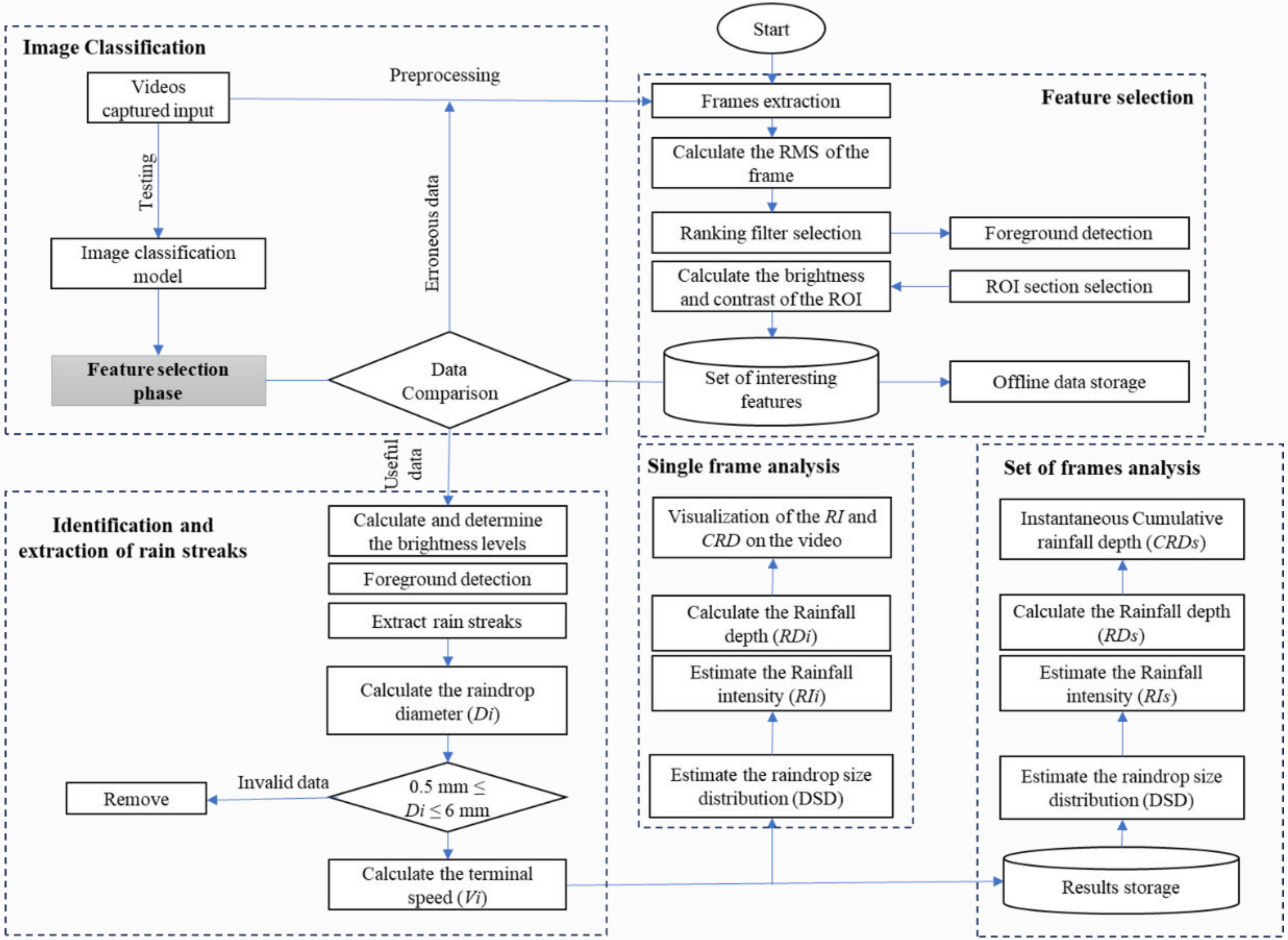


Image Classification

Videos captured input

Preprocessing

Testing

Image classification model

Erroneous data

Feature selection phase

Data Comparison

Useful data

Start

Feature selection

Frames extraction

Calculate the RMS of the frame

Ranking filter selection

Foreground detection

Calculate the brightness and contrast of the ROI

ROI section selection

Set of interesting features

Offline data storage

Identification and extraction of rain streaks

Calculate and determine the brightness levels

Foreground detection

Extract rain streaks

Calculate the raindrop diameter (D_i)

$0.5 \text{ mm} \le D_i \le 6 \text{ mm}$

Invalid data

Remove

Calculate the terminal speed (V_i)

Single frame analysis

Visualization of the *RI* and *CRD* on the video

Calculate the Rainfall depth (RD_i)

Estimate the Rainfall intensity (RI_i)

Estimate the raindrop size distribution (DSD)

Set of frames analysis

Instantaneous Cumulative rainfall depth (CRD_s)

Calculate the Rainfall depth (RD_s)

Estimate the Rainfall intensity (RI_s)

Estimate the raindrop size distribution (DSD)

Results storage

Low-intensity

High-intensity

Case Studies-Rainfall monitoring from videos captured by CCTV cameras and smartphones.

EXPERIMENT

- The code has been implemented using Python language.
- It was run on a personal computer with an Intel Core i9-9820.

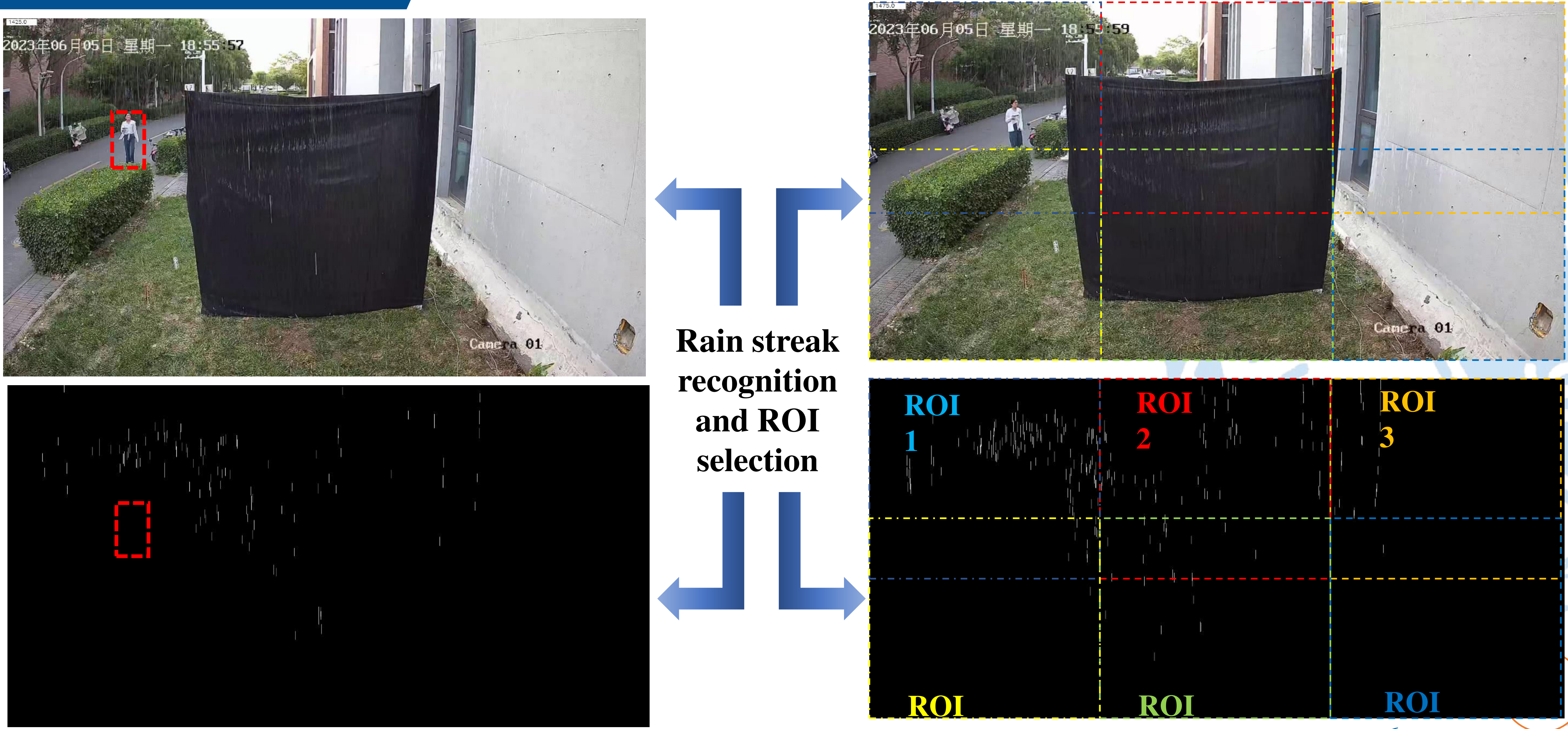
Purpose of the experiment

- Use various videos of rainy events to determine relationships among brightness levels, classification thresholds, and image filtering.
- Determine the optimal focus distance and check camera video quality at several positions.

Type	Date	Duration (minutes)	Frame rate per second	Total frames	Frame size (pixel)	Notes
Baseline 1	3/06/2023	50	25	1250	1920 x 1080	Evaluating the brightness level, erosion and dilation methods
Baseline 2	4/06/2023	40		1000		Verifying the formulas defined for the rainfall estimation
Rain event 1	4/08/2023	46		2760		Video to test and estimate the rainfall estimation
Rain event 2	5/08/2023	78		4680		

Case Studies-Rainfall monitoring from videos captured by CCTV cameras and smartphones.

EXPERIMENT



Rain streak recognition and ROI selection

EXPERIMENT

- For the analysis, it was recorded different rainy events (light, moderate, and heavy) with different scenarios.
- Evaluating the camera resolution, video quality, and model performance at different positions and video backgrounds.

CCTV camera details:

Type	DS-IPC-T14HV3-LA (small camera)	DS-IPC-B14HV3-LT (big camera)	Smartphone
f	2.8 mm	6 mm	13 mm
w_{sensor}	4.8 mm	4.8 mm	4.8 mm
h_{sensor}	3,6 mm	3.6 mm	3.6 mm
d_f	1000 mm	1500 mm	800 mm

Where f is the focal length, w_{sensor} and h_{sensor} are the width and height of the camera sensor, respectively, d_f is the focus distance

Small Camera Scenes

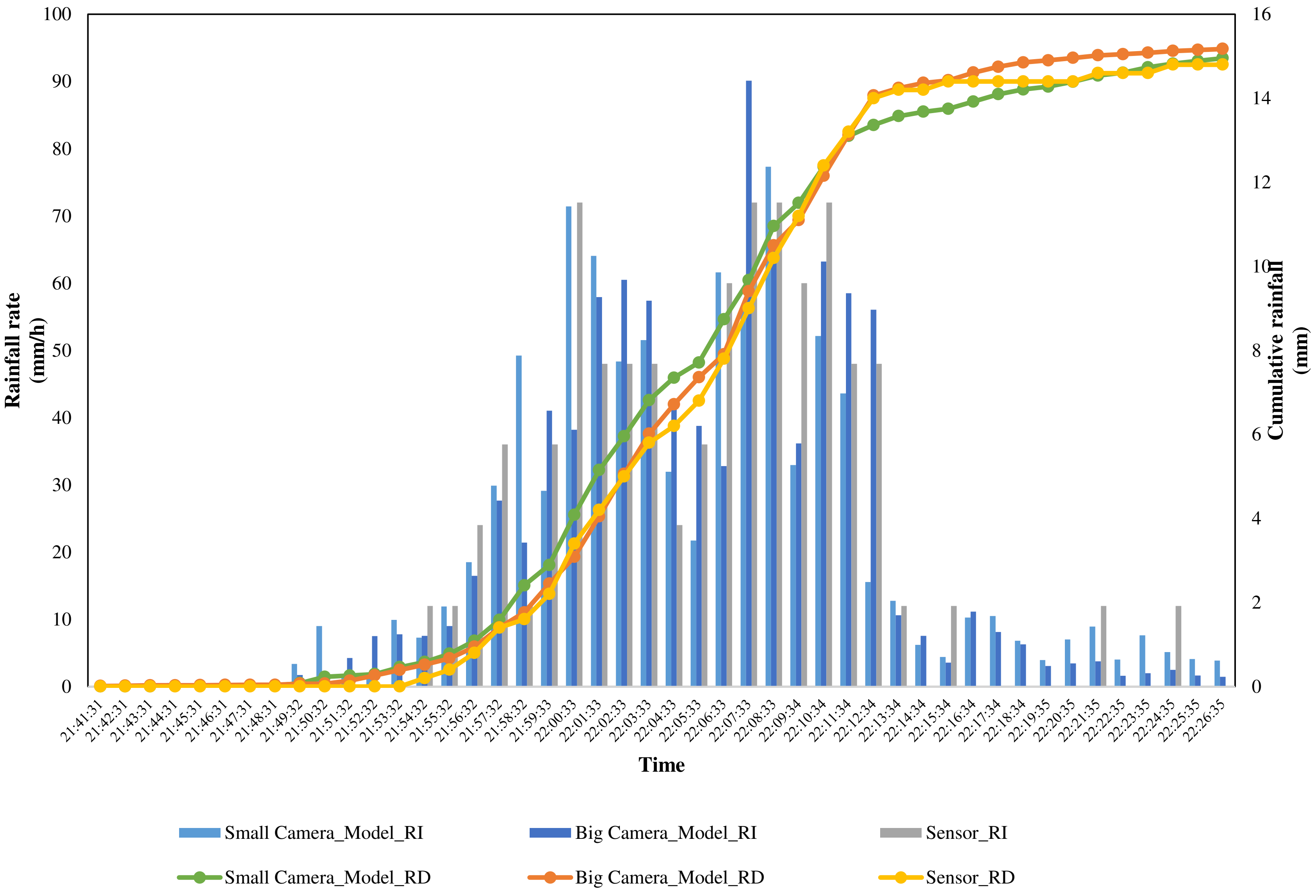
Big Camera Scenes

4/08/2023

5/08/2023

Case Studies-Rainfall monitoring from videos captured by CCTV cameras and smartphones.

RESULTS

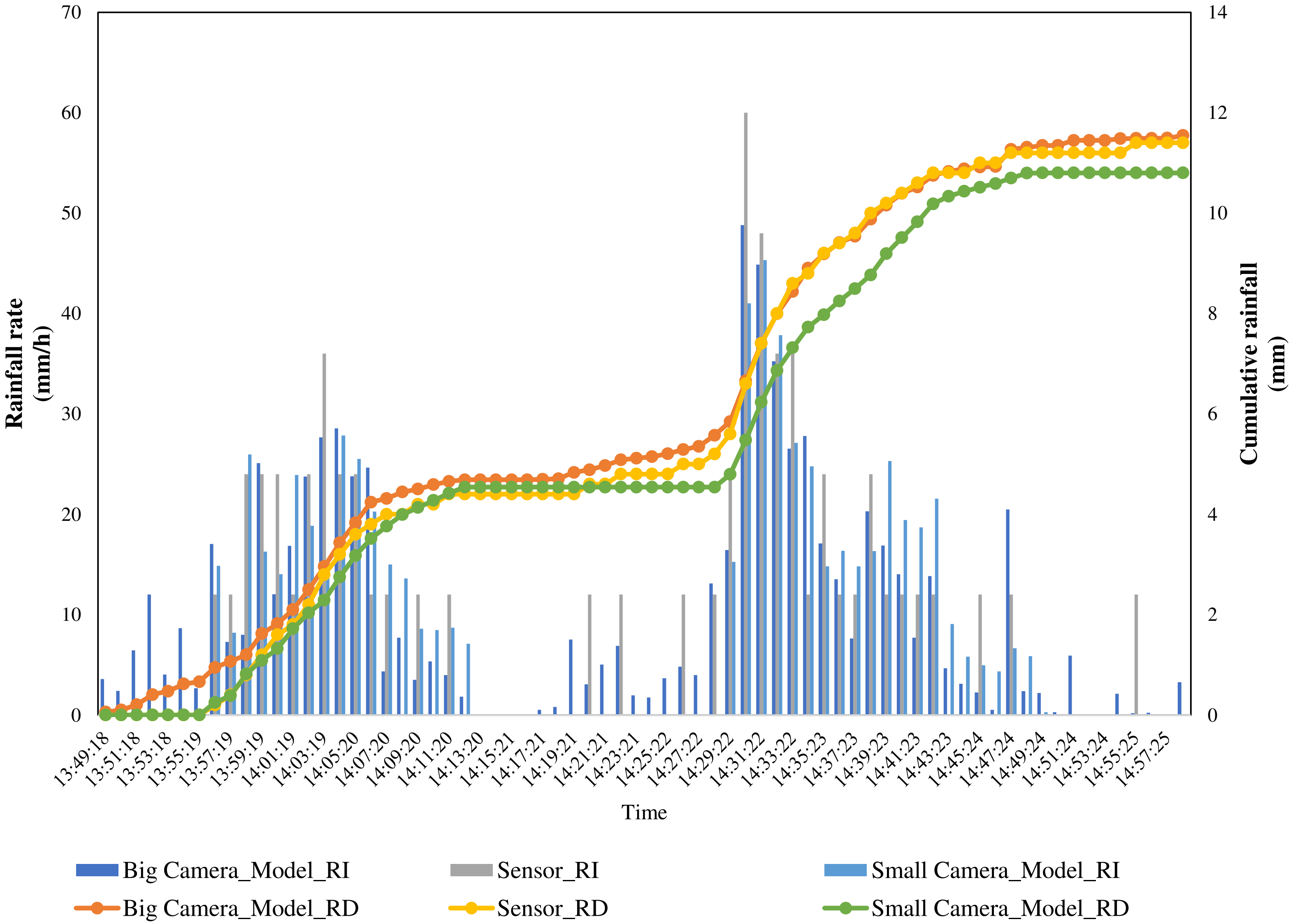


Rainfall was recorded on August 4

Camera	Start time	End time	ER	MAE	RMSE
Big camera	21:40:31	22:26:34	0.07	0.22	0.27
Small camera			0.12	0.36	0.50

Case Studies-Rainfall monitoring from videos captured by CCTV cameras and smartphones.

RESULTS



Rainfall was recorded on August 5

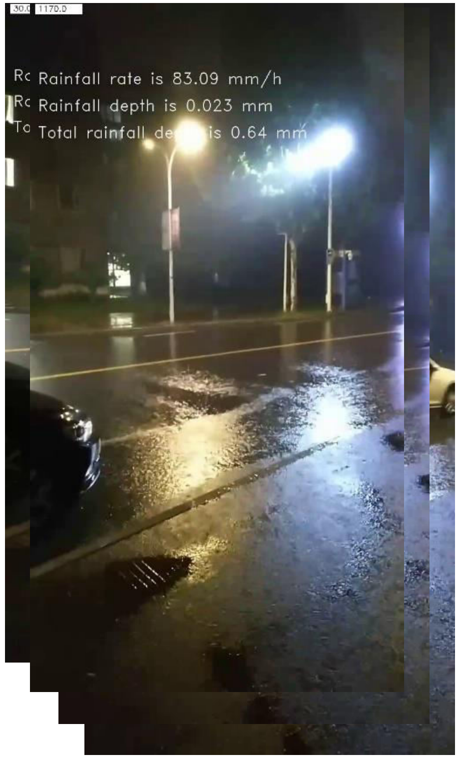
Camera	Start time	End time	ER	MAE	RMSE
Big camera	13:48:18	14:58:25	0.12	0.24	0.30
Small camera			0.06	0.41	0.55

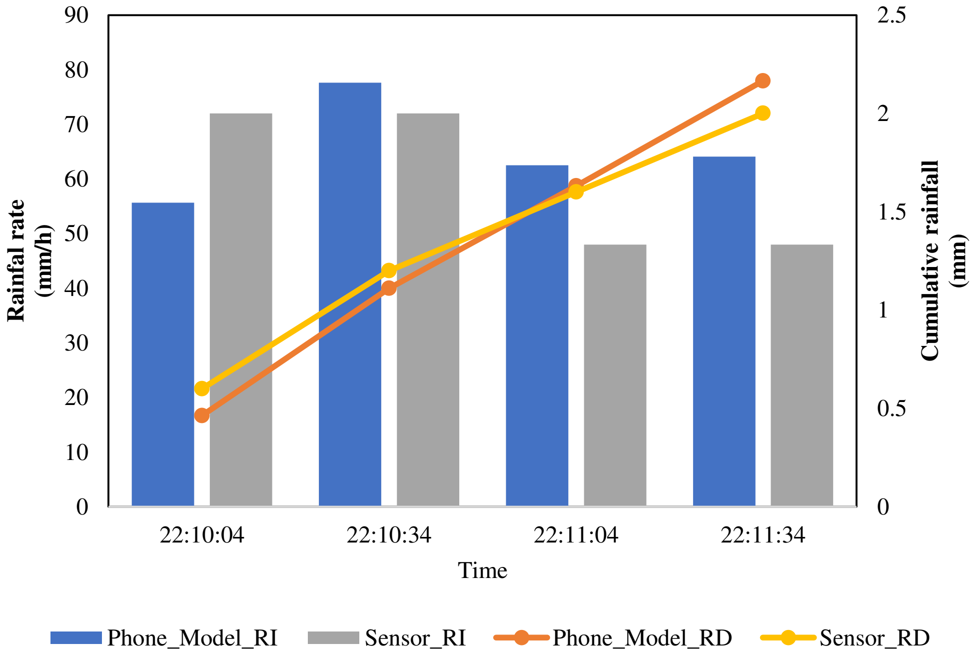
Case Studies-Rainfall monitoring from videos captured by CCTV cameras and smartphones.

RESULTS

Rainfall was recorded using a smartphone

Type	Date	Duration (minutes)	Frame rate per second	Total frames	Frame size (pixel)
Rain event	4/08/2023	2	30	120	720x1280



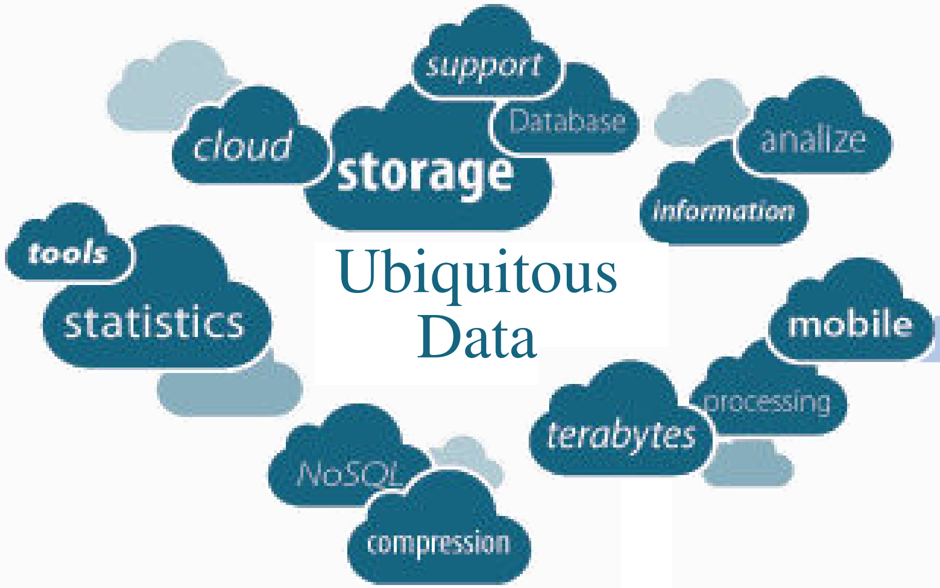


Start time	End time	ER	MAE	RMSE
13:48:18	14:58:25	0.10	0.11	0.12

CONCLUSION

- Thus, the proposed model has shown good performance in analyzing different rain events with a complex background, improving the raindrop detection in the frames of the video captured.
- The model provided rainfall estimations with a relative error (RE) between 0.07 and 0.12.
- More importantly, we enhanced the rain streak recognition using precise parameters for each scene recorded, focusing the analysis on specific frames (frame analysis) instead of the whole video.
- Moreover, we have enhanced the scene identification to use the correct filters for image processing and retrieved enough information for accurate rainfall monitoring

Case Studies-Balance big data and low quality

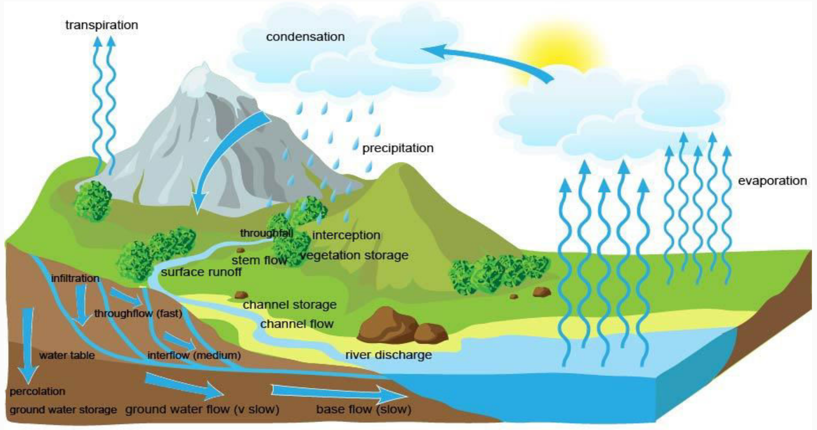


Ubiquitous Data

Wide Coverage (Big Data)

Low Quality (Differing Errors)

hydrology cycle simulation

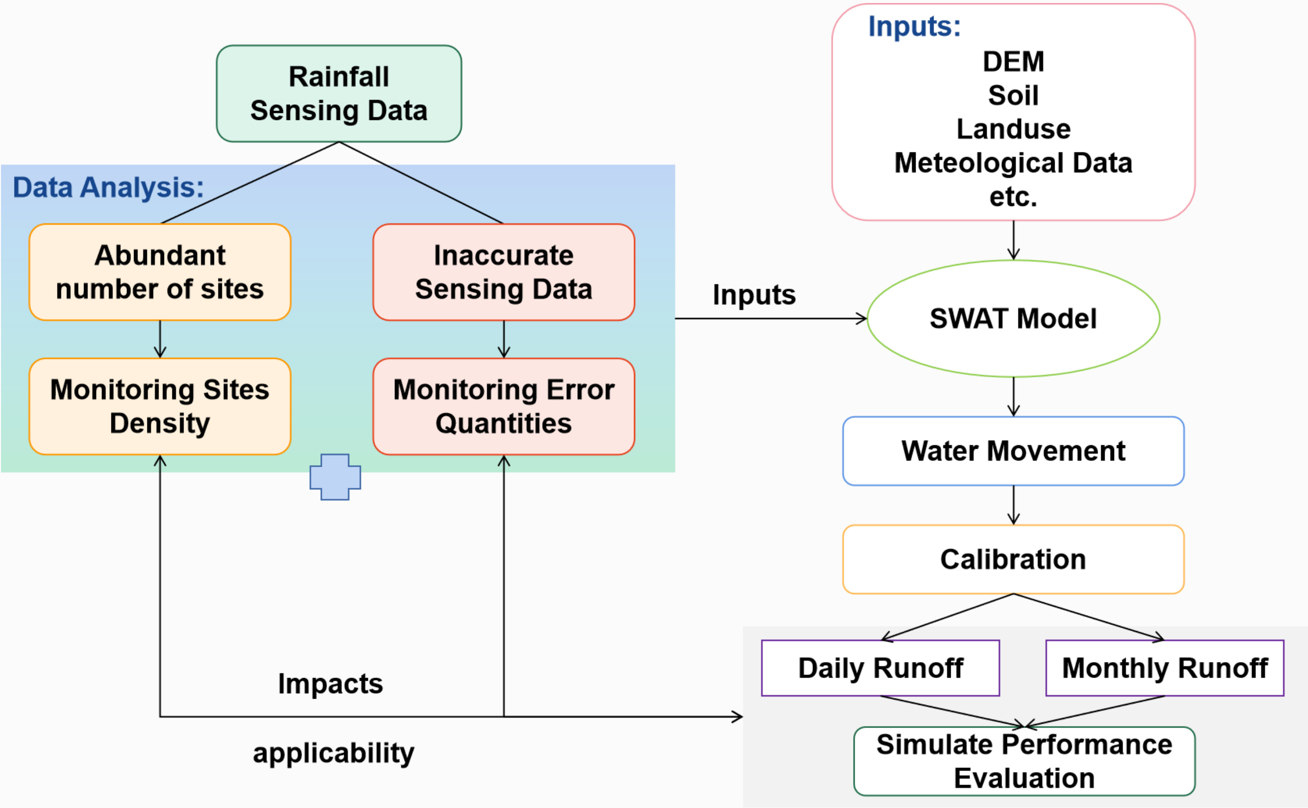


How to Balance?

- Ubiquitous data would be discarded or refine the collection methodology to improve data quality?
- Find the balance point between site distribution density and error in improving runoff simulation.

METHOD

Preliminary Theoretical Experimental Research



Rainfall Sensing Data

Data Analysis:

Abundant number of sites

Inaccurate Sensing Data

Monitoring Sites Density

Monitoring Error Quantities

Inputs:
DEM
Soil
Landuse
Meteological Data
etc.

Inputs

SWAT Model

Water Movement

Calibration

Daily Runoff

Monthly Runoff

Simulate Performance Evaluation

Impacts

applicability

Assumption

1. Truth Rainfall Series

The public datasets of CMADS (resolution: 1/8°) & Kriging interpolation

2. Density Sampling

Uniformly distributed sites

from 0.25 to 0.0025 /km²

3. Error Sampling

Normal Distribution - Monte Carlo Sampling

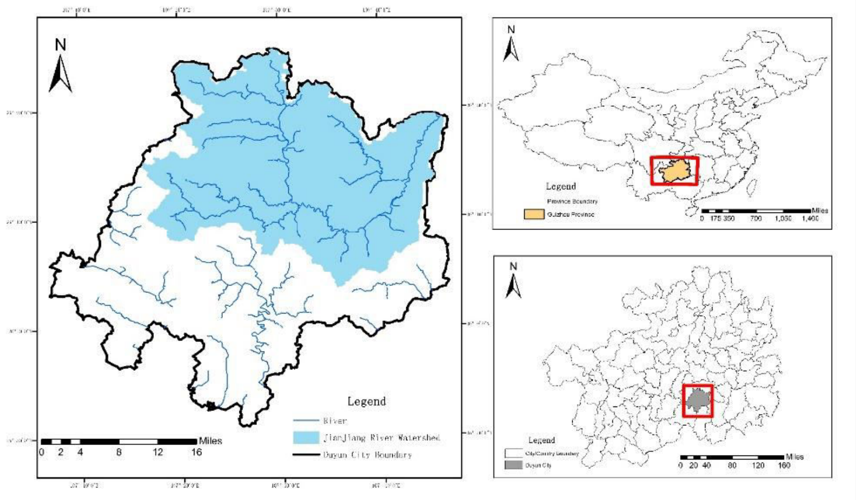
$$E \sim N(\beta \cdot I_{\text{true}}, (\alpha \cdot I_{\text{true}})^2)$$

$$\beta = 0\ ;\ \alpha \in (0.1, 0.2, 0.3, 0.4, 0.5)$$

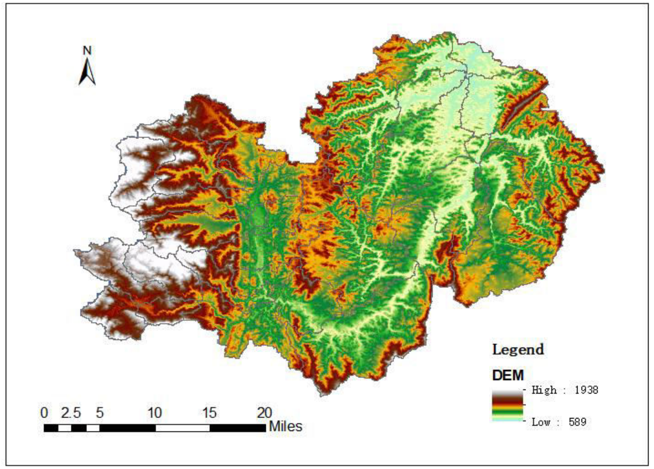
4. Iterations of Sampling

To minimize sampling randomness,
Iterations = 100

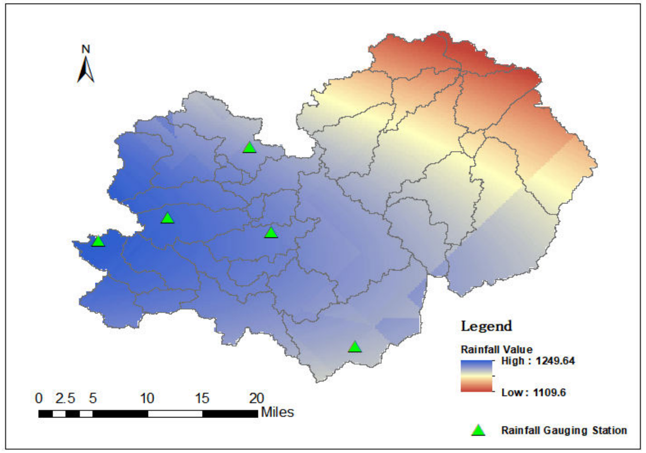
STUDY AREA



Location



DEM (30m×30m)



Spatial distribution of rainfall

◆ Jianjiang River watershed is a tributary of the Yangtze River, located in Duyun, southwest of China;

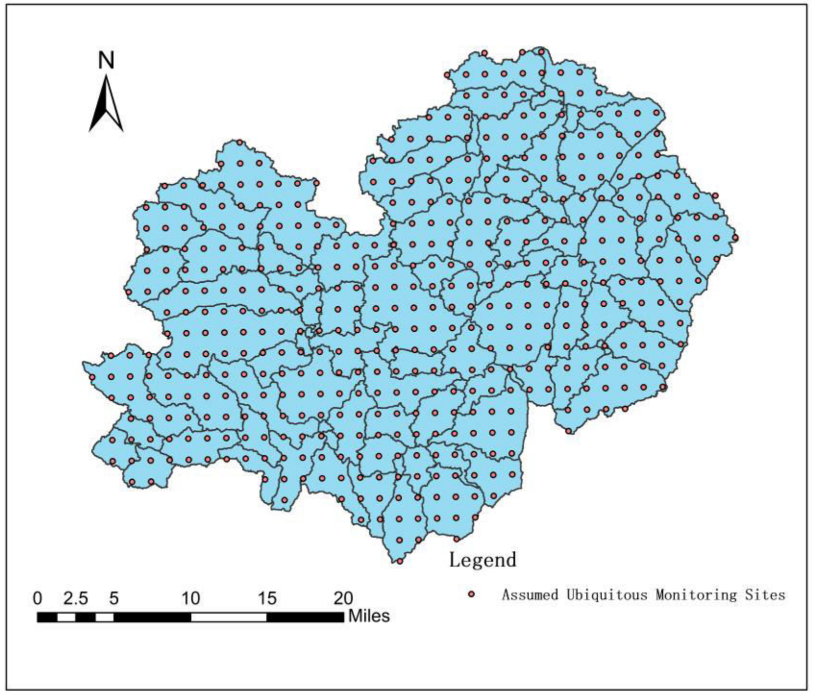
◆ The watershed area is 2,158.8 km^2 ;

◆ The area receives an average annual rainfall of 1,431 mm, with notable seasonality；

◆ The rainfall distribution in the basin gradually decreases from upstream to downstream, with a maximum difference in rainfall of nearly 150mm/year;

◆ There are 5 rain gauges stations in the watershed, which are not representative of global trends.

STUDY AREA



- **Subcatchments: 95**
- **Basic scheme:**
  monitoring network with free-error
- **Time Series**
  2012/1/1——2012/12/31

Parameters of the SWAT model[1]

CN2	ALPHA_BF	CH_K2	GWQMN	GW_REVAP	EPCO
0.18	0.57	205.49	665	0.19	0.54

Simulation skill evaluation

Nash-Sutcliffe model efficiency (NS)

$$NS = 1 - \frac{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{sim,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{sim,ave}\right)^2}$$

Root Mean Squared Error (RMSE)

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{sim,i}\right)^2}$$

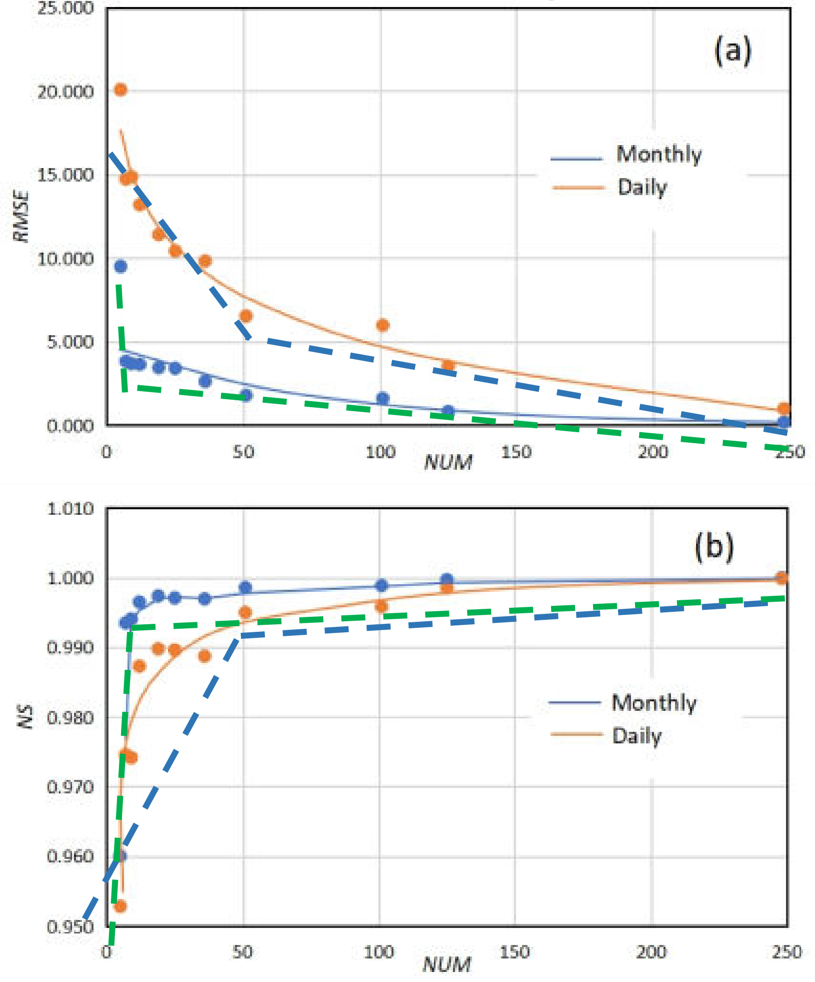
Case Studies-Balance big data and low quality

STUDY AREA

Schemes	**Variables**
Basic scheme	498 rainfall monitoring sites（Resolution: 0.25/km^2） with free-error
Density of rainfall monitoring sites scheme	*T1*:498 sites, 0.250/km^2; *T2*:248sites, 0.11 km^2; *T3*:123sites, 0.056 /km^2; *T4*:99sites, 0.045 /km^2; *T5*:49 sites, 0.023 /km^2; *T6*:34sites, 0.158 /km^2; *T7*:25sites, 0.116 /km^2; *T8*:19sites, 0.009 /km^2; *T9*:12 sites, 0.006 /km^2; *T10*:9sites, 0.004 /km^2; *T11*:7sites, 0.003 /km^2; *T12*:5sites, 0.0025 /km^2;
Error quantity of rainfall monitoring sites scheme	*E1*: rainfall data error α=10%; *E2*: rainfall data error α= 20%;*E3*:rainfall data error α=30%; *E4*: rainfall data error α=40%;*E5*: rainfall data error α=50%
Dual variation scheme of density and error quantity	T1~T2 combined with E1~E5

RESULTS

1. Effects of Rainfall Sensing Data Density



The relationship between monitoring density and runoff simulation performance

◆ With the **increase in monitoring density**, the **accuracy** of runoff simulation continues to **improve**, especially for monthly runoff simulation.

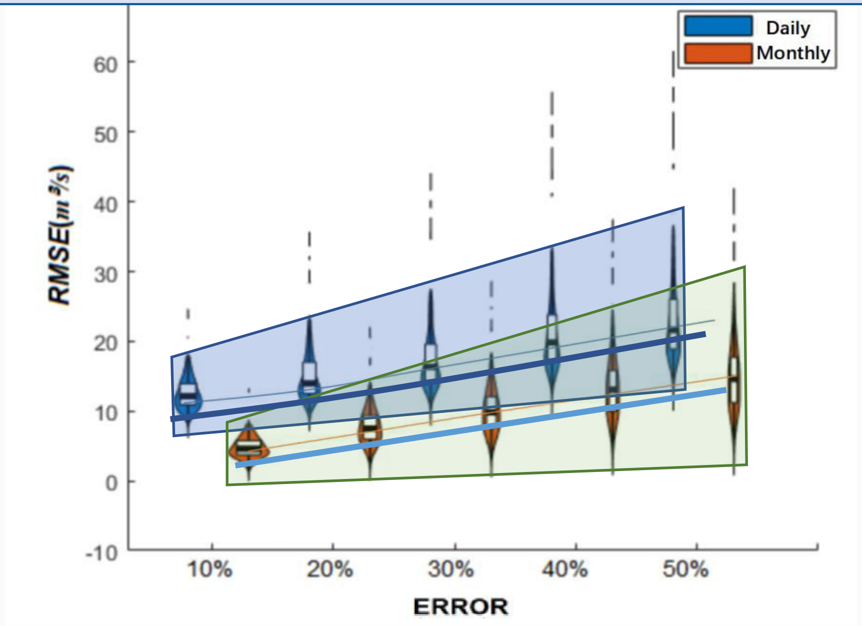
◆ When the number of sites is more than 9 (**0.004/km^2**), the monthly runoff simulation effect increases rapidly, and then the increase slows down;

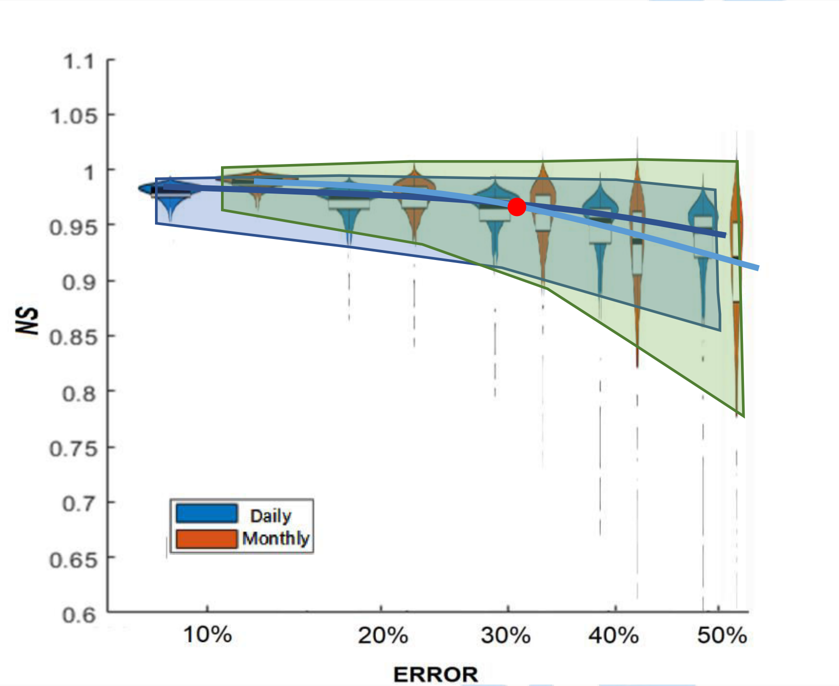
◆ The **turning point** of daily runoff simulation is at the point where the number of monitoring sites is about 50 (**0.025/km^2**).

RESULTS

2 Effects of Rainfall Sensing Data Error

- As the amount of **error increases**, the **performance variation range** of runoff simulation continues to **increase**.
- For the **RMSE** index, the **monthly** runoff simulation performance is **better** than the **daily** runoff simulation under different error schemes.

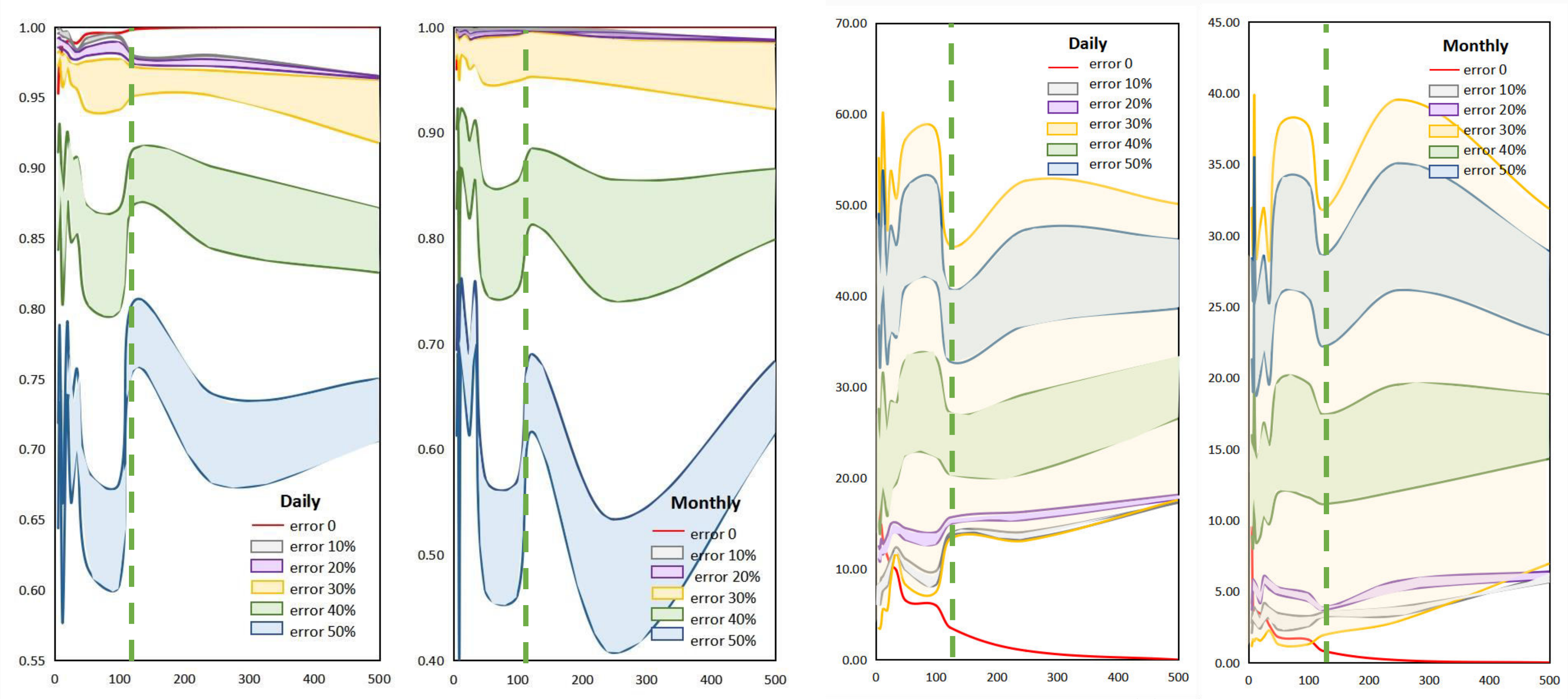




- For **NS**, when the error quantity is greater than **30%**, daily runoff simulation performs better than monthly runoff simulation.
- As can be seen the trend orange and blue lines from the figure, it is better to **control the error range at 30%** (turning point).

RESULTS

3 Combined Effects of Rainfall Sensing Data Density and Error



(a) ***NS***

(b) ***RMSE***

The impact of variation of monitoring density and error quantity on runoff simulation performance

- ◆ When the sites number is less than **100**, the sensing error has a large random effect on the runoff simulation;
- ◆ For monitoring sites at more than **0.05/km²**, the effect of error on runoff trends to stabilize;
- ◆ When error is greater than **30%**, the range of performance influence variation is larger.

◆ Therefore, in the practical application of rainfall sensing data, the error quantity needs to be **controlled to within 30%**, while the density of the monitoring sites distrubtion should be greater than **0.05/km²**.

Case Studies-Balance big data and low quality

CONCLUSION

Limitations

- uniformly distributed in space and to have similar level of individual error
- the single hypothetical case cannot be generalized to all watersheds
- limited high resolution truth rainfall rields and the uniform parameters for all schemes

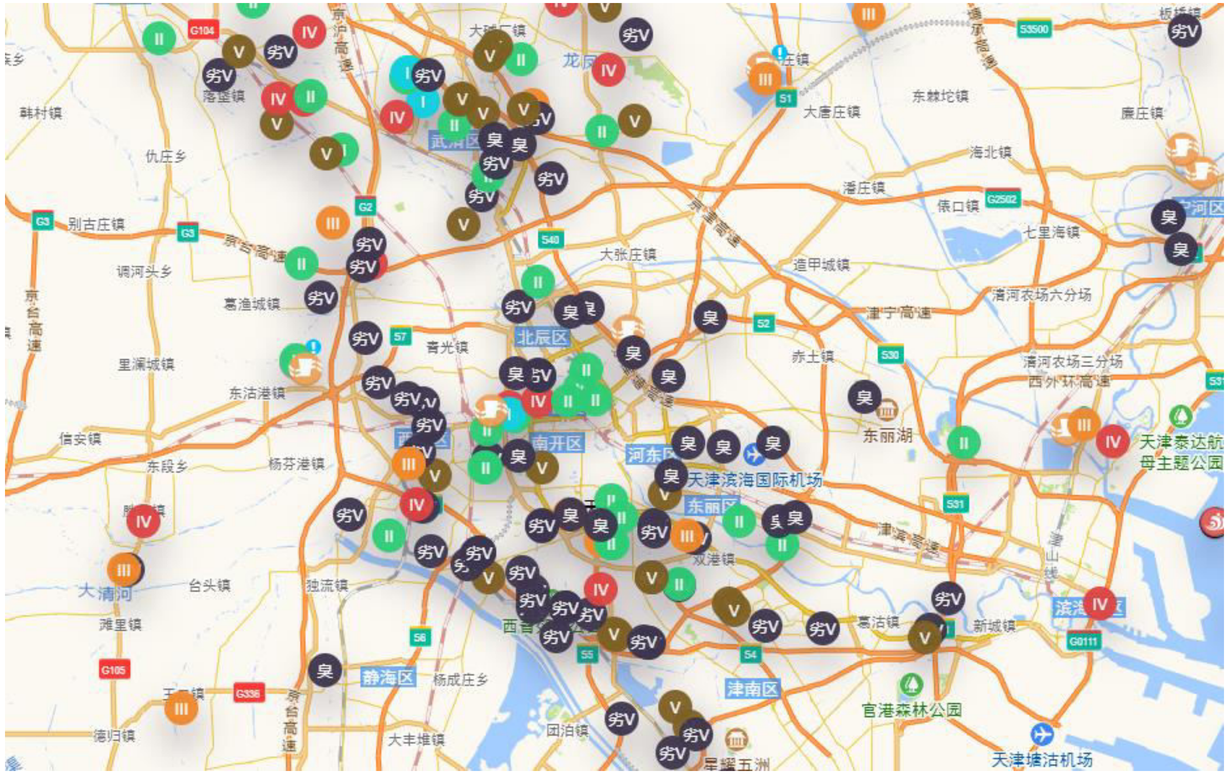
Future development directions

- It will analyzed the impact based on characteristics of different sensing data
- This research results need to be verified in more typical regions
- It will be considered the uneven distribution of data and the other implcations of factors

04

Conclusions and prospects

The rapid development of science and technology, Internet technologies and portable devices represented by smartphones and sensors are becoming increasingly powerful. All these new emerging technologies provide a good foundation as well challenges for hydrological research




Hush City's icon. (c) Antonella Radicchi 2017

Hush City

Goal To empower people to identify and evaluate quiet

more»

Task To use Hush City app to identify & evaluate urban

more»

Where Global, anywhere on the planet

本市共45个空气监测点 AQI均值234 全国排名377位

The complexity of the water environment itself places higher demands on data, and relying solely on a limited number of professional data station is difficult to meet this demand.

In the future, new devices and new sensors provide more possibility in data collection pattern, together with public participation, the hydrological research will step on a new stage and show more perspectives.

Thank you for listening

Contact: mingnawang@hotmail.com