Unlimited K-water

Application of GPM IMERG satellite-based precipitation products for flood runoff simulation in a dam watershed

1st NARBO Webinar

Challenges of "New Normal" river basin management:

The pandemic is not over yet, the flood control must go on

Younghyun Cho

K-water Research Institute, K-water (Korea Water Resources Corporation)

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Introduction

Background

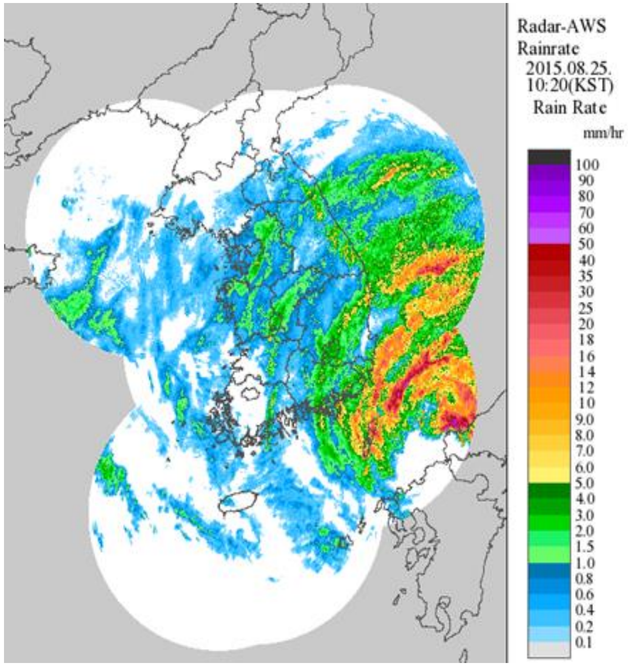
- Since most of South Korea is consisted of mountainous areas (about 65%), the spatial distribution of precipitation during rainfall storm event is highly variable.
- Especially, in the dam watershed, which is a typical mountainous terrain, the shape and pattern of rainfall and the resulting changes in the outflow show complicated characteristics.
- Therefore, it is often unlikely to use the areal rainfall, which is estimated by averaged method (e.g. Thiessen polygon) with gauge observations, for flood runoff analysis and the introduction of the radar-based spatially distributed rainfall is required for hydrological simulation.

Introduction

RAR (Radar-AWS Rainrates)

- Quantitative precipitation estimations (QPEs) using the real time Z-R relationship based on radar reflectivity (Z) and rain gauge observations (R)

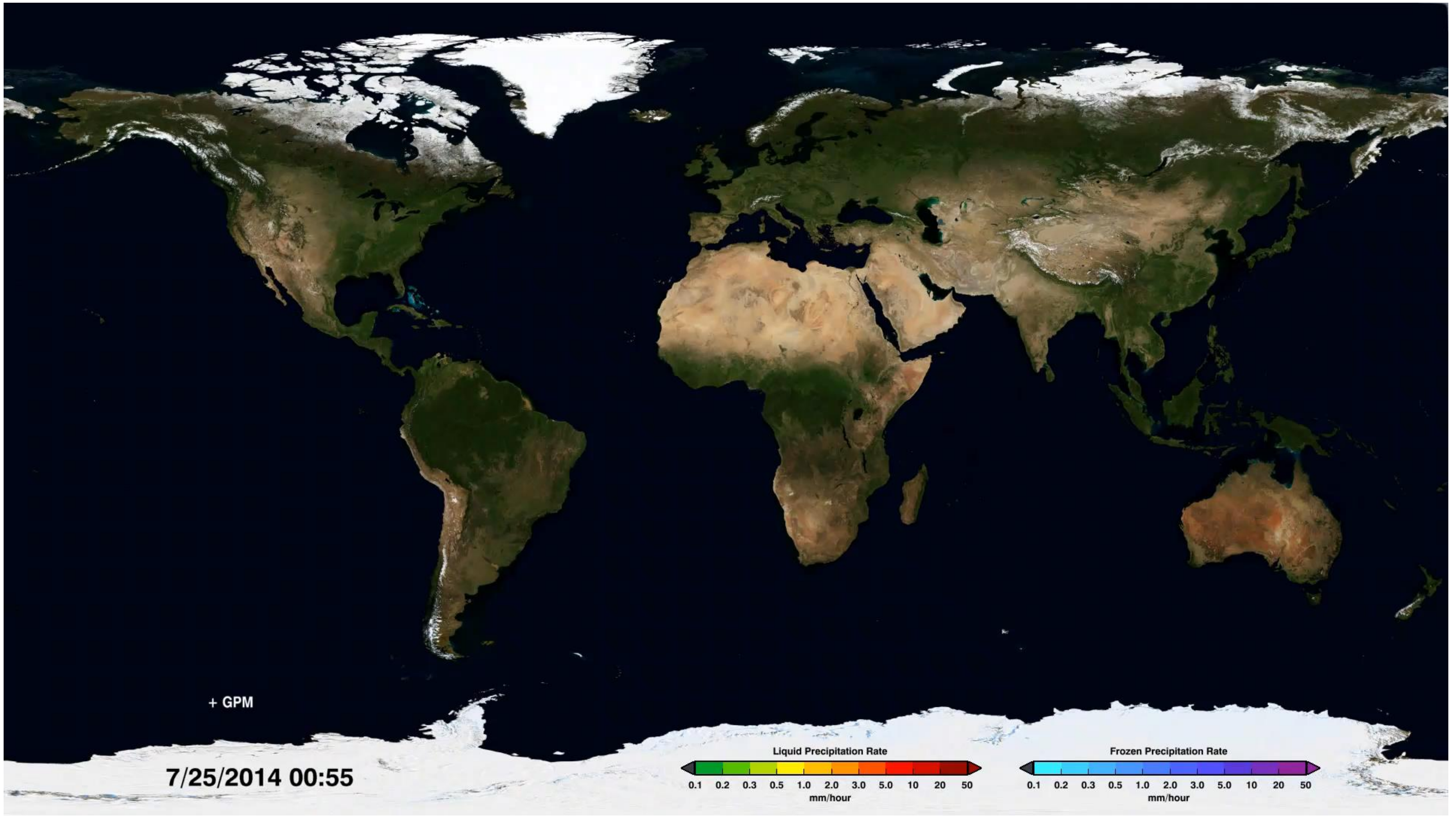
- KMA (Korea Meteorological Administration) has continuously improved the "Radar-AWS Rainrates (RAR)" data production technology to provide more accurate radar-based precipitation estimations, showing considerable accuracy compared to the ground observations.



**Latest version: RAR ver. 2.0 (2015. 9)*

GPM IMERG

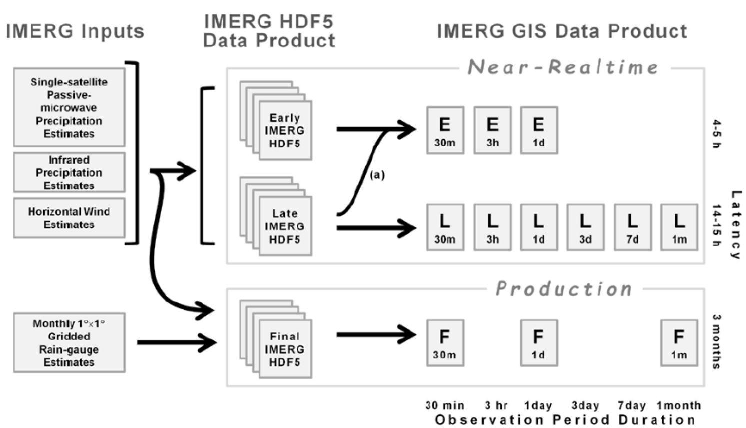
IMERG (Integrated Multi-satellitE Retrievals for GPM)



GPM IMERG

Data specifications

- Spatial resolution: 0.1˚ x 0.1˚ (roughly 10 x 10 km), from 60˚N – 60˚S
- Temporal resolution: half-hourly, daily, and monthly (final only), value-added products at 3 hours, 1, 3, and 7 days are also available
- Map system: WGS84 (GCS, default)
- Multiple runs accommodate different user requirements for latency and accuracy
  - "Early" – 4~5 hours (flash flooding)
  - "Late" – 14~15 hours (crop irrigation)
  - "Final" – 3 months (research data)



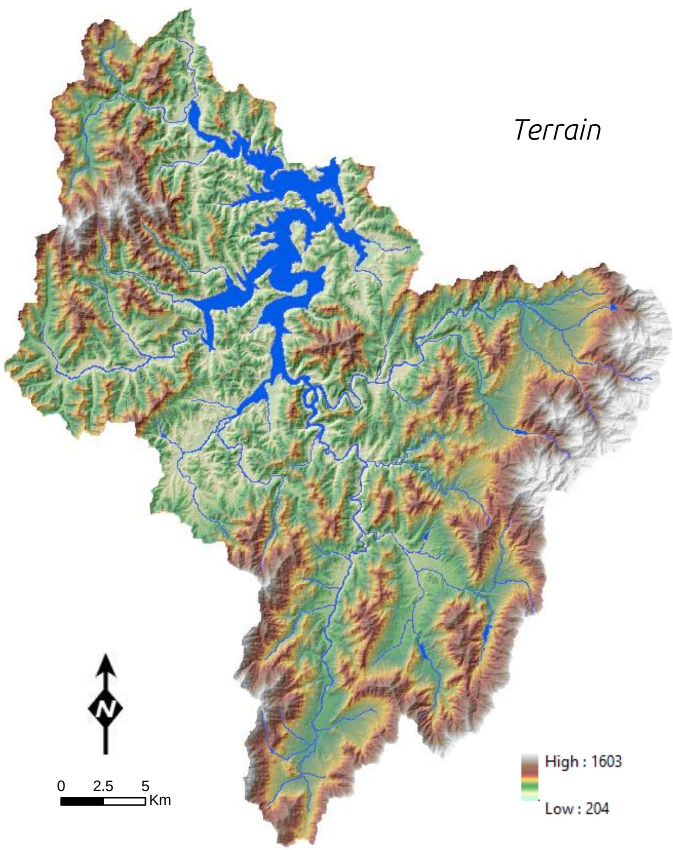
GPM IMERG

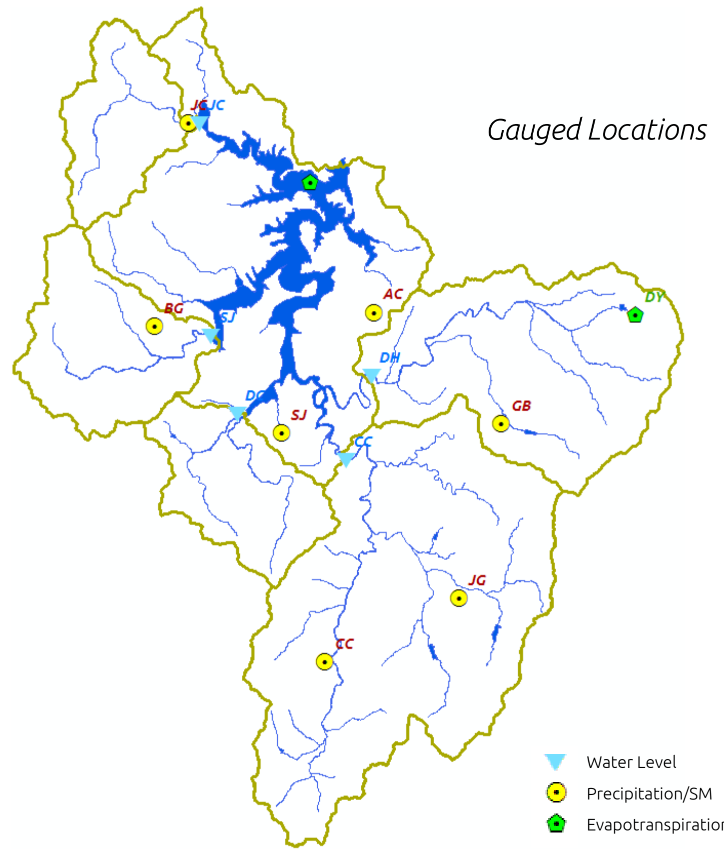
GPM_3IMERGHH (V06)

- File name: 3B-HHR.MS.MRG.3IMERG.$YYYY$MM$DD-S$HHMMNN-EHHMM$NN.$MMMM.V06B.HDF5.nc4
- Spatial resolution: 0.1° x 0.1° (roughly 10 x 10 km), from 90°N – 90°S (60°N – 60°S full)
- Temporal resolution: half-hourly (final run, 3.5 months latency)
- Version 6 of IMERG was released in April 2019; the first version to cover the approximately 20-year period from June 2000 to the present (TRMM and GPM era)
- Data access: https://disc.gsfc.nasa.gov/

Study Area

Yongdam dam watershed

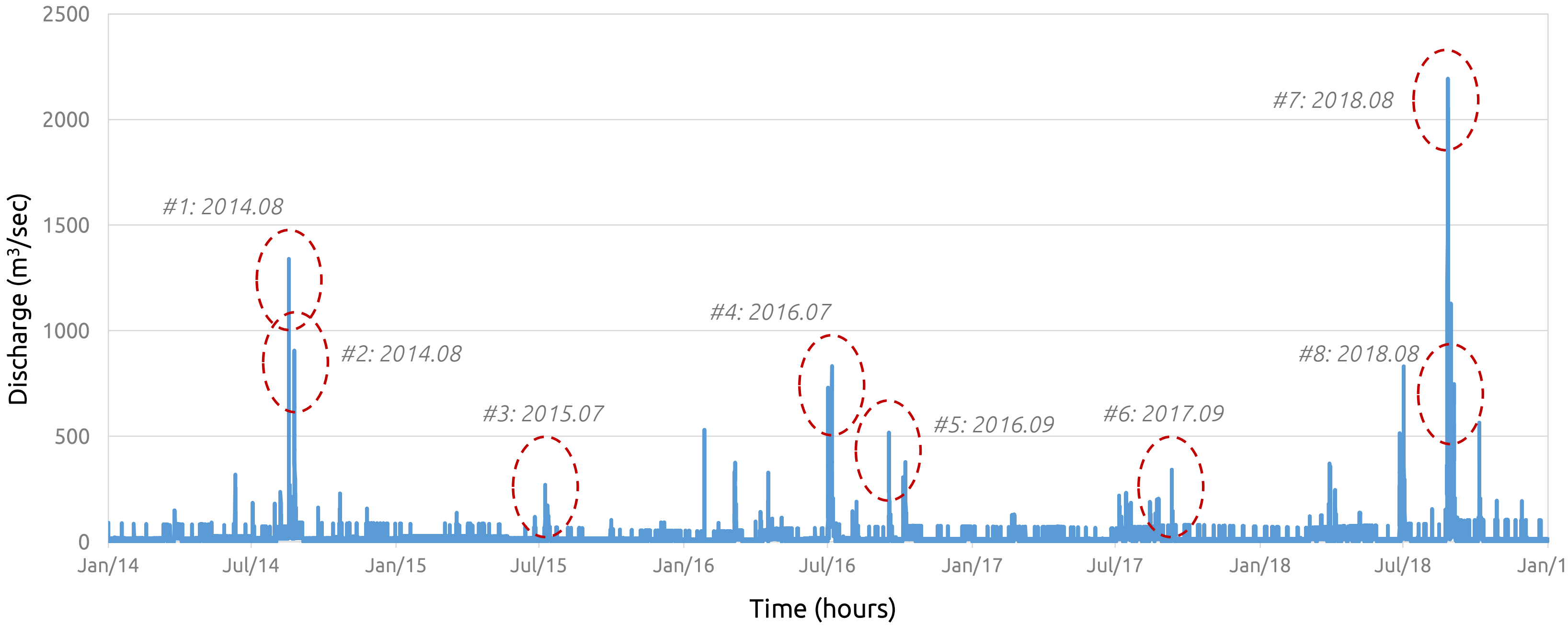




Storm Events

Storm event selection

- 8 storm events (hourly) from 2014 to 2018



Storm Events

Independent single event (2014 to 2018, hourly)

Storm Events (#: Period)	Precipitation Total (mm)													
	Gauged data								Radar-based data			Satellite-based data		
	GB	*JG*	*CC*	*SJ*	*BG*	*JC*	*AC*	*Areal average*	*Min.*	*Max.*	*Areal average*	*Min.*	*Max.*	*Areal average*
1: 2014.08.17. 13:00~08.20. 12:00	97	114	128	100	121	100	101	*108.3*	64.8	146.9	*88.7*	96.5	174.2	*134.4*
2: 2014.08.24. 01:00~08.28. 24:00	90	71	64	106	57	87	101	*82.2*	37.4	100.1	*58.9*	80.9	113.2	*99.5*
3: 2015.07.08. 13:00~07.11. 12:00	51	37	47	77	59	61	69	*57.3*	16.8	65.3	*38.1*	9.2	81.2	*39.0*
4: 2016.07.01. 13:00~07.03. 12:00	119	128	153	125	101	124	115	*122.9*	12.3	183.5	*96.9*	116.7	152.3	*138.9*
5: 2016.09.16. 13:00~09.19. 24:00	147	129	158	148	134	145	162	*146.1*	15.3	145.2	*101.1*	91.6	121.3	*102.0*
6: 2017.09.10. 01:00~09.12. 24:00	69	77	78	73	73	57	78	*71.8*	5.1	77.8	*50.6*	32.2	56.1	*42.1*
7: 2018.08.25. 13:00~08.30. 12:00	245	286	331	316	288	269	285	*286.3*	22.7	305.9	*198.6*	128.4	218.9	*189.4*
8: 2018.08.30. 13:00~09.02. 12:00	84	110	98	84	69	100	61	*86.0*	4.8	113.3	*56.7*	50.2	110.7	*71.0*

This dashed marker is wrong; removing.

**SCS CN method does not account for infiltration recovery during intervals of no rain*

IMERG Data Processing

Procedure

<Data Processing>	*<Program>*
IMERG Conversion & Geo-referencing in ArcGIS - netCDF4 to ASCII **Projection: WGS84 to SHG gird (ITRF2000)*	*Python script in ArcGIS (ArcPy)* *<developed>*
HEC-DSS file Generation - ASCII to DSS grid	*HEC-GridUtil* *<asc2dssGrid.exe>*

IMERG Data Processing

IMERG Conversion & Geo-referencing in ArcGIS

- IMERG (netCDF4 file); need to convert to ASCII file for practical uses
  **Projection: WGS84 to SHG (ITRF2000) grid*

- Python script

  - *nc4toasc.py* (ArcPy module for using multiple geoprocessing tools)

Make NetCDF Raster Layer
<IMERG grid>

Rename: 3B-HHR.MS.MRG.3IMERG.$YYYY$MM$DD-S$HHMMNN-EHHMM$NN.$MMMM.V06B.HDF5.nc4
→ *3b-hhr.ms.mrg.3imerg.$YYYY$MM$DD-s$HHMMNN.asc*

↓ *matching*

Project Raster
<ITRF2000> ← GCS (Ellipsoidal) <GRS1980> *true*

↓

Raster to ASCII
<SHG grid>

IMERG Data Processing

HEC-DSS file generation

- ASCII to DSS grid

- HEC-GridUtil

  - *asc2dssGrid.exe* (bridges the gap between raster GIS and grids in DSS)

**ASCII file (3b-hhr.ms.mrg.3imerg.$YYYY$MM$DD-s$HHMMNN.asc) – header info.*

Name	Description
NCOLS	Number of grid columns (integer)
NROWS	Number of grid rows (integer)
YLLCORNER	Lower-left Y coordinate (real)
CELLSIZE	Cell size (real); width of a square cell
NODATA_VALUE	Value to indicate a null cell, where a value is either missing or has been removed (default: -9999)

Rename: 3b-hhr.ms.mrg.3imerg.$YYYY$MM$DD-s$HHMMNN.asc
→ *IMERG_$YYYY$MMDDHH$MM.dss*

Hydrologic Modeling

HEC-HMS

Model Development

- HEC-GeoHMS (with Arc Hydro Tools)

  **Basin Model, Grid Cell file generation*

- HEC-HMS — ***HEC-GridUtil***

  **Clark Unit Hydrograph Transform / ModClark Transform* ← - - - - - - - - *.dss grid file*

Event Simulation

- Performance test → Calibration/Validation

  **Combining observed data*

Results Evaluation

- Comparison with gauged and radar/satellite-based rainfall simulation results

Hydrologic Modeling

HEC-HMS

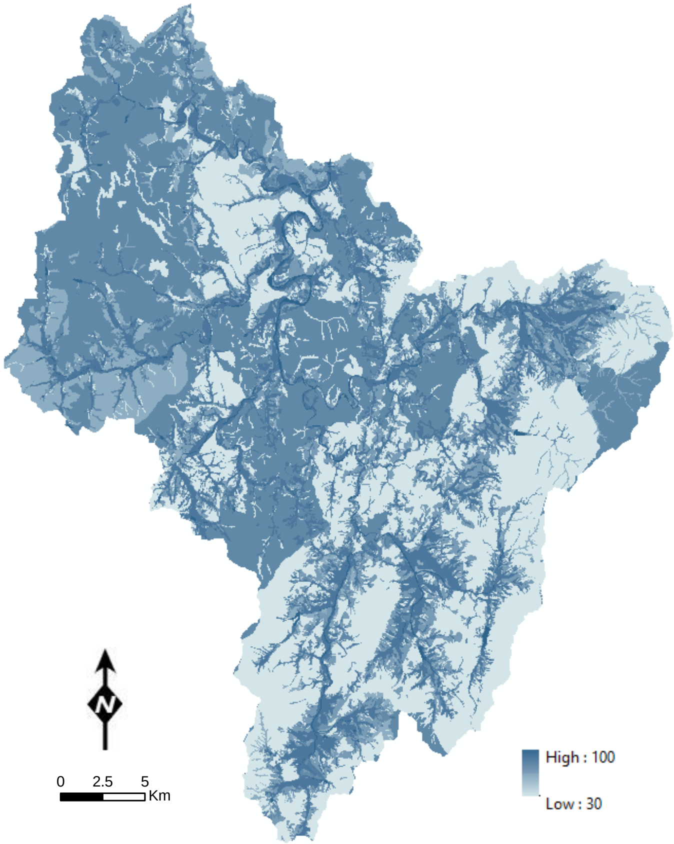
- Calculation methods

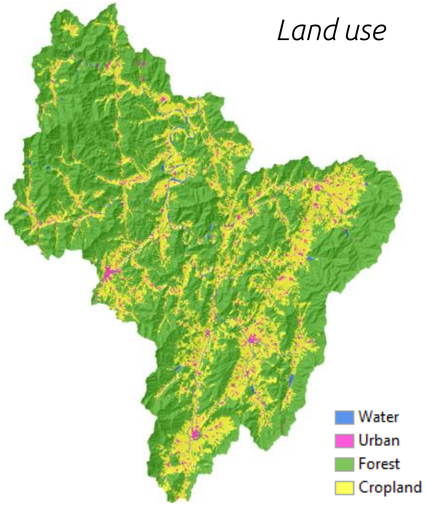
Hydrologic Element	Calculation Type	Methods	
		Gauged data simulation	Radar/Satellite-based data simulation
Subbasin	Ruoff-volume	SCS curve number (CN)	Gridded SCS CN
	Direct-runoff (Transform)	Clark Unit Hydrograph	Modified Clark Method (ModClark)
	Baseflow	Recession	
Reach	Routing	Muskingum	
Precipitation		Gage Weights (Thiessen polygon)	Gridded Precipitation (RAR, IMERG)
Discharge		Time-series data	Time-series data

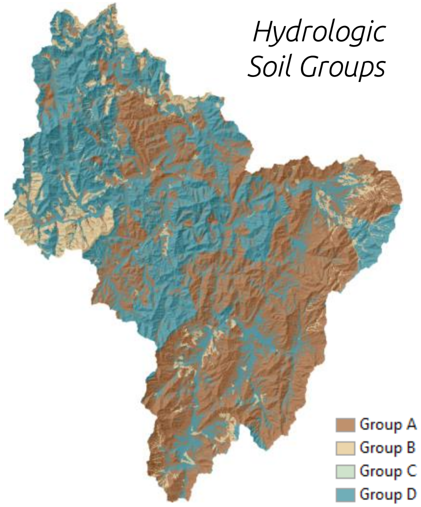
**Simulation run: consists of basin model, meteorological model, and control specification*

Hydrologic Modeling

SCS Curve Number

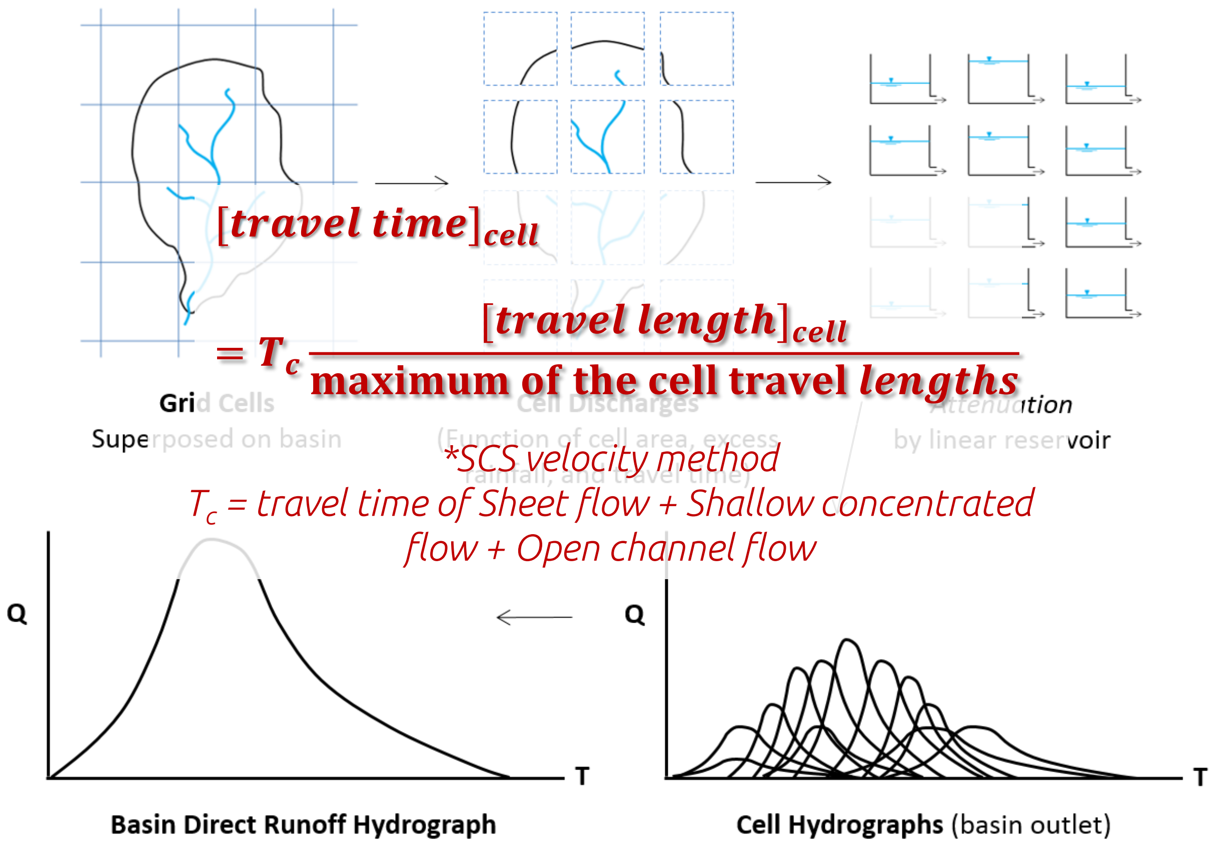






Hydrologic Modeling

ModClark



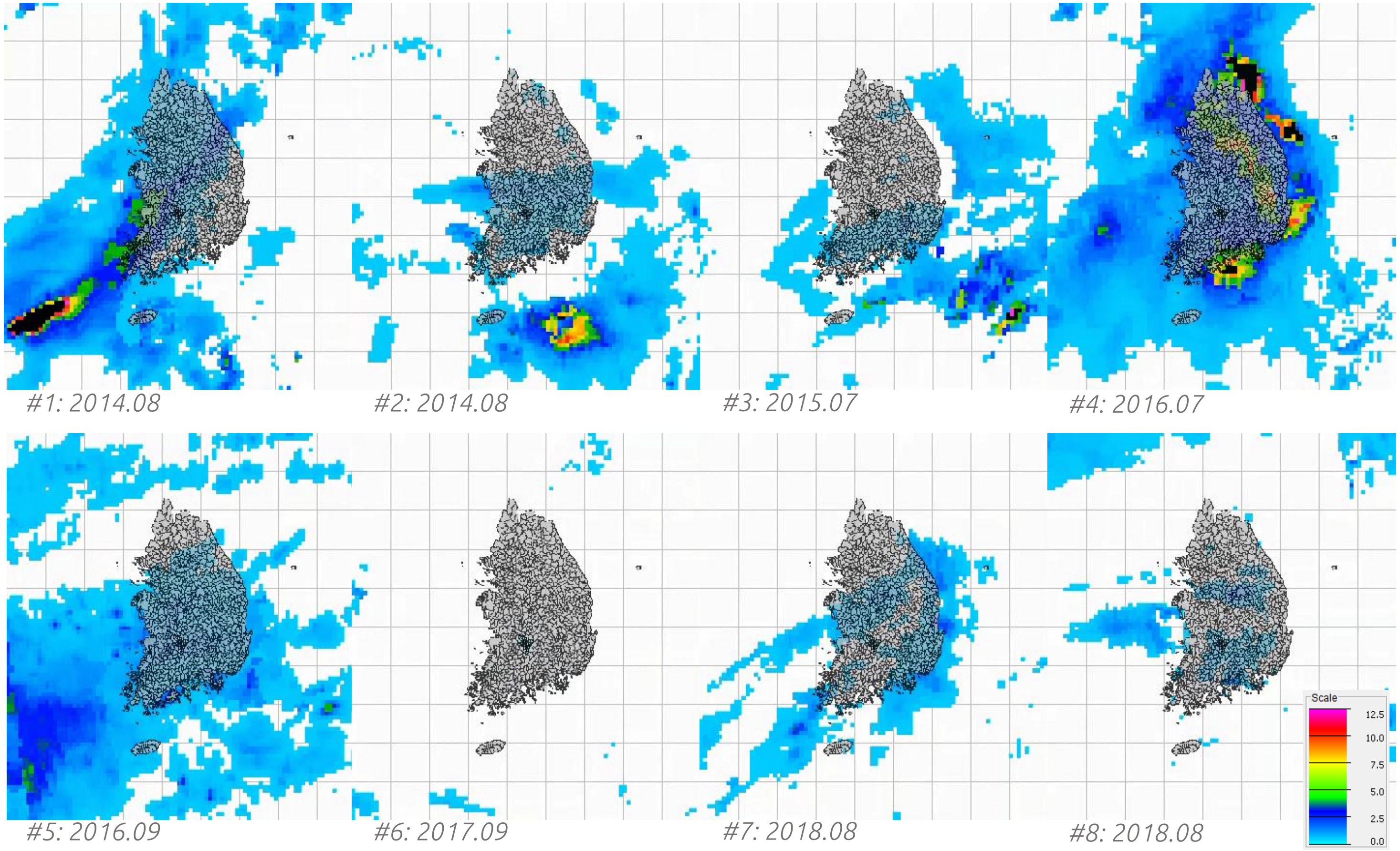
$$[\boldsymbol{travel\ time}]_{cell} = \boldsymbol{T_c} \frac{[\boldsymbol{travel\ length}]_{cell}}{\textbf{maximum of the cell travel } \boldsymbol{lengths}}$$

**SCS velocity method*

T_c = travel time of Sheet flow + Shallow concentrated flow + Open channel flow

IMERG QPEs

Spatiotemporal representation (2014 to 2018, sub-hourly)

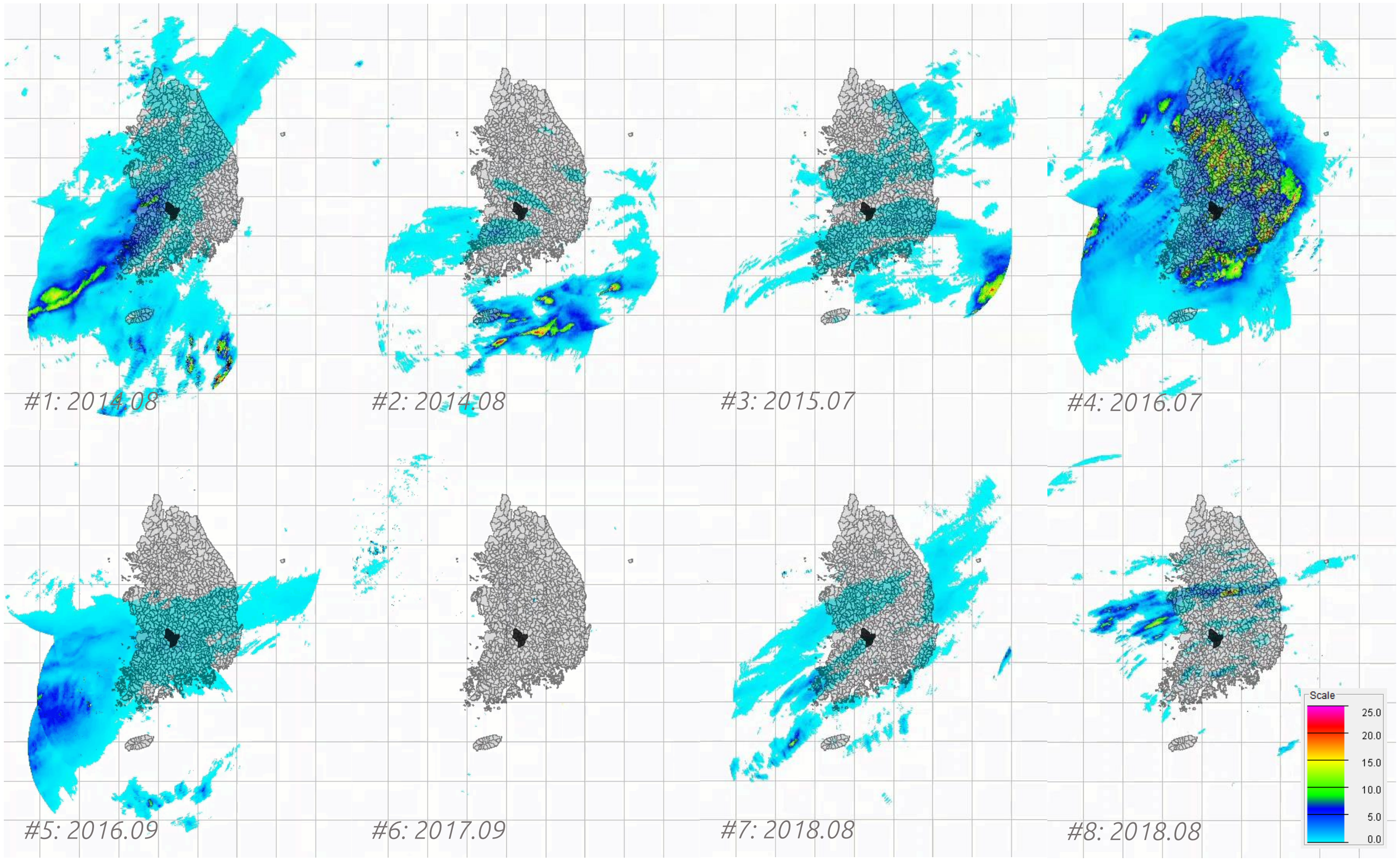


#1: 2014.08 #2: 2014.08 #3: 2015.07 #4: 2016.07

#5: 2016.09 #6: 2017.09 #7: 2018.08 #8: 2018.08

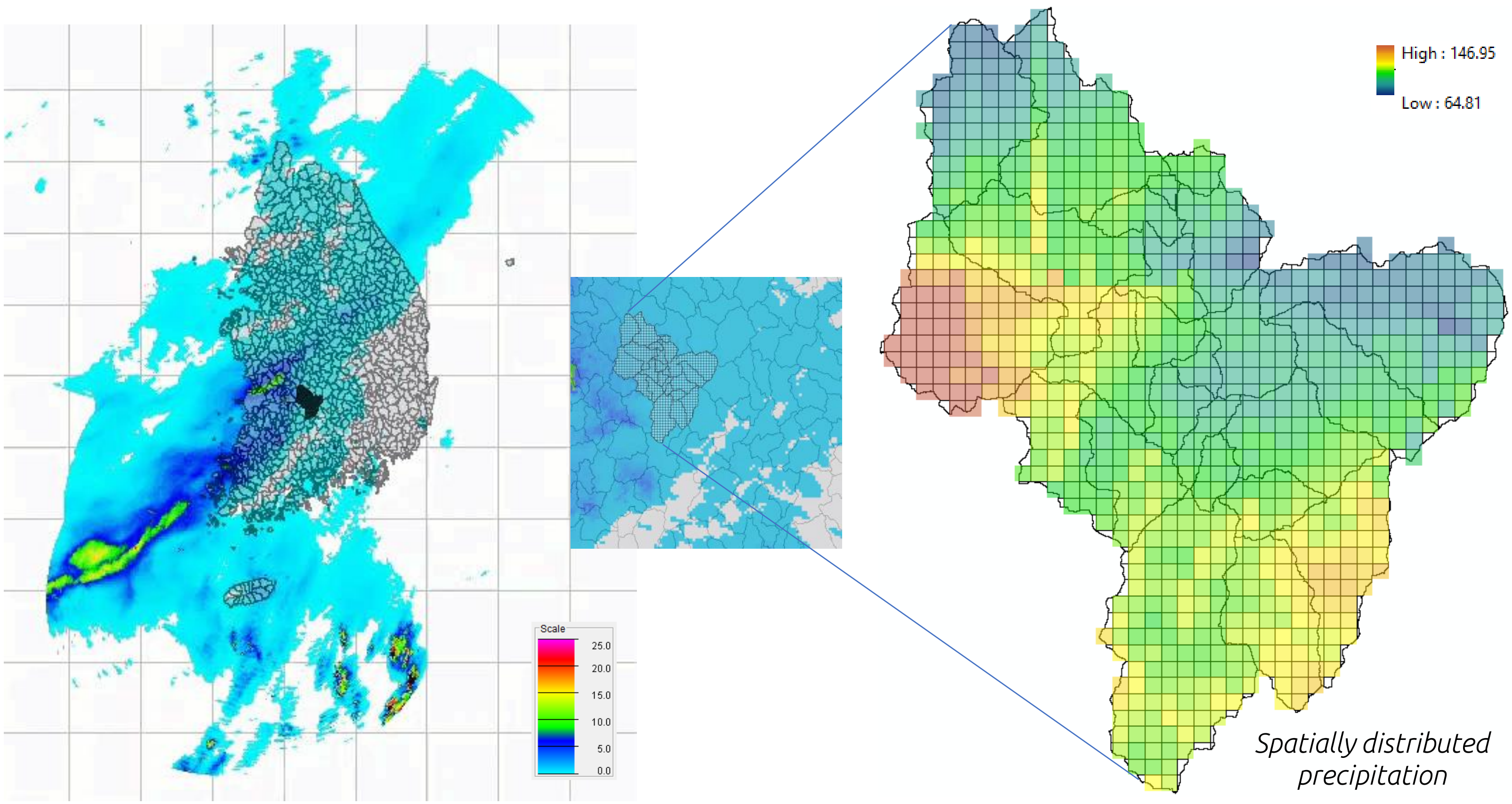
RAR QPEs

Spatiotemporal representation (2014 to 2018, hourly)



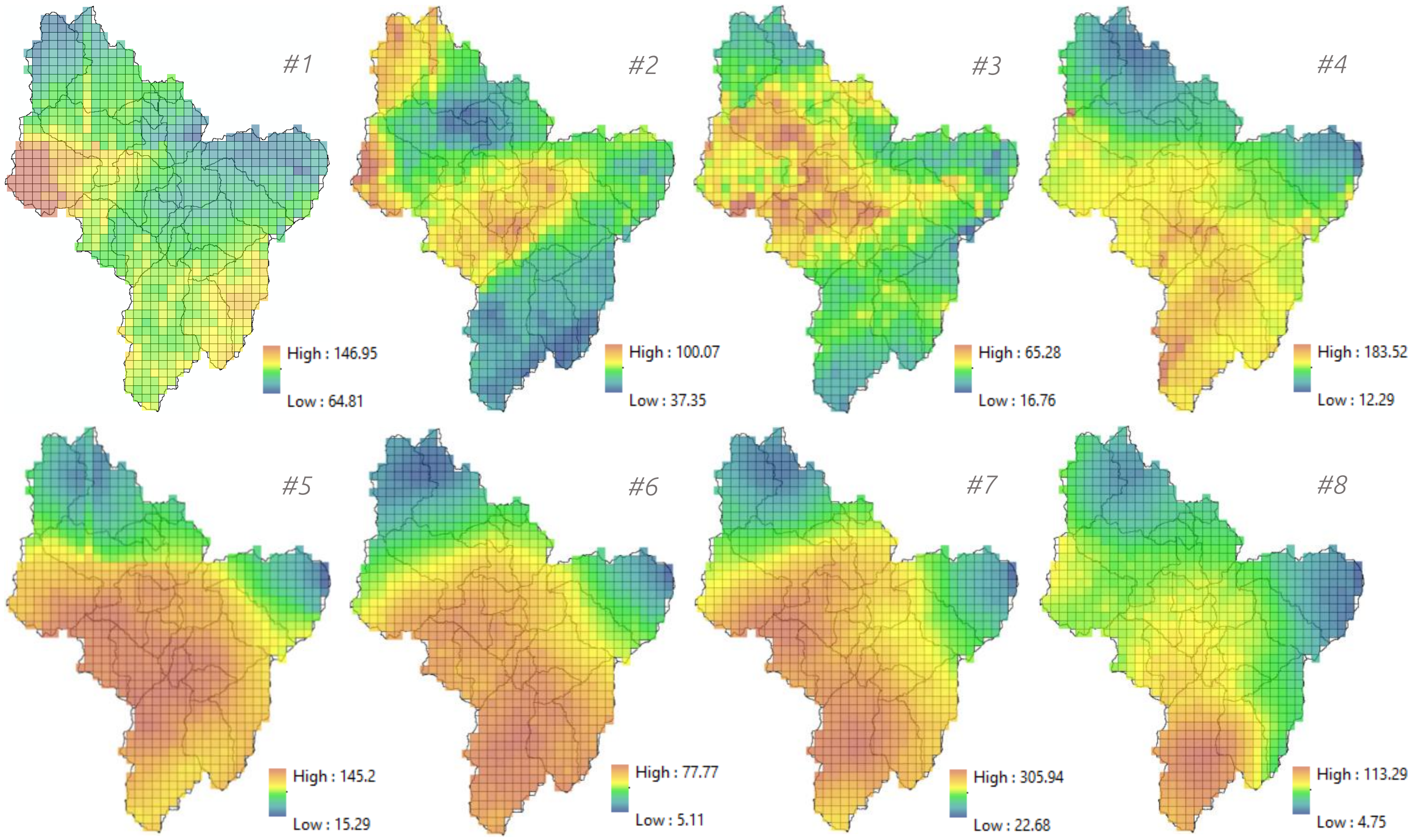
RAR QPEs

Spatiotemporal representation – storm event (#1)



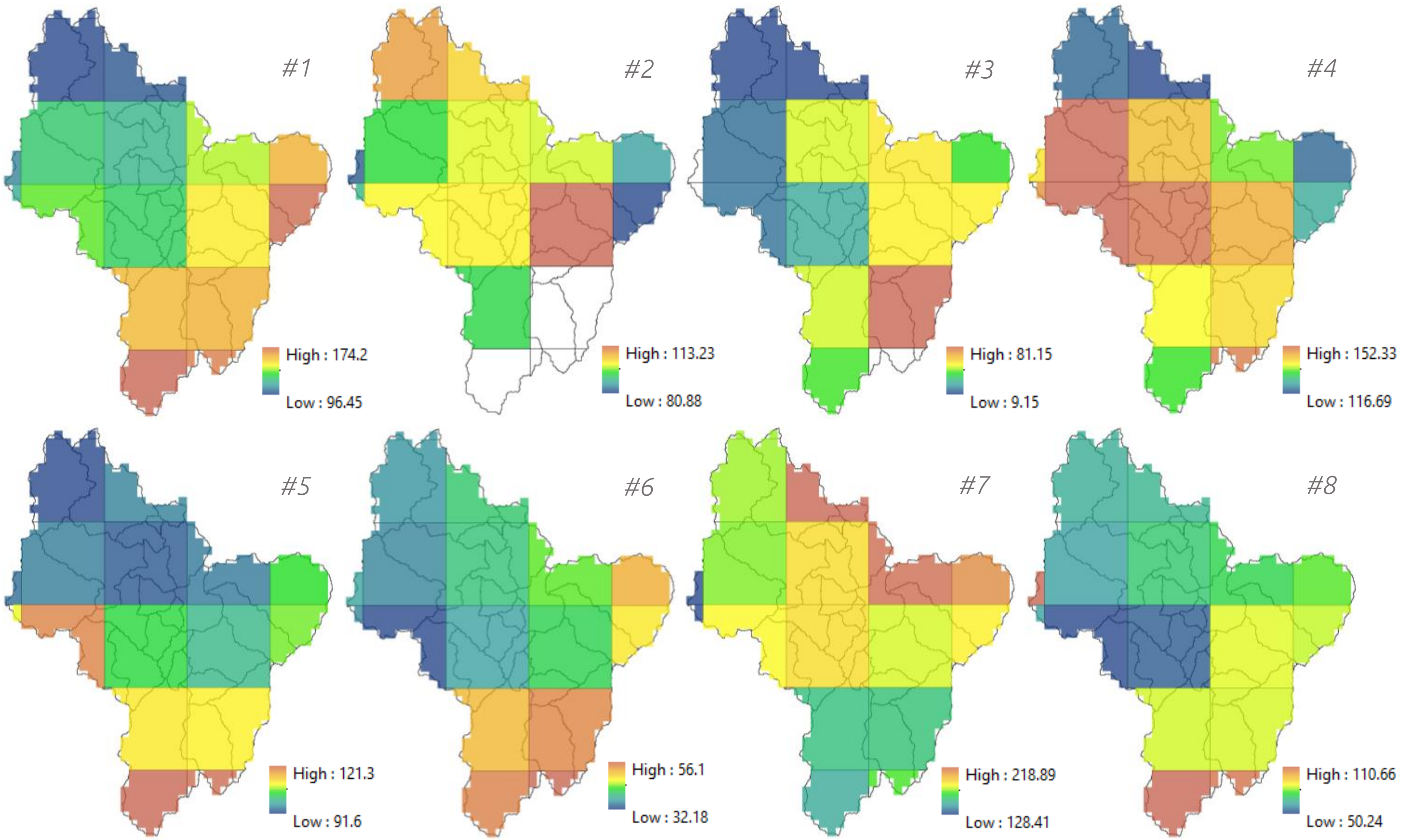
RAR QPEs

Spatial variability



IMERG QPEs

Spatial variability

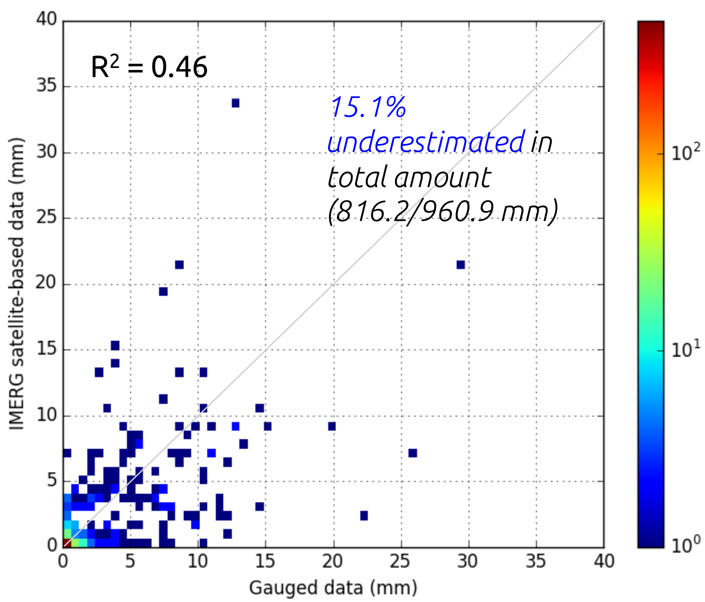


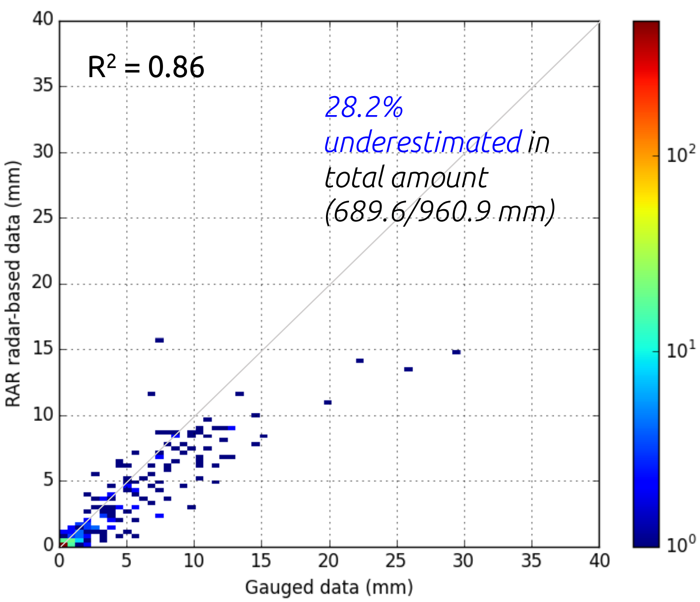
IMERG QPEs

Validation (scatter density plot)

- Correlation (R^2)

  - Areal average for satellite/radar-based and gauged data: 0.46/0.86
  - Underestimated trends in larger values of IMERG/RAR QPEs

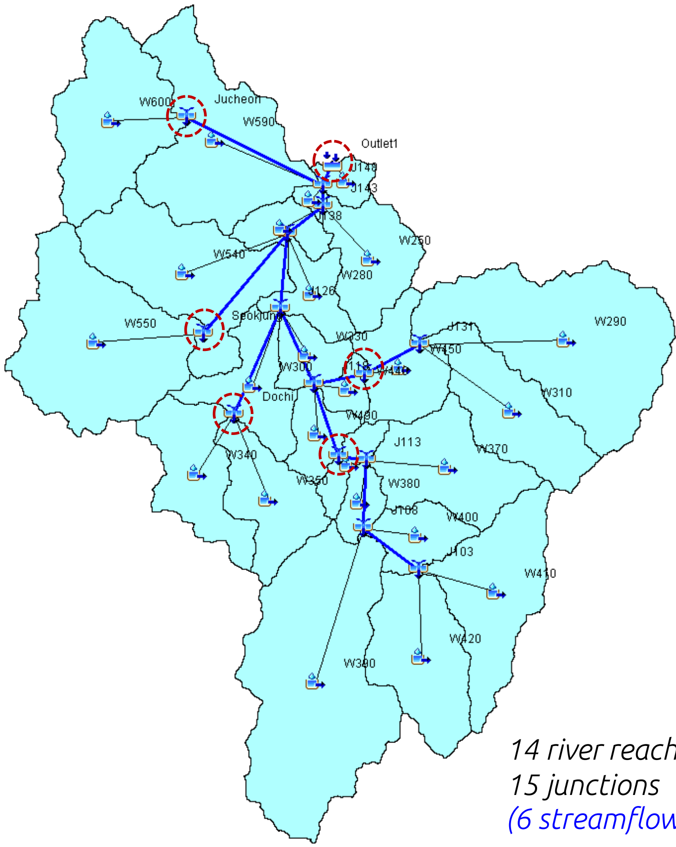




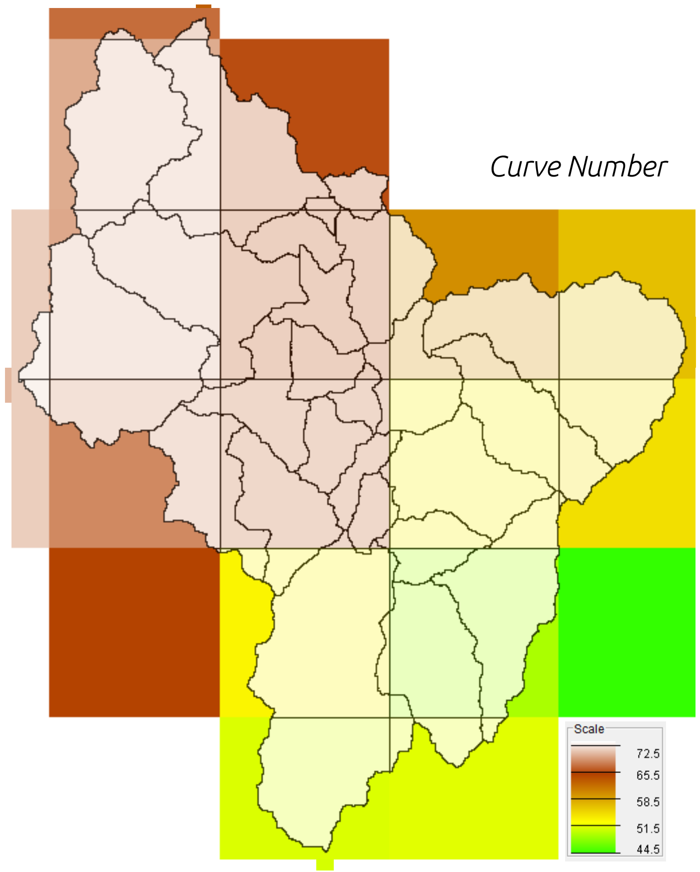
Model Development

Basin model

**Stream network definition: 3% threshold of watershed area*



14 river reaches
15 junctions
(6 streamflow gauges)



Model Calibration

Parameters

- Initial values

<table>
<tr><th rowspan="2">Hydrologic Element</th><th rowspan="2">Process</th><th colspan="2">Initial parameter values</th></tr>
<tr><th>Gauged data simulation</th><th>Radar/Satellite-based data simulation</th></tr>
<tr><td rowspan="3">Subbasin</td><td>Loss</td><td>SCS CN
- Curve Number: determined
- Initial abstraction (mm): 0
- Impervious(%): 0</td><td>Gridded SCS CN
- Curve Number Grid: determined
- Ratio: 0.05
- Factor: 1.0</td></tr>
<tr><td>Transform</td><td colspan="2">Clark UH / ModClark
- Time of concentration (HR): determined
- Storage coefficient (HR): 2.0</td></tr>
<tr><td>Baseflow</td><td colspan="2">Recession
- Initial discharge (m^3/s): observed
- Recession constant: 0.2
- Ratio to peak: 0.4</td></tr>
<tr><td>Reach</td><td>Routing</td><td colspan="2">Muskingum
- Muskingum K (HR): 0.25
- Muskingum X: 0.25
- Number of subreaches: 1</td></tr>
</table>

Model Calibration

Parameters

- Calibrated parameters

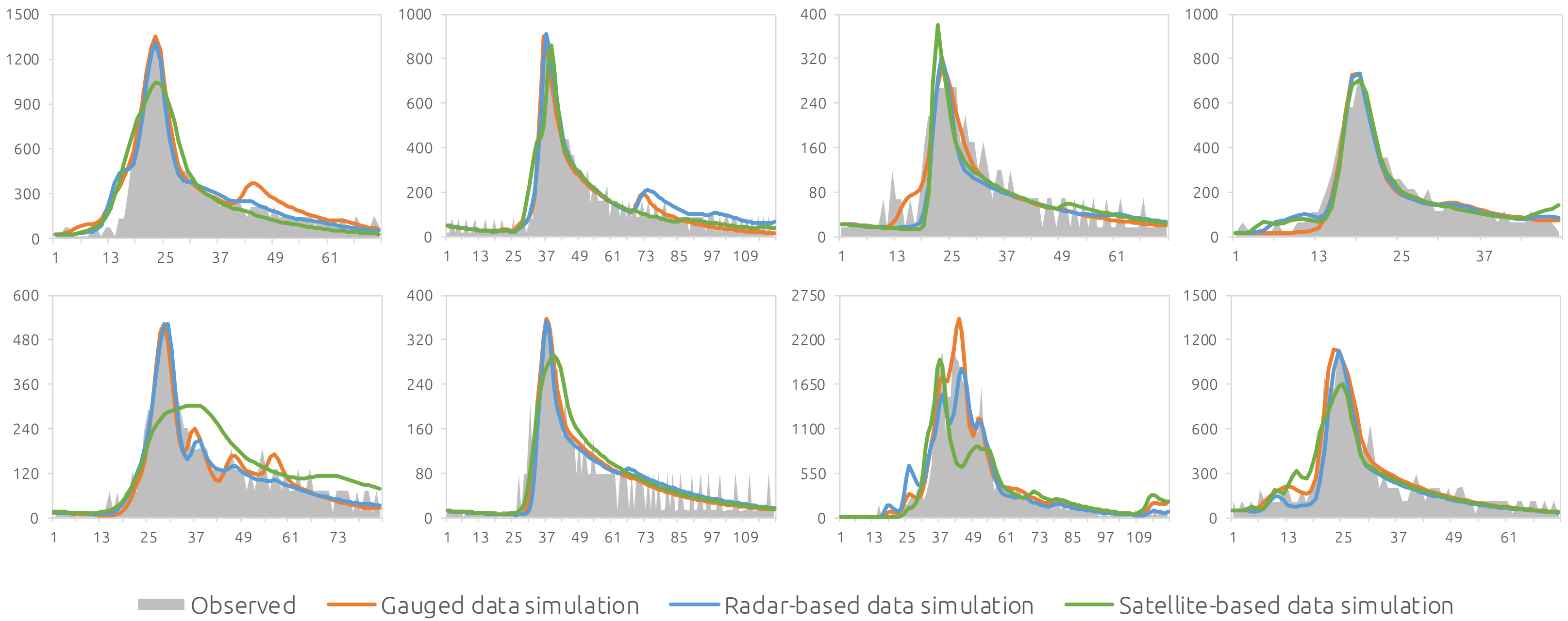
Storm Events (#)	Gauged data simulation						Radar-based data simulation						Satellite-based data simulation					
	Loss		Transform		Routing		Loss		Transform		Routing		Loss		Transform		Routing	
	I_a	*Im.*	T_c	*R*	*K*	*X*	*Ra.*	*Fa.*	T_c	*R*	*K*	*X*	*Ra.*	*Fa.*	T_c	*R*	*K*	*X*
1	-	✓	-	-	-	-	-	✓	-	✓	-	-	-	✓	-	✓	-	-
2	-	✓	-	✓	✓	-	-	✓	-	✓	-	-	-	✓	✓	-	✓	-
3	-	✓	✓	✓	✓	-	✓	✓	-	-	-	-	-	✓	✓	-	✓	-
4	✓	-	✓	-	✓	-	✓	✓	-	-	✓	-	-	✓	-	-	-	-
5	✓	-	✓	-	✓	-	✓	-	-	-	-	-	-	✓	-	✓	✓	-
6	-	✓	✓	✓	✓	-	✓	✓	✓	✓	-	-	-	✓	-	✓	✓	-
7	-	✓	-	✓	-	-	✓	✓	-	-	-	-	-	✓	-	-	-	-
8	-	✓	-	✓	✓	-	✓	✓	-	✓	✓	-	✓	✓	-	✓	✓	-

**No changes for CN & N. of subreaches; Baseflow parameter values are the same for both model simulations*

Model Performance

Comparison

- Graphical results



**X-axis represents simulation time (hours) and Y-axis represents discharge (m^3/sec)*

Model Performance

Comparison

- Statistical results

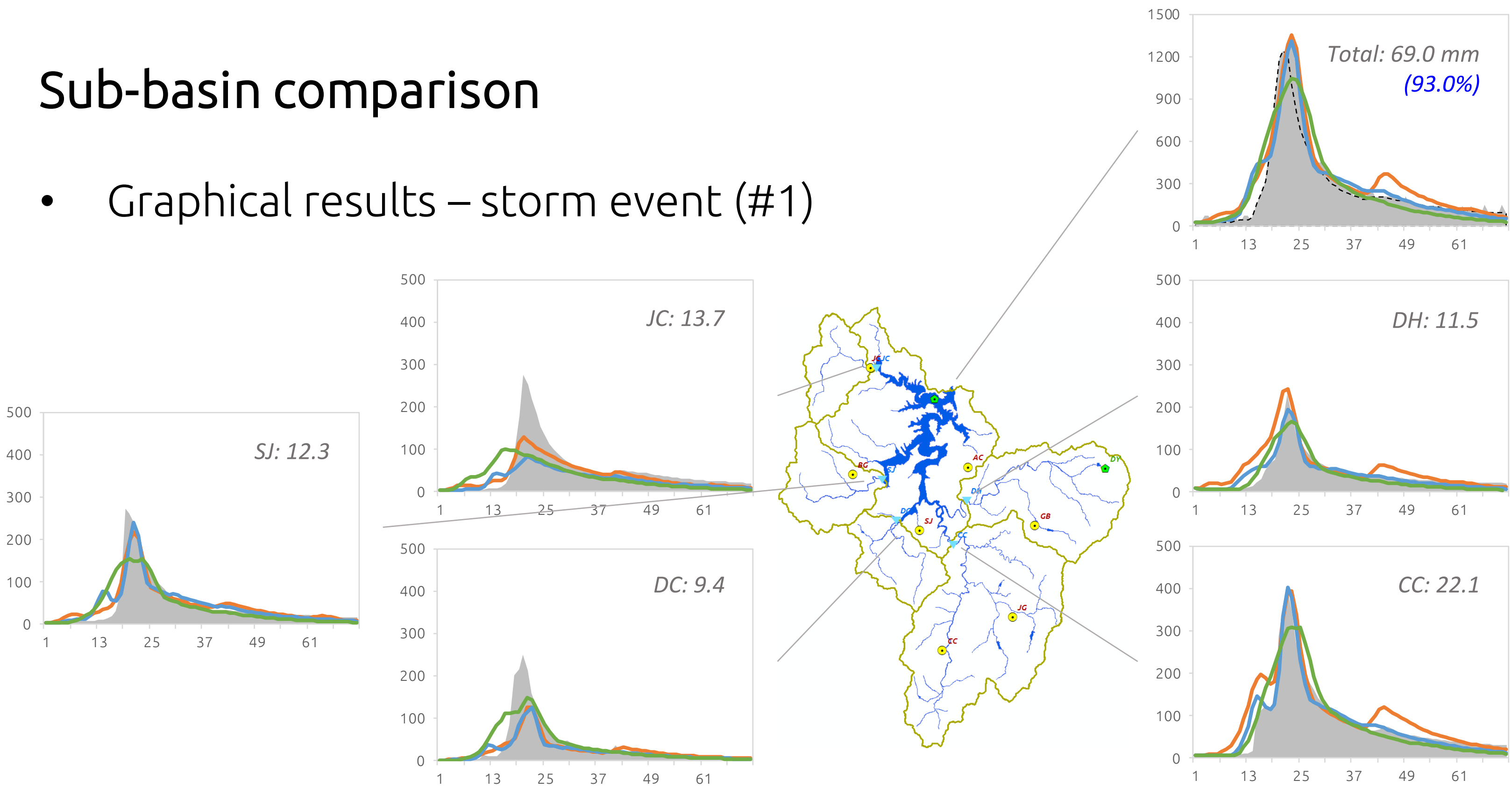
Storm Events (#)	Gauged data simulation			Radar-based data simulation			Satellite-based data simulation		
	E_{NS}	R^2	*PBIAS(%)*	E_{NS}	R^2	*PBIAS(%)*	E_{NS}	R^2	*PBIAS(%)*
1	0.914	0.937	16.97	0.914	0.914	4.01	0.878	0.878	-1.20
2	0.941	0.945	-5.61	0.919	0.925	9.54	0.842	0.843	-3.14
3	0.844	0.853	-9.05	0.716	0.752	-18.06	0.663	0.697	-13.90
4	0.920	0.928	-7.35	0.921	0.920	-2.57	0.906	0.905	-0.99
5	0.893	0.902	-6.69	0.912	0.921	-7.28	0.611	0.629	14.35
6	0.800	0.812	0.38	0.763	0.765	-0.63	0.773	0.790	9.05
7	0.930	0.948	11.87	0.895	0.896	-0.18	0.670	0.673	-7.34
8	0.921	0.925	1.43	0.865	0.891	-17.64	0.861	0.878	-7.19
Avg.	*0.895*	*0.906*	*7.42*	*0.863*	*0.873*	*7.49*	*0.776*	*0.787*	*7.15*

E_{NS} and R^2 arithmetic mean; PBIAS arithmetic mean of absolute value

Model Performance

Sub-basin comparison

- Graphical results – storm event (#1)



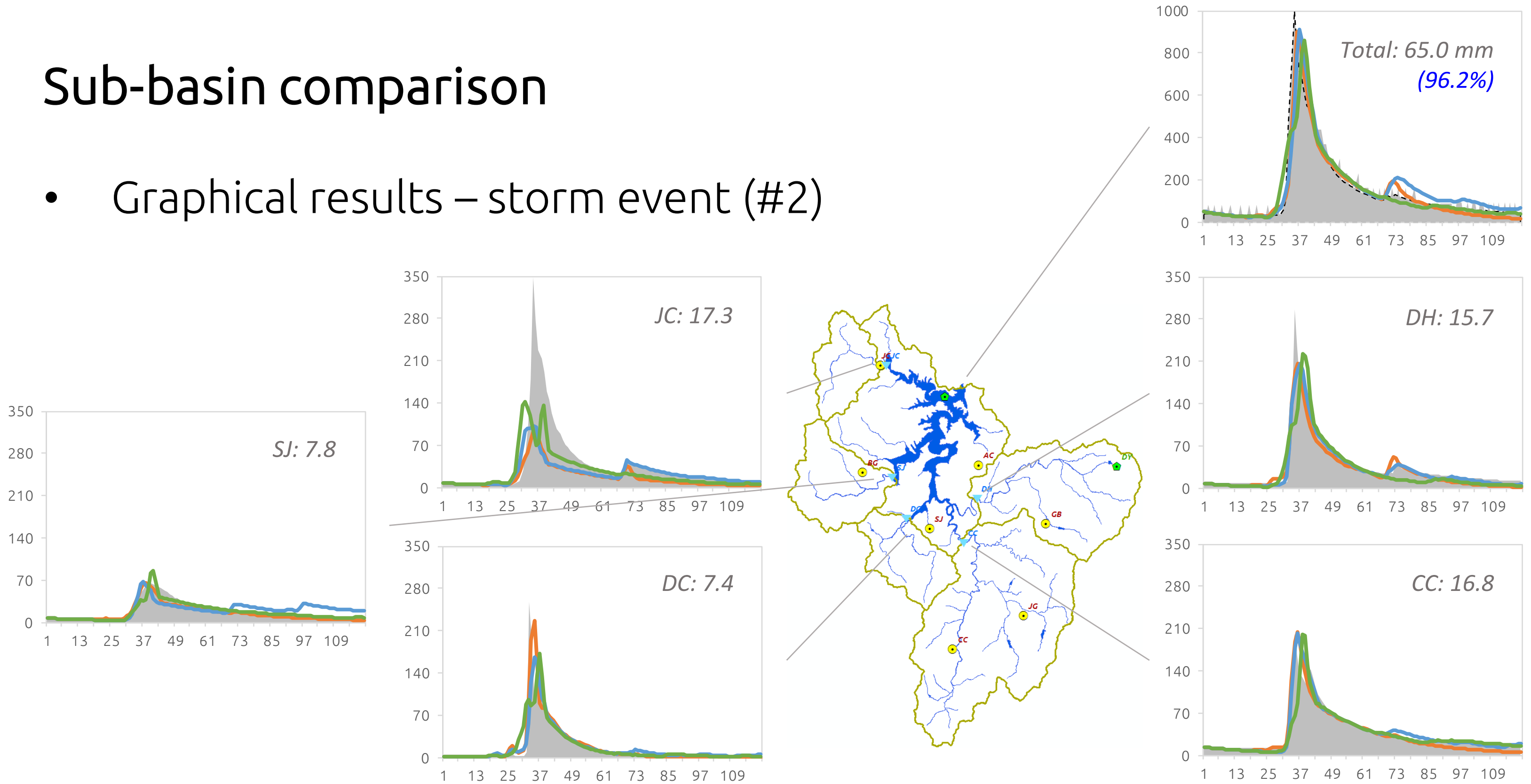
Observed Gauged data simulation Radar-based data simulation Satellite-based data simulation

**X-axis represents simulation time (hours) and Y-axis represents discharge (m³/sec)*

Model Performance

Sub-basin comparison

- Graphical results – storm event (#2)



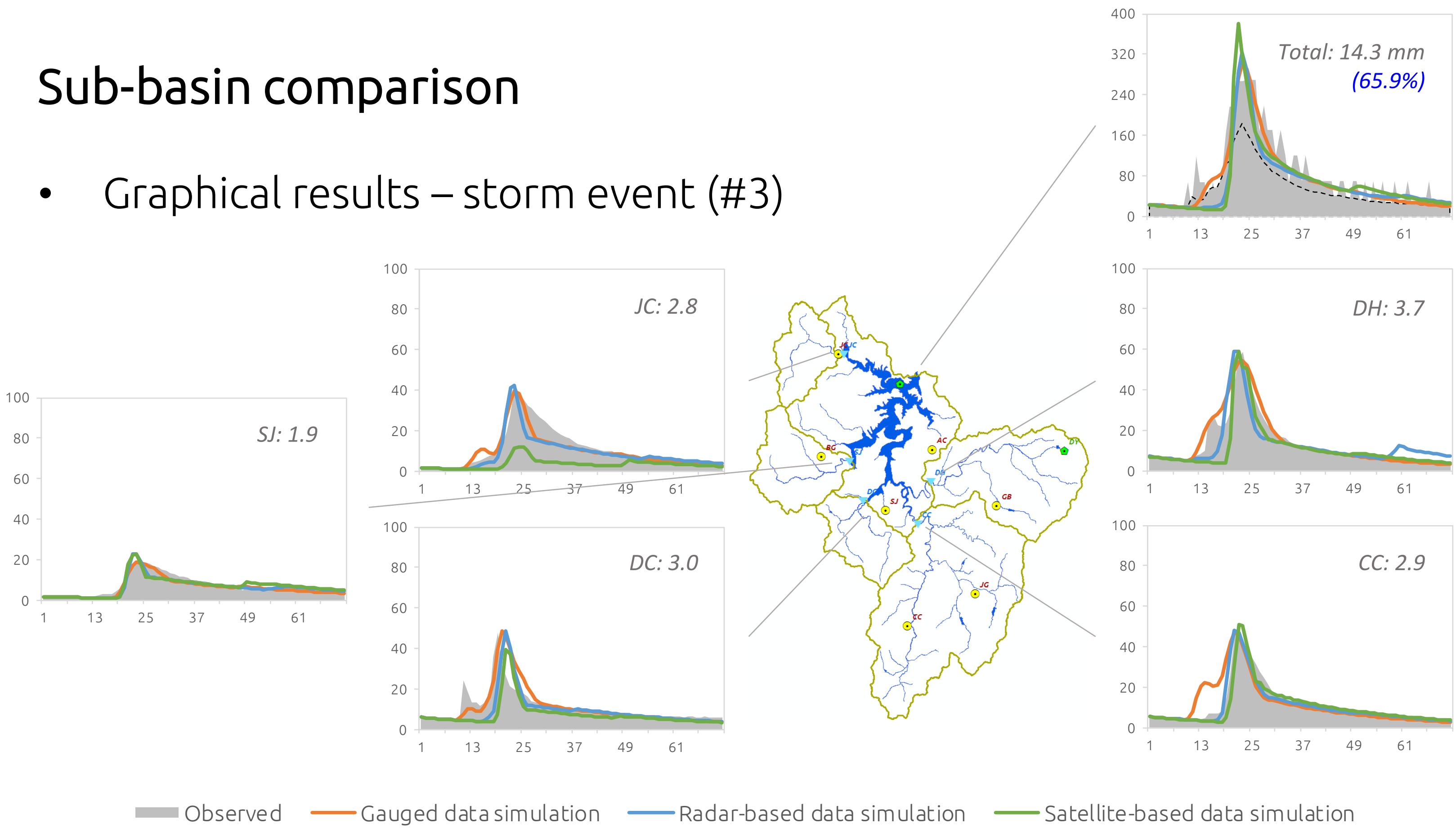
Observed — Gauged data simulation — Radar-based data simulation — Satellite-based data simulation

**X-axis represents simulation time (hours) and Y-axis represents discharge (m^3/sec)*

Model Performance

Sub-basin comparison

- Graphical results – storm event (#3)

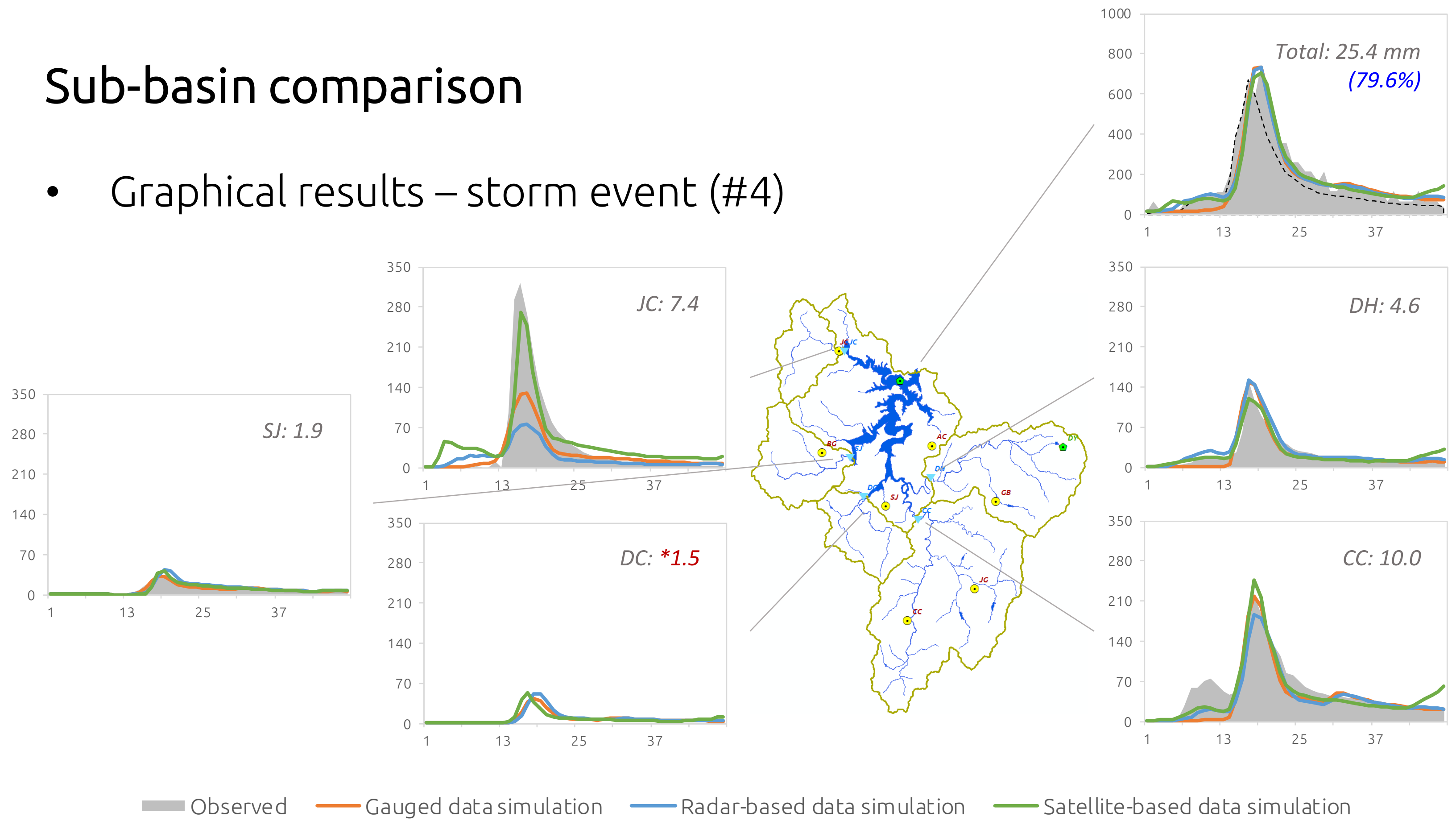


**X-axis represents simulation time (hours) and Y-axis represents discharge (m³/sec)*

Model Performance

Sub-basin comparison

- Graphical results – storm event (#4)

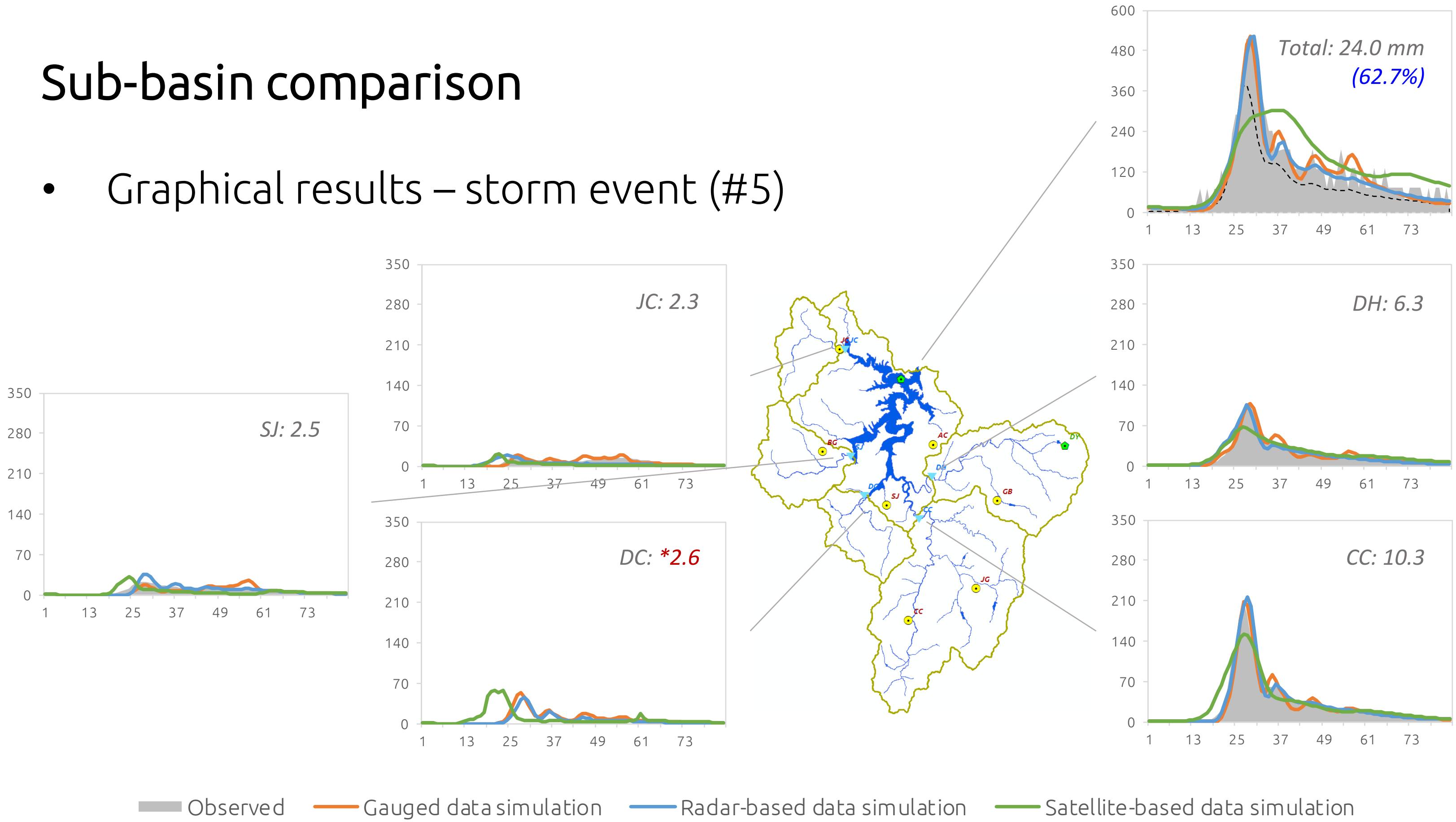


X-axis represents simulation time (hours) and Y-axis represents discharge (m^3/sec)

Model Performance

Sub-basin comparison

- Graphical results – storm event (#5)

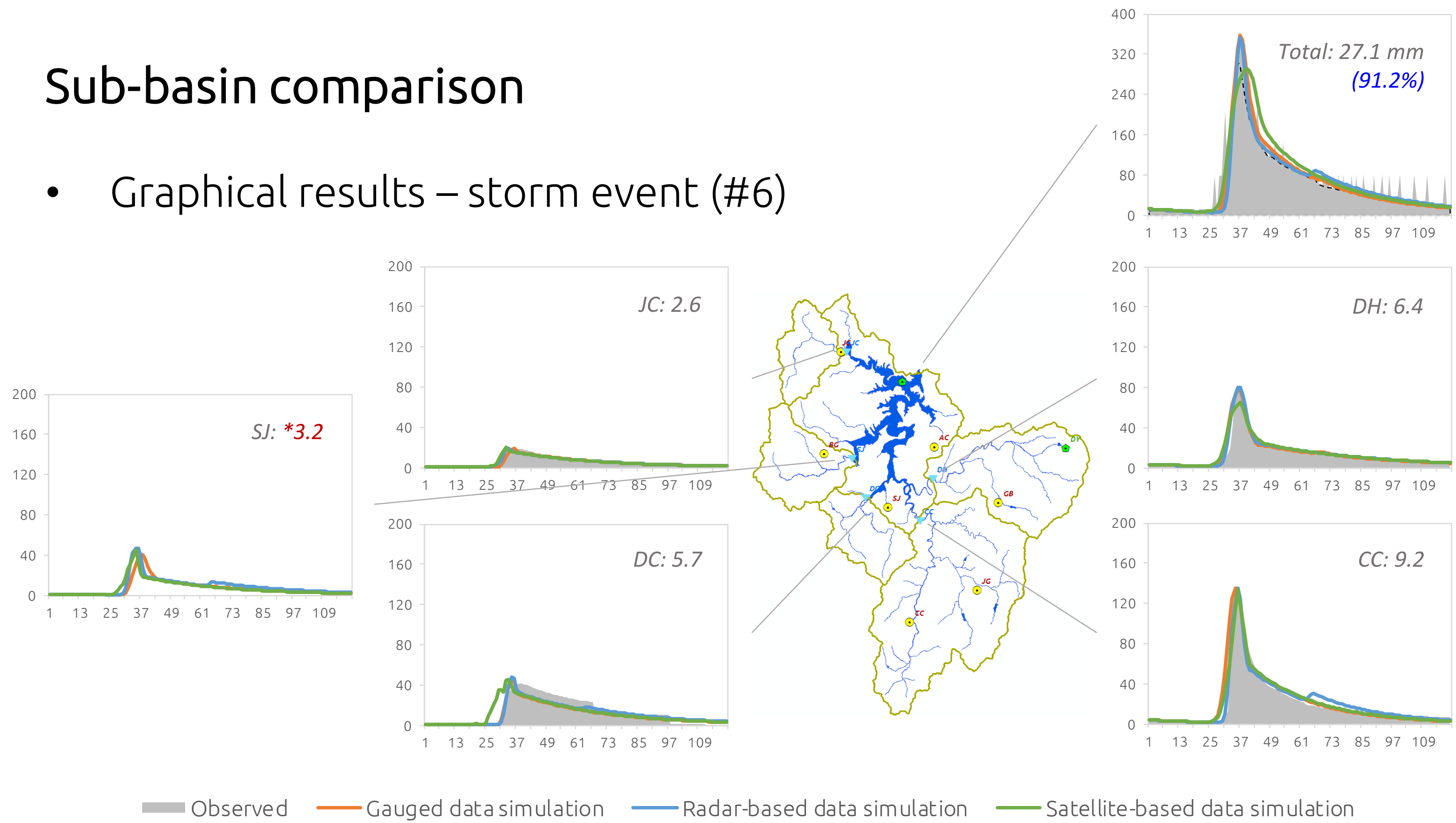


*X-axis represents simulation time (hours) and Y-axis represents discharge (m^3/sec)

Model Performance

Sub-basin comparison

- Graphical results – storm event (#6)

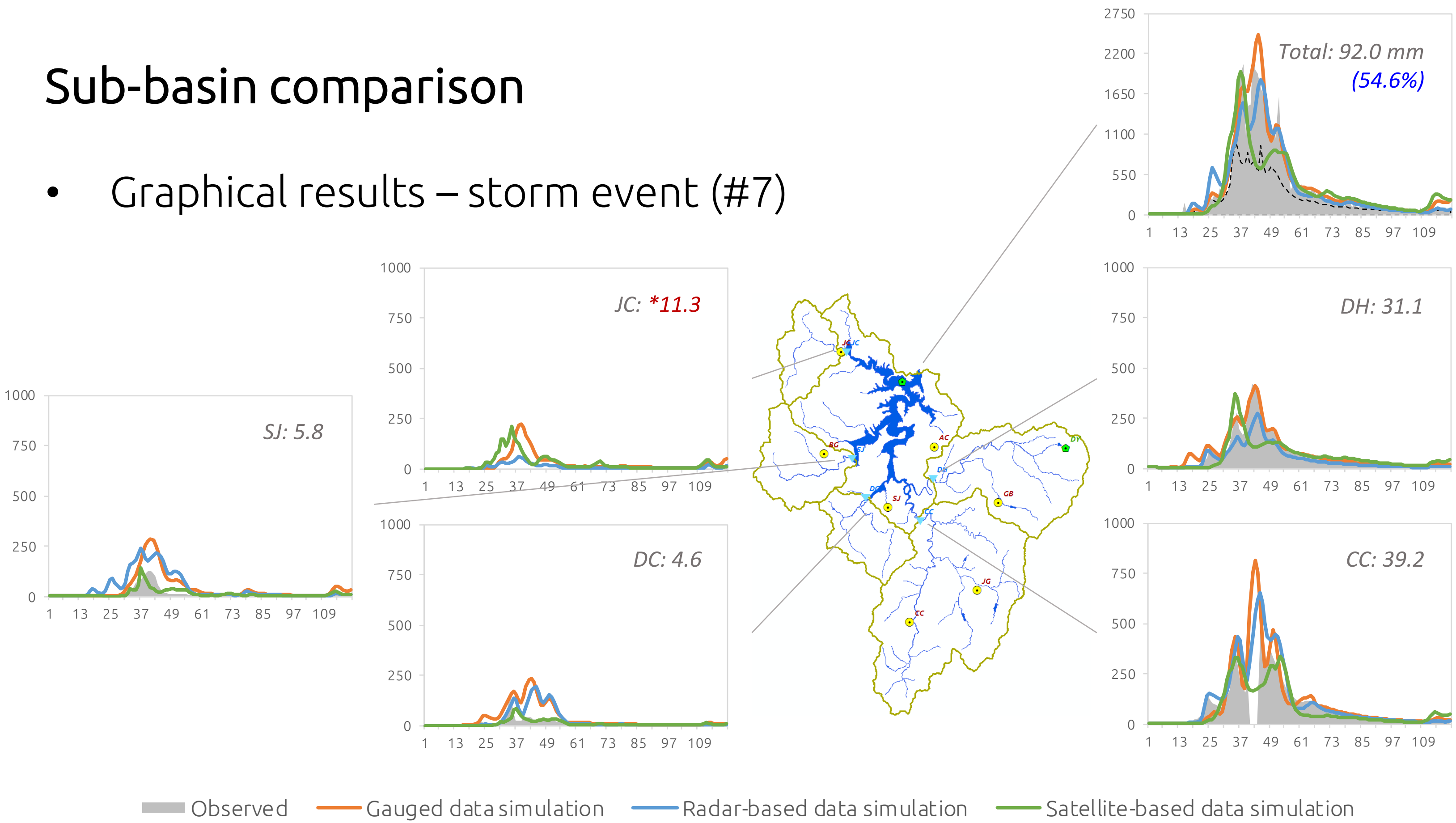


**X-axis represents simulation time (hours) and Y-axis represents discharge (m^3/sec)*

Model Performance

Sub-basin comparison

- Graphical results – storm event (#7)

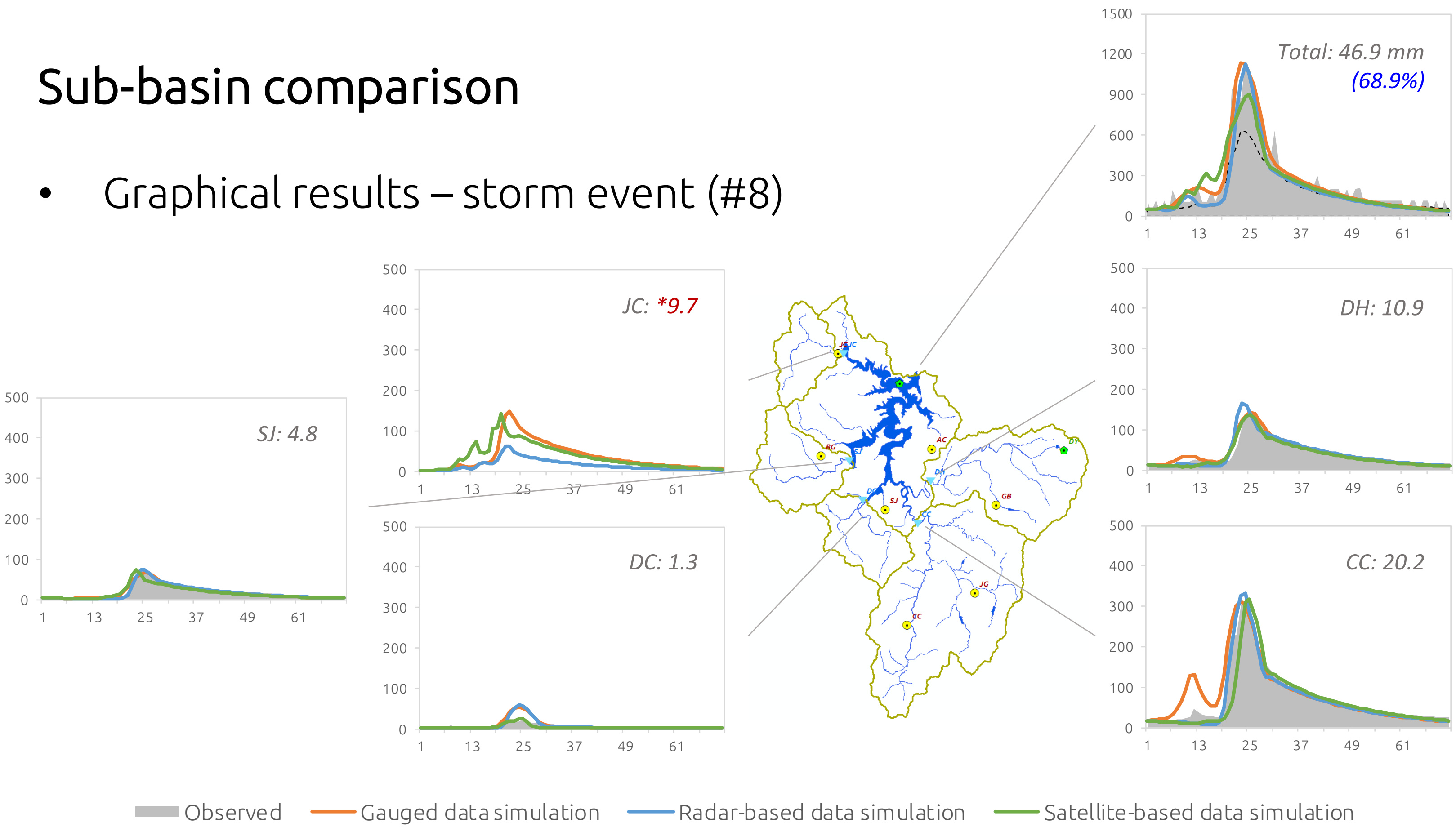


*X-axis represents simulation time (hours) and Y-axis represents discharge (m^3/sec)

Model Performance

Sub-basin comparison

- Graphical results – storm event (#8)



**X-axis represents simulation time (hours) and Y-axis represents discharge (m^3/sec)*

Model Performance

Sub-basin comparison

- Statistical results (E_{NS})

Storm Events (#)	Gauged data simulation					Radar-based data simulation					Satellite-based data simulation				
	CC	*DH*	*DC*	*SJ*	*JC*	*CC*	*DH*	*DC*	*SJ*	*JC*	*CC*	*DH*	*DC*	*SJ*	*JC*
1	0.81	0.55	0.61	0.88	0.68	0.93	0.90	0.60	0.80	0.35	0.88	0.82	0.73	0.69	0.27
2	0.92	0.92	0.71	0.88	0.38	0.93	0.92	0.66	0.48	0.40	0.71	0.70	0.65	0.89	0.44
3	0.66	0.93	0.51	0.92	0.85	0.93	0.73	0.15	0.80	0.74	0.89	0.75	-0.10	0.74	-0.14
4	0.74	0.81	*-	0.86	0.60	0.81	0.85	*-	0.76	0.31	0.83	0.89	*-	0.77	0.79
5	0.95	0.95	*-	0.08	*0.65	0.96	0.90	*-	0.61	*-0.42	0.91	0.85	*-	-0.28	*-1.18
6	0.86	0.91	0.82	*-	0.94	0.96	0.95	0.86	*-	0.86	0.95	0.90	0.61	*-	0.79
7	*-0.74	0.95	*-4.58	*-2.02	*-	*-0.03	0.79	*-2.89	*-3.09	*-	*0.64	0.49	*0.40	*0.57	*-
8	0.85	0.94	*-1.19	0.97	*-	0.94	0.83	*-1.46	0.96	*-	0.74	0.94	*0.60	0.86	*-
Avg.	*0.83*	*0.87*	*0.66*	*0.77*	*0.69*	*0.92*	*0.86*	*0.57*	*0.74*	*0.53*	*0.84*	*0.79*	*0.47*	*0.61*	*0.43*

*Observation (streamflow) error

Conclusions

Summary

- A set of programs for IMERG data processing were developed to conduct hydrologic simulation using HEC-HMS with 8 storm events.
- HEC-HMS basin models were developed with subbasins and grid cells.
- IMERG data shows poor spatial variability and underestimated trends in larger values for validation against gauged observations (R^2 0.46).

  \- Need to extensive calibrations for loss & transform parameters in HEC-HMS
- IMERG data is possibly used as a precipitation input for flood runoff simulation in data-sparse regions due to the reasonable model performance (E_{NS} 0.78, R^2 0.78, and *PBIAS* 7.2%) under extensive calibration

  \- Radar-based QPEs clearly captured the event (others completely missed it)

Further Study

Distributed-Clark

HYDROLOGICAL SCIENCES JOURNAL
https://doi.org/10.1080/02626667.2018.1516042

A spatially distributed Clark's unit hydrograph based hybrid hy
(Distributed-Clark)

Younghyun Cho, Bernard A. Engel and Venkatesh M. Merwade

JANUARY 2017 CHO AND ENGEL

NEXRAD Quantitative Precipitation Estimations for Hyd
Using a Hybrid Hydrologic Model

YOUNGHYUN CHO

BERNARD A. ENGEL

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RESEARCH ARTICLE

WILEY

Spatially distributed long-term hydrologic simulation using a continuous SCS CN method-based hybrid hydrologic model

Younghyun Cho[1,2] | Bernard A. Engel[1]

Thanks for listening!