

TRAVEL REPORT FORM

출장보고서

결 재	선임연구 원	팀장	부서장	부서장
	10/12	10/12	10/13	대결 10/13
협 조	이승수	조재필	김형진	유진호
	팀장	부서장		
	10/12	10/12		
	이현록	유진호		

I. Reporter 보고자

Department 소속	Position 직위(직급)	Name 성명	Travel Date 날짜	Note 비고
응용사업팀	선임연구원	이승수	10/4~10/6	
응용사업팀	선임연구원	박경원		
정보서비스팀	선임연구원	이성규		

II. Major Activities 주요업무 수행내용

1. Main Contents and Activities 주요내용 및 활동

- 교토대학 우지가와 오픈랩 방문
- Prof. Nakagawa Hajime, Prof. Kenji Kawaike 와의 면담
- 부산시 대상 수행 예정 사업인 '위성 데이터를 이용한 실시간 도시침수 예측 시스템' 개발 및 운영에 관한 개별 분야 발표
- 상기 시스템 운영 및 개도국 대상 사업에 관련된 토의

2. Relevance to APEC Climate Center's Activities 결론 및 소감

- 최근 일본에서 증가하고 있는 강력한 슈퍼 태풍으로 인해 이전에 경험해 보지 못한 극한 강우의 발생 빈도가 증가하고 있으며 이로 인한 재방풍괴/침수/홍수/산사태 등과 같은 자연재해가 증가하고 있음.
- 방재 선진국이라 할 수 있는 일본에서도 재난 발생 감지시 대응할 수 있는 매뉴얼과 시스템 그리고 전파 수단이 완벽하지는 않았음
- 이로 인하여 방재대책에 대한 기본 컨셉을 새롭게 수정하고 있으며 그중에 하나가 실시간 예측 기반 대응 시스템임.
- 현재 APCC에서 개발한 1시간 30분 정도의 리드타임을 가진 예측 시스템에 대하여 정확도와 효율적인 피난 시스템, 활용방안에 대한 활발한 토의가 있었으며 특히, 도로 침수 예측 시스템과 네비게이션의 접목에 대해 큰 관심을 보였음.
- 일본에서는 레이더 자료를 이용한 실시간 침수 예측 시스템을 개발할 예정이며, 이와 관련하여 지속적인 협력에 대한 논의가 있었음.
- 본 워크숍을 기반으로 하여 보다 활발한 네트워크를 구축할 수 있다면 연구를 위한 협력 뿐만 아니라 향후 개도국 지원 사업과 관련한 협력도 충분히 도모할 수 있을 것으로 판단됨.

III. References 참고사항

(with attachment of any information or report in case of attendance of conferences, workshops and meetings) 학술대회, 워크숍, 회의 등 참석 시 관련 정보 및 문서 첨부

1. Presented and Collected Materials 주요 수집자료

발표 자료 (박경원, 이승수, 이성규)

수집 발표 자료 (Prof. Kenji Kawaike)

2. Suggestions and Remarks 건의사항

Development of Short-term Rainfall Forecasting System Using Satellite and Radar

APEC Climate Center
Kyungwon Park, Sangmin Jang

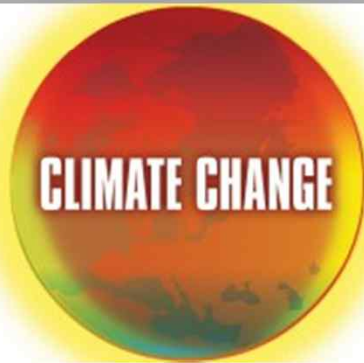
Contents

- 💡 Background
- 💡 Satellite Rainfall
- 💡 Satellite based Rainfall Forecasts
- 💡 Radar Rainfall Forecasts
- 💡 Multi-sensor Blending
- 💡 Conclusions



Background

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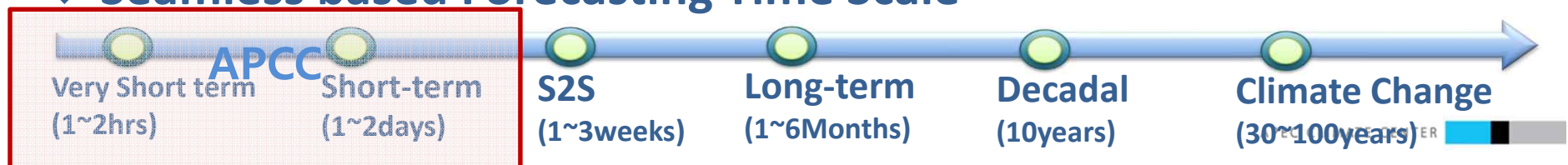


• Photo: adapted from Google



Extreme Rainfall
and Flooding

❖ Seamless based Forecasting Time Scale



Flooding : Busan, South Korea

(Case: 25 August 2014)

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➤ Extreme Rainfall : 130mm/h

- Affected: 191 person
- Lives: 4, Injury: 5, Disappearance: 1
- Damage: (Road: 56, House: 1,253)
- Agricultural Damage: 235ha
- Small Dam Collapse: 50ea



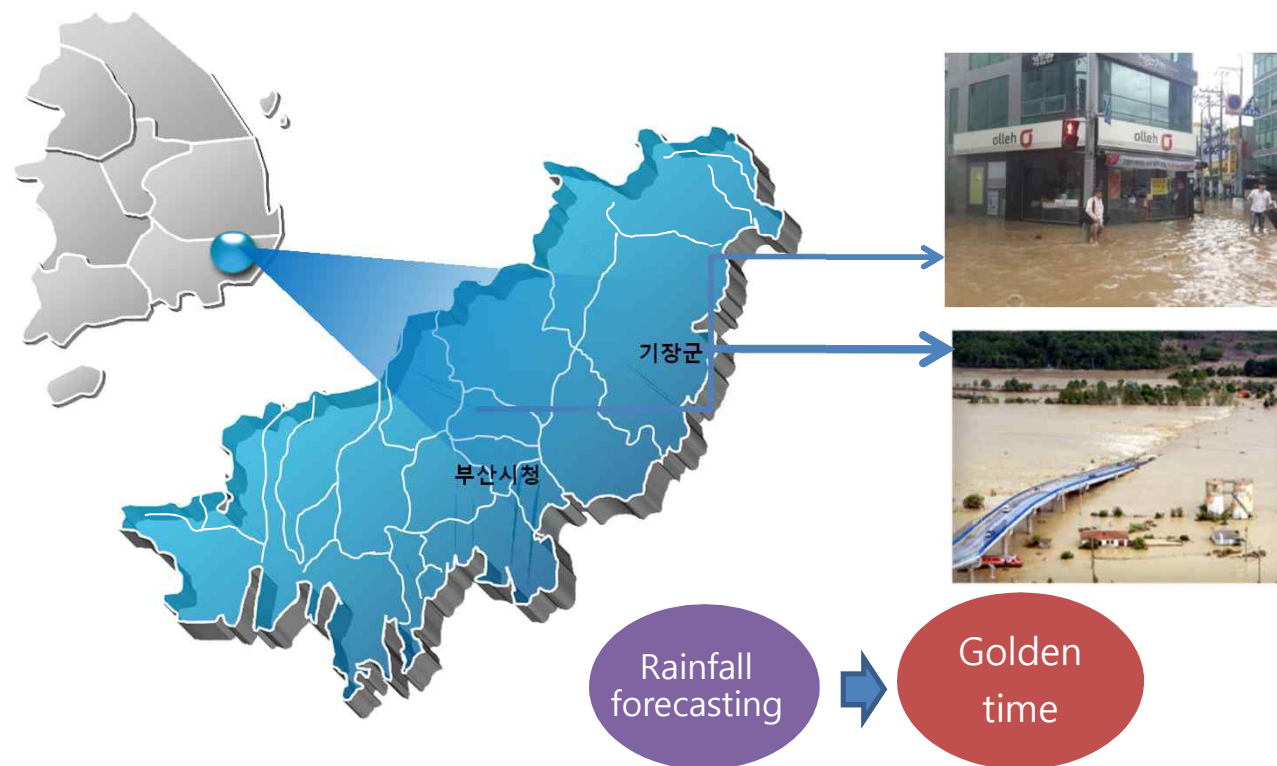
• Photos adapted from Google



Flooding : Busan, South Korea

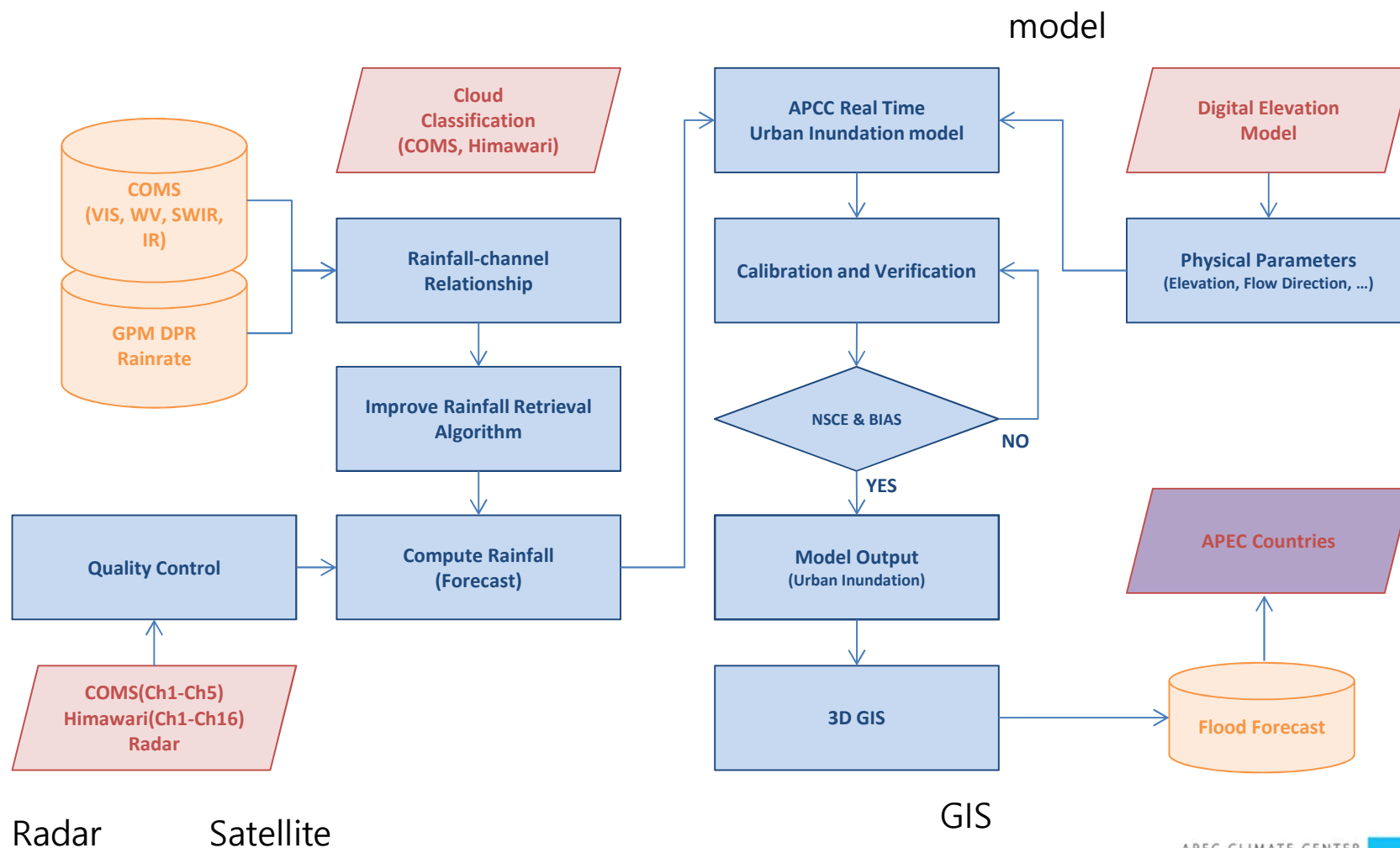
(Case: 25 August 2014)

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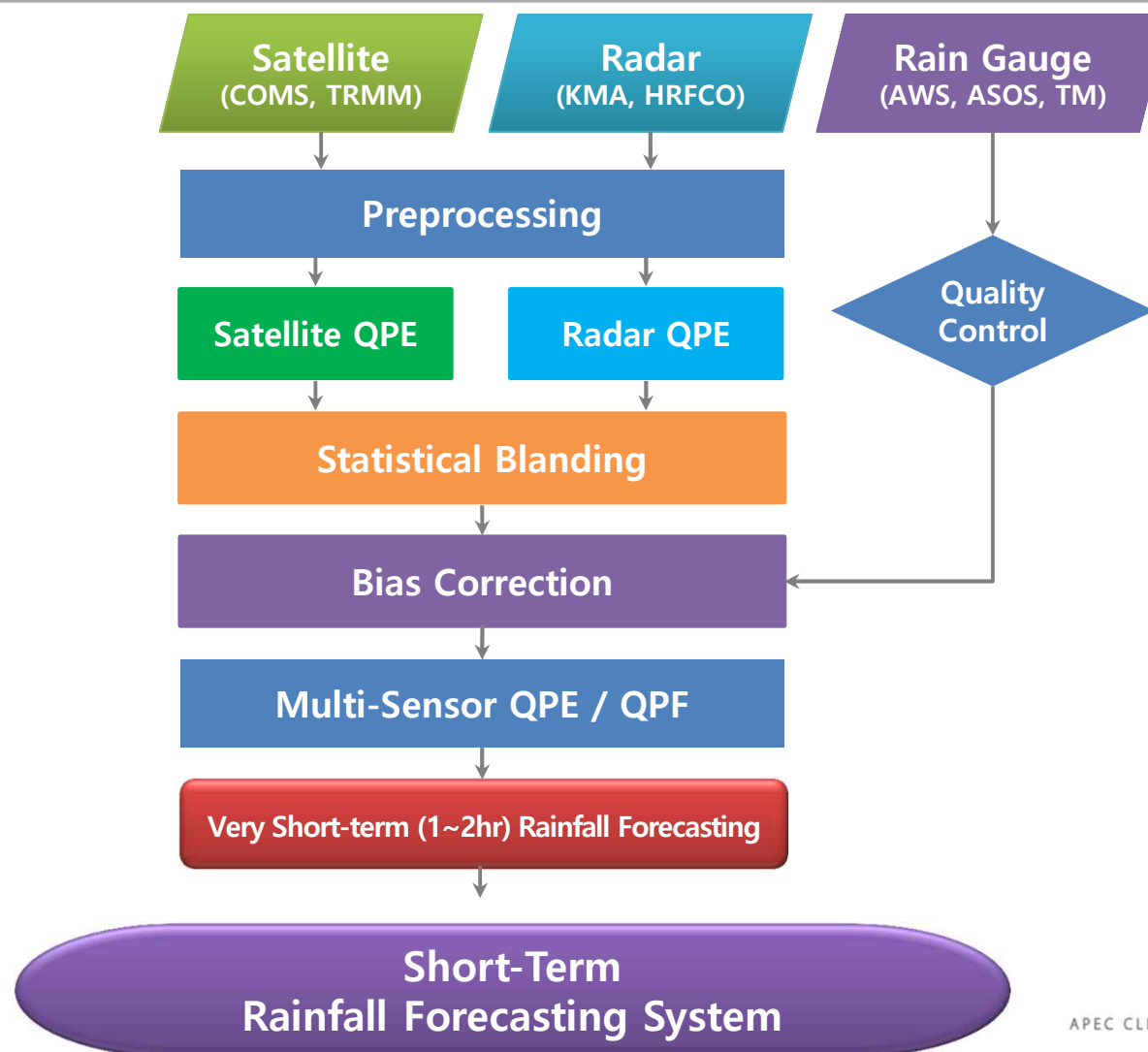
Flowchart of main system

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Flow Chart of rainfall forecasting

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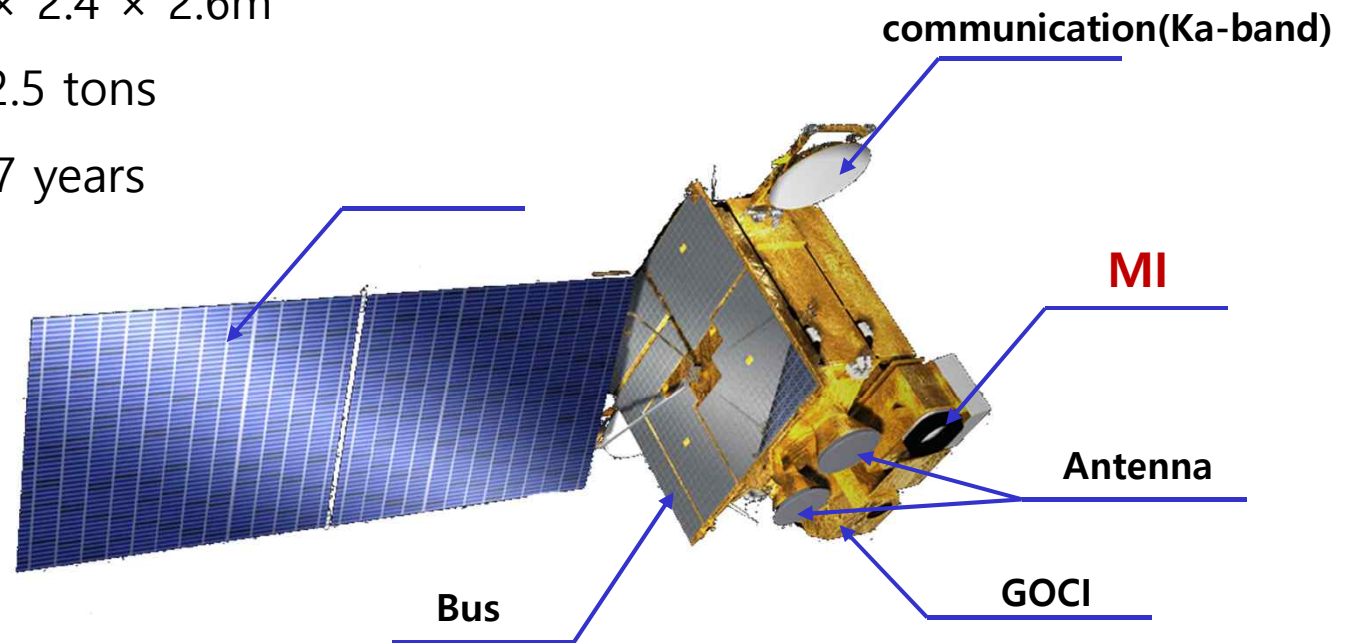


Satellite rainfall algorithm

Communication, Ocean and Meteorological Satellite (COMS)

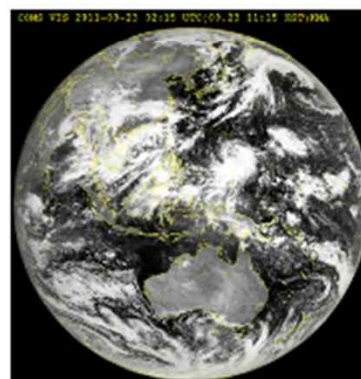
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- Korea's first geostationary multi-purpose satellite which is stationed at an altitude of 36,000 km above the Earth's equator
- Launched successfully from the Guiana Space Center, Kourou in French Guiana, South America on June 27, 2010
- Dimensions: $2.2 \times 2.4 \times 2.6\text{m}$
- Mass at launch: 2.5 tons
- Operational life: 7 years

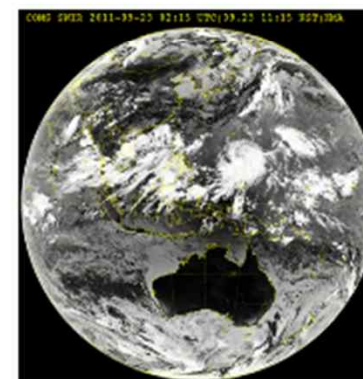


COMS Channels

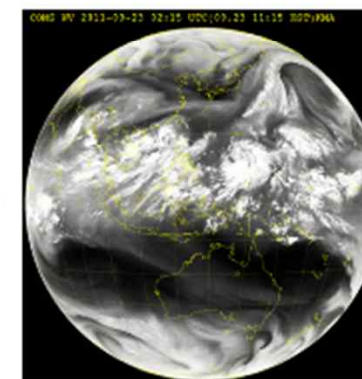
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[Visible (VIS)]

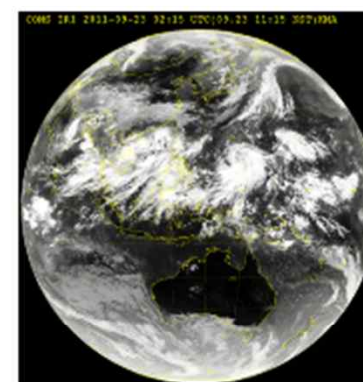


[Short Wave Infrared (SWIR)]

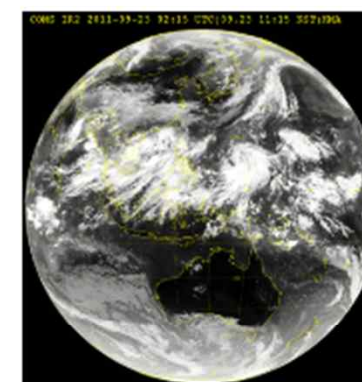


[Water Vapor (WV)]

Channel	Center wavelength (μm)	Wavelength range (μm)	Spatial resolution (km)
Visible	0.675	0.55~0.8	1
Shortwave infrared	3.75	3.5~4.0	4
Water vapor	6.75	6.5~7.0	4
Infrared 1	10.8	10.3~11.3	4
Infrared 2	12.0	11.5~12.5	4



[Infrared 1 (IR1)]



[Infrared 2 (IR2)]

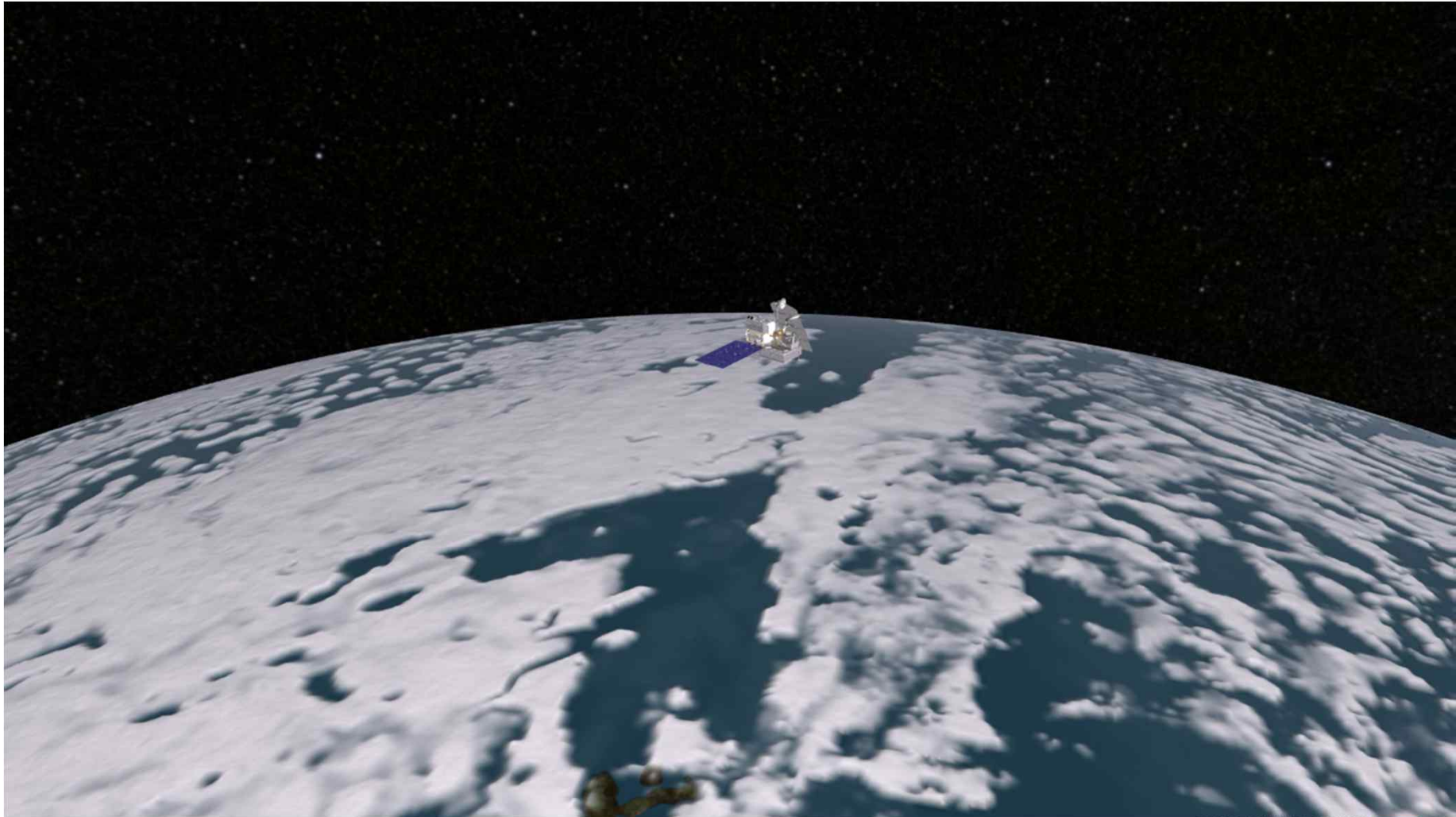
Sample images of 5 channels of the COMS meteorological imager

GPM(Global Precipitation Mission)



GPM(Global Precipitation Mission)

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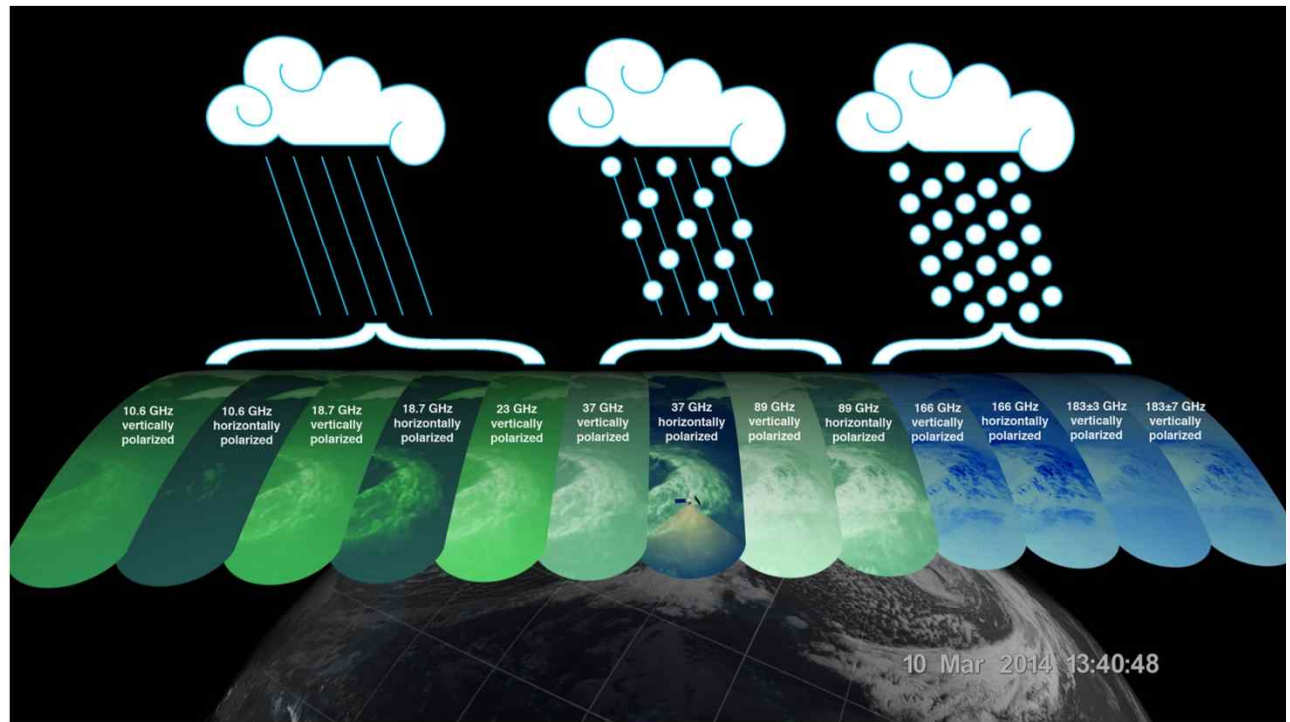
Dual Precipitation Radar(DPR)

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GMI(GPM Microwave Imager)

APEC



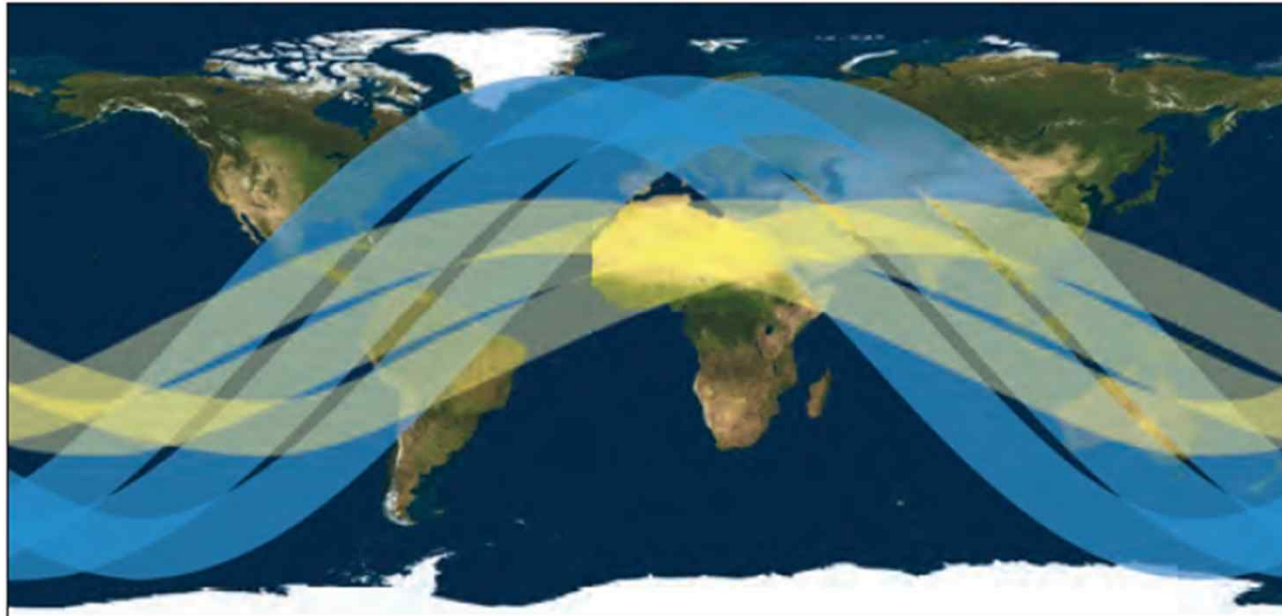
NASA 제공



GPM(Global Precipitation Mission)

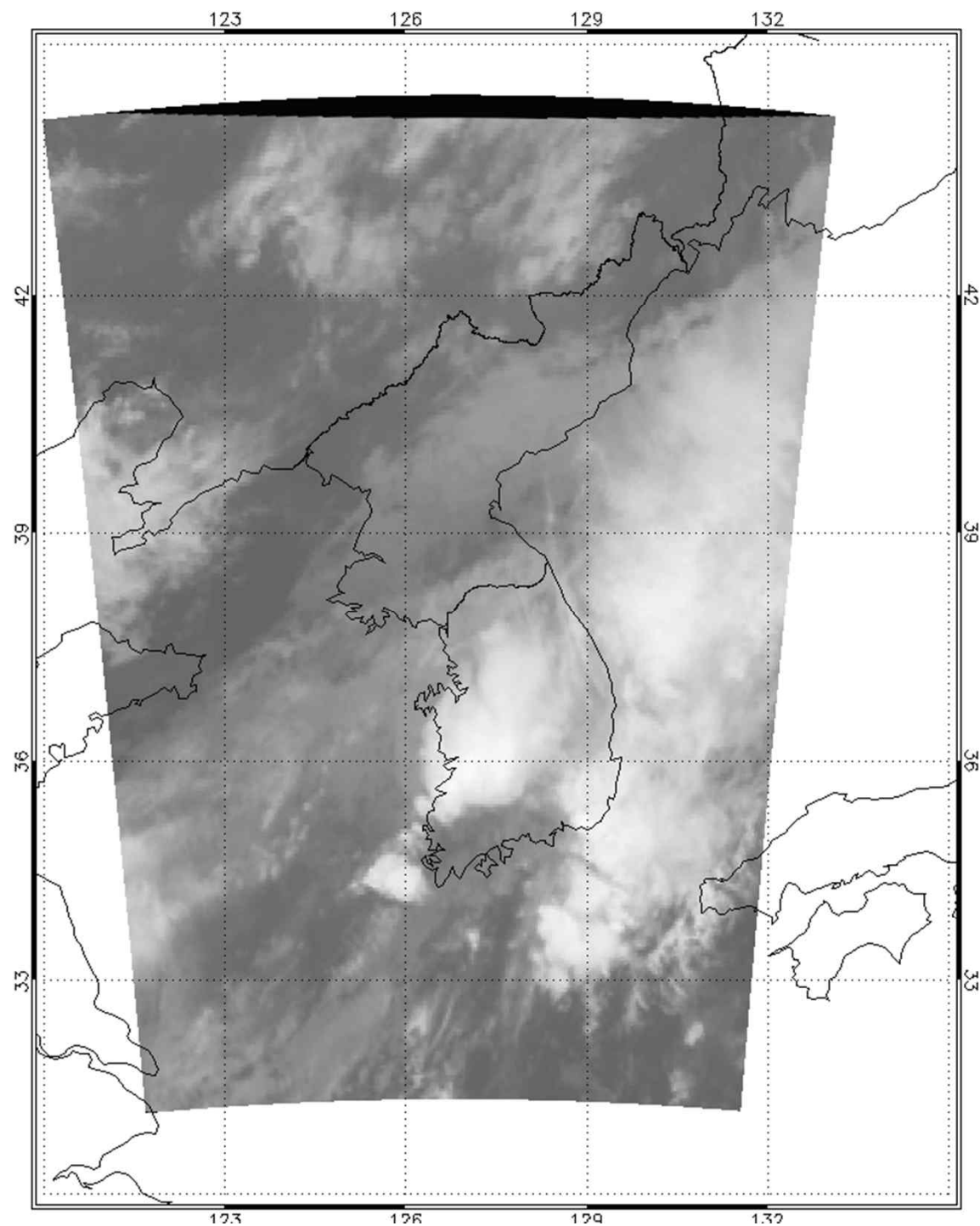
APEC

TRMM, GPM orbit



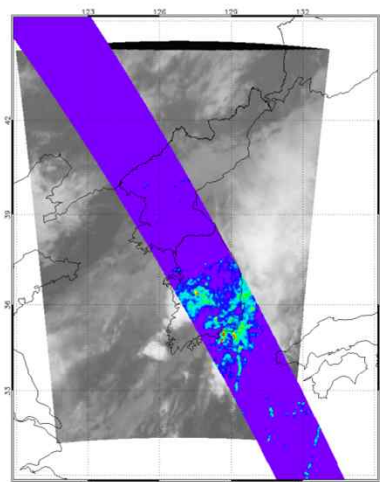


2014.8.7 COMS image

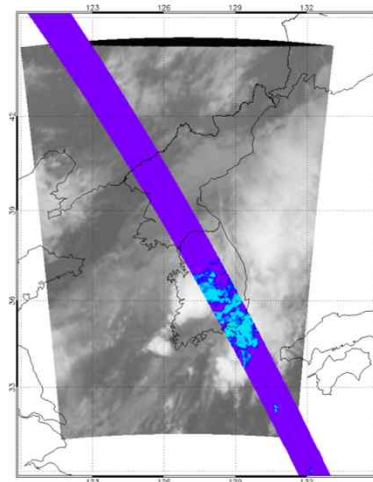


GPM Measurement Korea

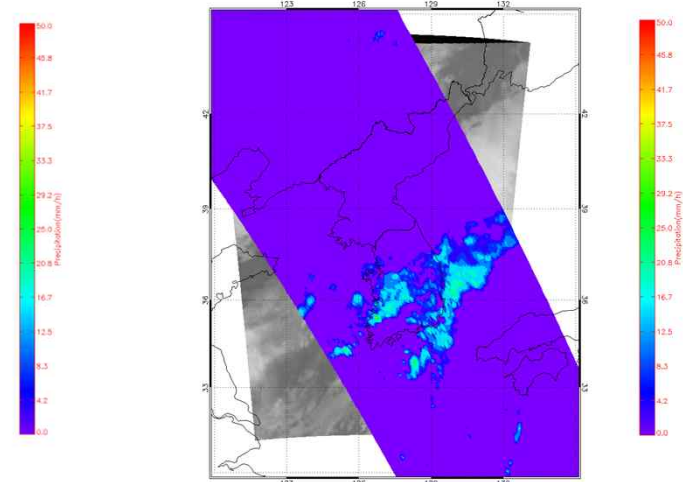
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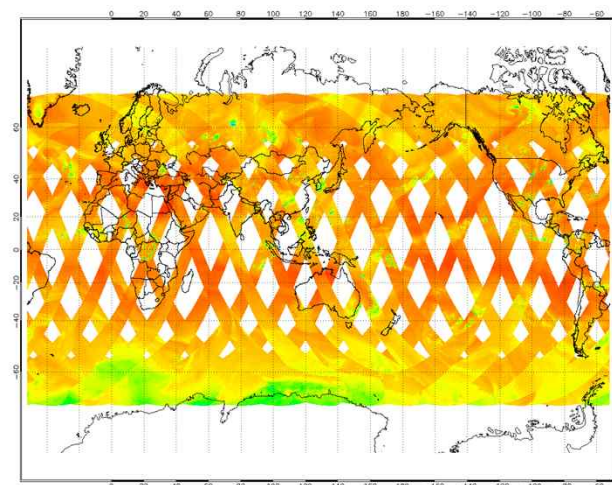
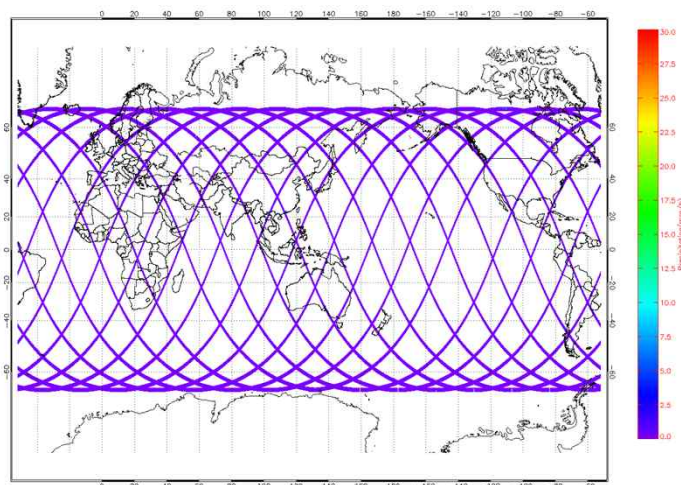
Ku(14GHz)



DPR(14+35GHz)



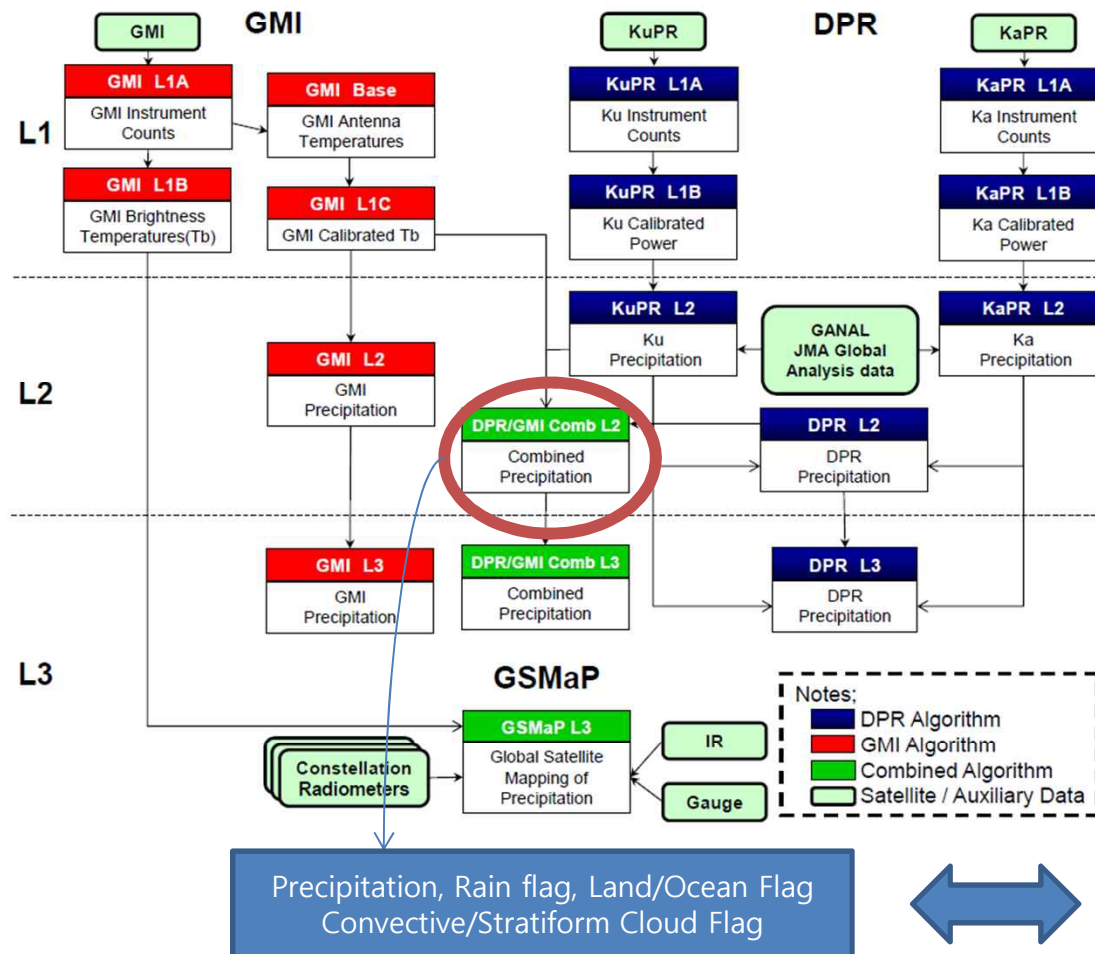
GMI(6-183GHz)



Satellite rainfall retrieval algorithm

GPM, COMS database(2014 July)

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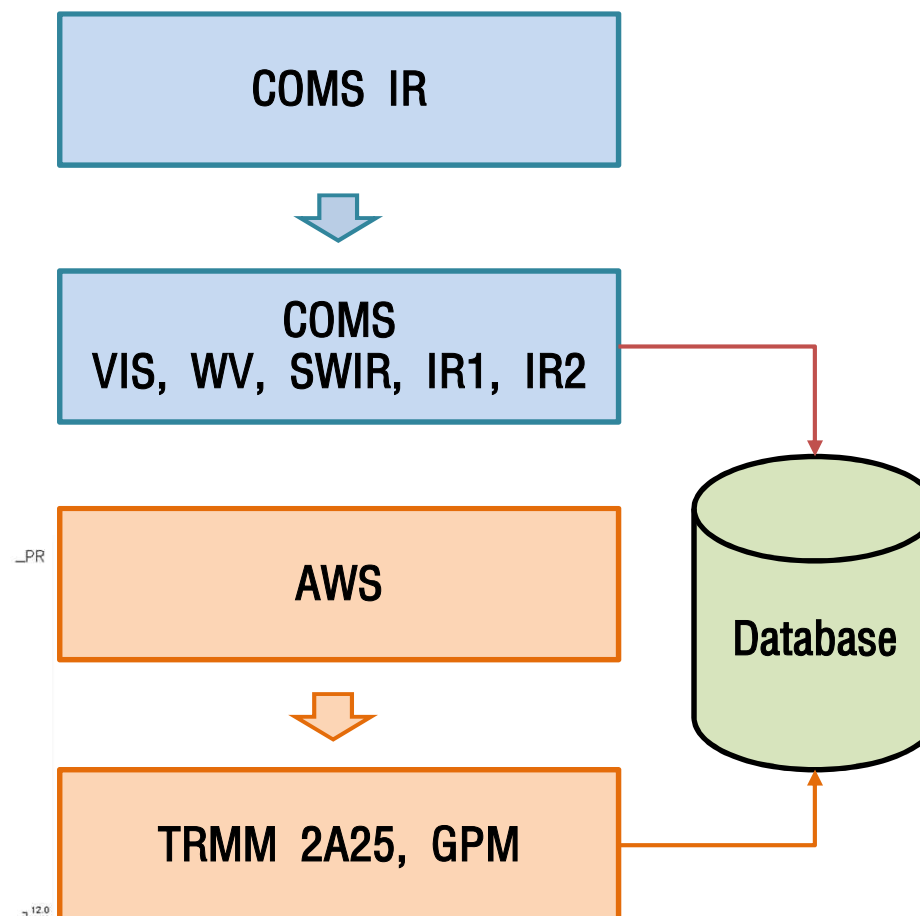
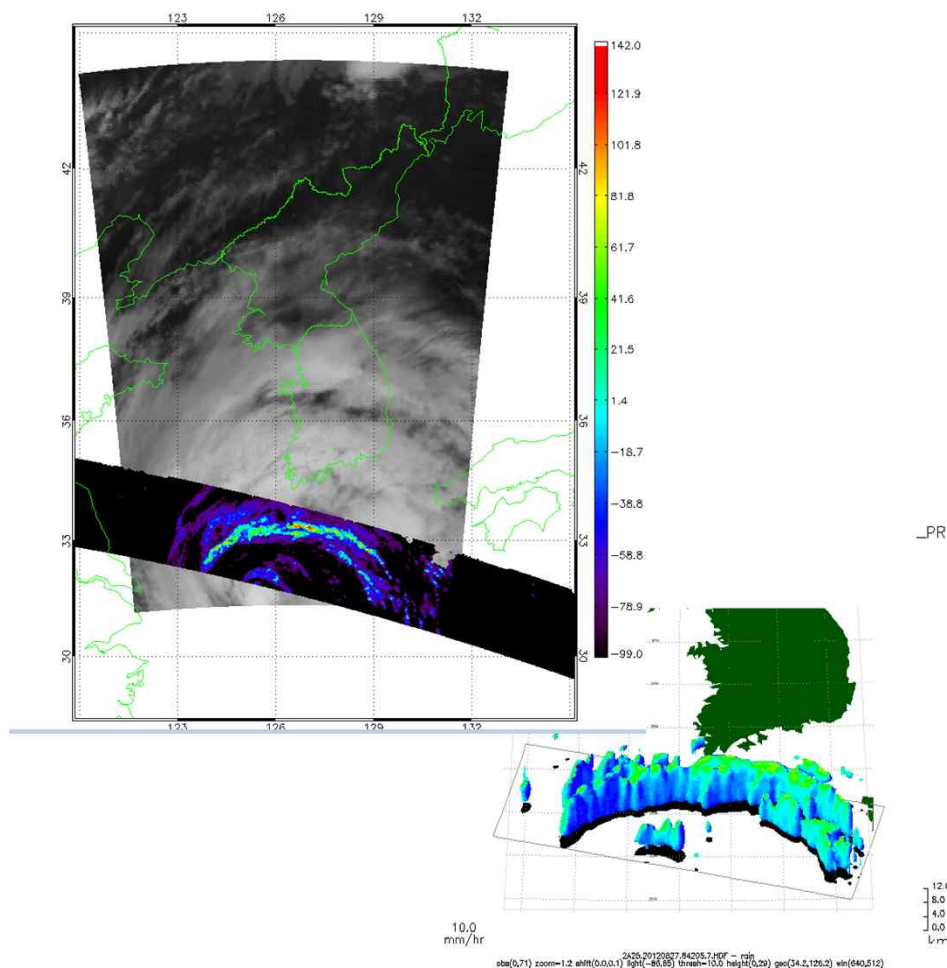
Visible
SWIR
WV
IR1
IR2

3.7um-6.7um, 6.7um, visible, ir1

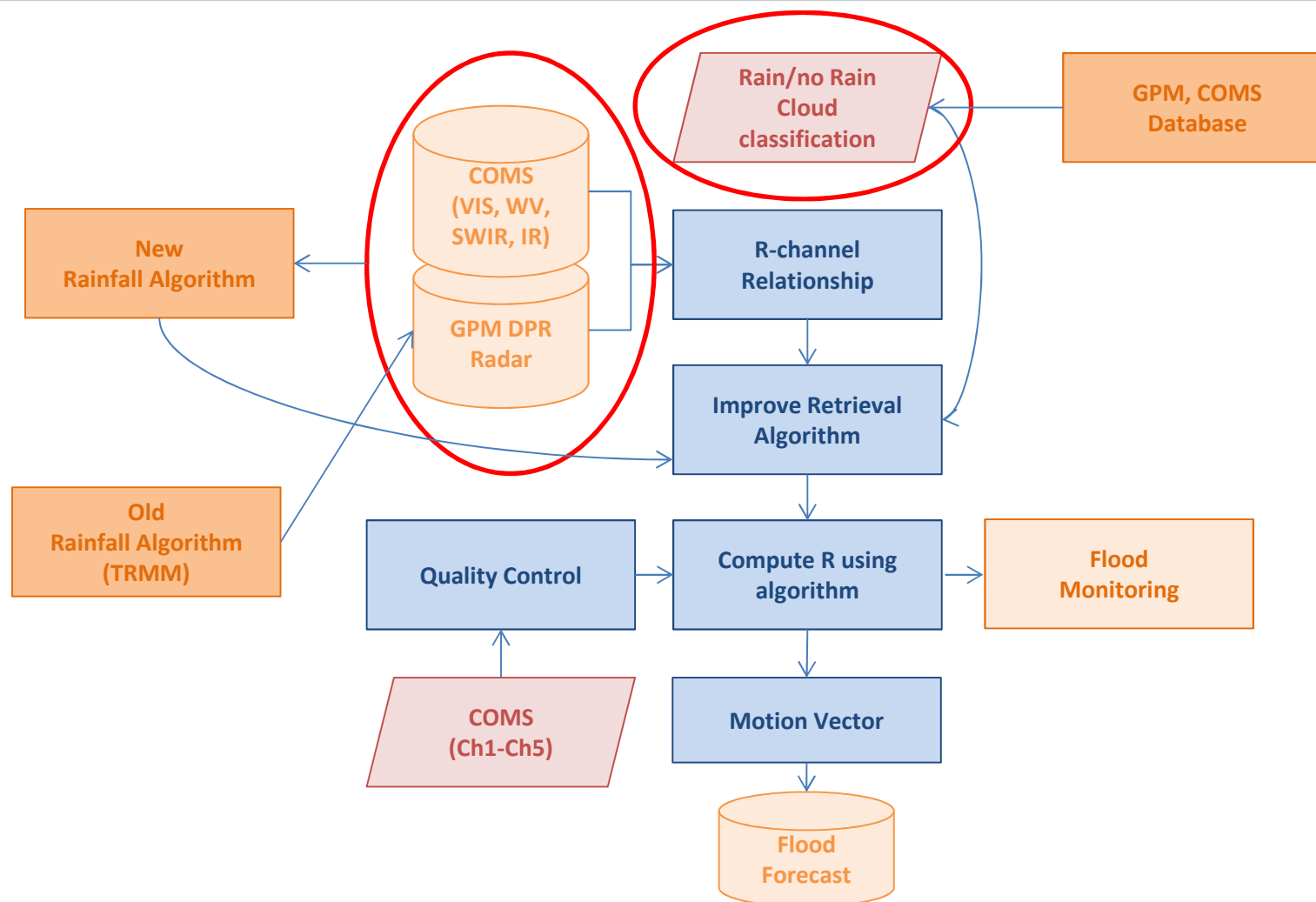
Rainfall algorithm

Rainfall Algorithm using TRMM

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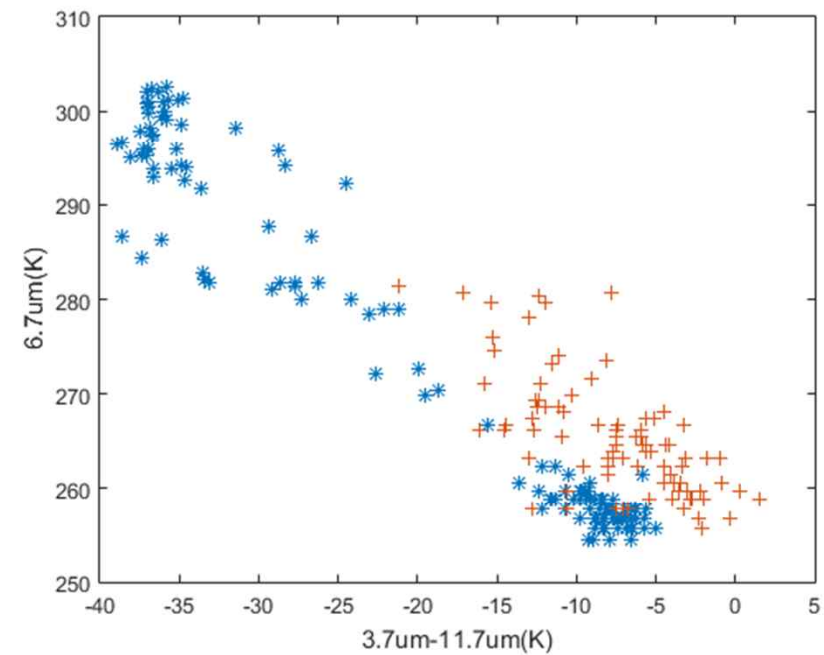
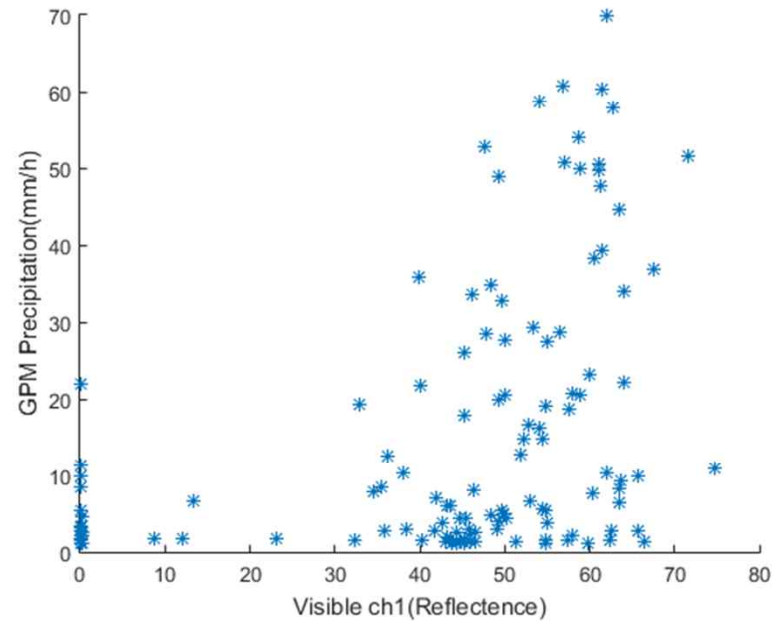


Flowchart

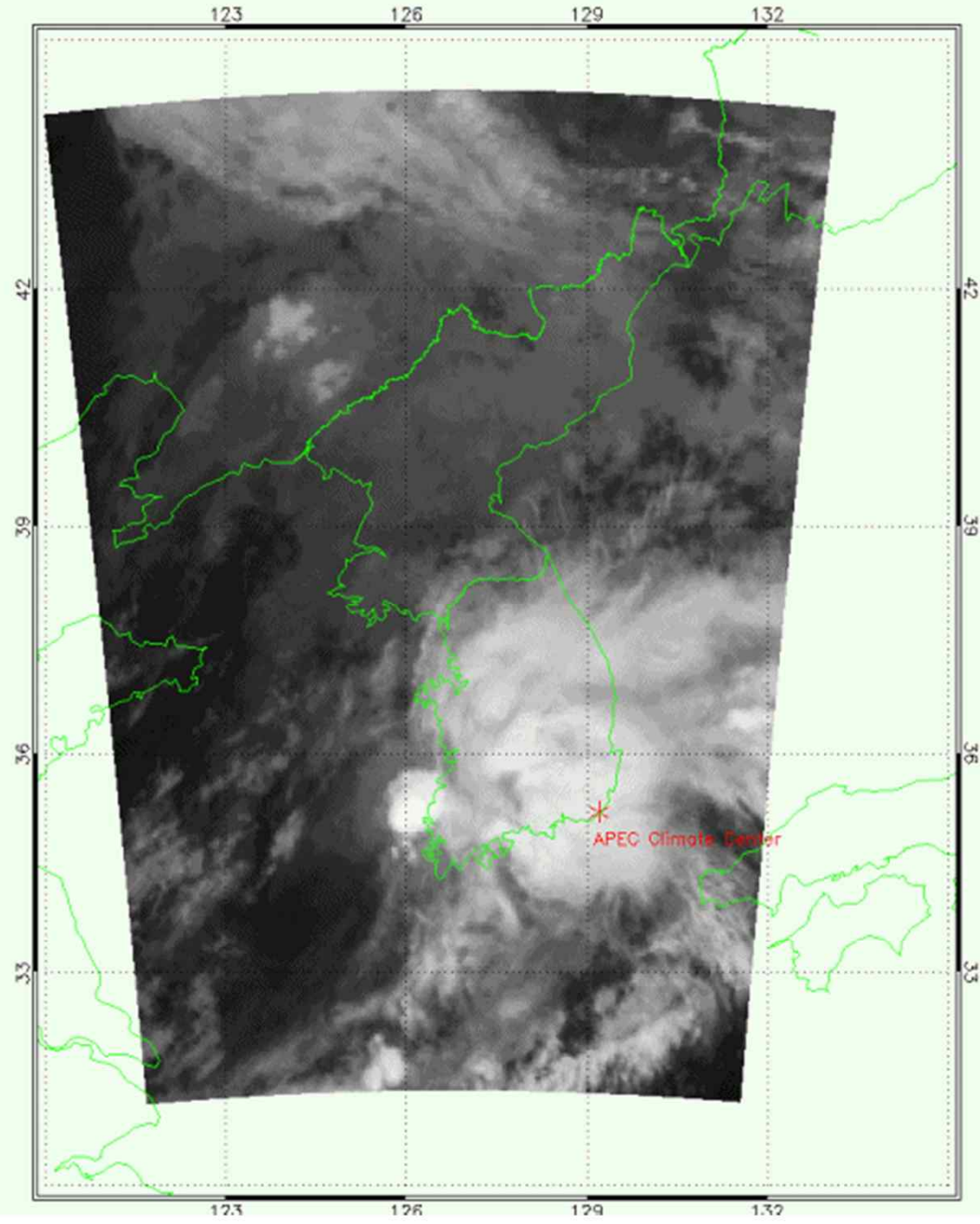


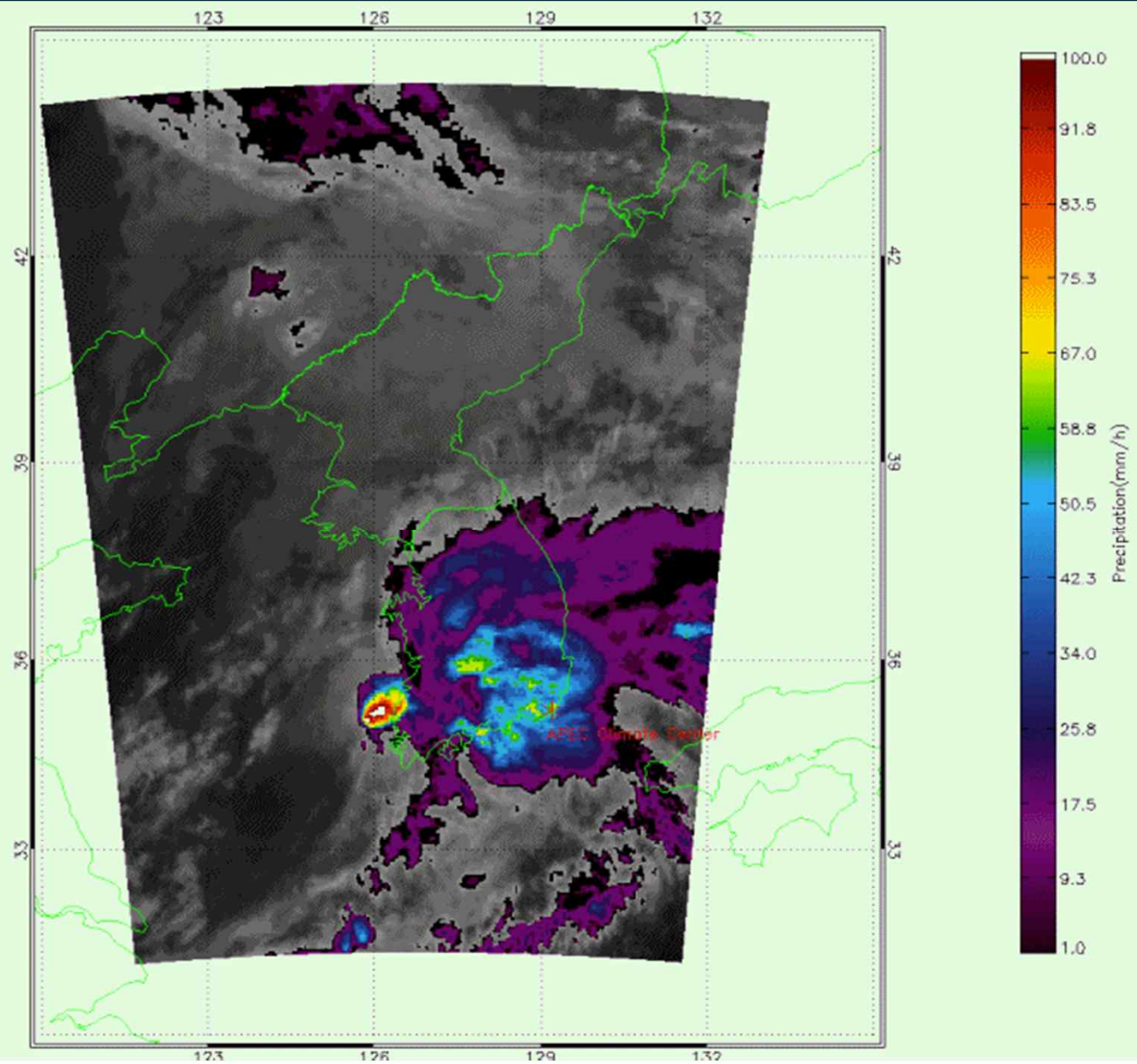
Clouds classification(Rain/no rain)

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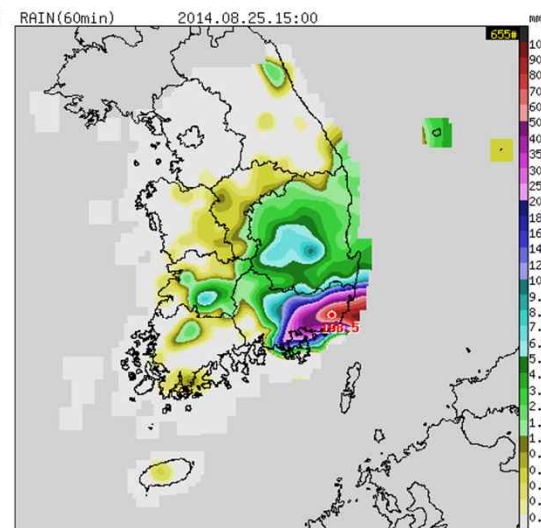
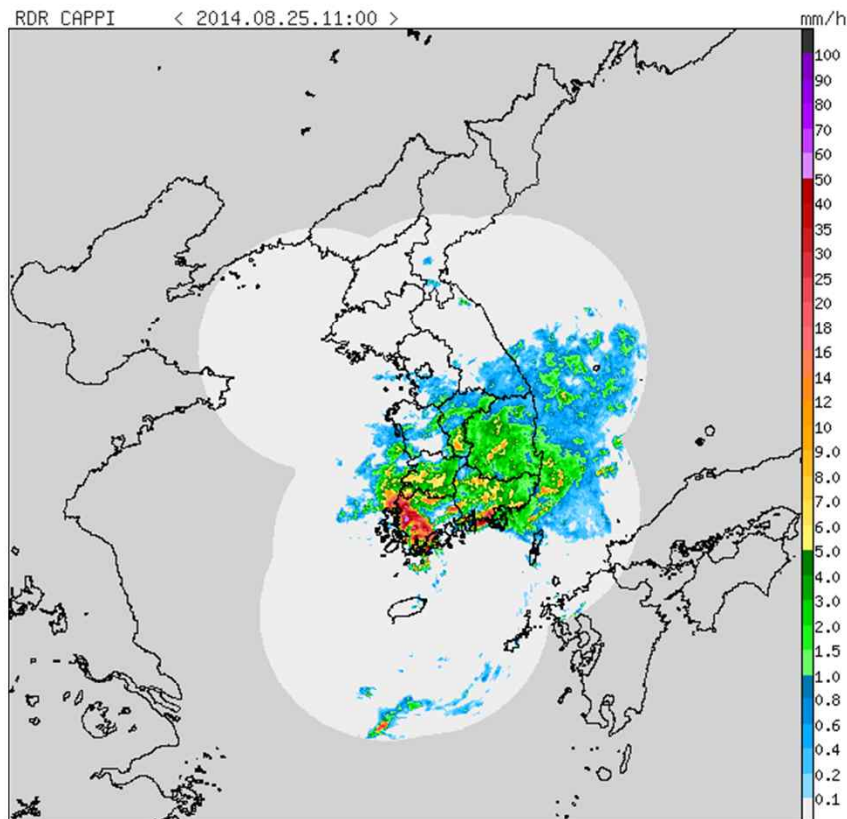
A scatter plot showing the relationship between COMS IR1 Brightness Temperature (K) on the x-axis and GPM Precipitation (mm/h) on the y-axis. The x-axis ranges from 210 to 250 K, and the y-axis ranges from 0 to 60 mm/h. Black dots represent individual data points from the COMS vs GPM comparison. A solid black line represents the 'New algorithm' fit, which shows a decreasing trend in precipitation as brightness temperature increases, starting at approximately 40 mm/h at 215 K and ending near 5 mm/h at 250 K.





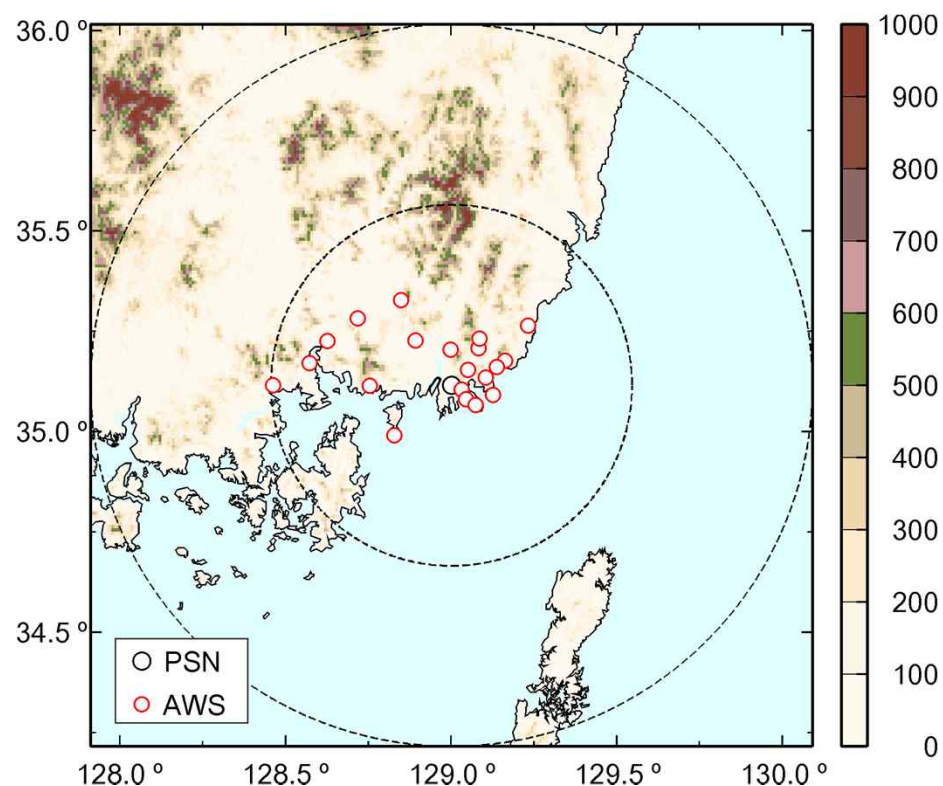
Case study - Busan(2014.08.25)

APCC

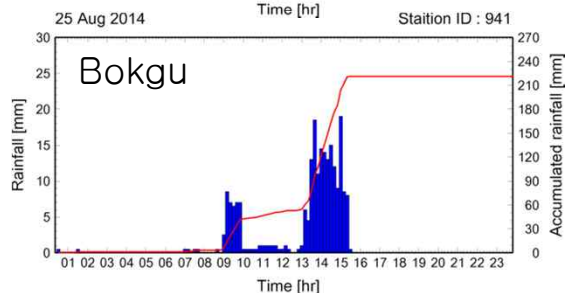
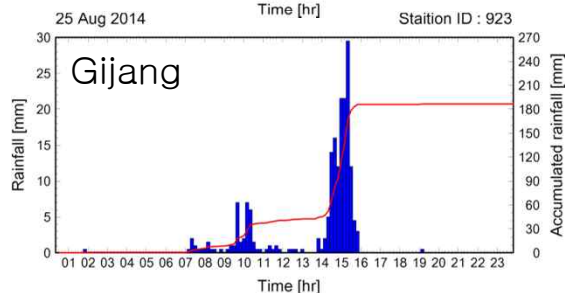
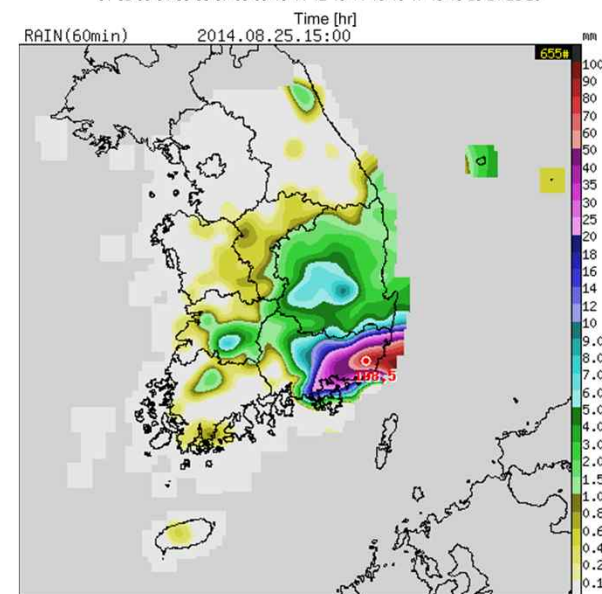
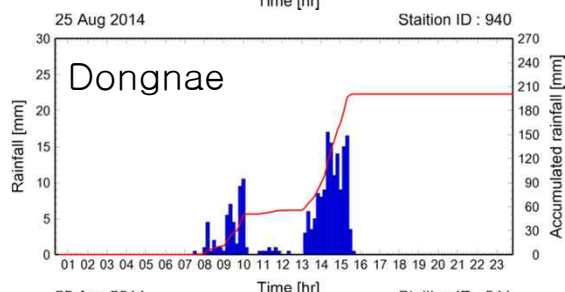
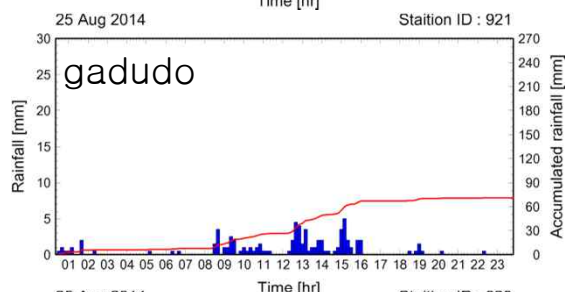
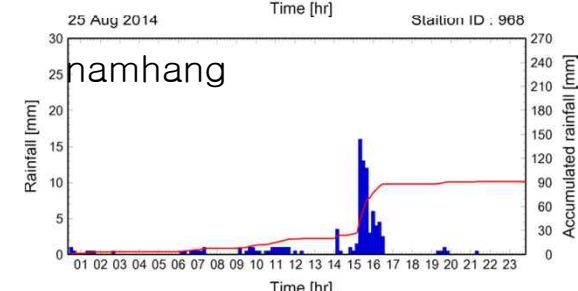
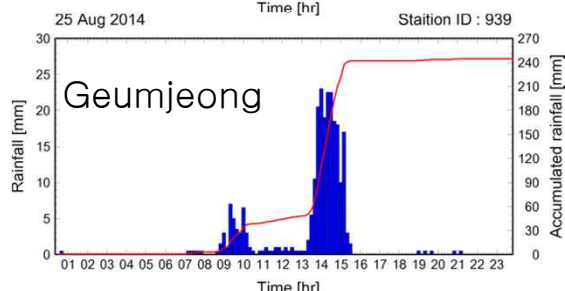
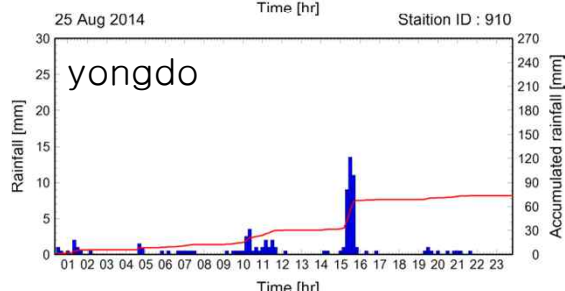
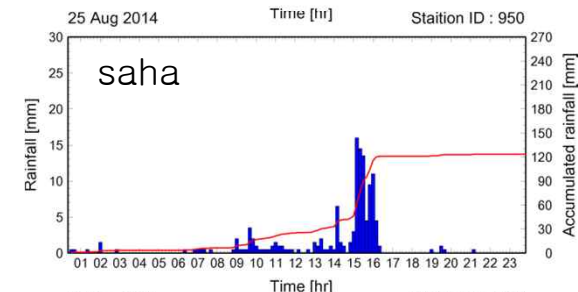
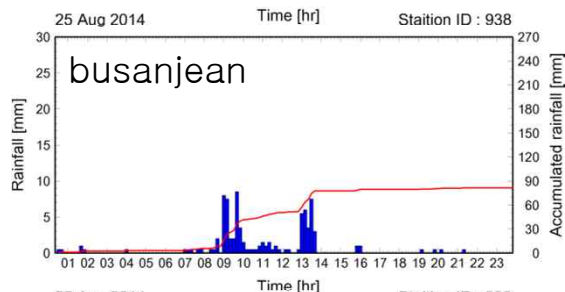
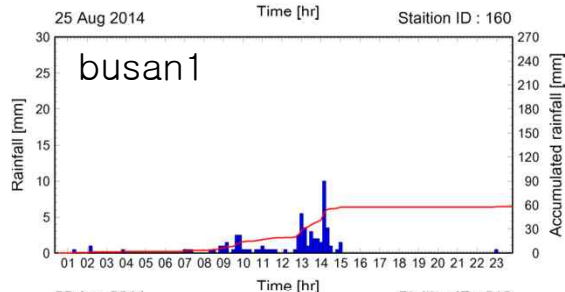
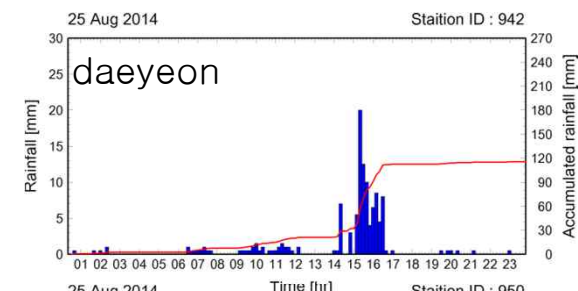
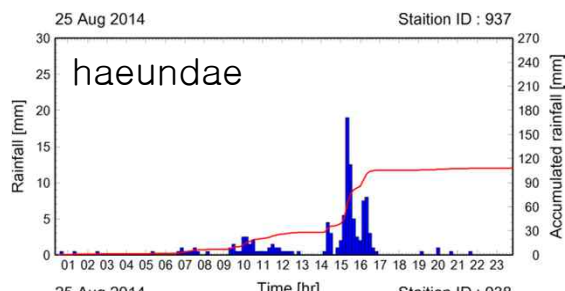
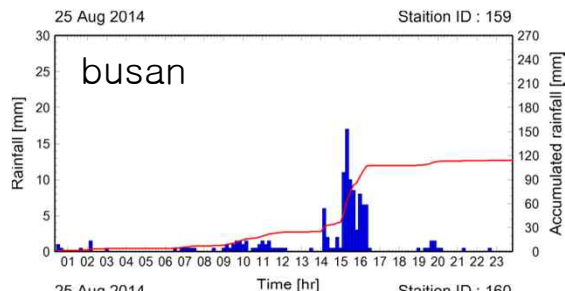


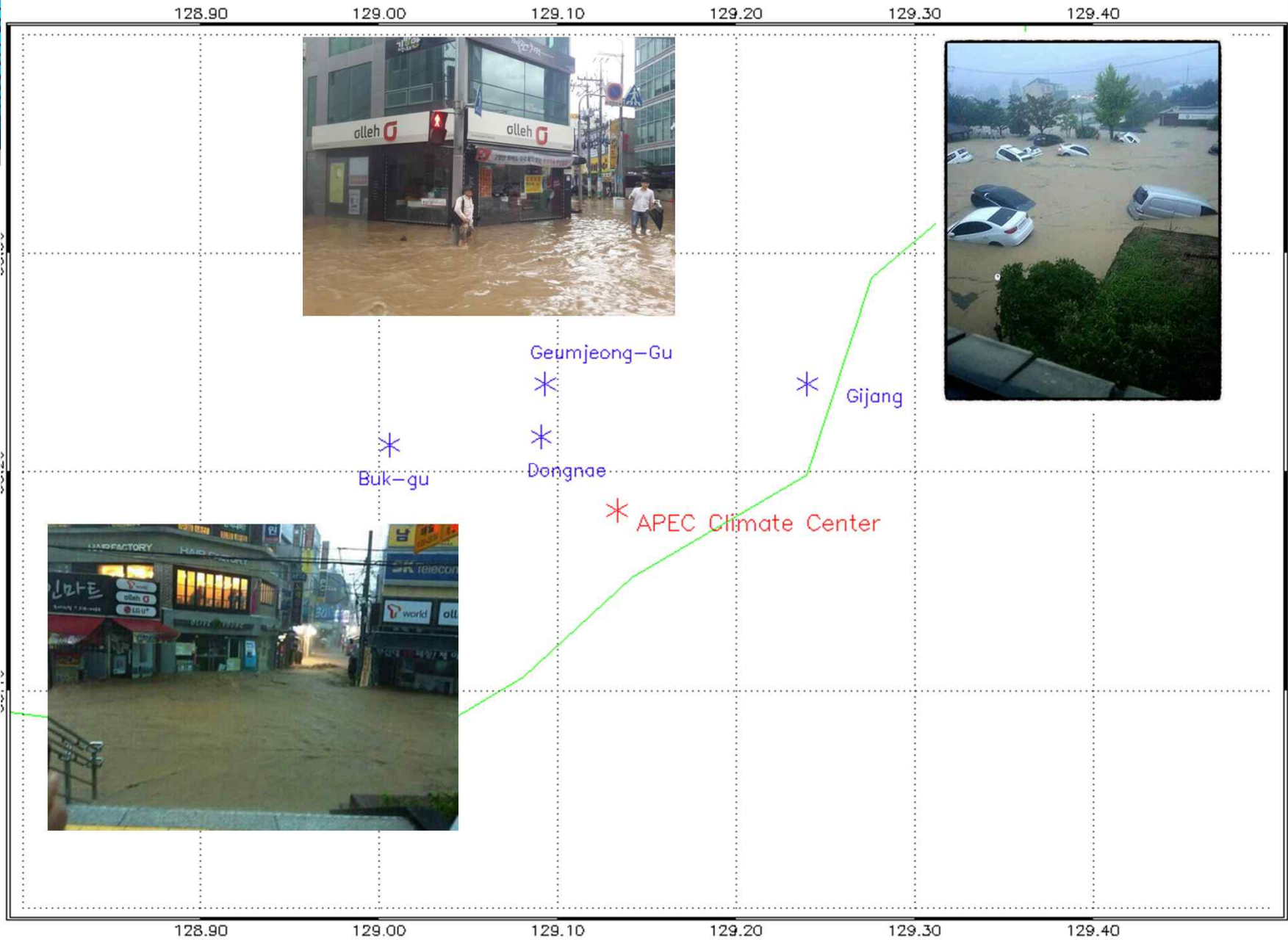
S-band weather radar, AWS

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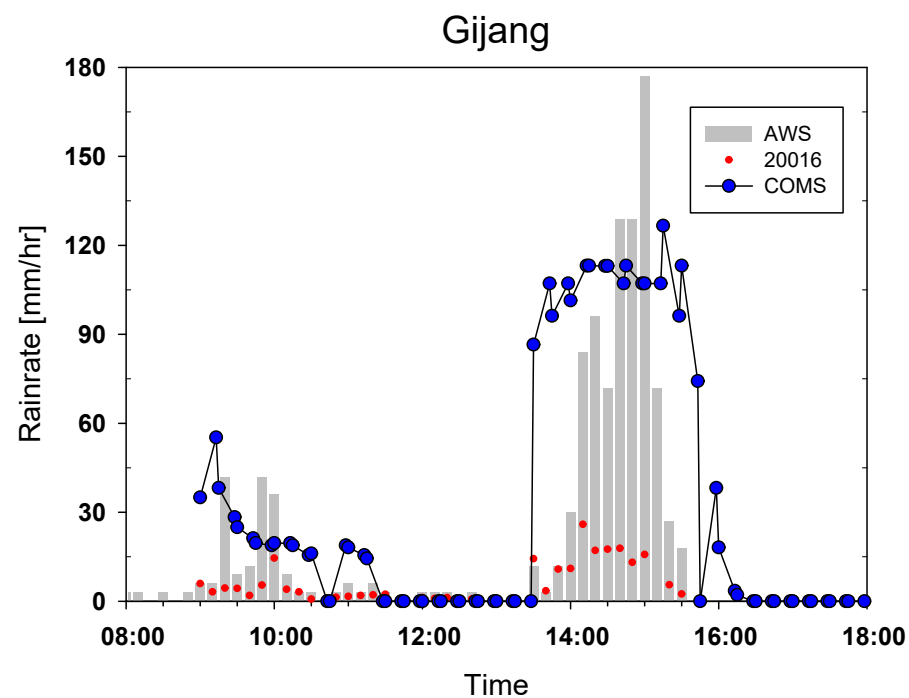
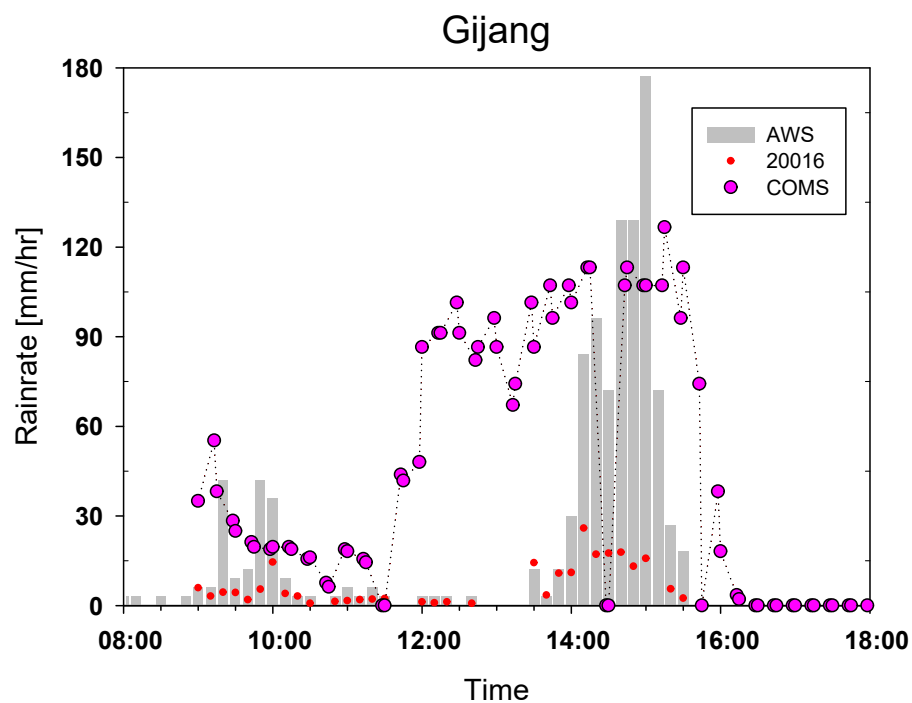
Radar site	PSN
Wavelength	11.06 cm (S-band)
Bin spacing	250 m
Range	240 km
Number of elevation angle	13 (0.05° ~ 15.83°)
Scan interval	10 minute
Location	35.1153°N, 29.0014°E





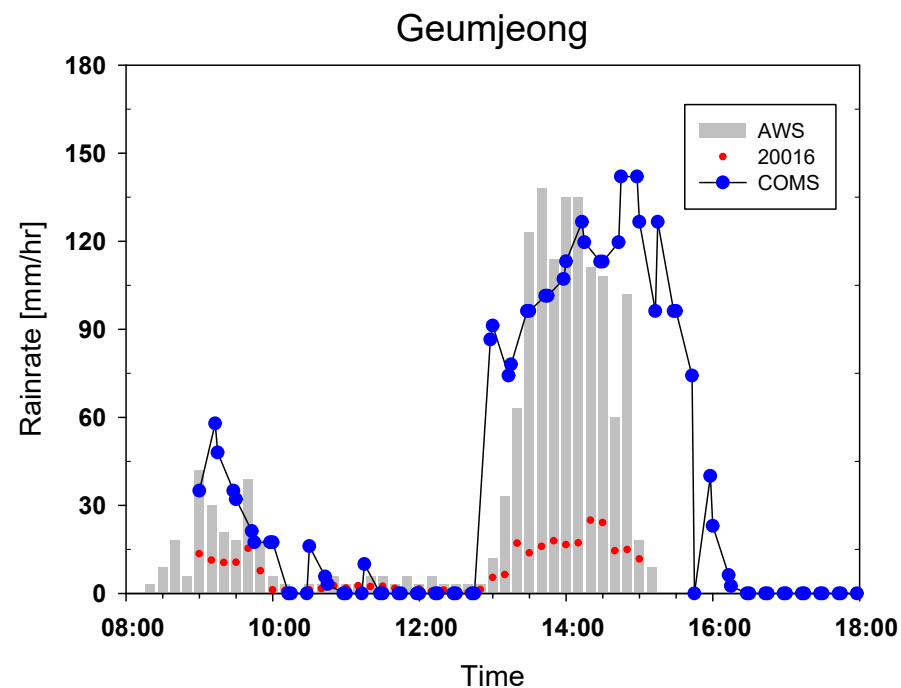
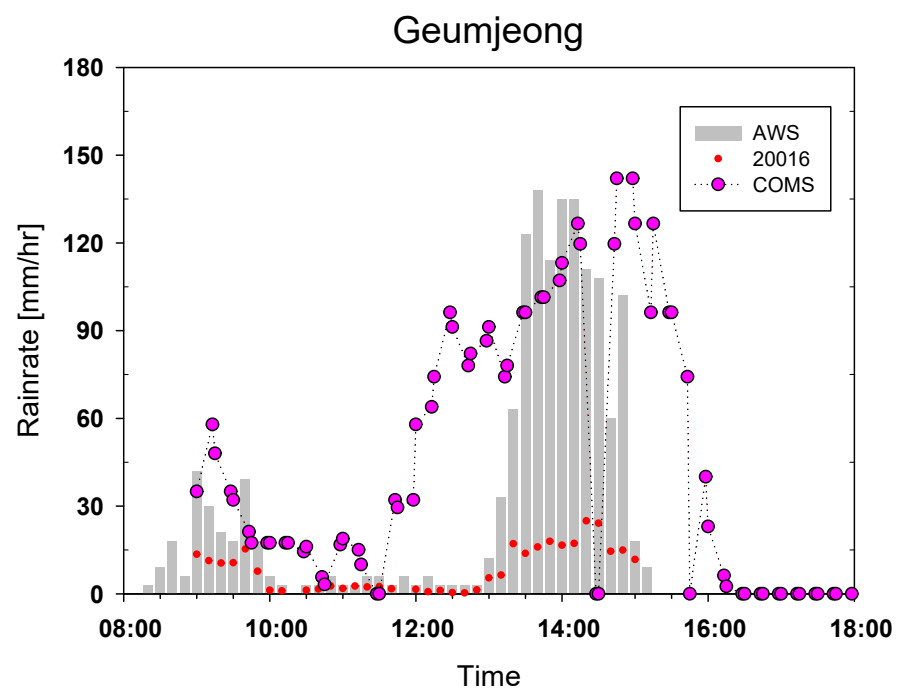
COMS vs AWS, Radar(rain/no rain)-Gijang

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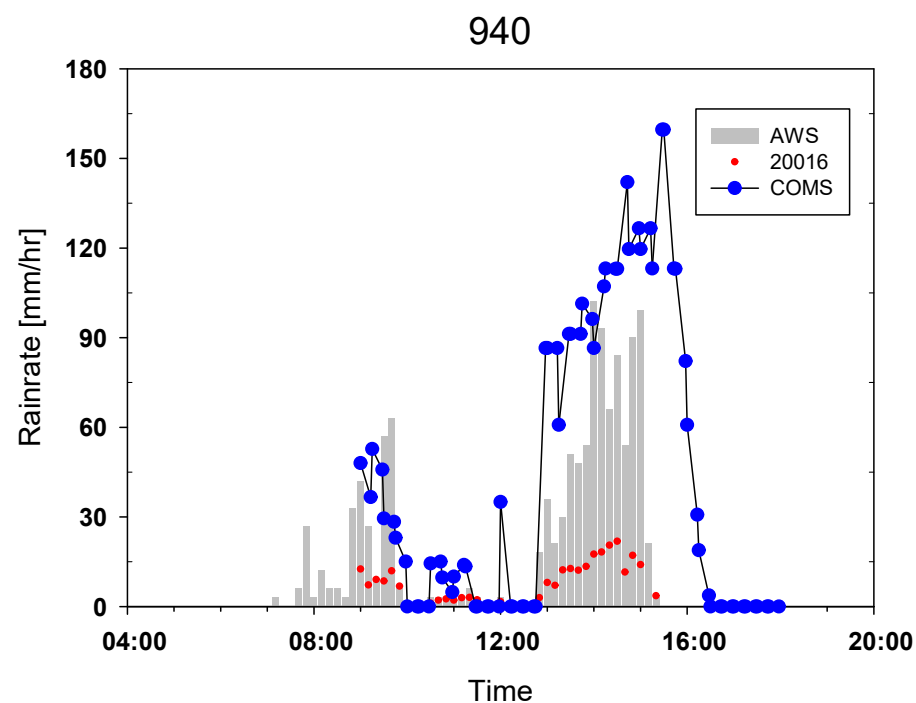
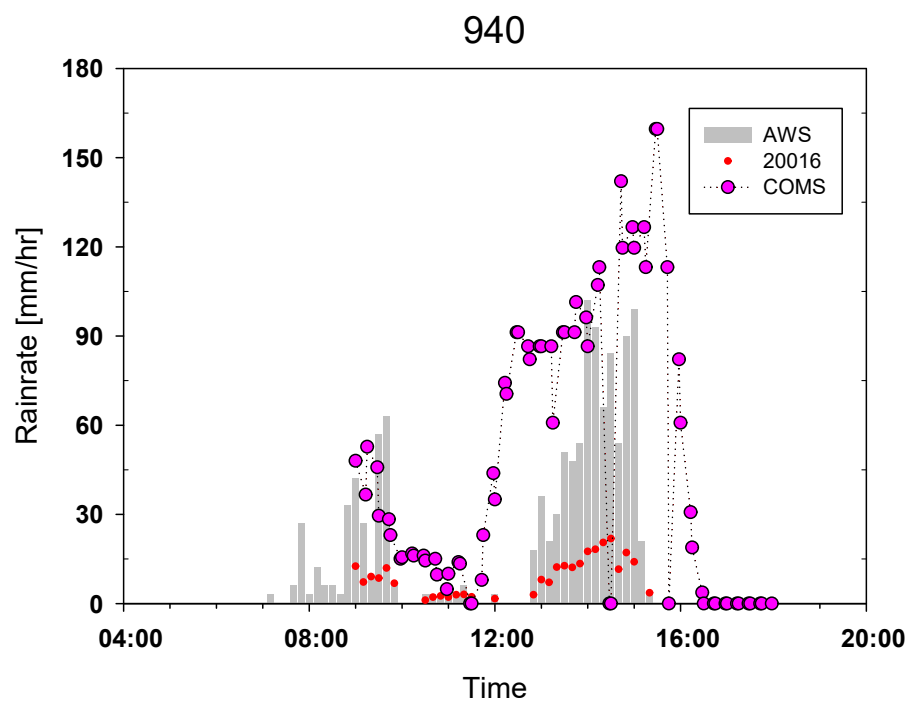
COMS vs AWS, Radar(rain/no rain)-Geumjeong

APEC



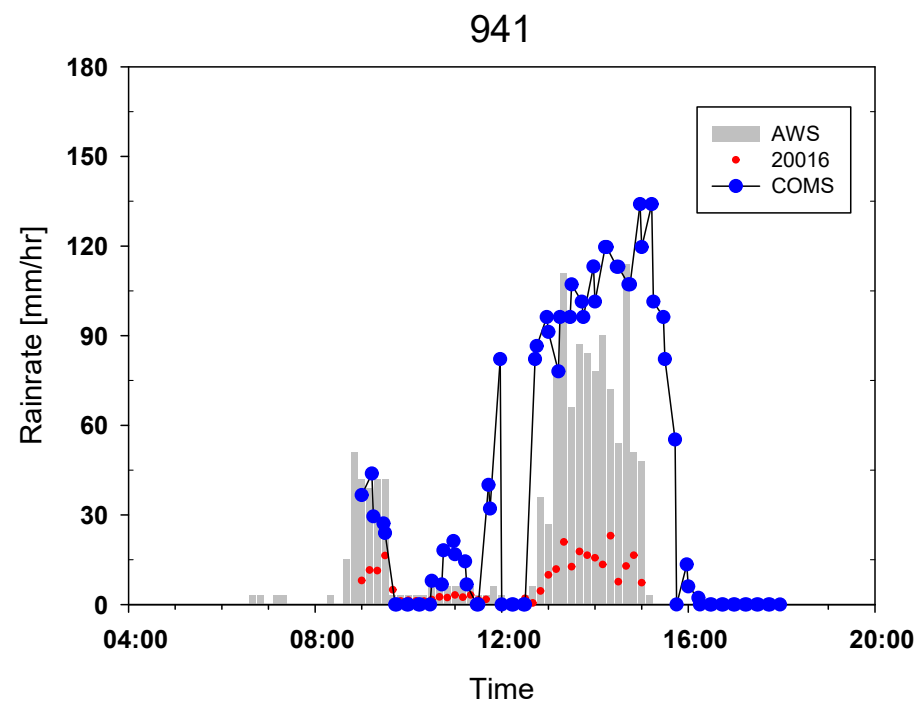
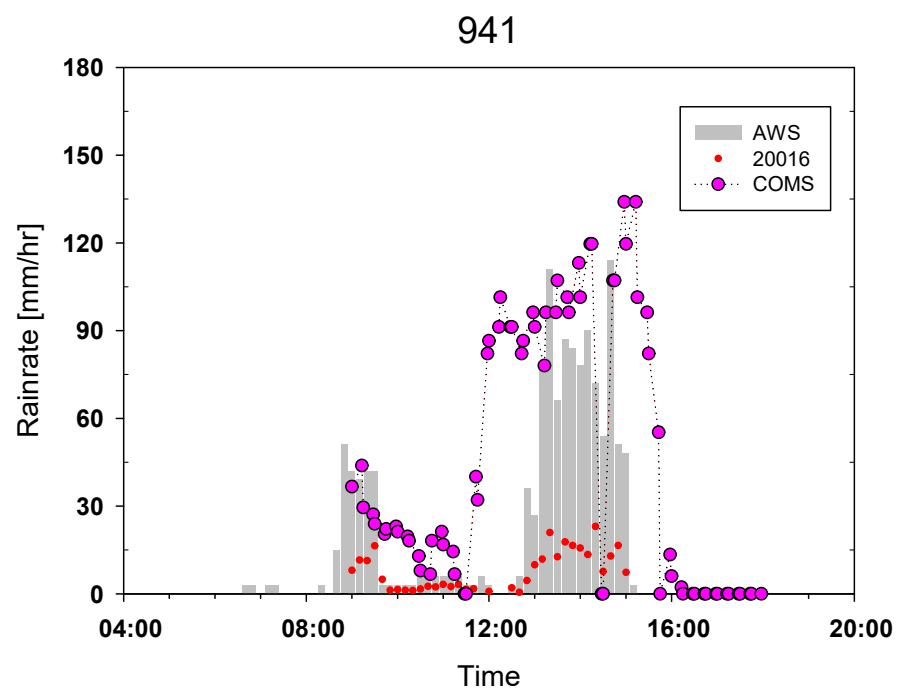
COMS vs AWS, Radar(rain/no rain)-Dongnae

APCC



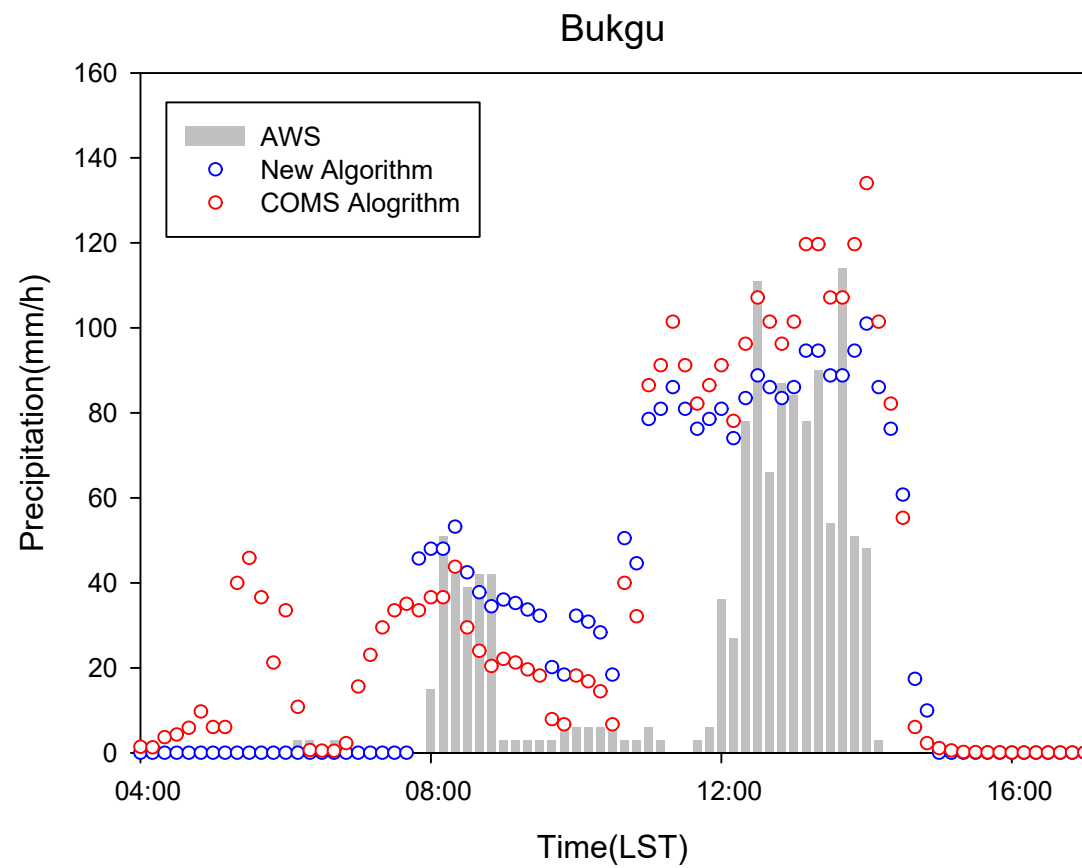
COMS vs AWS, Radar(rain/no rain)-Bukgu

APCC



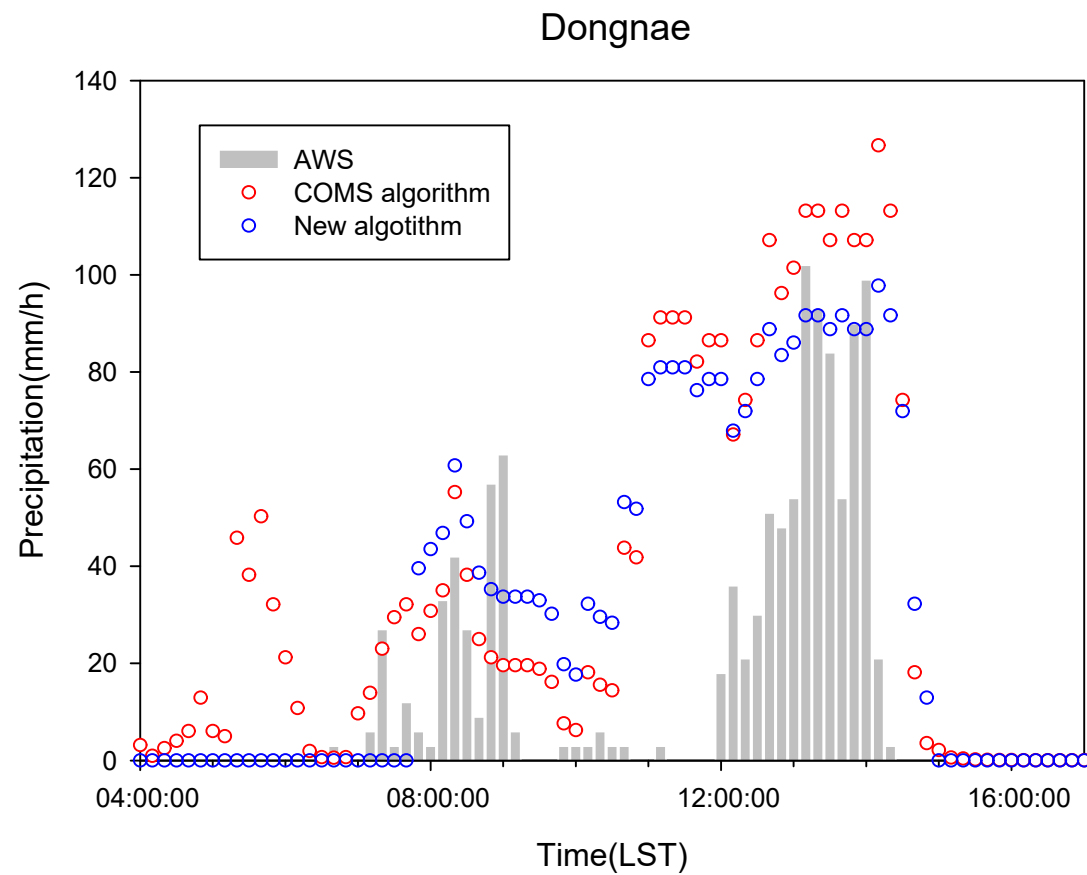
New COMS Rainfall Algorithm - Bukgu

APCC



New COMS Rainfall Algorithm - Dongnae

APCC

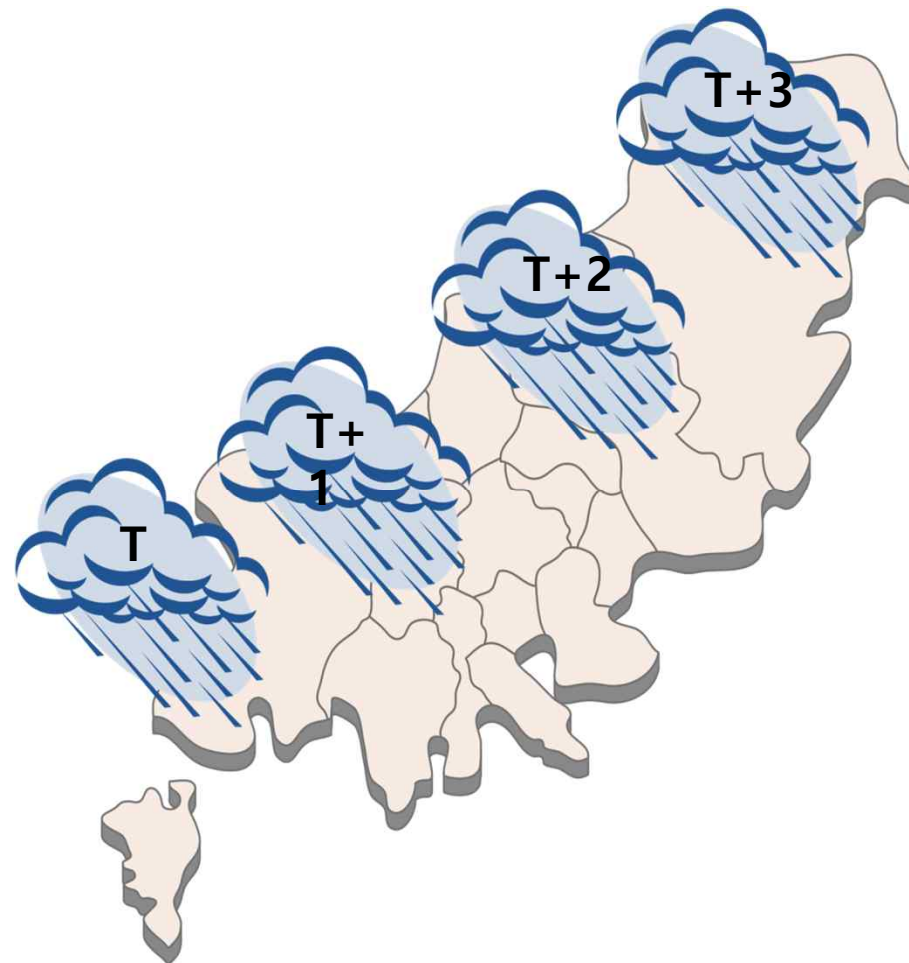


Satellite rainfall forecasting

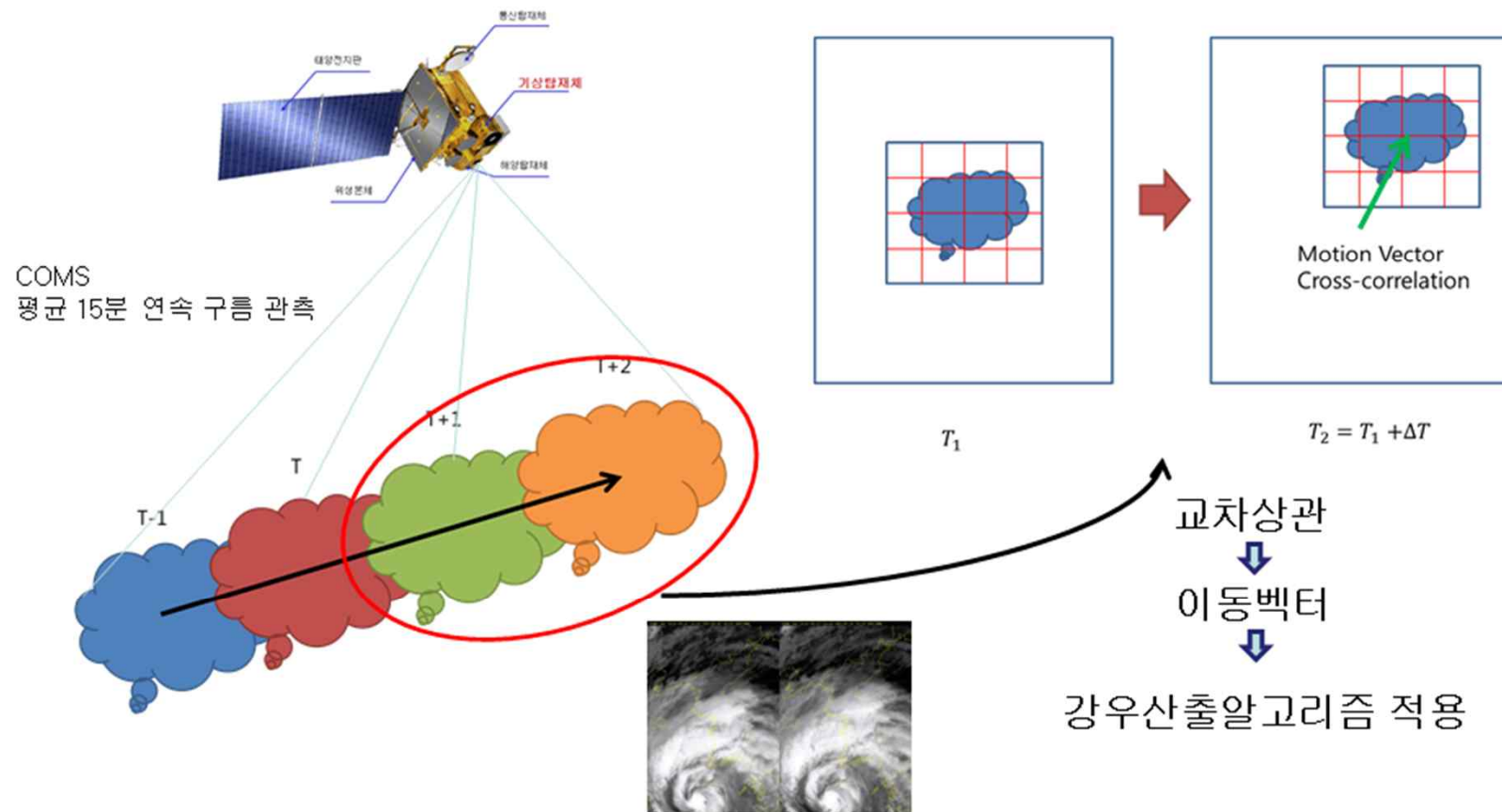


Methodology

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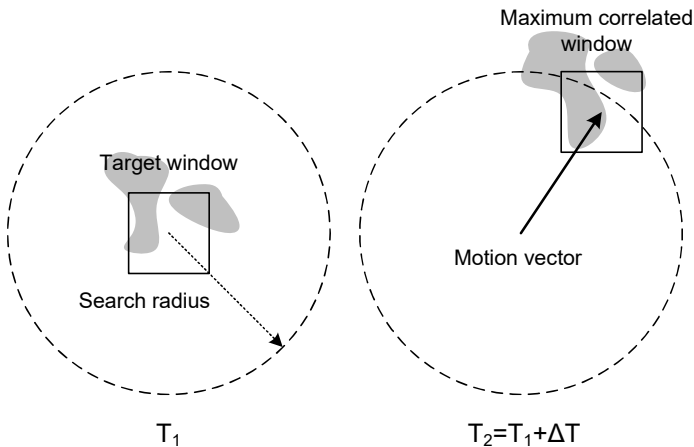
Methodology



Motion vector

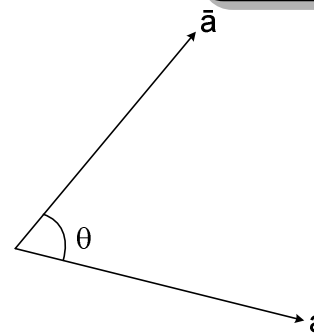
Correlation

$$R = \frac{n \sum Z_1 Z_2 - \sum Z_1 \sum Z_2}{\sqrt{n \sum Z_1^2 - (\sum Z_1)^2} \sqrt{n \sum Z_2^2 - (\sum Z_2)^2}}$$



Where, Z_1 and Z_2 are the radar reflectivity at T_1 and $T_1 + \Delta T$ respectively.

Consistency Check

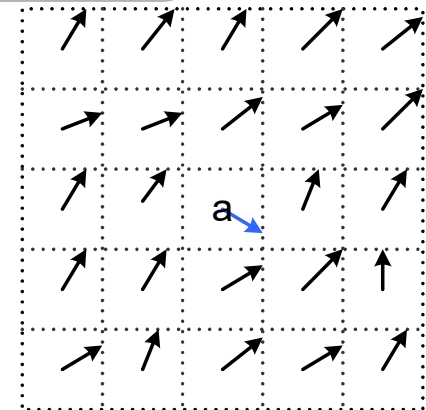


If $\theta > 90^\circ$, a will be replaced by $\bar{a}$.

where a : a motion vector (TREC vector)

$\bar{a}$: the local mean vector of a 's neighborhood
(which is calculated from the set of 25 vectors located around it)

θ : deviation between $\bar{a}$ and a



Objective Analysis

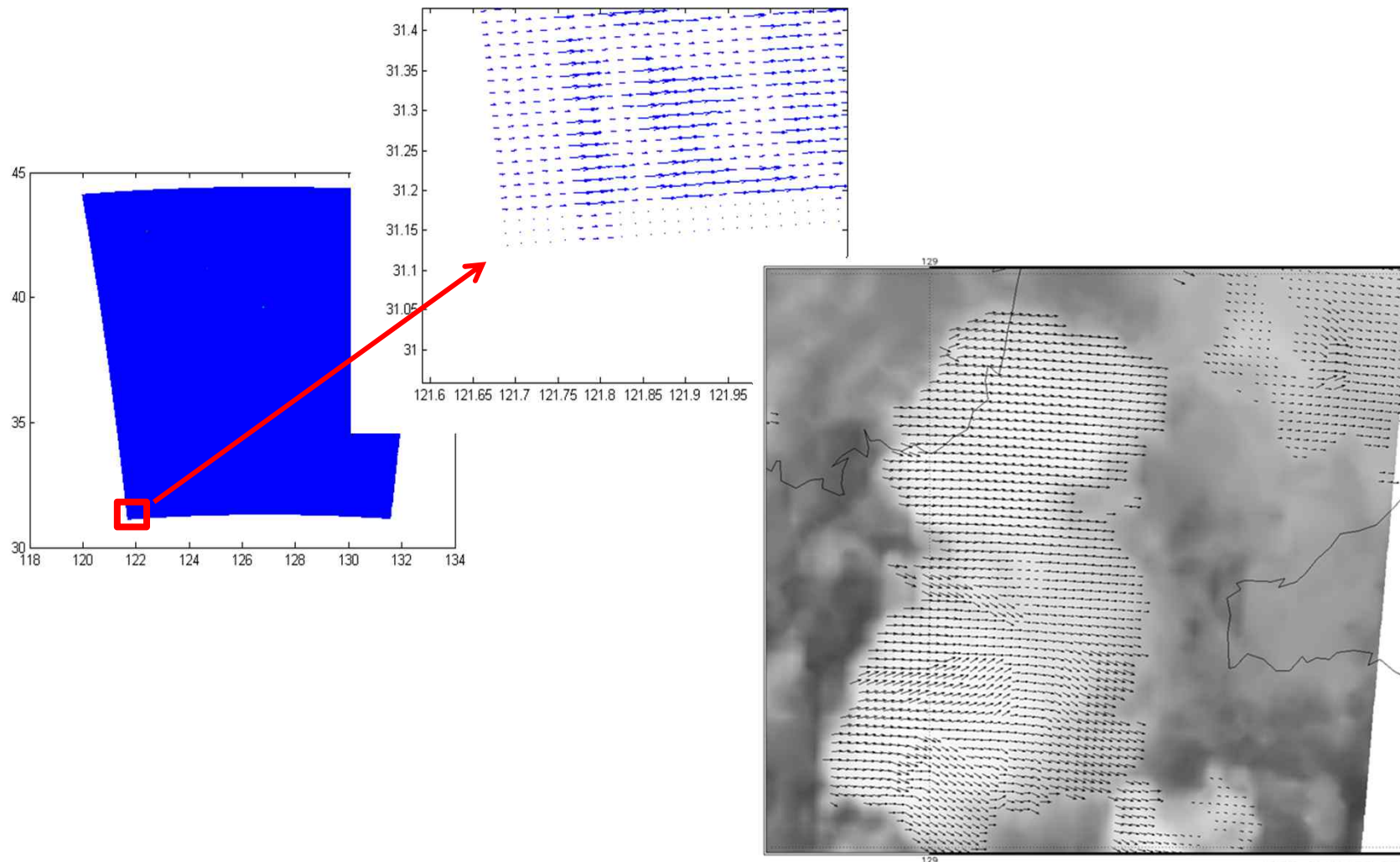
$$s^*(i, j) = s_0(i, j) + \Delta s(i, j)$$

$$\Delta s(i, j) = \frac{\sum_k w(i, j, k) \times \Delta s(k)}{\sum_k w(i, j, k)}$$

$$w(i, j, k) = \begin{cases} \frac{R^2 - d^2}{R^2 + d^2} & \text{if } d^2 < R^2 \\ 0 & \text{if } d^2 > R^2 \end{cases}$$

Cloud motion vector

APCC



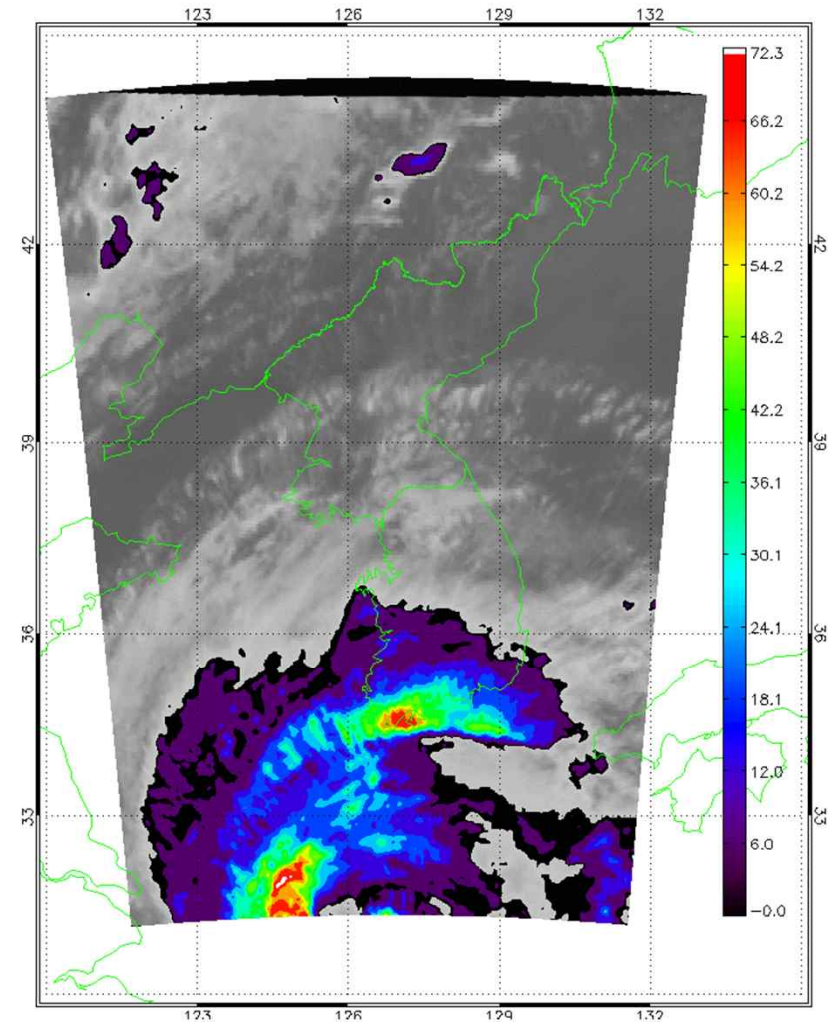
Verification: Typhoon BOLAVEN

APCC

Typhoon BOLAVEN (August 27, 2012)



Source: <https://www.google.co.kr/>



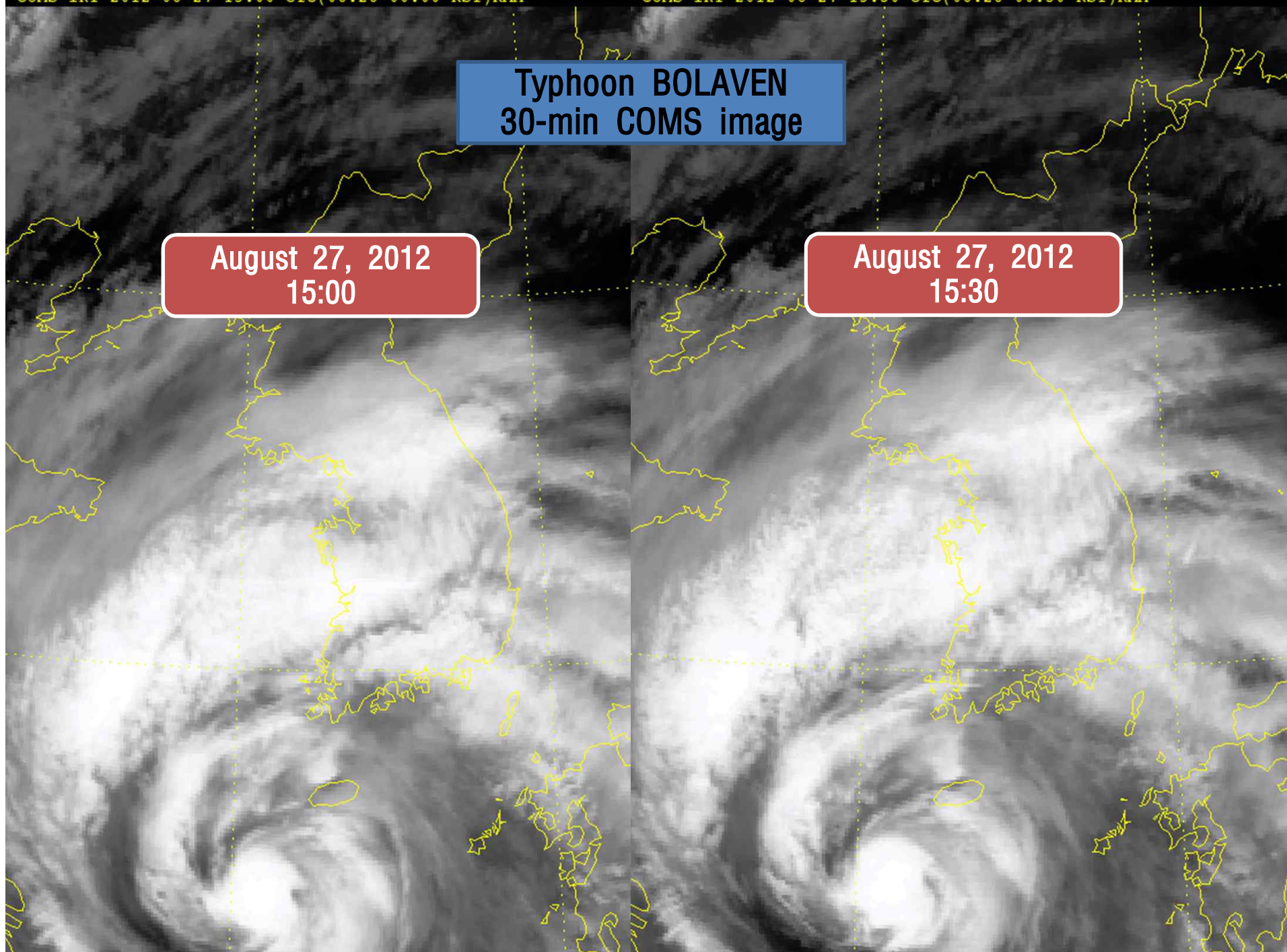
COMS IR1 2012-08-27 15:00 UTC(08.28 00:00 KST)KMA

COMS IR1 2012-08-27 15:30 UTC(08.28 00:30 KST)KMA

**Typhoon BOLAVEN
30-min COMS image**

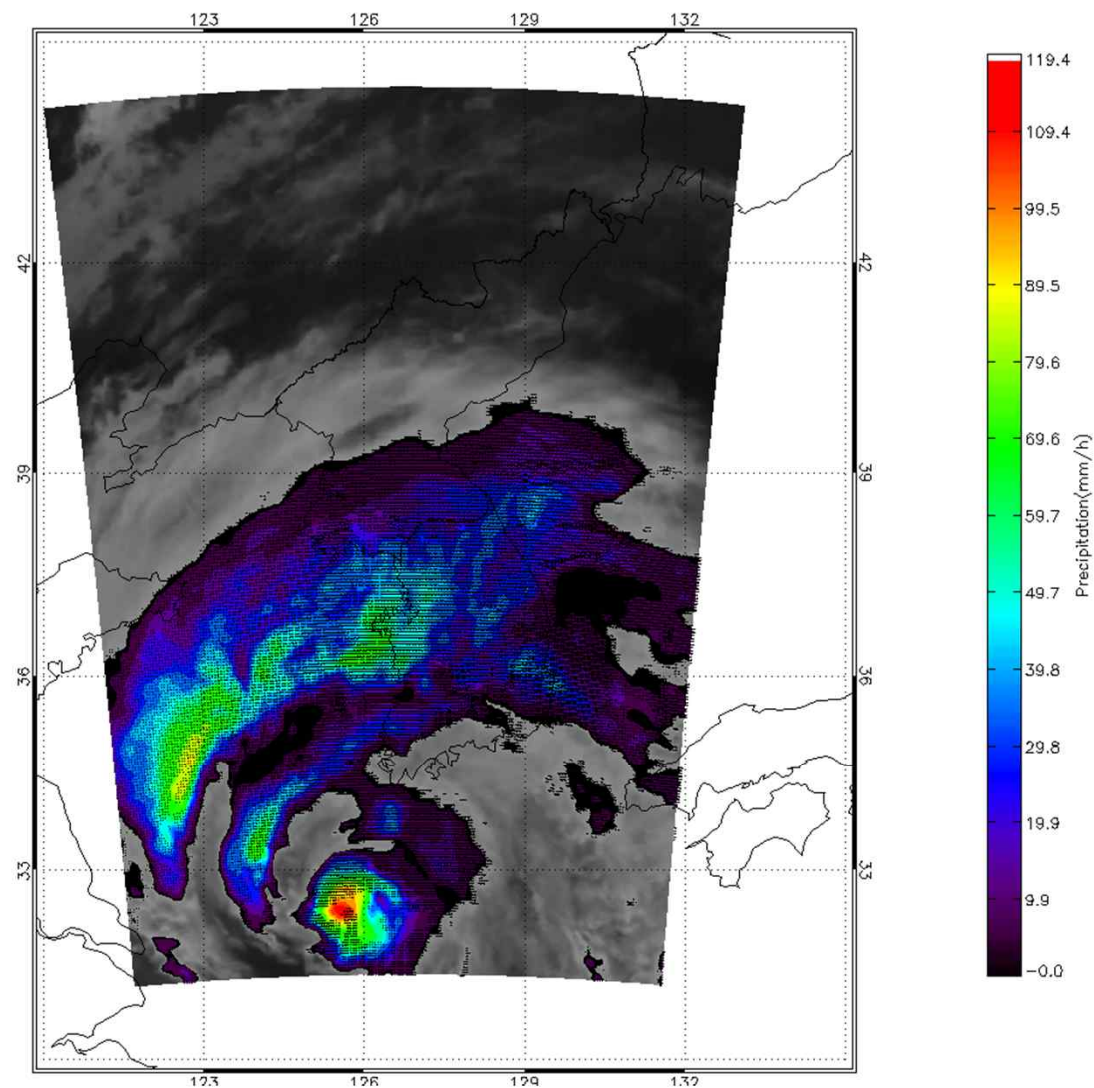
**August 27, 2012
15:00**

**August 27, 2012
15:30**



Cloud motion vector

APCC



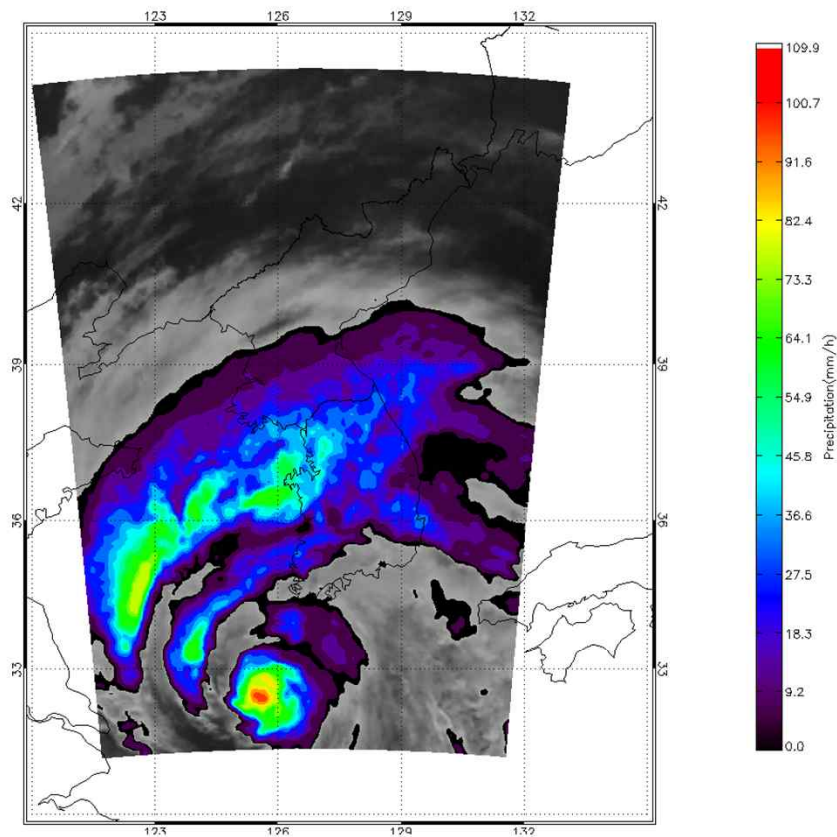
C CLIMATE CENTER

Case study : Bolaven

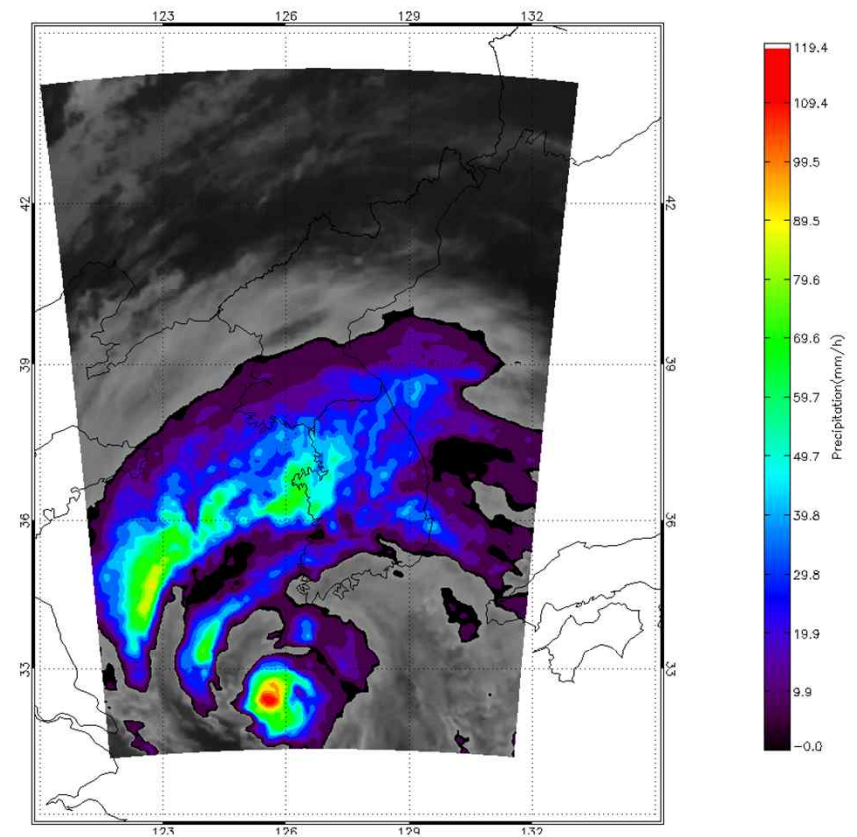
(leadtime : 15min)

APEC

(a) observed



(b) forecast



2012/08/27 15:30(UTC)

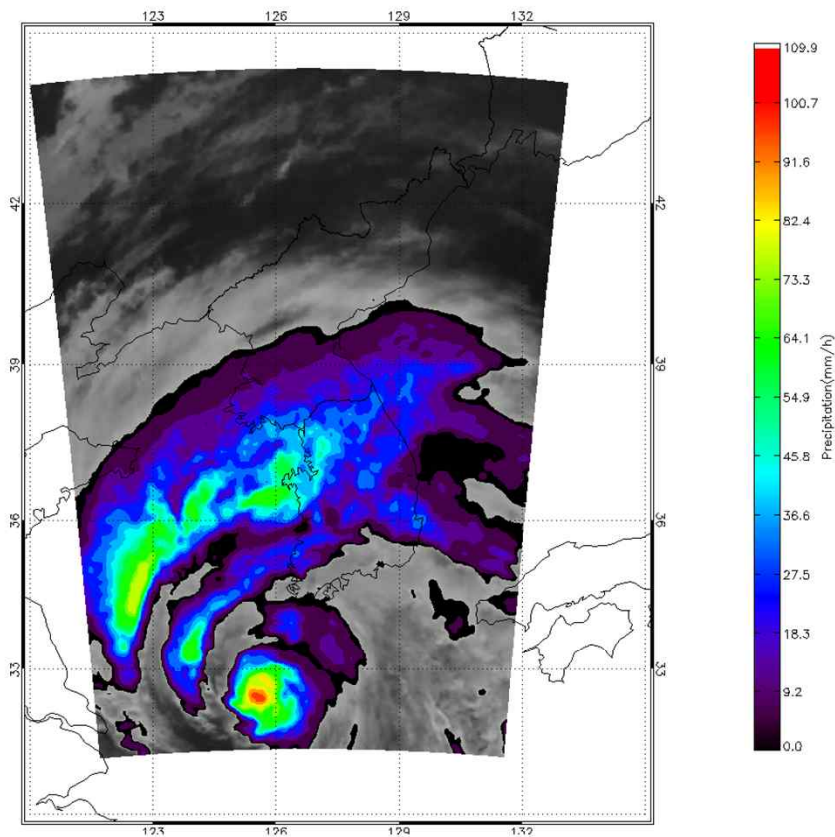
APEC CLIMATE CENTER

Case study : Bolaven

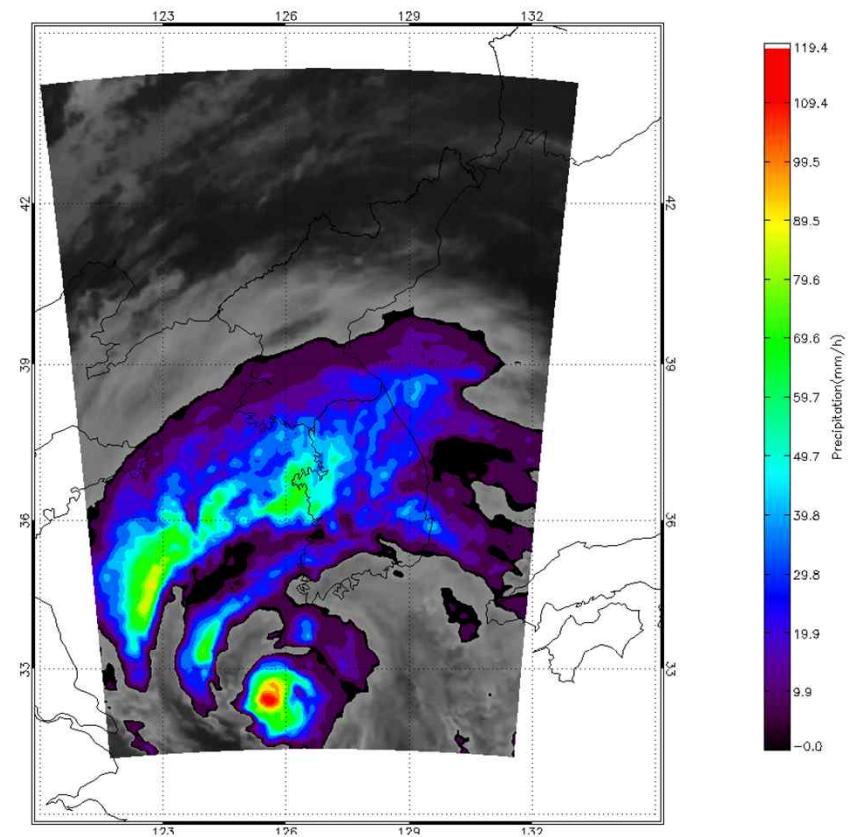
(leadtime : 1hour)

APEC

(a) observed



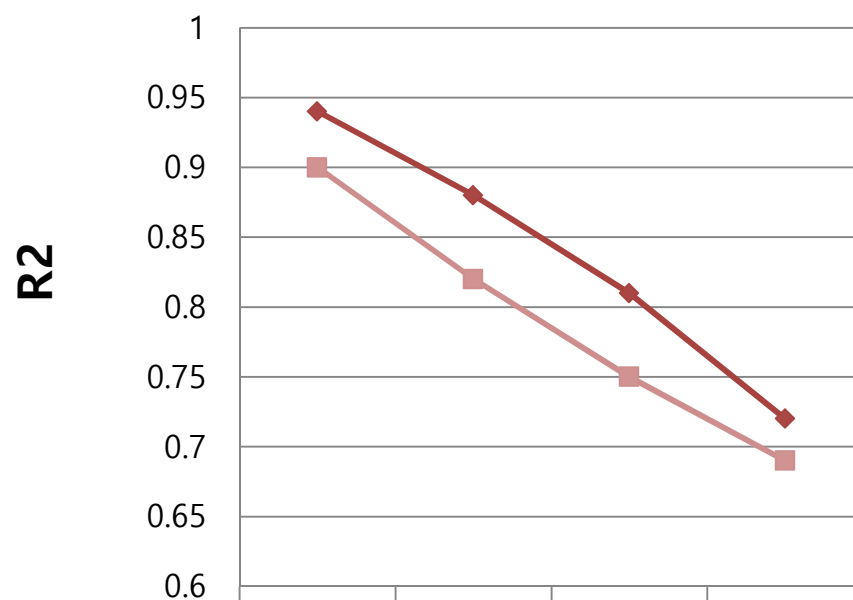
(b) forecast



2012/08/27 15:30(UTC)

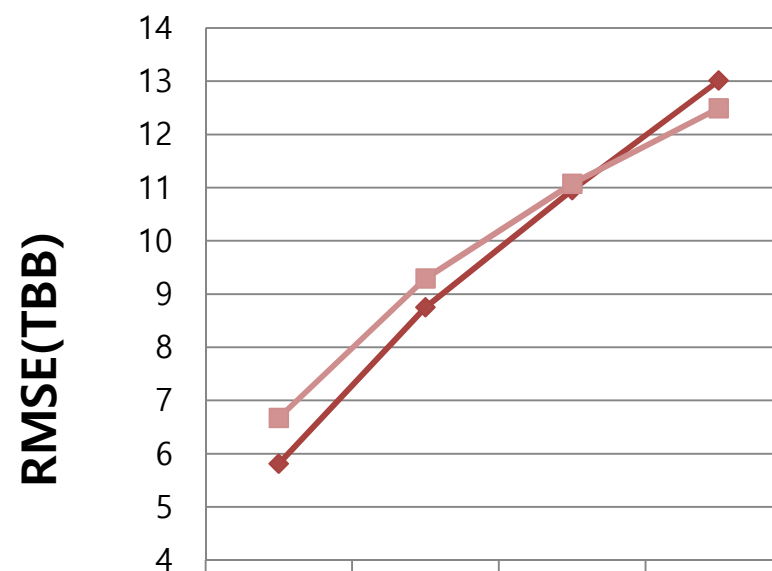
APEC CLIMATE CENTER

Performance of Rainfall Forecasting



◆ BOLABEN	0.94	0.88	0.81	0.72
■ Extreme Rainfall	0.9	0.82	0.75	0.69

Lead Time



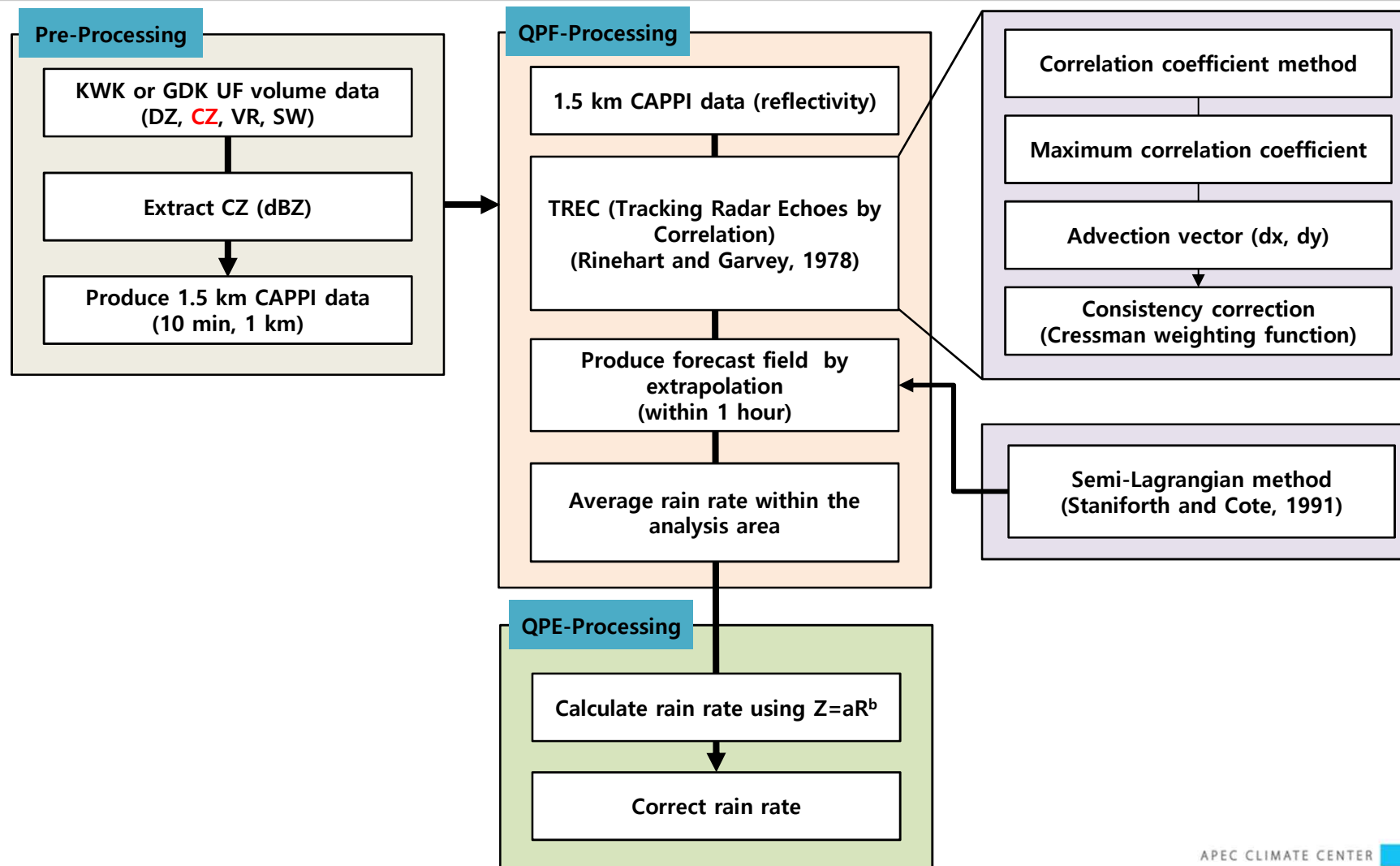
◆ BOLABEN	5.81	8.75	10.95	13.01
■ Extreme Rainfall	6.67	9.29	11.07	12.49

Lead Time

Radar

APCC QPE/QPF Processing flowchart

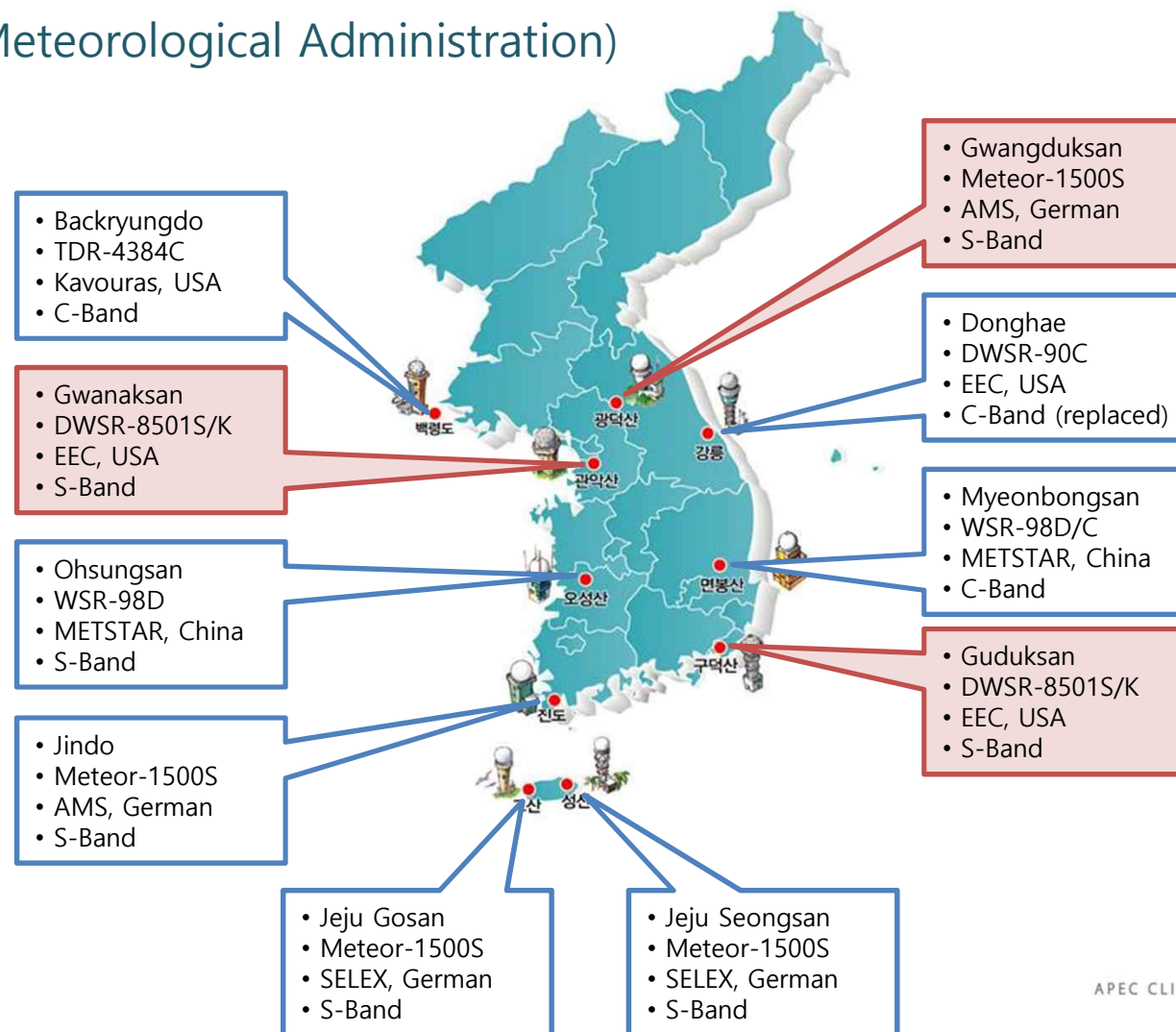
APCC



Radar Stations in South Korea

APEC

- KMA (Korea Meteorological Administration)





QPF algorithms

APCC

- Area tracking algorithms

- TREC (Tracking Radar Echoes by Correlation, Rinehart and Garvey, 1978)

- VET (Variational Echo Tracking, Laroche and Zawadzki, 1994)

- Cell tracking algorithms

- TITAN3D (Thunderstorm Identification Tracking Analysis and Nowcasting, Dixon and Wiener, 1993)

- SCIT3D (Storm Cell Identification and Tracking, Johnson et al., 1998)

- TRACE3D (Handwerker, 2002)

- CELLTRACK2D (Kyznarova and Novak, 2005)

- TRT2D (Thunderstorm Radar Tracking, Hering et al., 2004)

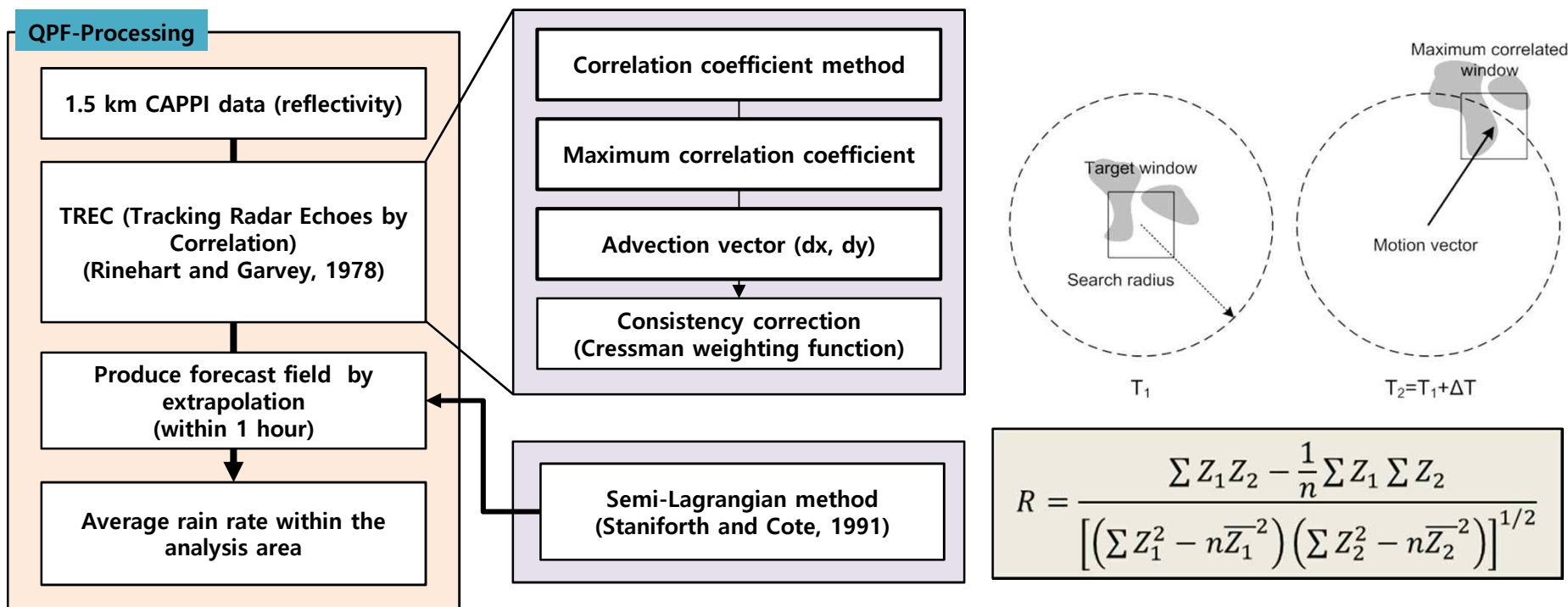
- QPF systems

- Auto Nowcast (USA), CARDS (Canada), AMV (Finland), GANDOLF (UK), S-PROG (Australia and Spain), INCA and GaliMet (Austria), MAPLE (Canada), NIMROD (UK), STEPS (UK and Australia), SWIRLS (Hong Kong), TRT (Switzerland)



TREC (Tracking Radar Echoes by Correlation)

APEC

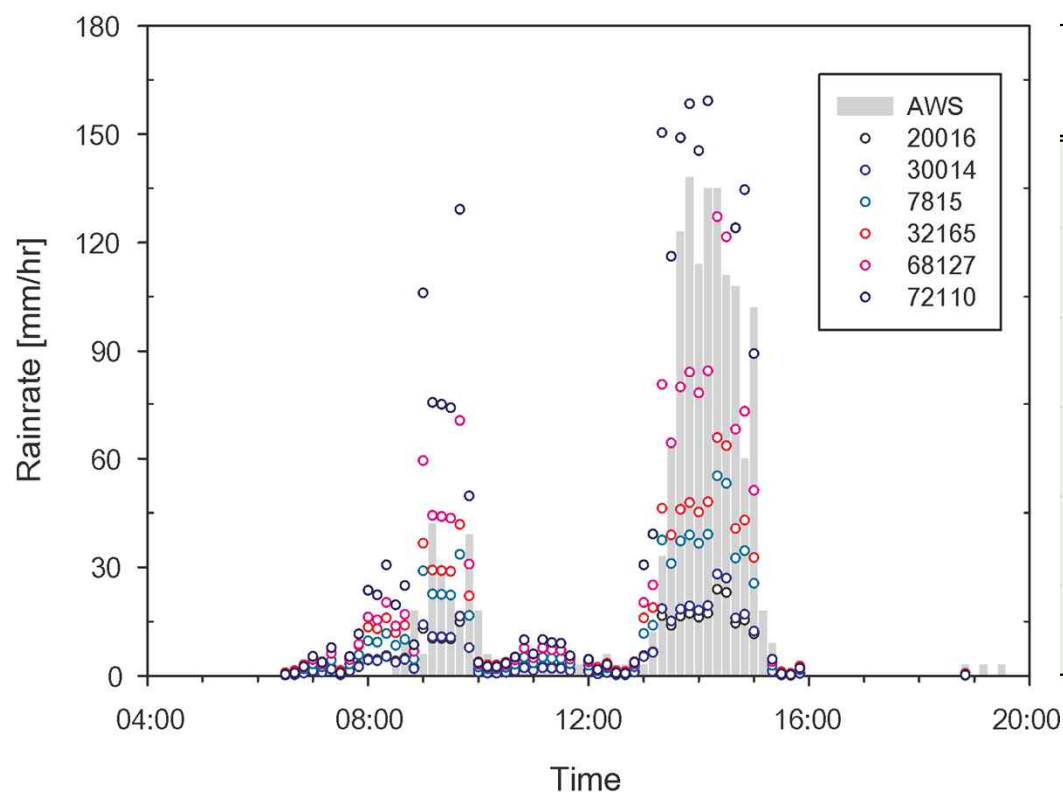


Target window size	Search radius	Lead time	Input resolution		Output resolution	
			Time	Spatial	Time	Spatial
10 X 10 km	7 km	1 ~2 hours	2.5 min	0.5 km	2.5 min	0.5 km
			5 min	1 km	5 min	1 km
			10 min		10 min	

Improvement of QPE

■ Optimal Z-R relation

Station ID: 939



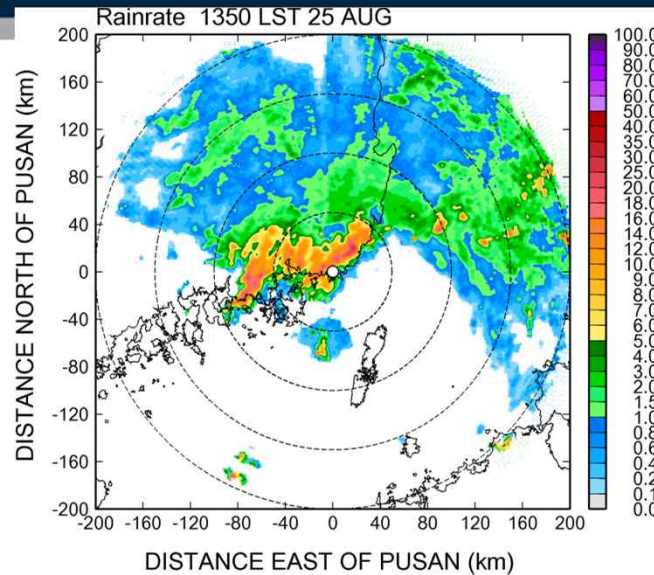
$$z \text{ (dB)} = aR^b$$

Study	a	b	Precipitation type
Marshall and Palmer (1948)	200	1.6	Stratiform
Woodley et al.(1975) Gagin et al.(1985)	300	1.4	Convective
You et al. (2005)	78	1.5	Convective
J. Wilson	32	1.65	Tropical
1:Modified Z-R	68	1.27	-
21:Modified Z-R	72	1.10	-

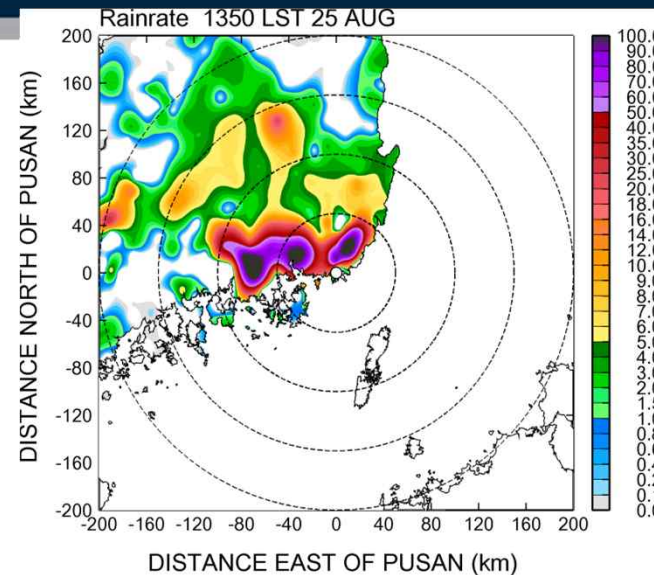
Comparison of Radar Rainfall Estimation

Observed: 25. Aug., 2015 13:50 LST

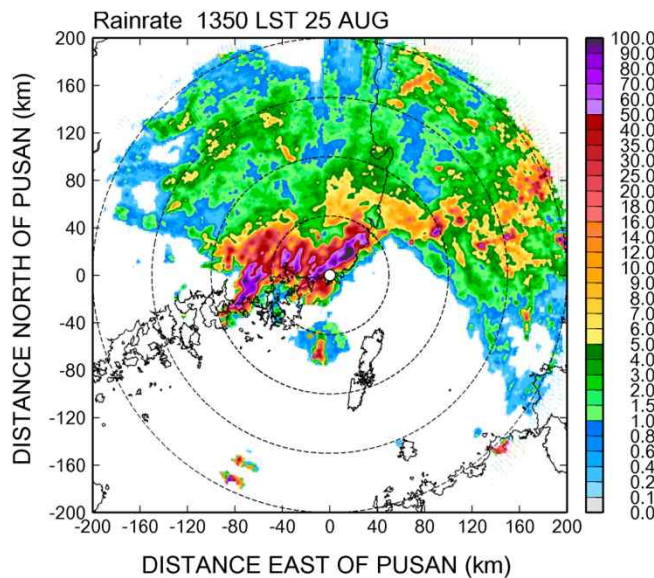
Default Z-R (200R^{1.6})



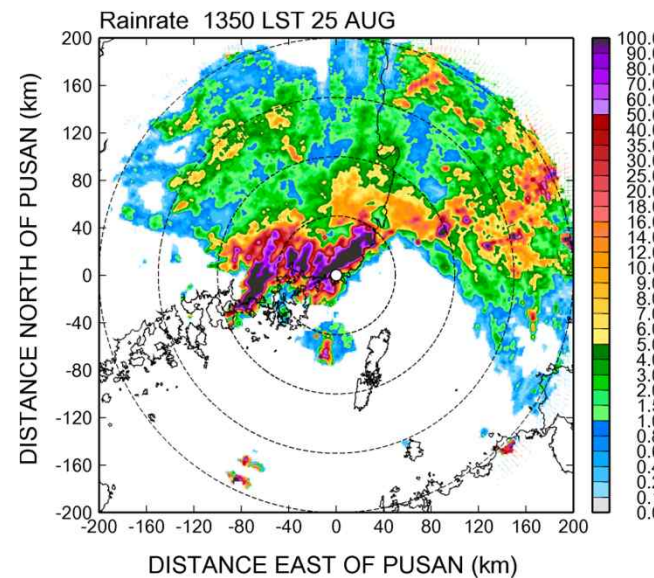
AWS Observations



1:Modified Z-R (68R^{1.27})



21:Modified Z-R (72R^{1.10})

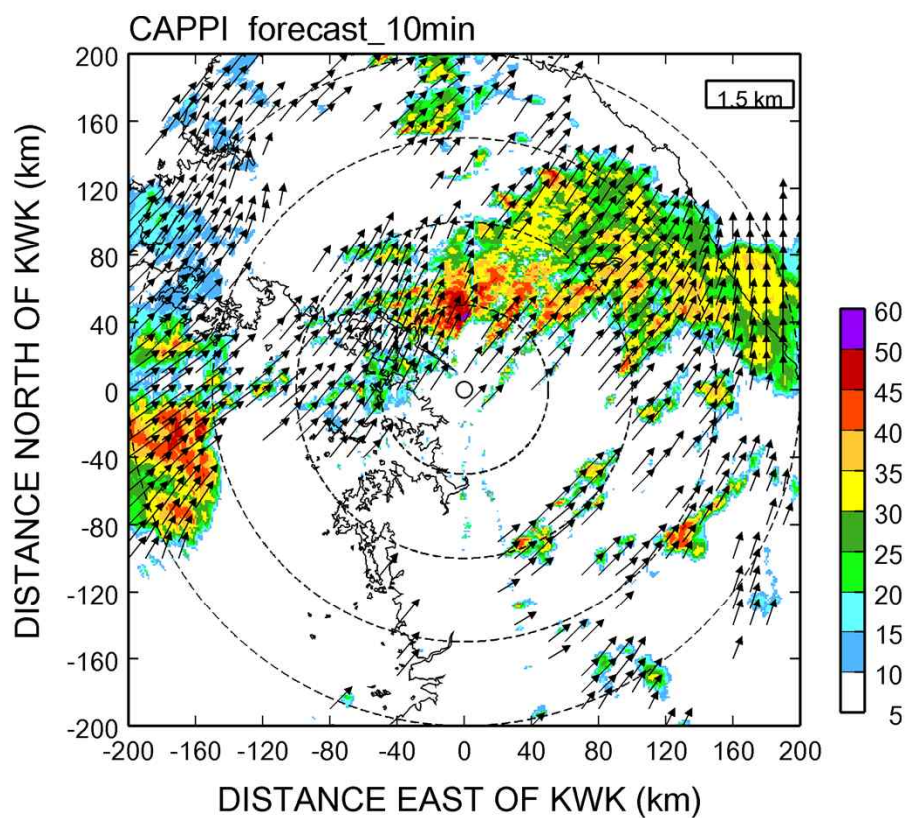


Estimation of QPF

APEC

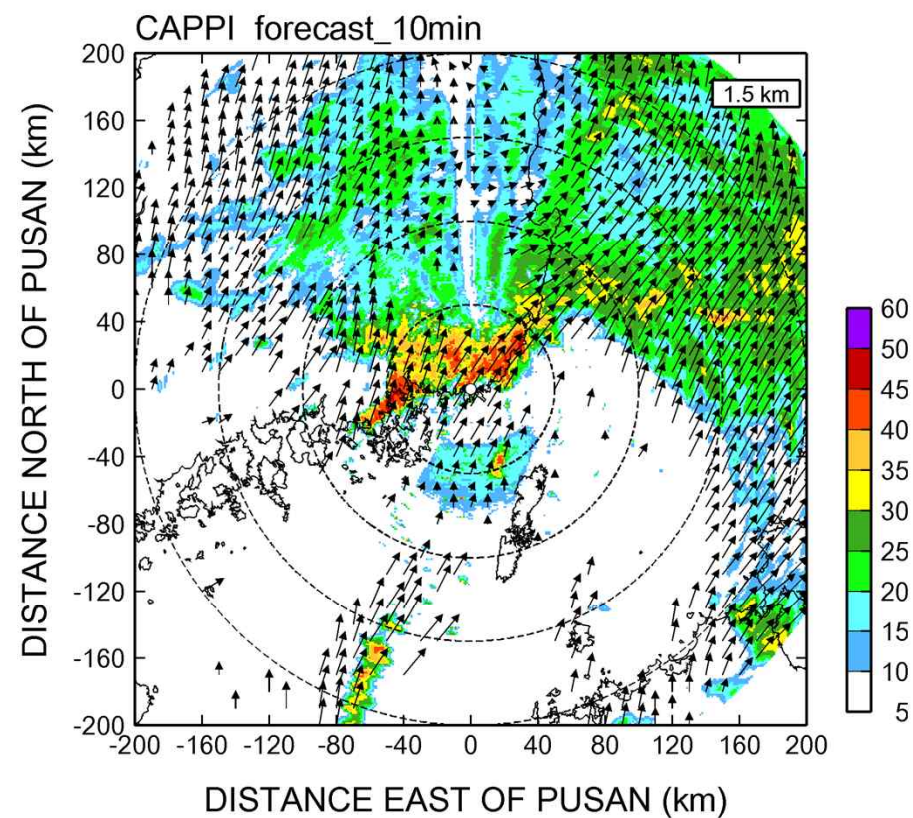
➤ Kwanaksan Radar (SEOUL)

- 2011. 07. 27 rainfall event



➤ Guduksan Radar (BUSAN)

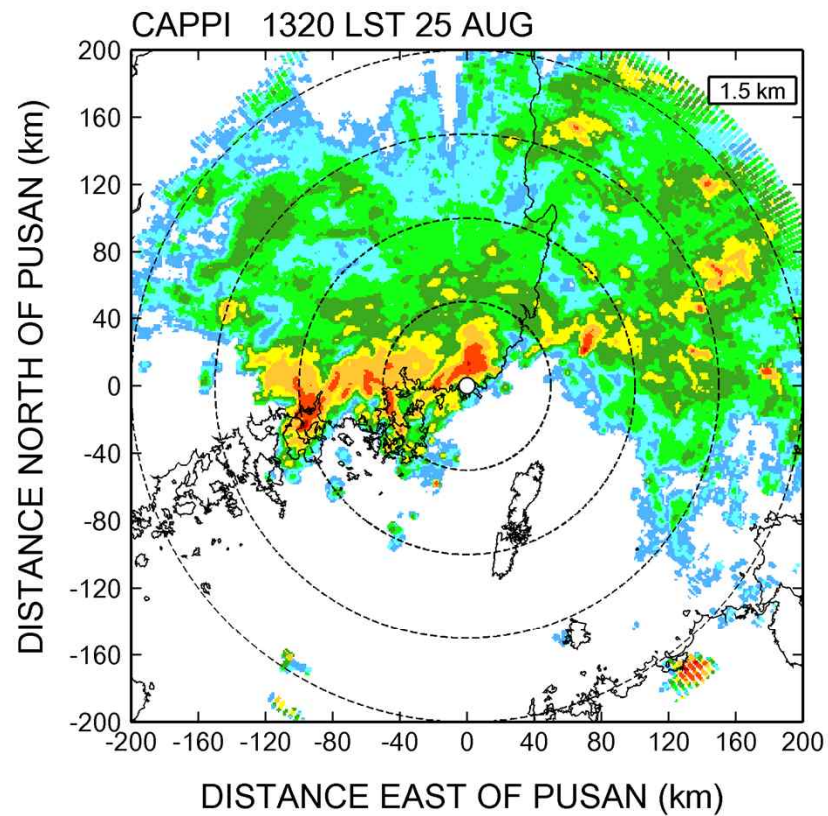
- 2014. 08. 25 rainfall Event



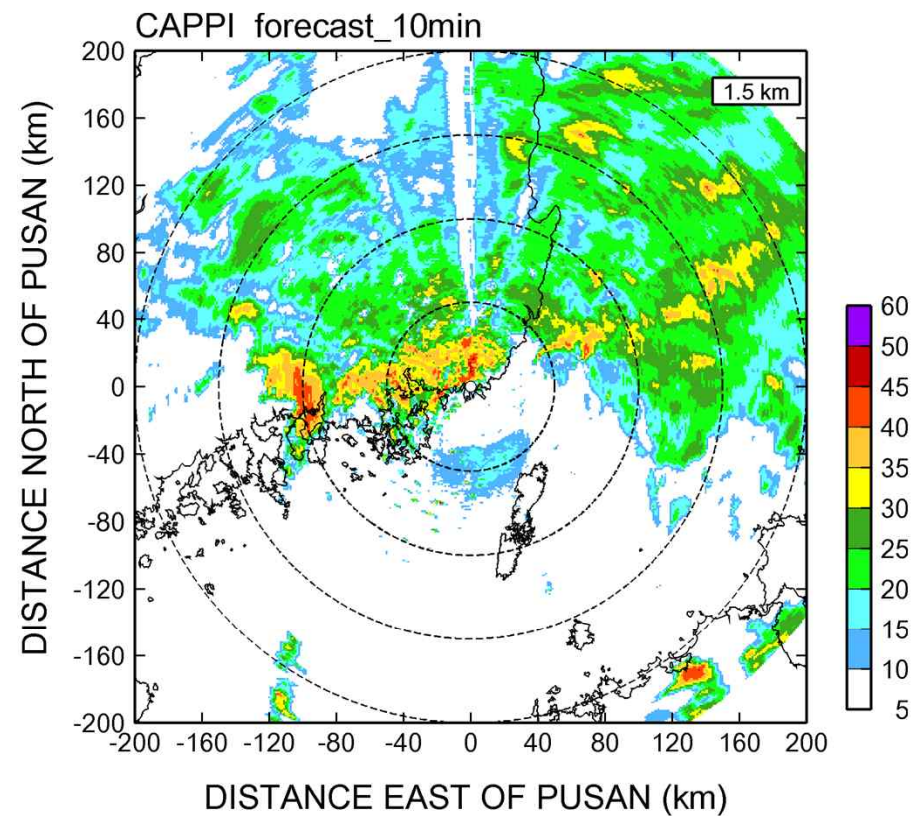
Very Short-term Rainfall Forecasting

APCC

Observed



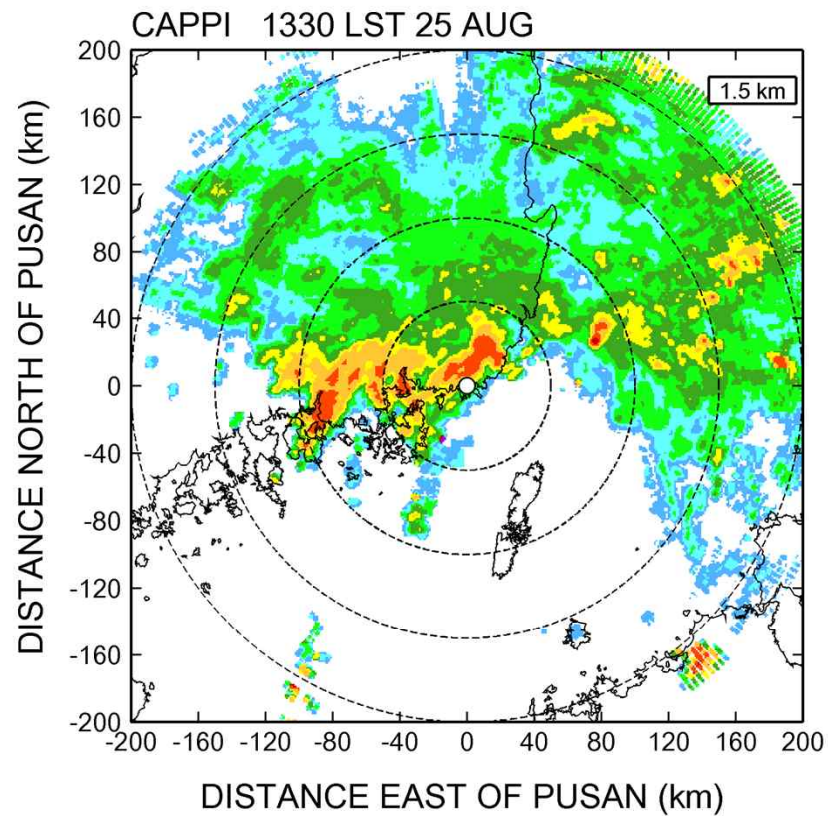
Forecasting



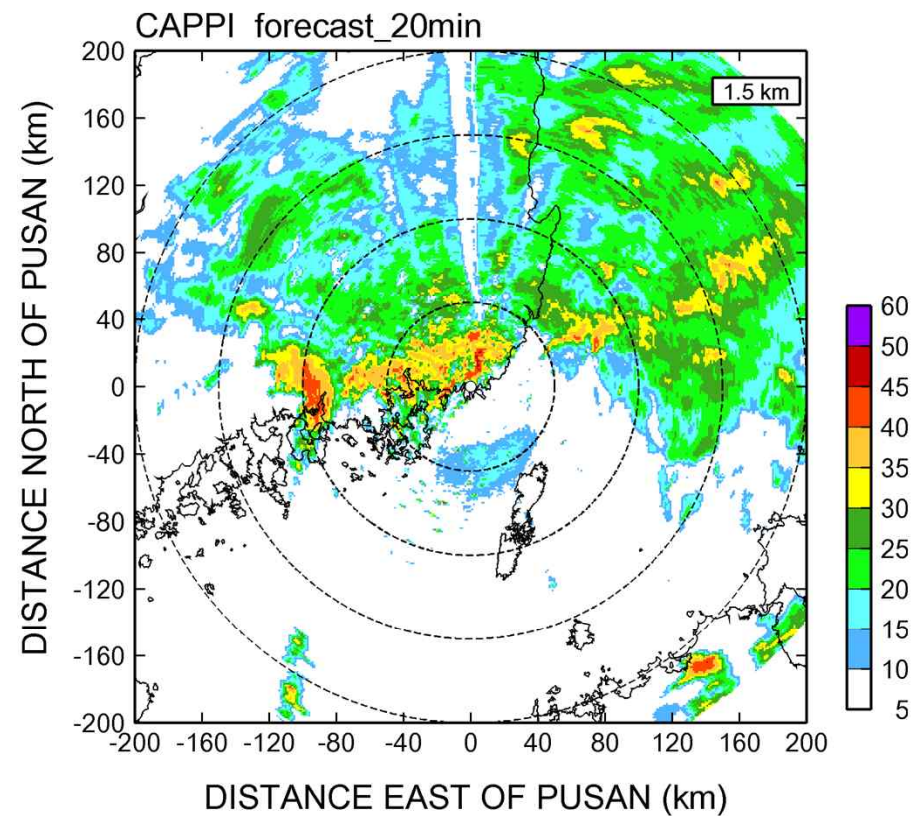
Very Short-term Rainfall Forecasting

APCC

Observed



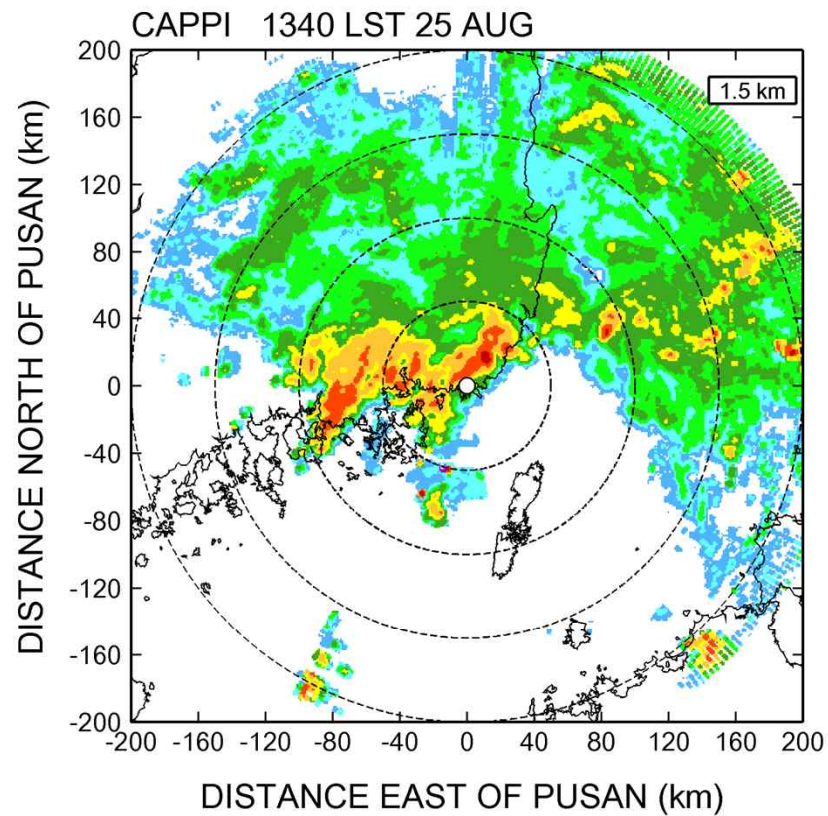
Forecasting



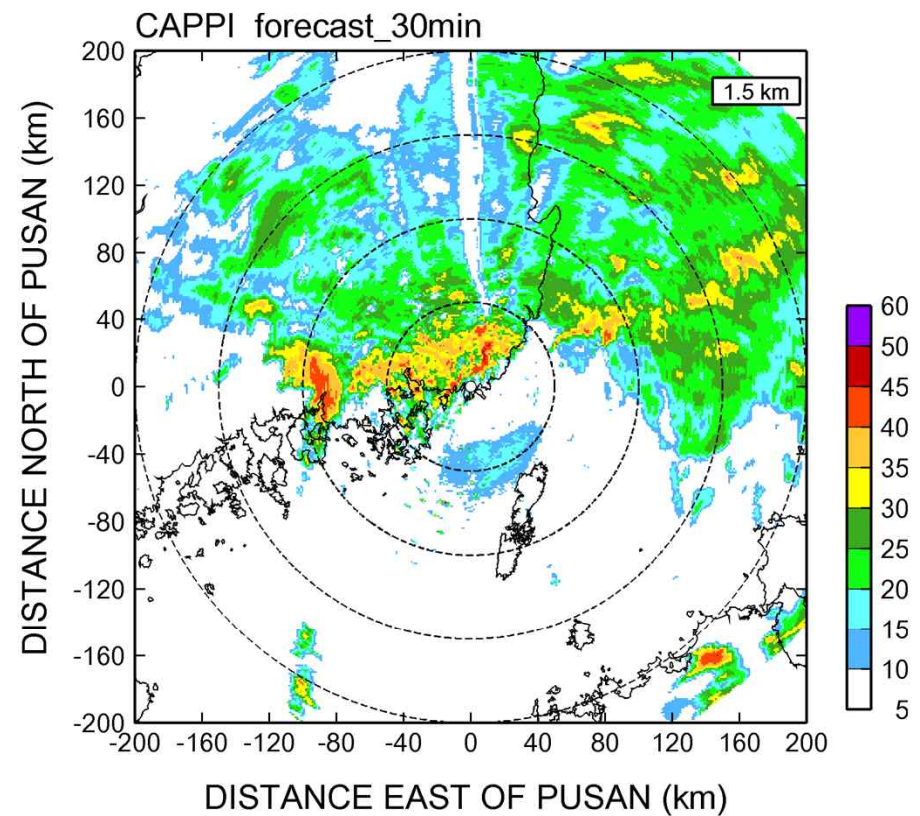
Very Short-term Rainfall Forecasting

APCC

Observed



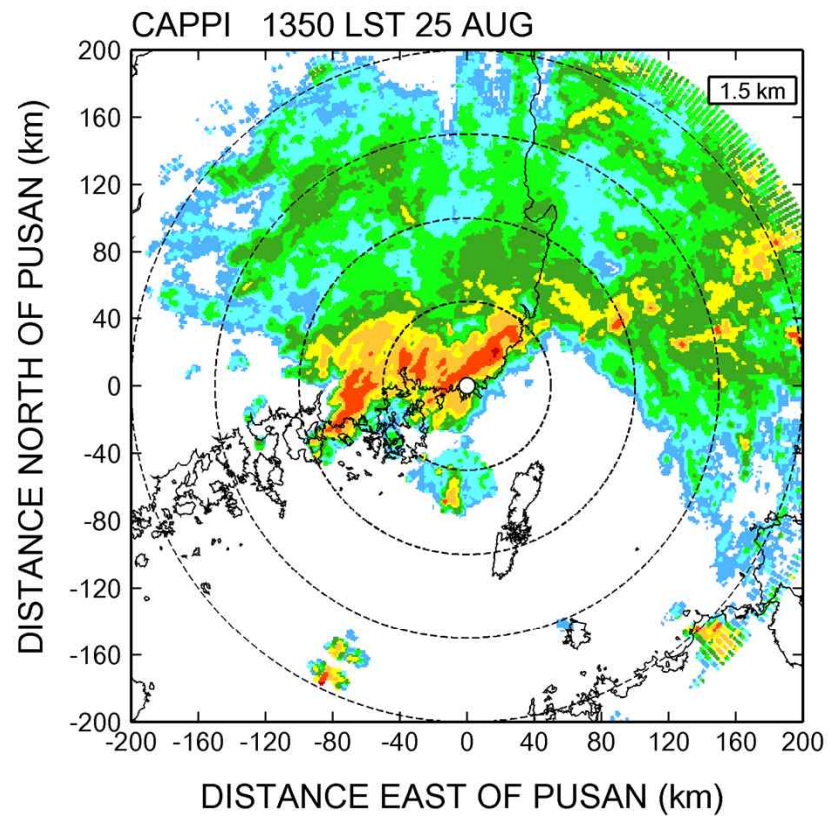
Forecasting



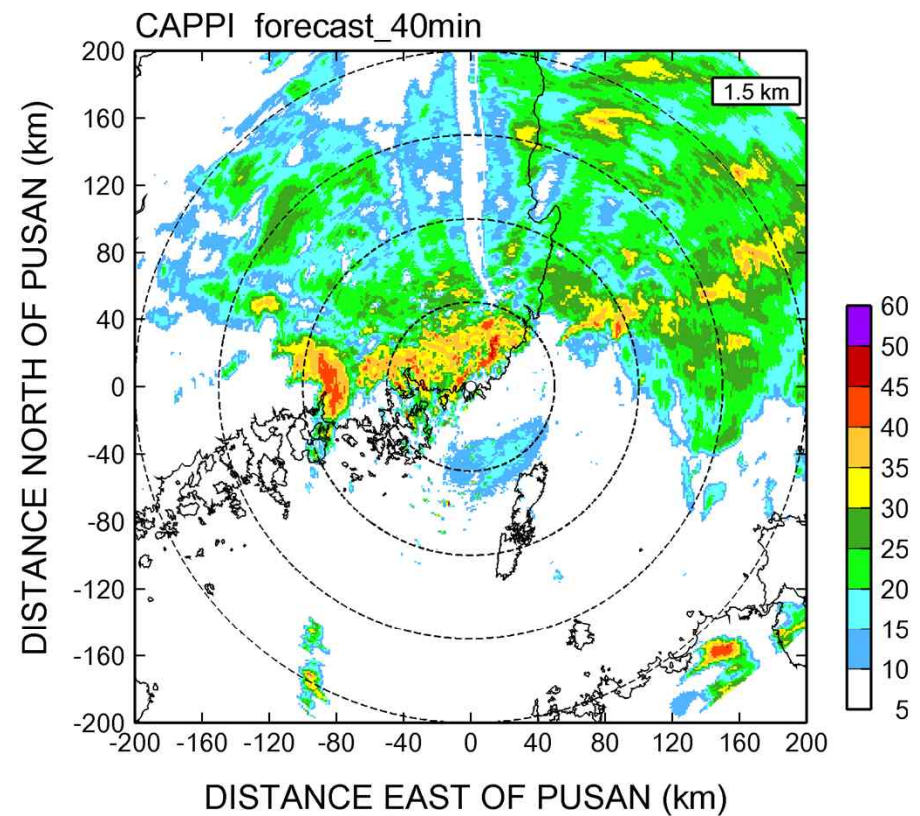
Very Short-term Rainfall Forecasting

APCC

Observed



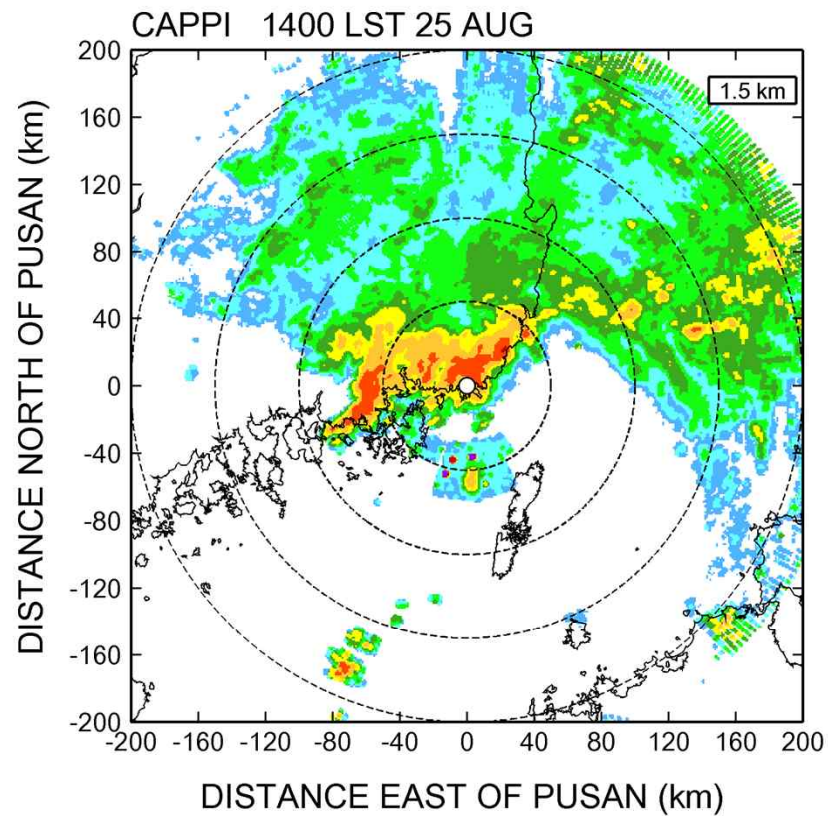
Forecasting



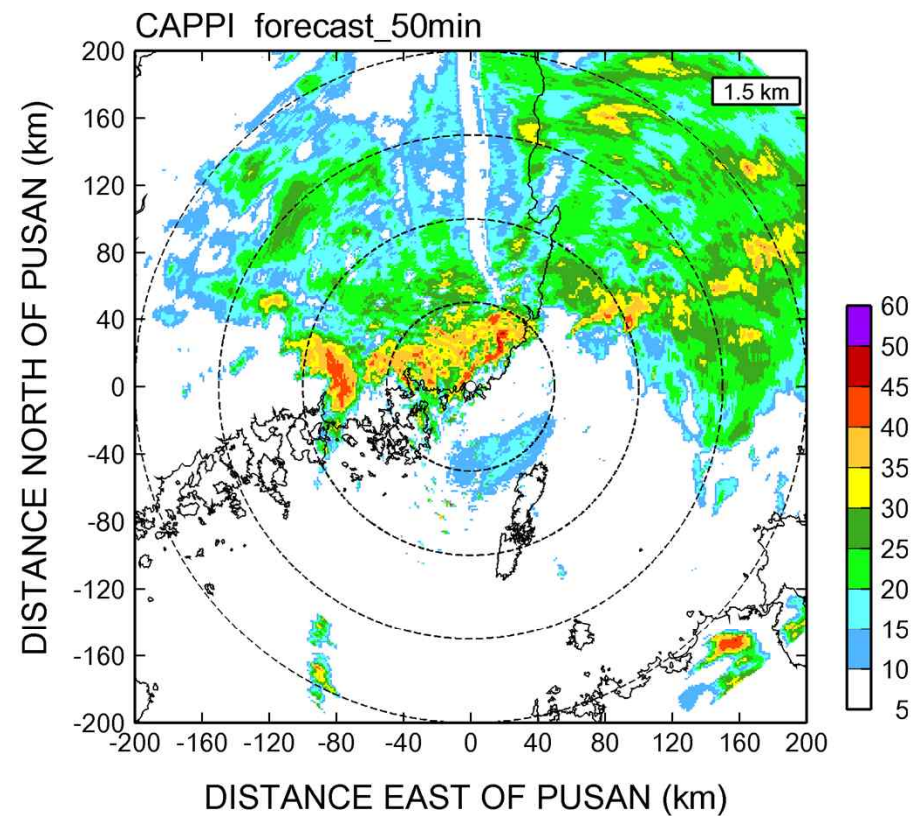
Very Short-term Rainfall Forecasting

APCC

Observed



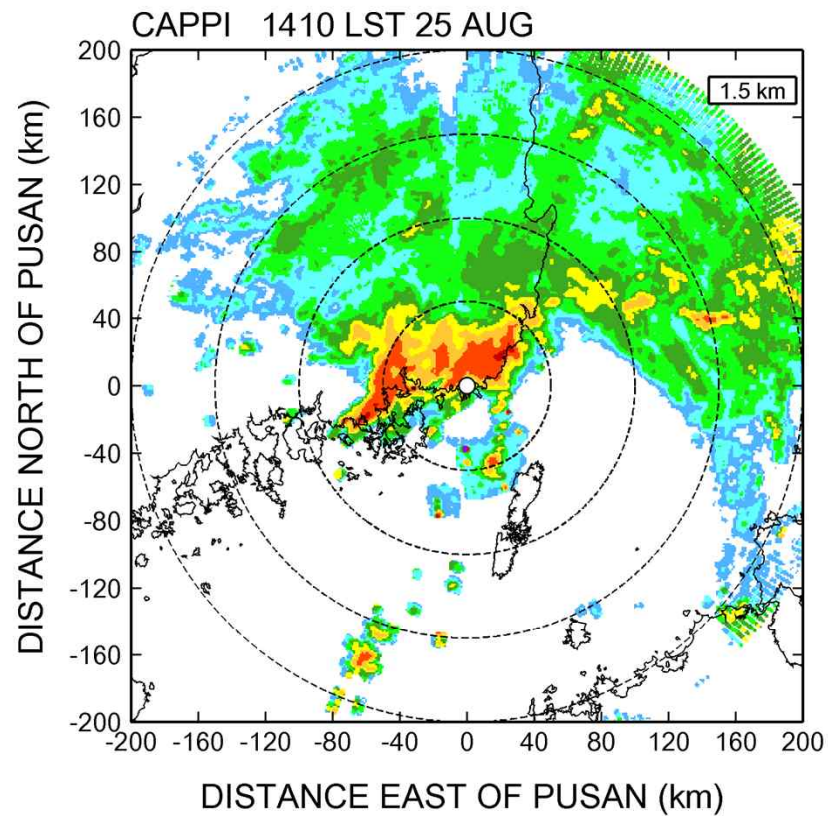
Forecasting



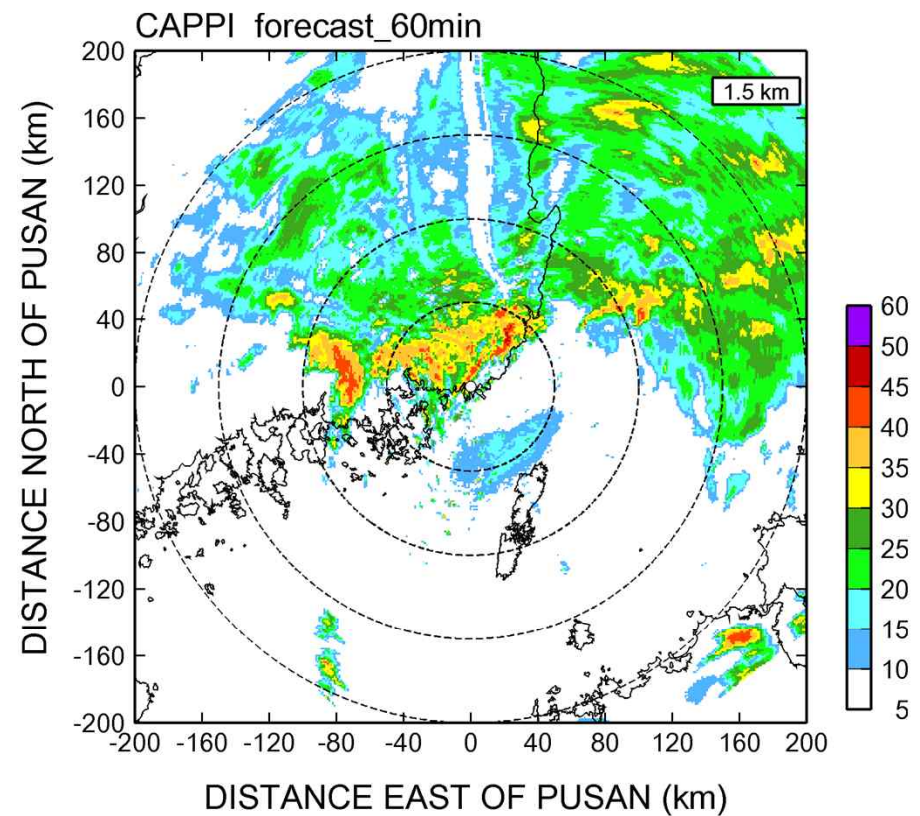
Very Short-term Rainfall Forecasting

APCC

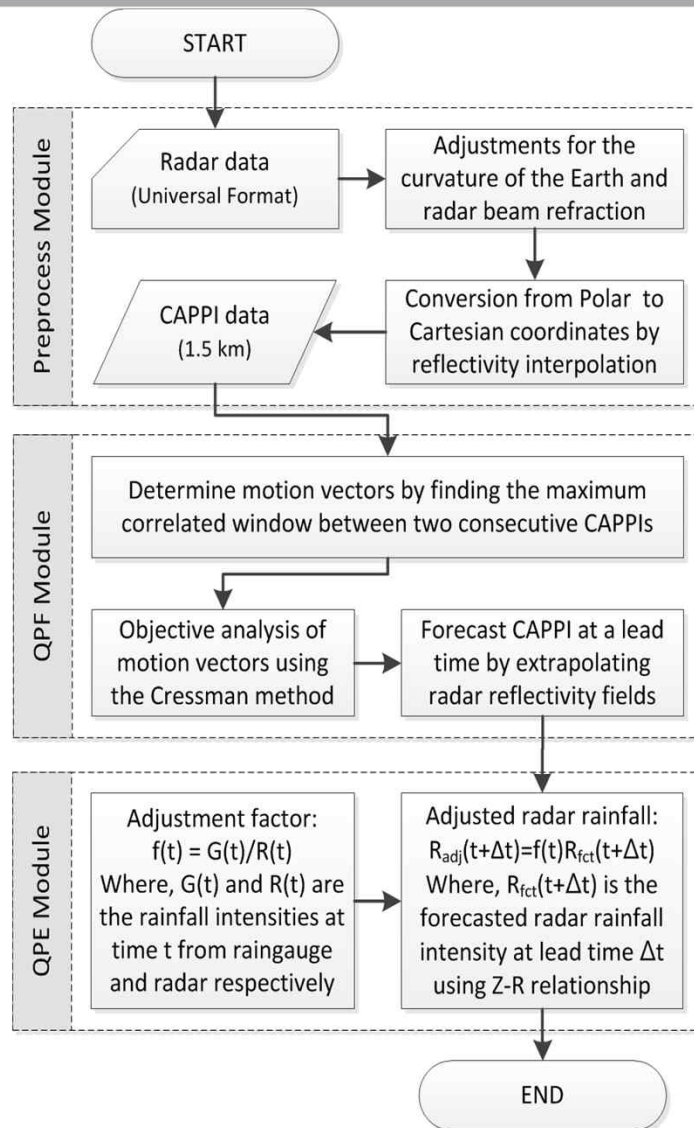
Observed



Forecasting

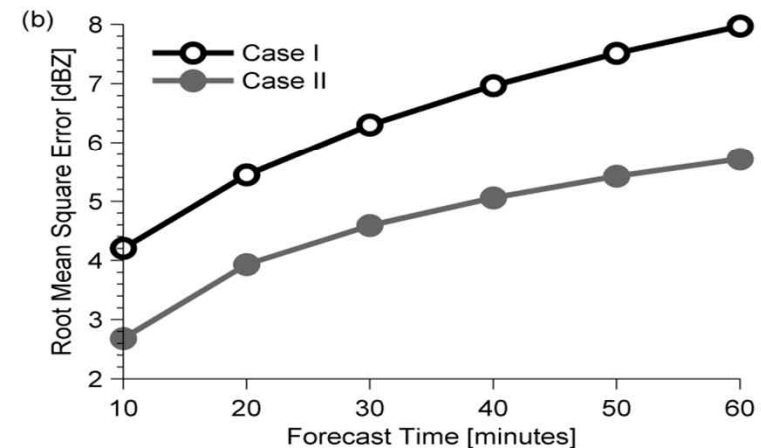
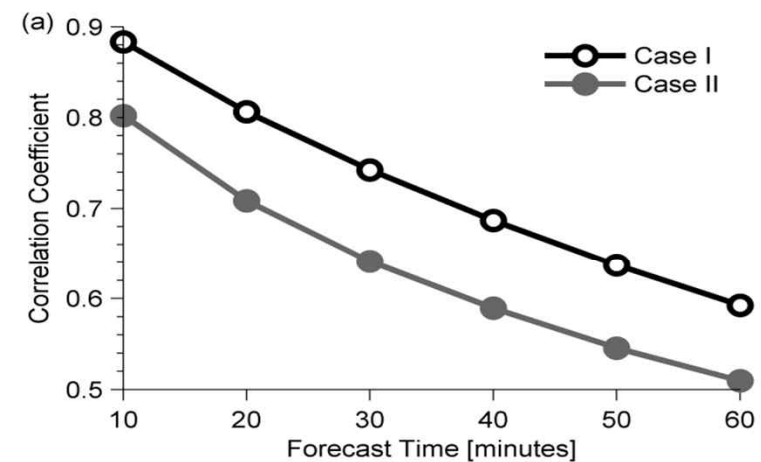


Performance of Rainfall Forecasting



CASE 1 : 2011. 07. 27

CASE 2 : 2012. 07. 05



Future work



From NASA

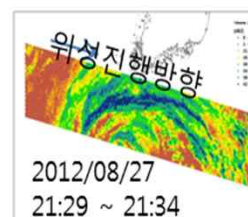
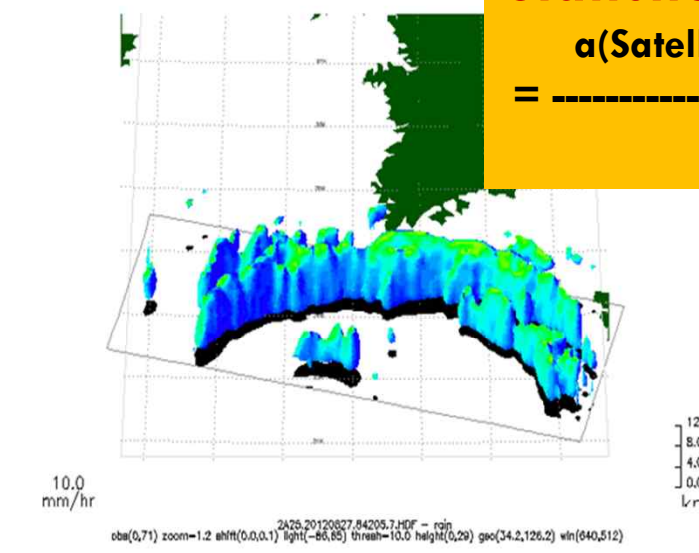
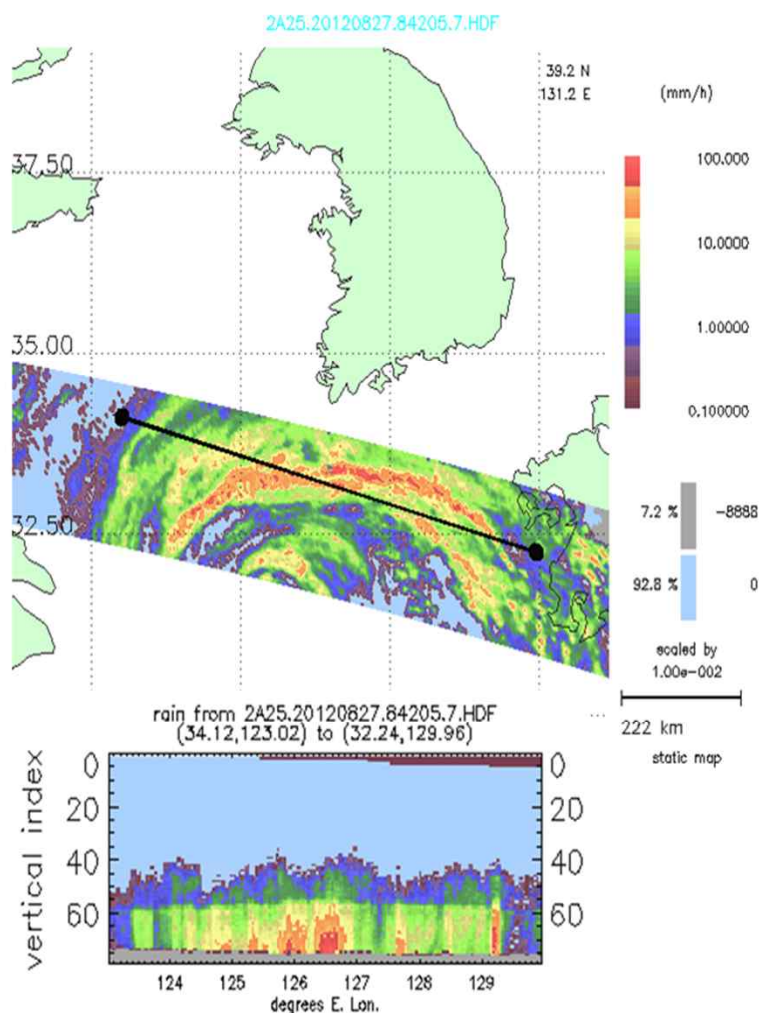
Multi-Sensor Blending (Radar+Satellite)

APCC

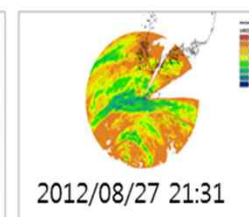
Statistical Blending:

$$a(\text{Satellite}) + b(\text{Radar})$$

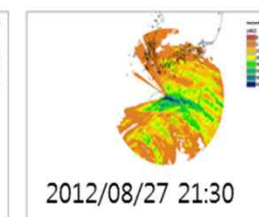
$$= \frac{\quad}{2}$$



TRMM 2A25



고산 레이더 CAPPI

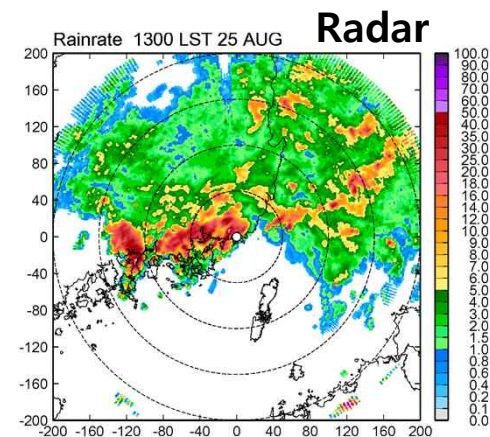
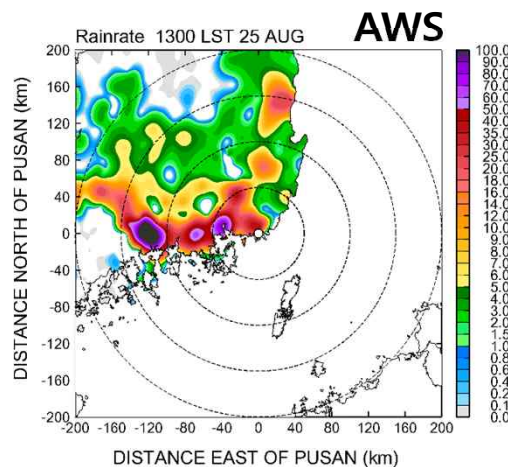
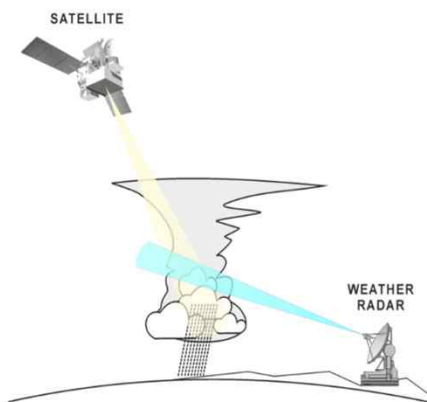


성산 레이더 CAPPI

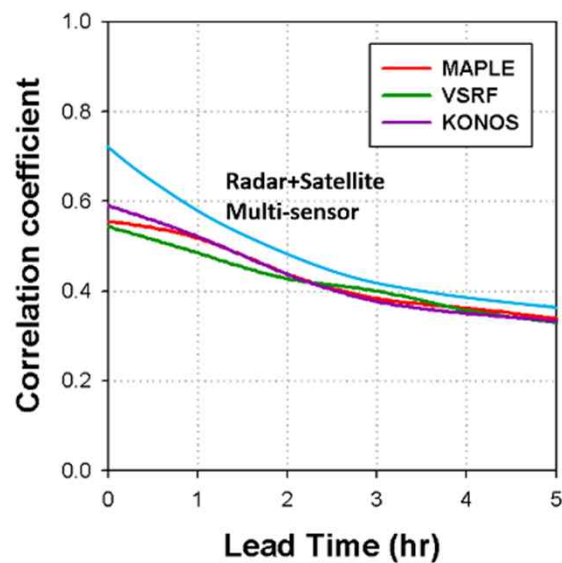
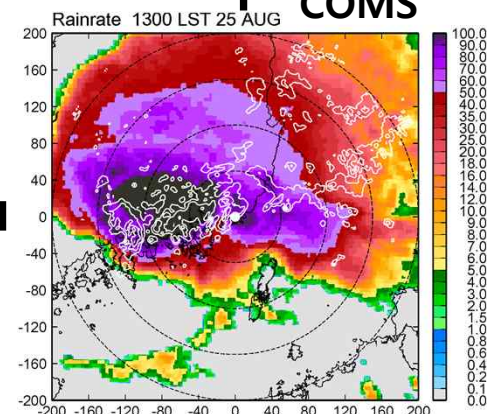
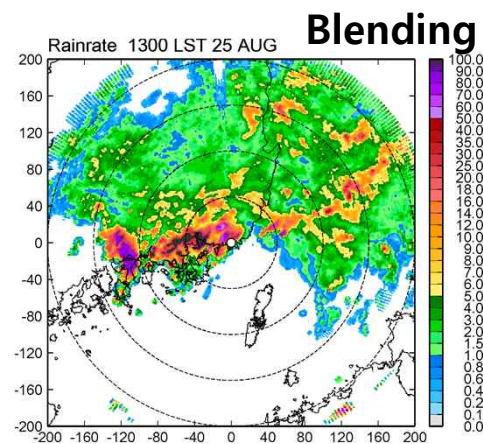
태풍 "볼라벤"의 수직분포

Multi-Sensor Blending (Radar+Satellite)

APCC



+



Himawari 8

APEC

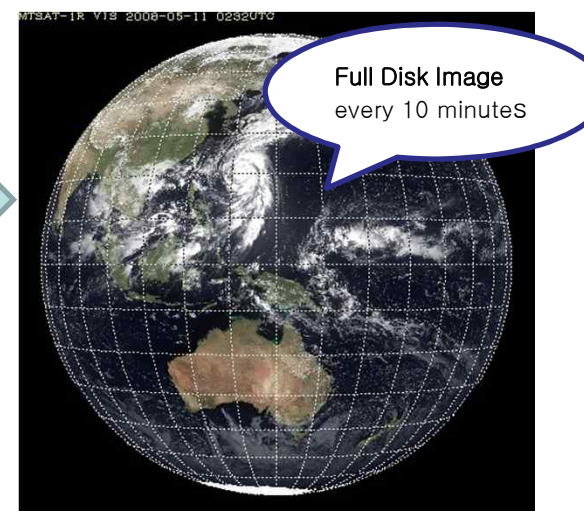


Himawari 8

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	Band	Central Wavelength [μm]	Spatial Resolution	
X	1	0.43 - 0.48	1km	RGB Composited True Color Image
	2	0.50 - 0.52	1km	
X	3	0.63 - 0.66	0.5km	
X	4	0.85 - 0.87	1km	1.3 μm for GOES-R
X	5	1.60 - 1.62	2km	
X	6	2.25 - 2.27	2km	
X	7	3.74 - 3.96	2km	Water Vapour
X	8	6.06 - 6.43	2km	
X	9	6.89 - 7.01	2km	
X	10	7.26 - 7.43	2km	
X	11	8.44 - 8.76	2km	SO ₂
X	12	9.54 - 9.72	2km	O ₃
X	13	10.3 - 10.6	2km	Atmospheric Windows
X	14	11.1 - 11.3	2km	
X	15	12.2 - 12.5	2km	
X	16	13.2 - 13.4	2km	CO ₂

X: ABI

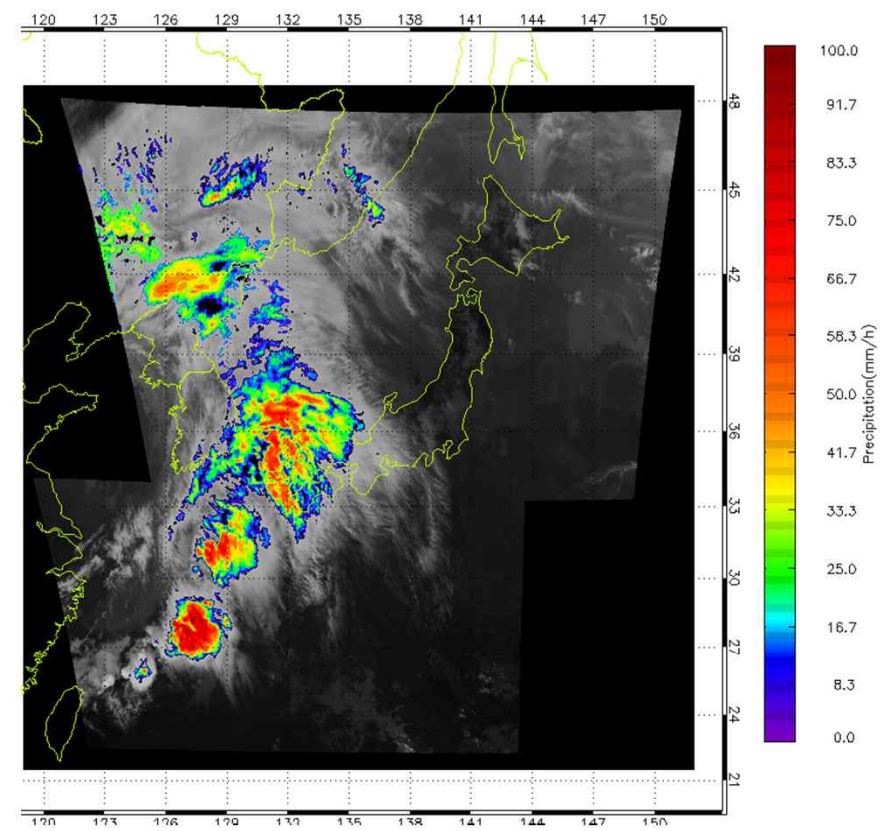
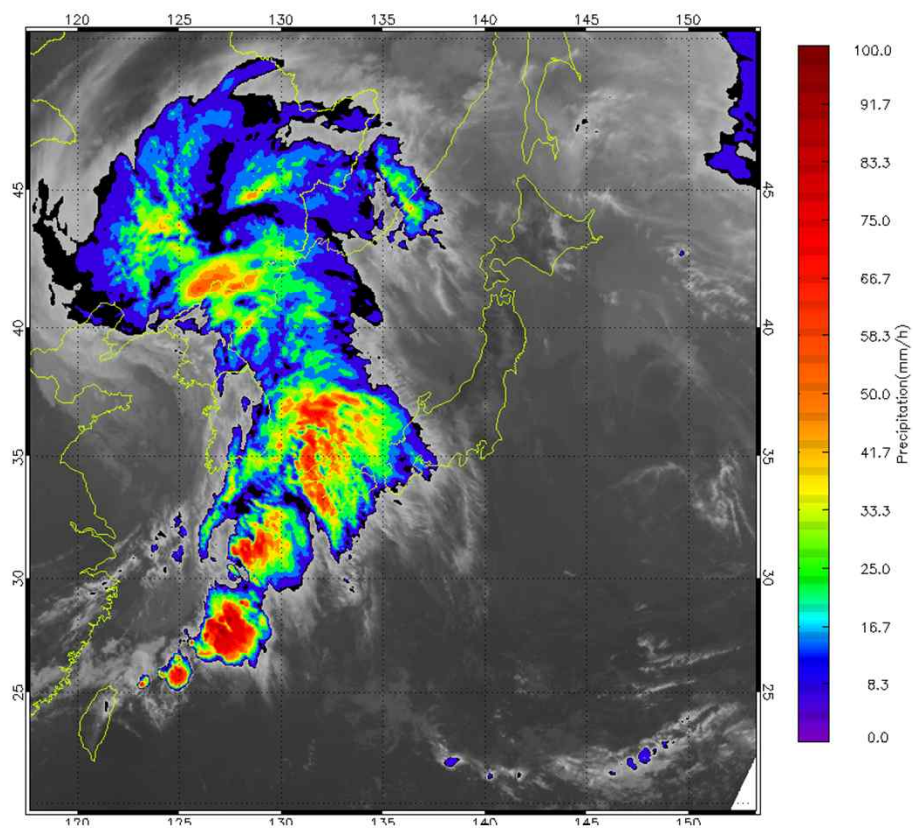


Band	Central Wavelength [μm]	Spatial Resolution
1	0.55 - 0.90	1km
2	3.50 - 4.00	4km
3	6.50 - 7.00	4km
4	10.3 - 11.3	4km
5	11.5 - 12.5	4km

as of MTSAT-1R/2 and COMS

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Conclusions

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- We developed **very short-term** (1-2 hours) **rainfall forecasting system**
- Developing robust techniques in Quantitative Precipitation Estimation (**QPE**) and Quantitative Precipitation Forecasting (**QPF**) by **radar and satellite** data
- We performed statistical **multi-sensor blending** from radar QPE and satellite image QPE dataset.
- The forecast rainfalls are used as input data for **urban runoff simulation** by integrated flood warning system



Thank you

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Fax: +82-51-745-3999
E-mail: skyoon@apcc21.org

APEC Climate Center

Development and Application of 1D-2D fully Coupled Urban Inundation Model for Real-time Forecasting System using Satellite and Radar Data

Seungsoo Lee, APEC Climate Center

2016.10. 5



Introduction

Urban inundation damages...



Residential area



Underground space



Houses inundation



Traffic jam



Huge property damages



Waterborne epidemic

Introduction

Hard Countermeasure		Soft Countermeasure	
• Development flood control facilities • Improvement of river bank • Construction of sewerage system • Construction of permeable layers		• Improvement of disaster information transmission system • Escape guiding system • Numerical analysis • Real-time prediction of inundation	
Advantage	Disadvantage	Advantage	Disadvantage
• Clear effects • Long time for construction	• Huge amount of budget • social conflict	• Relatively low budget • Easy to get results	• Scenario based • Hard to PR

Introduction

➤ What are needed for the **real-time prediction** of urban inundation?

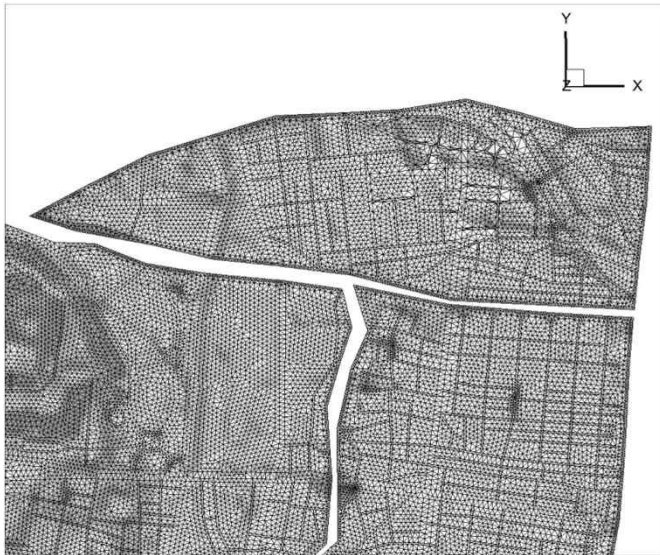
- **Facile** data collection and **Easy** pre-processing
- **Low** calculation load
- **Acceptable** accuracy

➤ To secure high calculation speed and acceptable accuracy....

- Using fine **DEM** data
 - Considering **land use** (building, road, mountain area, park, etc.)
 - Simplified sewer network
 - **Adaptive mesh Refinement Method (ARM)**
 - **Parallel computing**
- } **Accuracy**
- } **Speed**

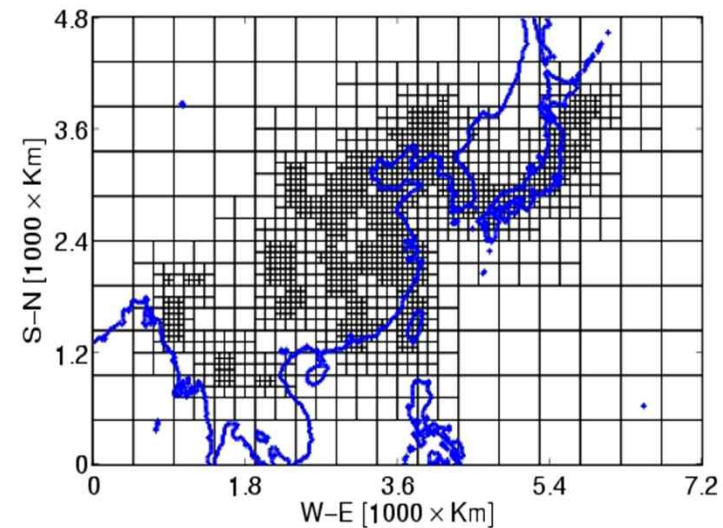
Introduction

➤ Using unstructured mesh



(Osaka area, Lee et al., 2015)

➤ Using fine DEM data with adaptive mesh

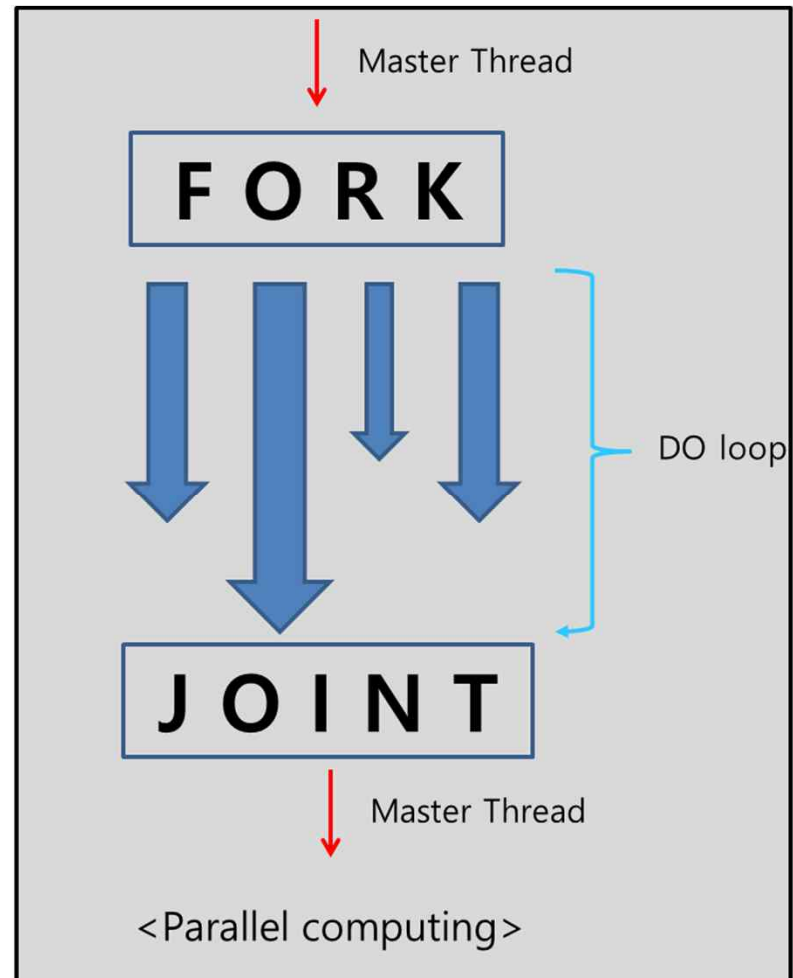
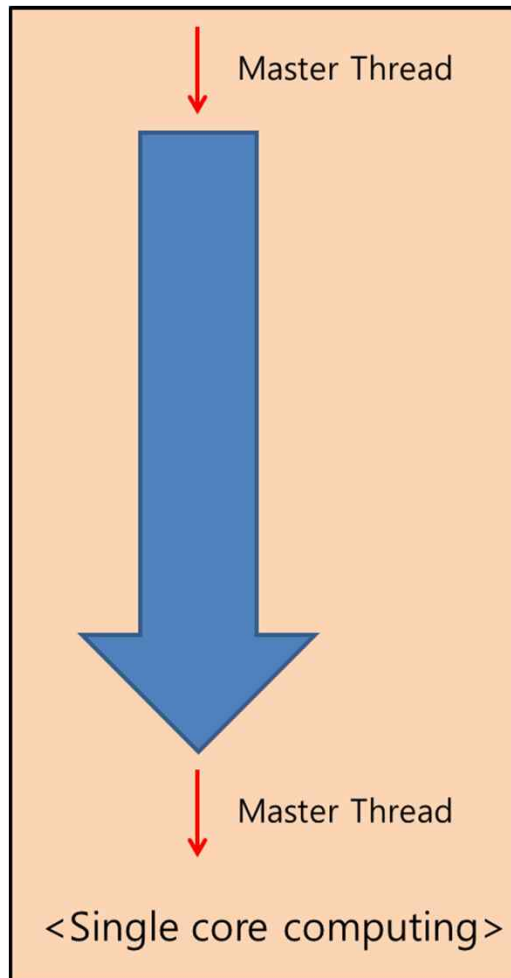


(Source :
http://www.mcs.anl.gov/~emconsta/Pictures/Research/grid_refined.jpg)

Unstructured mesh may guarantee high accuracy result, but generating it is huge **time consuming** works and its accuracy may be depending on modeler's **subjectivity**.

Introduction

➤ Parallel Computing (OpenMP)



Development of 2D ARM model

➤ Governing Equation

$$\frac{\partial h}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = ql$$

$$\frac{\partial M}{\partial t} + \frac{\partial(uM)}{\partial x} + \frac{\partial(vM)}{\partial y} = -gh \frac{\partial H}{\partial x} - \frac{gn^2 M \sqrt{u^2 + v^2}}{h^{4/3}}$$

$$\frac{\partial N}{\partial t} + \frac{\partial(uN)}{\partial x} + \frac{\partial(vN)}{\partial y} = -gh \frac{\partial H}{\partial y} - \frac{gn^2 N \sqrt{u^2 + v^2}}{h^{4/3}}$$

h : water depth (*m*)

H : water elevation (*m*)

u : x-direction water velocity (*m/s*)

v : y-direction water velocity (*m/s*)

M : *uh*(x-direction flux) (*m²/s*)

N : *vh*(y-direction flux) (*m²/s*)

ql : source term (*m/s*)

g : acceleration of gravity (*m²/s*)

n : Manning's roughness coefficient

Development of 2D ARM model

➤ Leap-frog method

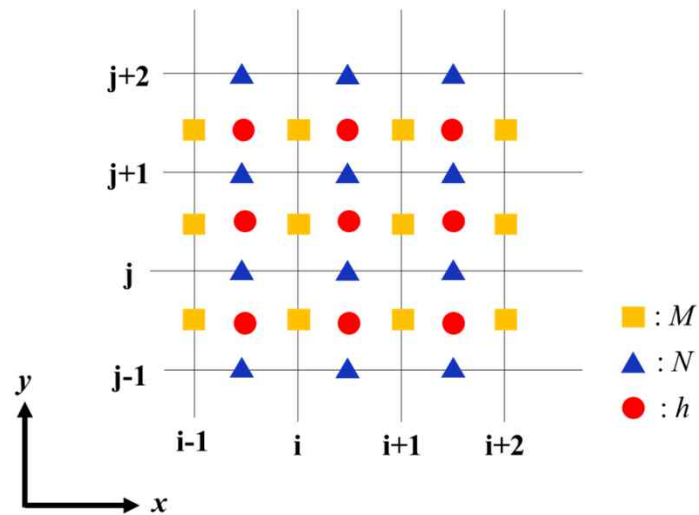


Fig. Location of each variable

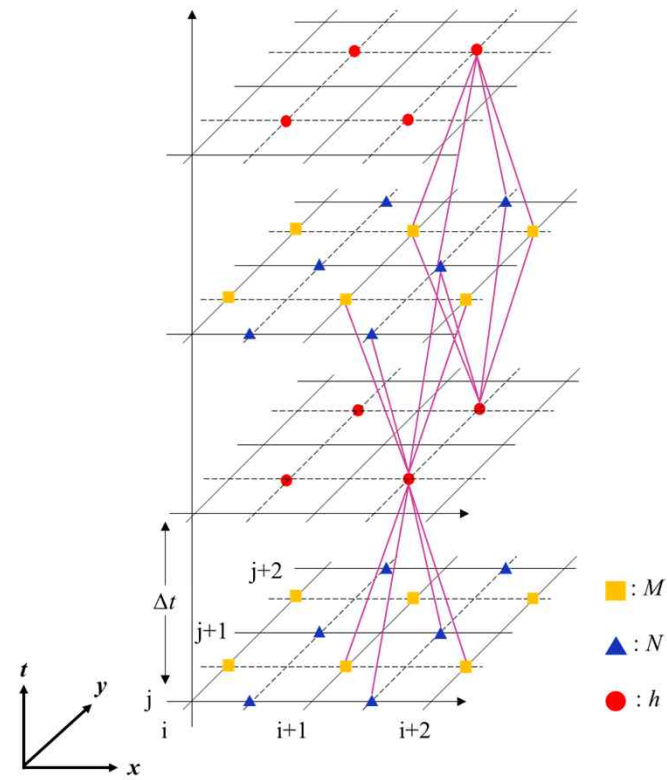


Fig. Concept of Leap-Frog method

Development of 2D ARM model

➤ Discretization method (Homogeneous mesh)

✓ Continuity equation

$$\frac{h_{i+1/2,j+1/2}^{n+3} - h_{i+1/2,j+1/2}^{n+1}}{2\Delta t} + \frac{M_{i+1,j+1/2}^{n+2} - M_{i,j+1/2}^{n+2}}{\Delta x} + \frac{N_{i+1/2,j+1}^{n+2} - N_{i+1/2,j}^{n+2}}{\Delta y} = ql_{i+1/2,j+1/2}^{n+2}$$

✓ X-direction momentum equation

$$\begin{aligned} & \frac{M_{i,j+1/2}^{n+2} - M_{i,j+1/2}^n}{2\Delta t} + convx(x) + convx(y) \\ &= -g \frac{(h_{i-1/2,j+1/2}^{n+1} + h_{i+1/2,j+1/2}^{n+1})(H_{i+1/2,j+1/2}^{n+1} - H_{i-1/2,j+1/2}^{n+1})}{2\Delta x} \\ & - gn_{i,j+1/2}^2 \frac{(M_{i,j+1/2}^n + M_{i,j+1/2}^{n+2})\sqrt{(u_{i,j+1/2}^n)^2 + (v_{i,j+1/2}^n)^2}}{2[(h_{i-1/2,j+1/2}^{n+1} + h_{i+1/2,j+1/2}^{n+1})/2]^{4/3}} \end{aligned}$$

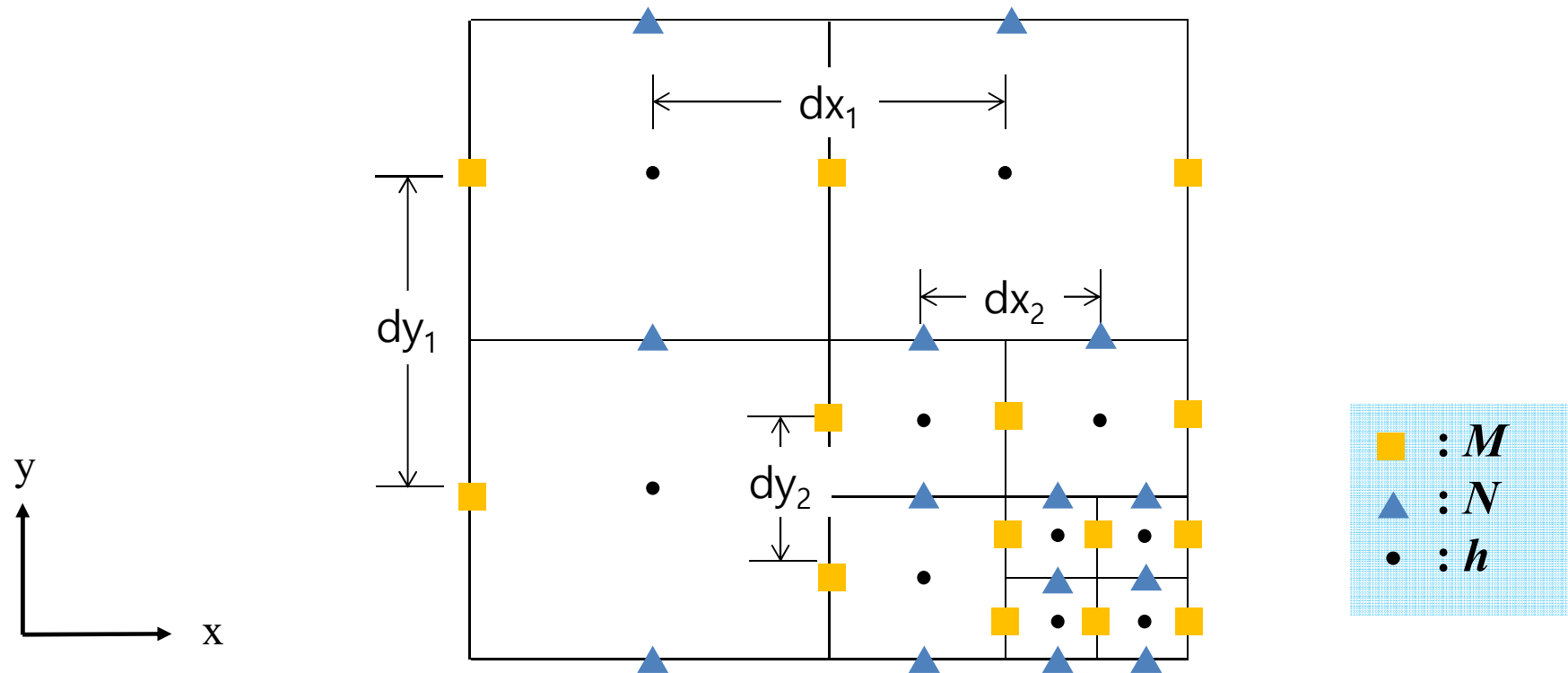
✓ Y-direction momentum equation

$$\begin{aligned} & \frac{N_{i+1/2,j}^{n+2} - N_{i+1/2,j}^n}{2\Delta t} + convy(x) + convy(y) \\ &= -g \frac{(h_{i+1/2,j-1/2}^{n+1} + h_{i+1/2,j+1/2}^{n+1})(H_{i+1/2,j+1/2}^{n+1} - H_{i+1/2,j-1/2}^{n+1})}{2\Delta x} \\ & - gn_{i+1/2,j}^2 \frac{(N_{i+1/2,j}^n + N_{i+1/2,j}^{n+2})\sqrt{(u_{i+1/2,j}^n)^2 + (v_{i+1/2,j}^n)^2}}{2[(h_{i+1/2,j-1/2}^{n+1} + h_{i+1/2,j+1/2}^{n+1})/2]^{4/3}} \end{aligned}$$

Where, $convx(x)$, $convx(y)$: x-direction convection terms
 $convy(x)$, $convy(y)$: y-direction convection terms

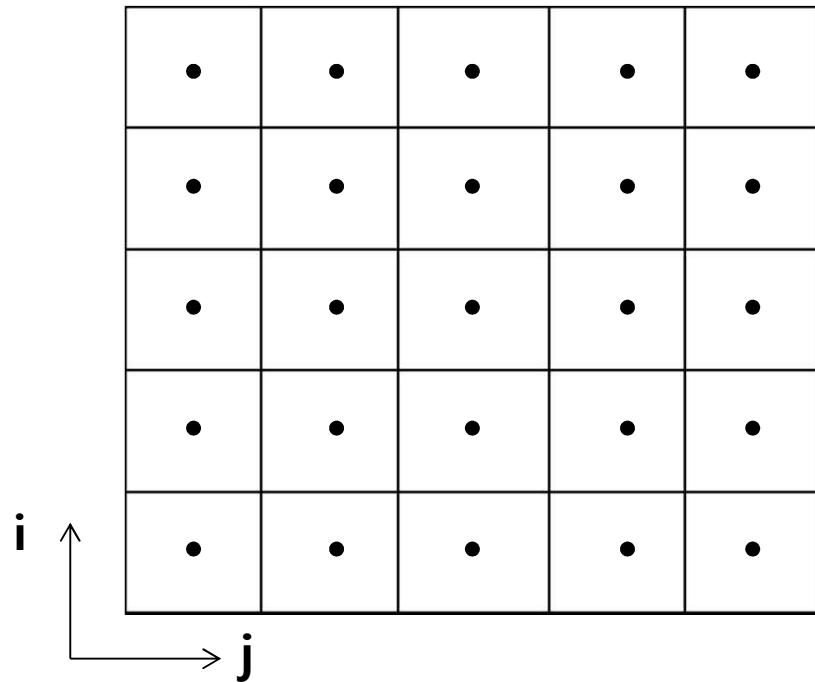
Development of 2D ARM model

➤ Using fine DEM data with ARM

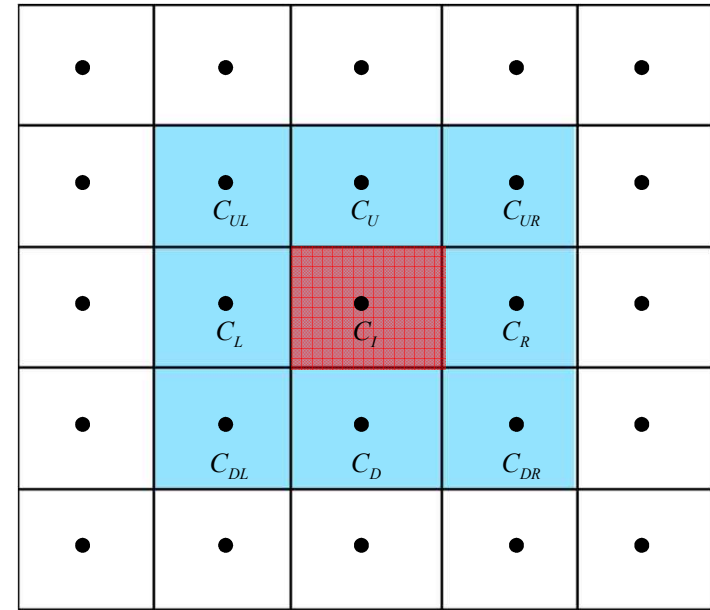


Saving calculation load, easy to depict complex topography

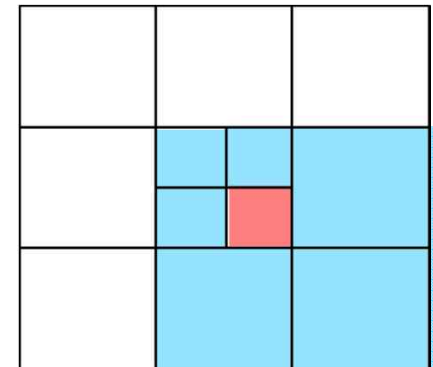
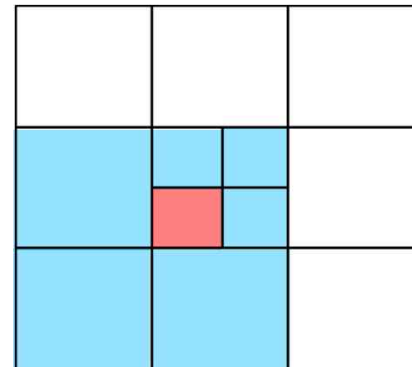
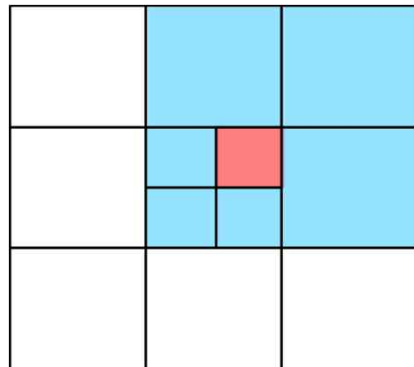
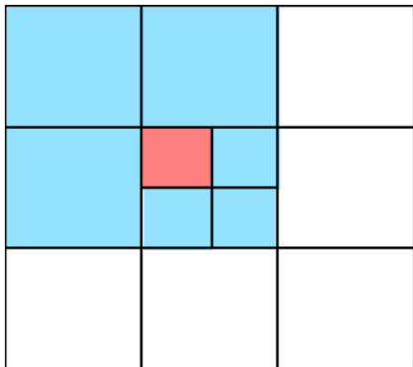
Development of 2D ARM model



<Homogeneous mesh>



<Non-homogeneous mesh>



Development of 2D ARM model

➤ Discretization method (Non-homogeneous mesh)

✓ Continuity equation

$$\frac{h_{C_I}^{n+3} - h_{C_I}^{n+1}}{2\Delta t} + \frac{M_{C_R}^{n+2} - M_{C_I}^{n+2}}{\Delta x} + \frac{N_{C_U}^{n+2} - N_{C_I}^{n+2}}{\Delta y} = ql_{C_I}^{n+2}$$

✓ X-direction momentum equation

$$\begin{aligned} & \frac{M_{C_I}^{n+2} - M_{C_I}^n}{2\Delta t} + convx(x) + convx(y) \\ &= -g \frac{(h_{C_I}^{n+1} + h_{C_L}^{n+1})(H_{C_I}^{n+1} - H_{C_L}^{n+1})}{2\Delta x} \\ & \quad - gn_{C_I}^2 \frac{(M_{C_I}^n + M_{C_I}^{n+2})\sqrt{(u_{C_I}^n)^2 + (v_{C_I}^n)^2}}{2[(h_{C_L}^{n+1} + h_{C_I}^{n+1})/2]^{4/3}} \end{aligned}$$

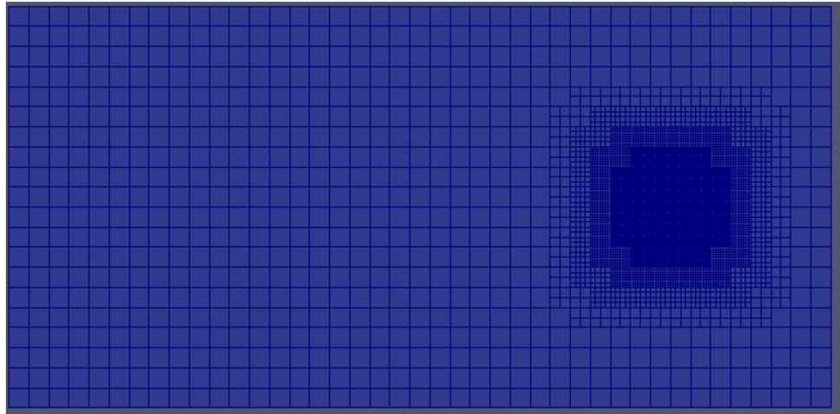
✓ Y-direction momentum equation

$$\begin{aligned} & \frac{N_{C_I}^{n+2} - N_{C_I}^n}{2\Delta t} + convy(x) + convy(y) \\ &= -g \frac{(h_{C_I}^{n+1} + h_{C_D}^{n+1})(H_{C_I}^{n+1} - H_{C_D}^{n+1})}{2\Delta x} \\ & \quad - gn_{C_I}^2 \frac{(N_{C_I}^n + N_{C_I}^{n+2})\sqrt{(u_{C_I}^n)^2 + (v_{C_I}^n)^2}}{2[(h_{C_D}^{n+1} + h_{C_I}^{n+1})/2]^{4/3}} \end{aligned}$$

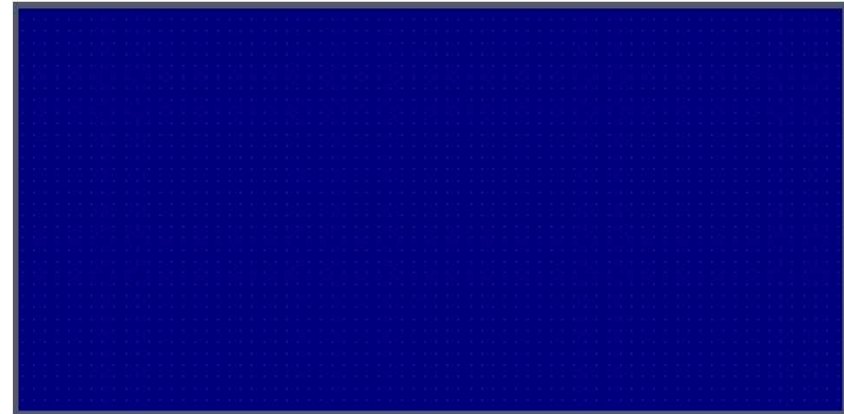
Where, $convx(x)$, $convx(y)$: x-direction convection terms
 $convy(x)$, $convy(y)$: y-direction convection terms

Test and Comparison

➤ Conditions



<ARM >



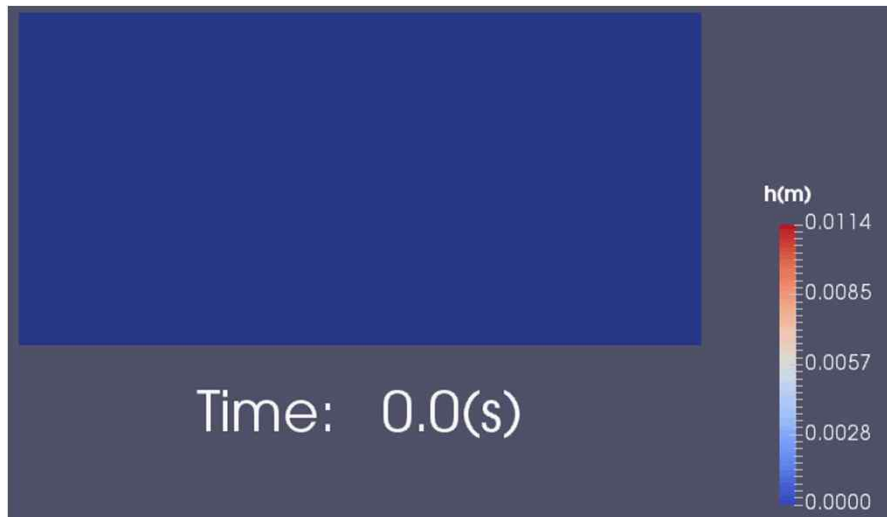
<Homogeneous mesh>

- Length : 8.2m
- Width : 4.0m
- Slope : 0.001
- Roughness : 0.011
- Inflow : $0.004m^3/s$
- Downstream depth : $0.006m$

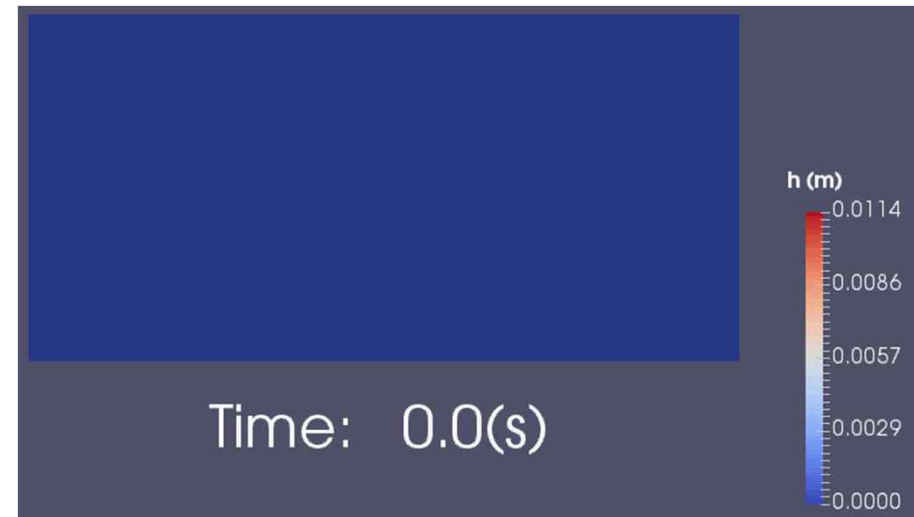
- Coarsest mesh size : 0.2m
- Finest mesh size : 0.0125m
- Max refine level : 4th
- $dt = 0.002(s)$
- Total calculation : 180 sec

Test and Comparison

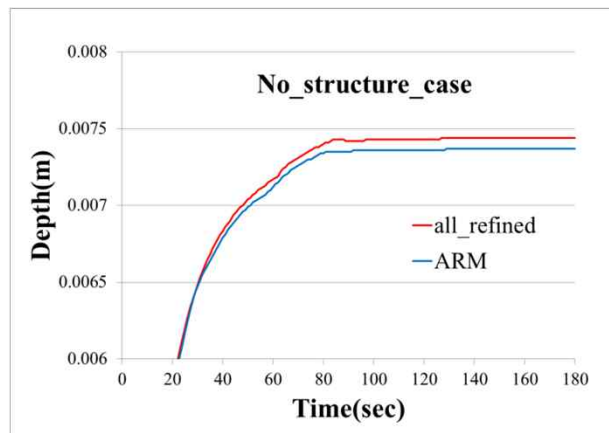
➤ no structure cases



<ARM>



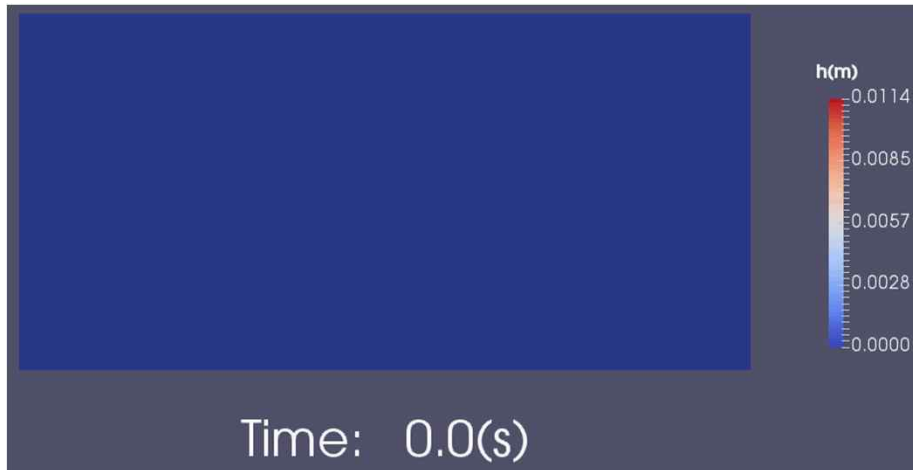
<Homogeneous mesh>



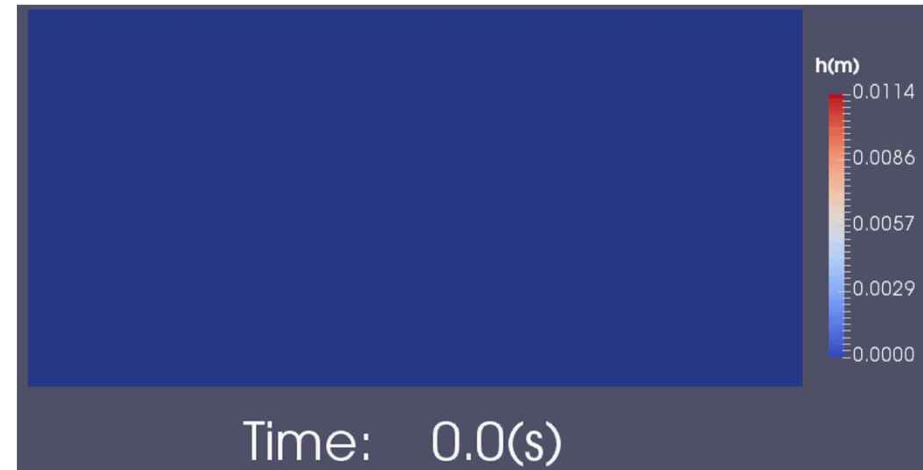
- ✓ Although all_refined case shows higher water depth than ARM case the dis is less than **the criteria** (0.001m) for modelling

Test and Comparison

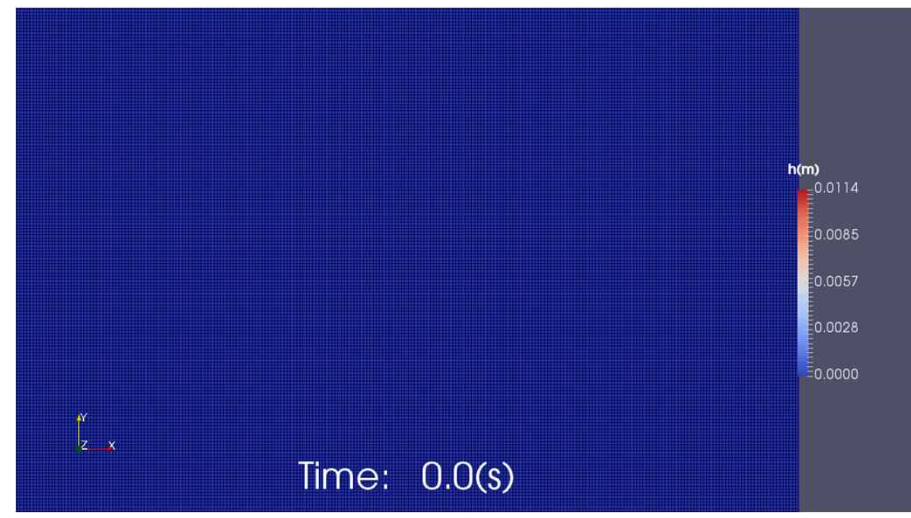
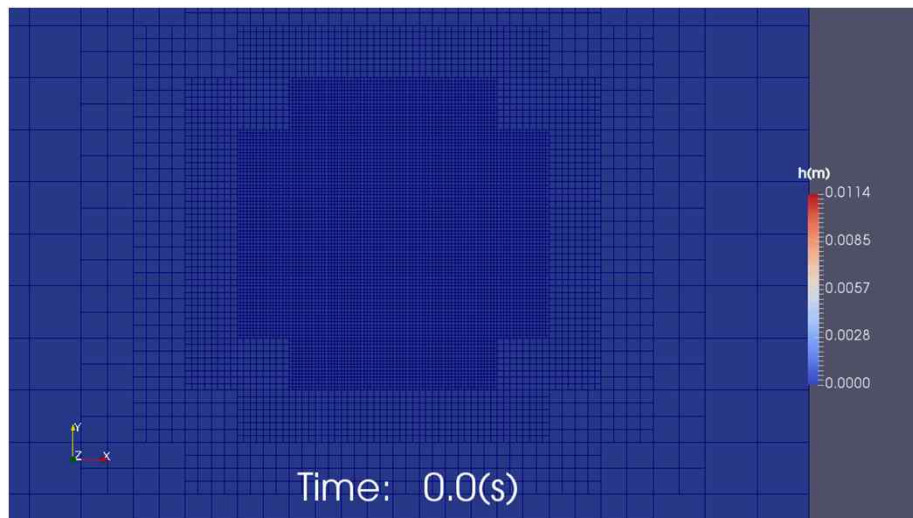
➤ structure cases



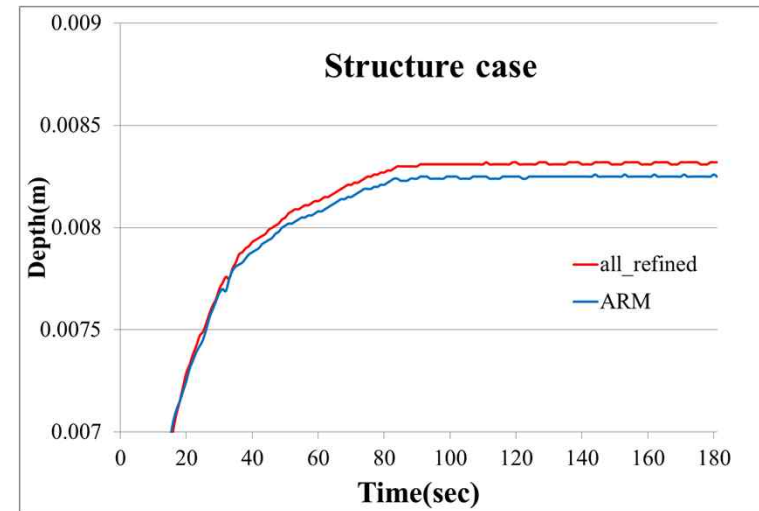
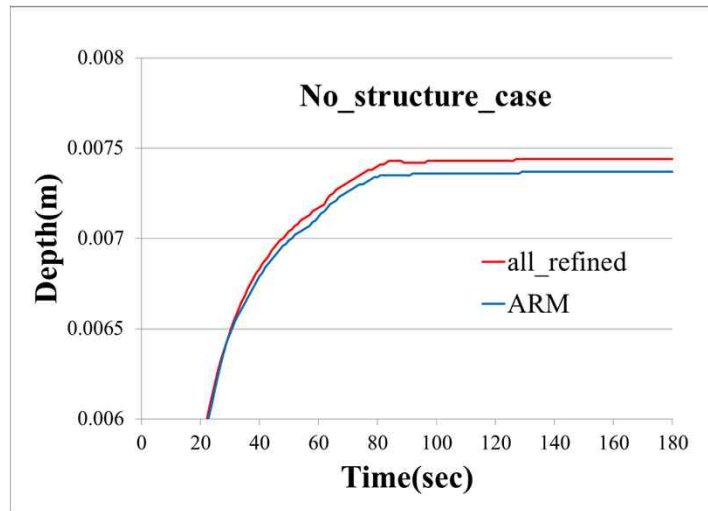
<ARM>



<Homogeneous mesh>



Test Results



Index	All refined mesh	ARM	Ratio (all refined / ARM)
No. of Meshes	209,920	11,416	18.4
Running time (sec)	4,687	235	19.9
Output file (mb)	44.7	2.4	18.6

✓ Calculation time did not consider writing time of output files

✓ **ARM model** is able to save huge amount of saving **data capacity** as well as **running time**.

Application

➤ Flood damages(2014.08.25)



<Market area>



<Street area>



<Entrance of subway>



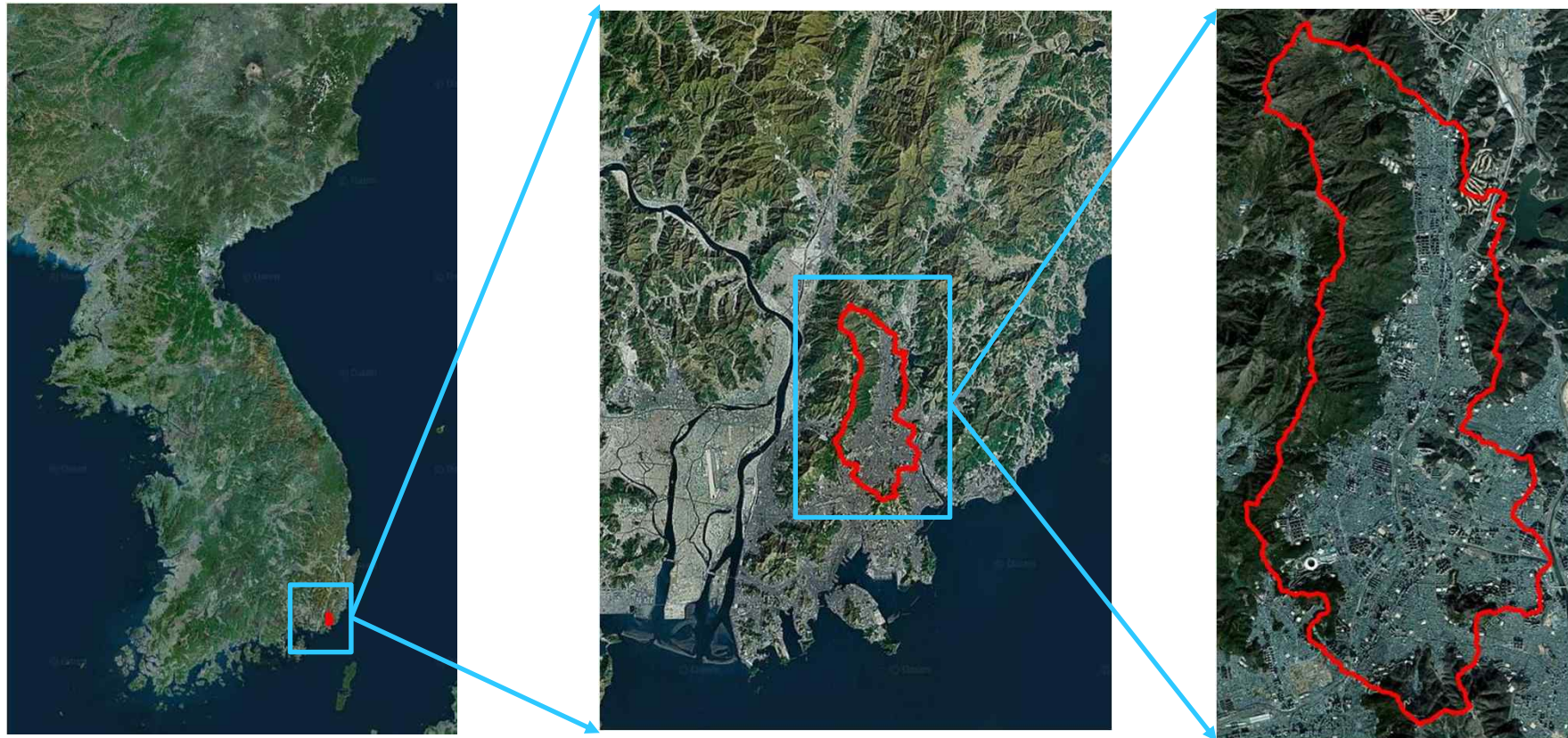
<Parking area>



<Road collapse>

Application

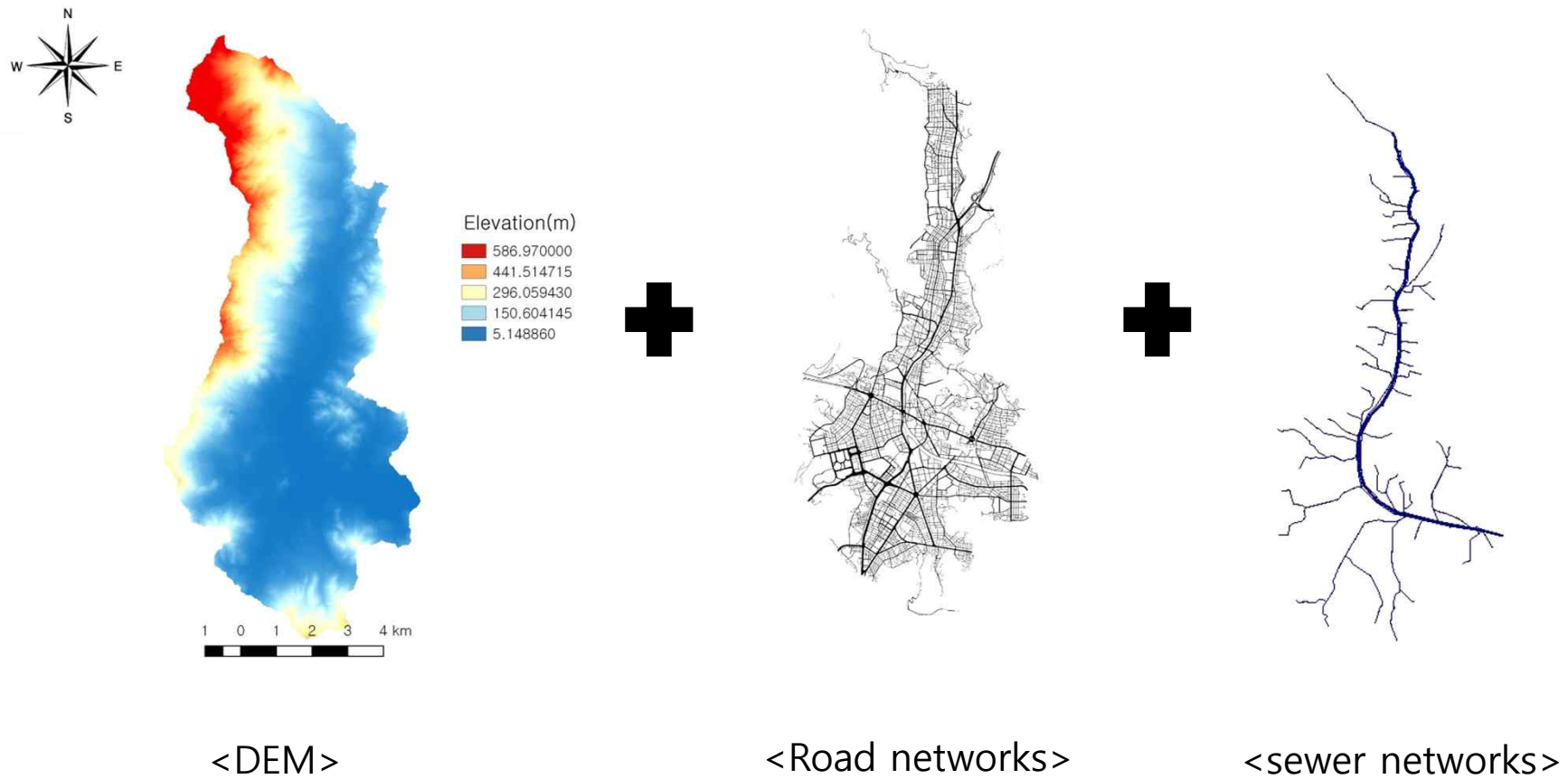
➤ Study basin



Oncheon-cheon basin is out target area where severe urban inundation had been occurred.

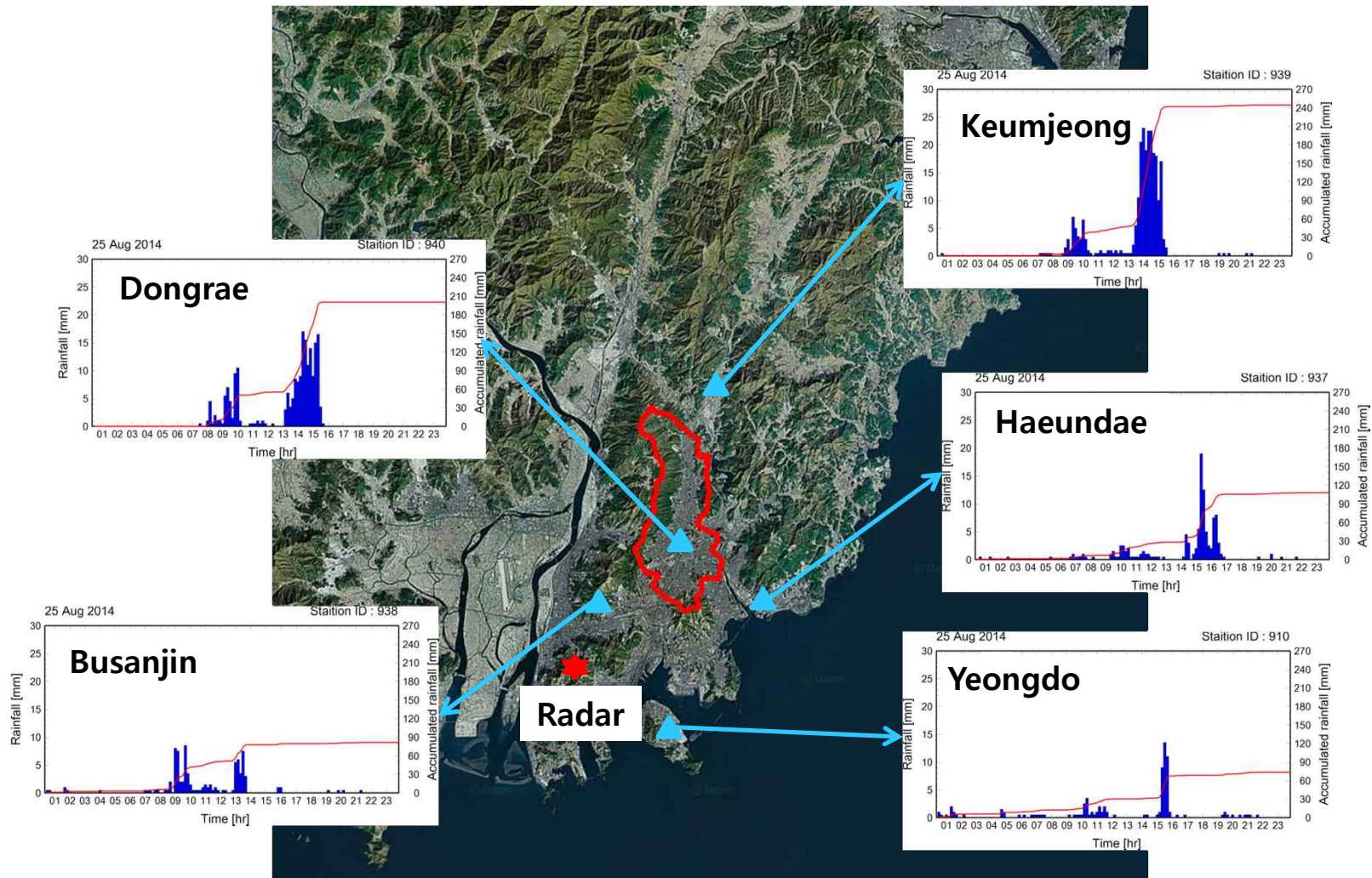
Application

➤ Model input data



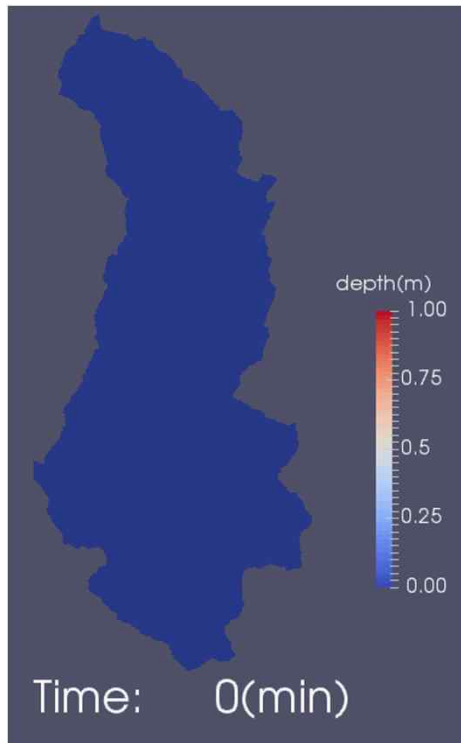
Application

➤ Recorded rainfall data (AWS, 2014.8.25)

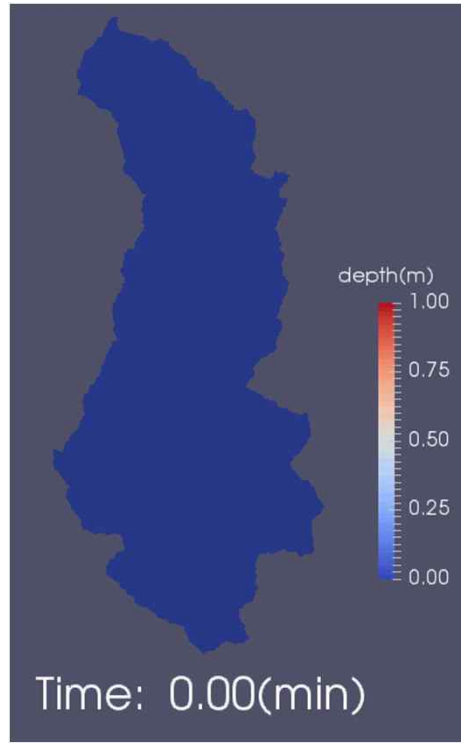


Application

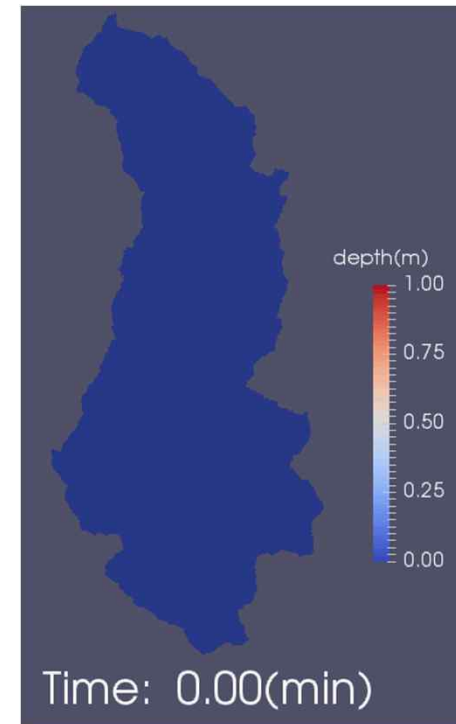
➤ Case study (3 hour simulation)



<50mm/h>



<100mm/h>



<200mm/h>

- Homogeneous rainfall (50mm/h, 100mm/h, 200mm/h)
- Simulation time : 3h
- Downstream of river and manhole: Open boundary

Application

➤ Recorded rainfall data (2014.8.25)

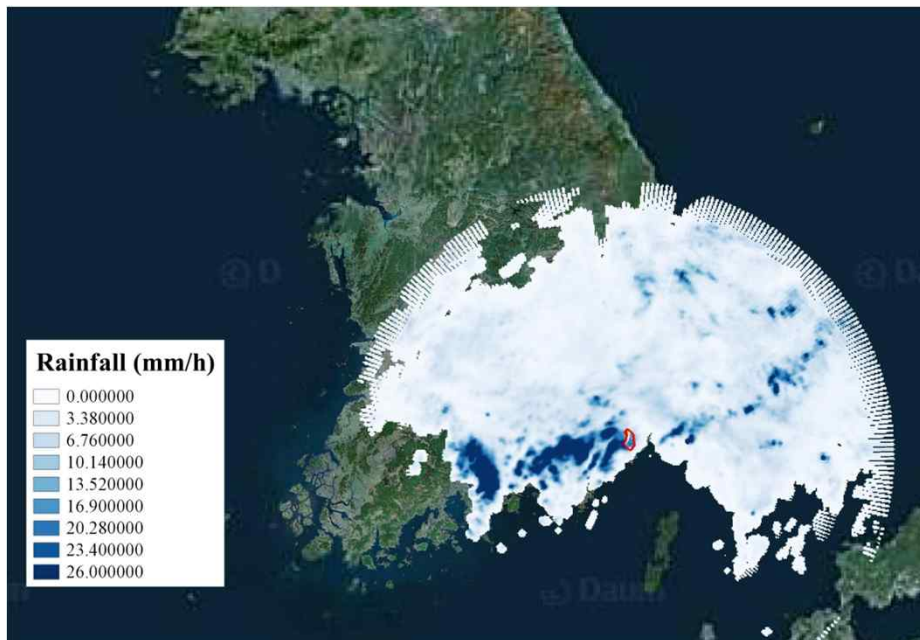


Fig. Position and boundary of the Radar

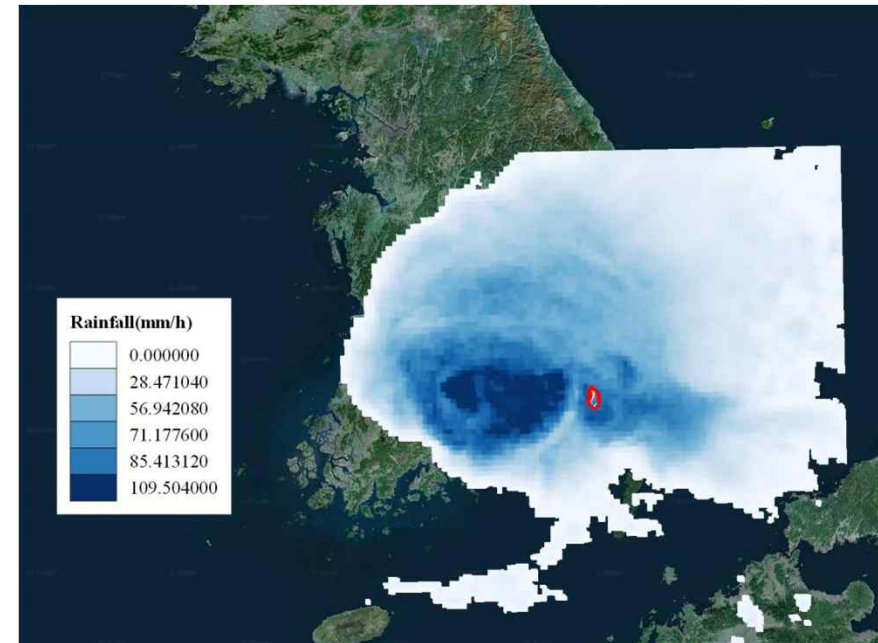
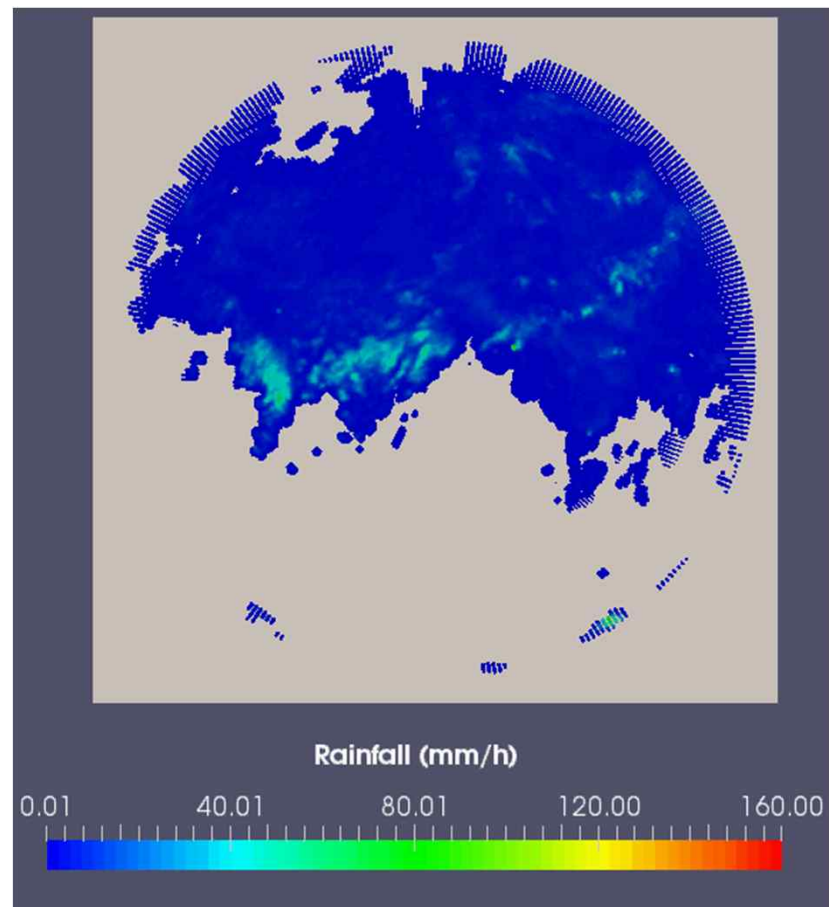


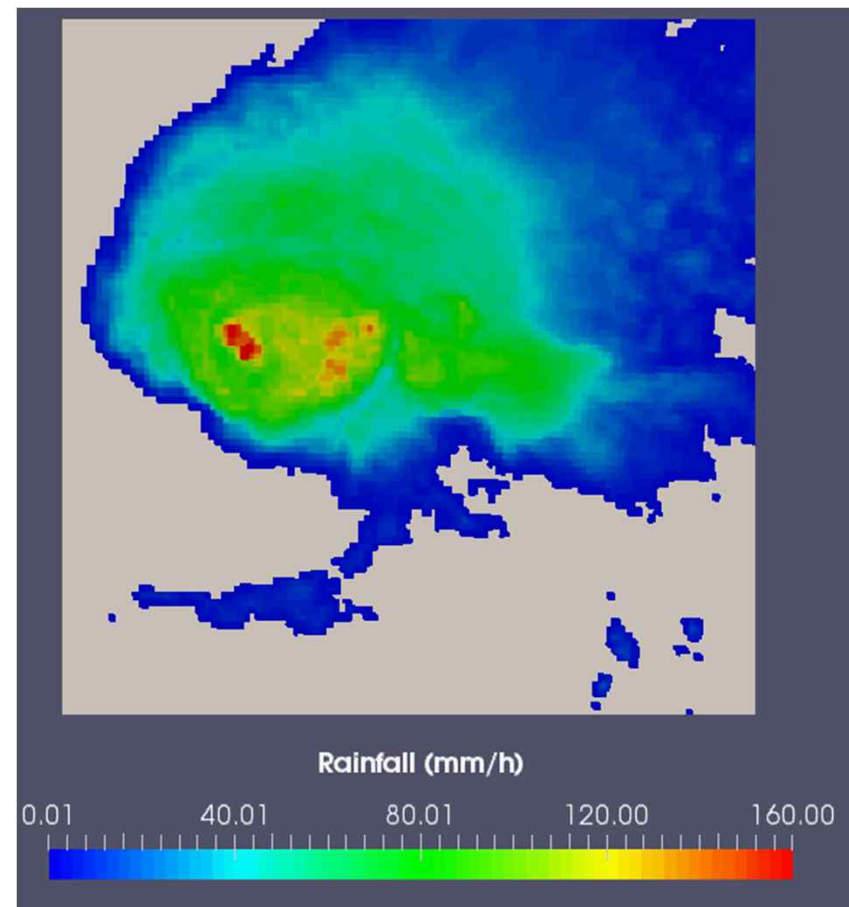
Fig. Position and boundary of the Satellite

Application

➤ Radar data (13:00~16:00)

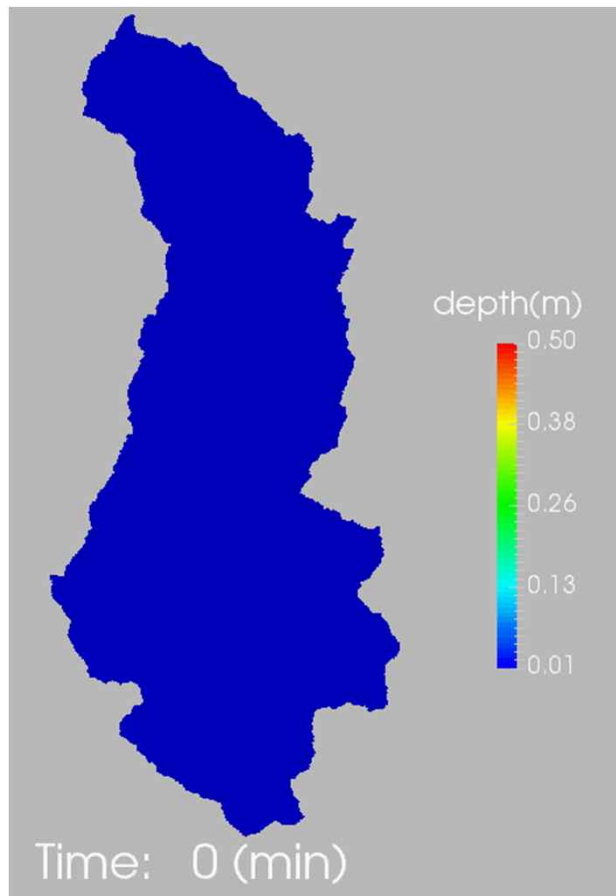


➤ Satellite data (13:00~16:00)



Application

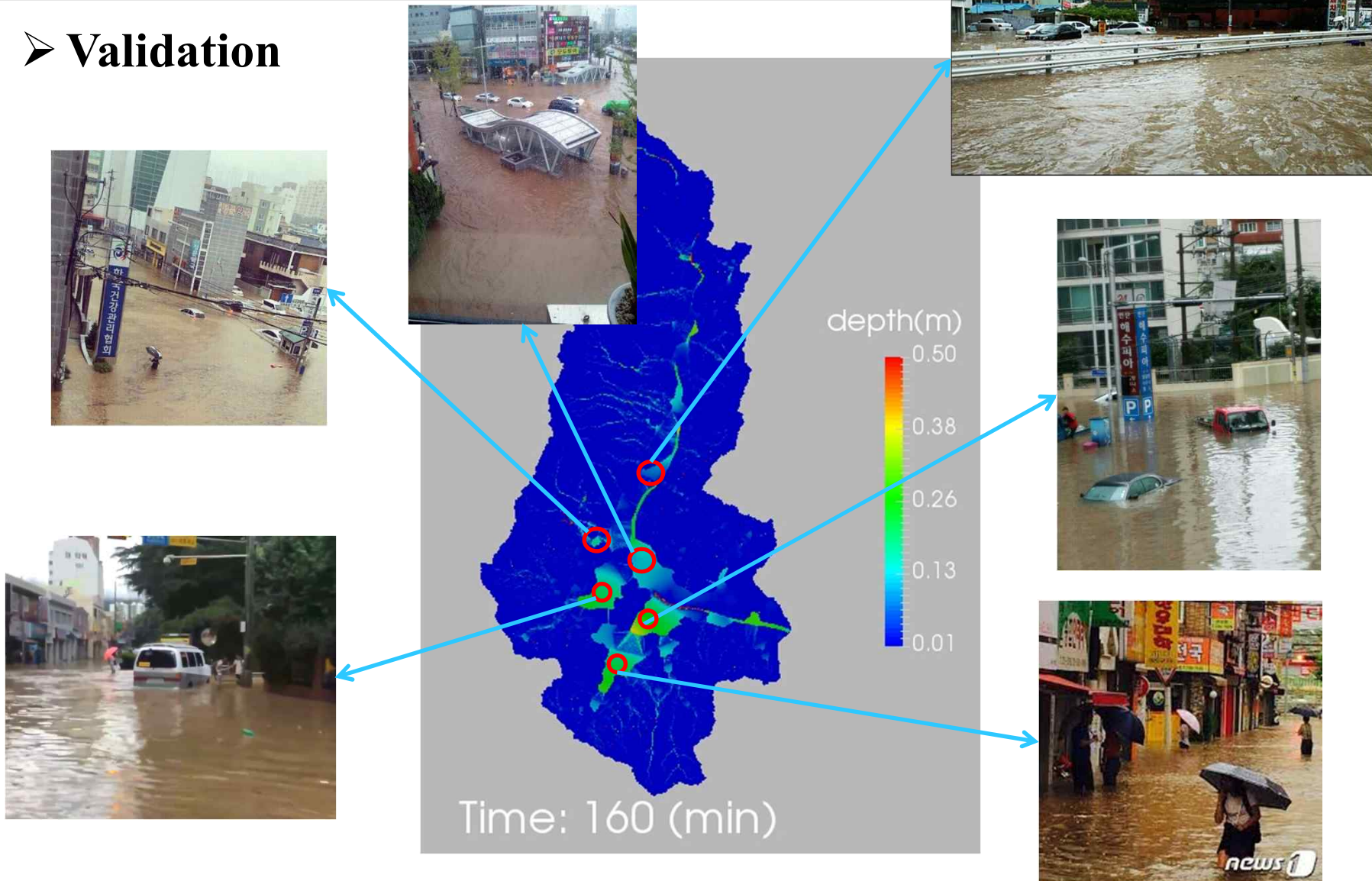
➤ Homogeneous Mesh (3 hours)



- Basin area : 55.6km^2
- Mesh size : $10\text{m} \times 10\text{m}$
- $\text{dt} : 0.2 \text{ sec}$
- Radar data
- Outlet open boundary condition
- $1,063\text{sec} = 17.7\text{min}$

Application

➤ Validation



Summary

➤ Achievement

- Mesh refine method based Parallel computing
- Acceptable Calculation time for the real-time forecasting
- Usage of Radar data

➤ Limitation

- River flow
- Downstream Boundary condition
- Initial value
- Validation

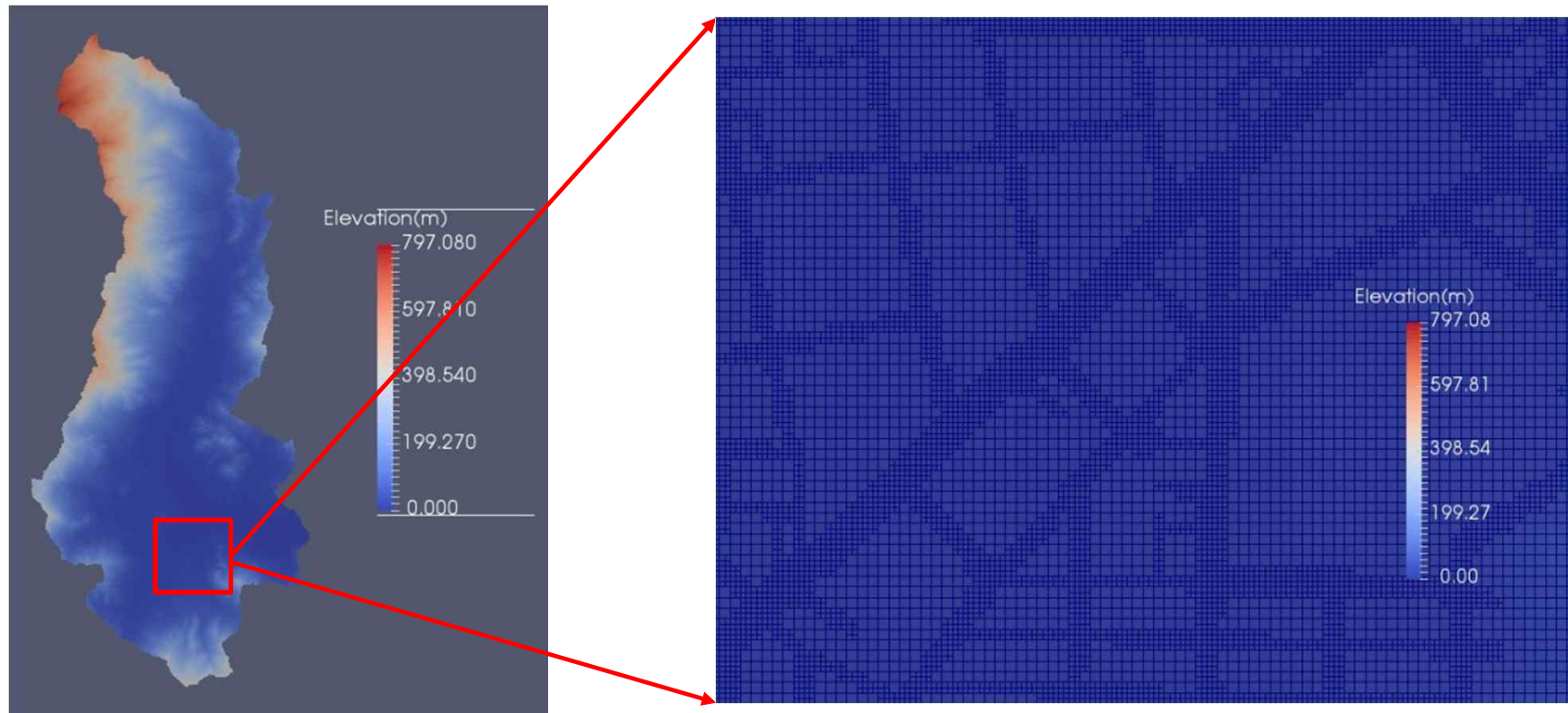


Future works

- Parameter calibration
- Model Validation
- Decision for appropriate boundary condition
- Reducing calculation time (MPI)

Future works

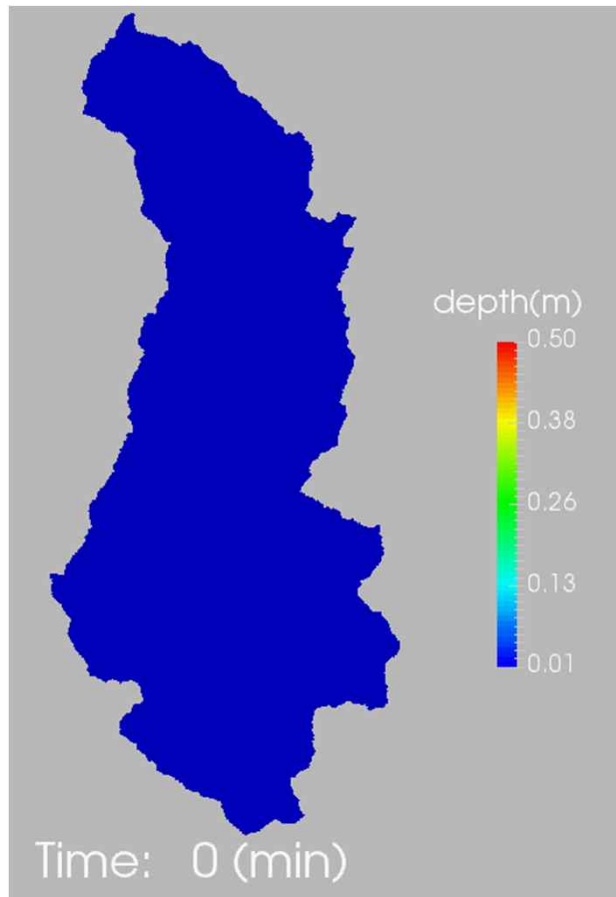
➤ Mesh Refinement Method



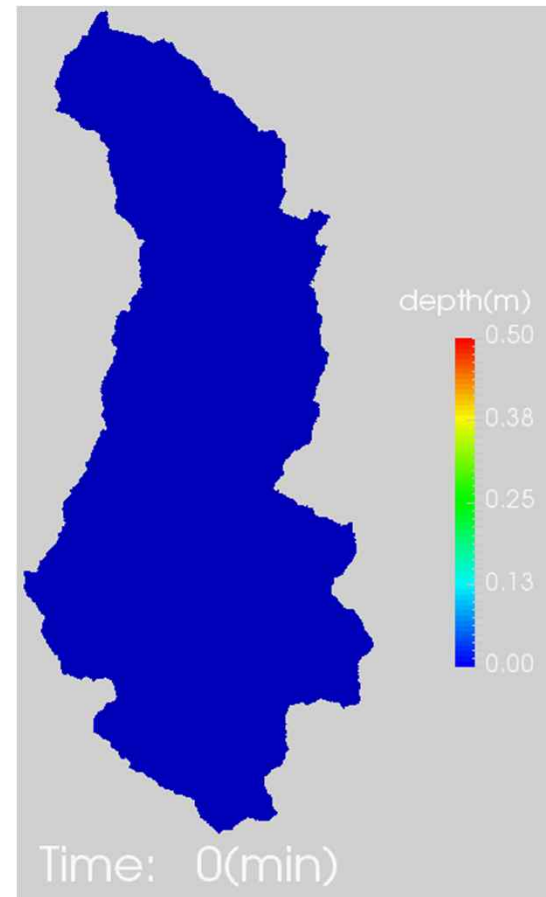
Basically, DEM resolution is $10\text{m} \times 10\text{m}$ and road meshes are $5\text{m} \times 5\text{m}$. Storm drains are distributed on the road meshes and connected with sewer pipes.

Future works

➤ Simulation result (13:00~16:00)



<Radar>



<Satellite>

Future works

➤ Comparison

Index	Refined mesh	Homogeneous Mesh
Area (km ²)	55.6	
Number of Cell	556,009	899,574
dt (sec)	0.2	0.05
Calculation time (3 hour)	17.7 min	148 min

Hybri-Parallel Computing Method will be adopted soon!
(MPI + OpenMP)



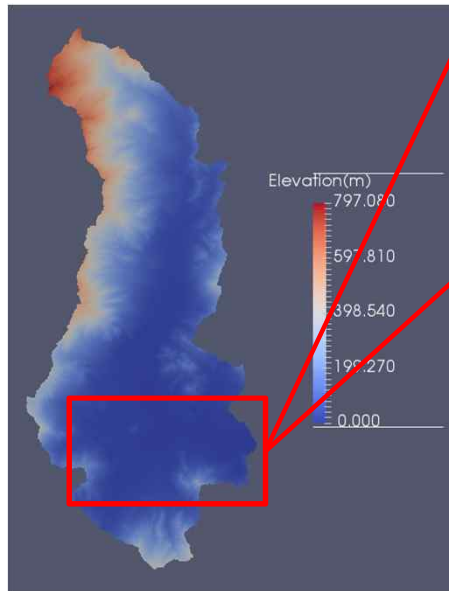
Thank You for Your Attention!



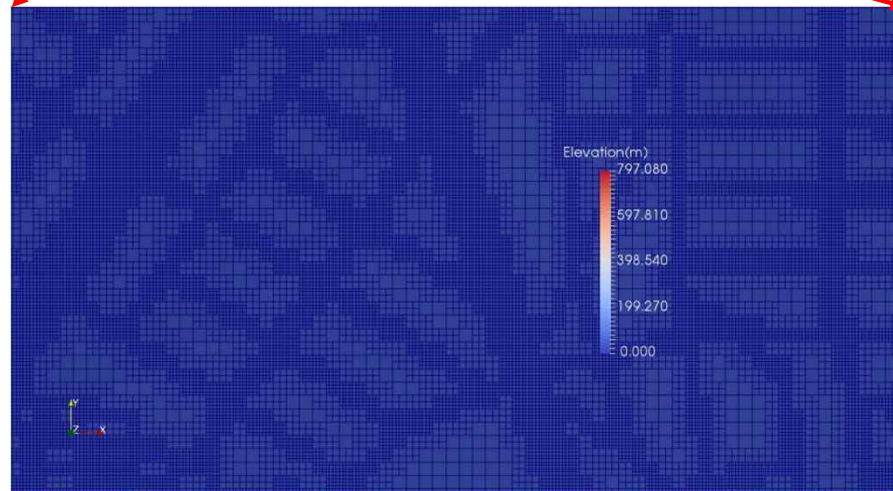
Summary

- Real-time prediction of urban inundation is crucial strategy in disaster risk management aspect.
- Facile data collection, easy pre-processing, low calculation load and acceptable accuracy are essential key factors for the real-time prediction.
- ARM based on high resolution may satisfy above statements.
- In this study, ARM model based on FDM and leap-frog is developed for estimating its applicability.
- It can depict detail topography at specific area by fine mesh, and reduce total calculation load.
- Developed model can be used for the real-time prediction of urban inundation by coupling with sewer analysis model.

Future works

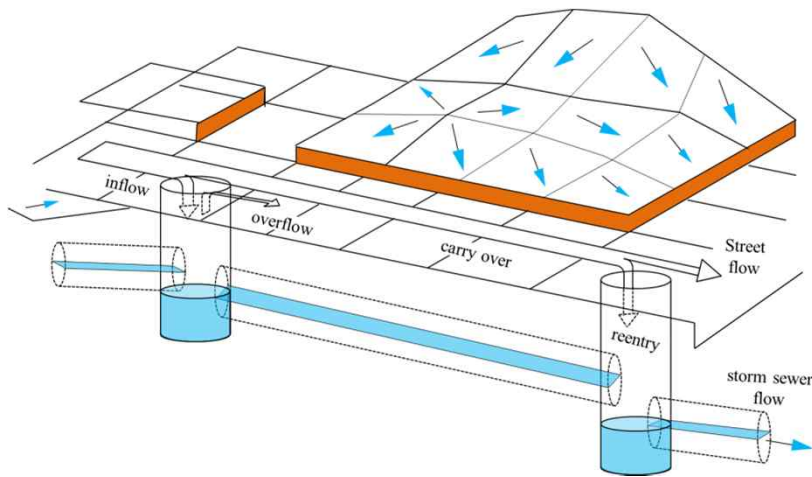


<Oncheon-cheon watershed>

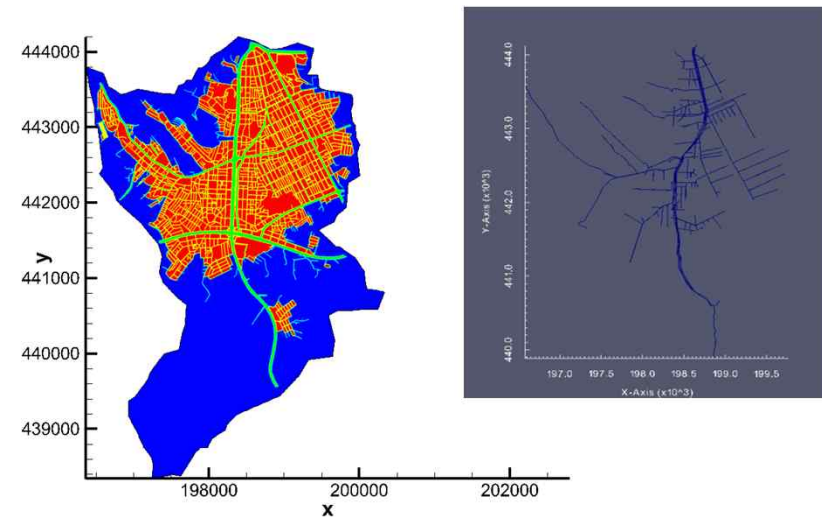


<Refined road (Cell level = 2)>

Future works

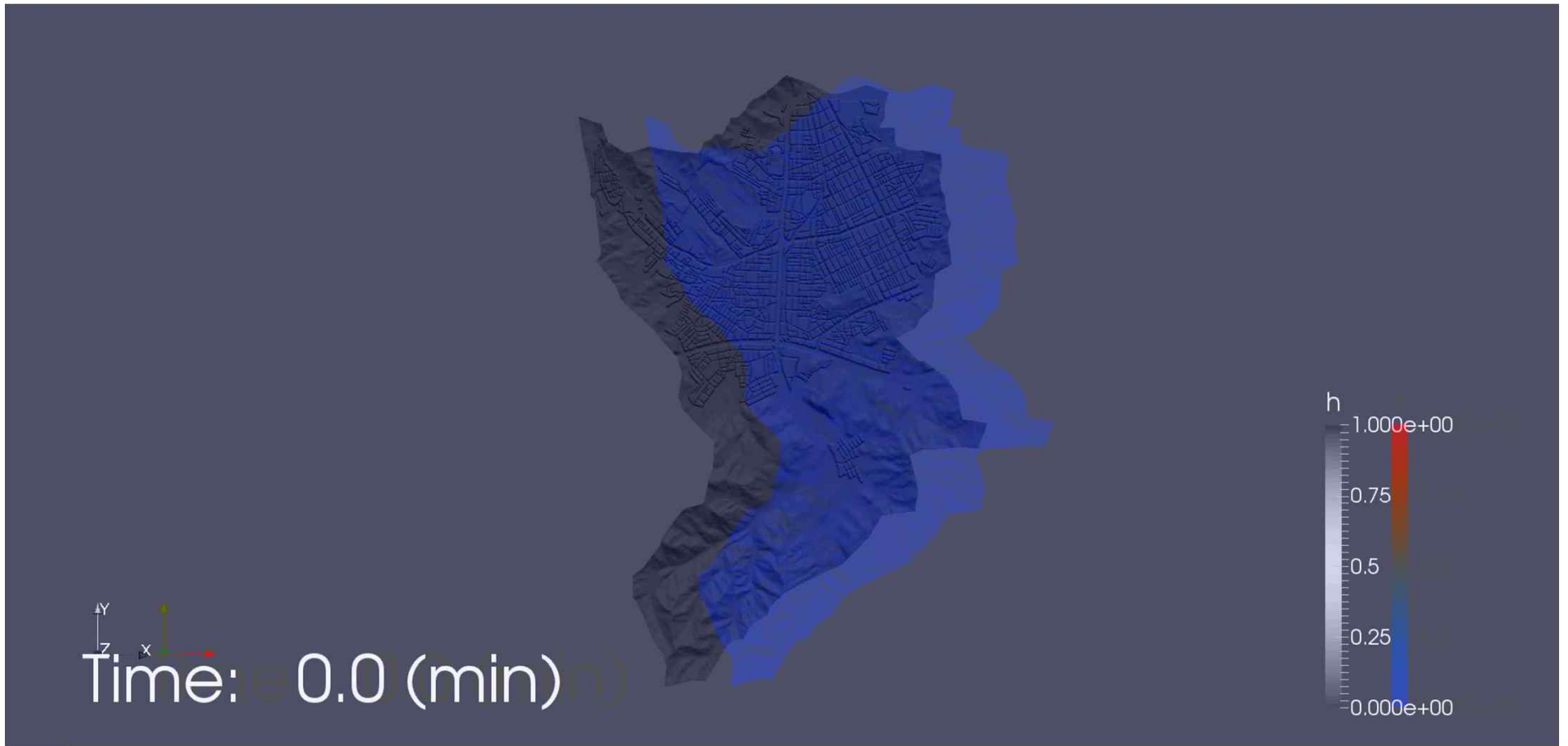
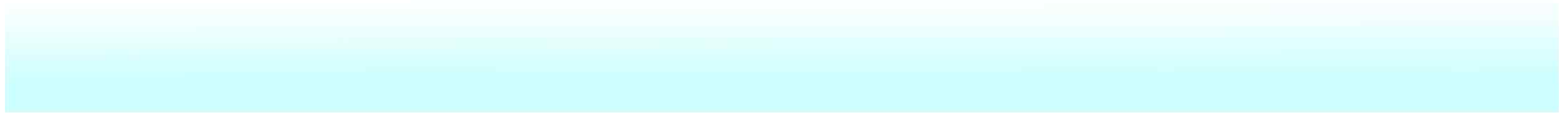


<Concept of dual drainage system, smith (1993)>

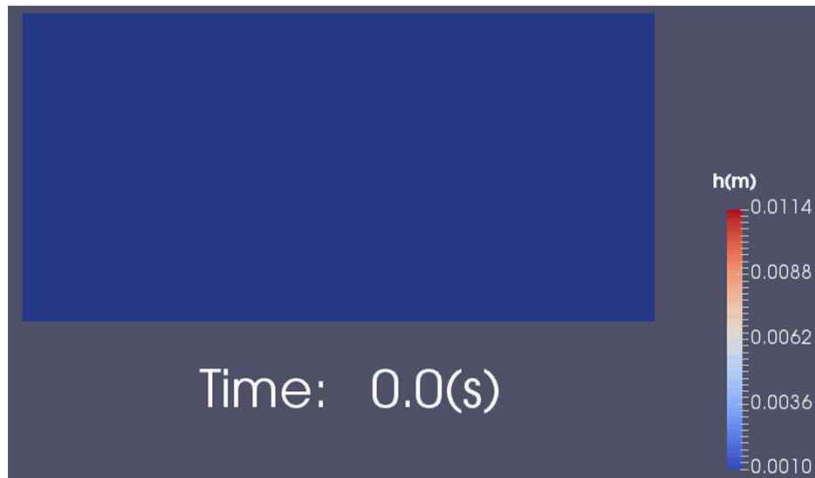


<considering land use with ADR and coupling with sewer network model>

In order to actualize the real-time forecasting of urban inundation, sewer network model should be coupled with 2D flood model under parallel computing to secure reality and acceptable running time.



Test and comparison (manhole)

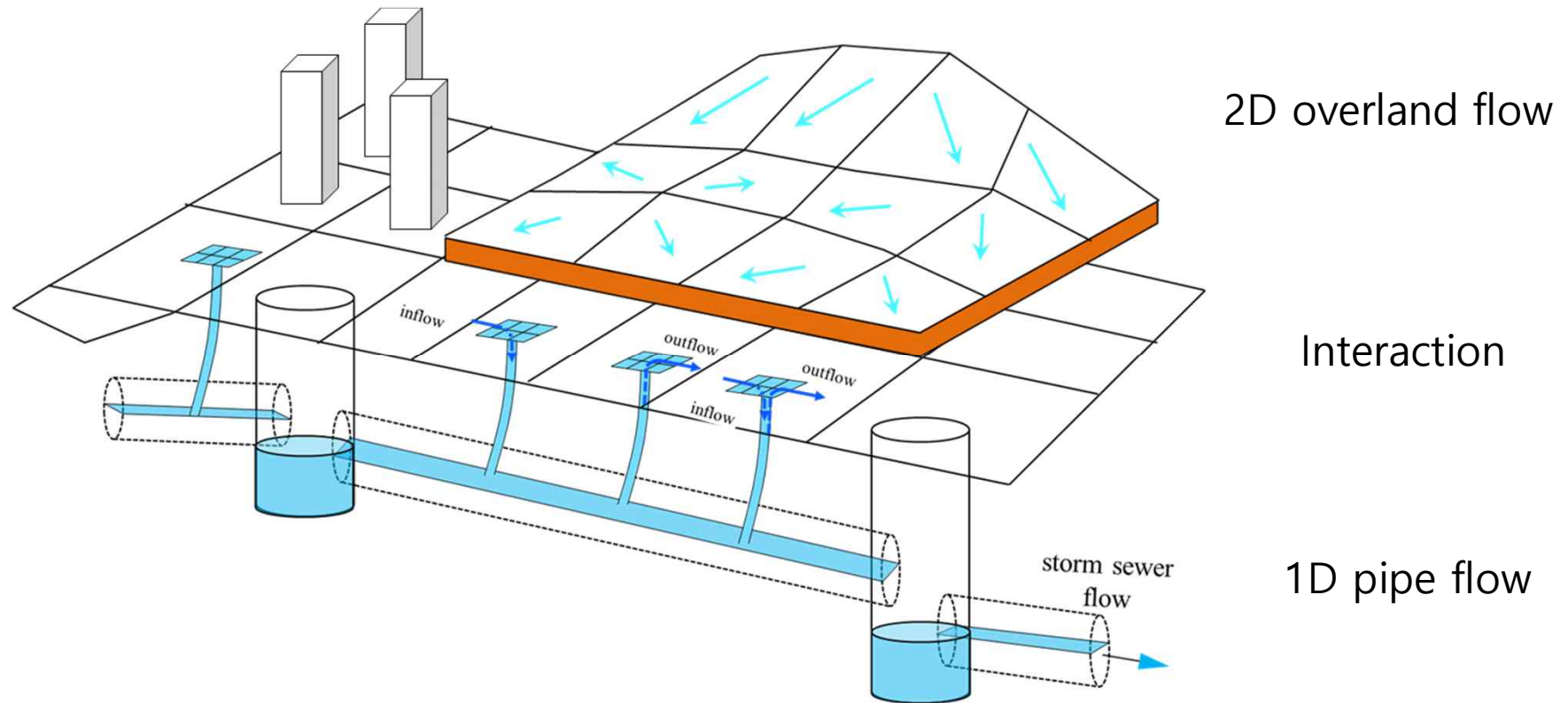


Adaptive mesh



Homogeneous mesh

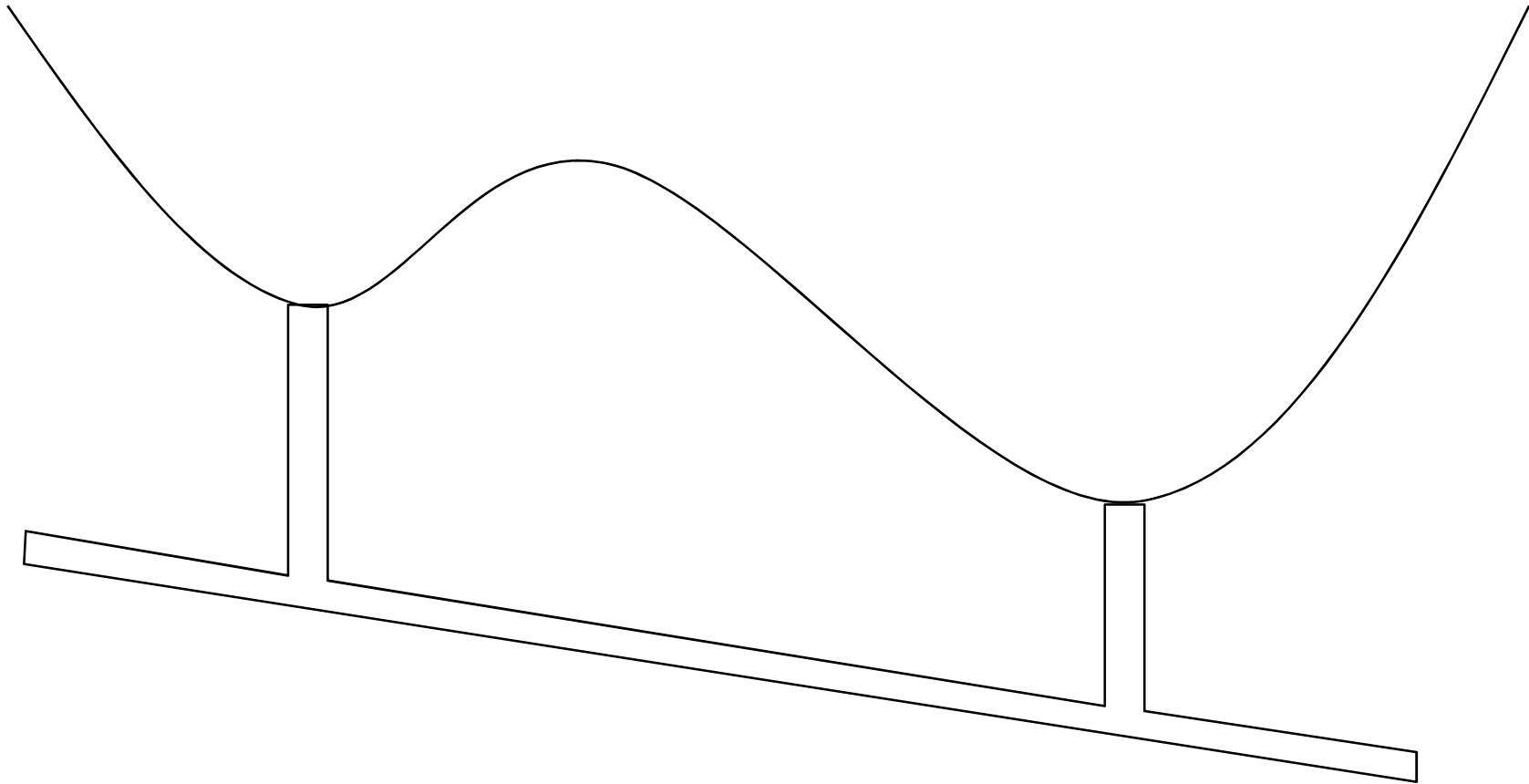
Conventional Concept

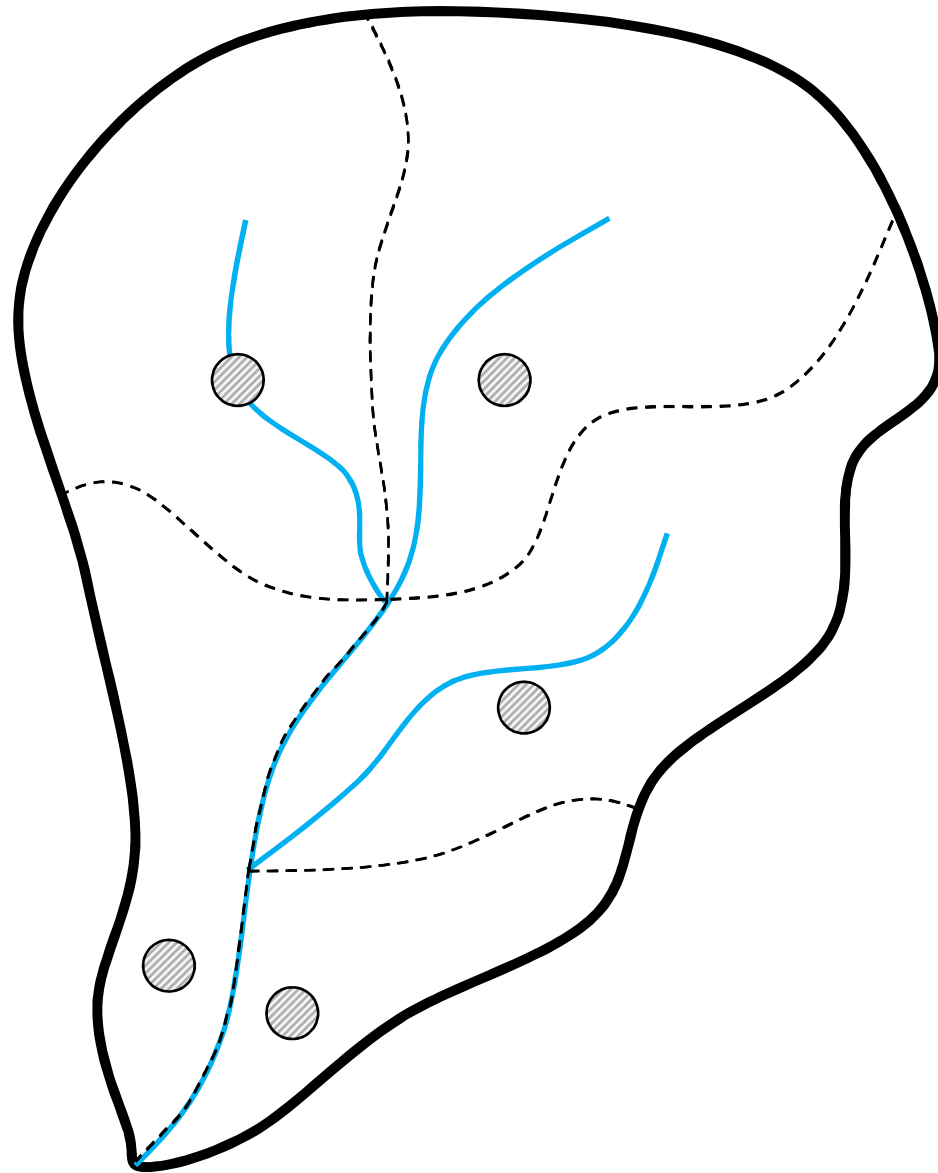


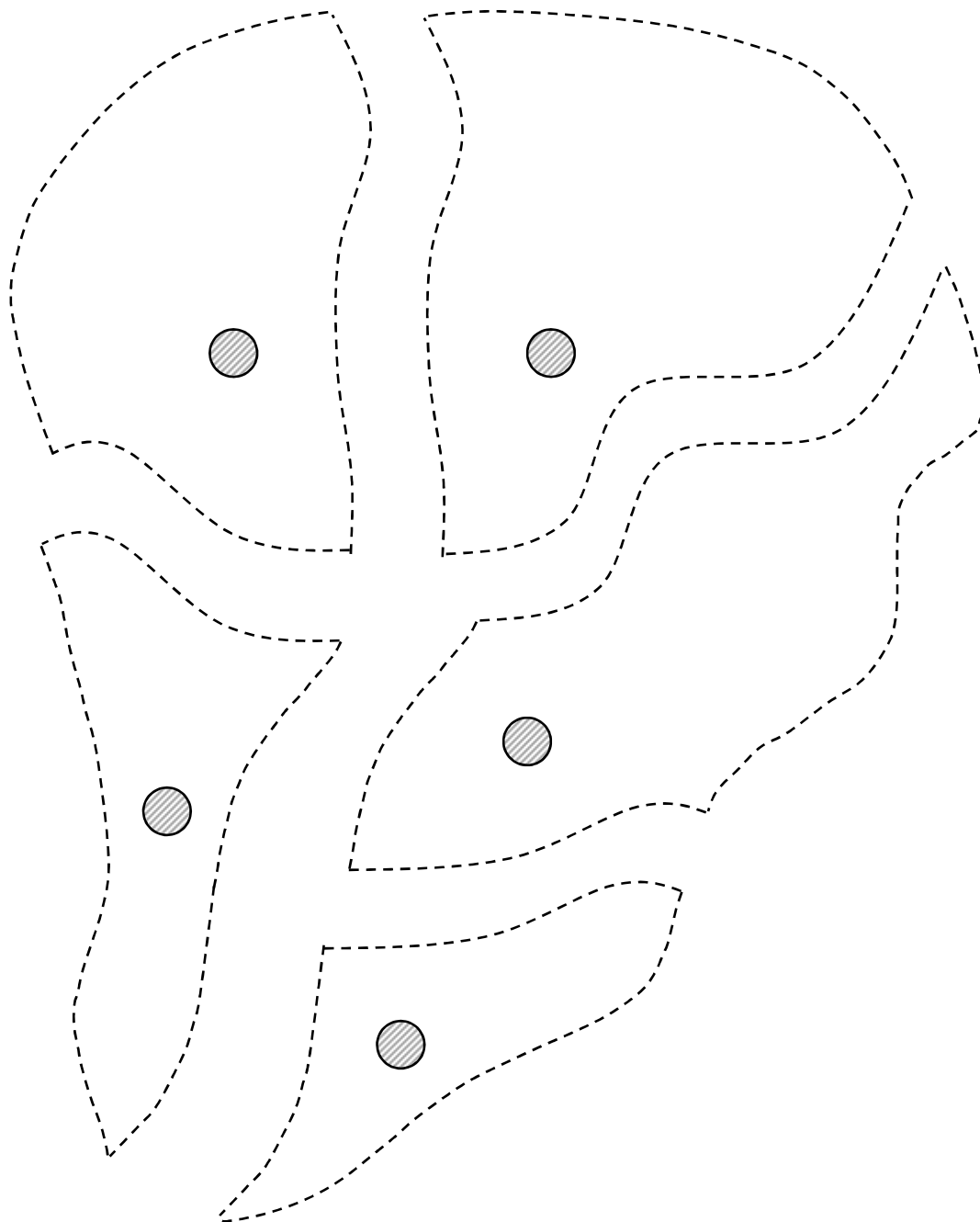
Advantage : High accuracy, detail description for topography

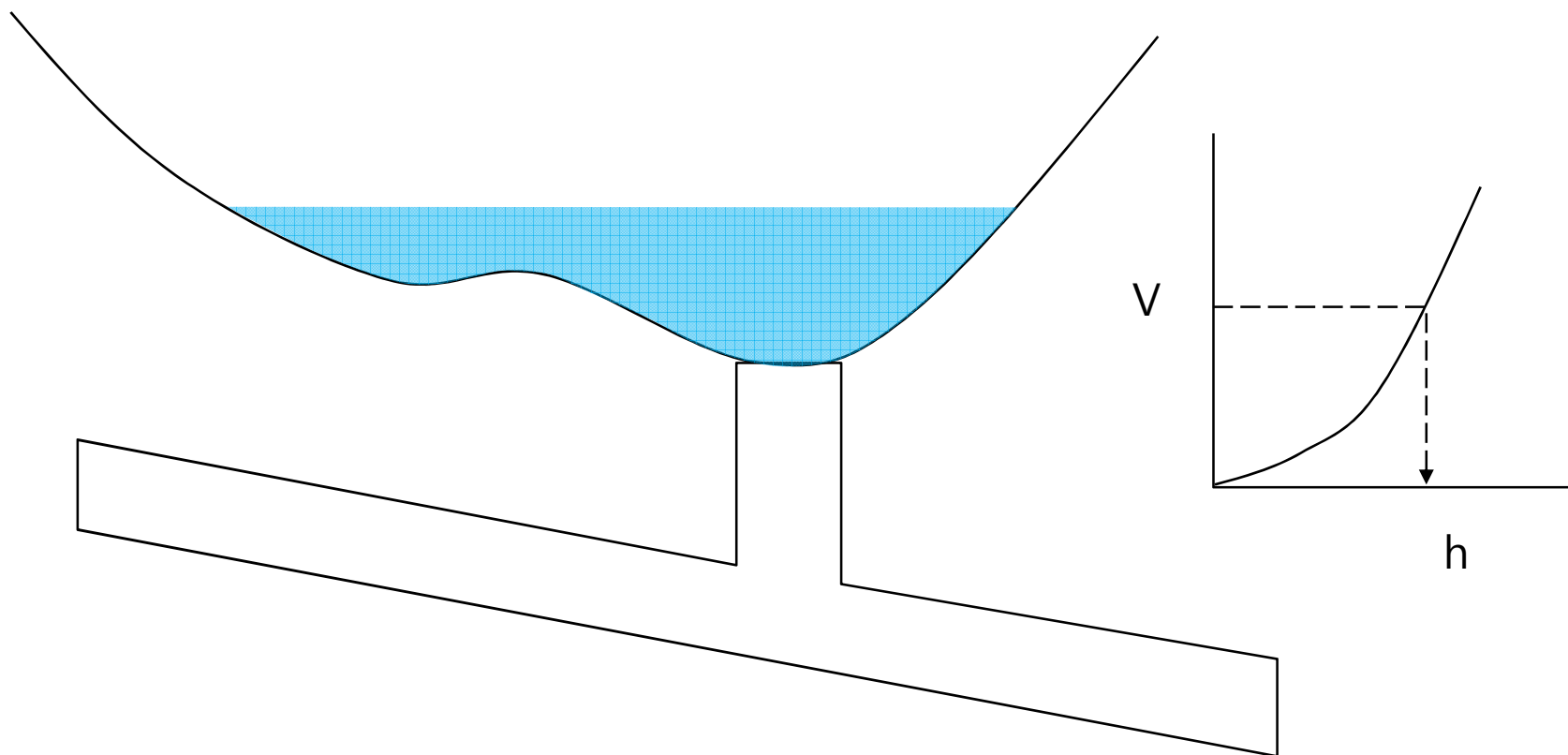
Disadvantage : Necessity of many input data, huge load for calculation

New concept for real-time prediction









Integrating Prediction Models and 3D Visualization for Real-time Urban Inundation Prediction System

Seongkyu Lee, Research Fellow, APCC
(geoslegend@apcc21.org)

About US

Rainfall Prediction Model



Dr. Kyungwon Park

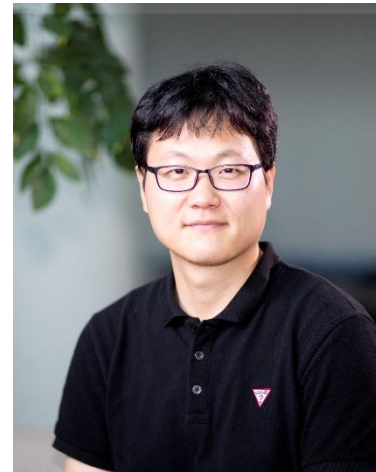
- Remote Sensing Research
- Satellite-based Short-Term Rainfall Prediction Modelling
- Satellite-Radar Ensemble Modelling



Dr. Sangmin Jang

- Radar Meteorological Research
- Radar-based Short-Term Rainfall Prediction Modelling
- Satellite-Radar Ensemble Modelling

Urban Inundation Model



Dr. Seungsoo Lee

- Urban Inundation Research
- Urban Inundation Modelling
- Short-Term Rainfall Prediction Data-based Urban Inundation Modelling

2D & 3D GIS-based Web Service



Dr. Seongkyu Lee

- Spatial Information Research
- Integration of Prediction Models Using GIS Techniques
- Design and Development of 2D & 3D GIS-Based Web Service

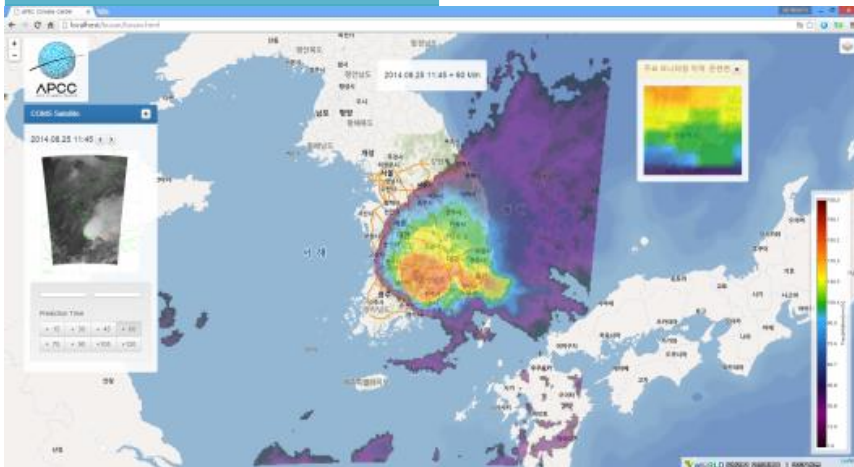
Contents

- **History**
- **Real-time Urban Inundation Prediction System**
 - **Key Issues**
 - **System Architecture**
 - **FOSS4G in System Architecture**
 - **Demonstrations**
- **Future Work**

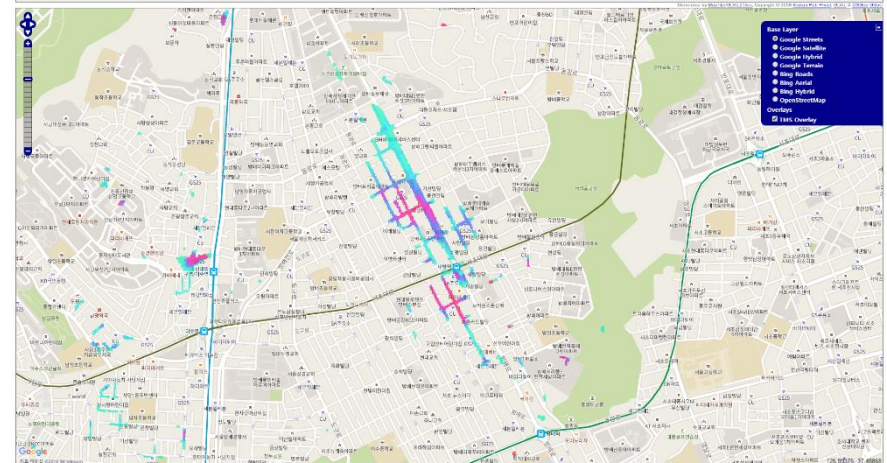
History

Rainfall and Urban Inundation Prediction System

Mid-2015

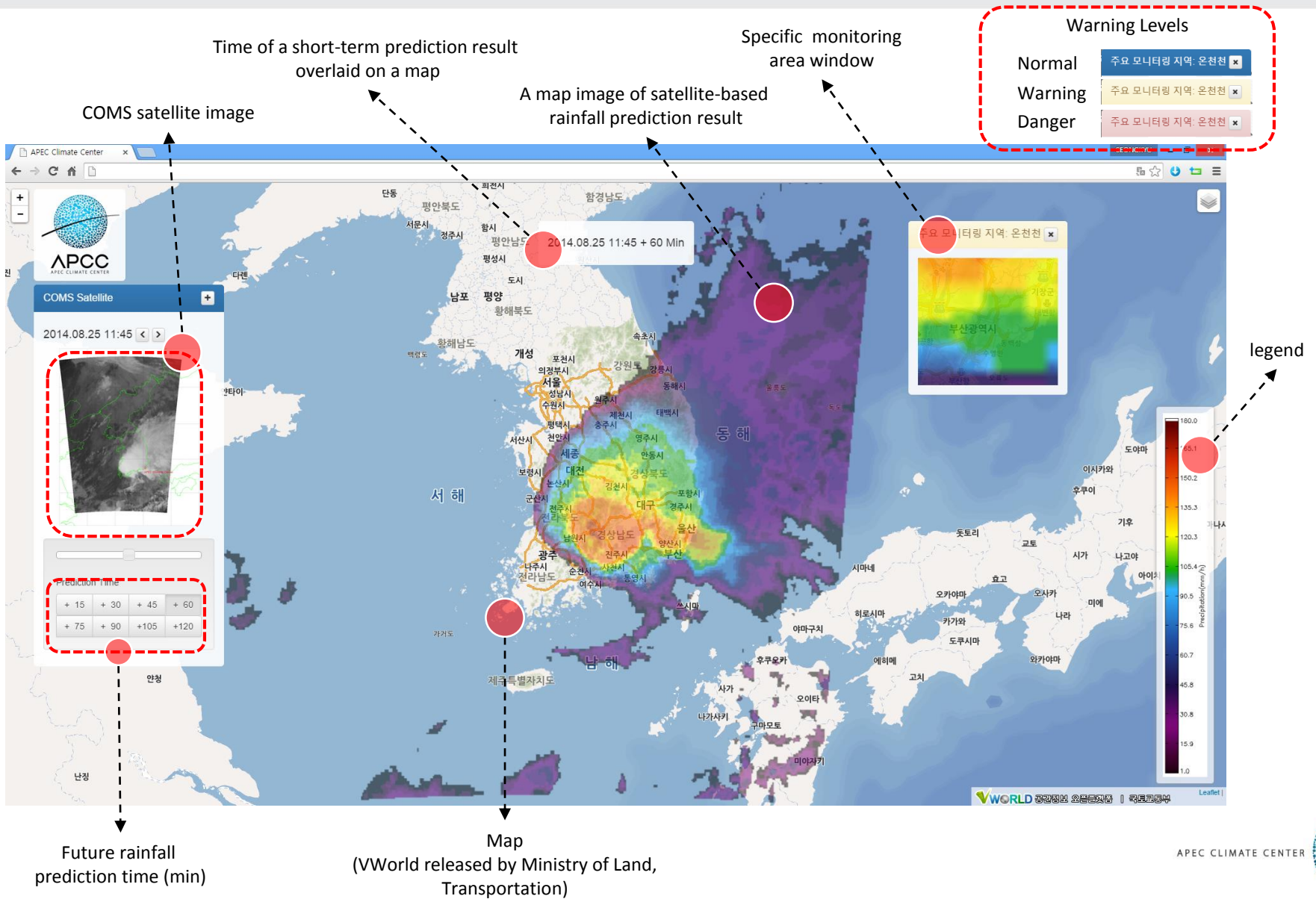


Early 2016

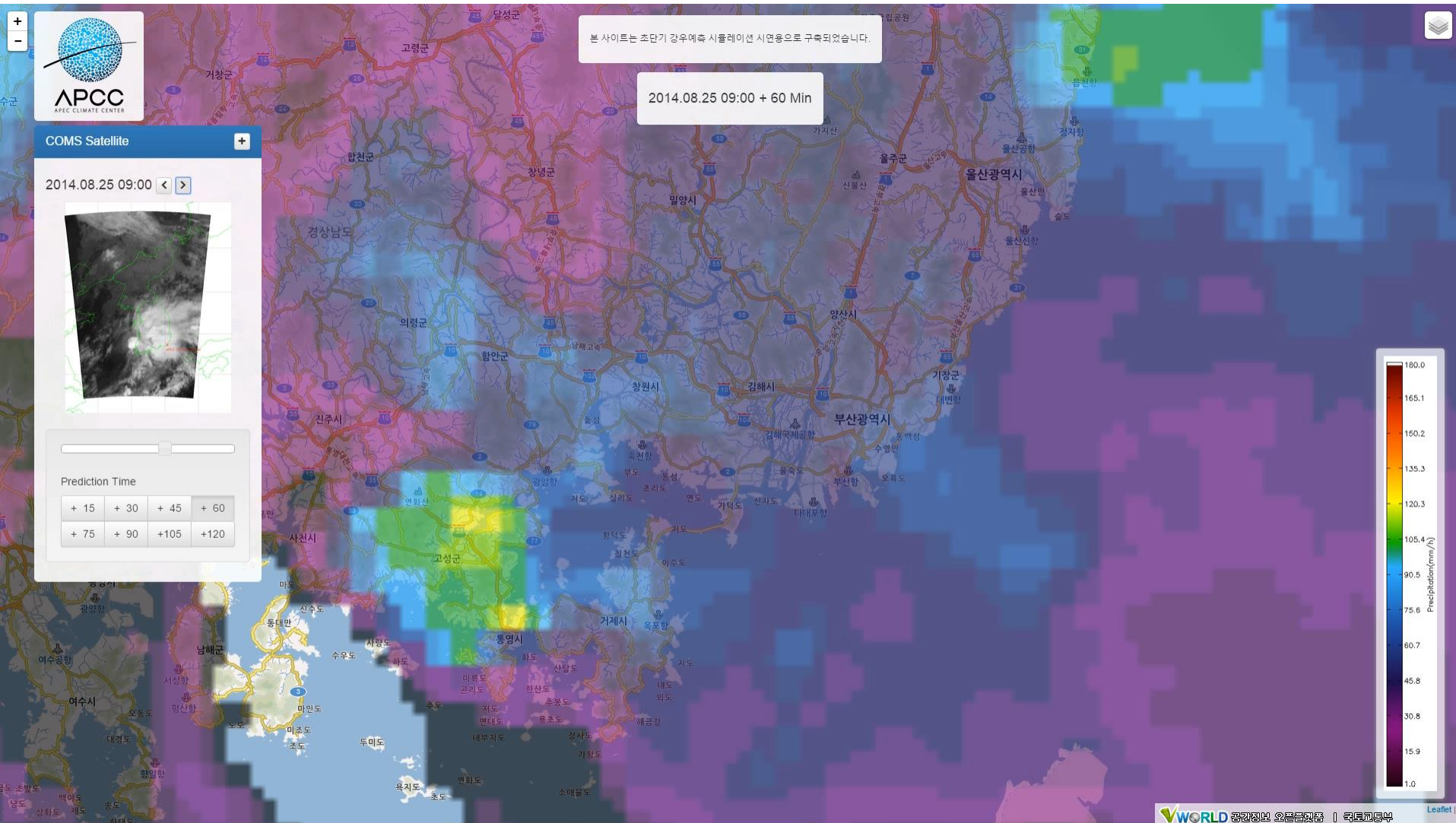


- Design and development of a prototype of 2D GIS-based Web Service
- Visualization of satellite-based rainfall prediction results
- Data processing by using commercial software
- Development of data processing method for visualizing temporal prediction data calculated by urban inundation model

History (cont'd)



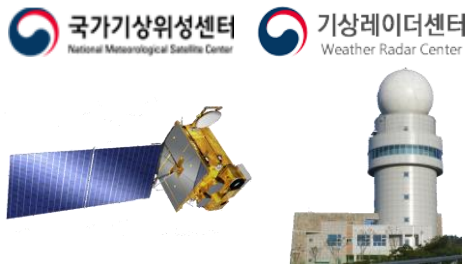
History (cont'd)



Real-time Urban Inundation Prediction System

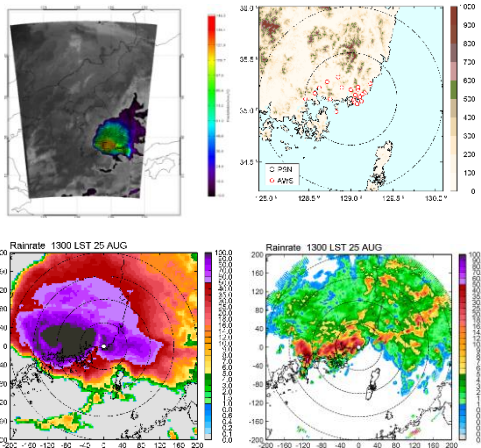
Main Components:

Meteorological data

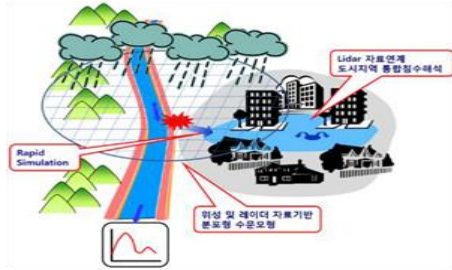


Satellite

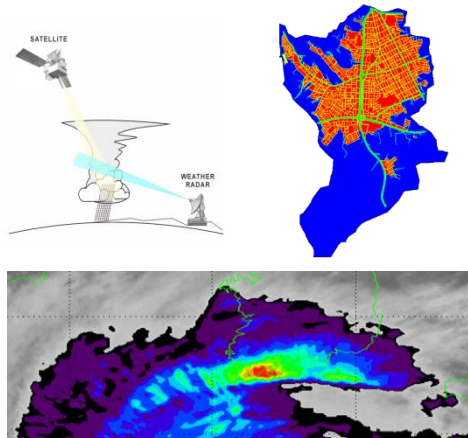
Radar rain-gauge



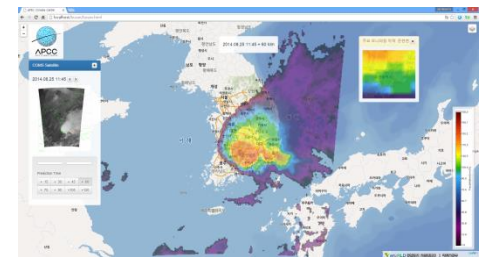
Prediction models



Concept of Rainfall and urban inundation prediction model

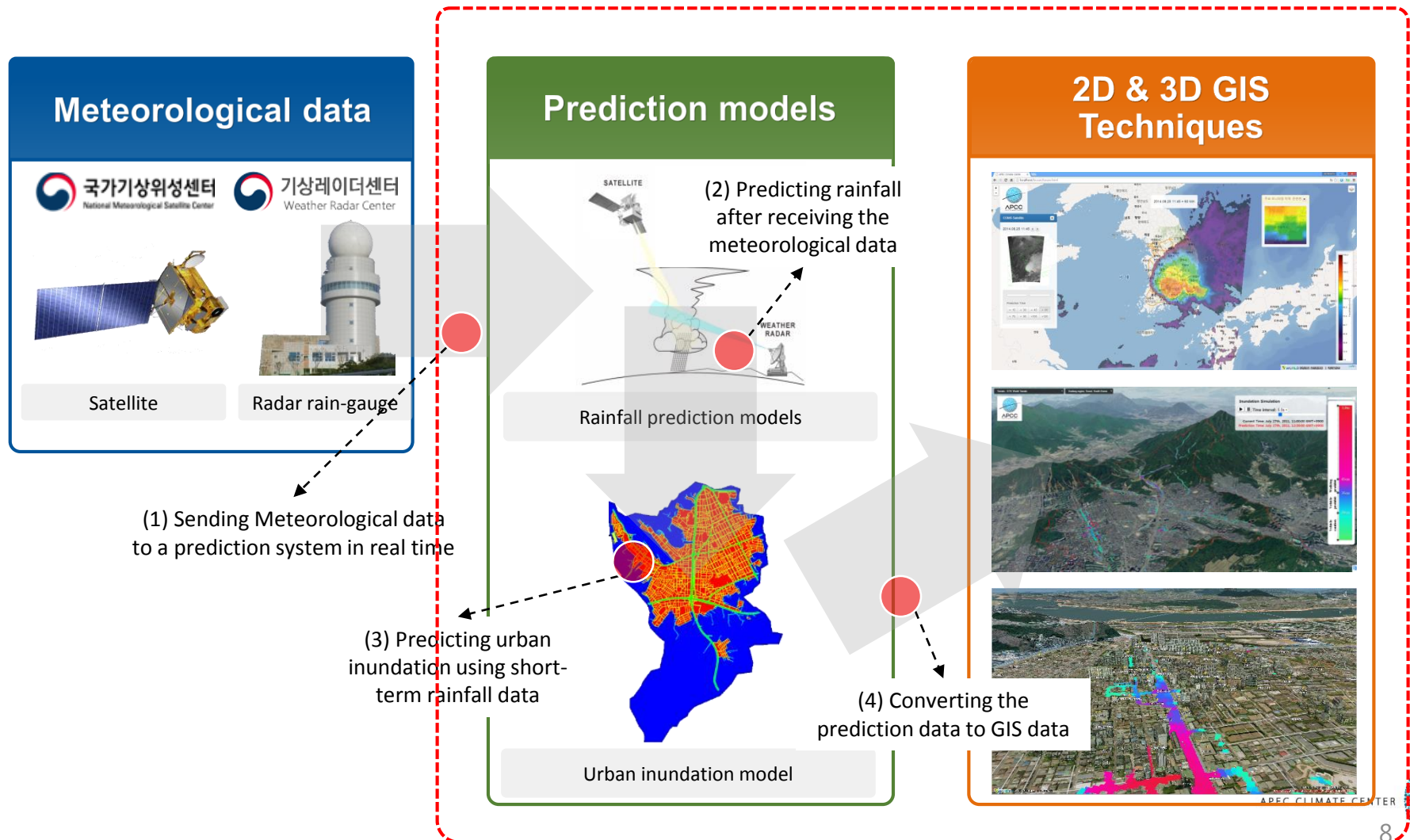


2D & 3D GIS Techniques



Real-time Urban Inundation Prediction System

Concept of Real-time Urban Inundation Prediction Processes



Key Issues

In Prototype Design of Real-time Urban Prediction System

- 1 Cost of Commercial software
- 2 Performance of a prediction model
- 3 Integration of prediction models and 3D visualization using GIS techniques



How to avoid the cost of commercial software?

Why We Use FOSS4G alternative to Commercial Software?

A Mission of APEC Climate Center

- Developing and providing Climate Information Service for **developing countries** around Asia-Pacific region



Asia-Pacific Region
(<https://en.wikipedia.org/wiki/Asia-Pacific>)

Commercial Software



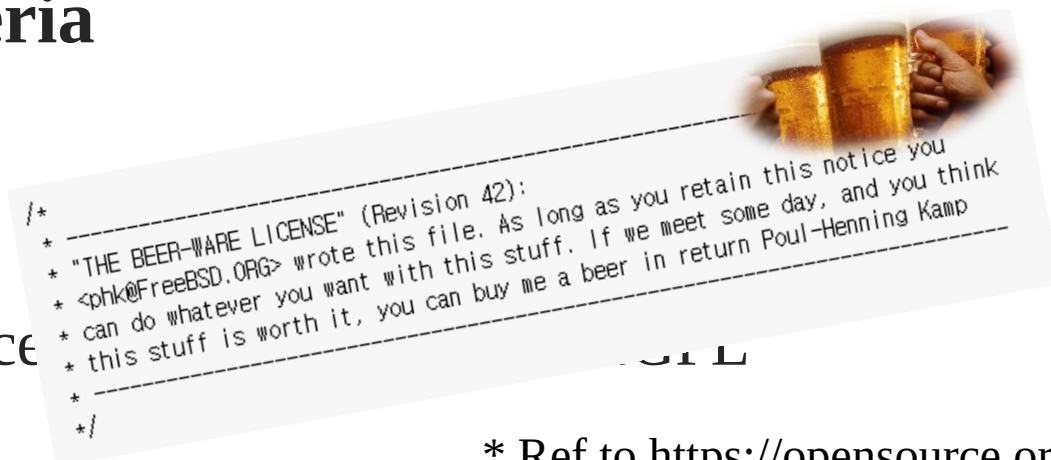
FOSS(4G)



How to avoid the cost of commercial software?

FOSS4G selection criteria

- Open Source License
 - MIT, BSD, Apache License
- Open Source Community
 - Activate Community rather than Inactivate Community
- **Necessity of Open Source Software or Open Source Library**
 - Essential features rather than powerful features



* Ref to <https://opensource.org/>

How to improve the running time of a prediction model?

Parallel Computing

- CPU-based Parallel Computing 
- GPGPU-based Parallel Computing  
- Distributed Computing **MPICH2** 

Hybrid Parallel Computing

- Combining CPU (or GPGPU or CPU+GPGPU)-based parallel Computing and distributed computing



How to improve the running time of a prediction model? (Cont'd)

Parallelization Method: Satellite-based rainfall prediction model

Measurement

Analysis

Parallelization

Measurement

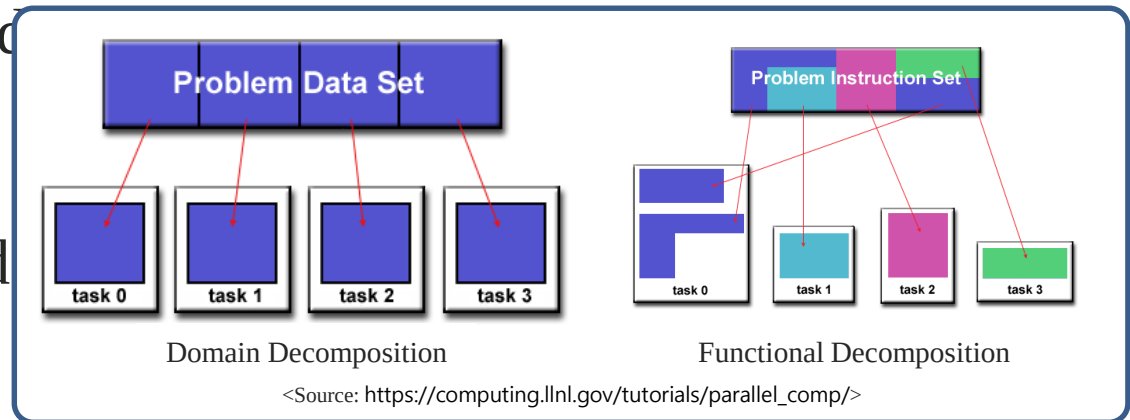
- To measure the elapsed

Analysis

- To analyze the elapsed

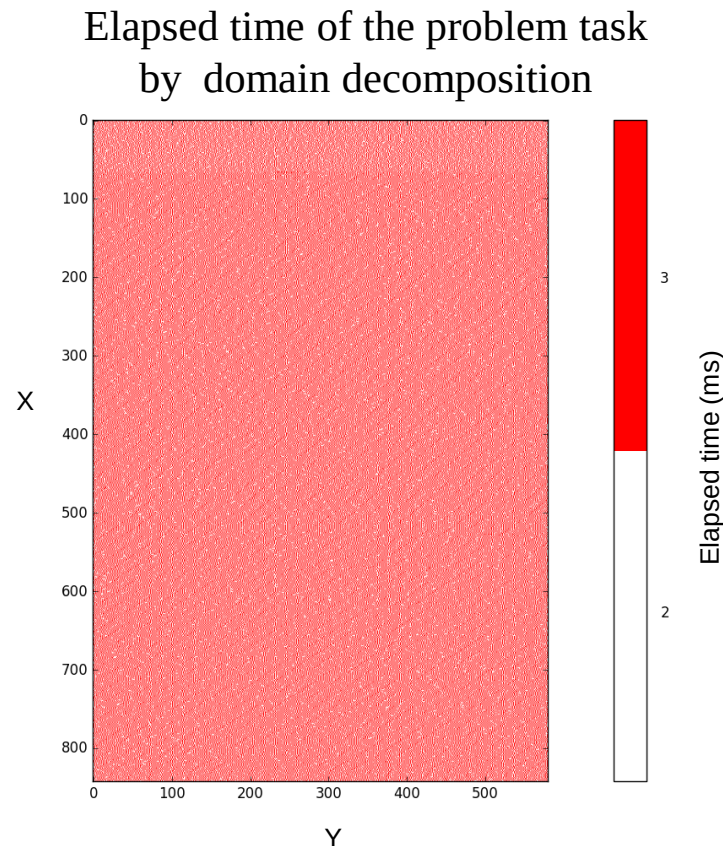
Parallelization

- To parallelize the problem part using decomposition method



How to improve the running time of a prediction model? (Cont'd)

Parallelization Method: Satellite-based rainfall prediction model



Sum: 1,211,995 ms Average: 2.48 ms
Std.Dev: 0.50 ms ※ Whole running time: 1,285,192 ms

Computing Environment

- CPU: Intel(R) Xeon(R) CPU E5-2643 v3 @ 3.40GHz (24 cores)
- Memory: 8GB * 10ea (80 GB)
- OS: CentOS 6.5 (final) x86_64 bit
- Programming language: Python 2.7 64bit
- Number of CPU cores in parallel computing: 8 cores

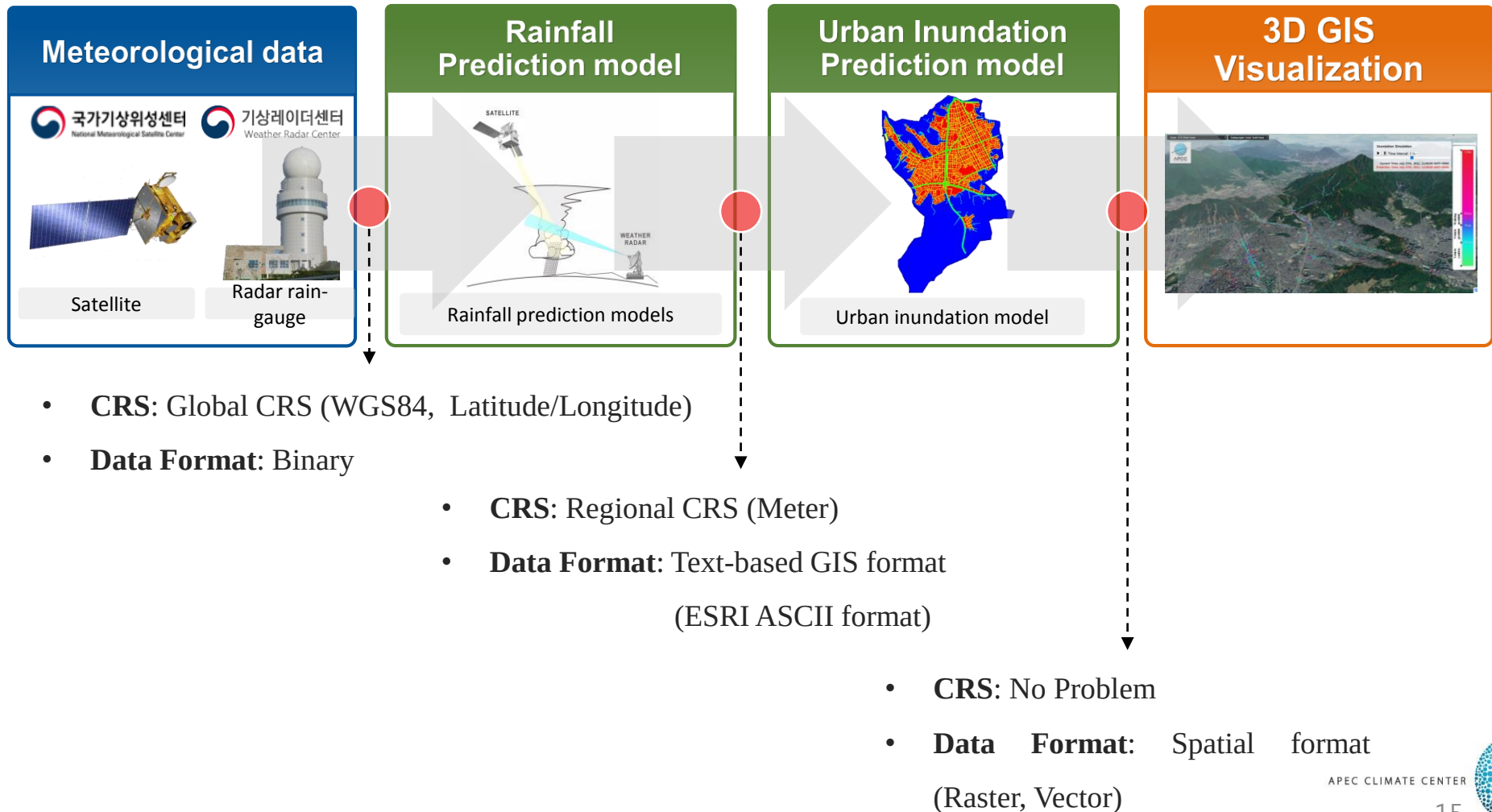
Comparison of results (843 x 580)

- Serial algorithm: 1,211,995 ms (00:20:11.995)
- Parallel algorithm: 493,104 ms (00:08:31.104)

> Speedup: 2.5x <

How to integrate prediction models and 3D visualization using 3D GIS techniques?

CRS and Data Format Requirements

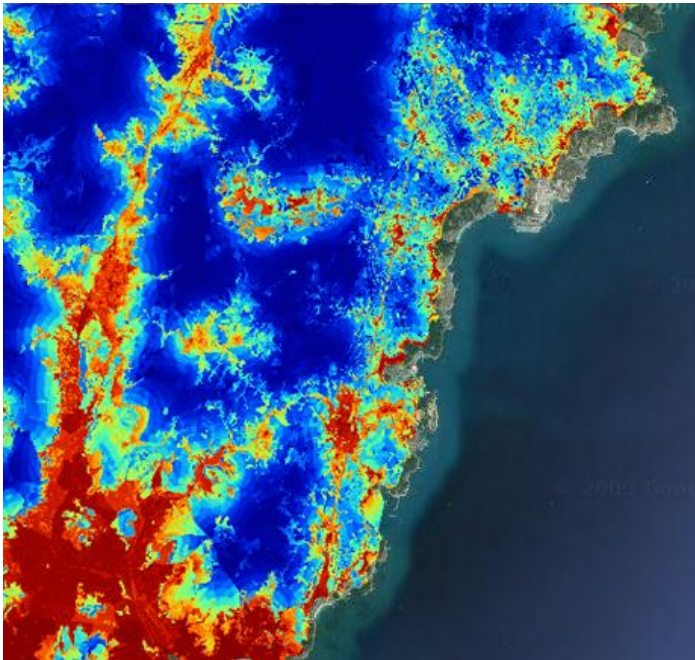


How to integrate prediction models and 3D visualization using 3D GIS techniques? (Cont'd)

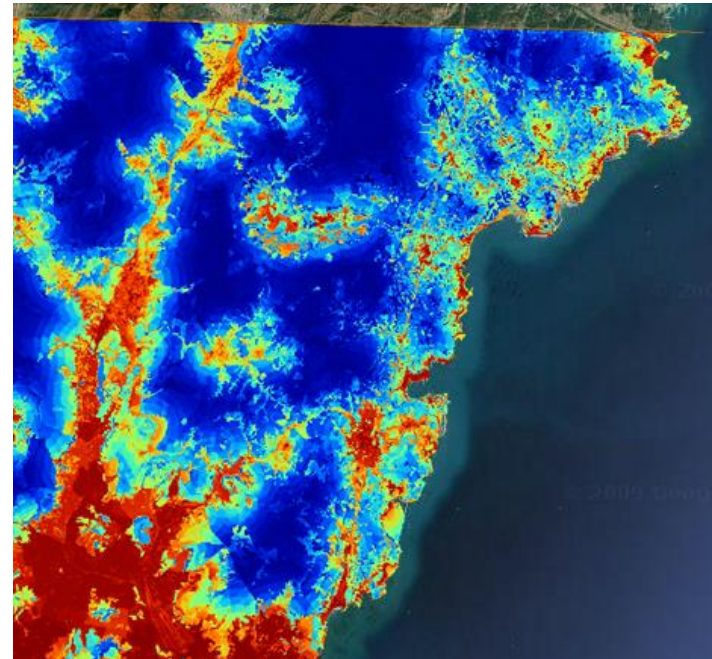
Coordinate Reference System (CRS)

- CRS provide a standardized way of describing locations. Many different CRS are used to describe geographic data. The CRS that is chosen depends on when the data was collected, the geographic extent of the data, the purpose of the data, etc.

<Source: <https://www.nceas.ucsb.edu/~frazier/RSpatialGuides/OverviewCoordinateReferenceSystems.pdf>>



Incorrect CRS

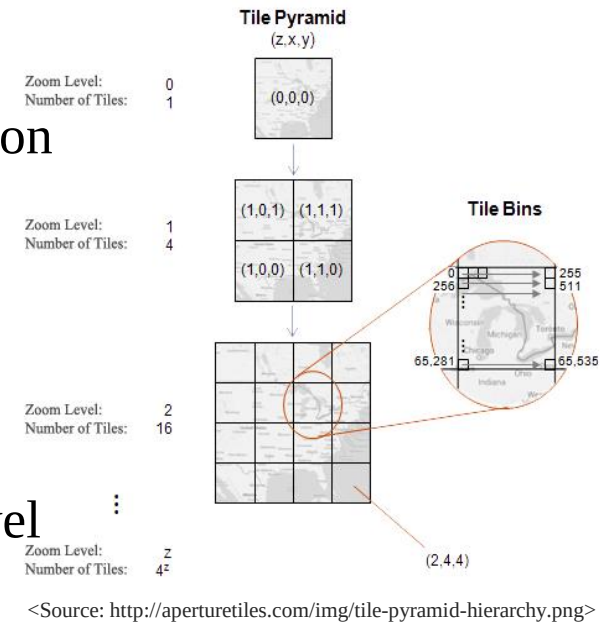


Correct CRS

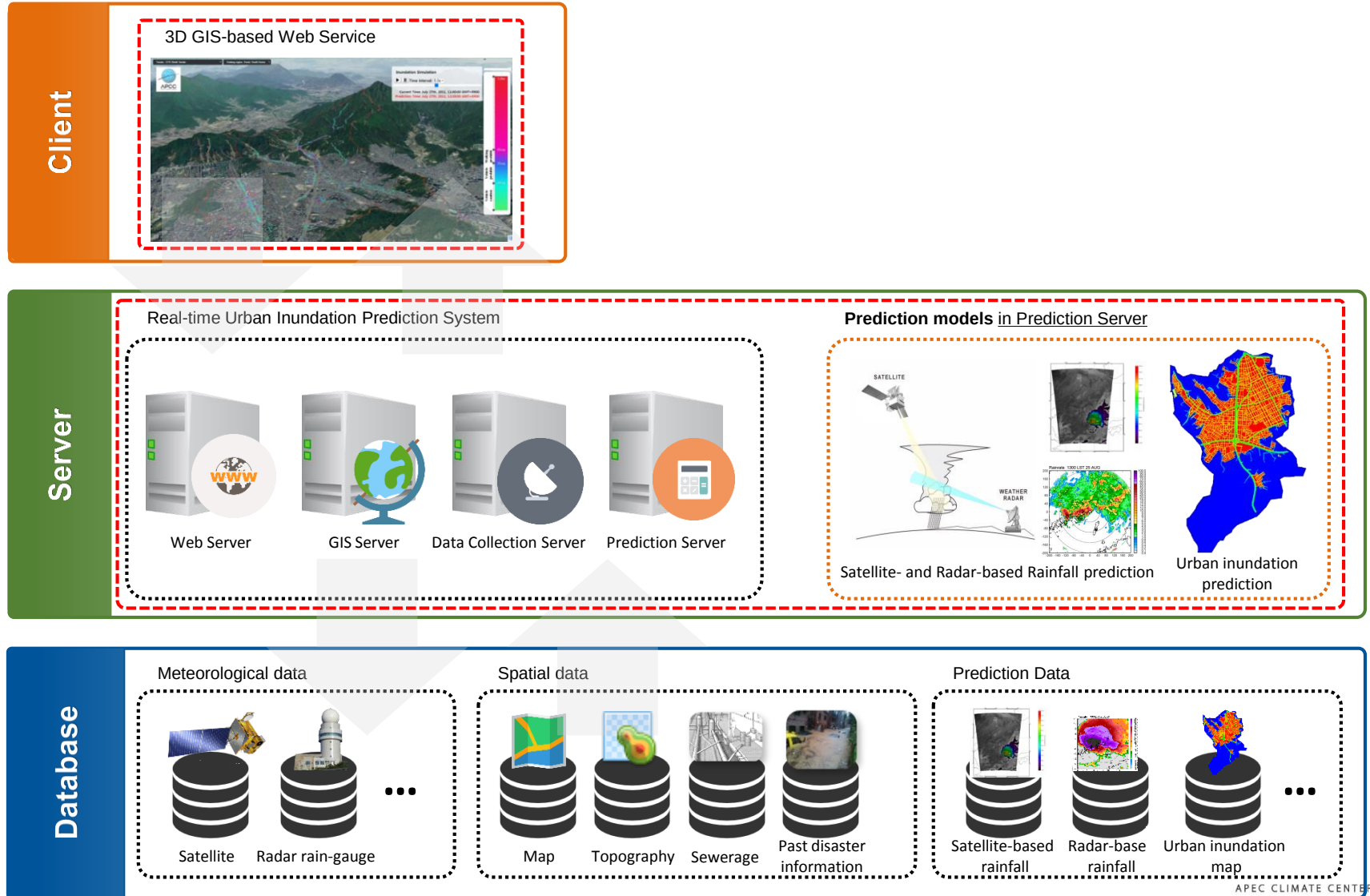
How to integrate prediction models and 3D visualization using 3D GIS techniques? (Cont'd)

Tiled map

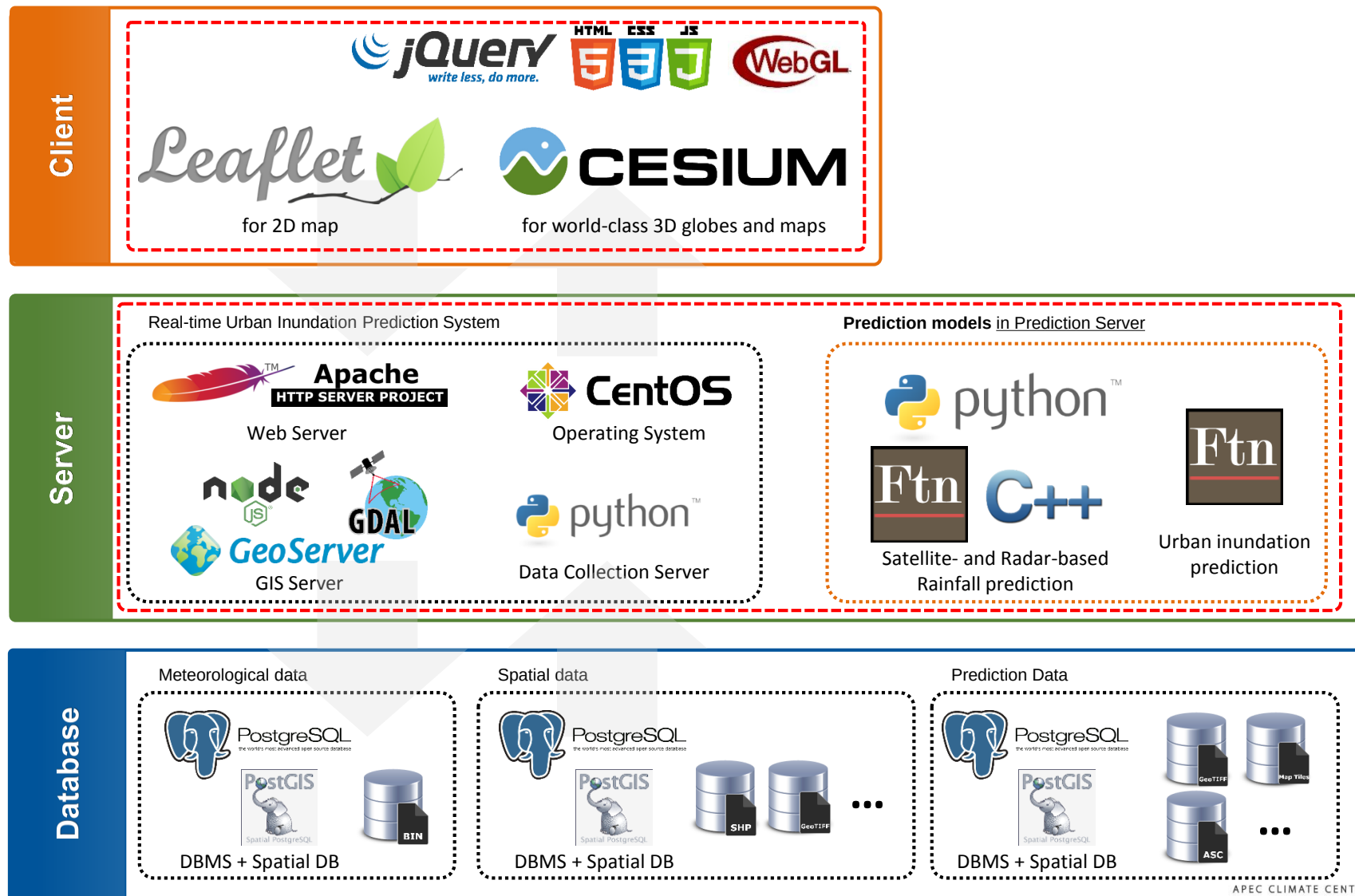
- Map images generated by using tile pyramid structure
 - Google map, Bing Map, Open Street Map, and so on
- Pros:
 - Map image size is small
 - Map image can be quickly loaded over internet
- Cons:
 - Lots of map images are generated by the zoom level
 - Tile map creation takes a long time
- Creation process of tile map
 - At each zoom level, the map is divided into tiles and only the tiles that overlap the screen are downloaded and rendered. Each tile is square and the map is divided into tiles as follows:
 - At zoom level 0, one tile represents the entire world. The coordinates of that tile are $(x, y) = (0, 0)$.
 - At zoom level 1, the world is divided into 4 tiles arranged in a 2 x 2 grid.
 - At zoom level N, the world is divided into 4^N tiles arranged in a $2^N \times 2^N$ grid.



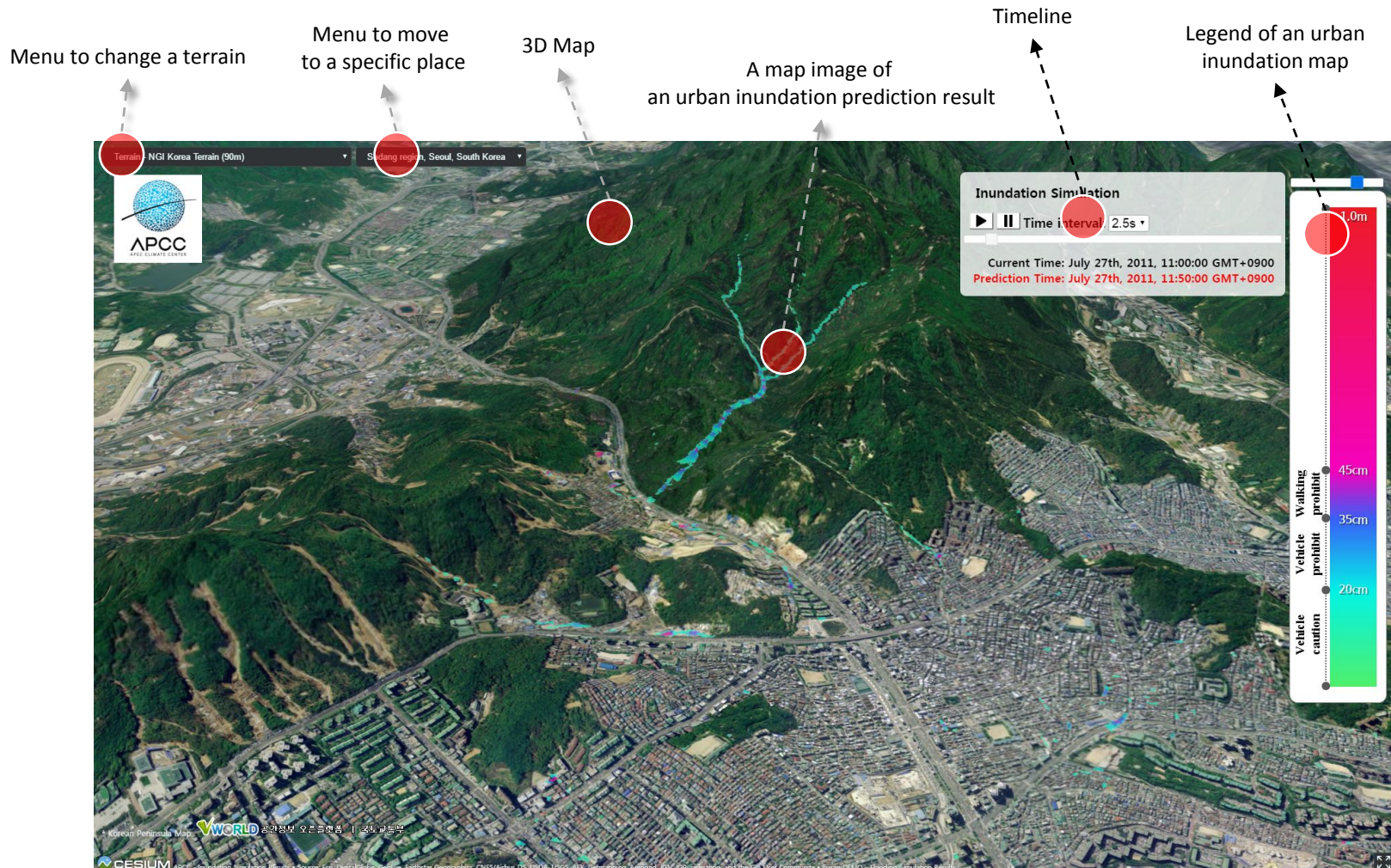
System Architecture



FOSS4G in System Architecture



Layout of Demo System



Demonstration

Terrain - NGI Korea Terrain (90m)

City



Inundation Simulation

▶ || Time interval: 3.0s ▼

Current Time: July 27th, 2011, 11:00:00 GMT+0900



* Korean Peninsula Map:  공간정보 오픈플랫폼 | 국토교통부

 APCC - Inundation Simulation Results • Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Demonstration with 3D Building



Future Work

Disaster Risk Management Platform

Internet of Things



<source: <http://bb-smartsensing.com/wp-content/uploads/2014/06/bb-wizzard-floodwaters.png>>

Car navigation



<source: <http://performance10.com/PEG/13756607021687.jpg>>

Argumented Reality



<source: http://www.t-immersion.com/sites/default/files/ti_outdoor2.jpg>



Thank you.

ありがとうございます。

Current study on flood inundation in Japan



October 5, 2016
Ujigawa Open Laboratory, Kyoto Univ.

Disaster Prevention Research Institute,
Kyoto University, Japan



Kenji KAWAIKE (川池健司)



Contents

- Recent flood inundation disasters in Japan
 - Damage of Kyoto caused by Typhoon 1318
 - Kanto Tohoku heavy rainfall in 2015
- Study on numerical simulation of the Kinu River flood
- Summary

Recent flood inundation disasters in Japan

Study on numerical simulation of the Kinu River flood

Summary



Kanto Regional Development Bureau,
Ministry of Land, Infrastructure, Transport and Tourism, Japan



Damage of Kyoto caused by Typhoon 1318

Outline

3:00, Sep. 13, typhoon No.18 originated.
6:00, Sep. 16, air pressure of 965 hPa was recorded.
8:00, Sep. 16, the typhoon landed on Toyohashi City.

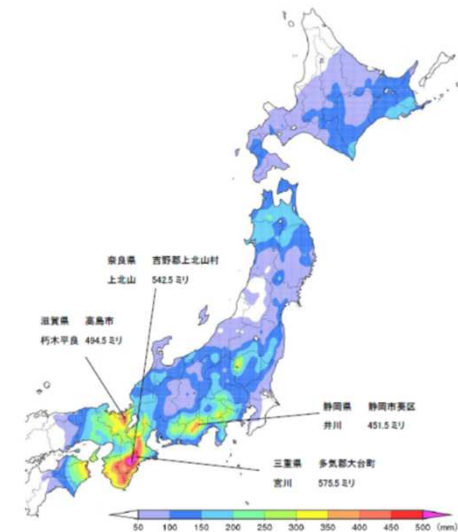
Total Precipitation during Sep. 15-16

Miyagawa, Mie Pref. 575.5mm

Kamikitayama, Nara Pref. 542.5mm

Totally 6 people were killed and 1 person was missing all over the country.

Evacuation advisory or order was issued for 500,000 households, 1.2 million people in the Kinki Region.



(b) 9月15日～16日の総降水量



Damage of Kyoto caused by Typhoon 1318

Principal affected areas

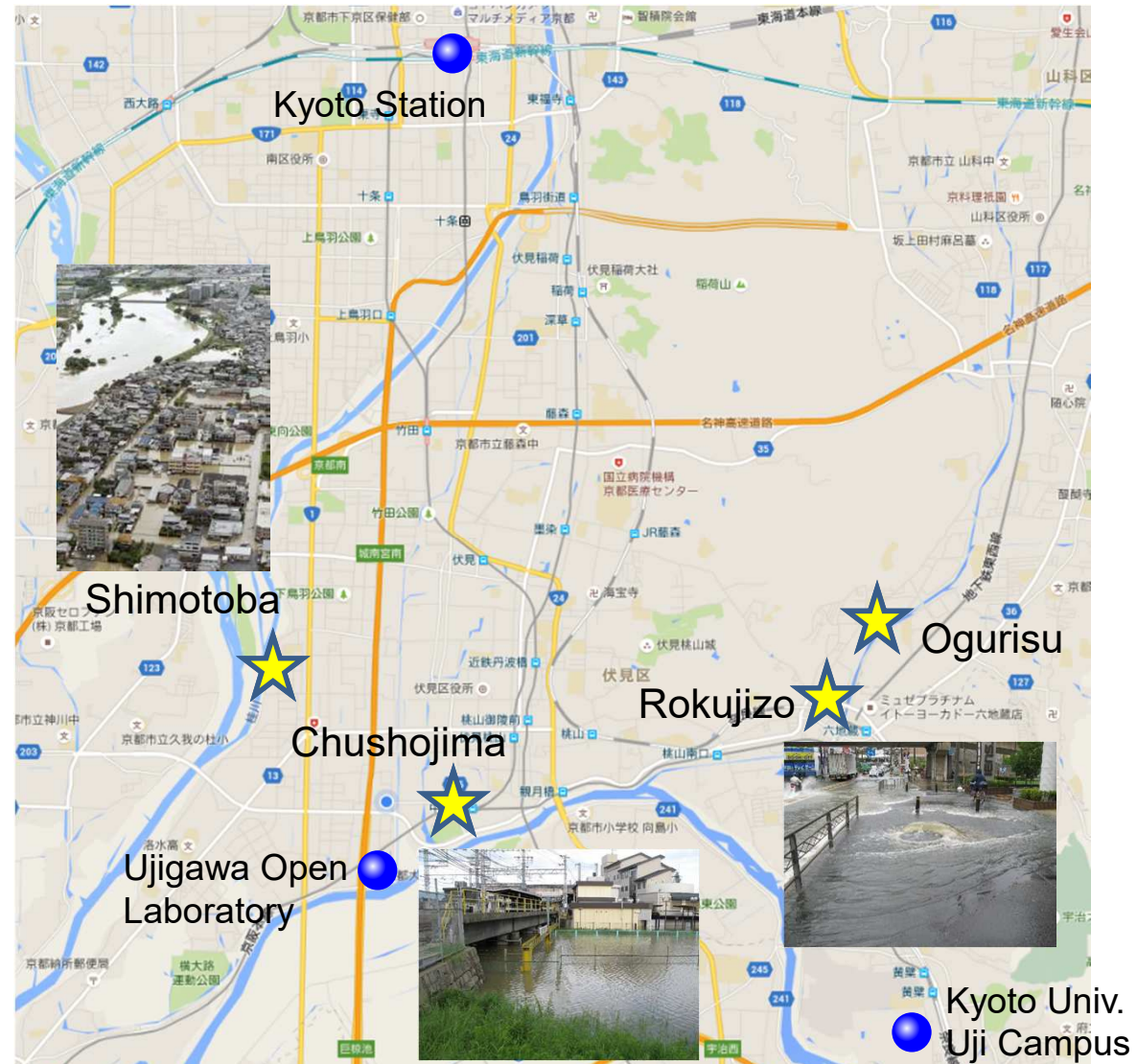




Damage of Kyoto caused by Typhoon 1318



Katsura River
around the Togetsu Bridge
at Arashiyama
(Asahi Shimbun)





Damage of Kyoto caused by Typhoon 1318



Yamashina River near Rokujizo Sta.





Damage of Kyoto caused by Typhoon 1318



Overflow from a manhole at Rokujizo (六地藏)



Damage of Kyoto caused by Typhoon 1318

Submerged underpass next to the Chushojima (中書島) Sta.





Damage of Kyoto caused by Typhoon 1318



**Inundation at the ●● Open Laboratory of ▲▲
University
near the Chushojima Sta.**



Damage of Kyoto caused by Typhoon 1318



Ogurisu Area

A staff of pumping station was exhausted for a long time operation of the pumps. Stopping the pumps, he was trying to remove some obstacle in the pump, but failed and was injured to lose his consciousness.

The pumps remained stopping and the sluice gate is closed. Stormwater continued to be stored in the residential area.

Consequently, this area was severely inundated with 2 m depth in some area.

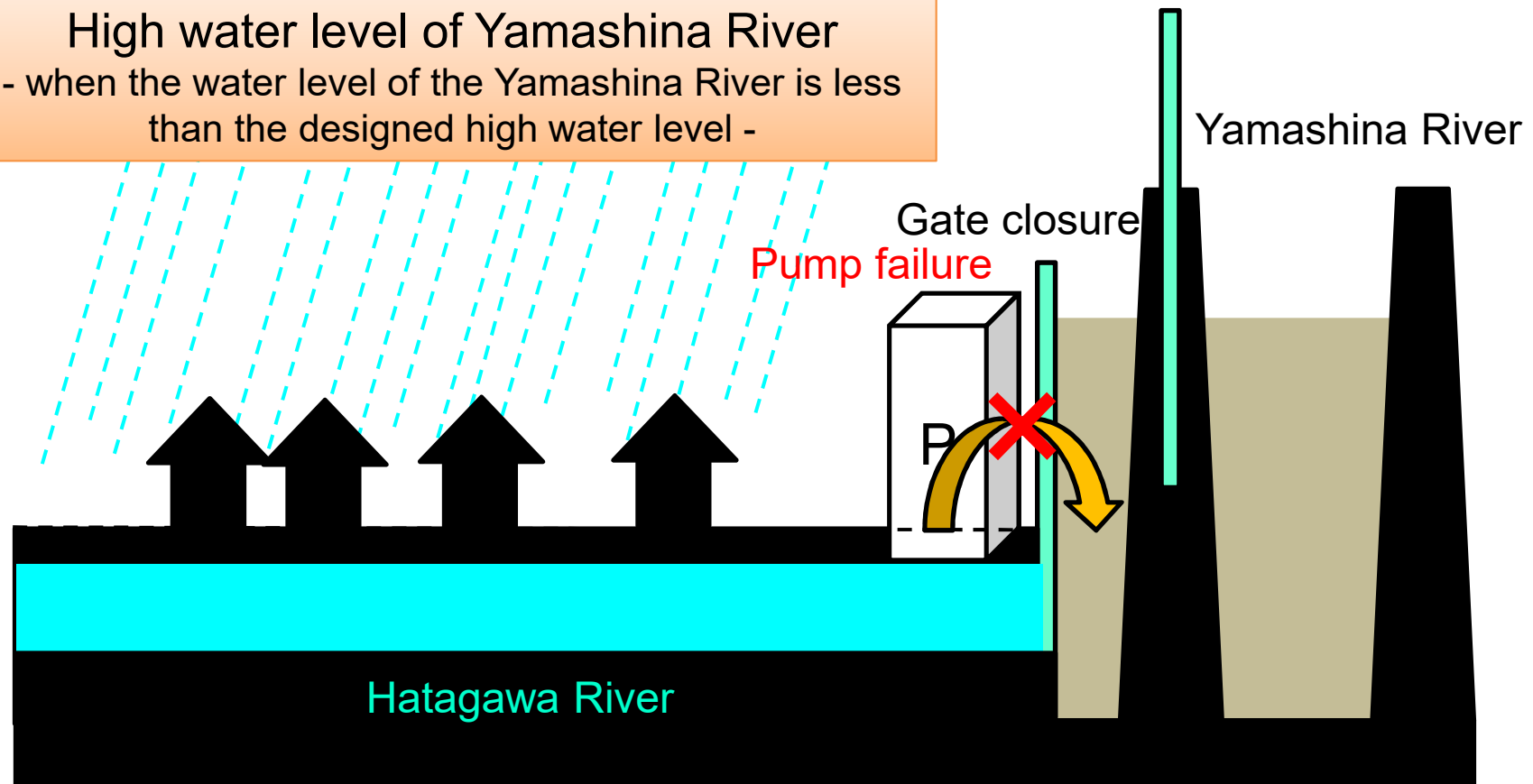
According to the Kyoto City guideline, one more staff must have been there, but wasn't because of simultaneous occurrence of heavy rainfall in all over the city area.



Damage of Kyoto caused by Typhoon 1318

What happened in Ogurisu?

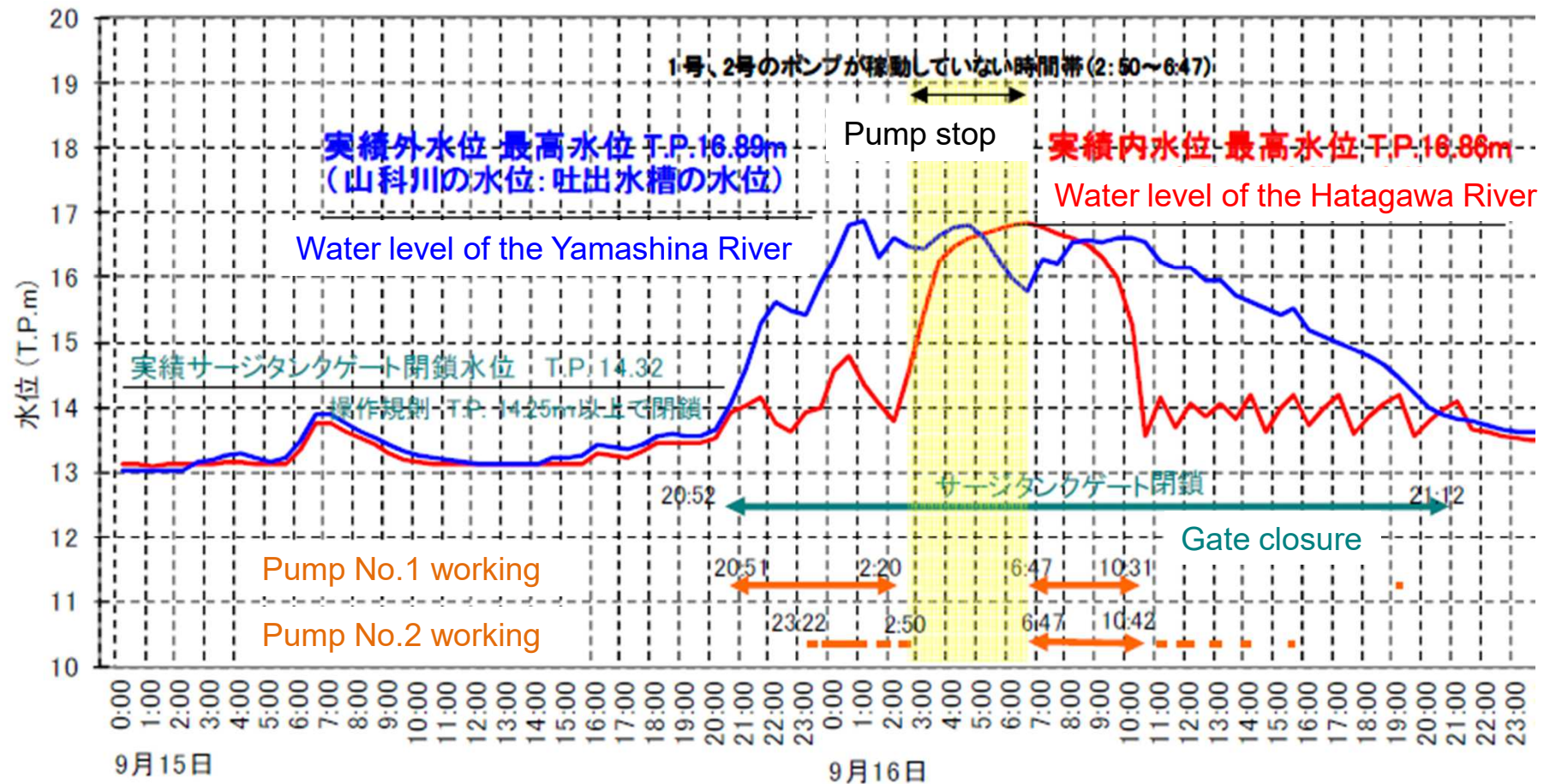
High water level of Yamashina River
- when the water level of the Yamashina River is less than the designed high water level -





Damage of Kyoto caused by Typhoon 1318

What happened in Ogurisu?





Damage of Kyoto caused by Typhoon 1318

(Kyoto Shimbun)



-  Inundated area due to pump failure
-  Inundated area with ordinary pump operation

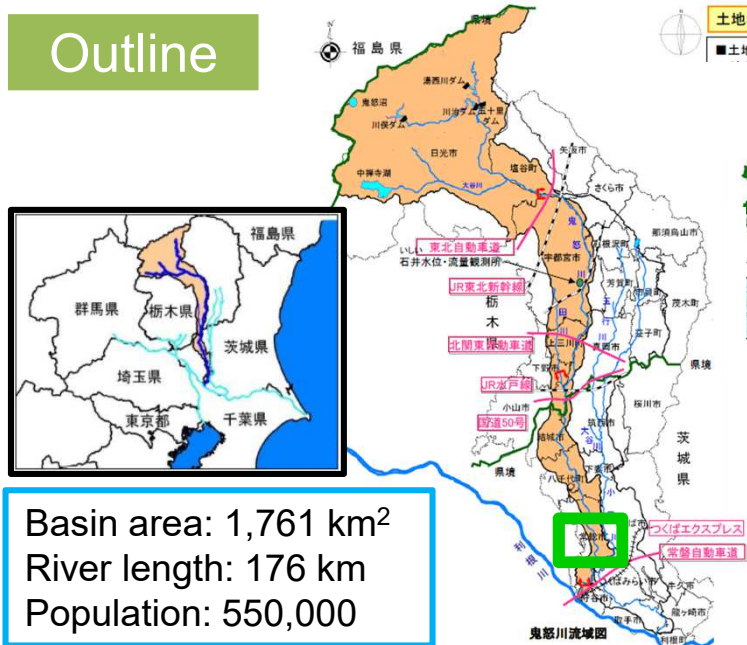
Inundated area estimated
by Kyoto City





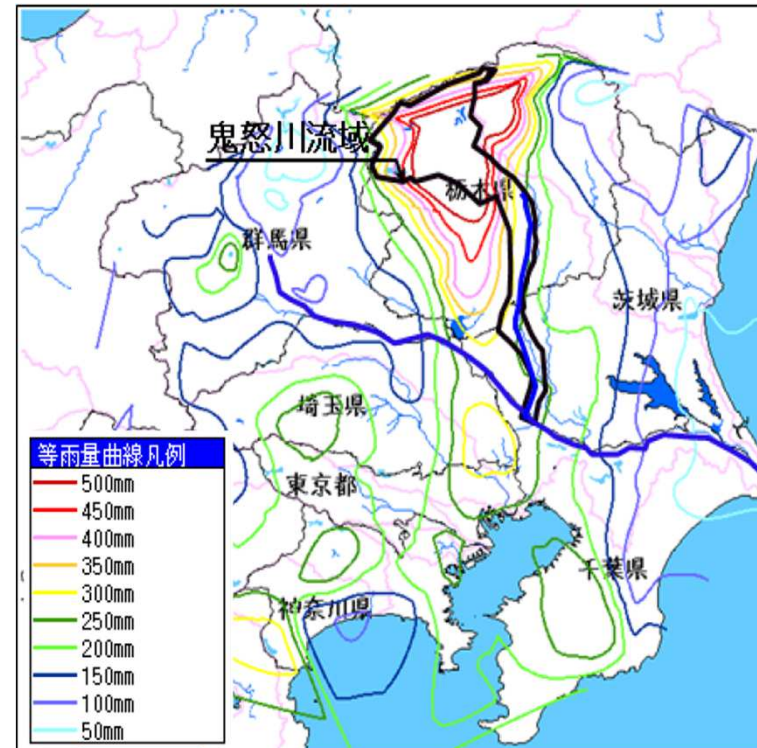
Kanto Tohoku heavy rainfall in 2015

Outline

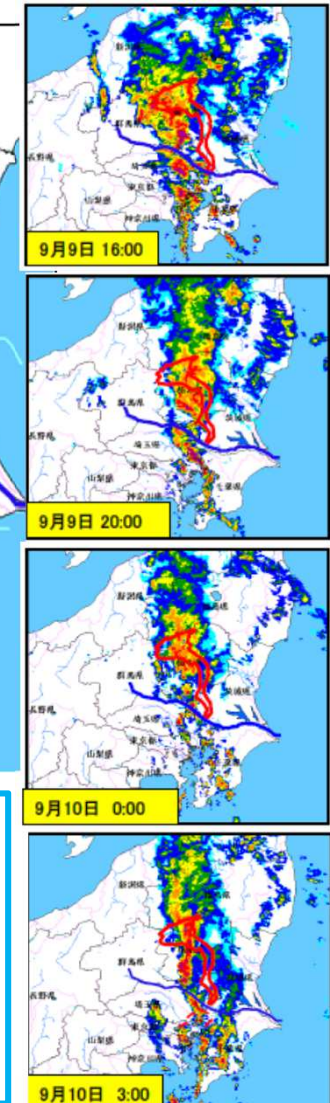


561.5 mm precipitation during 24 hours at Ikari

↓
Dyke breach and overtopping happened in Joso City.
Totally 8 people were killed,
and 78 people were injured.
More than 20,000 houses were inundated.

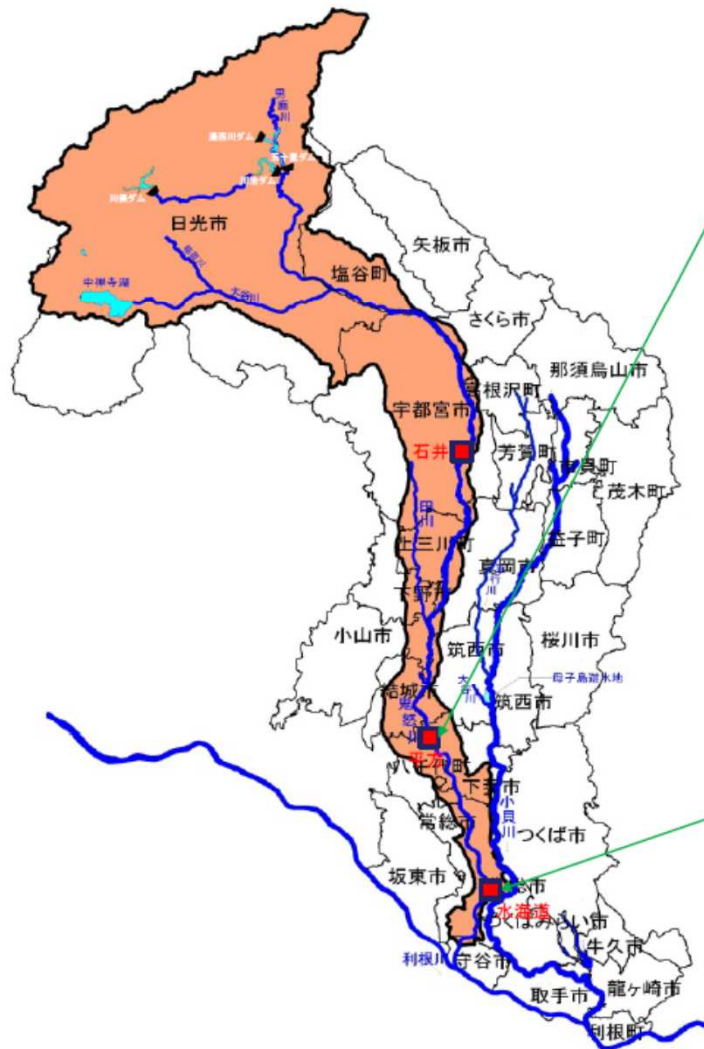


In the upstream basin area, more than 550 mm precipitation was observed during 24 hours.
But the damage was concentrated in the downstream area.

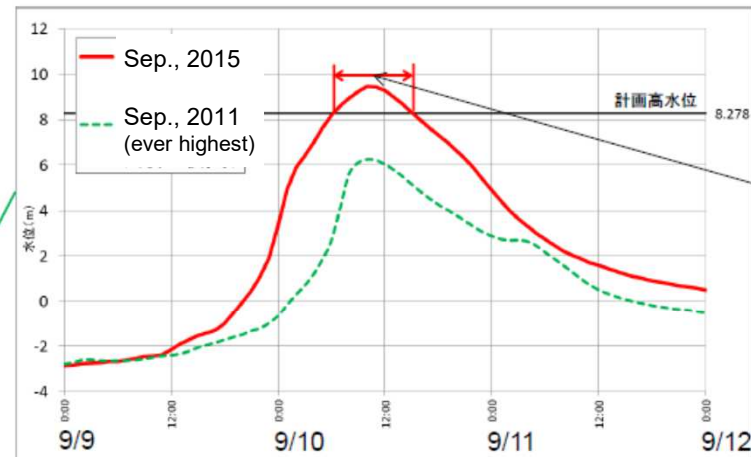




Kanto Tohoku heavy rainfall in 2015



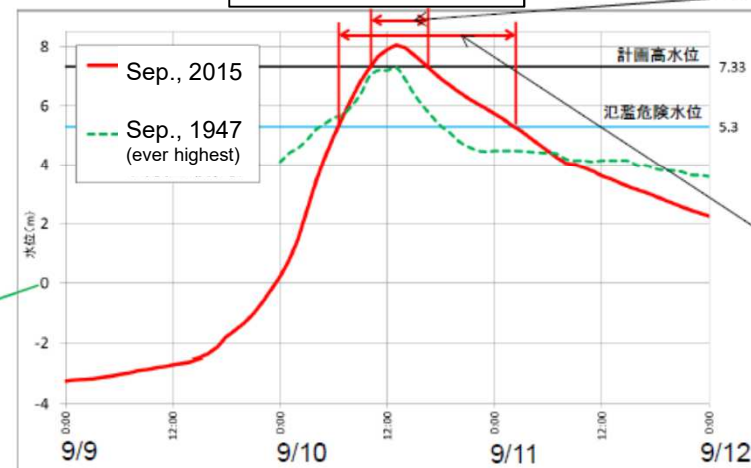
Hirakata



Exceeding the designed high water level (for 8 hours)

※ゼロ点高: YP+22.044m
※昭和25年から観測開始(時刻水位)

Mitsukaido



Exceeding the designed high water level (for 5 hours)

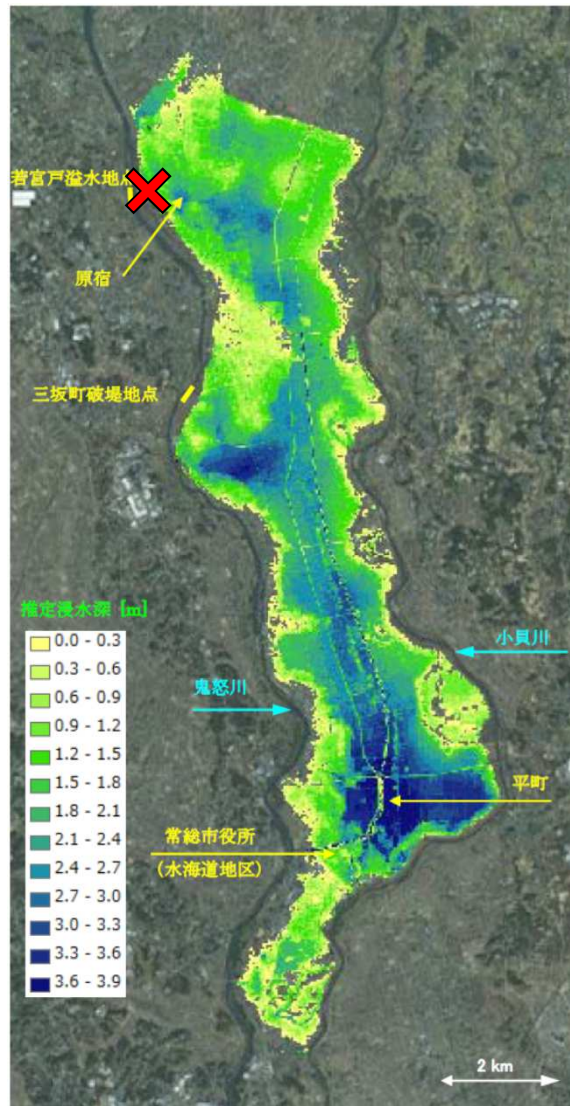
Exceeding the dangerous water level (for 19 hours)

※ゼロ点高: YP+9.914m
※昭和11年から観測開始(時刻水位)

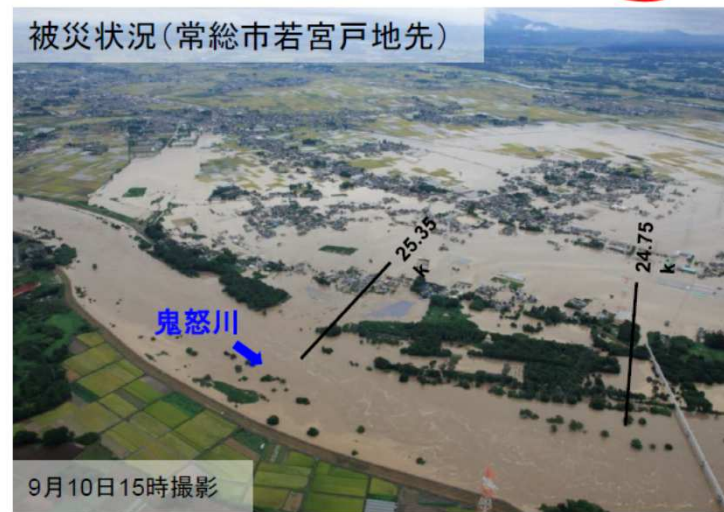
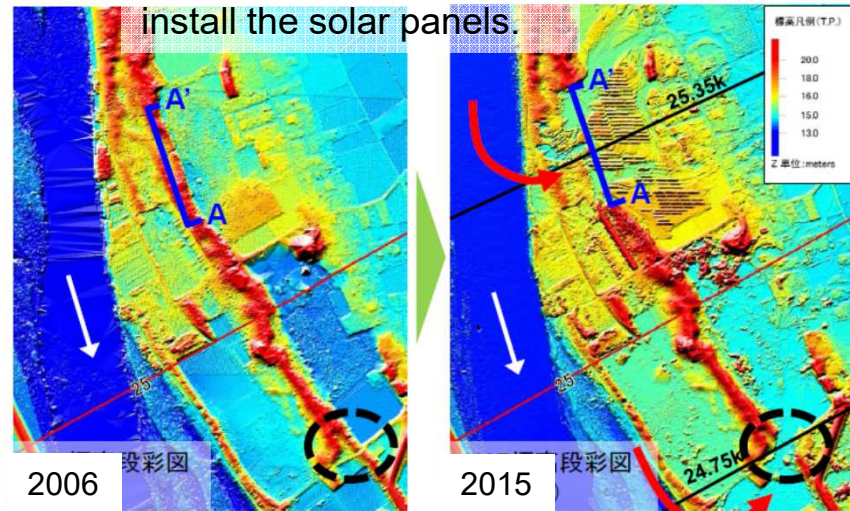
※氾濫危険水位は最新の設定水位を記載。
※横軸の時刻は今回出水の時刻を表示。
※平成27年9月洪水に関する数値は速報値であり、今後の精査により変更する可能性があります。



Kanto Tohoku heavy rainfall in 2015



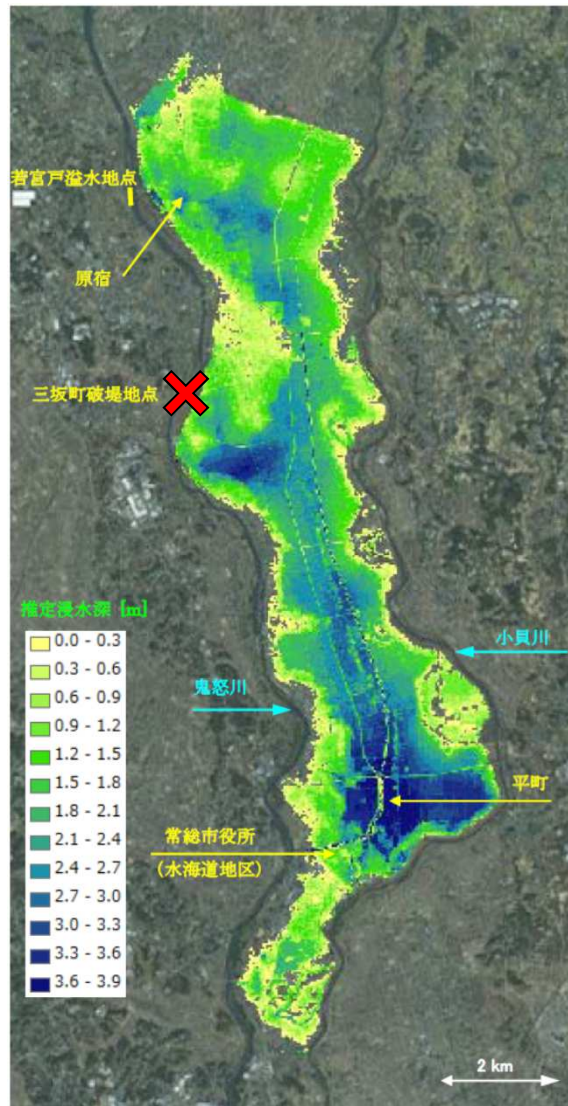
Elevation is decreased to
install the solar panels.



(All the photos are from MLIT)



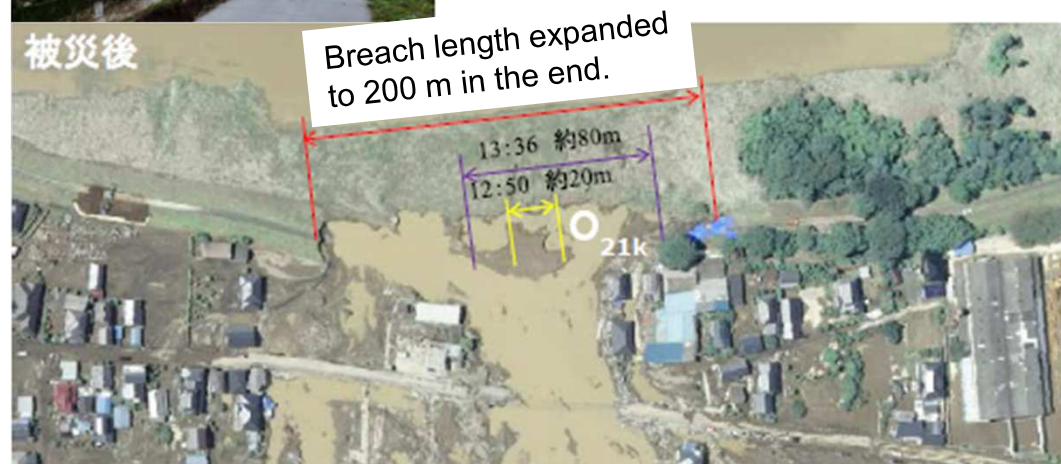
Kanto Tohoku heavy rainfall in 2015



Dyke breach was initiated by overtopping.



(All the photos are from MLIT)





Kanto Tohoku heavy rainfall in 2015

Information from MLIT to Joso City

(cited from JSCE report)

22:54, Sep. 9 The water level will reach the dangerous level at Kawashima.

Overtopping will happen at Wakamiyado.

Promote to prepare of evacuation advisory and shelters.

Predicted water level
at each point

23:00 cautious level

00:15 dangerous level

1:23, 2:06, Sep. 10 Promote to issue of evacuation advisory and order.

4:00, Sep. 10 Send the assumed inundation map with overtopping at Wakamiyado.

4:48, Sep. 10 Promote to use the assumed inundation map.

5:58, Sep. 10 Overtopping will start at Wakamiyado.

(around 6:30 overtopping at Wakamiyado)

06:30 inundation occurrence

7:11, Sep. 10 Overtopping will occur somewhere in the lower reaches.

08:00 inundation occurrence

11:42, Sep. 10 Overtopping at Kami-misaka

(around 12:50 dyke breach at Kami-misaka)

13:20 inundation occurrence



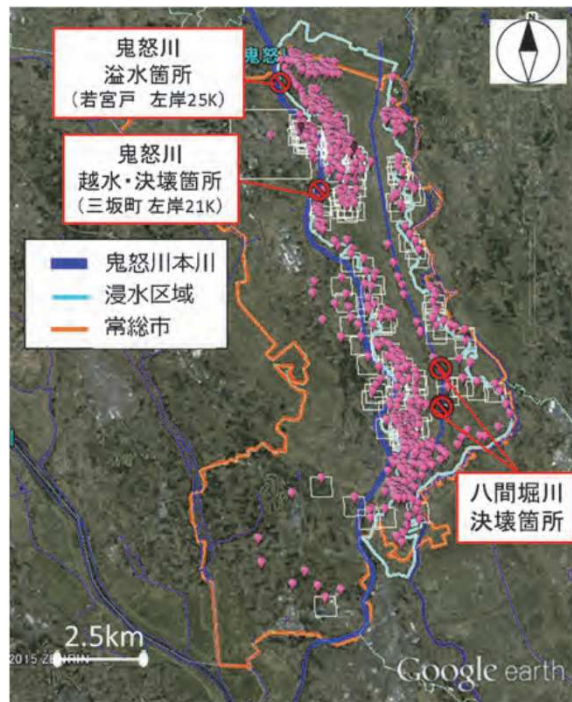
Kanto Tohoku heavy rainfall in 2015

Evacuation of Joso City residents

(cited from JSCE report)

Hearing survey (Chuo Univ.)

Number of answer: 516



Locations of hearing survey

災害時自宅にいた人の避難状況 (N=489)

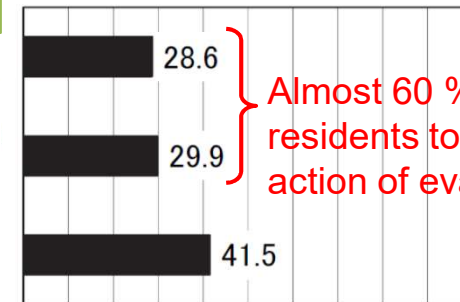
Did you evacuate?

I evacuated to the shelter.

I evacuated somewhere safe other than the shelter.

I didn't evacuate, but stayed at home.

0 10 20 30 40 50 60 70 80 90 100 (%)



Almost 60 % of residents took some action of evacuation.

Have you ever seen the hazard map?

(N=516)

I checked it with my family members.

I know how dangerous my place is to see it.

I know how dangerous my place is even without seeing it.

I don't know what it is, and have never seen it.

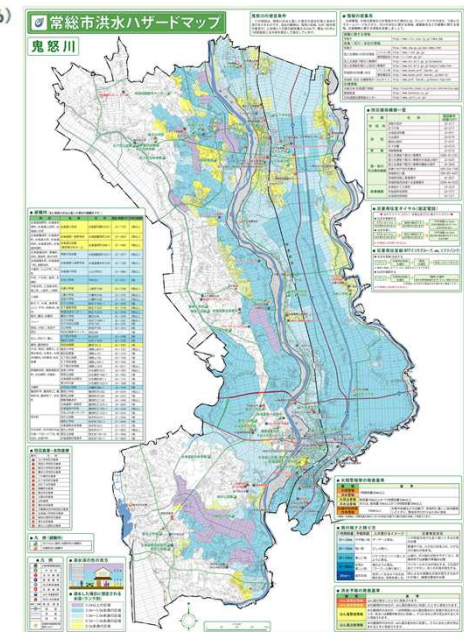
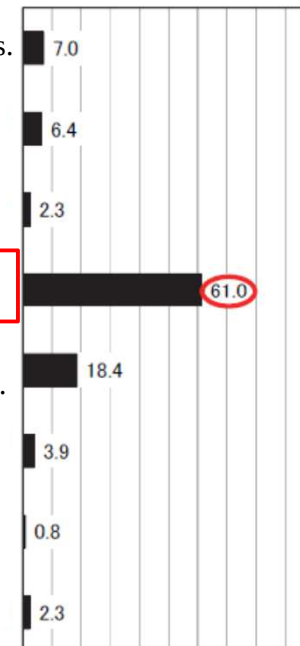
I have ever seen, but don't know where it is.

I know where it is, but don't know what it

I don't care because I will check it when it is necessary.

No answer

0 10 20 30 40 50 60 70 80 90 100 (%)





Kanto Tohoku heavy rainfall in 2015

Evacuation of Joso City residents (cited from JSCE report)



Approximately 4,300 people were rescued by helicopters or boats.



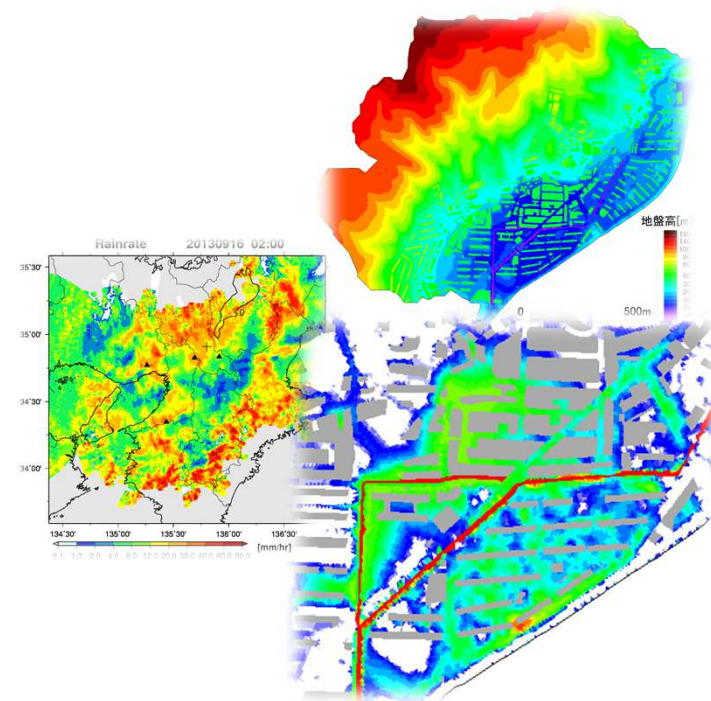
(Photos are from Mainichi Shimbun)

Real-time prediction of flood propagation might have contributed to help them with early evacuation.

Recent flood inundation disasters in Japan

Study on numerical simulation of the Kinu River flood

Summary



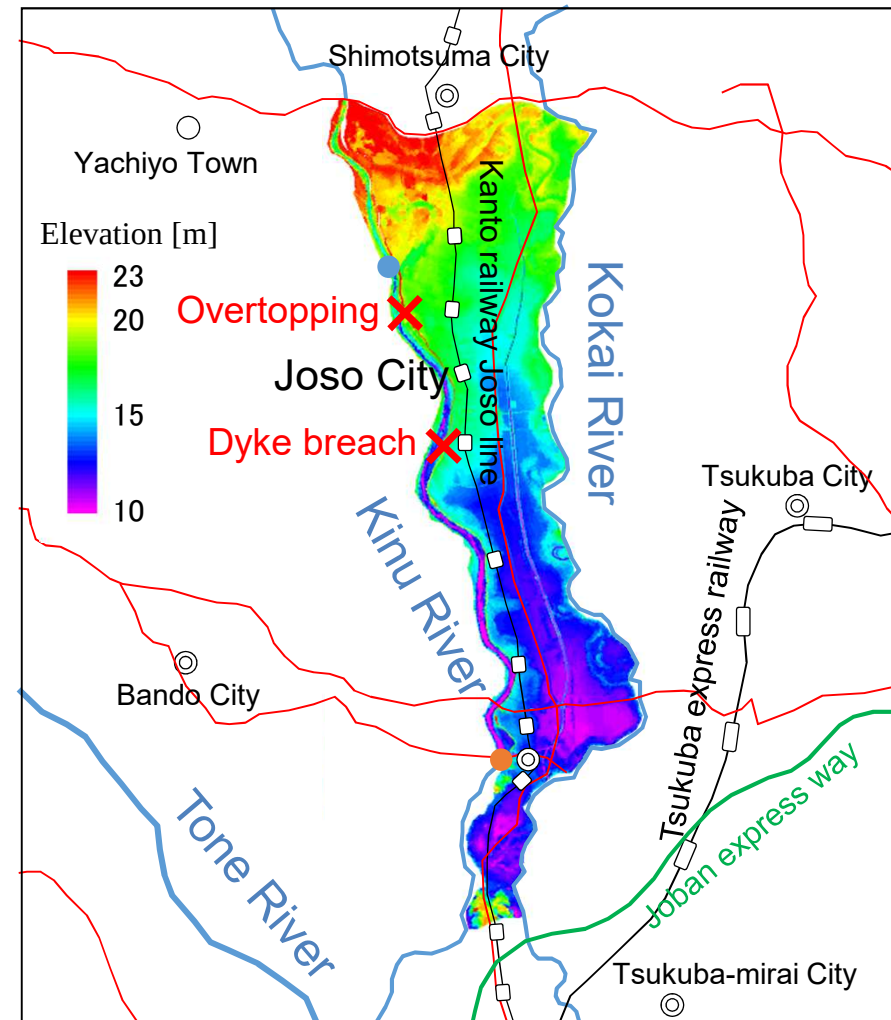


Study on numerical simulation of the Kinu River flood

We tried to carry out numerical simulations of inundation water flow and sedimentation.

The model used here is basically two-dimensional inundation flow model.

The study area is between the Kinu River and the Kokai River.





Study on numerical simulation of the Kinu River flood

Governing equations

Continuity equation of fluid

$$\frac{\partial h}{\partial t} + \frac{\partial(uh)}{\partial x} + \frac{\partial(vh)}{\partial y} = r_e - q_g + i$$

x, y-directional momentum equations of fluid

$$\begin{aligned} \frac{\partial(uh)}{\partial t} + \frac{\partial(u^2h)}{\partial x} + \frac{\partial(uvh)}{\partial y} &= -gh \frac{\partial(z_b + h)}{\partial x} - \frac{\tau_{bx}}{\rho_T} \\ \frac{\partial(vh)}{\partial t} + \frac{\partial(uvh)}{\partial x} + \frac{\partial(v^2h)}{\partial y} &= -gh \frac{\partial(z_b + h)}{\partial y} - \frac{\tau_{by}}{\rho_T} \end{aligned}$$

Continuity equation of sediment component

$$\frac{\partial(Ch)}{\partial t} + \frac{\partial(Cuh)}{\partial x} + \frac{\partial(Cvh)}{\partial y} = -Cq_g + iC_*$$

Continuity equation of bed elevation

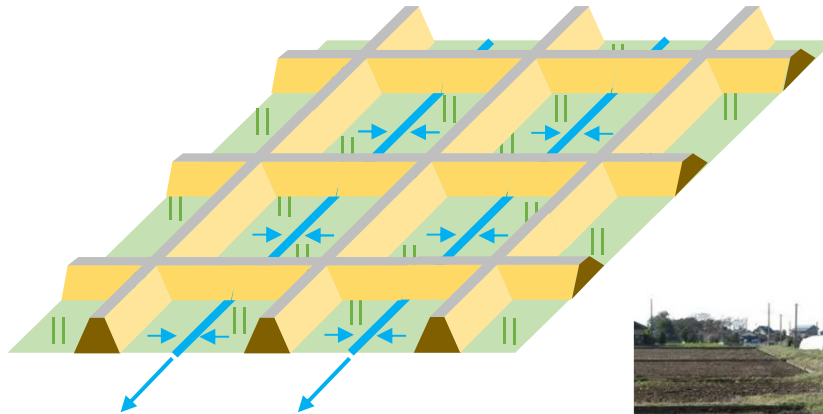
$$\frac{\partial z_b}{\partial t} + i = 0$$



Study on numerical simulation of the Kinu River flood

Modeling of paddy field

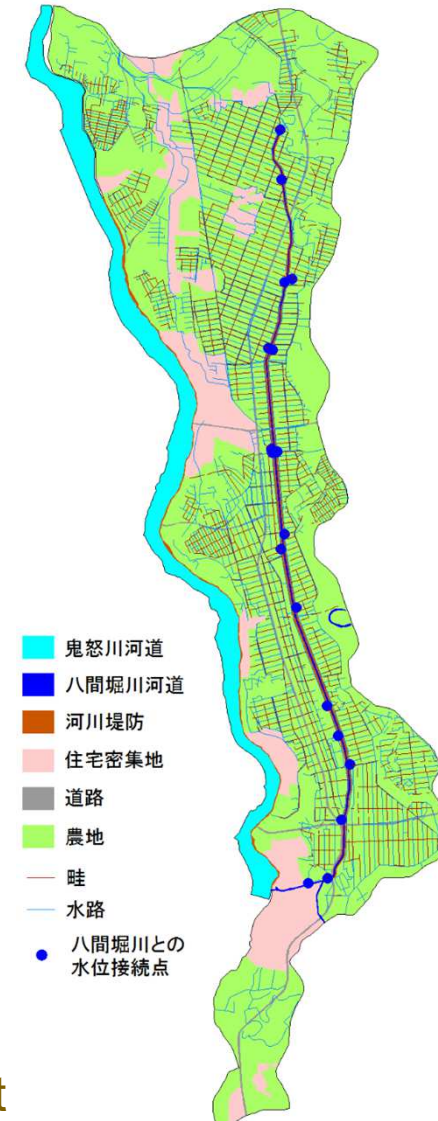
Most of the inundated area is used as paddy field.



Irrigation channel



Ridge = higher street





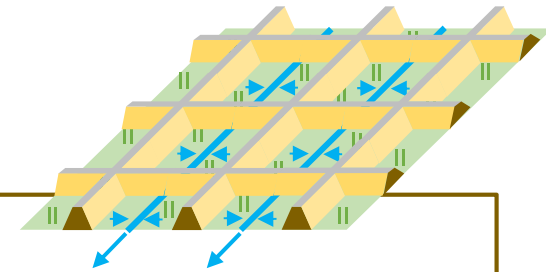
Study on numerical simulation of the Kinu River flood

Modeling of paddy field

Most of the inundated area is used as paddy field.

Ridge → vertical wall of 0.5 m high

- If the water depth exceeds the ridge height, overflow discharge is calculated by means of weir equation.



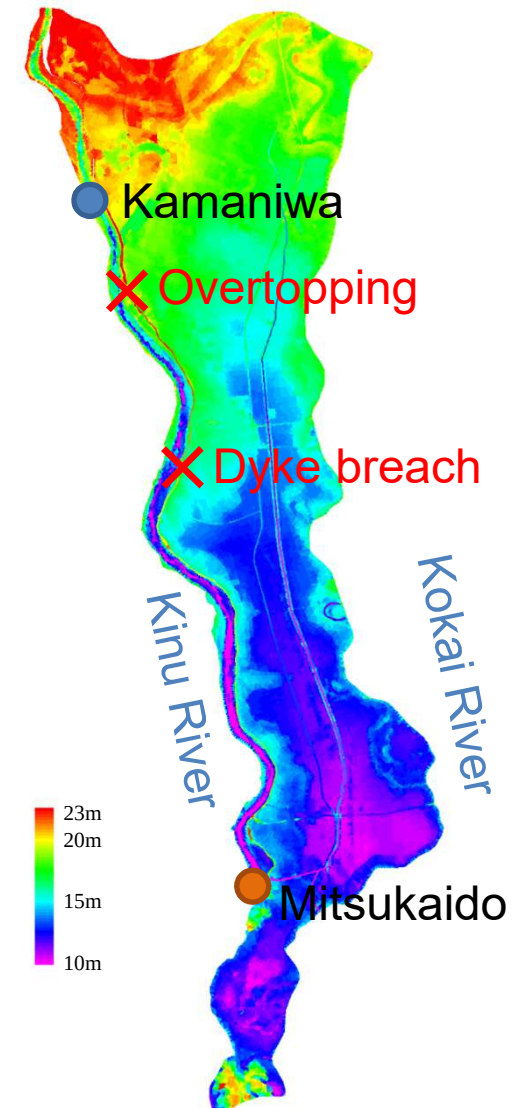
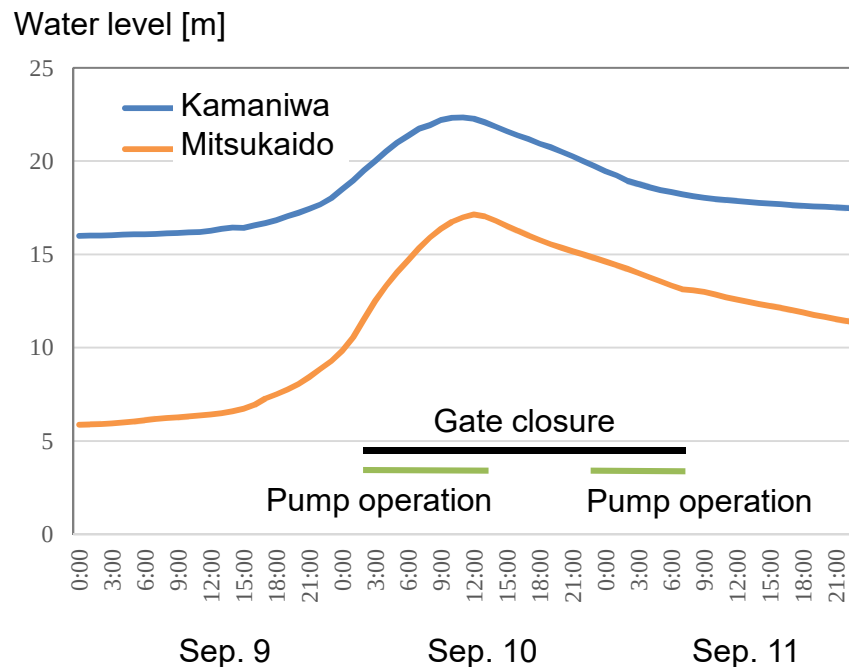
Irrigation channel → One-dimensional channel network (node - link)
5.0 m wide & 2.5 m deep
2.0 m wide & 1.0 m deep

- Divided into 20 m segments, 1-D unsteady flow computation
- Interaction discharge with overland meshes is calculated by means of weir equations, comparing the water levels.
- If the thickness of deposition reached the channel depth, there is no inflow discharge from the ground surface.
- Connected to the Hakkembori River at 20 points



Study on numerical simulation of the Kinu River flood

- Triangular unstructured meshes of 100 m size (35,000)
- Observed water levels at Kamaniwa and Mitsukaido are used as the boundary conditions.
- Forerunning rainfall at Shimotsuma
- Uniform sediment concentration in the Kinu River





Study on numerical simulation of the Kinu River flood

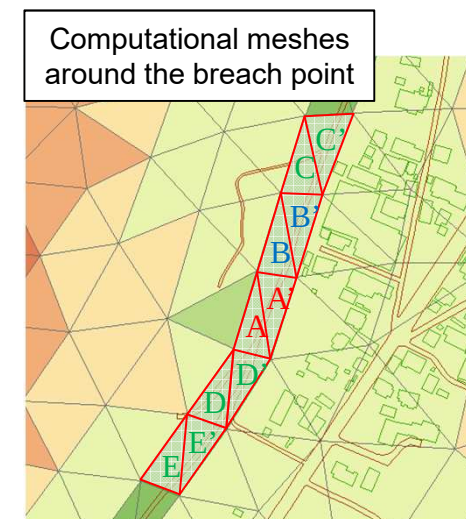
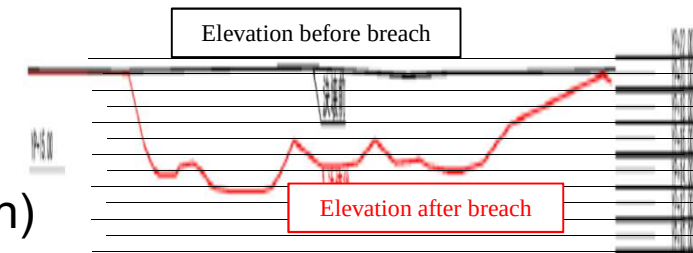
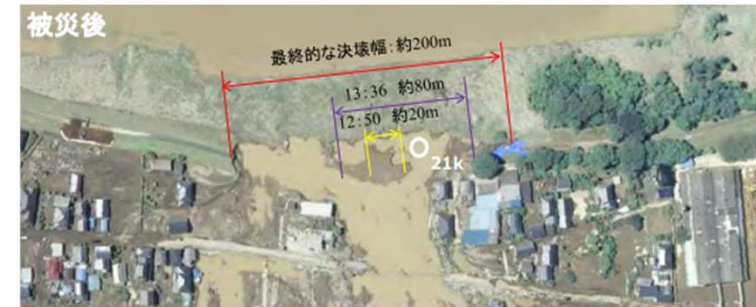
Modeling of dyke breach

Length 20 m at 12:50, 80 m at 13:36
linearly expanding between them
(mesh **A**, **A'** → mesh **B**, **B'**)

After 13:36, expanding at the same speed
up to 200 m
(mesh **C**, **C'** upstream direction,
mesh **D**, **D'** and **E**, **E'** downstream direction)

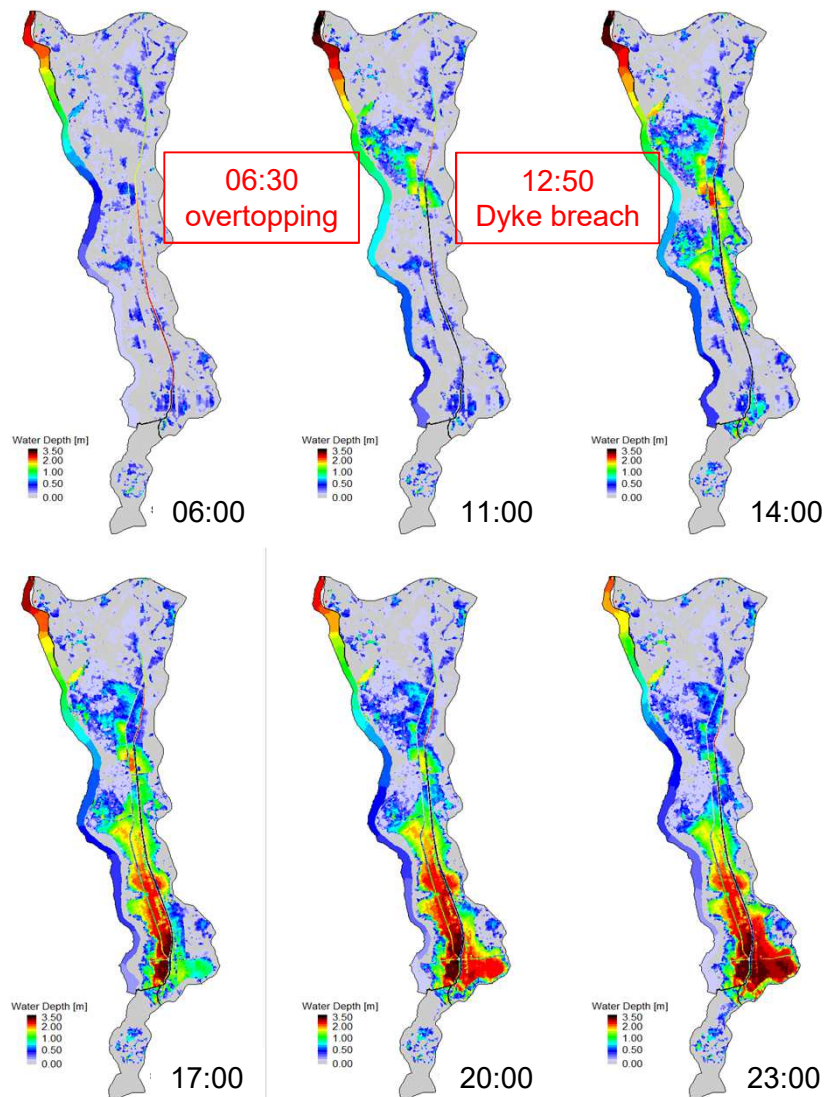
Height The elevation of the breached meshes decreases
to the elevation of after-breach instantaneously.

Calculation Flow discharge is calculated using the above
elevation at each time.
The calculated discharge is corrected
depending on the ratio of breach length to
the mesh side length.





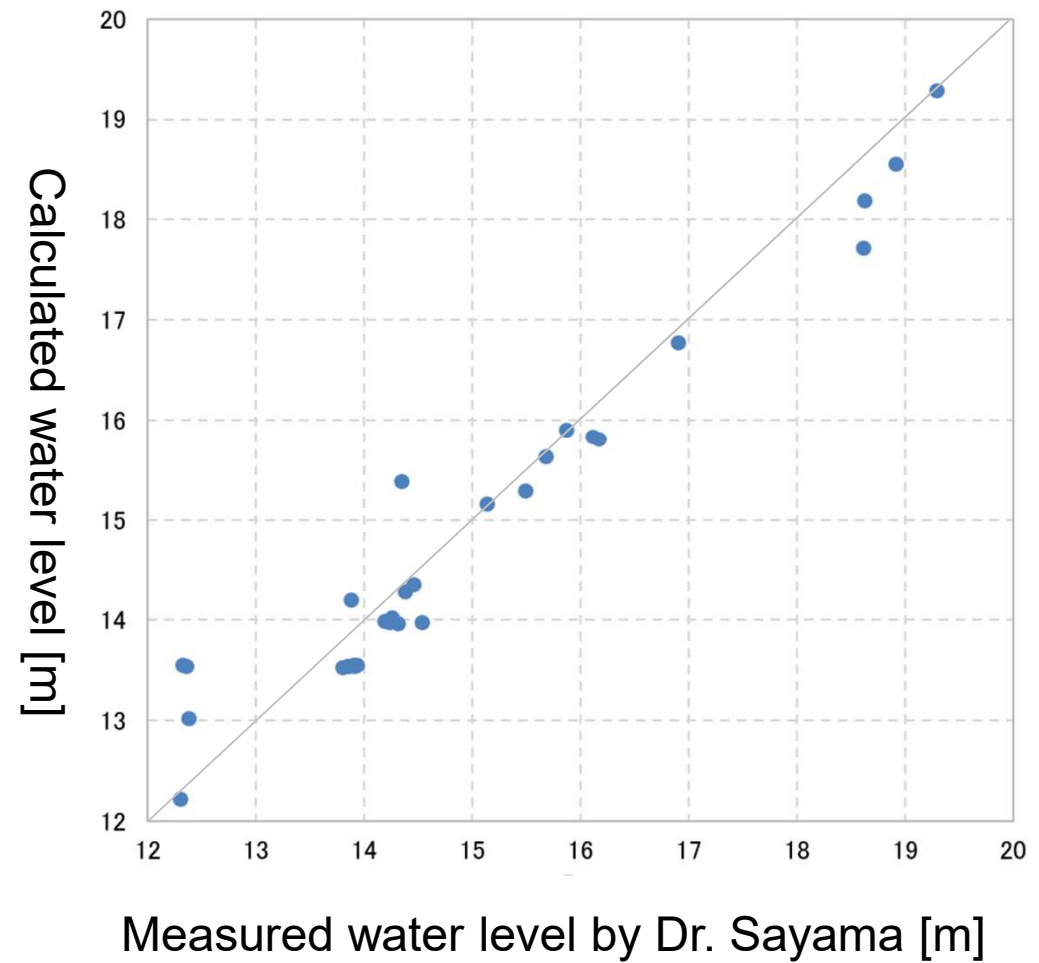
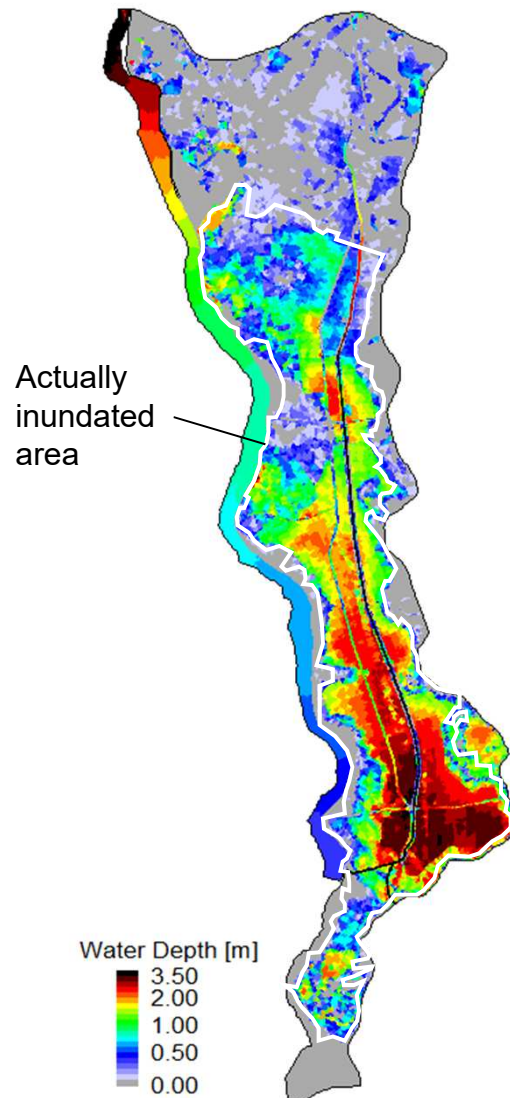
Study on numerical simulation of the Kinu River flood



- Forerunning rainfall was collected to the Hakkembori River through irrigation channels.
- Inundated areas initiated by the forerunning rainfall was overestimated.
- Flood water expanded the inundated area to the southern part through the Hakkembori River and the irrigation channels.
- The main part of the inundation flow arrived at the Mitsukaido area around 17:00.
- The calculated propagation velocity of inundation flow is much faster than the observed one.



Study on numerical simulation of the Kinu River flood





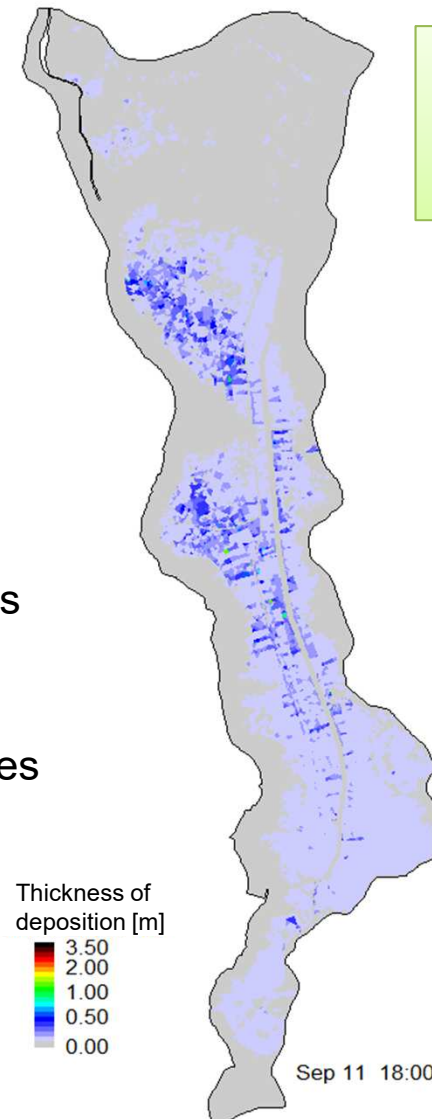
Study on numerical simulation of the Kinu River flood

Deposition on the ground surface (18:00, Sep. 11)

A lot of sediment is deposited around the overtopping point and the dyke breach point.

The maximum height is approximately 50 cm.

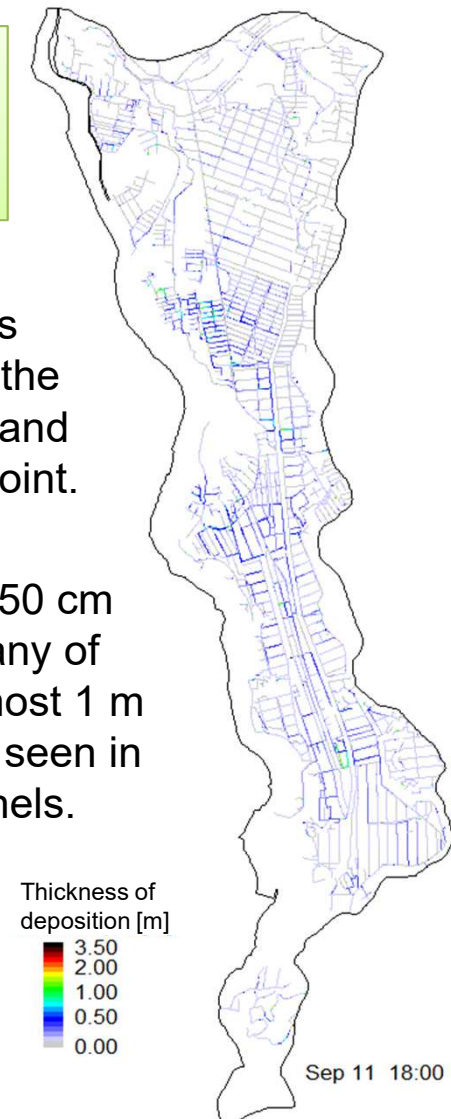
The effects of the ridges can be seen.



Deposition on the irrigation channel (18:00, Sep. 11)

A lot of sediment is deposited around the overtopping point and the dyke breach point.

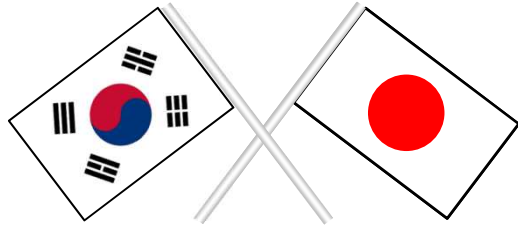
The deposition of 50 cm can be seen in many of channels, and almost 1 m deposition can be seen in some of the channels.





Summary

- Because of increase of intense rainfall, large-scale flood disasters occur in many places. Sometimes large area is inundated with large amount of water, such as the flood disaster of the Kinu River.
- If the real-time prediction was realized, the information of inundation water propagation can be transmitted to the local government.
- However, the local government staffs cannot always utilize those information efficiently.
- The influence of deposited sediment is significant for drainage process of inundated water as well as the direct damage to rice crops.



감사합니다! *Thank you very much
for your kind attention!*

ご清聴ありがとうございました