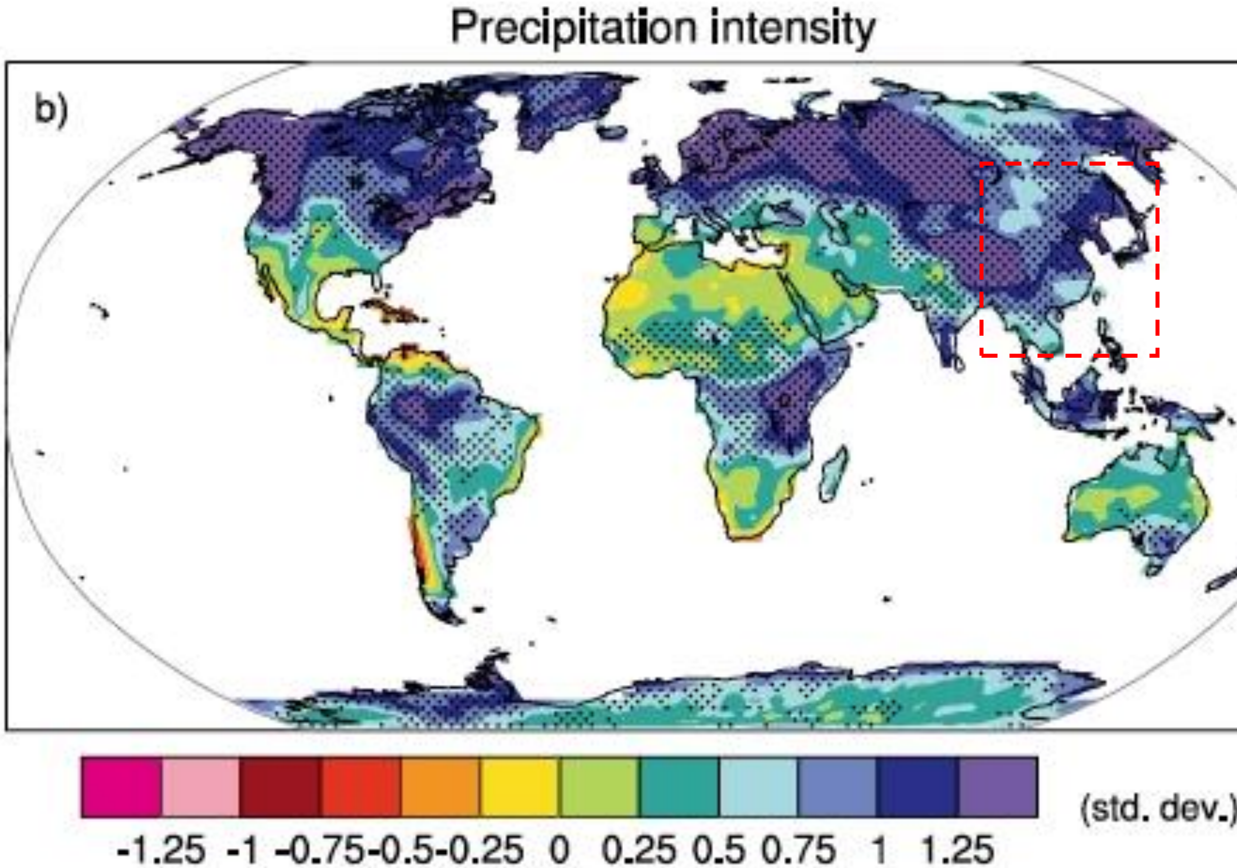
Ensemble forecasts to support decision making at basin scale during heavy Precipitation

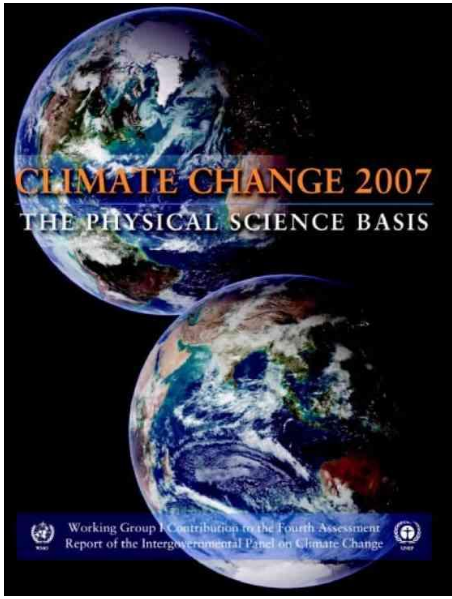
Oliver Saavedra Valeriano[1,2], M. Ryo[1], T. Koike[3], Tinh Ngoc[4]

1)Tokyo Institute of Technology
2) Egypt-Japan University of Science and Technology
3) University of Tokyo
4)Ministry Of Natural Resources and Environment, Vietnam

Projected changes in extremes



IPCC AR4



It is *very likely* that heavy precipitation events will continue to become more frequent. > 90%

Projections for extreme weather events

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[d]	*Virtually certain*[d]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[e]	*Likely (nights)*[d]	*Virtually certain*[d]
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely* > 90%
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely* > 67%
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f,h]	*Likely*[i]

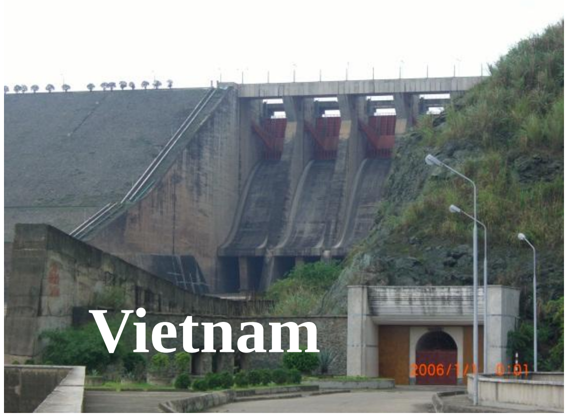
Floods in South-East-Asia

- Heavy rainfall brings expected rainfall for agriculture but they might also turn into floods causing damages.

Need 1: Emission of flood warning to perform evacuation timely

- Basins with existing gated dams when operated effective and jointly they are able to reduce flood damage dramatically.

Need 2: Dam release decision to reduce flood peaks and store volume for water-use



Flood Management tools

- Dam Release Support System (DRESS)

  Goal: Dam release decision support to reduce flood peaks and store volume for water-use

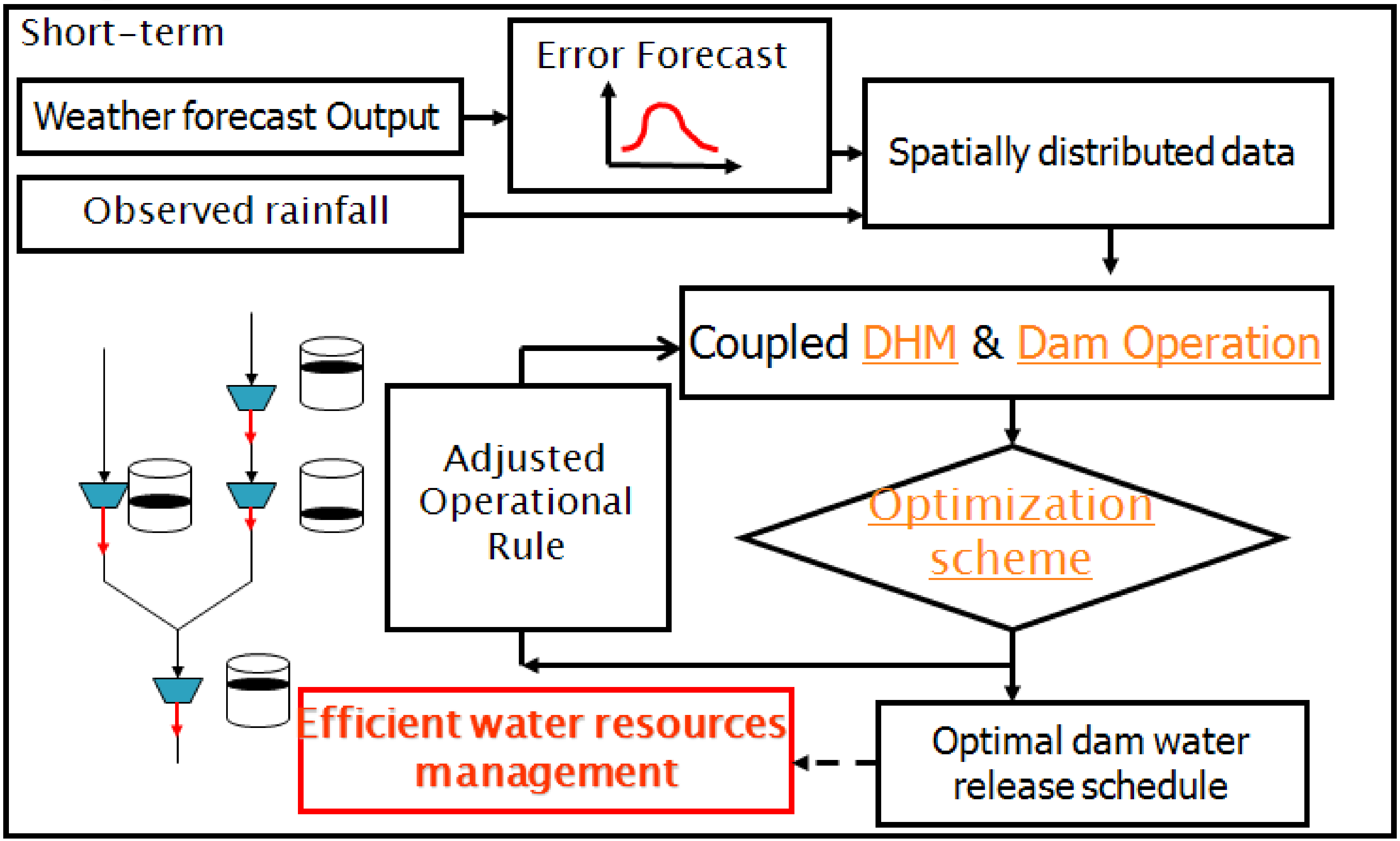
- Flood Warning Support System (FLOWSS)

  Goal: Emit flood warning to perform evacuation timely

Dam REleasе Support System DRESS

- Using Quantitative Precipitation Forecasts
- Based on Ensemble Method
- Applied in Tone River, Japan

DRESS system



Integrated error evaluation

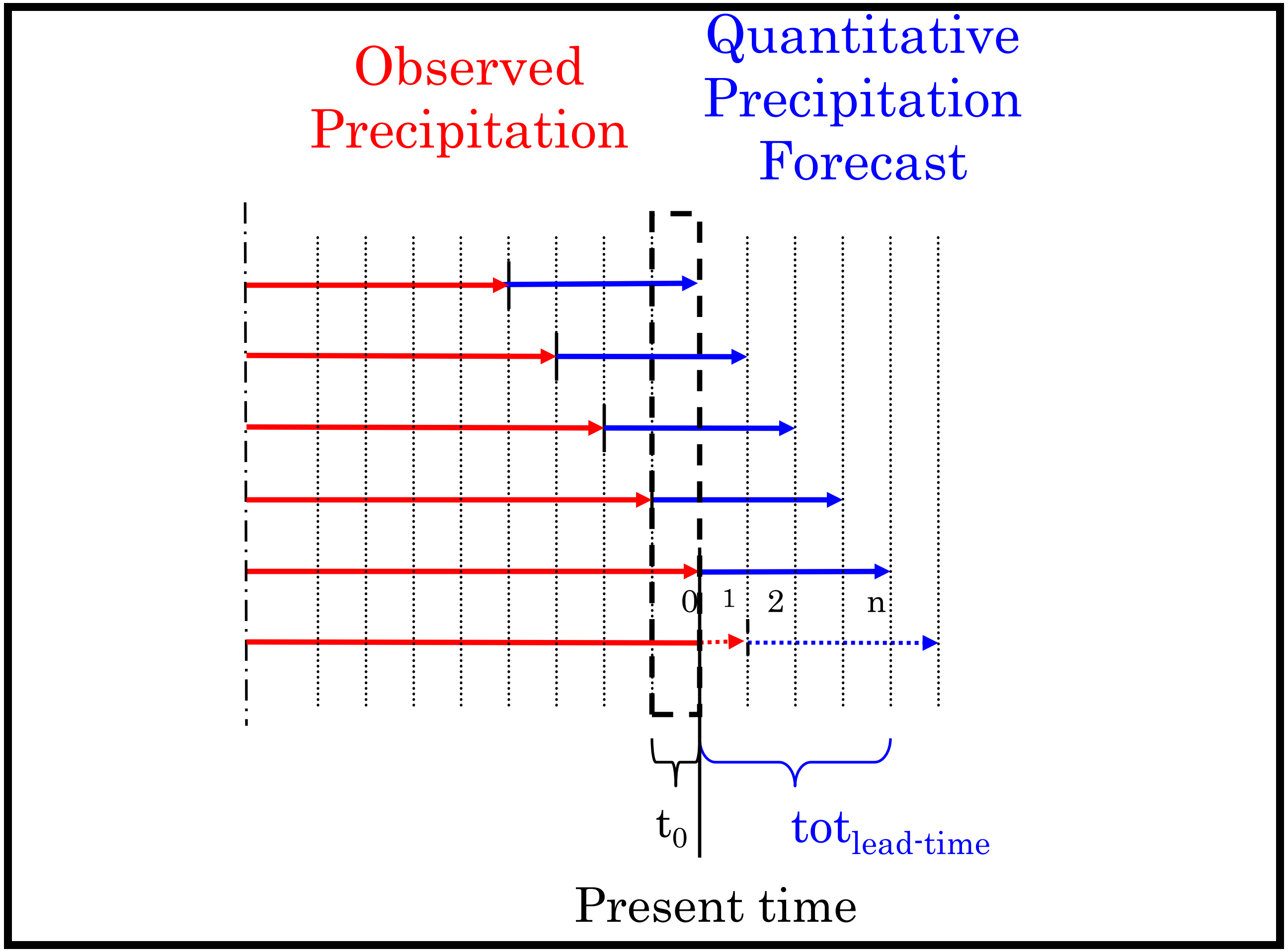
Forecast error can be defined by

1. **Location**: analysis area defined sub-basins

2. **Intensity**: ratio of maxima and mean

3. **Extension**: % of covered evaluated area

Error evaluation window



Intensity **Extension**

$$Total\,ratio = 0.5\times\left\{\frac{High\_Intensity_{QPF}}{High\_Intensity_{OBS}}\right\} + 0.5\times\left\{\frac{Mean\_Intensity_{QPF}}{Mean\_Intensity_{OBS}}\right\}$$

Contingency Table for Rain Events

	Too little	Approx. Correct	Too much
Close	Underestimate	Hit	Overestimate
Far	Missed event	Missed Location	False alarm

Ebert & McBride (2000)

Ensemble member generation of QPF

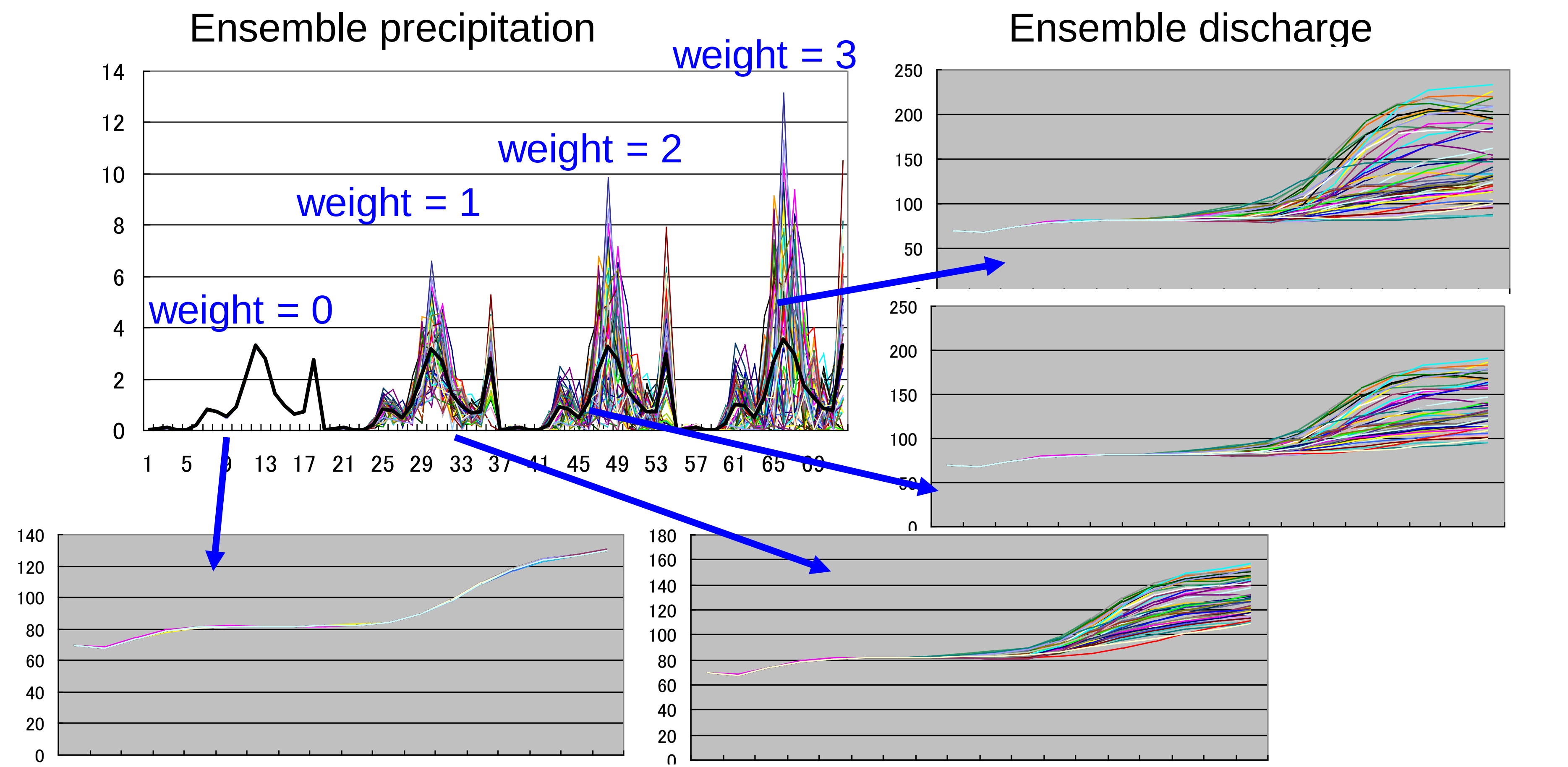
$$GP(x,y)_k = Max\left\{ QPF(x,y) \times (1 + A\varepsilon\, N(0,1) \times wi_{sub} + B\varepsilon\, N(0,1) \times wi_{tot}),\ 0 \right\}$$

N(0,1) : Gaussian normal distribution

Saavedra Valeriano et al., 2010a

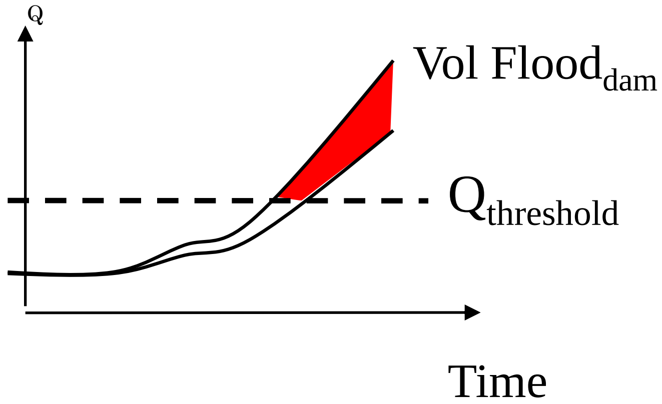
wi_{sub} : weight per sub basin; **wi_{tot}** : weight per area

A, B : preference

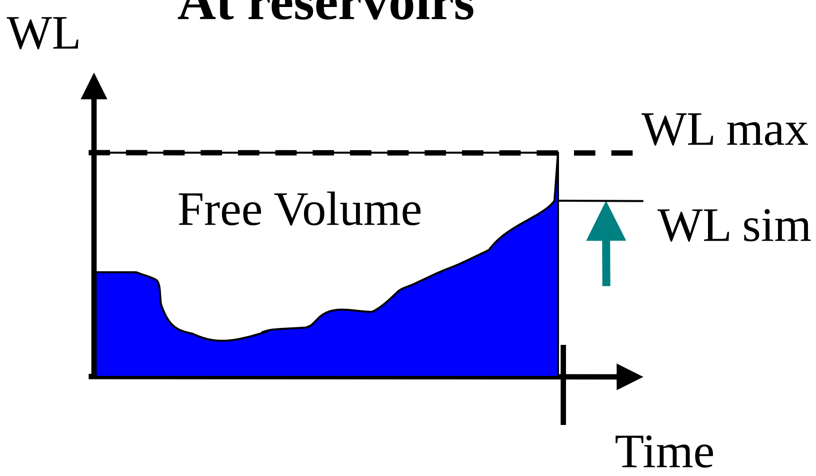


Combined Objective Function

At Control Point



At reservoirs



$$\sum Vol\_free\_dams = \sum Vol\_\max\_dam - Vol\_sim$$

Saavedra Valeriano et al., 2010b

$$Minimize \quad \{Z = weight\_1 * Vol\_flood + weight\_2 * \sum Vol\_free\_dams\}$$

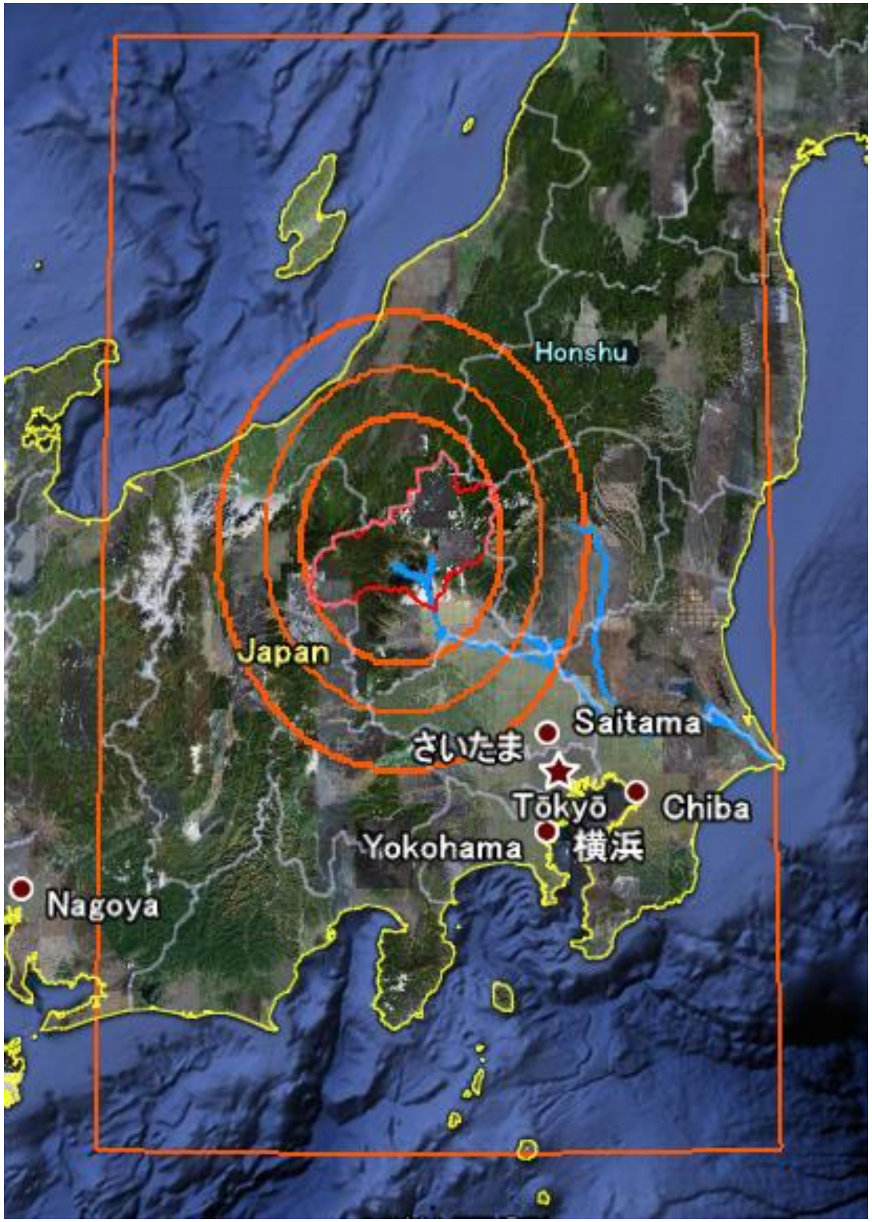
Upper bound: $\mu + \sigma$

$Opt\_var_{dam} = release_{dam}$

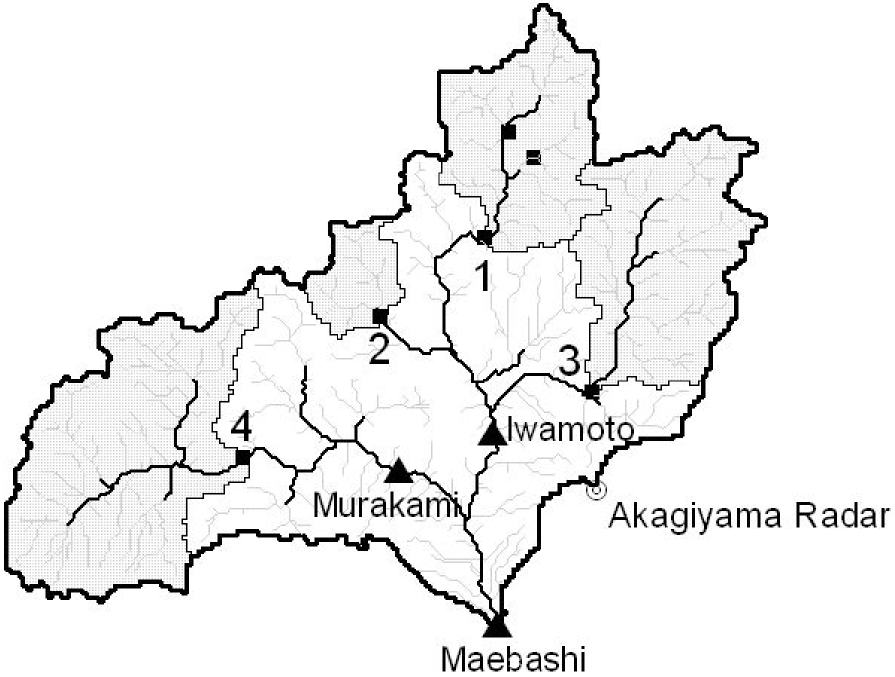
Initial guess: μ

Lower bound: $\mu - \sigma$

Upper Tone Reservoir System, Japan



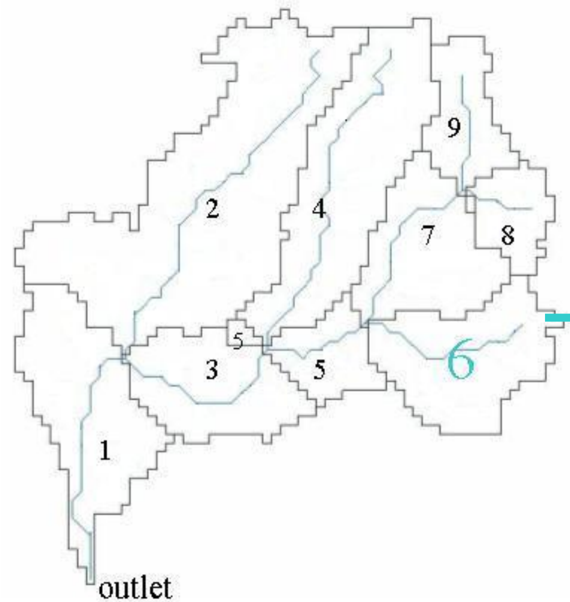
1. Fujiwara (12%)
2. Aimata (3%)
3. Sonohara (15%)
4. Yamba (21%)

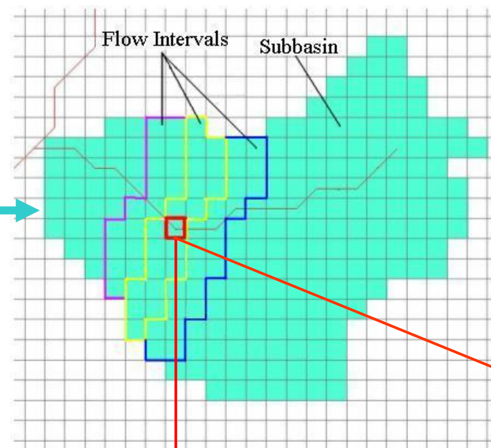


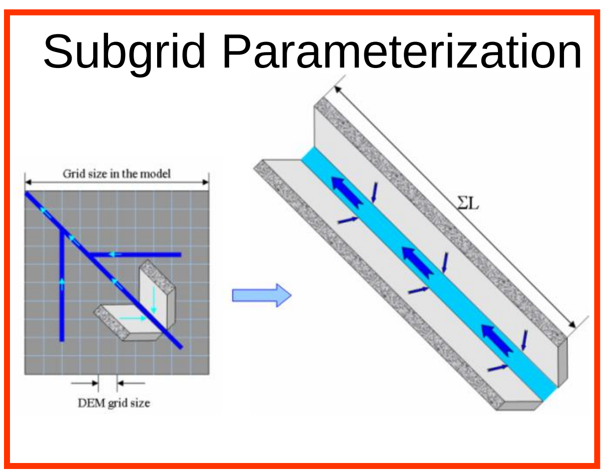
The reservoir system comprises 3304 km^2

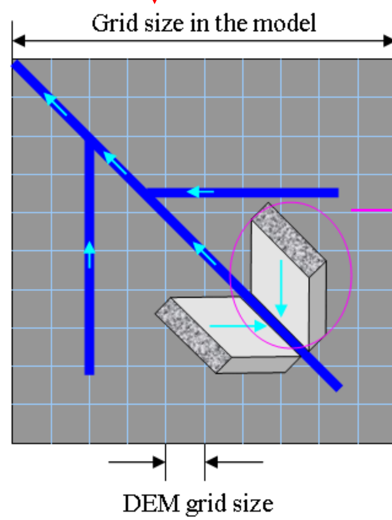
WEB-DHM

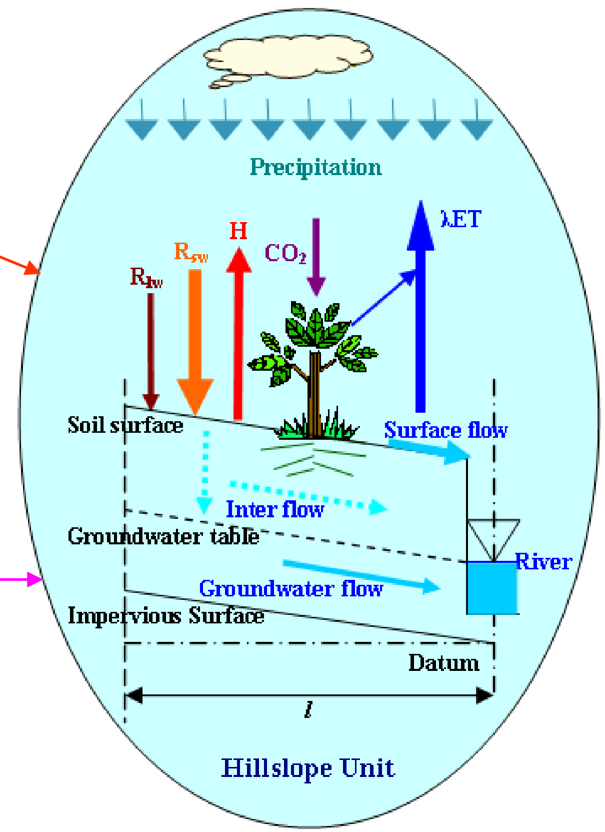
(Water and Energy Budget-based Distributed Hydrological Model)





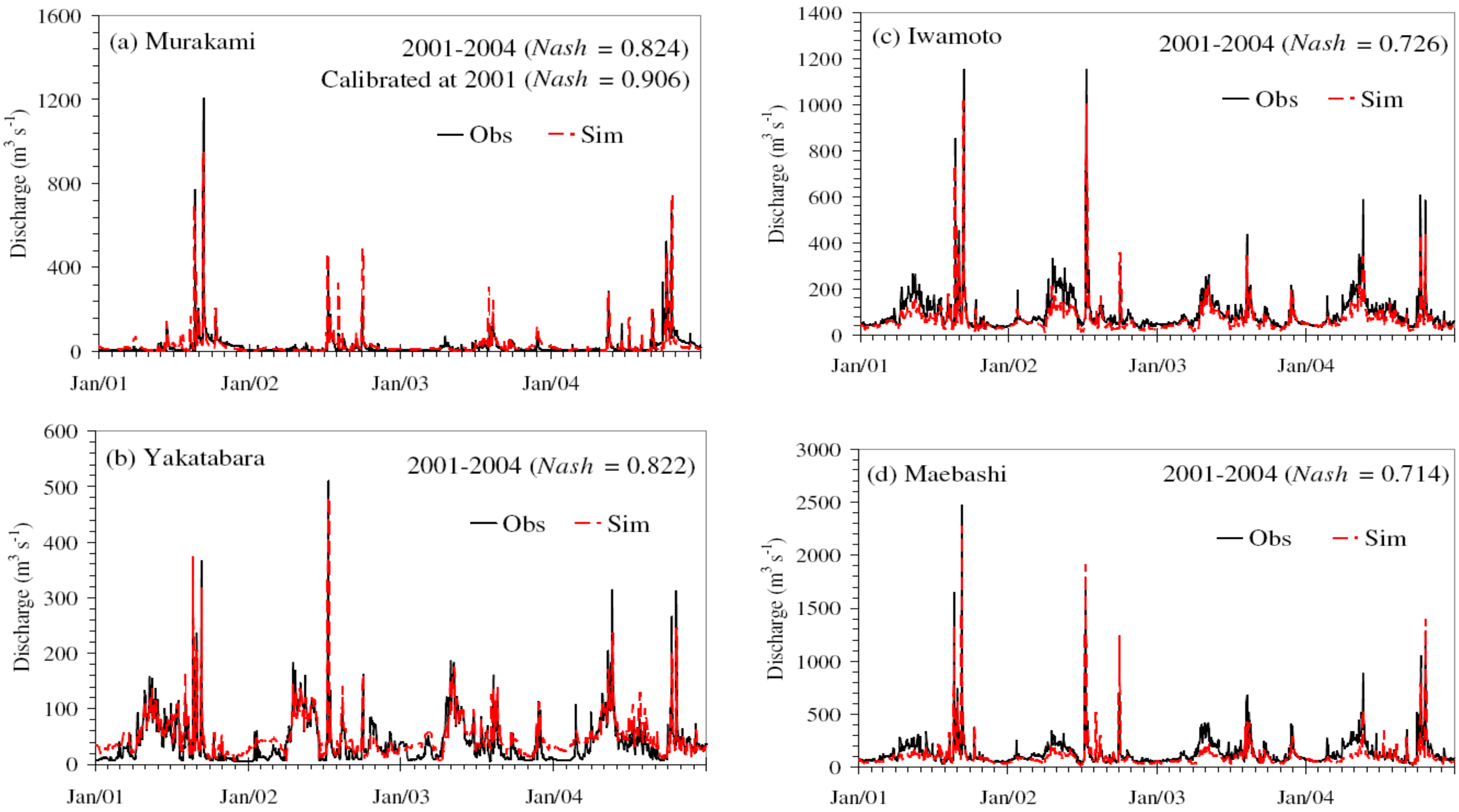






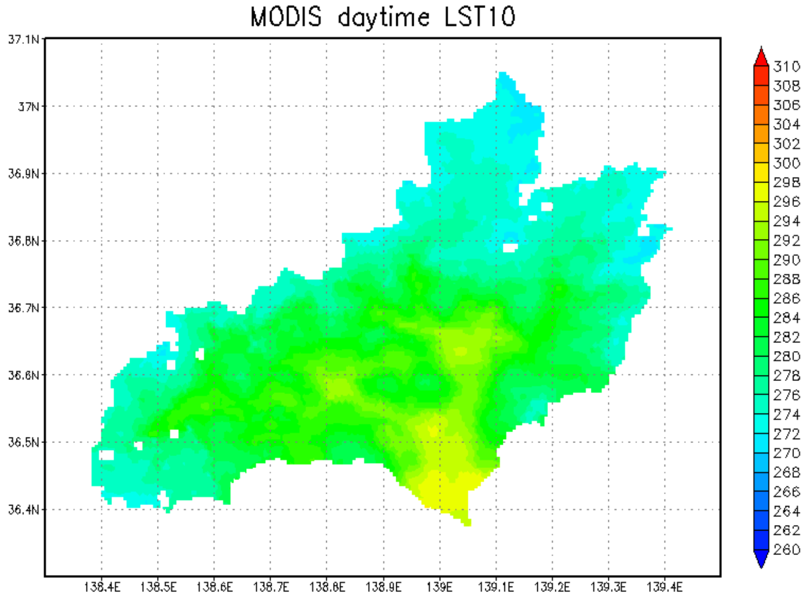
Wang, Koike et al., 2009

Hydrographs (2001-2004)

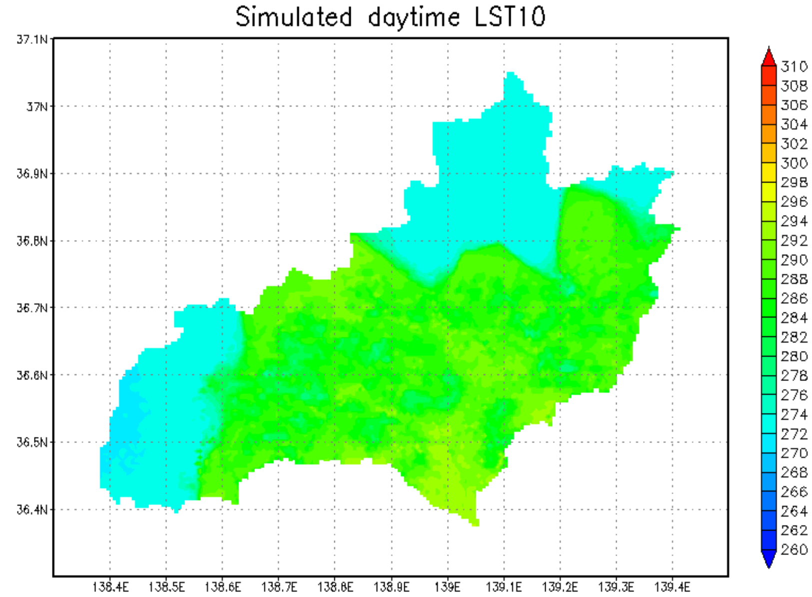


Land Surface Temperature validation

Satellite Observation



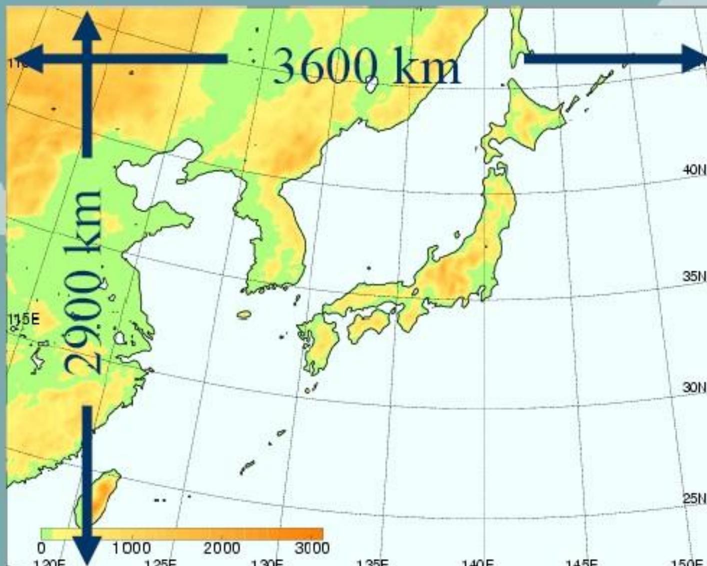
WEB-DHM simulation



10:30 March 13, 2001 (JST)

Wang, Koike et al., 2009

Meso scale model (MSM) at JMA



Computational domain

Use a non-hydrostatic model (JMANHM) operationally.

Until Feb. 2006, From Mar. 2006,

Horizontal resolution : 10km → 5km

Forecast 4 times a day → 8times a day

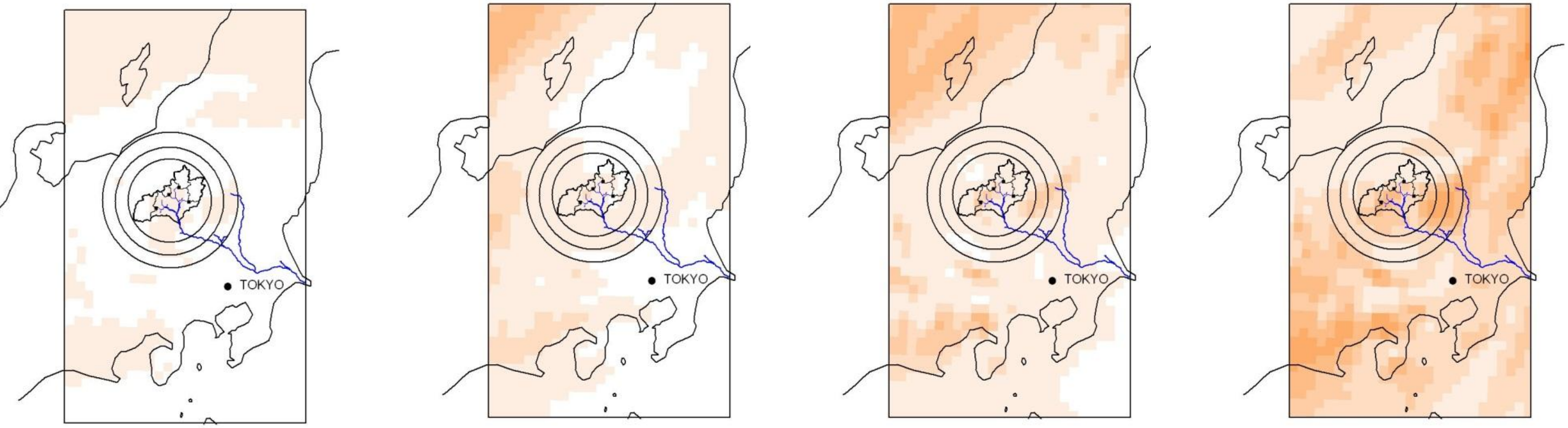
Forecast hour: 18hours → 15 hours

- Dynamics
  - Split explicit scheme(HE-VI)
  - Stable operation with relatively large time step : 40 seconds →24 seconds
- Moist process
  - Cloud microphysics(3-ice : cloud ice, snow, graupel)
  - Convective parameterization (Kain-Fritsch)

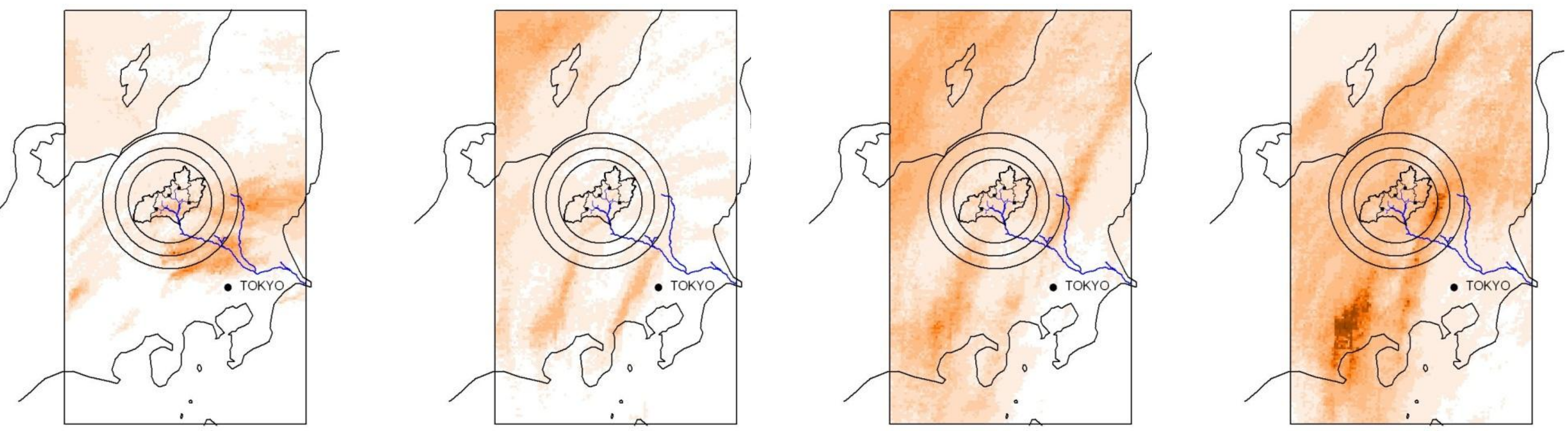
JMA, 2007

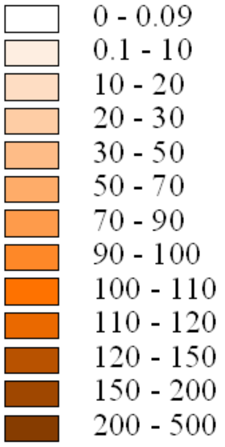
2002.07.09.21z→ 2002.07.10.15z

FORECAST



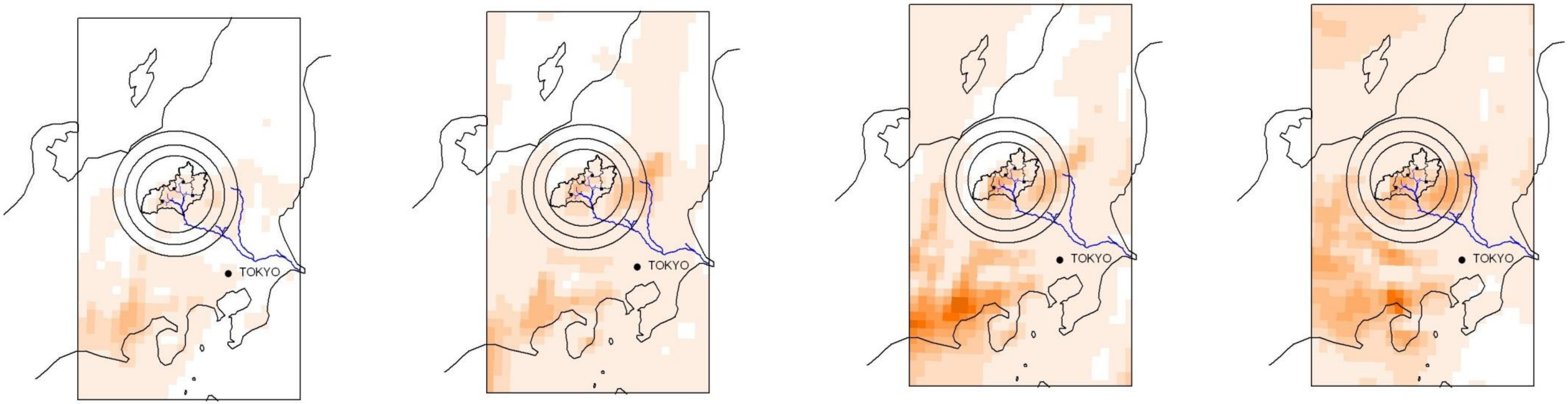
OBS. RADAR



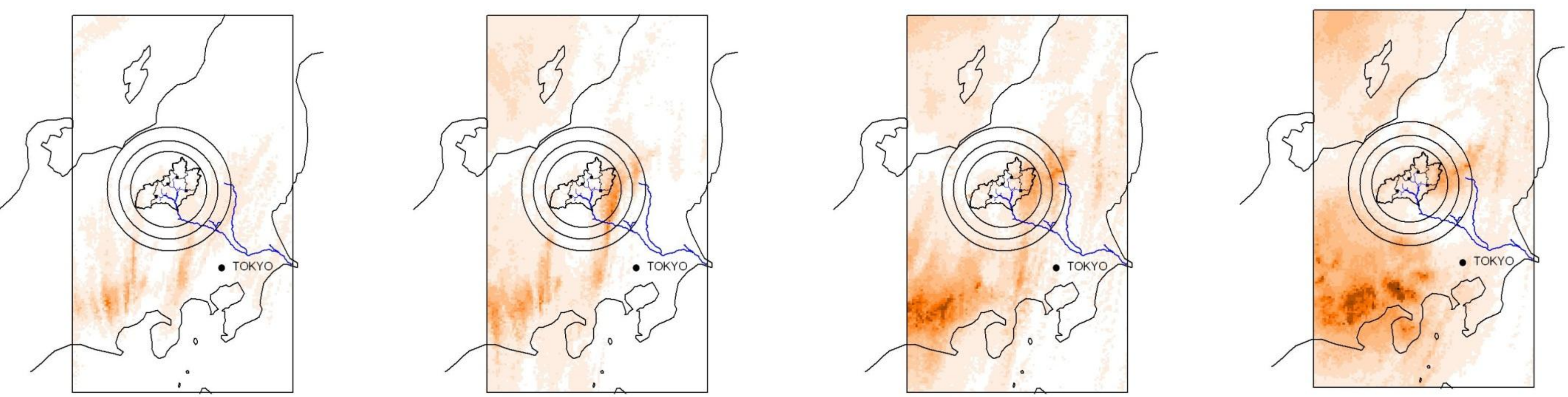


2003.08.08.21z→ 2003.08.09.15z

FORECAST

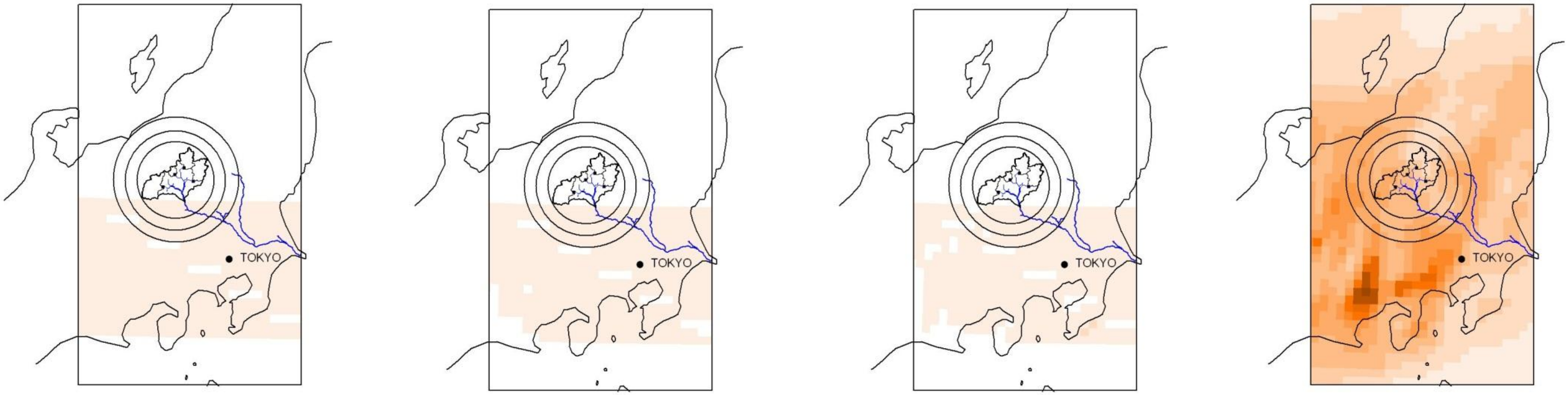


OBS. RADAR

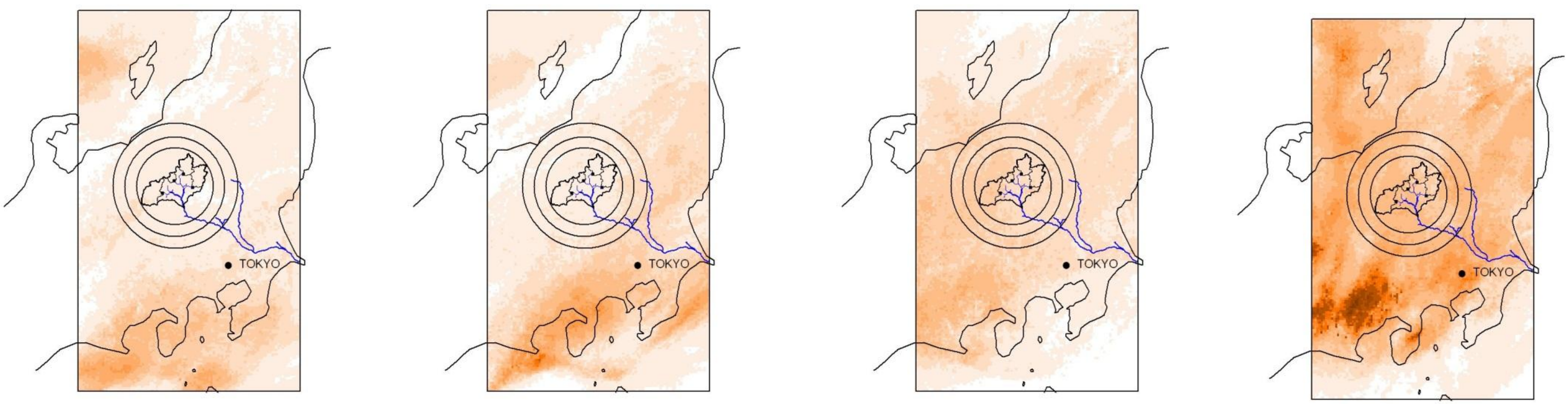


2004.10.20.03z→ 2004.10.20.21z

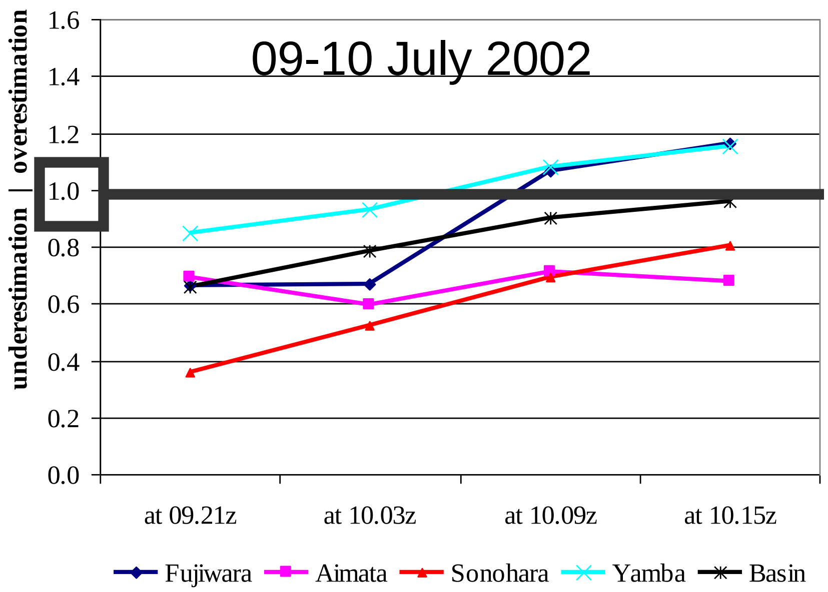
FORECAST(GPV2)

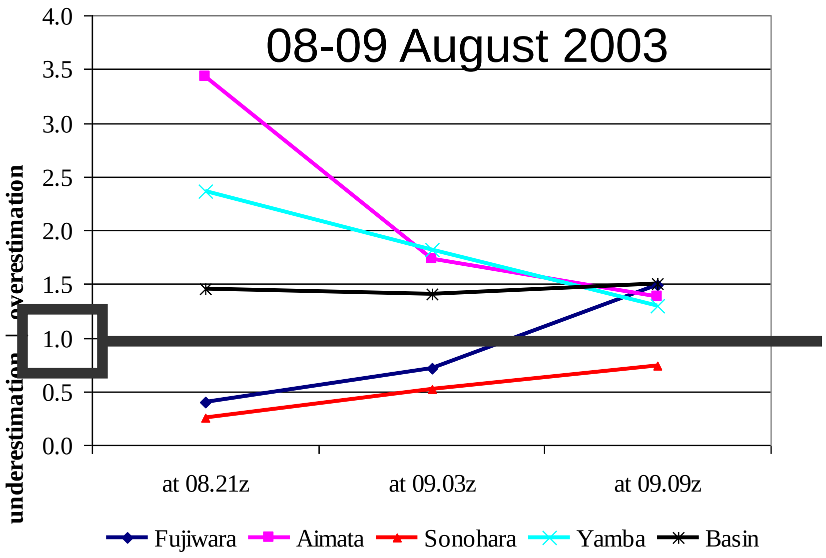


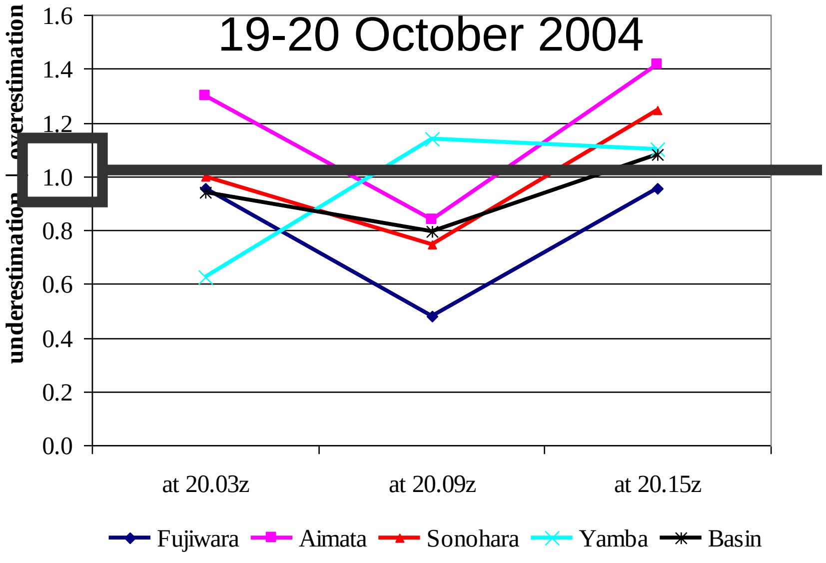
OBS. RADAR



Precipitation ratios QPF over RAD







Weighting Table

Ratio = $Intensity_{QPF} / Intensity_{OBS}$

(50% of maxima & 50% of mean)

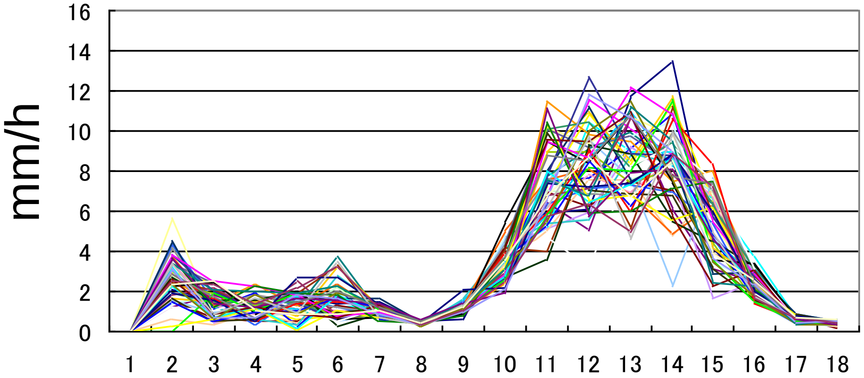
> 1	Overestimation
≈ 1	Very close forecast
< 1	Underestimation

Intensity ratio ranges

	0 - 0.1	**0.1 - 0.4**	**0.4 - 0.7**	**0.7 - 0.9**	**0.9 - 1.1**	**1.1 - 1.3**	**1.3 - 1.6**	**1.6 - 1.9**	**> 2.0**
At basin	2.0	1.5	1.0	0.5	**0.0**	0.5	1.0	1.5	2.0
1st buffer	3.0	2.5	2.0	1.5	**1.0**	1.5	2.0	2.5	3.0
2nd buffer	4.0	3.5	3.0	2.5	**2.0**	2.5	3.0	3.5	4.0
3rd buffer	5.0	4.5	4.0	3.5	**3.0**	3.5	4.0	4.5	5.0
All domain	6.0	5.5	5.0	4.5	**4.0**	4.5	5.0	5.5	6.0

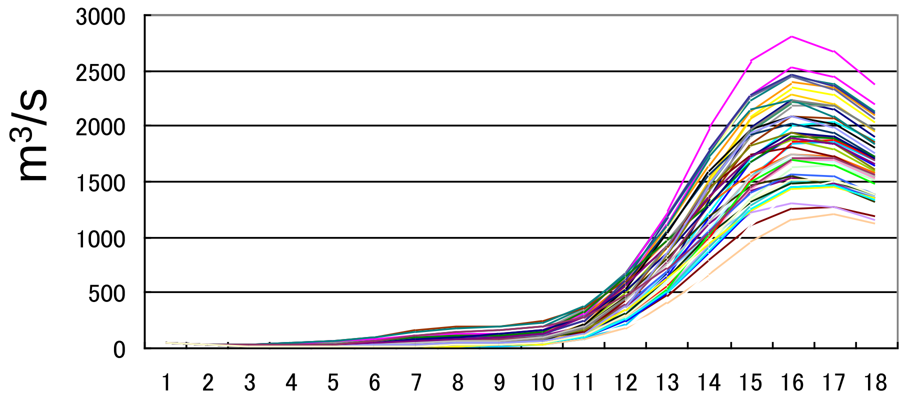
Event 2002 Jul 7~

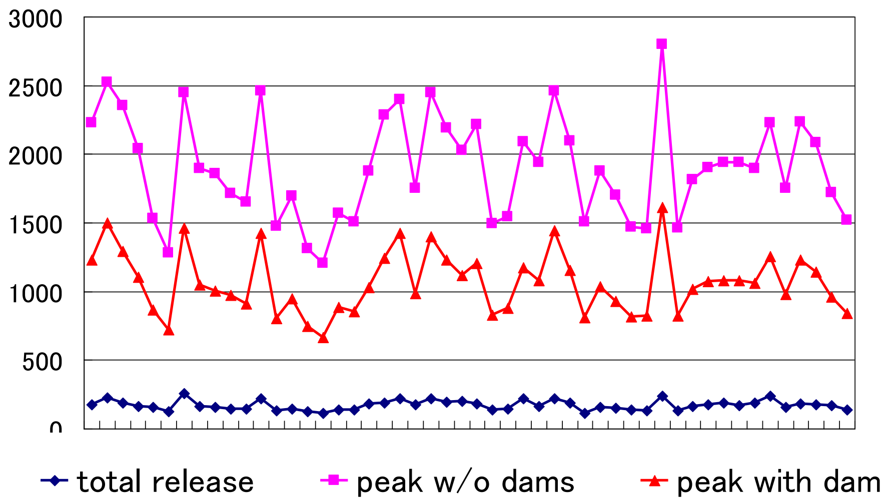
Ensemble precipitation forecast



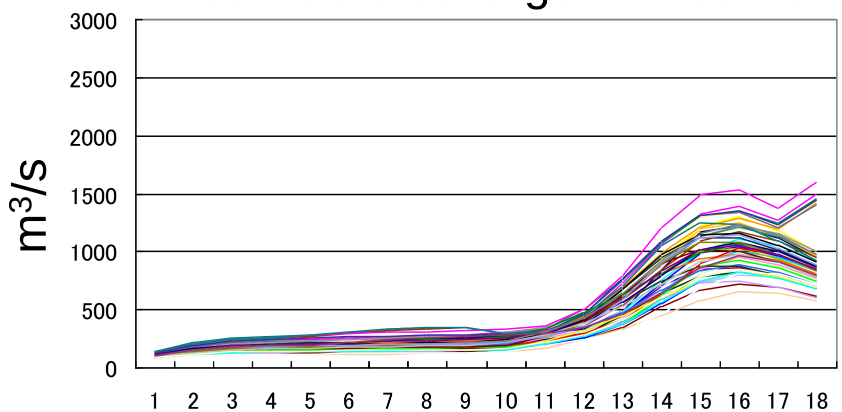
weight1 = 1; weight2 = 0.5; Weight3 = 0.5

Ensemble discharge w/o dams



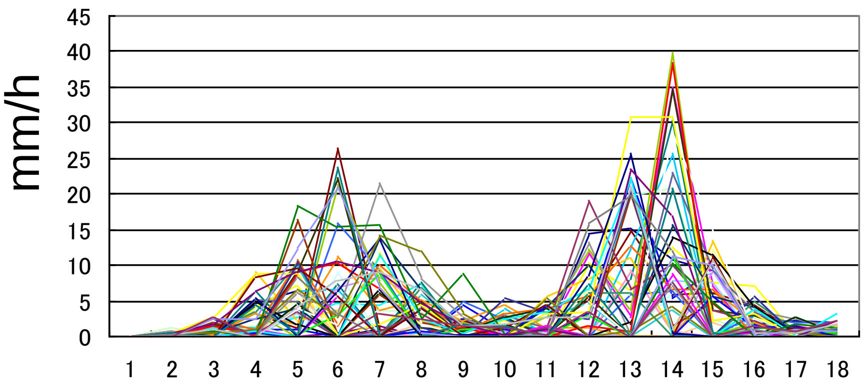


Ensemble discharge with dams

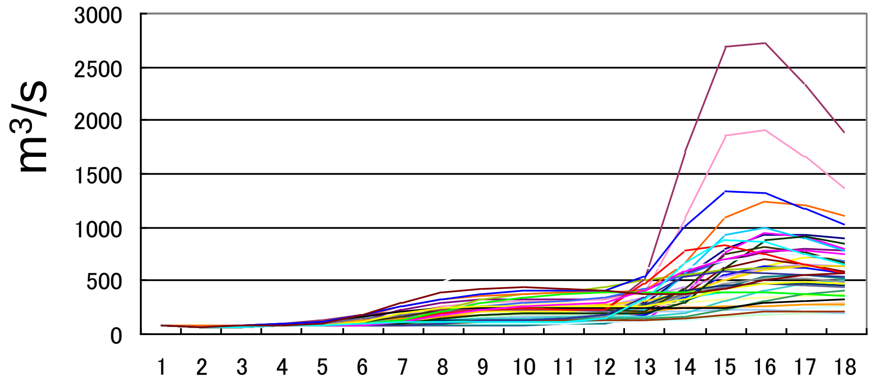


Event 2004 Oct 8~

Ensemble precipitation forecast



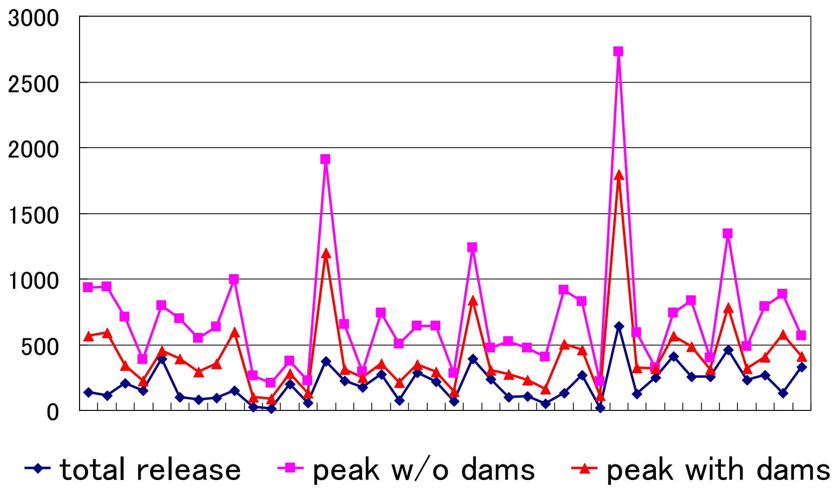
Ensemble discharge w/o dams

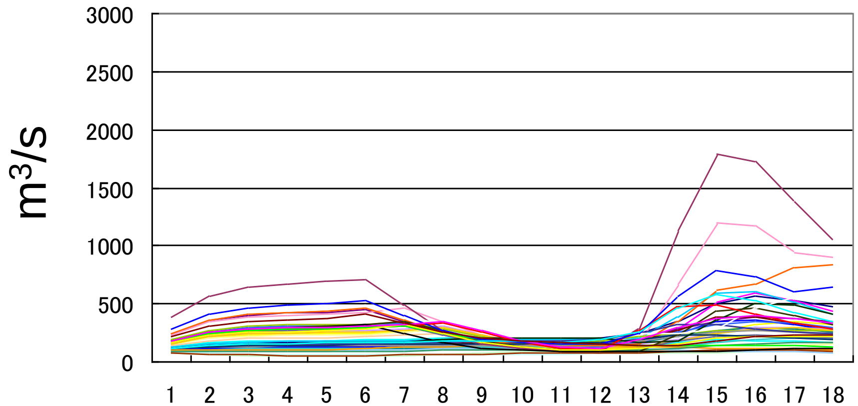


weight1 = 6; weight2 =6; Weight3 = 6

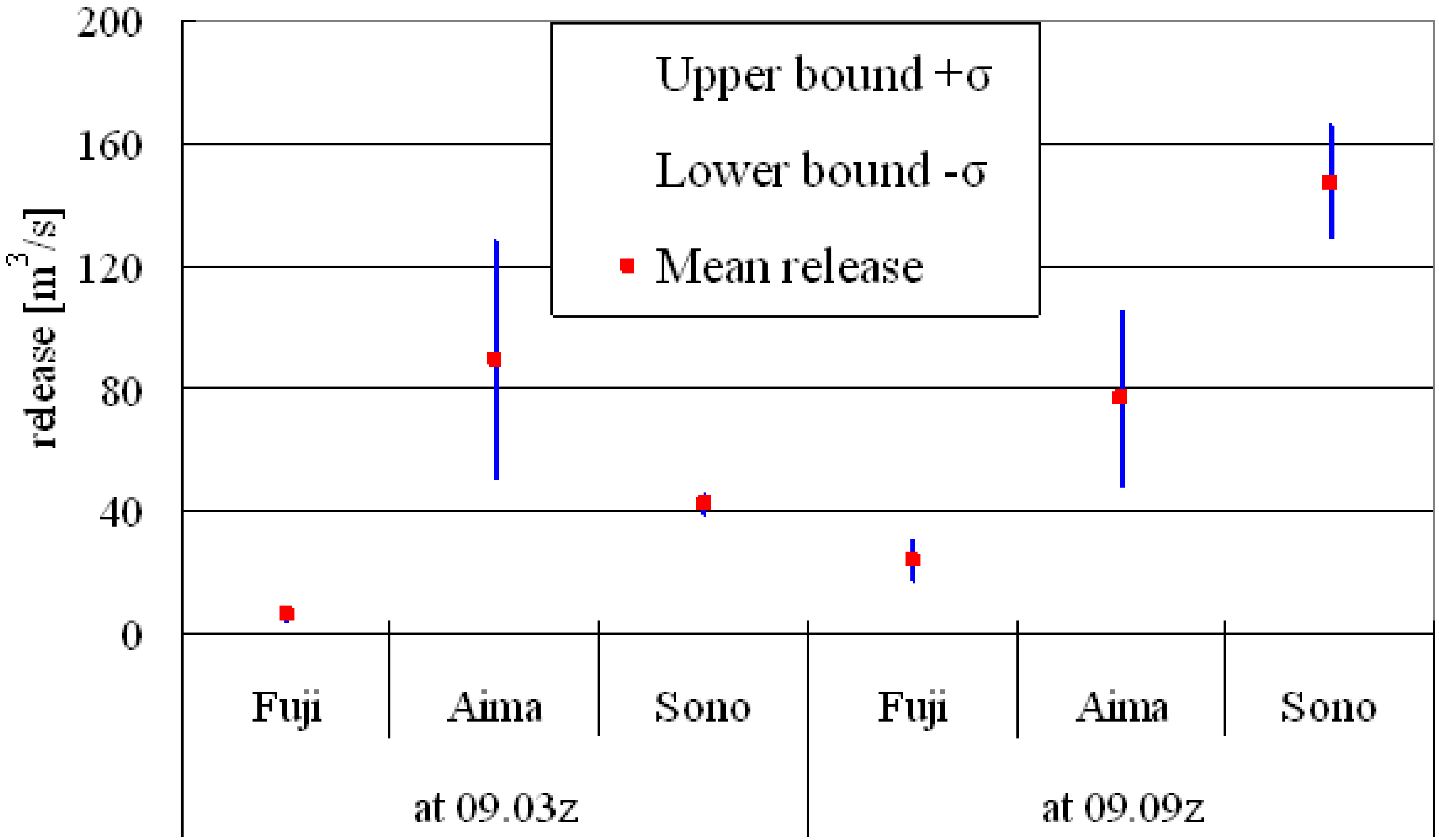
80%→ start system

Ensemble discharge with dams



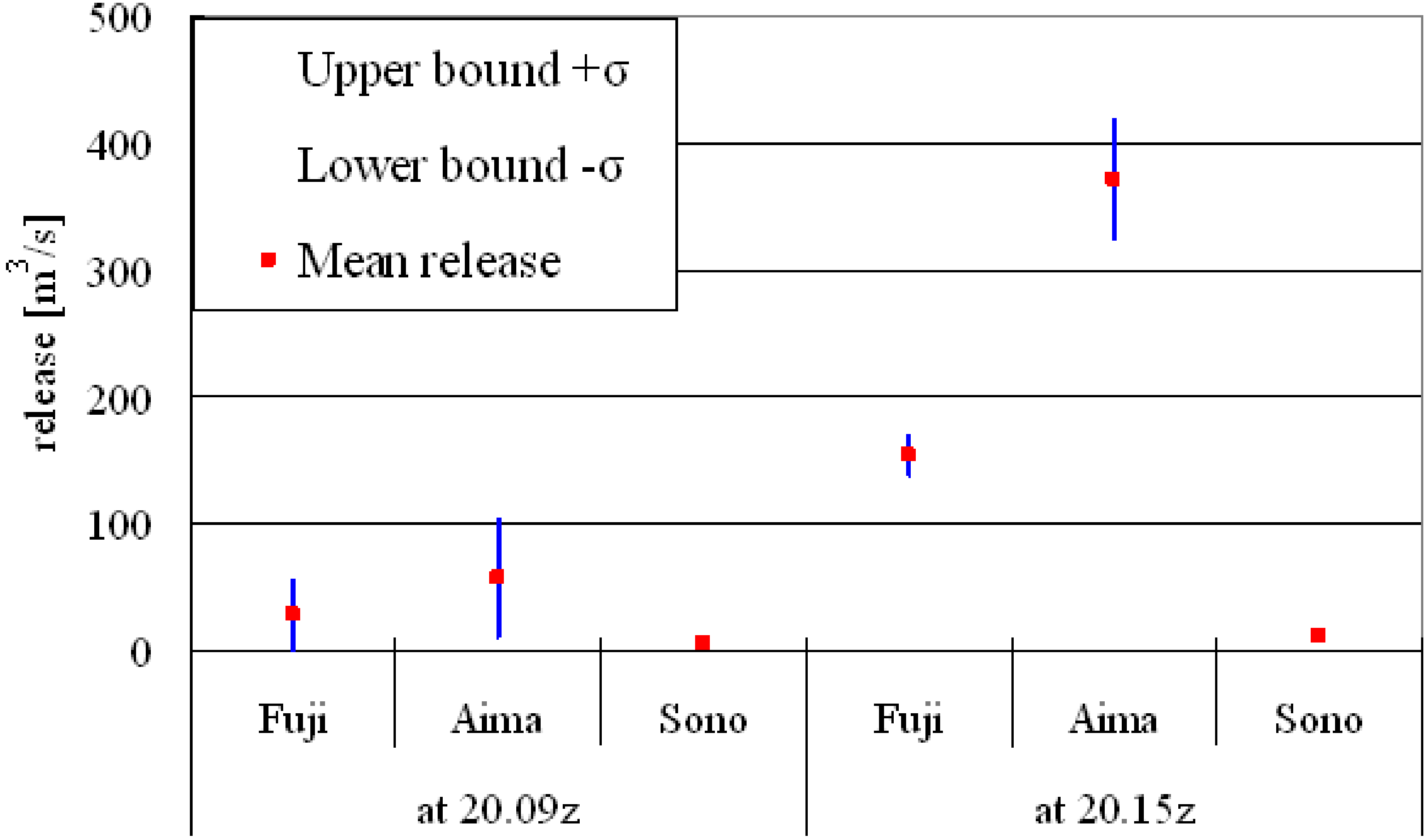


Dam release uncertainties
event 9-10 Jul 2002



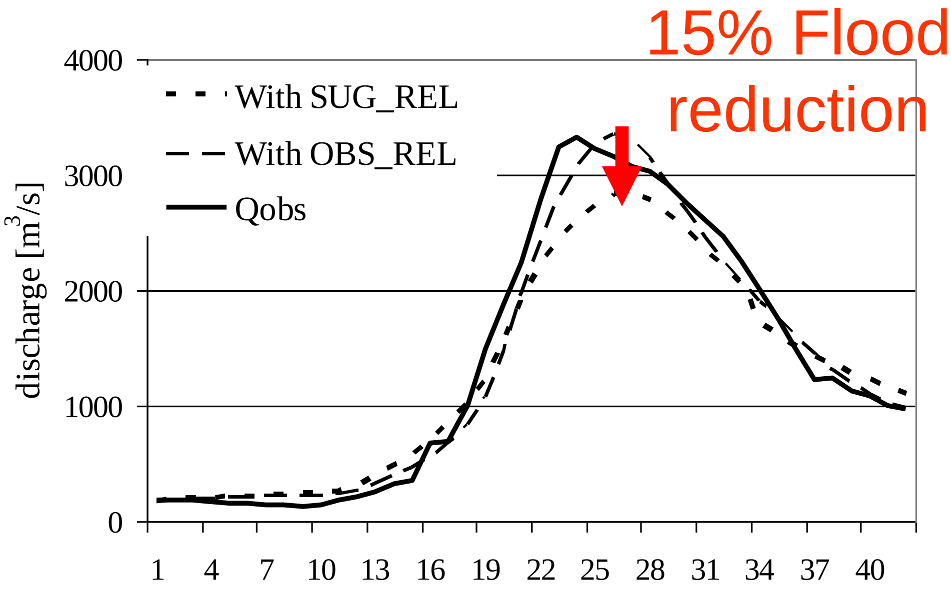
Saavedra, Koike et al., 2010a

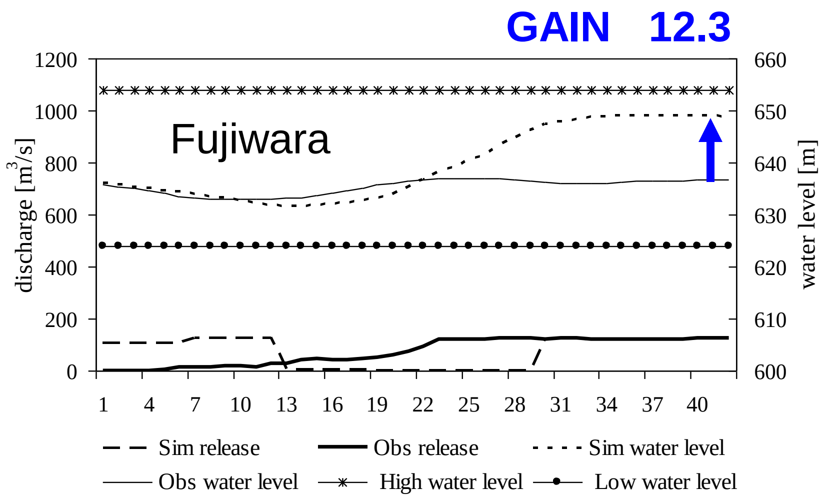
Dam release uncertainties event 19-20 Aug 2004

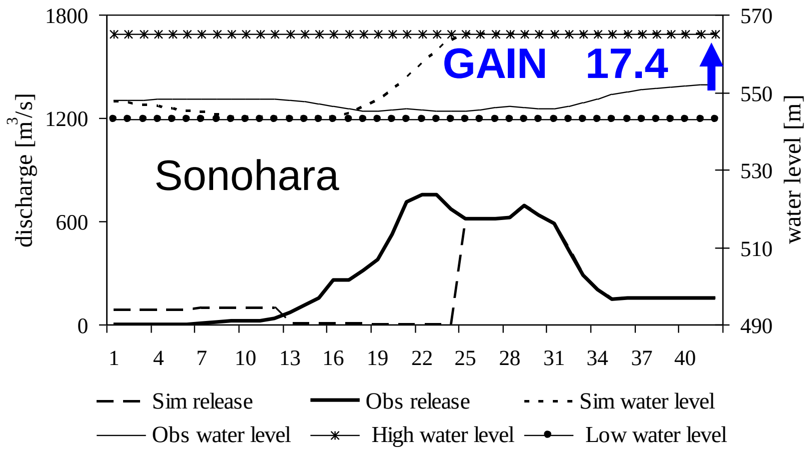


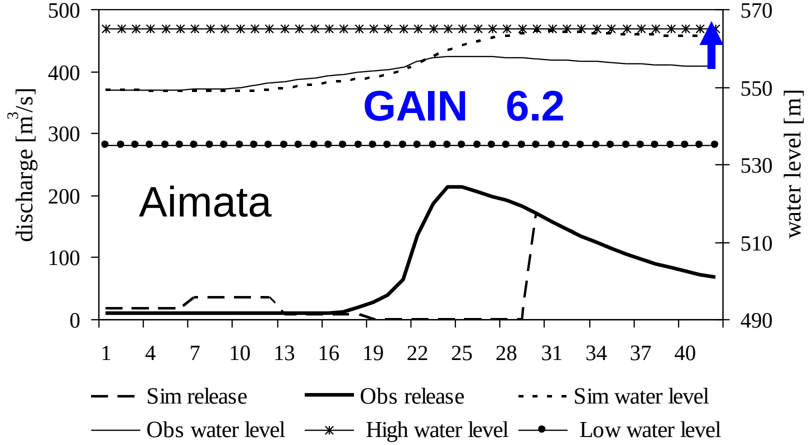
Saavedra, Koike et al., 2010a

Results: event 2002 Jul 9~11



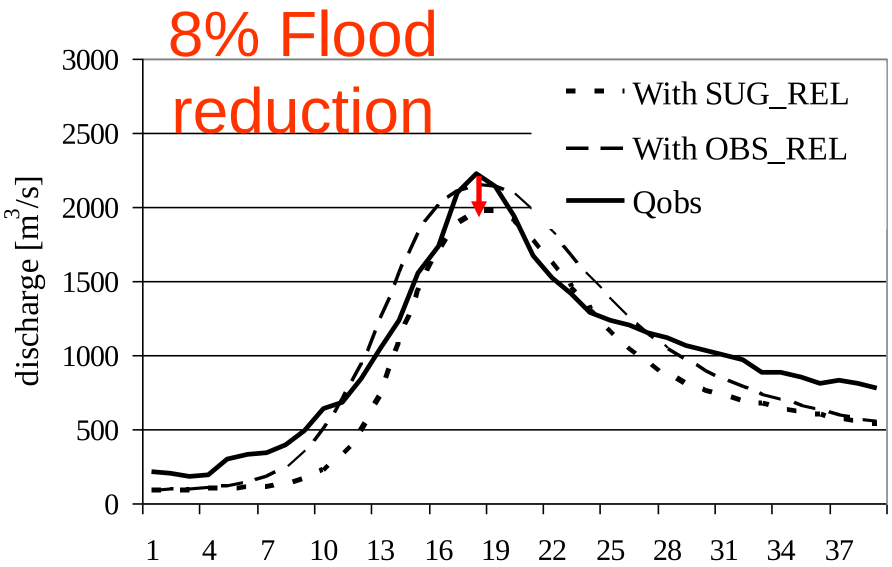


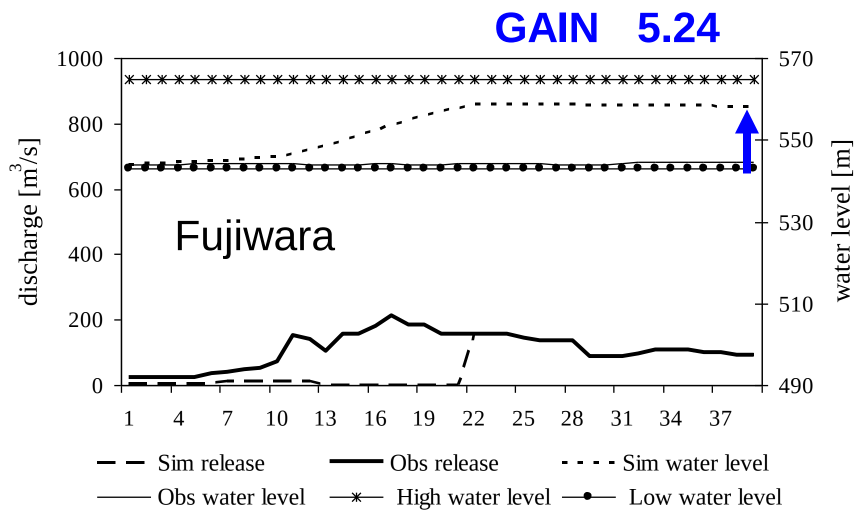


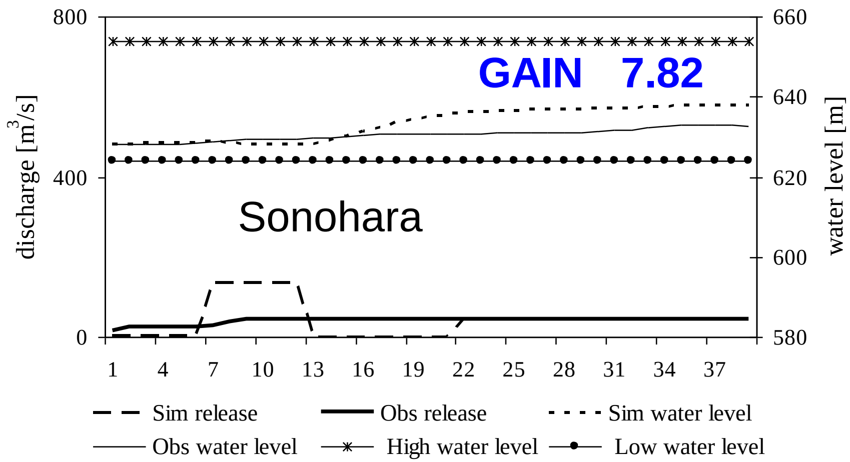


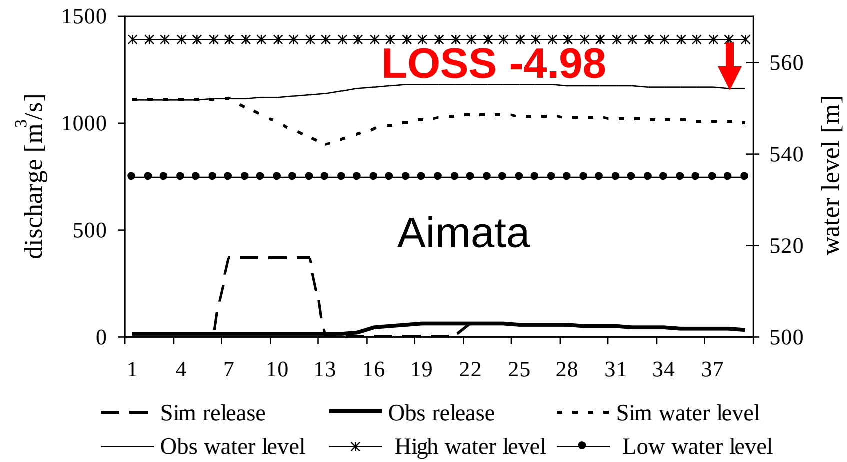
TOTAL GAIN 35.9

Results: event 2004 Oct 20~









TOTAL GAIN 8.08

Evaluation of the DRESS system's performance

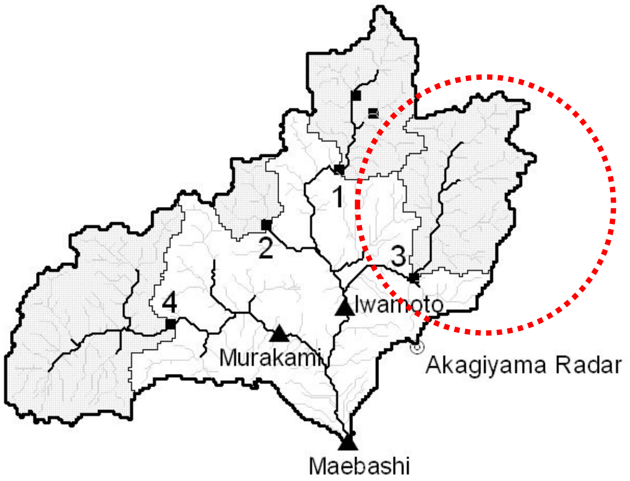
Event	Flood Peak reduction at control point [%]	Gain or Loss at Fujiwara reservoir [MCM]	Gain or Loss at Aimata reservoir [MCM]	Gain or Loss at Sonohara reservoir [MCM]	Total Gain or Loss, reservoirs [MCM]
2002.07	18.14	10.45	8.28	17.43	17.43
2003.08	28.03	5.36	-1.76	11.85	11.85
2004.10	7.6	5.24	-4.98	7.82	7.82

Saavedra, Koike et al., 2010a

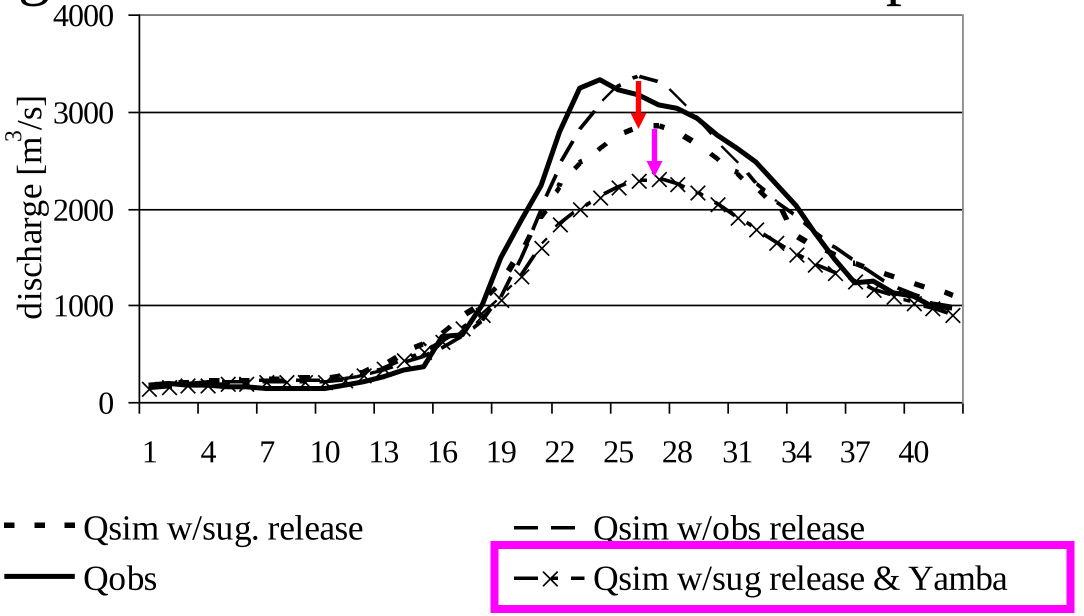
Recommendations

1) Find balance e.g. Katashina river

	Contributing Areas	Storage Capacity [MCM]
1. Fujiwara	12%	90
2. Aimata	3%	25
3. Sonohara	15%	20.3
4. Yamba	21%	107.5



2) Constructing new dams vs. Enhanced dam operation



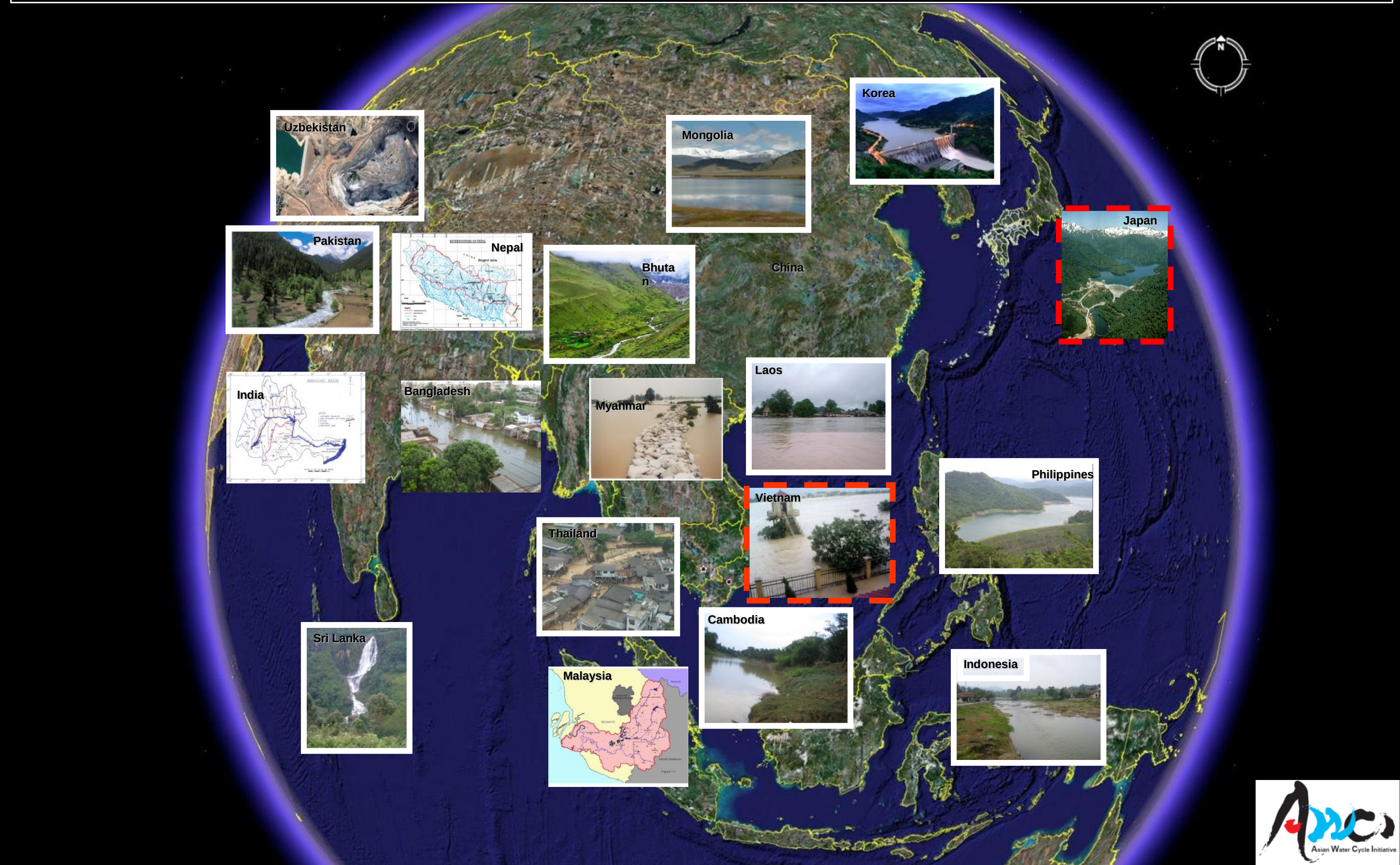
Saavedra, Koike & Wang, 2010c

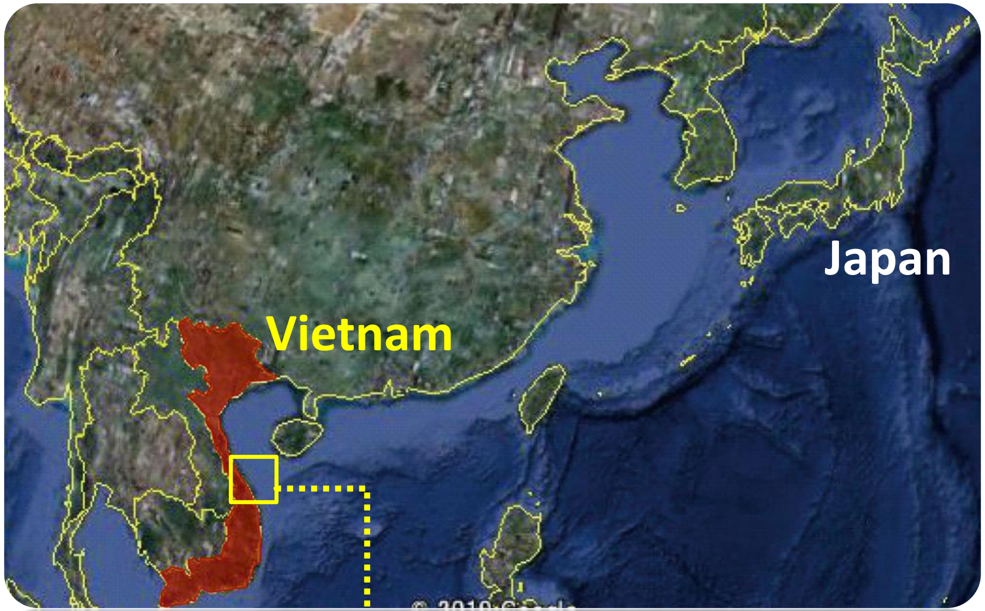
Flood Warning Support System FLOWSS

- Using Quantitative Precipitation Forecasts
- Based on Ensemble Method
- Applied in the Huong River, Vietnam

GEOSS Asian Water Cycle Initiative (AWCI)

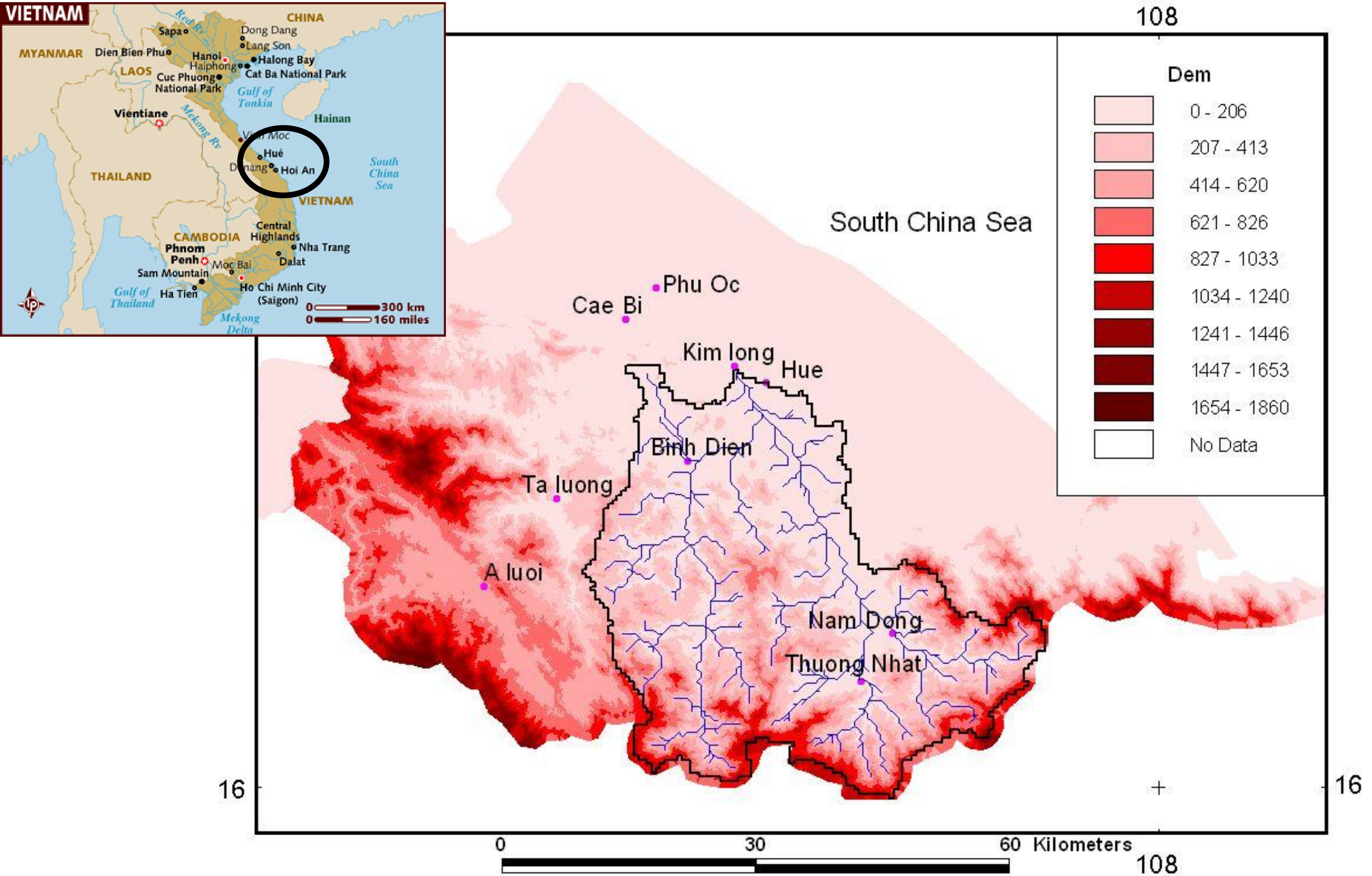
18 River Basins for Initial Demonstration



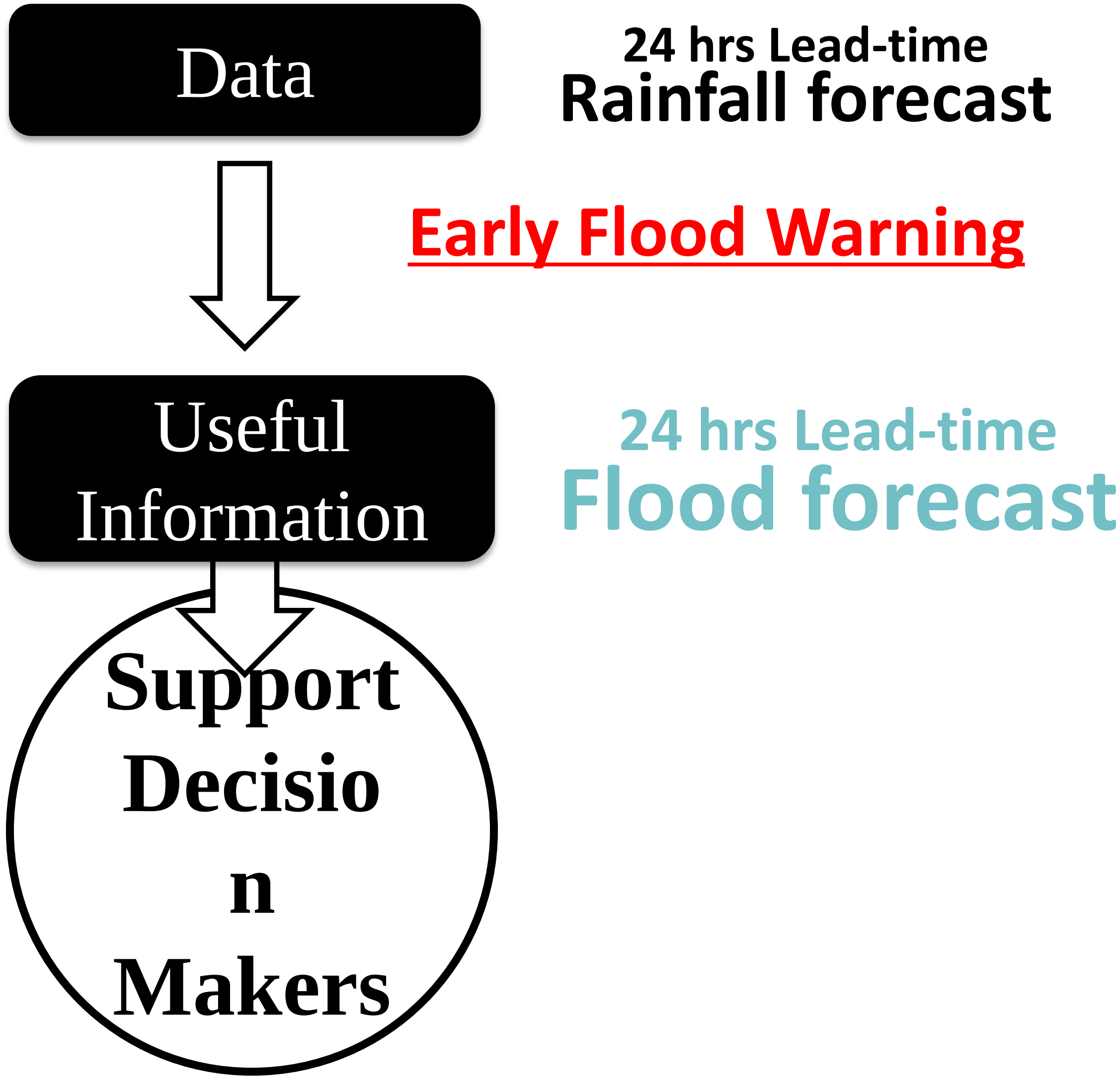


Huong River basin

Huong River, Vietnam



Objective.


Data
24 hrs Lead-time
Rainfall forecast
Early Flood Warning
Useful Information
24 hrs Lead-time
Flood forecast
Support Decision Makers

Rain forecast

⇩

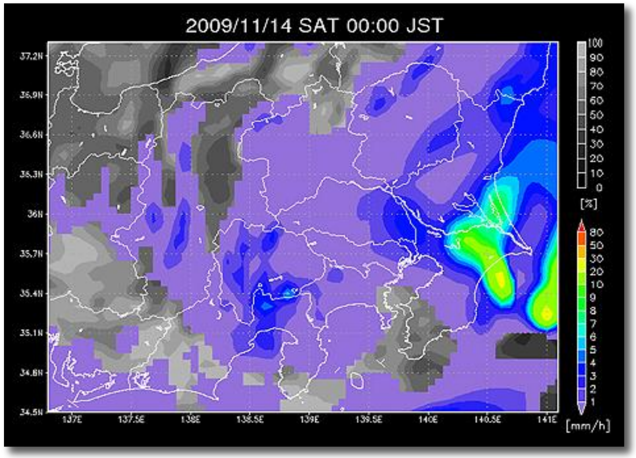
Evaluation

⇩

Probabilistic Approach

⇩

Simulation

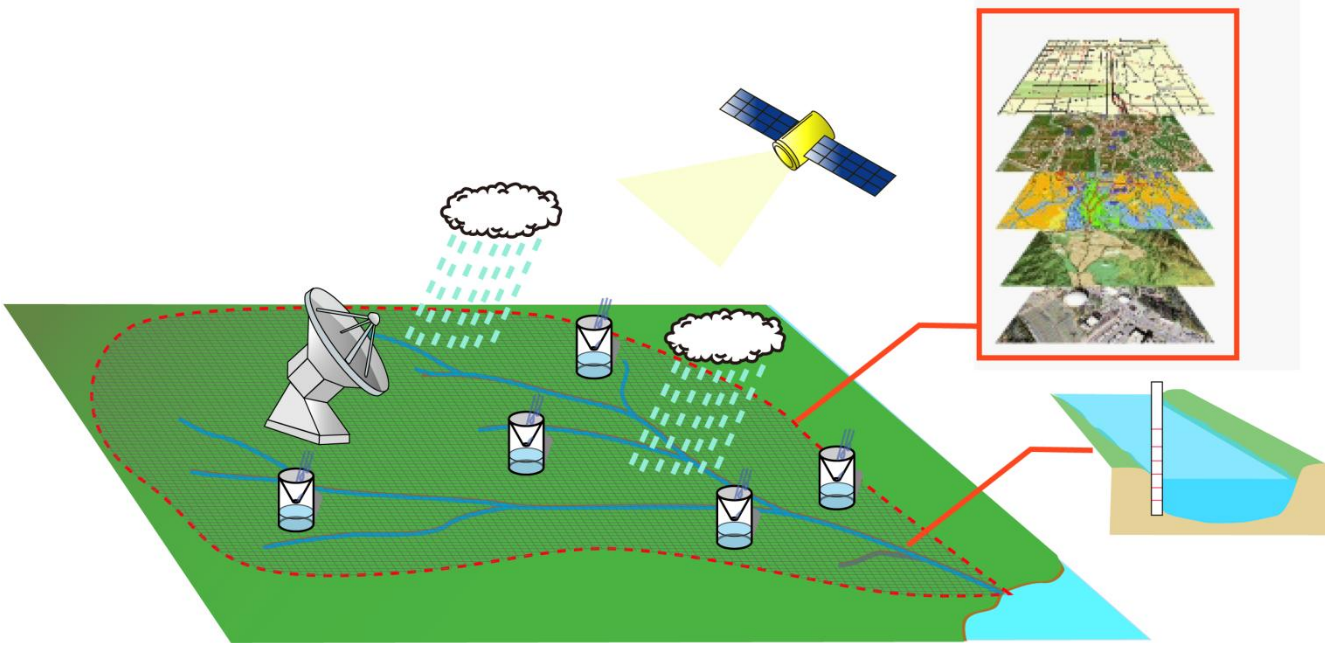


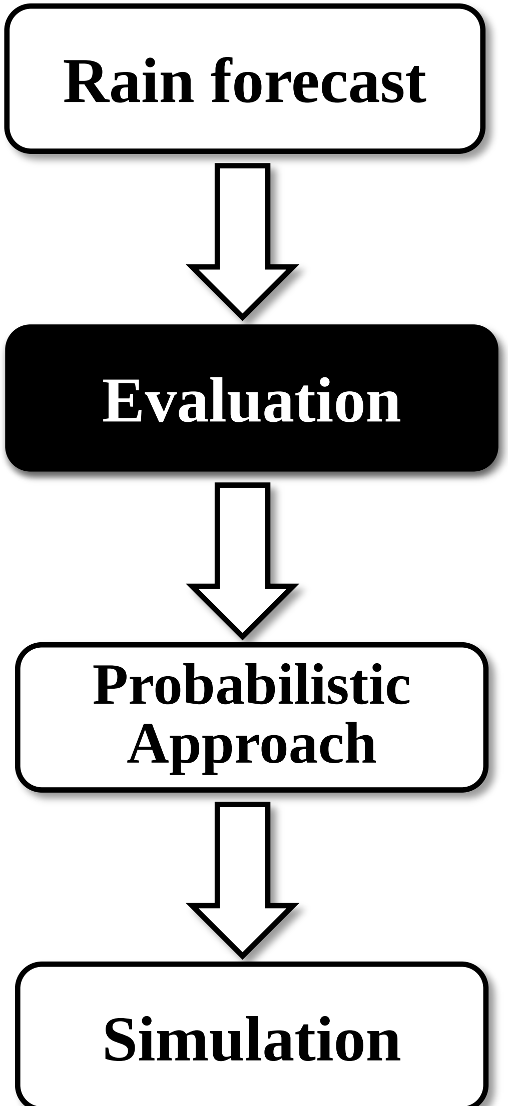
Grid Point Value (GPV)

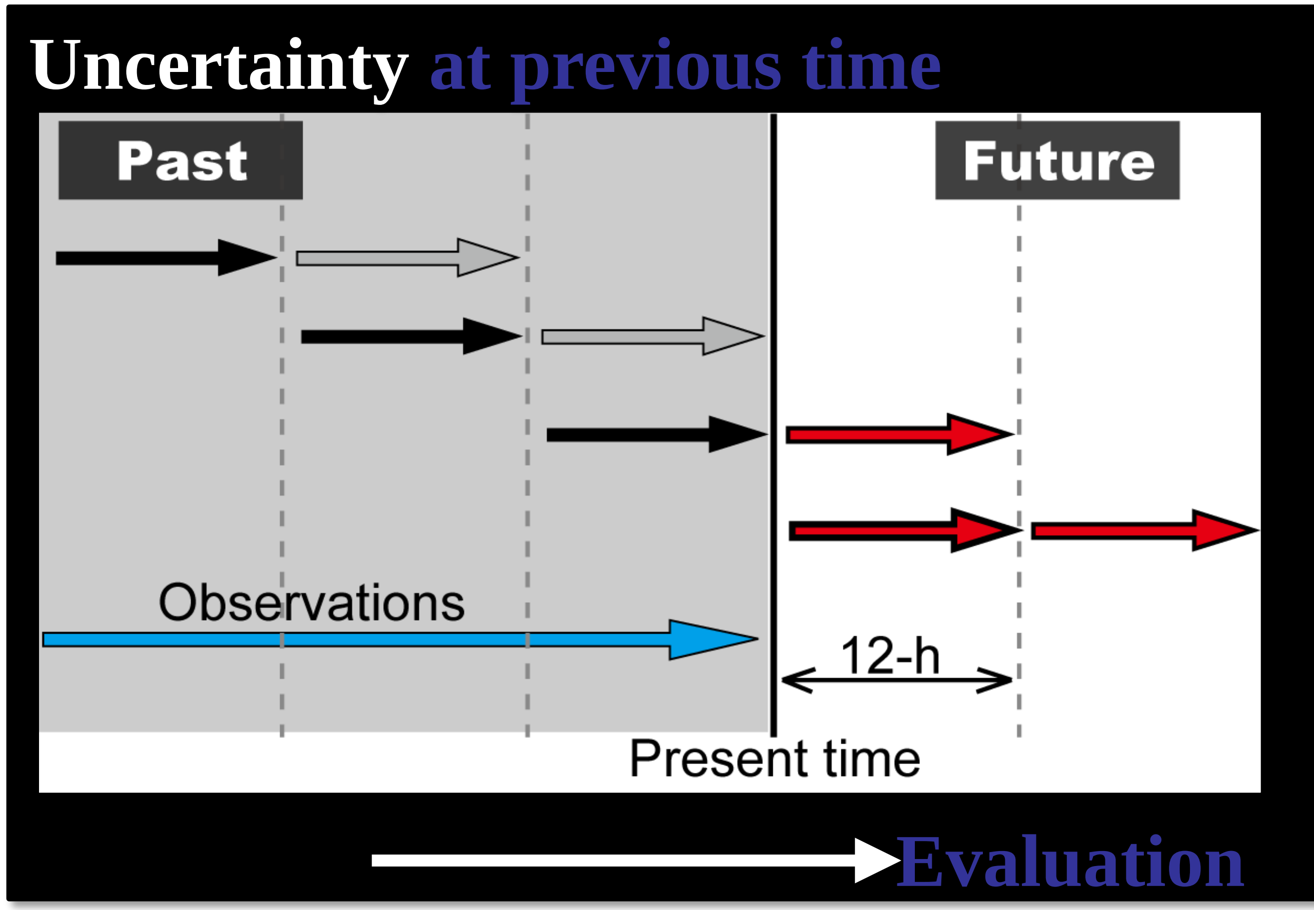
24 hrs lead-time

Global scale

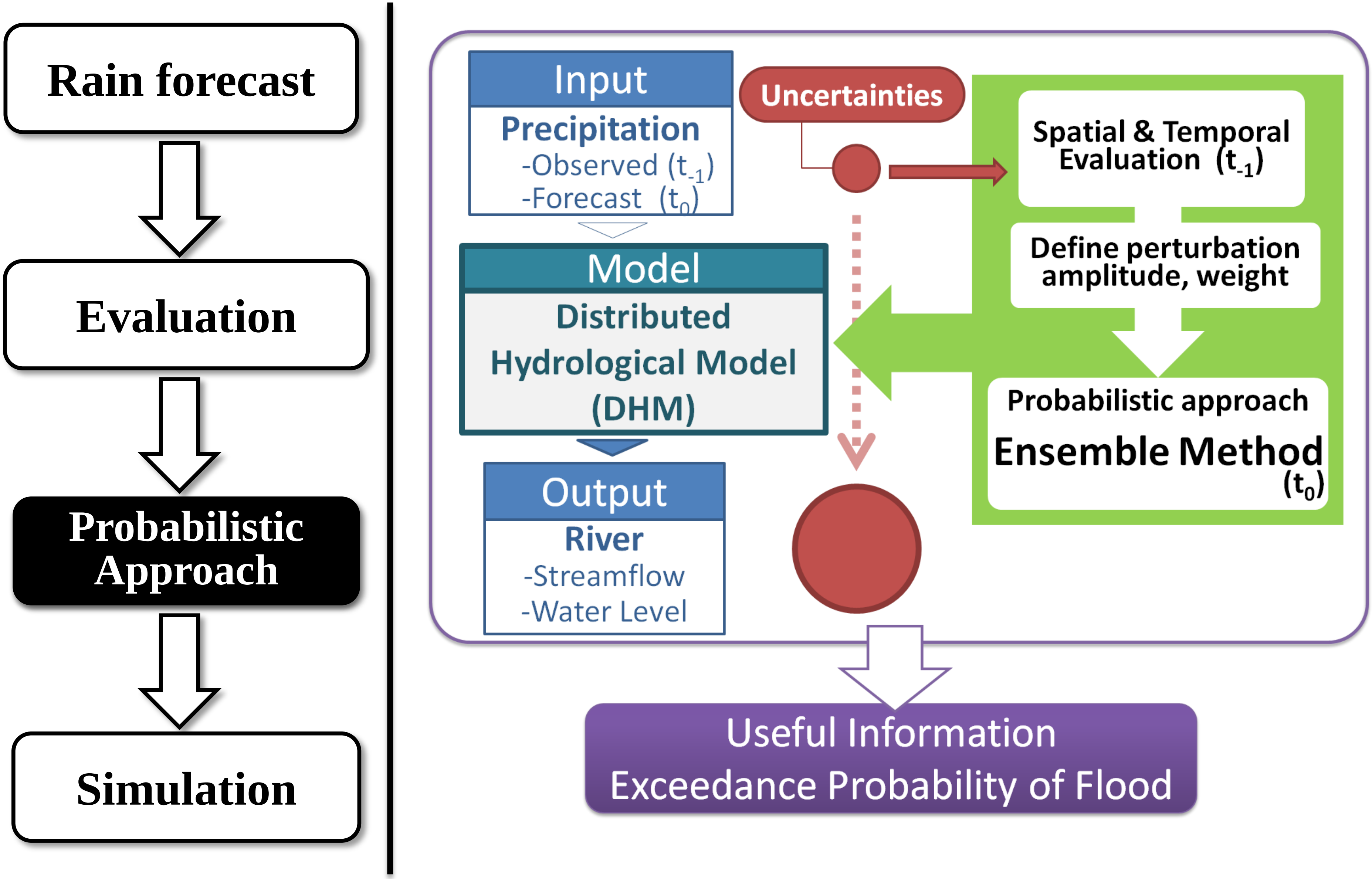
Twice per day




Rain forecast
Evaluation
Probabilistic Approach
Simulation


Uncertainty at previous time
Past
Future
Observations
12-h
Present time
Evaluation

Forecast


Rain forecast
Evaluation
Probabilistic Approach
Simulation
Input
Precipitation
-Observed (t_{-1})
-Forecast (t_0)
Model
Distributed Hydrological Model (DHM)
Output
River
-Streamflow
-Water Level
Uncertainties
Spatial & Temporal Evaluation (t_{-1})
Define perturbation amplitude, weight
Probabilistic approach
Ensemble Method (t_0)
Useful Information
Exceedance Probability of Flood

Rain forecast

↓

Evaluation

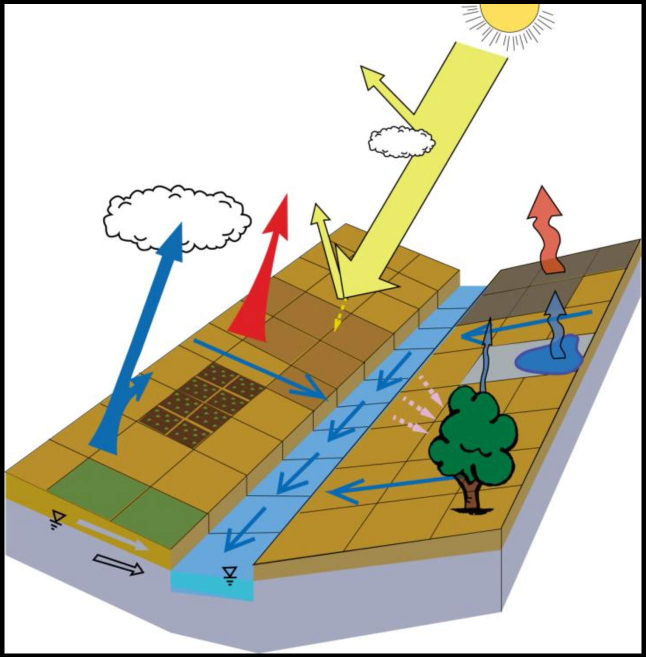
↓

Probabilistic Approach

↓

Simulation

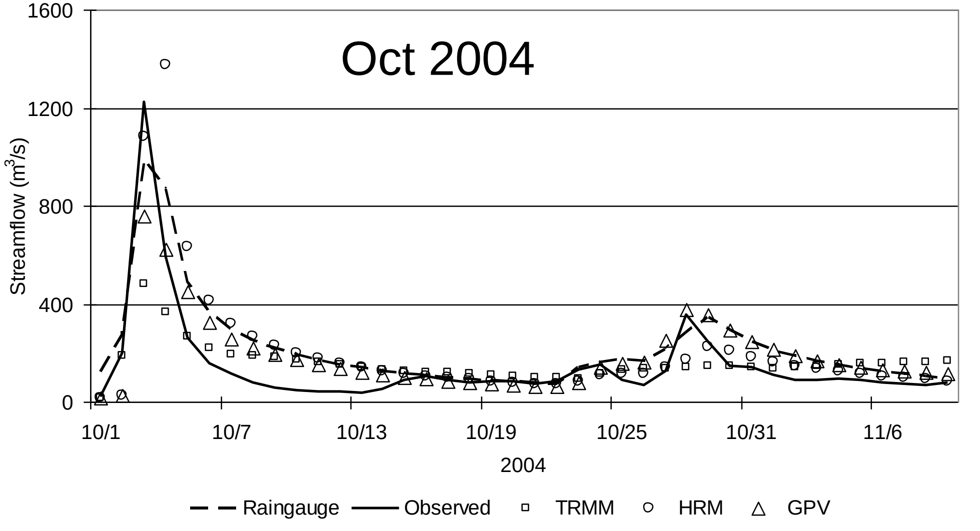
Distributed Hydrological

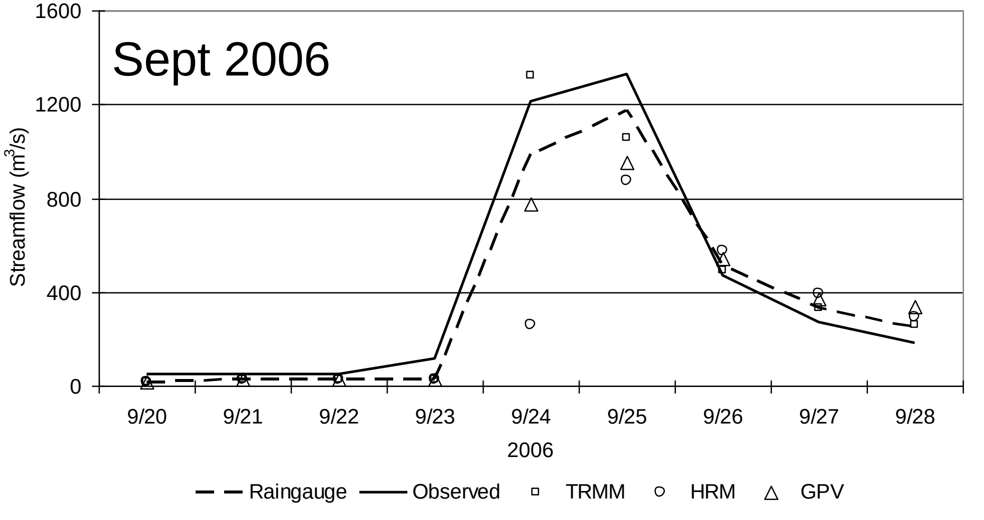


n scenarios

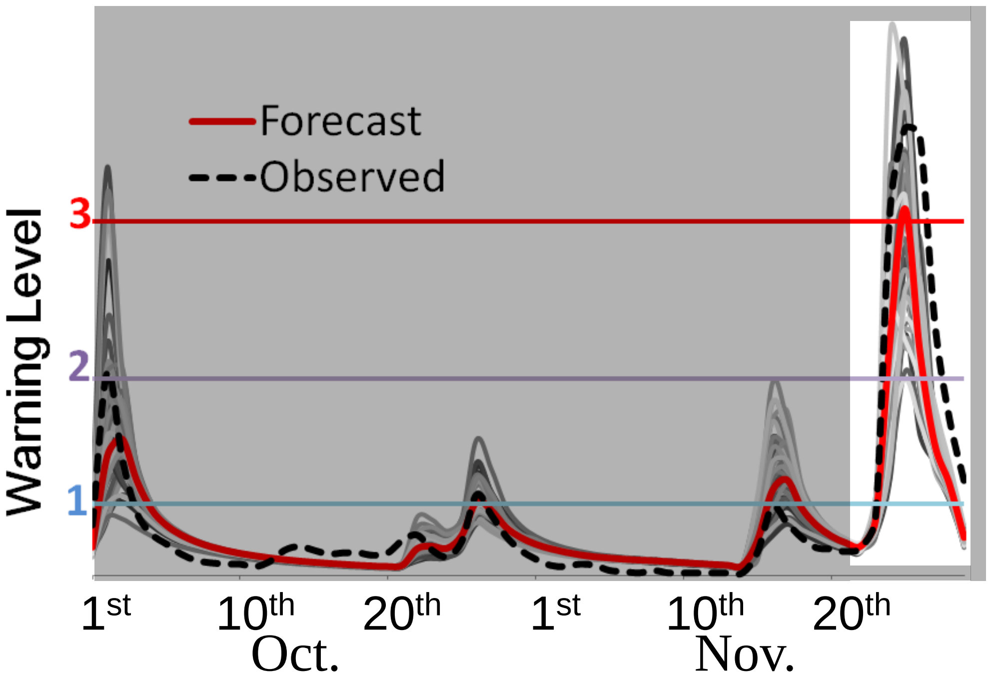
Rain → River W. L.

Results of the model





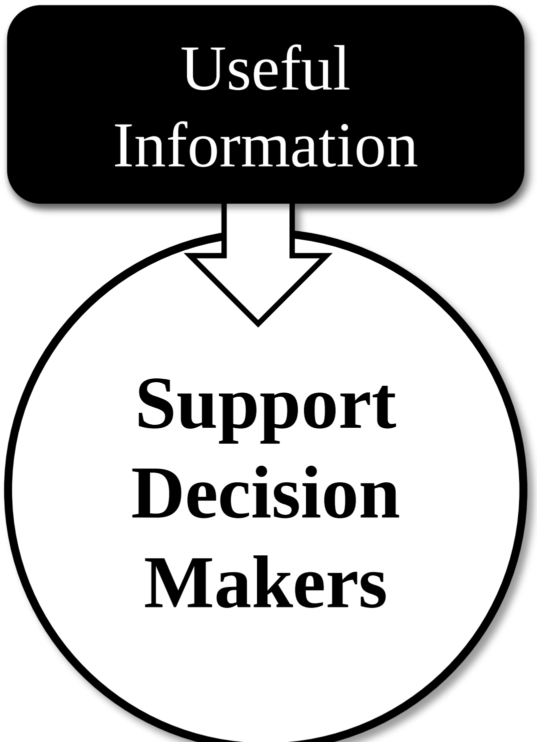
Saavedra, Koike et al., 2009



2004

Date		Nov.					
		24	**25**	**26**	**27**	**28**	29
Predicted exceedance probability (%)	W.L.3		8	52			
	W.L.2		74	96	72		
	W.L.1	6	96	96	96	96	96
Observed	W.L.	0.9	**3.1**	**3.5**	**3.5**	**2.4**	**1.7**

Saavedra Valeriano et al., 2012



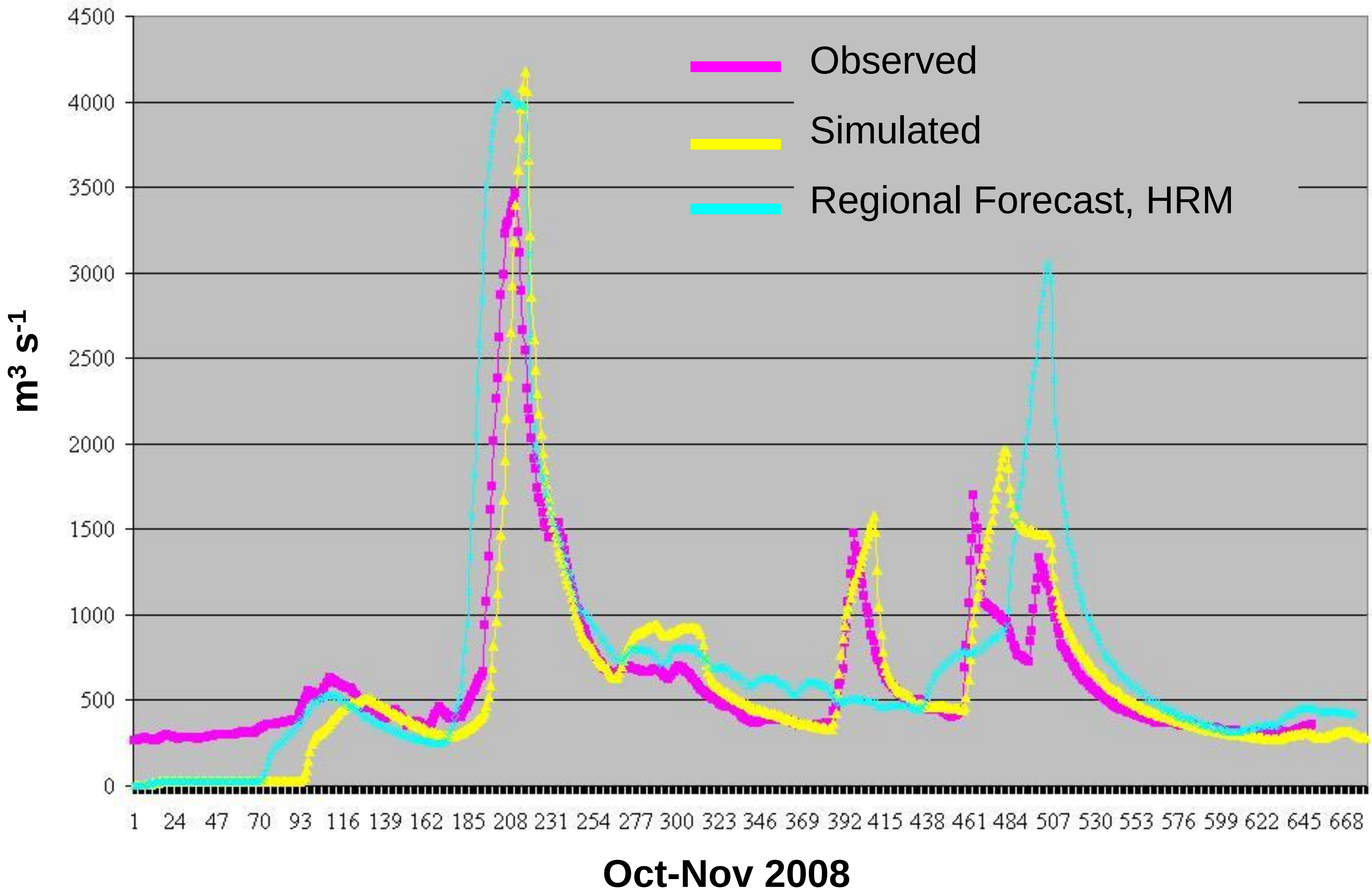
Extended Lead-time

6hrs → **24hrs**

with

Successful performance, but more events are needed and include two new dams

Results obtained by Vietnamese Forecasters @ MONROE/NHMS

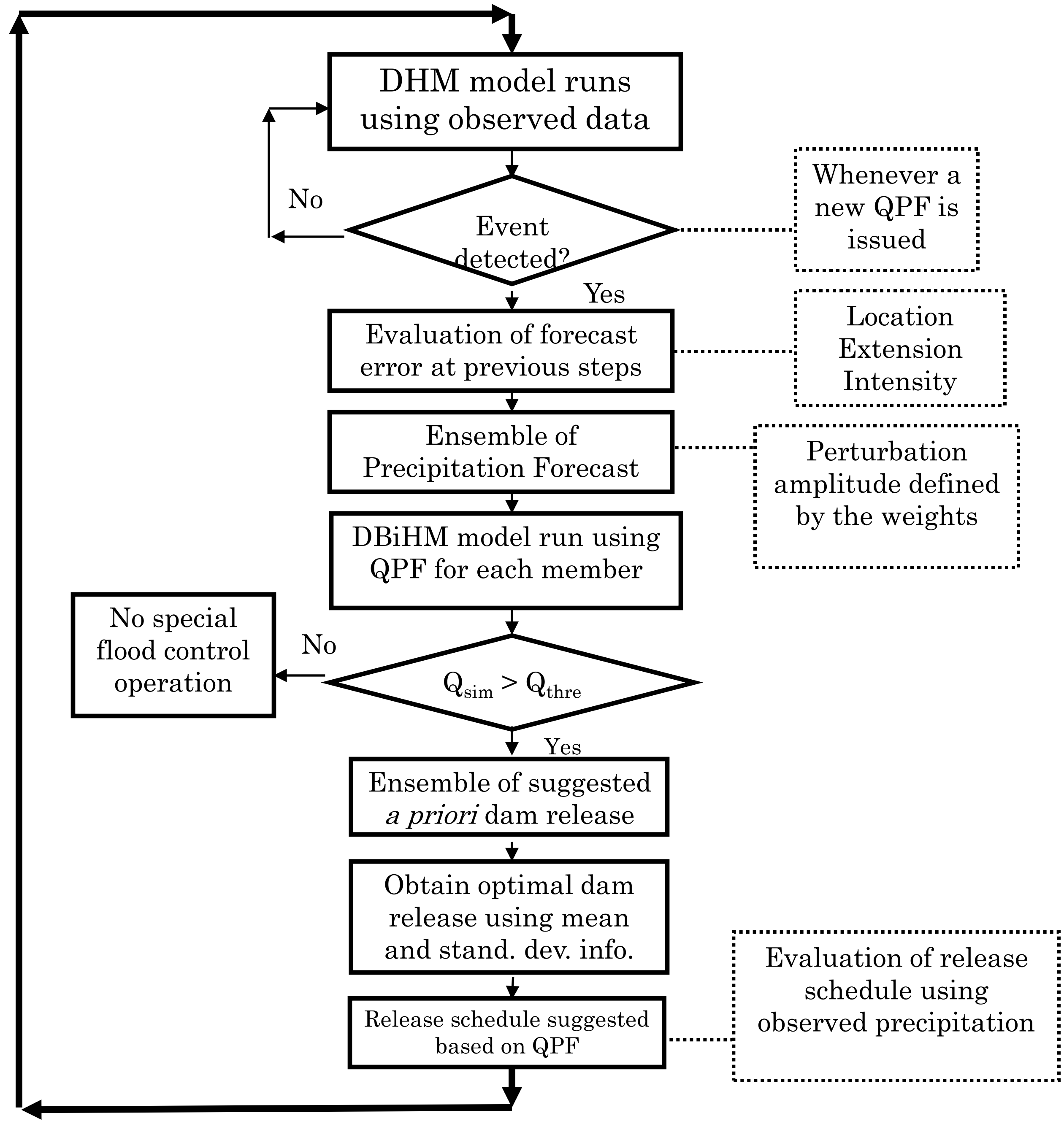



Thanks for your attention!
Angat Dam office

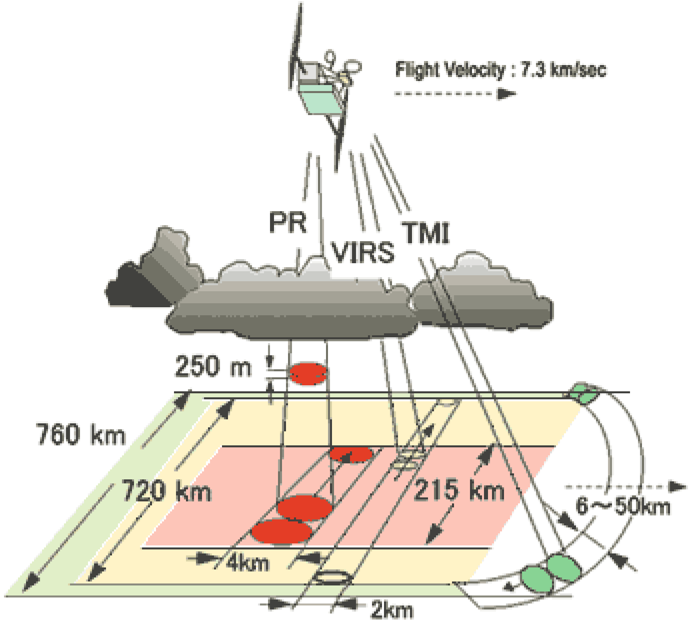
References

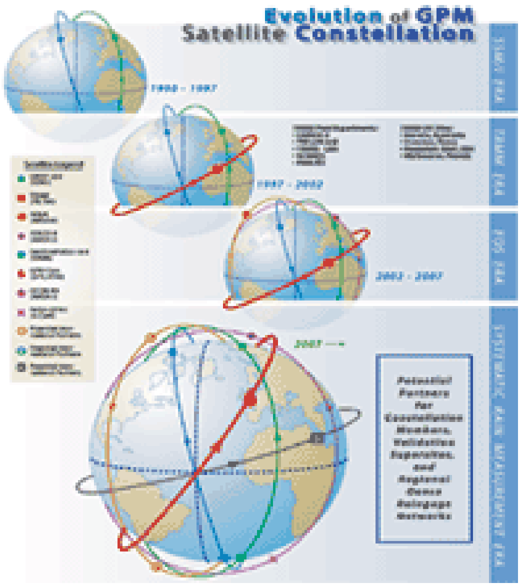
- Saavedra Valeriano, O.C., T. Koike, M. Ryo and S. Kanae (**2012**): “Real Time Flood Control using Quantitative Precipitation Forecast and Ensemble Approach in Rainfall Forecasting,” **book chapter in** “Rainfall Forecasting” Tommy Wong (ed), ISBN: 978-1-61942-134-9, **Nova Science Publishers**, pp. 233-276.
- Saavedra Valeriano, O., Koike, T., Yang, K., Graf, T., Li, X., Wang, L. & Han, X. (2010a): Decision support for dam release during floods using a distributed biosphere hydrological model driven by quantitative precipitation forecasts, **Water Resources Research**,Vol. 26, doi:10.1029/2010WR009502.
- Saavedra Valeriano, O., Koike, T., Yang, K. & Yang, D. (2010b): Optimal Dam Operation during Flood Season using a Distributed Hydrological Model and a Heuristic Algorithm, **Journal of Hydrologic Engineering**, ASCE, Vol. 15, Issue 7, pp. 580-586.
- Saavedra Valeriano, O., Koike, T., Yang, D., Nyunt, C., T., Khanh, D. V. & Chau, L.C. (2009) Flood simulation using different sources of rainfall in the Huong River, Vietnam. **Hydrological Sciences Journal**, 54(5), pp. 909-917.
- Wang, L., T. Koike, K. Yang, P. J.-F. Yeh (2009), Assessment of a distributed biosphere hydrological model against streamflow and MODIS land surface temperature in the upper Tone River Basin, **Journal of Hydrology**, Vol. 377, pp. 21–34.

Overview of DRESS System



TRMM sensor

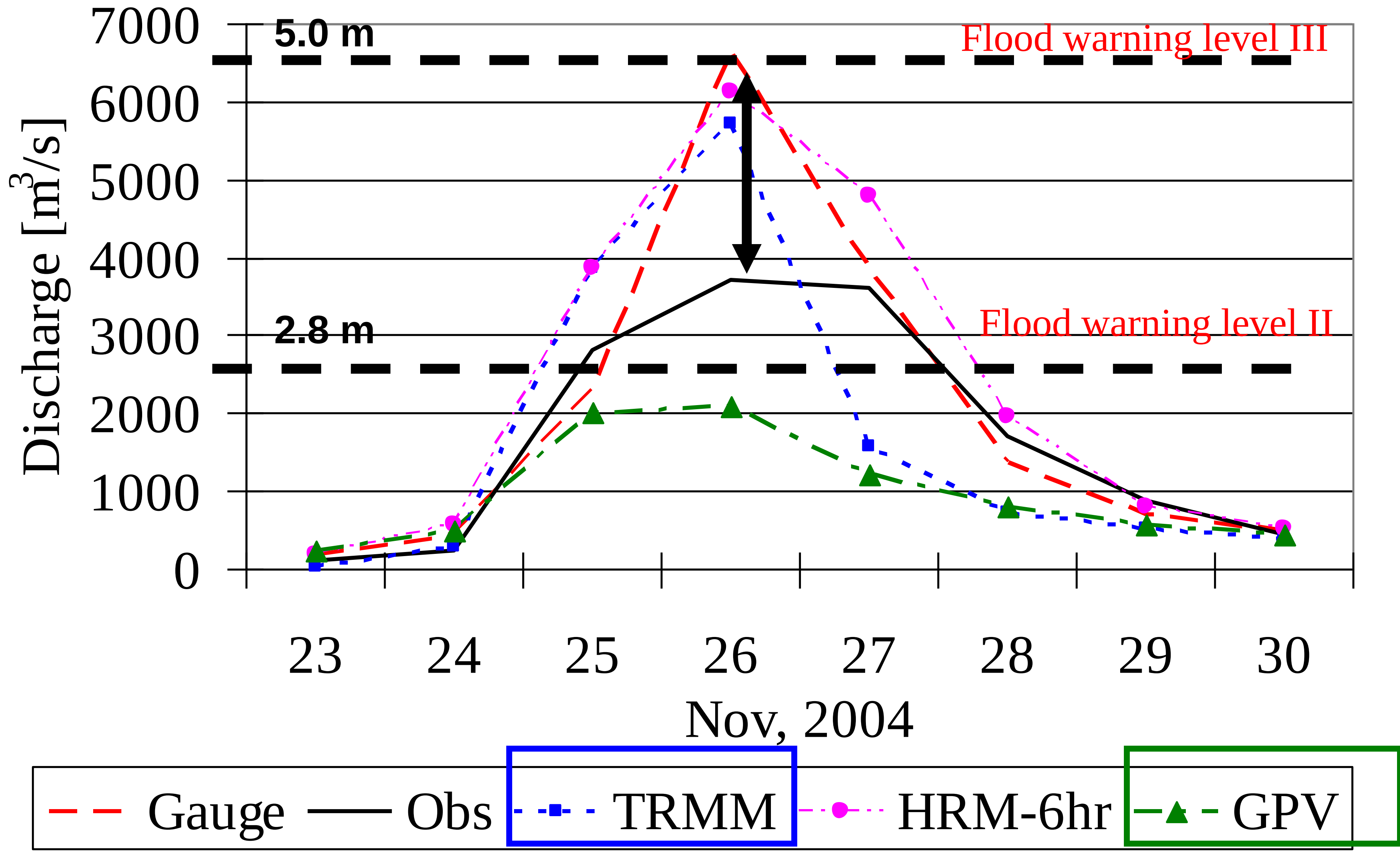




Global Satellite TRRM, 3hr, 0.25°
Nov 1997~
TRMM focuses mainly in tropical area

GPM, 3hr, 0.1°
will reach 95%

High Flows Simulation



Saavedra, Koike et al., 2009