Optimization of hydrological parameters of a distributed runoff model based on multiple flood events

Mamoru MIYAMOTO [1]
Kazuhiro MATSUMOTO [2]
Morimasa TSUDA [1]
Yuzuru YAMAKAGE [2]
Yoichi IWAMI [1]
Hirokazu ANAI [2,3]

1. International Centre for Water Hazard and Risk Management (ICHARM), Public Works Research Institute, Japan
2. Fujitsu Laboratories LTD.
3. Kyushu University

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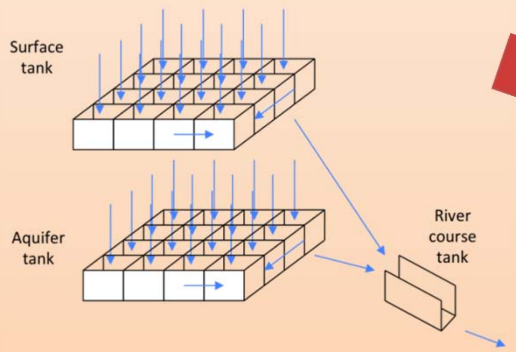
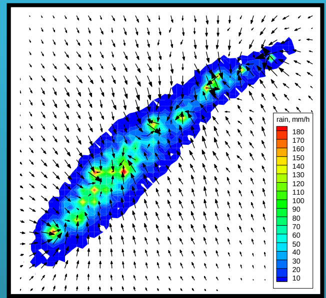
Technical Background

<u>Field of flood forecasting</u>

There is a real need for using distributed runoff model in order to consider spatial distribution.

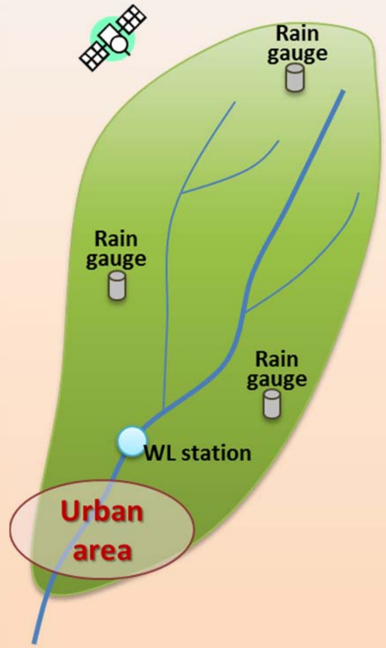


High resolution and high accuracy precipitation information



Precipitation observation by radar

- Distributed model takes a lot of time and trouble with calibration due to number of parameters.
- Commonly applicable calibration method is not established yet.



Objectives

【before flood】

Systemization of optimal parameter setting of flood forecasting model

【during flood】

Predictive accuracy improvement by real-time feedback based on data assimilation

Academic Background

Past studies
(e.g.)
- Global optimization such as SCE-UA, GA for tank model parameter (Tanakamaru et al. , 1996)
- Comparison of usability between SCE-UA and PSO (Tada, 2007)
- Evaluation of several error assessment functions (Fujiwara et al., 2003)
- Multipurpose optimization by multiple objective functions (Yapo et al., 1998)
-

There has been various studies on parameter optimization so far.

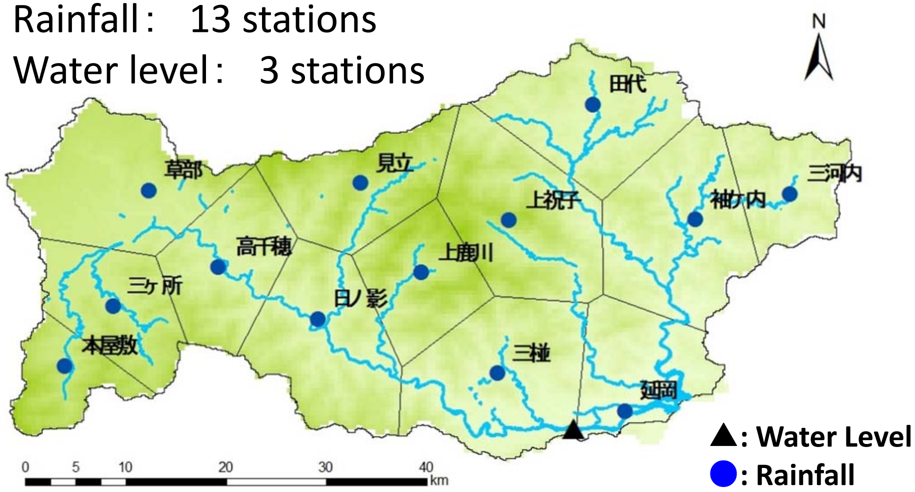
Most of past studies are geared toward specific flood or specific optimization method.

This study is …

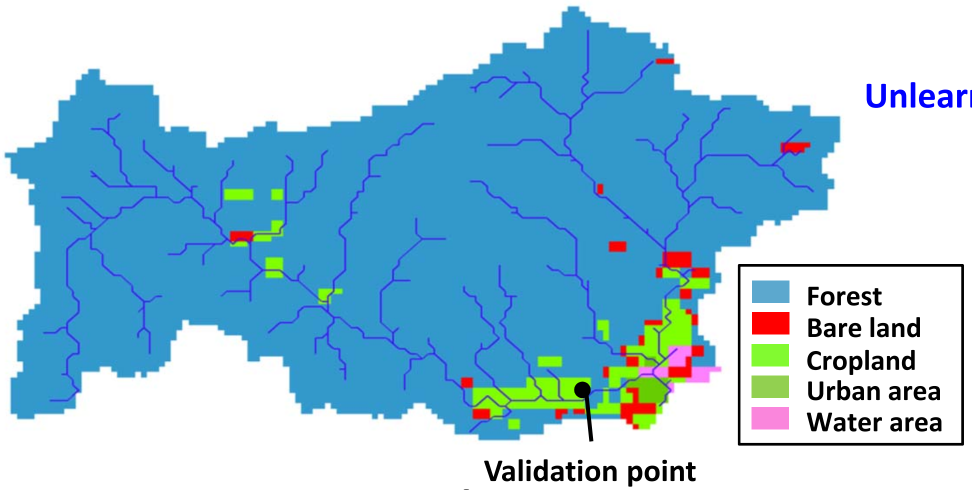
- **Comprehensive approach based on multiple floods and multiple optimization method**
- **Validation using unlearned flood case**

Target River basin; Gokase River basin

Area： 1,820km^2
Length： 270km
Rainfall： 13 stations
Water level： 3 stations



Rainfall and Water level stations



Land use

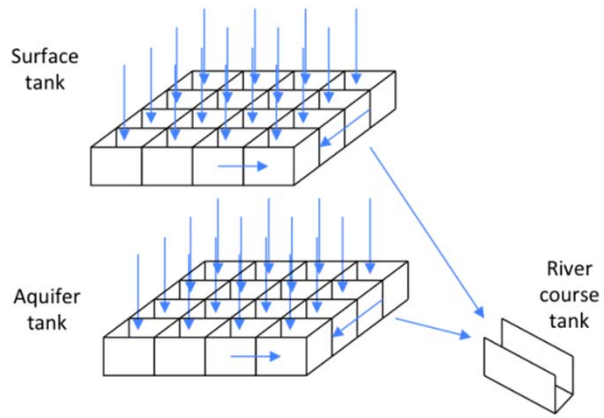
Target floods

Calibration							
Flood	Duration				Rain type	Peak discharge	Runoff rate
	year	start	end	days			
C-1	2004	8/28	9/1	4	Typhoon	6,116	0.86
C-2	2007	8/1	8/4	3	Typhoon	5,287	0.45
C-3	2007	7/2	7/17	15	Typhoon	4,435	0.80
C-4	2004	9/4	9/9	5	Typhoon	3,563	0.74
C-5	2006	8/17	8/20	3	Typhoon	2,795	0.52
C-6	2003	8/6	8/10	4	Typhoon	2,484	0.57
C-7	2004	10/18	10/22	4	Typhoon	2,482	0.50
C-8	2004	9/28	10/1	3	Typhoon	2,247	0.55
C-9	2002	7/25	7/29	4	Frontal	2,013	0.73
C-10	2003	5/29	6/2	4	Typhoon	1,956	0.74
C-11	2002	7/5	7/8	3	Frontal	1,708	0.66
C-12	2002	8/29	9/2	4	Frontal	1,694	0.57
C-13	2004	6/19	6/23	4	Typhoon	1,678	0.56
C-14	2006	6/23	6/29	6	Frontal	1,374	0.37
C-15	2003	9/10	9/14	4	Typhoon	1,350	0.50

Unlearned

Validation							
Flood	Duration				Rain type	Peak discharge	Runoff rate
	year	start	end	days			
V-1	2011	6/10	6/14	4	Frontal	1,253	0.36
V-2	2011	6/18	6/23	5	Frontal	1,087	0.36
V-3	2011	8/5	8/8	3	Frontal	1,134	0.48
V-4	2011	9/15	9/22	7	Frontal	2,796	0.43
V-5	2012	6/23	6/27	4	Frontal	1,884	0.48
V-6	2012	9/15	9/19	4	Frontal	1,990	0.56
V-7	2013	10/23	10/27	4	Frontal	1,424	0.47
V-8	2014	6/3	6/6	3	Frontal	1,190	0.40
V-9	2014	7/30	8/5	6	Frontal	1,500	0.53
V-10	2014	8/7	8/11	4	Typhoon	1,087	0.72

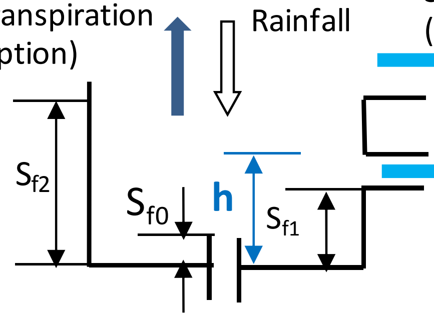
Structure of PWRI Distributed Model



Surface tank

Evapotranspiration (option)

Rainfall



Surface flow (Manning's law)

$$Q_{sf} = L\frac{1}{N}(h - S_{f2})^{\frac{5}{3}}\sqrt{i}$$

Roughness

Rapid unsaturated subsurface flow

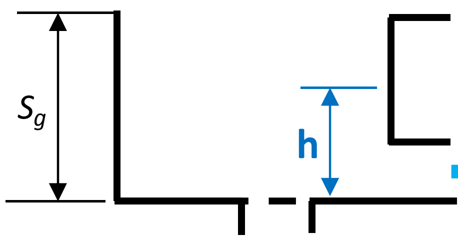
$$Q_{ri} = \alpha_n \cdot A \cdot f_0 \frac{(h - S_{f1})}{(S_{f2} - S_{f1})}$$

Infiltration capacity

Infiltration to subsurface tank or aquifer tank

$$Q_0 = A f_0 \frac{(h - S_{f0})}{(S_{f2} - S_{f0})}$$

Aquifer tank



Slow saturated subsurface flow

$$Q_{g1} = A_u^2 \cdot (h - S_g)^2 \cdot A$$

Runoff coefficient

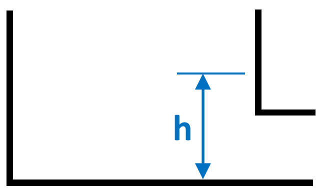
Aquifer base flow

$$Q_{g2} = A_g \cdot h \cdot A$$

Runoff coefficient

Unaccountable aquifer loss (option)

River



Flow of river course

$$Q_r = B\frac{1}{n}h^{5/3}\sqrt{i}$$

Roughness

Target parameters for optimization

- Final infiltration capacity: f_0
- Ground surface roughness: N
- Runoff coefficient（subsurface flow）: A_u
- Runoff coefficient （base flow）: A_g

Terms and Conditions of Optimization

Applied Opt. Algorisms

Software	Opt. algorisms
pyOpt	COBYLA
	KSOPT
	NSGA2
	SDPEN
Nlopt	LN_COBYLA
	GN_MLSL
	GN_MLSL_LDS
	LN_AUGLAG
	LN_NELDERMEAD
	LN_SBPLX
inspired	DEA
	GA
	PSO
	SA
R	BBO
	DFOPTIM_HJKB
	MCO_NSGA2
	PSO_PSOPTIM
	RMALSCHAINS

Criteria of selecting

1. No abnormal end
2. Not far outstrip the designed iteration
3. The best result in either cases of floods or error assessment functions

Error Assessment Functions

- Mean square error

$$E_M = \frac{1}{N}\sum_{i=1}^{N}(Q_{oi} - Q_{ci})^2$$

- Relative error

$$E_R = \frac{1}{N}\sum_{i=1}^{N}\frac{(Q_{oi} - Q_{ci})^2}{{Q_{oi}}^2}$$

- Logarithmic error

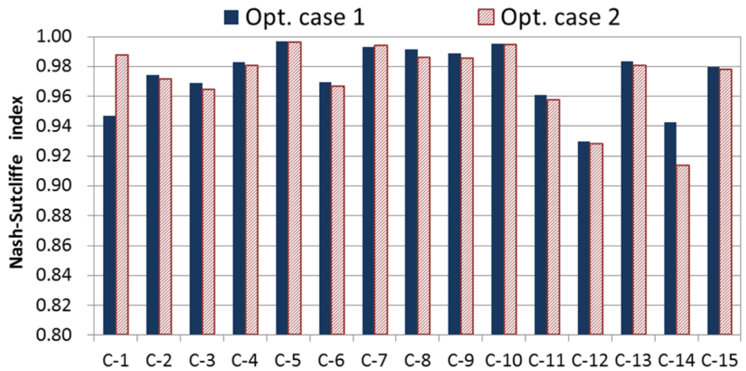
$$E_L = \frac{1}{N}\sum_{i=1}^{N}(\log Q_{oi} - \log Q_{ci})^2$$

Search Range

parameter	unit	maximum	minimum
Infiltration capacity f_0	cm/s	**5.0×10^{-2}**	**5.0×10^{-6}**
Ground surface roughness N	m$^{-1/3}$・s	**2.0**	**0.1**
Runoff coefficient A_u (subsurface flow)	(1/mm/day)$^{1/2}$	**0.6**	**0.05**
Runoff coefficient A_g (base flow)	1/day	**0.05**	**0.001**

Results of Optimization

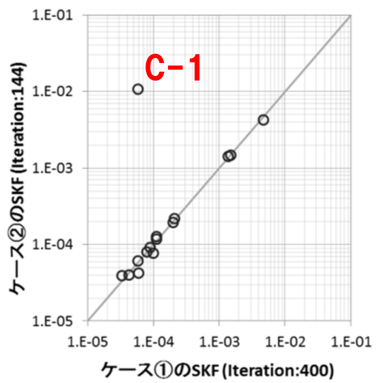
	Opt. case 1	Opt. case 2
iteration	400	144
Target land use	All	Only forest
Number of target parameters	12	4
Error assessment function	Mean square Relative Log	Mean square Relative



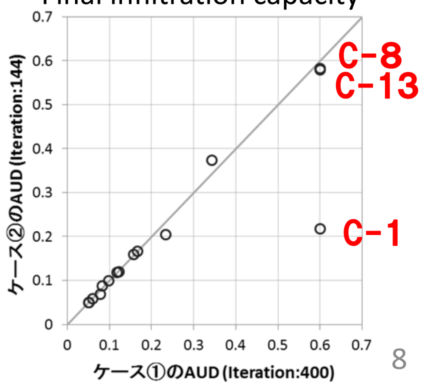
Reproducibility of each flood

The best algorithm for each flood calibration

	Opt. case 1			Opt. case 2	
	mean square	relative	log	mean square	relative
C-1	GN_MLSL_LDS	DEA	LN_SBPLX	LN_NELDERMEAD	LN_NELDERMEAD
C-2	SDPEN	SDPEN	SDPEN	LN_NELDERMEAD	LN_AUGLAG
C-3	MCO_NSGA2	SDPEN	SDPEN	BBO	LN_NELDERMEAD
C-4	DEA	NSGA2	GN_MLSL	PSO_PSOPTIM	LN_NELDERMEAD
C-5	SDPEN	PSO_PSOPTIM	MCO_NSGA2	LN_NELDERMEAD	RMALSCHAINS
C-6	PSO	PSO	RMALSCHAINS	LN_NELDERMEAD	NSGA2
C-7	LN_AUGLAG	SDPEN	RMALSCHAINS	LN_NELDERMEAD	PSO_PSOPTIM
C-8	PSO	RMALSCHAINS	GN_MLSL_LDS	NSGA2	LN_AUGLAG
C-9	SDPEN	SDPEN	SDPEN	LN_NELDERMEAD	LN_NELDERMEAD
C-10	SDPEN	SDPEN	MCO_NSGA2	LN_NELDERMEAD	LN_NELDERMEAD
C-11	SDPEN	DEA	SDPEN	LN_NELDERMEAD	NSGA2
C-12	SDPEN	SDPEN	SDPEN	LN_NELDERMEAD	LN_NELDERMEAD
C-13	PSO_PSOPTIM	SDPEN	SDPEN	NSGA2	LN_NELDERMEAD
C-14	SDPEN	PSO	PSO_PSOPTIM	PSO_PSOPTIM	PSO
C-15	PSO	SDPEN	SDPEN	LN_NELDERMEAD	LN_NELDERMEAD



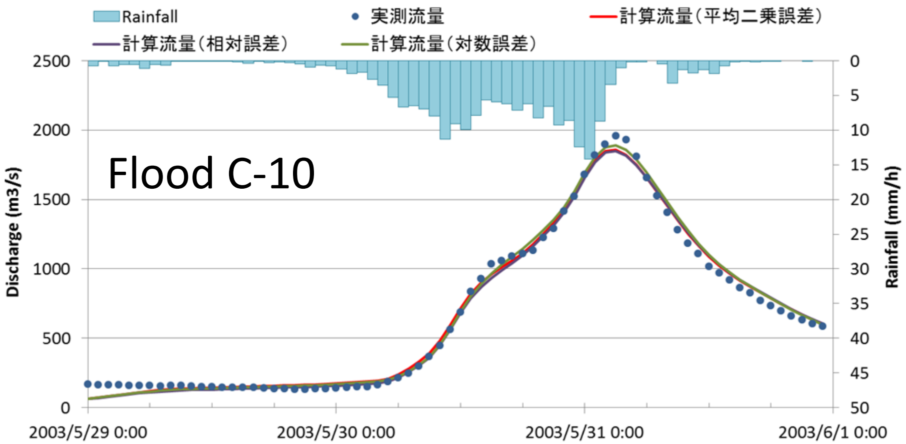
Final infiltration capacity

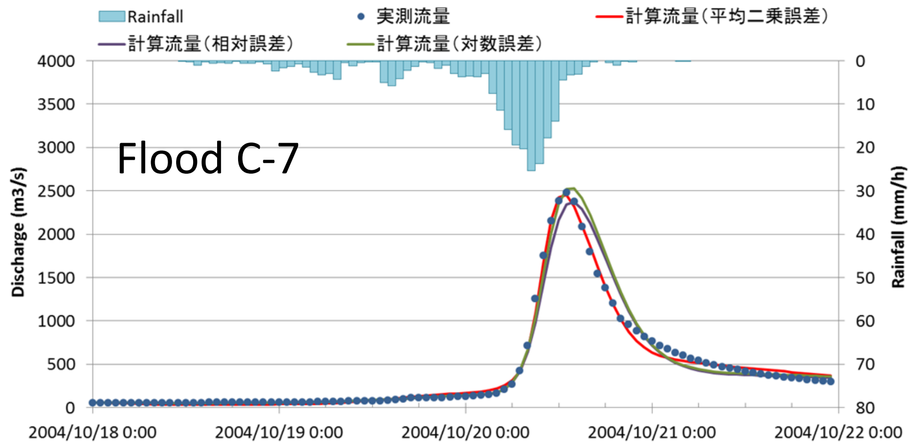


Runoff coefficient of subsurface fase flow

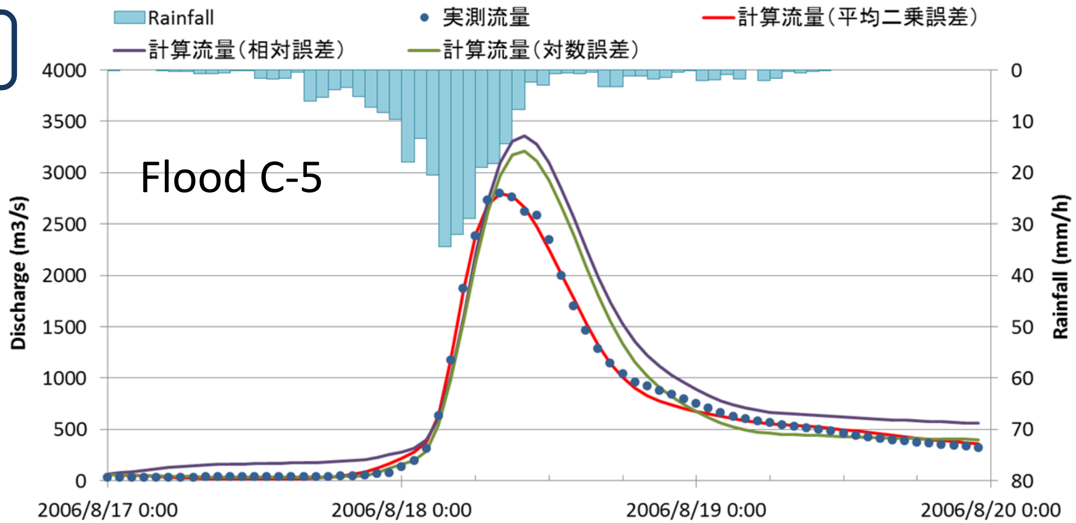
Effect of Error Assess Functions

Less effect of error assess function





Effect of error assess function



Mean square is better than others particularly around peak of hydrograph

Simulated discharge with optimized parameters

Results of Optimization

Flood	Duration				Rain type	Peak discharge	Runoff rate
	year	start	end	days			
C-1	2004	8/28	9/1	4	Typhoon	6,116	0.86
C-2	2007	8/1	8/4	3	Typhoon	5,287	0.45
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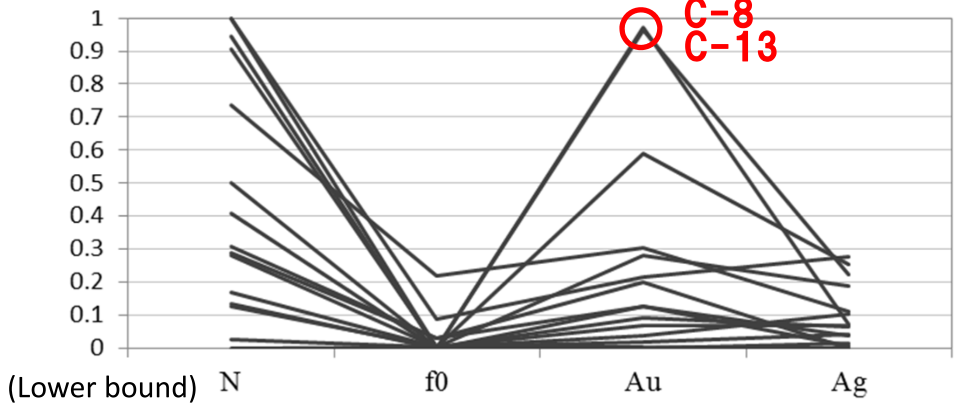
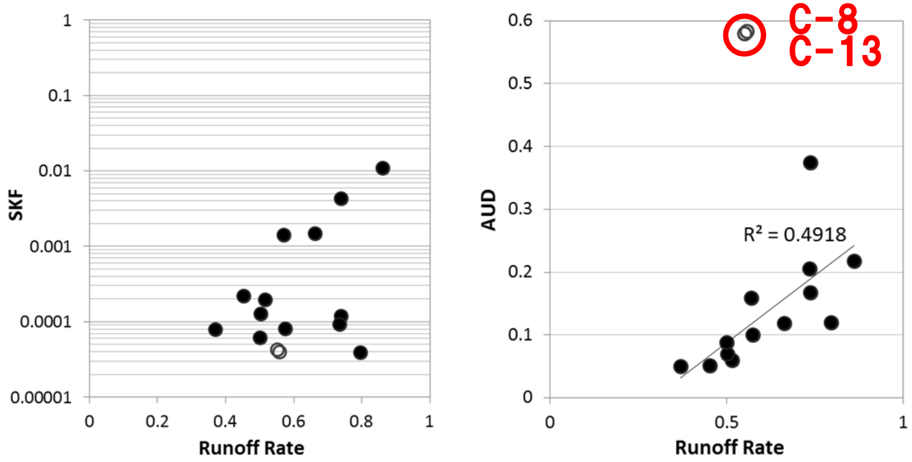


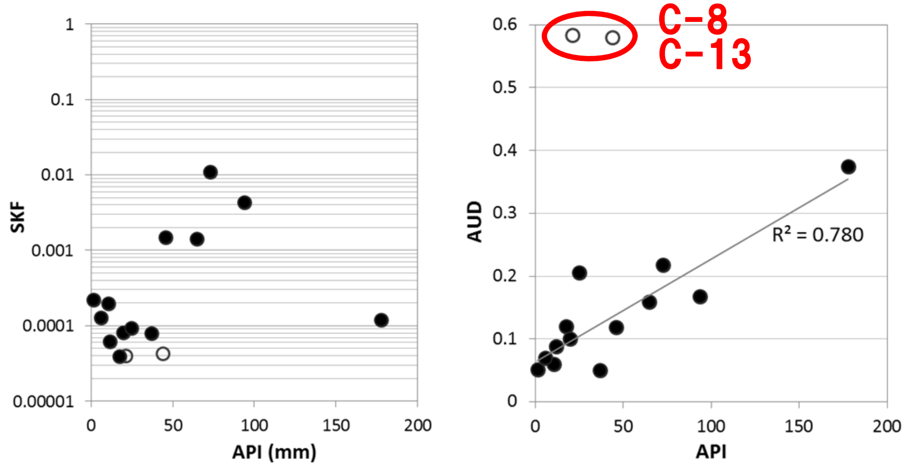
Distribution of optimized parameters

Antecedent Precipitation Index (14 days)

$$API = \sum_{i=1}^{n} \alpha^{i} \cdot R_i$$

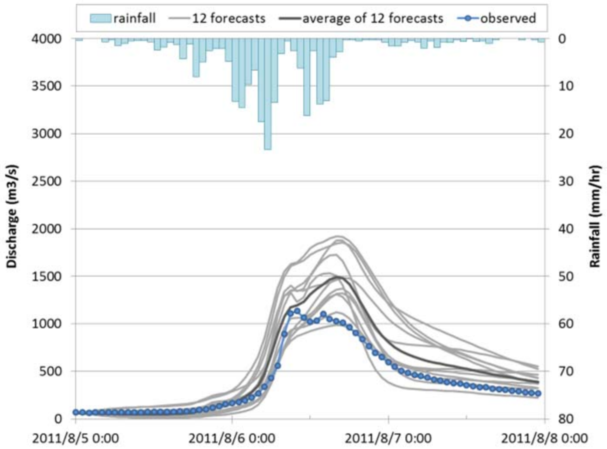


Relationship between runoff rate and optimized parameters

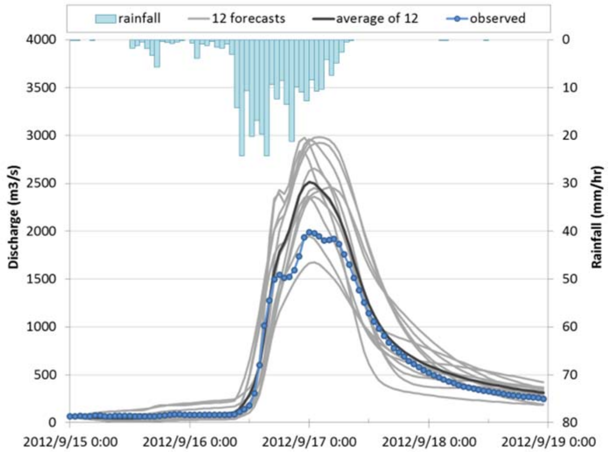


Relationship between API and optimized parameters

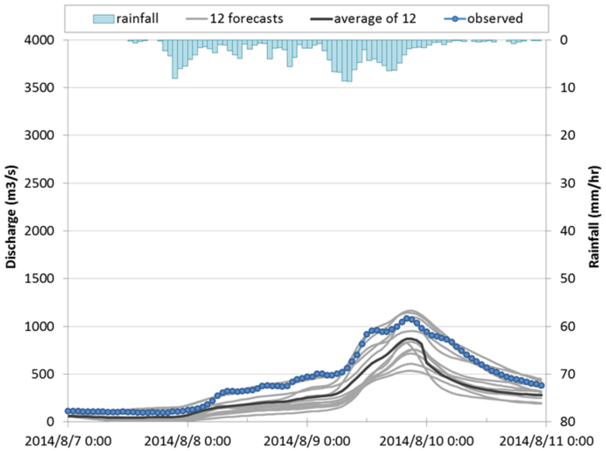
Validation with Unlearned Data



Flood V-3 Runoff rate : 0.48

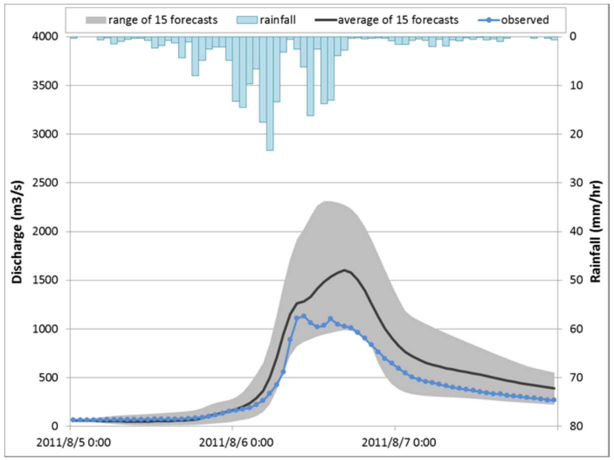


Flood V-6 Runoff rate : 0.56

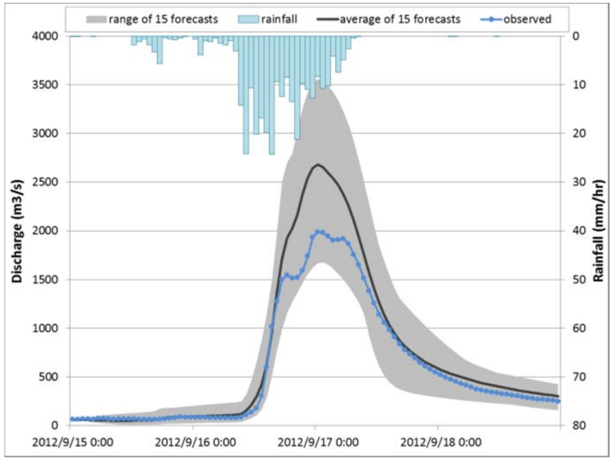


Flood V-10 Runoff rate : 0.72

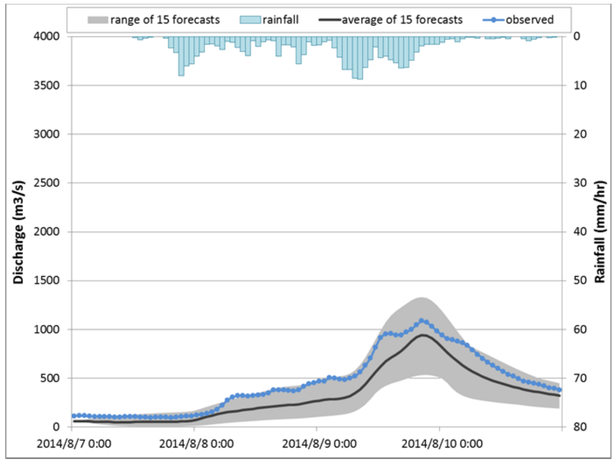
River discharge with calibrated parameters by 15 floods



Flood V-3 Runoff rate : 0.48



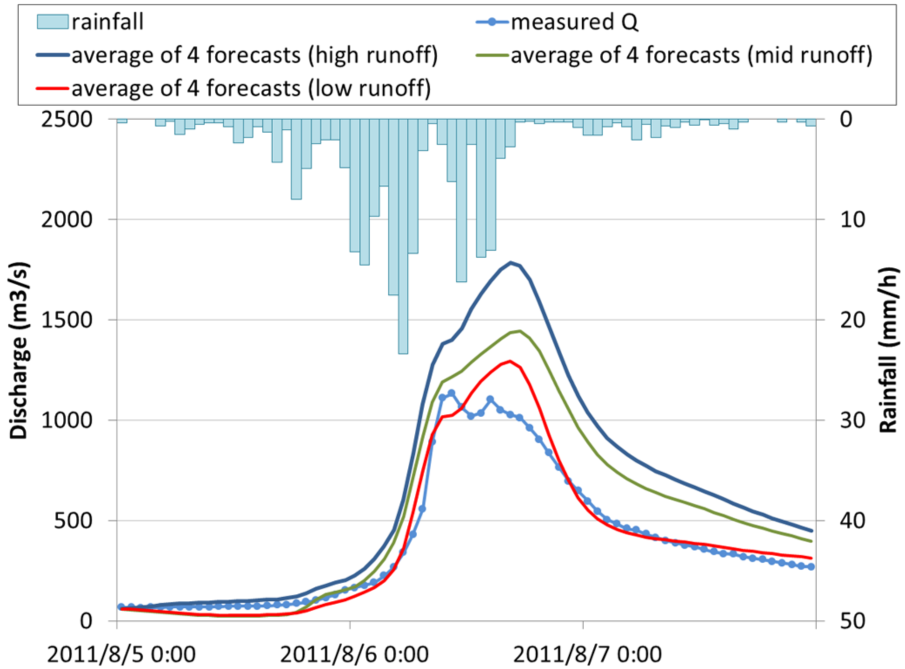
Flood V-6 Runoff rate : 0.56

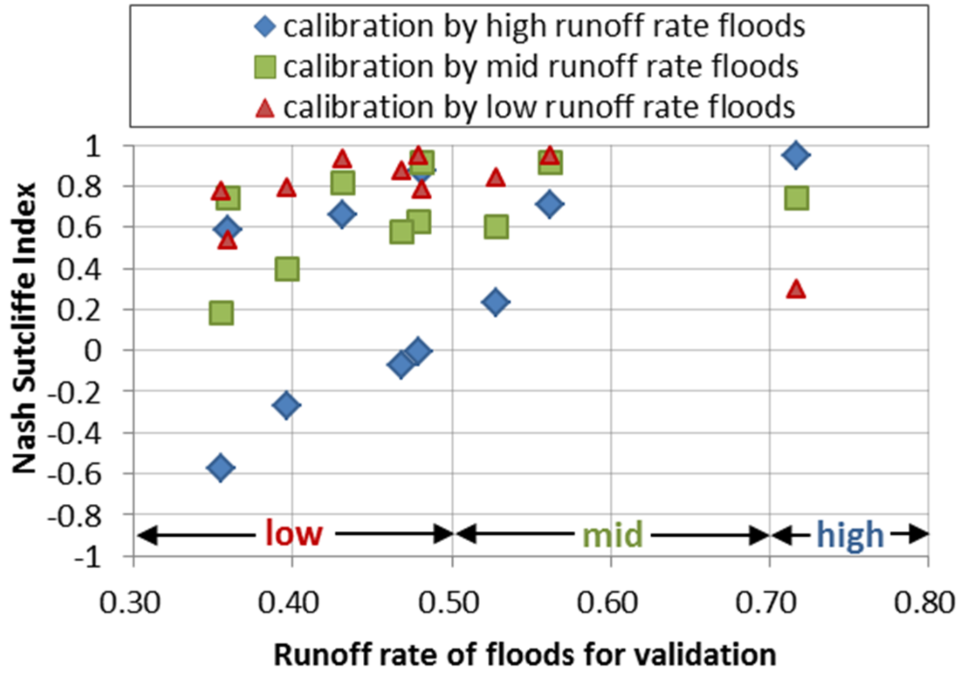


Flood V-10 Runoff rate : 0.72

Predictive width with calibrated parameters by 15 floods

Validation with Unlearned Data





Similarity of runoff rate between calibration and validation increases reproducibility.

It may be difficult to reproduce small-scale flood by the parameters calibrated by largest recorded flood…

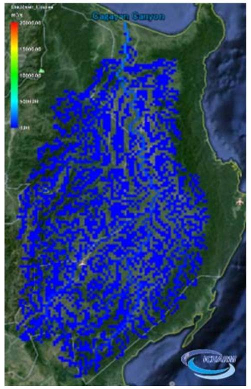
Conclusions

Hydrological parameters in distributed runoff model are calibrated by multiple optimized algorithms for each flood.

- Optimized parameters which are widely distributed by flood correlate with runoff rate and API. The cause of correlation with API is due to initial condition of soil moisture.
- It was confirmed in validation by unlearned flood that measured discharge is included within prediction width of 15 calibrated floods.
- The discharges forecasted by using the parameter sets in each category matched the observed discharges with high accuracy when they were applied to similar cases among the ten floods in terms of runoff rate.
- The results of this study suggested the possibility of improved future flood forecasting based on categorization of flood by runoff rate.

In addition...

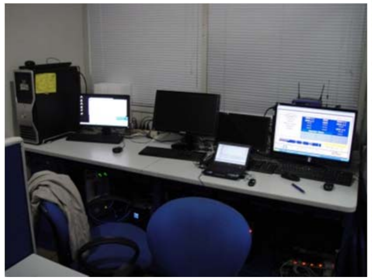
We are planning to implement the optimization method to the IFAS (Integrated Flood Analysis System), which is flood forecasting system developed by ICHARM.



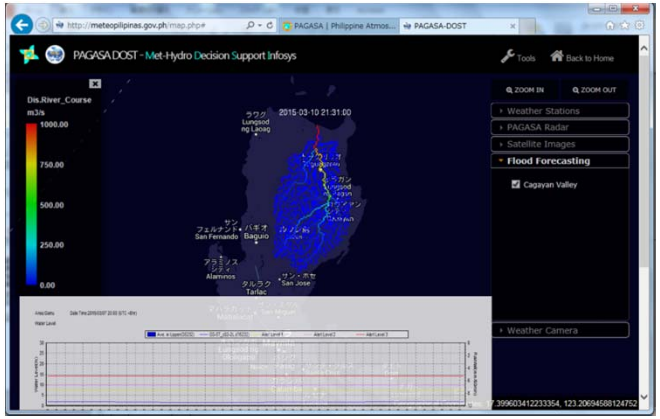
discharge

Specific discharge

Rainfall



IFAS



http://meteopilipinas.gov.ph/map.php#

Installed flood forecasting system in Philippines

Thank you for your kind attentions!

mmiyamoto@pwri.go.jp

PWRI ICHARM FUJITSU

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