Rainfall-Runoff-Inundation Prediction at the River Basin Scale

Development of RRI Model and Its Application to Climate Change Impact Assessment and Real-time Flood Inundation Predictions

1) Disaster Prevention Research Institute (DPRI), Kyoto University

2) International Centre for Water Hazard and Risk Management (ICHARM)

Takahiro Sayama[1)], Yusuke Yamazaki[2)], Yoichi Iwami[2)]

Summary of Rainfall-Runoff-Inundation (RRI) Model

- Since 2010 at ICHARM, Public Works Research Institute, Japan

- Concept: rainfall-runoff and inundation simulation at the river basin scale

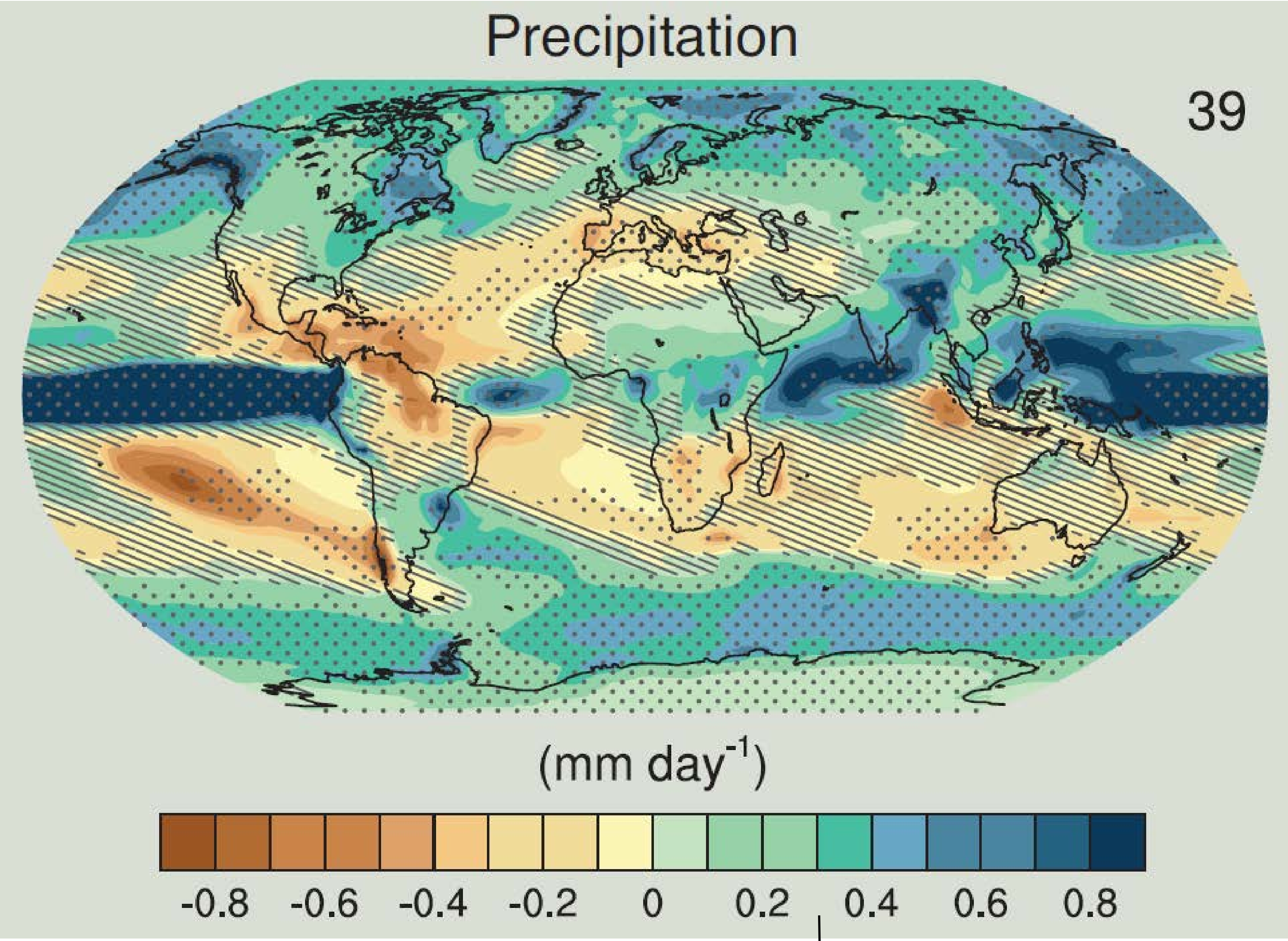
- Target: real time inundation predictions and risk assessment

- As of 2016, the package including Fortran source codes, English manual, GUI (Model builder + Viewer) are available through ICHARM webpage (http://www.icharm.pwri.go.jp/research/rri/rri_top.html)

- Recent advancement: GW, detail cross section, time and space accounting, coupling with WEB-DHM (mainly SiB2 component) and RRI.

- Practical applications at ICHARM: UNESCO Pakistan Project (Indus), JICA Thai Project (Chao Phraya), ADB Myanmar Project for hazard mapping (Irrawaddy)

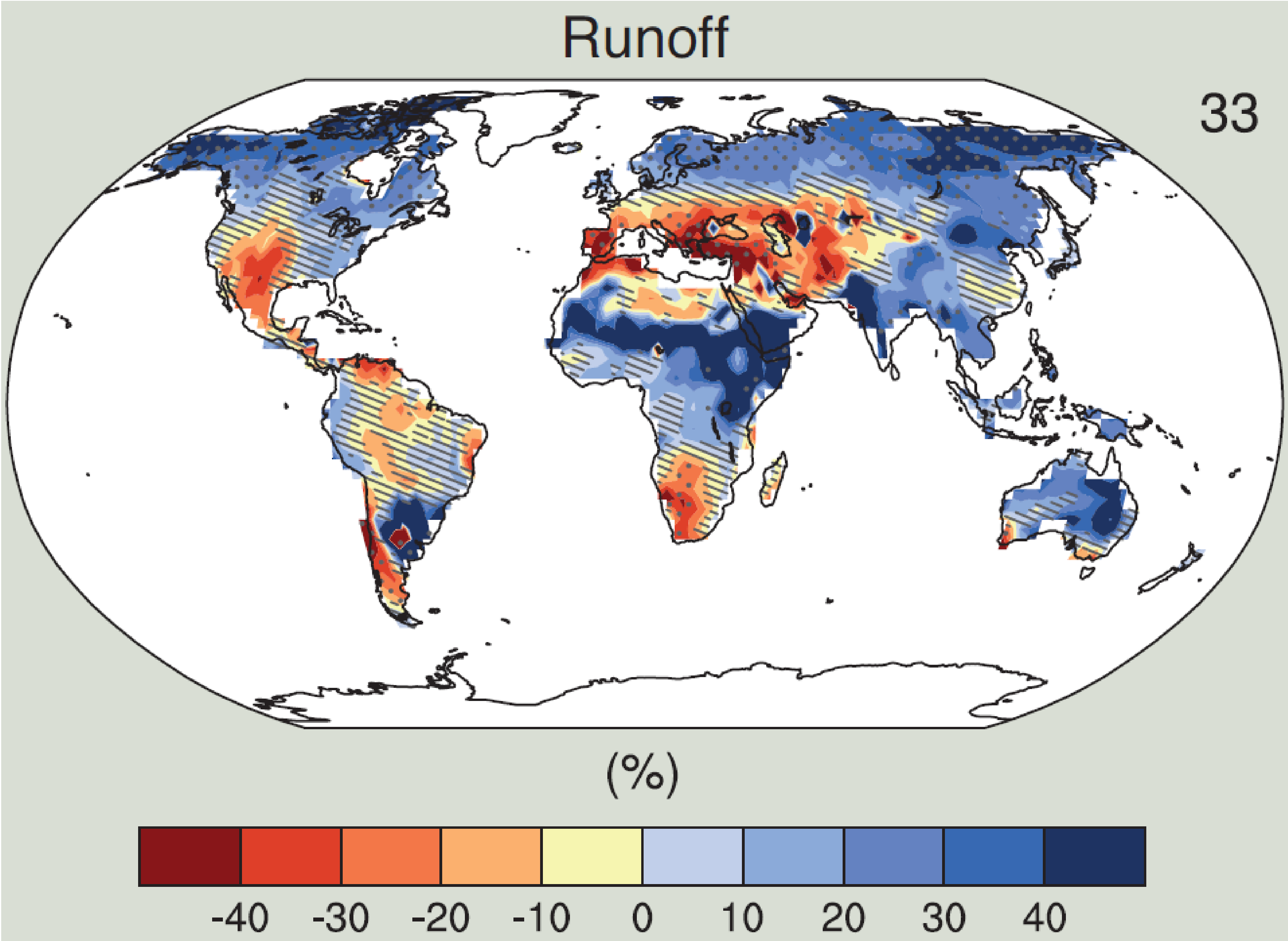
- Application for scientific studies: hydrologic sensitivity, climate change impact, effects of GW etc.



+ 100 mm/year

Annual Mean Change (CMIP5 : RCP8.5)
(2081-2100) – (1986-2005)

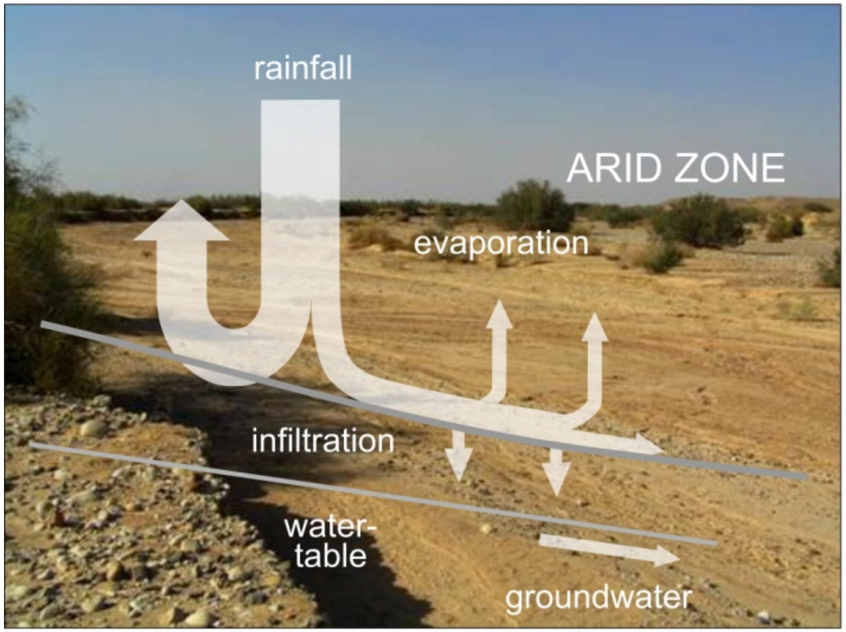
IPCC AR5 (WG1)

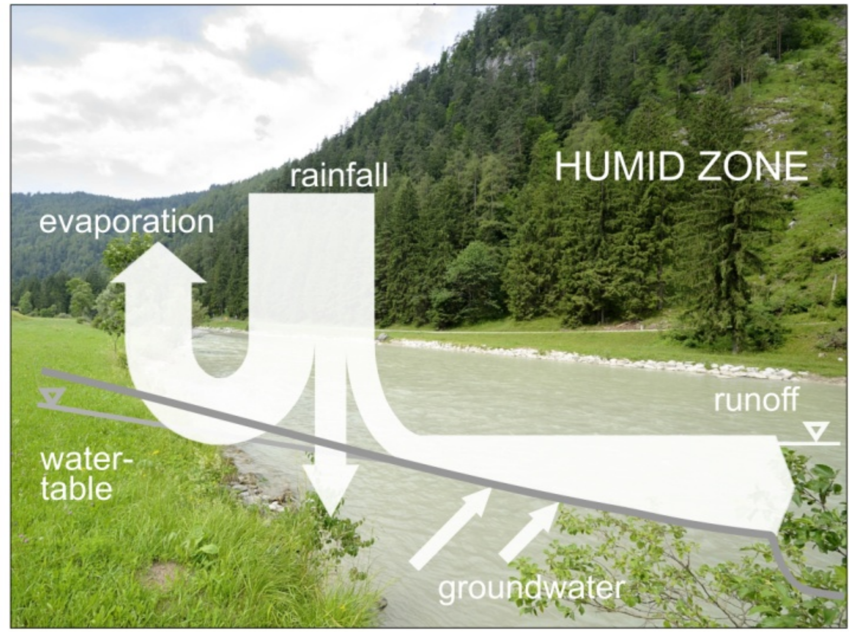


Annual Mean Change (CMIP5 : RCP8.5)
(2081-2100) – (1986-2005)

IPCC AR5 (WG1)

Hydrologic Sensitivity





How much runoff (*Q*) is expected to increase, in percentage term, with a 1% increase in rainfall (*P*)

$$\varepsilon_Q = \frac{dQ/Q}{dP/P}$$

(Schaake, 1990)

Elasticity of Flood Runoff and Inundation

How much runoff (*Q*) and inundation (ΔF) volumes are expected to increase, in percentage term, with a 1% increase in rainfall (*P*)

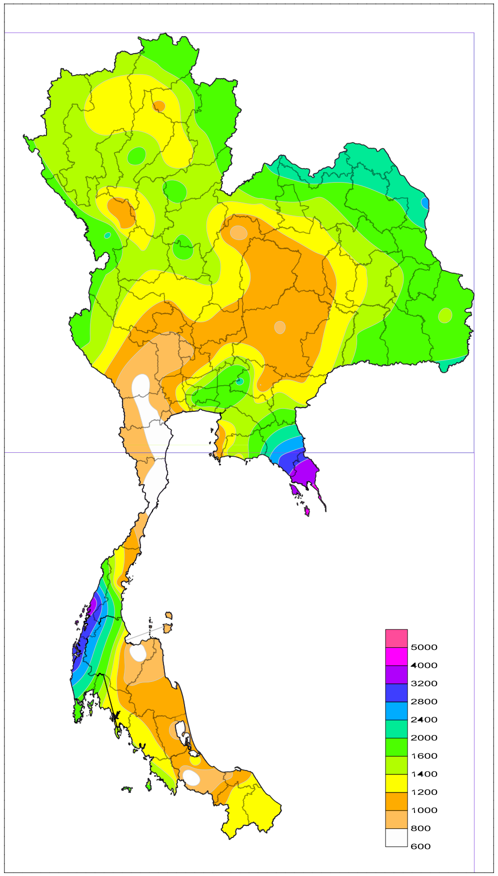
$$\varepsilon_Q = \frac{dQ / Q}{dP / P}$$

(Schaake, 1990)

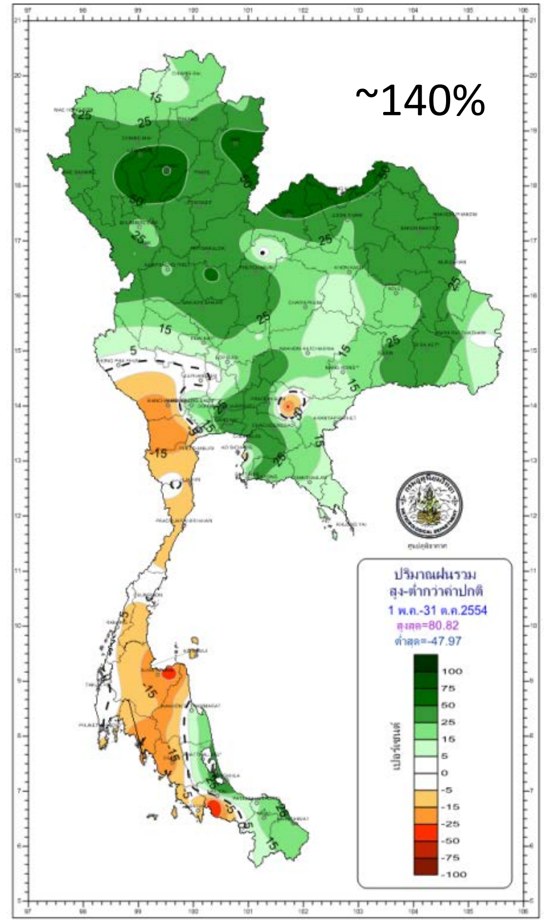
$$\varepsilon_F = \frac{d\Delta F / \Delta F}{dP / P}$$

(Sayama, NHESS, 2015)

Cumulative rainfall in millimeter
(May to October)



Departure of accumulative rainfall(%) (May to October)



TMD

<u>Six months rainfall in the basin</u>

in 2011 : 1400 mm

in past severe events (1995, 2006) : 1200 mm

in average years : 1000 mm

Approach

STEP1 : Rainfall-Runoff-Inundation simulation with observed rainfall

2 km resolution, 52 years : 1960-2011

⇒ Estimate rainfall and flood inundation volumes

⇒ Estimate elastisity of flood runoff and inundation to rainfall

STEP2: RRI simulation with MRI-AGCM projection

AGCM3.2S (20 km), AGCM3.2H (60 km) – RCP 8.5 scenario

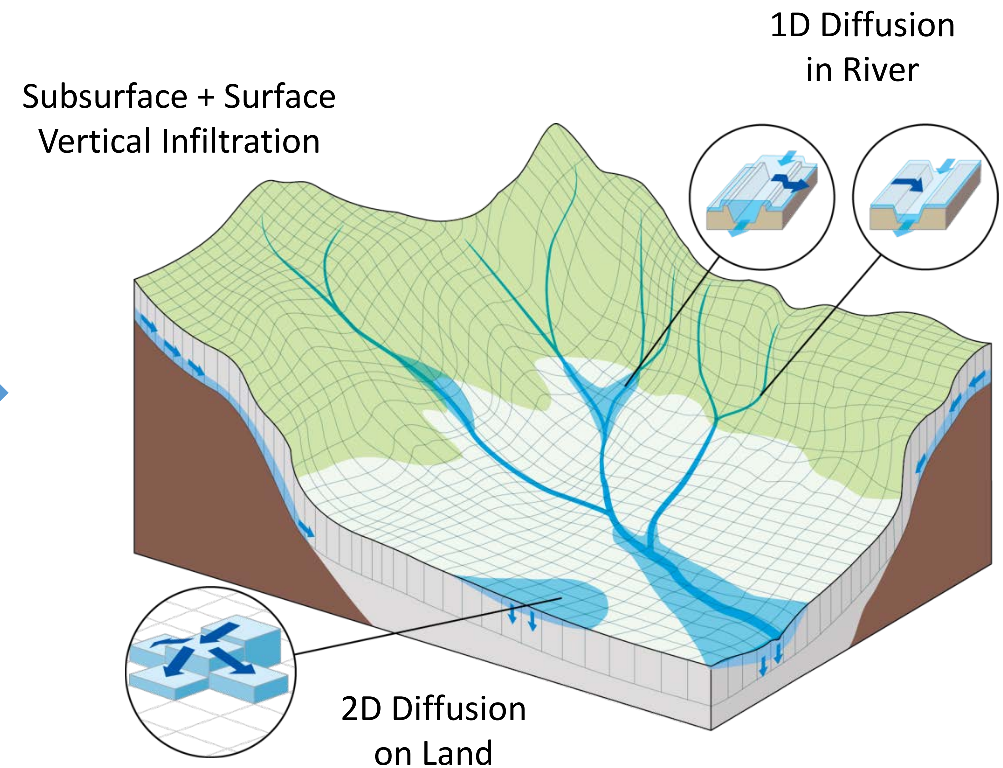
⇒ Present climate (1979-2003) : 1 cases (3.2S)

⇒ Future climate (2075-2099) : 4 cases (3.2S, 3.2H: 3 cases)

Rainfall-Runoff-Inundation Model

Input

- Rainfall
- DEM
- Land Cover
- Cross Sec.



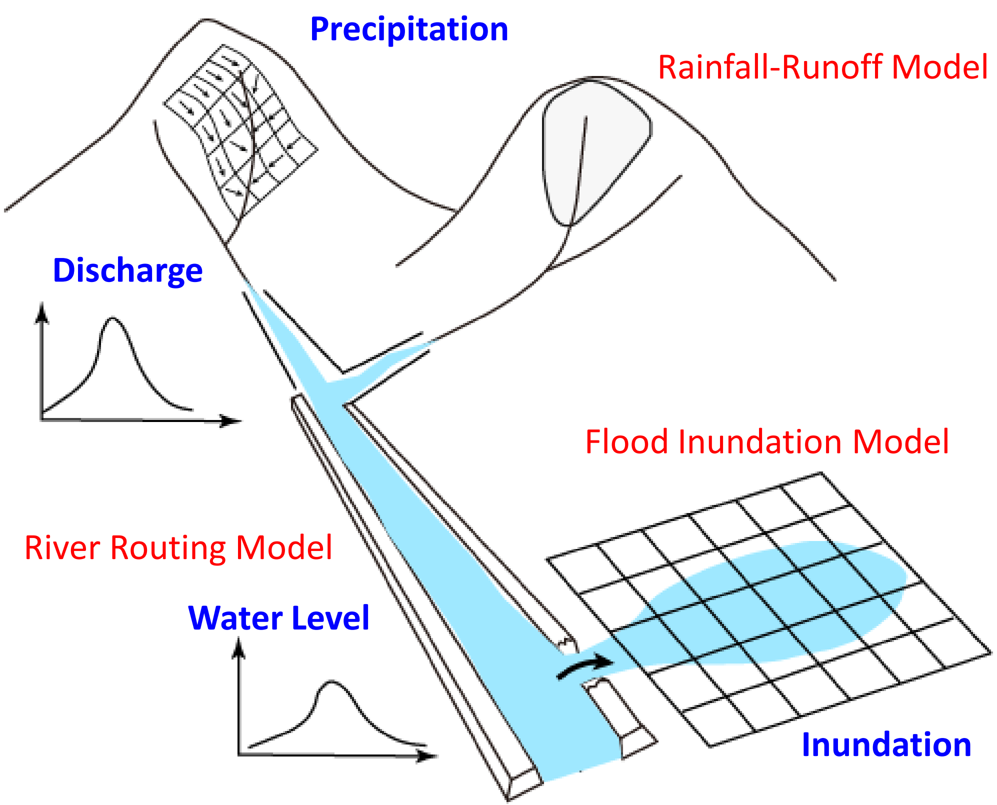
Output

- Discharge
- W. Level
- Inundation

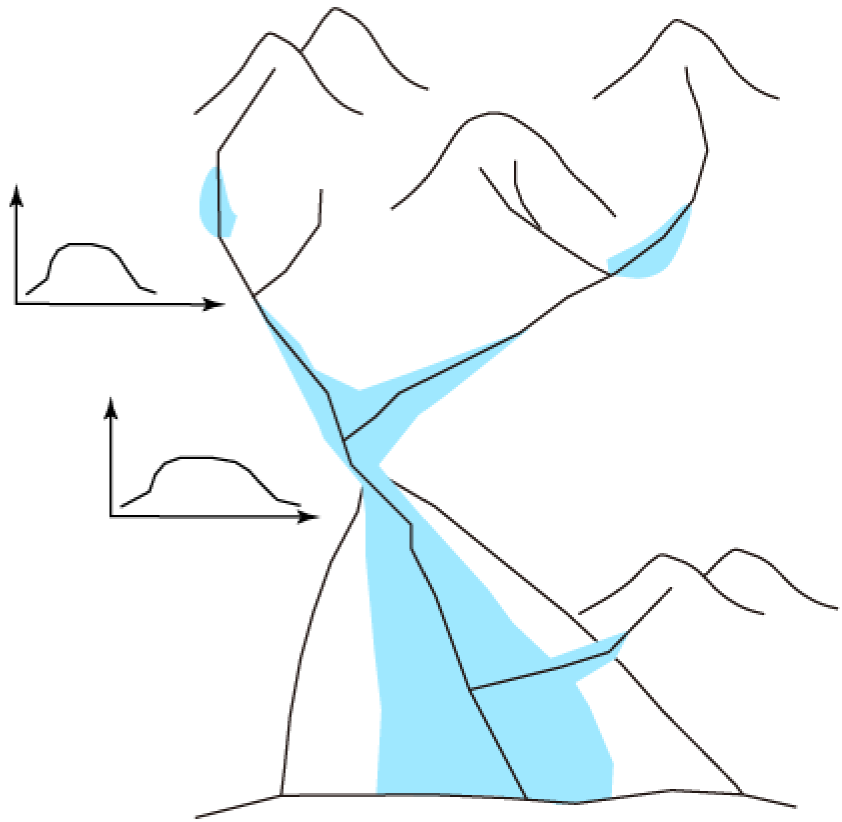
- Two-dimensional model capable of simulating rainfall-runoff and flood inundation simultaneously
- The model deals with slopes and river channels separately
- At a grid cell in which a river channel is located, the model assumes that both slope and river are positioned within the same grid cell

Sayama, T. et al.: Rainfall-Runoff-Inundation Analysis of Pakistan Flood 2010 at the Kabul River Basin, *Hydrological Sciences Journal*, 57(2), pp. 298-312, 2012.

Three kinds of models for flood predictions



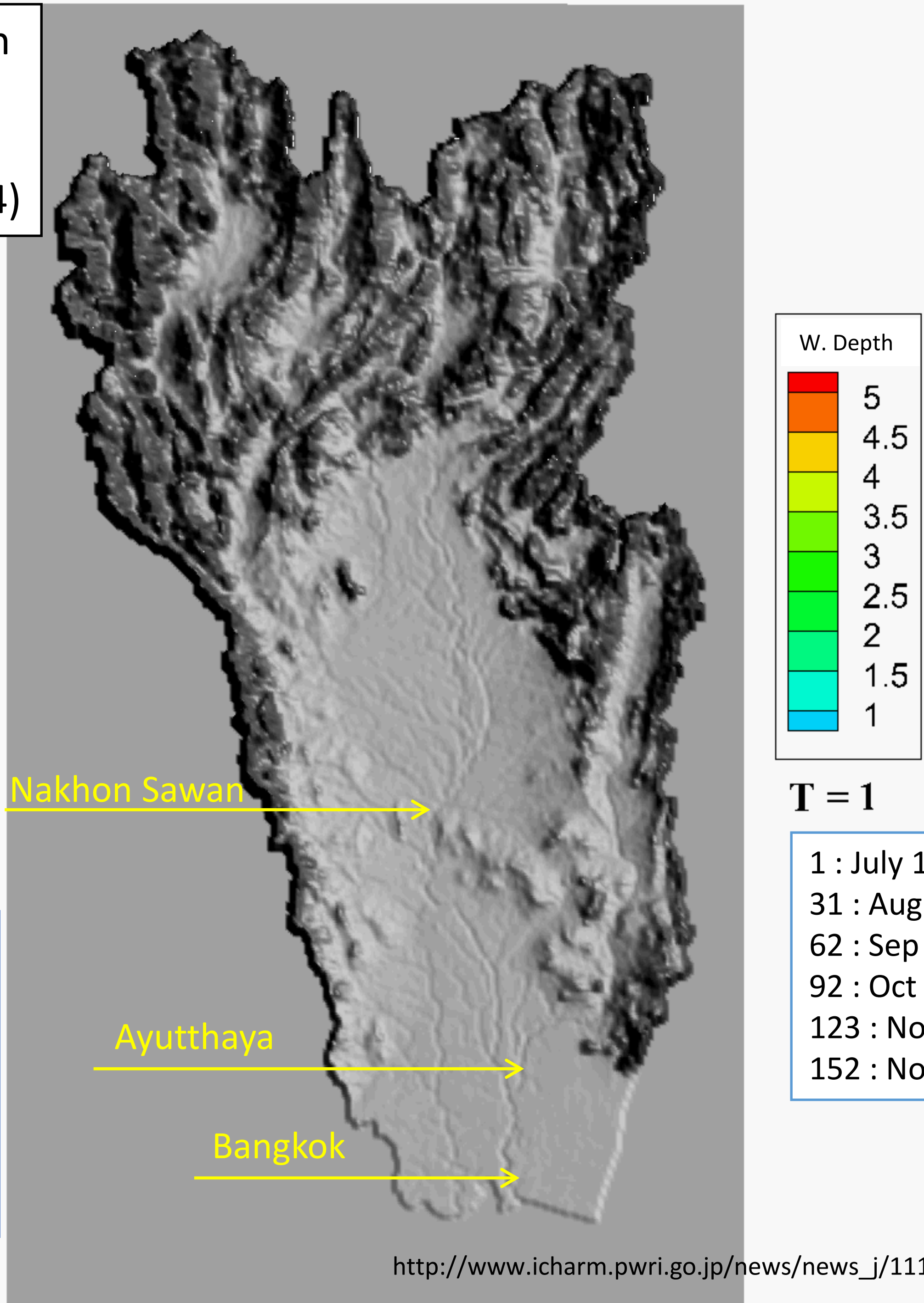
Rainfall-Runoff-Inundation



Motivations of using Rainfall-Runoff-Inundation Model

1. Rainfall-runoff and inundation cannot be separated with large inundation
2. Kinematic wave is not suitable for flat topography
3. Important for representing inundation process for better river predictions
4. Inundation itself may be of interest in flood forecasting or risk assessment

Rainfall-Runoff-Inundation Prediction of Thailand Flood 2011 (conducted on 2011/10/14)

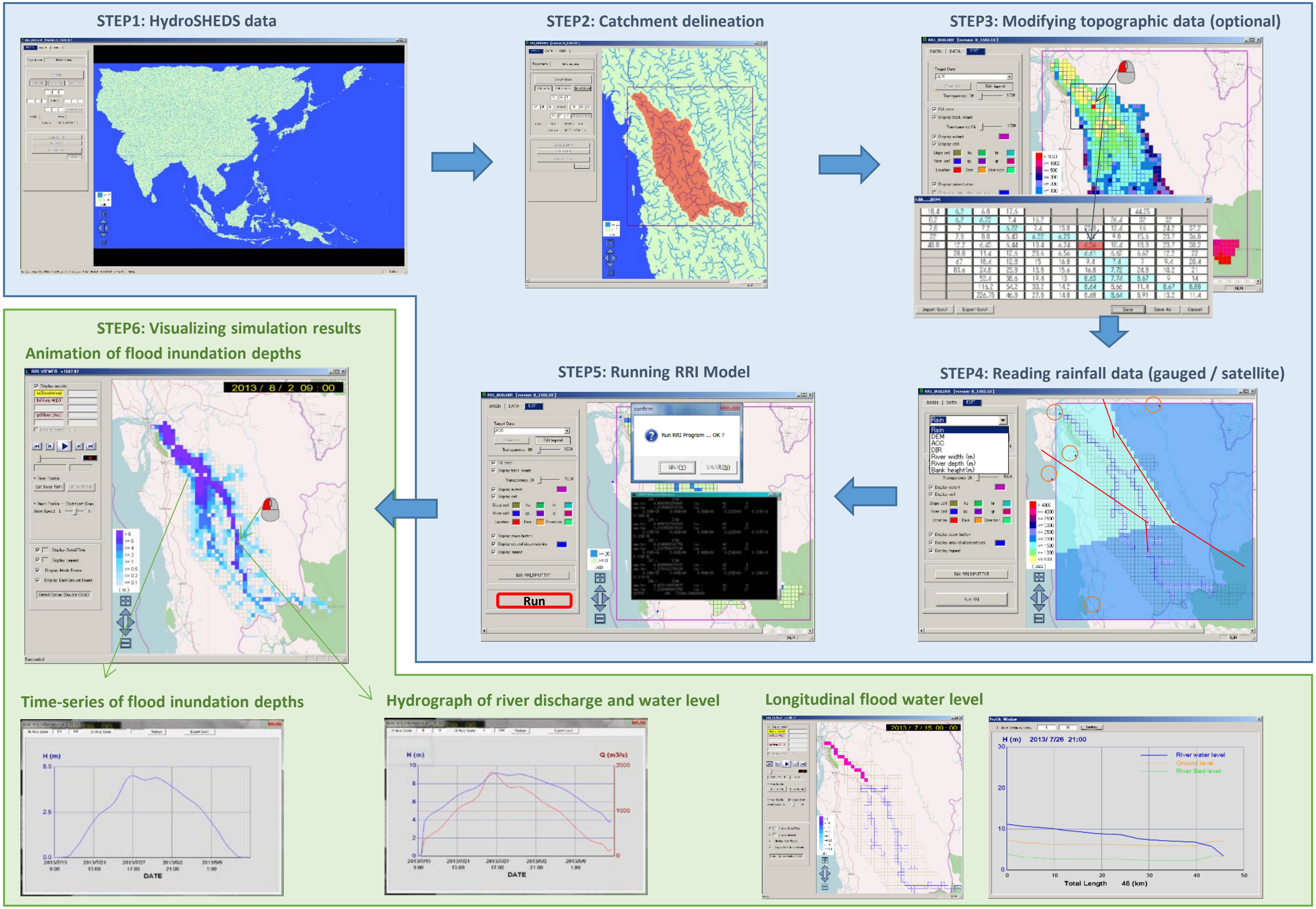


1 : July 1
31 : Aug 1
62 : Sep 1
92 : Oct 1
123 : Nov 1
152 : Nov 30

Simulation Domain : 163,293 km^2
Grid Size : 60sec (1776 x 1884 m)
Simulation Period :
2011/07/01 – 2011/11/30
Input Rainfall:
✓2011/07/01 – 2011/10/14
3B42RT (Satellite Based Rainfall)
(Every 3hours, Spatial Resolution: 0.25 deg)
✓2011/10/14 – 2011/10/21
JMA- GSM Weekly Weather Forecasting
(Forecasting Lead Time: 8 days, Update every 12 hours)
✓2011/11/15 – 2011/11/30
(Previous year's 3B42RT rainfall in the same period)

http://www.icharm.pwri.go.jp/news/news_j/111024_thai_flood_j.html

Model Building with RRI-GUI



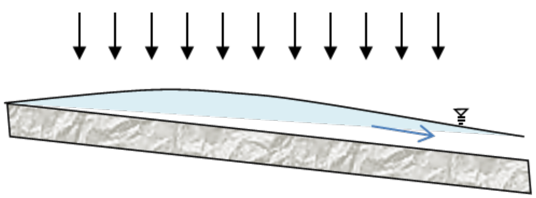
Three Conditions of Surface / Subsurface Flow

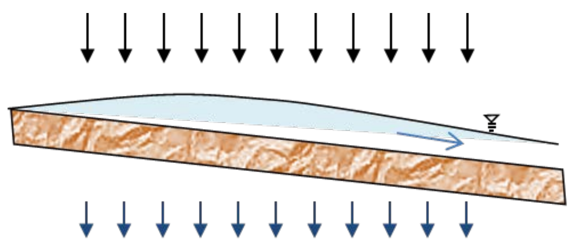
Surface / subsurface flow conditions

(A) Only overland flow (no infiltration loss, no subsurface flow)

(B) Vertical infiltration + Infiltration excess overland flow

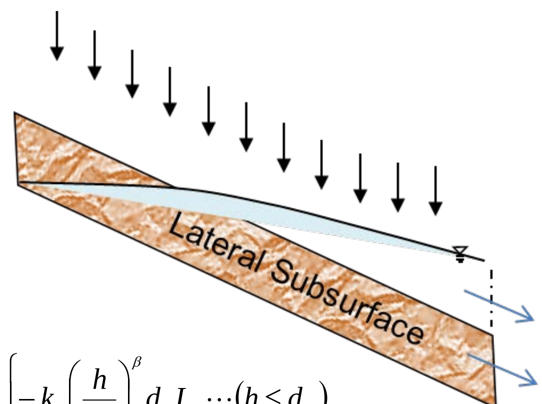
(C) Saturated subsurface + Saturation excess overland flow





Infiltration : Green Ampt Model

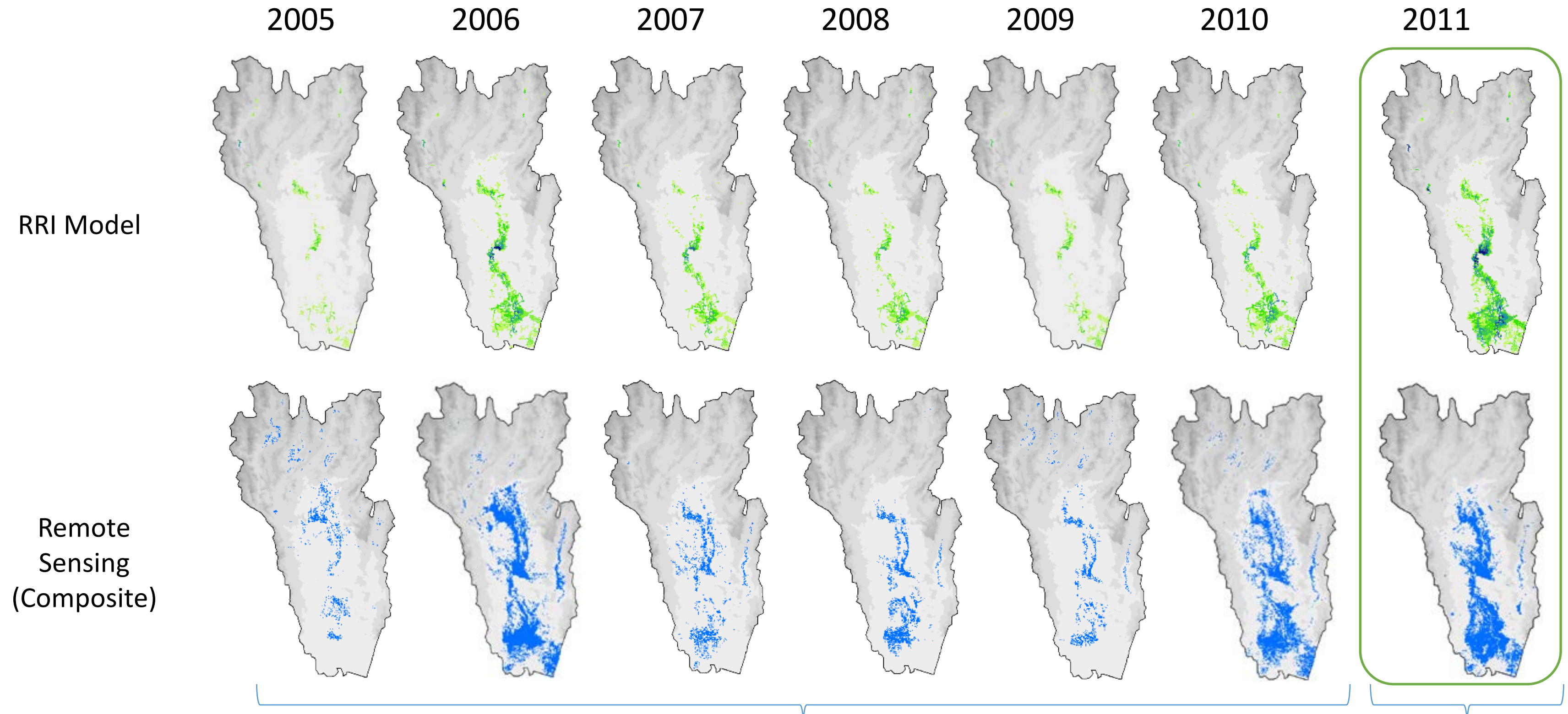
$$f = k_v \left[1 + \frac{(\phi - \theta_i) S_f}{F} \right]$$



$$q = \begin{cases} -k_m \left(\frac{h}{d_m} \right)^{\beta} d_m I & \cdots (h \le d_m) \\ -[k_m d_m + k_a (h - d_m)] I & \cdots (d_m < h \le d_a) \\ -[k_m d_m + k_a (h - d_m)] I + \frac{\sqrt{I}}{n} (h - d_a)^{\frac{5}{3}} & \cdots (d_a < h) \end{cases}$$

(Tachikawa et al., JSCE, 2004)

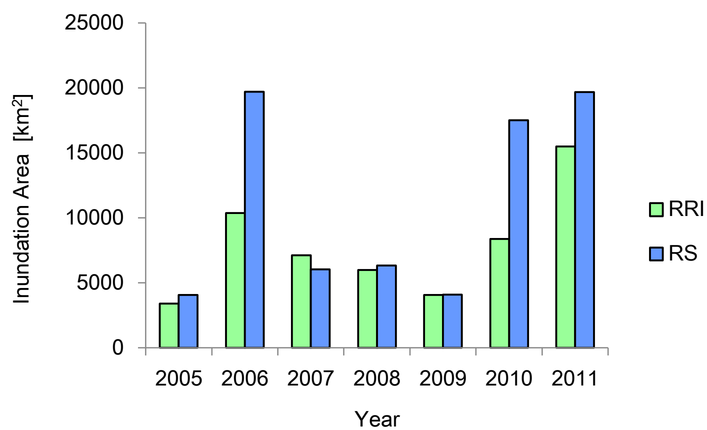
Annual Maximum Inundation Extent



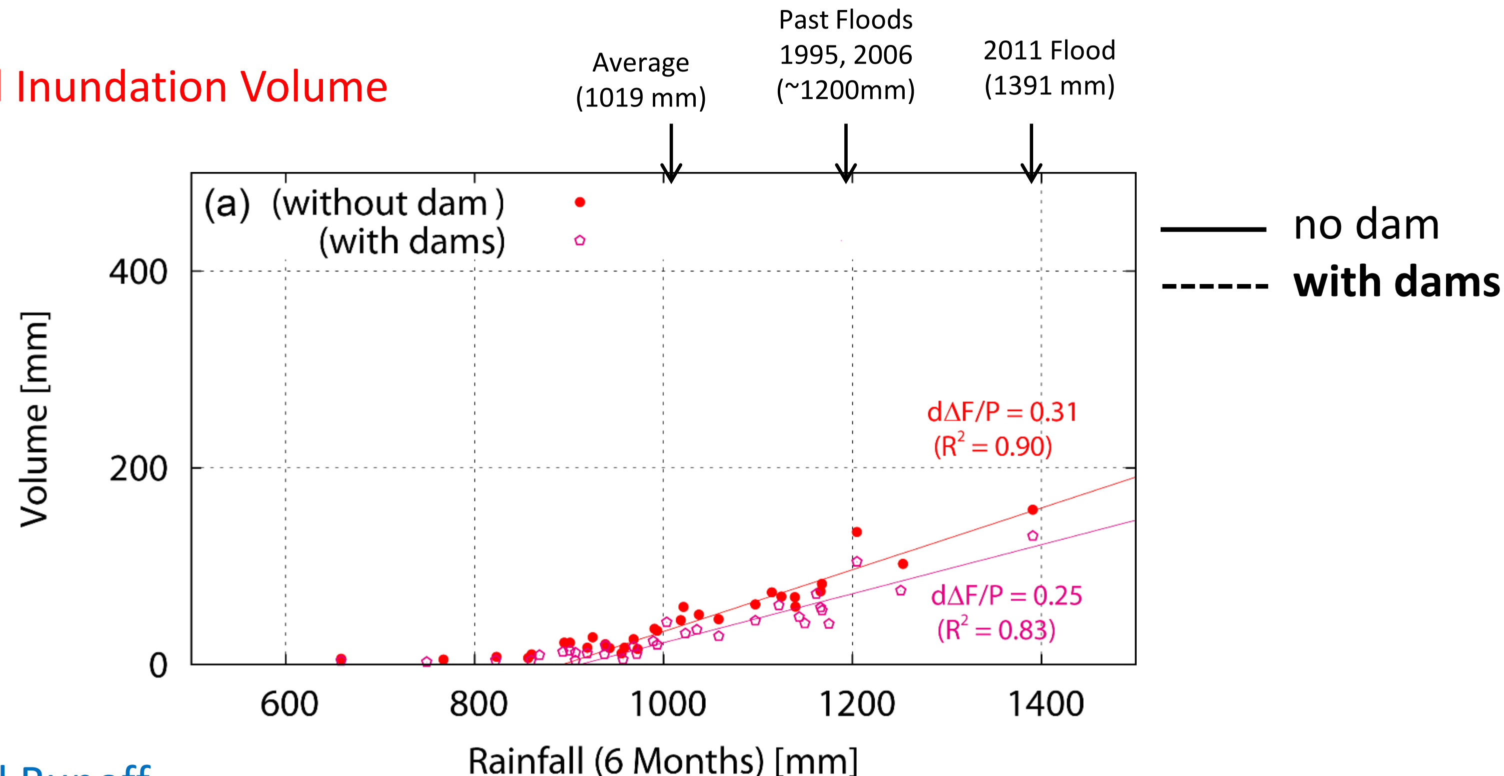
Source: GISTDA (Thailand)

Source: UNOSAT

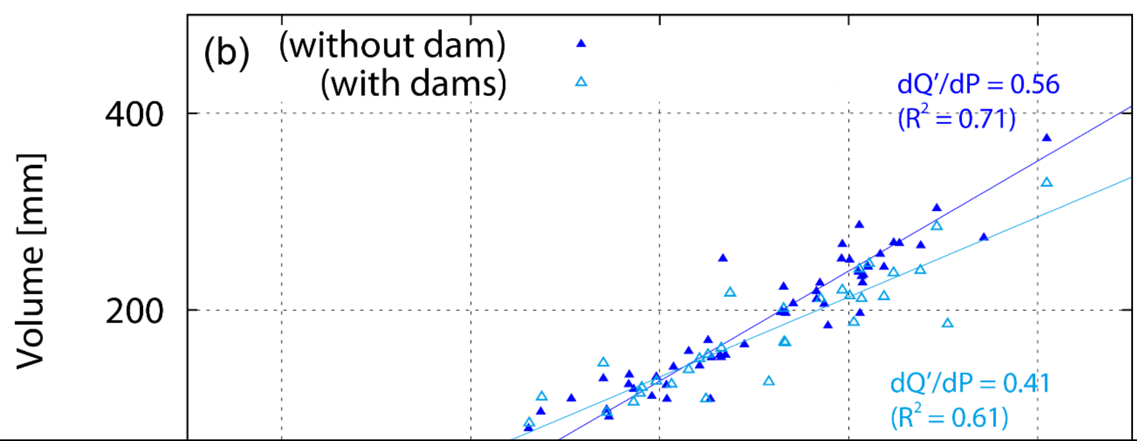
	Relative Error	FIT
2005	0.16	0.08
2006	0.47	0.31
2007	0.18	0.14
2008	0.05	0.15
2009	0.01	0.12
2010	0.52	0.25
2011	0.21	0.46
Avg.	0.23	0.21



Flood Inundation Volume



Flood Runoff



- ✓ $d\Delta F/dP$ = 0.25 with dams : + 200 mm rainfall → + 50 mm (= 8.2 billion m^3) inundation
- ✓ Available storages of Bhumipol and Sirikit dams in April 15, 2011 (six mo. before the peak) : 46 mm (=7.5 billion m^3)
- ✓ The dams contributed to reduce the inundation by 26 mm (=4.4 billion m^3)

Rainfall (8 Months) [mm]

Elasticity of Flood Runoff and Inundation

$$\varepsilon_Q = \frac{dQ / Q}{dP / P} \qquad \varepsilon_F = \frac{d\Delta F / \Delta F}{dP / P}$$

By taking 6 month rainfall = 1200 mm as the basis,

Elasticity of peak discharge at C2: ε_{pQ} = 1.5

Elasticity of total runoff: ε_Q = 2.3

Elasticity of flood inundation volume: ε_F = 4.2

Flood inundation volume increases by 4.2 %

if the monsoon rainfall increases by 1%

Sayama et al., Hydrologic sensitivity of flood runoff and inundation: 2011 Thailand floods in the Chao Phraya River basin, Nat. Hazard Earth Syst. Sci., 15, pp. 1 – 14, doi:10.5194/nhess-15-1-2015, 2015