Investigating the Effect of Initial Soil Moisture on River Discharge Using Pseudo-Discharge Data Generated by a Distributed Hydrologic Model

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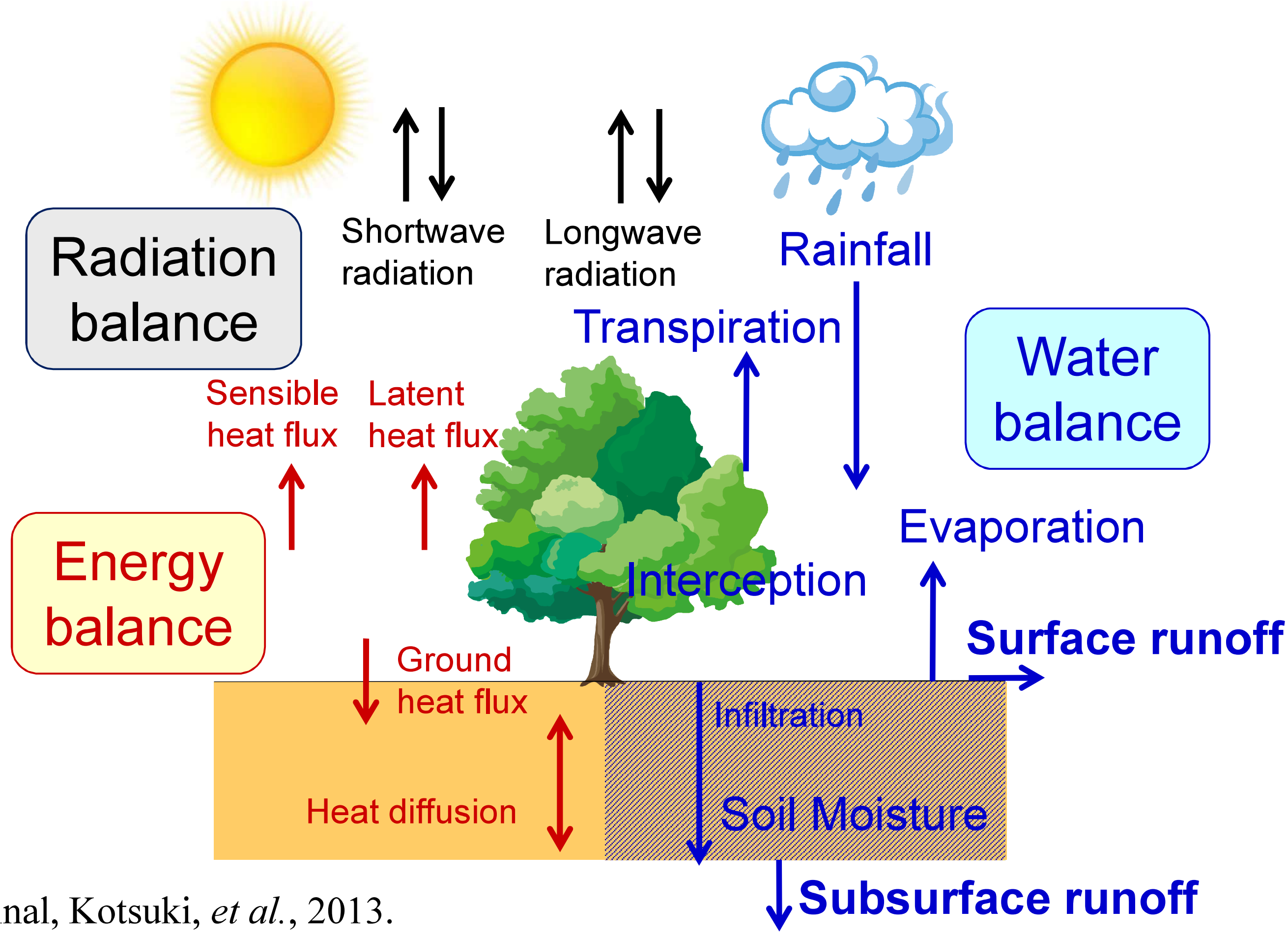
Introductions

- In general, for river planning or management in Japan, T-years annual maximum river discharge is utilized.
- For estimating T-years annual maximum river discharge, various type of spatial pattern and time series of rainfall are considered.
- However, **soil moisture as initial condition** is NOT considered because the impact of initial soil moisture on peak river discharge is assumed to be negligible.
- We'd like to **evaluate the impact of initial soil moisture on peak river discharge** comparing with that of rainfall pattern.

Methodology

- Developing a distributed hydrologic model
- Generating pseudo-river discharge
- Investigating the effect of initial soil moisture on peak river discharge

Land Surface Model



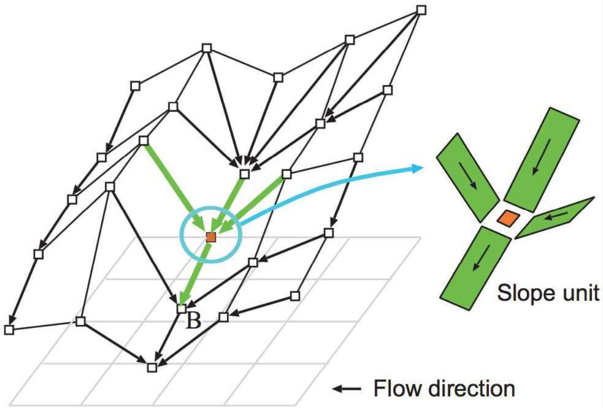
Original, Kotsuki, *et al.*, 2013.

Flow Routing Model

1K-FRM

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_L$$

$$Q = \alpha A^m$$

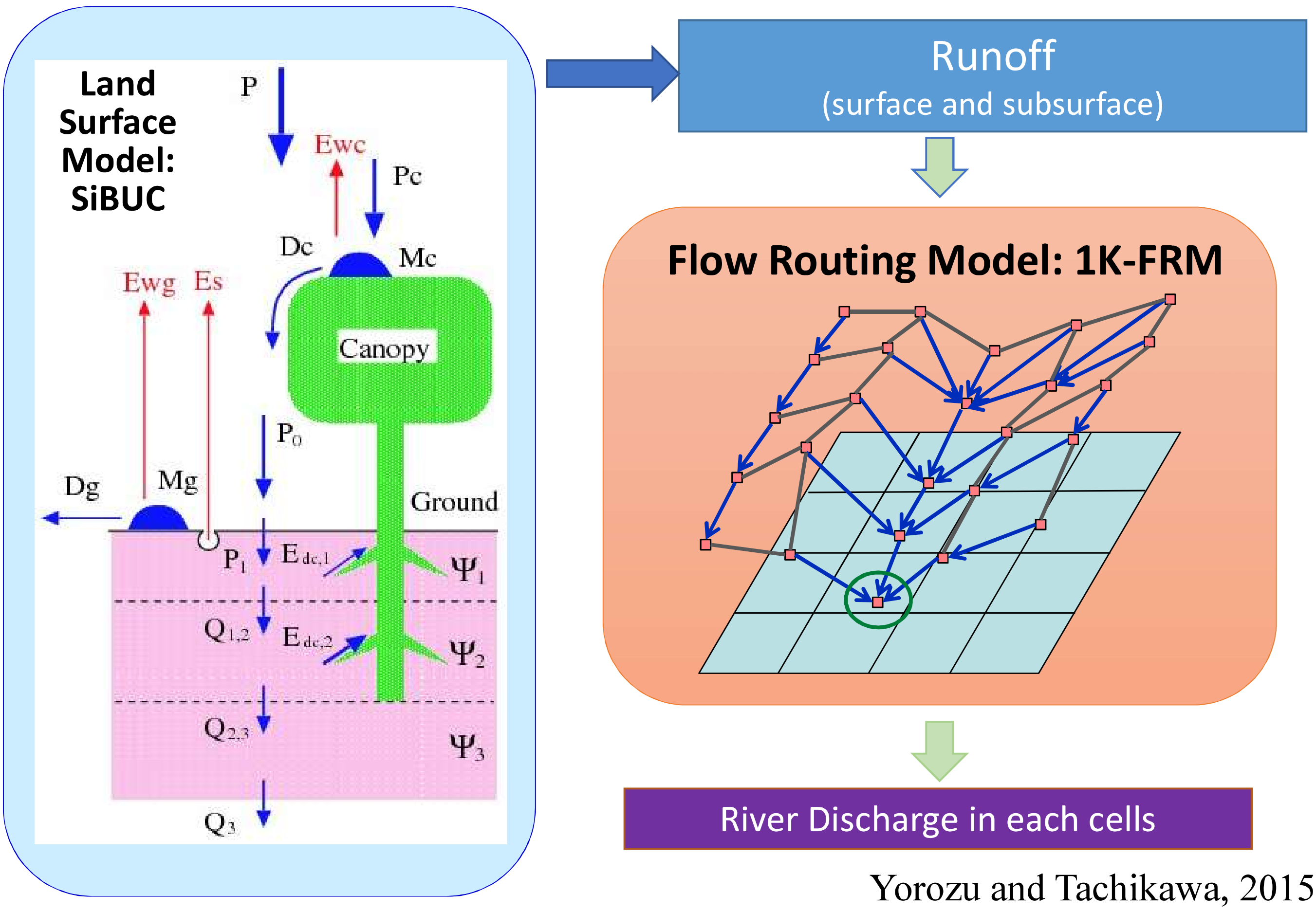


$$q_L = Q_s + Q_{sb} - W_{in}$$

A: cross section area, Q: discharge rate, t: time, x: distance,
q_L: lateral flow rate, α, m: coefficient,
Q_s: surface runoff rate, Q_{sb}: sub-surface runoff rate,
W_{in}: irrigation water withdrawal

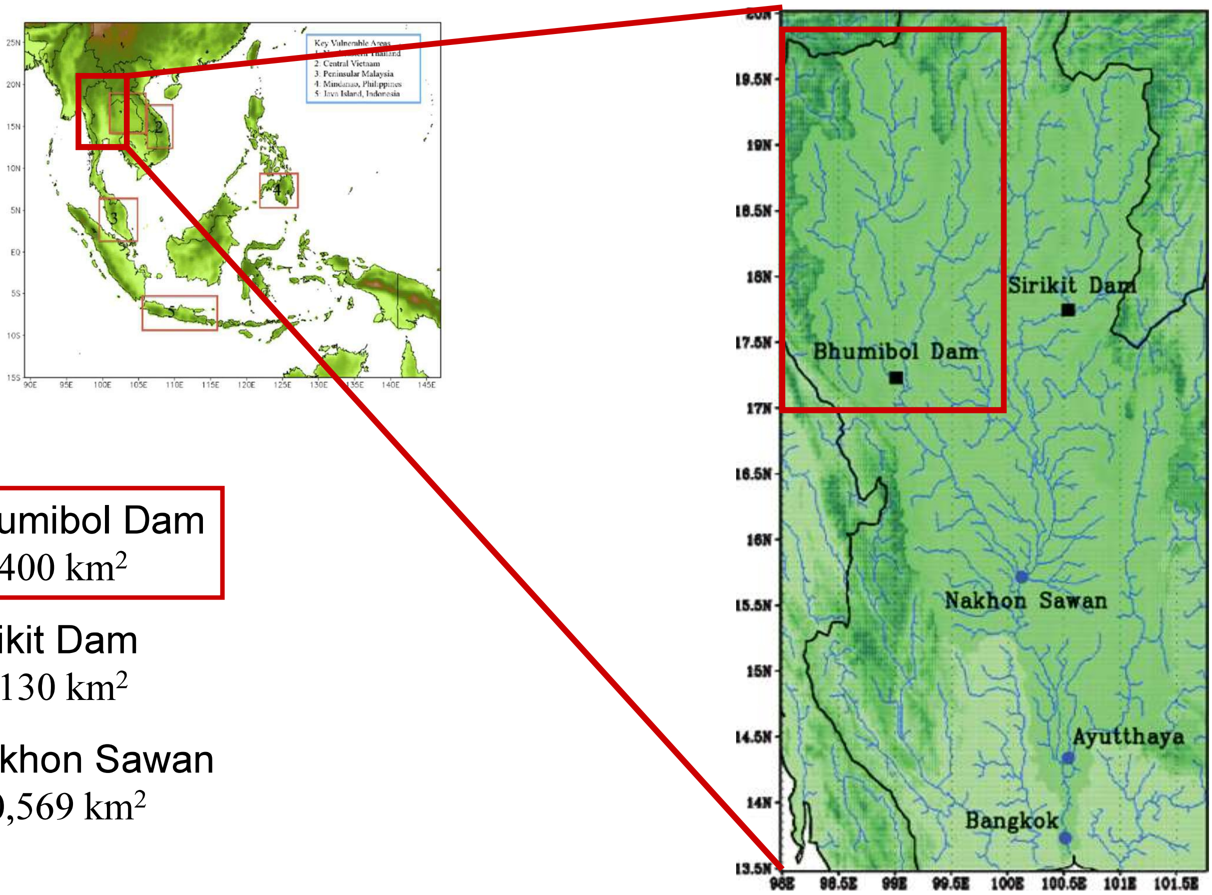
http://hywr.kuciv.kyoto-u.ac.jp/products/1K-DHM/1K-DHM.html

Hydrologic Model



Yorozu and Tachikawa, 2015.

Application Area



Bhumibol Dam
26,400 km^2

Sirikit Dam
13,130 km^2

Nakhon Sawan
110,569 km^2

Boundary and Simulation Design

Japanese 55-years Reanalysis: JRA-55

- ~ 60km (TL319) spatial resolution
- 6 hour temporal resolution
- Monthly rainfall amount is modified by CHIRPS satellite based rainfall product

MCD15A3 for vegetation

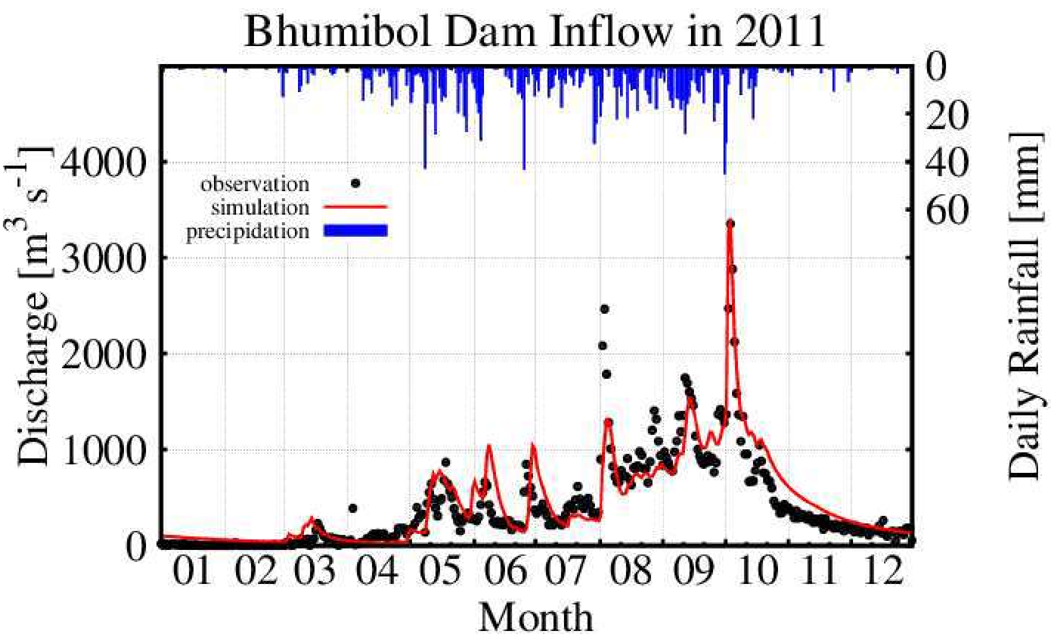
- Composited every 4 days at 1-kilometer resolution
- Aggregating 60km for SiBUC

Grid size in models

- Same as JRA-55 for SiBUC
- 1km for 1K-FRM

Kobayashi *et al.*, 2015., Funk *et al.*, 2015

Model Validation - 2011 Thailand flood



	Observation	Model
Peak discharge	3353 $m^3 s^{-1}$	3410 $m^3 s^{-1}$
Peak date	Oct/4th	Oct/4th

Nash-Sutcliffe coefficient: 0.79
Correlation coefficient: 0.90
RMSE: 219 $m^3 s^{-1}$

Yorozu *et al.*, 2018.

Methodology

- Developing a distributed hydrologic model
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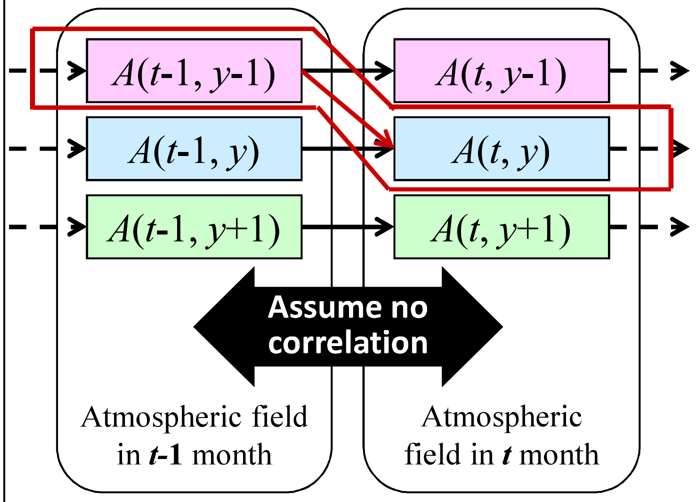
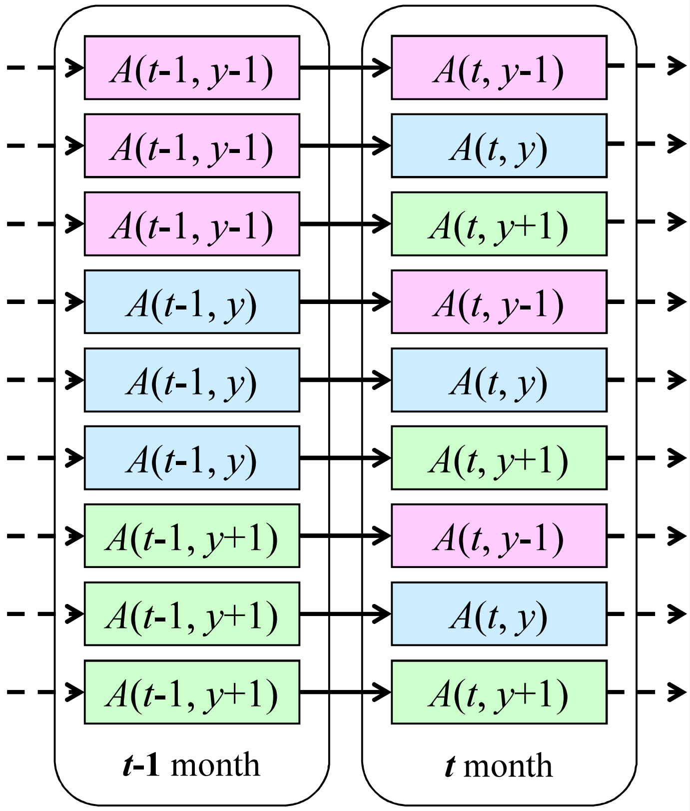
Generating Atmospheric Series

Actual time series of atmospheric field



Consider time series of atmospheric field for three years. If it can be assumed that atmospheric field in t-1 month is NOT correlated with that in t month, we think it is able to generate different time series of atmospheric field by recombining time series of atmospheric field.

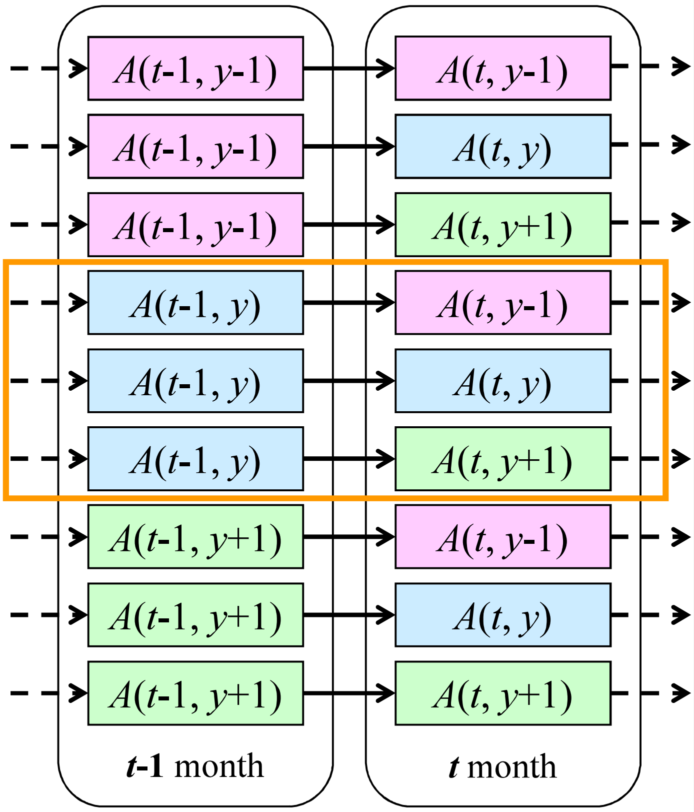
Generated time series



Evaluate Impact of Rainfall Pattern

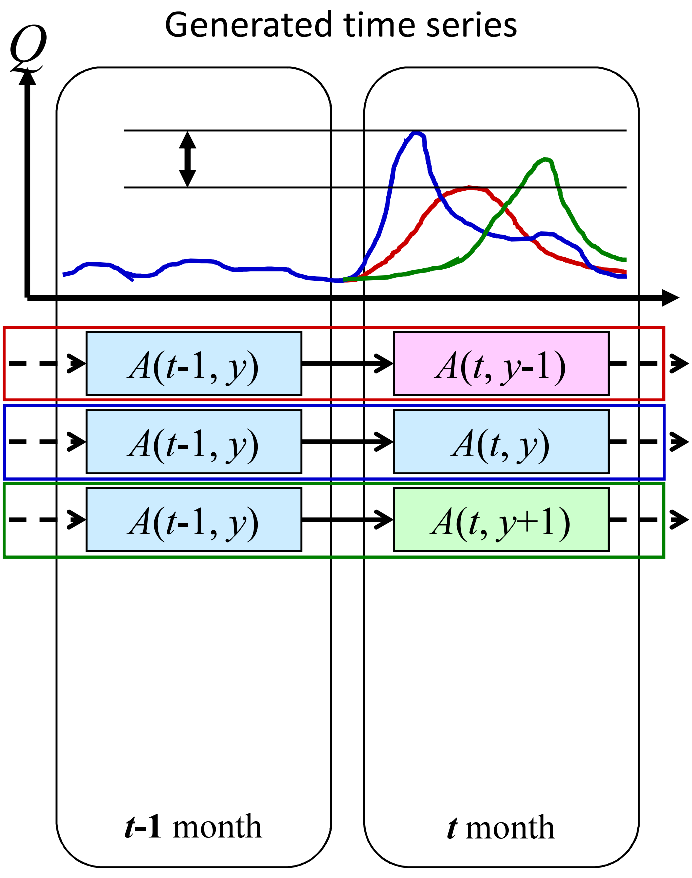
- By using generated atmospheric time series as a forcing to a distributed hydrologic model, large number of river discharge data can be calculated.

Generated time series



Evaluate Impact of Rainfall Pattern

- By using generated atmospheric time series as a forcing to a distributed hydrologic model, large number of river discharge data can be calculated.
- It is able to evaluate the impact of rainfall pattern on peak river discharge.



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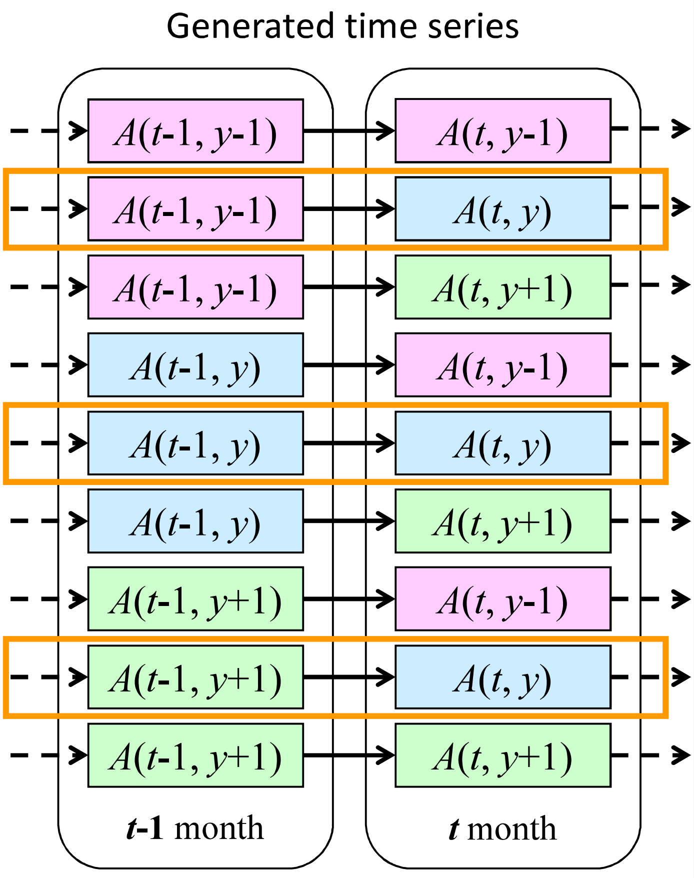

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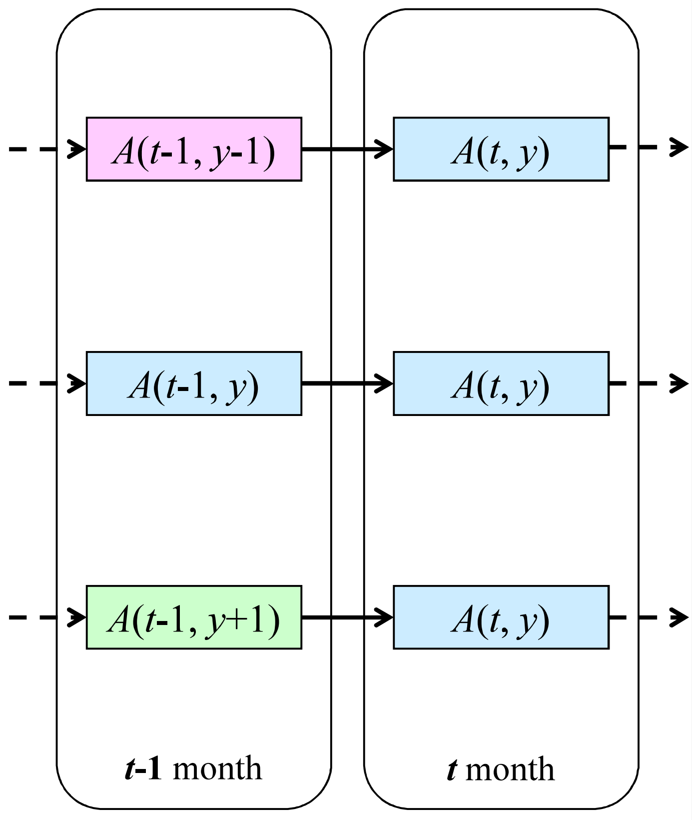
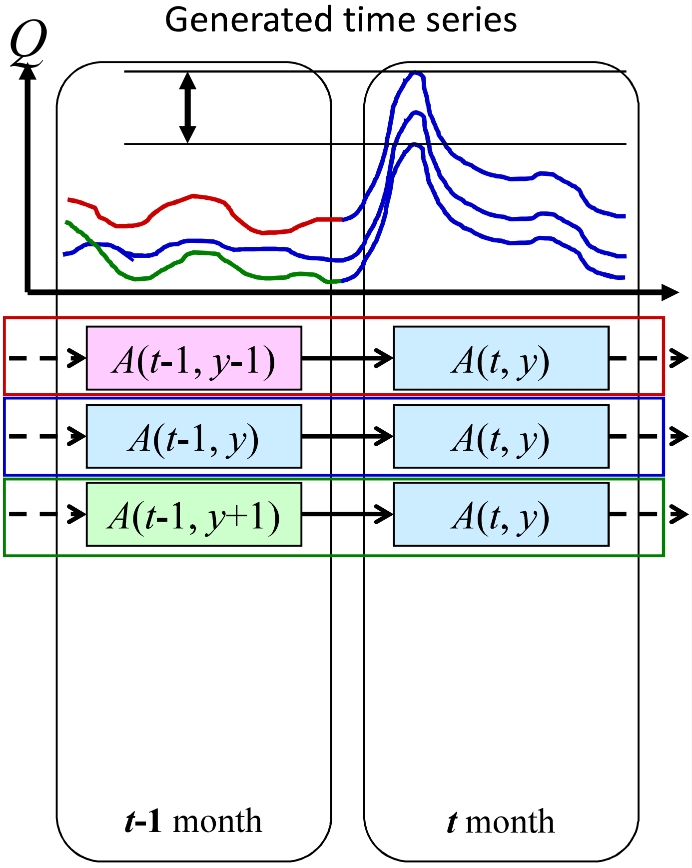


Evaluate Impact of Soil Moisture

- By using generated atmospheric time series as a forcing to a distributed hydrologic model, large number of river discharge data can be calculated.
- It is able to evaluate the impact of rainfall pattern on peak river discharge.
- It is able to evaluate the impact of initial soil moisture on peak river discharge.



Atmospheric Data Recombination

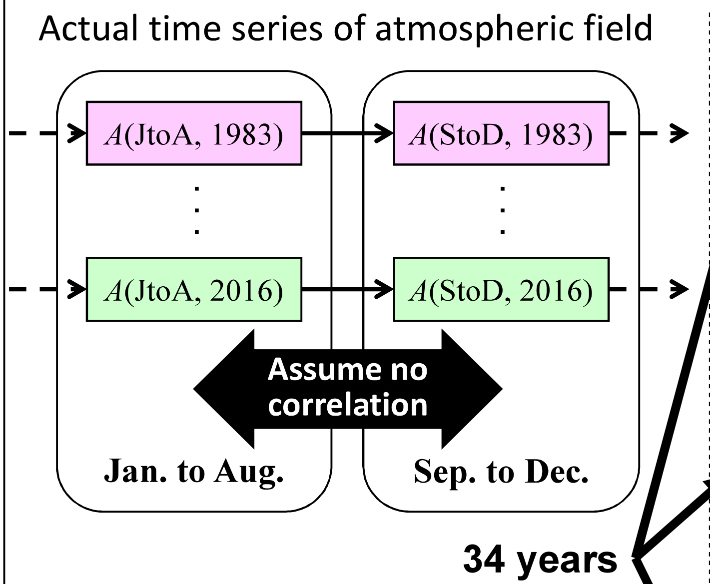
Japanese 55-years Reanalysis: JRA-55

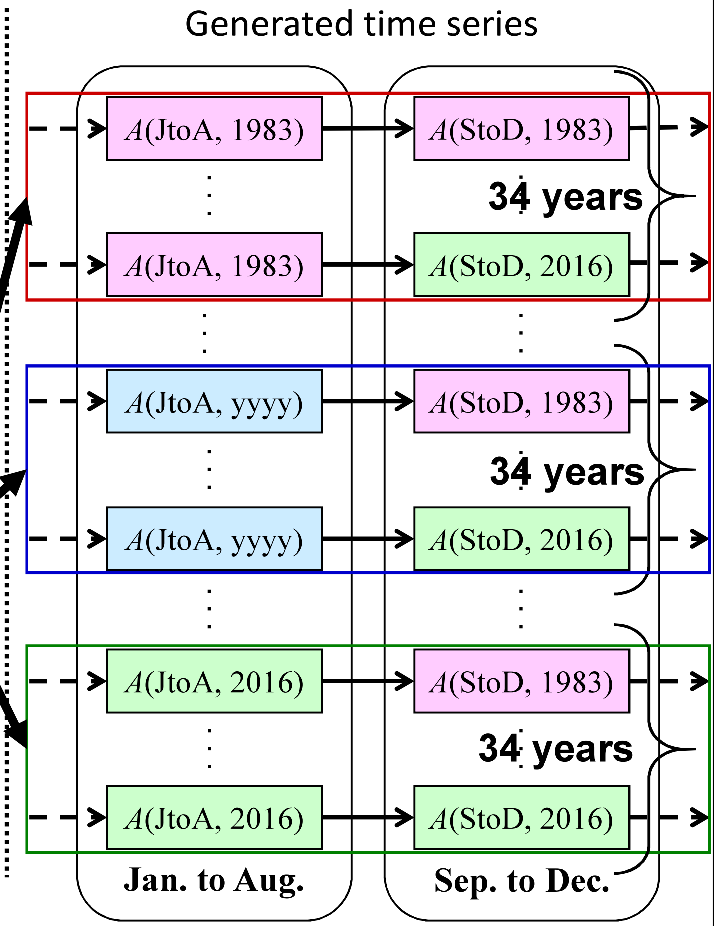
- ~ 60km (TL319) spatial resolution
- 6 hour temporal resolution for 1983 ~ 2016
- Monthly rainfall amount is modified by CHIRPS satellite based rainfall product

- The previous analysis concluded that atmospheric data between August and September could be assumed to be not related.
- Pseudo-atmospheric data ware generated by recombining atmospheric data between August and September.

Yorozu *et al.*, 2018.

Generating Atmospheric Series



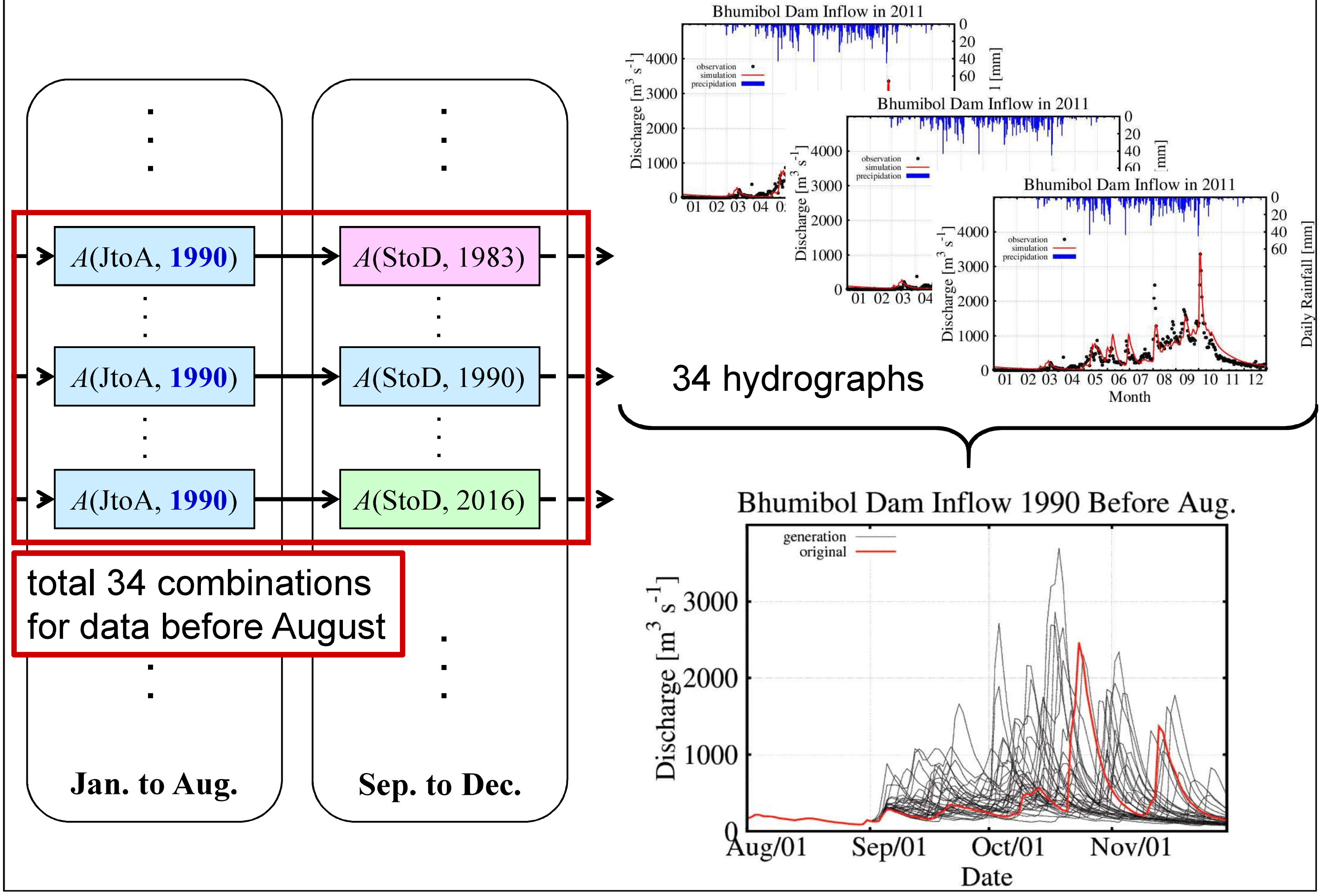


- Use JRA-55 from 1983 to 2016, total 34 years, as time series of atmospheric field.
- Total 34 time 34 years (1156 years) data is generated.

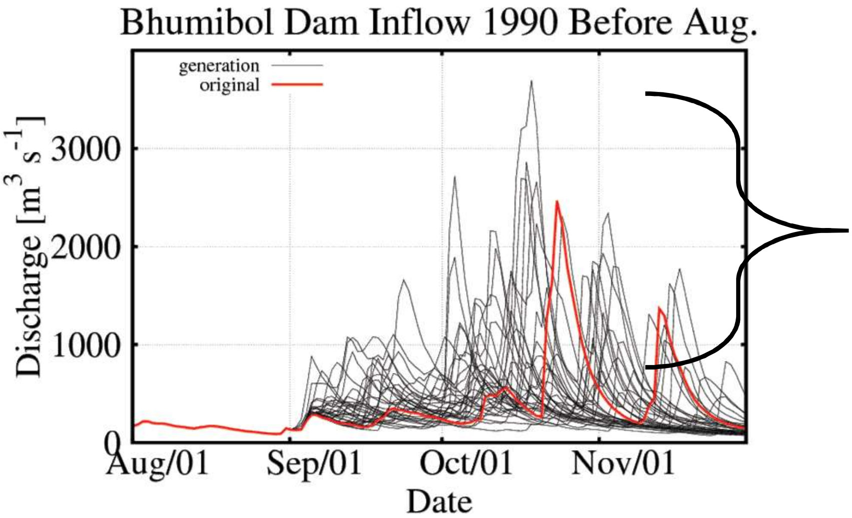
Methodology

- Developing a distributed hydrologic model
- Generating pseudo-river discharge data
- Investigating the effect of initial soil moisture on peak river discharge

Sim. with Same Initial Soil Moisture



Impact of Rainfall Pattern



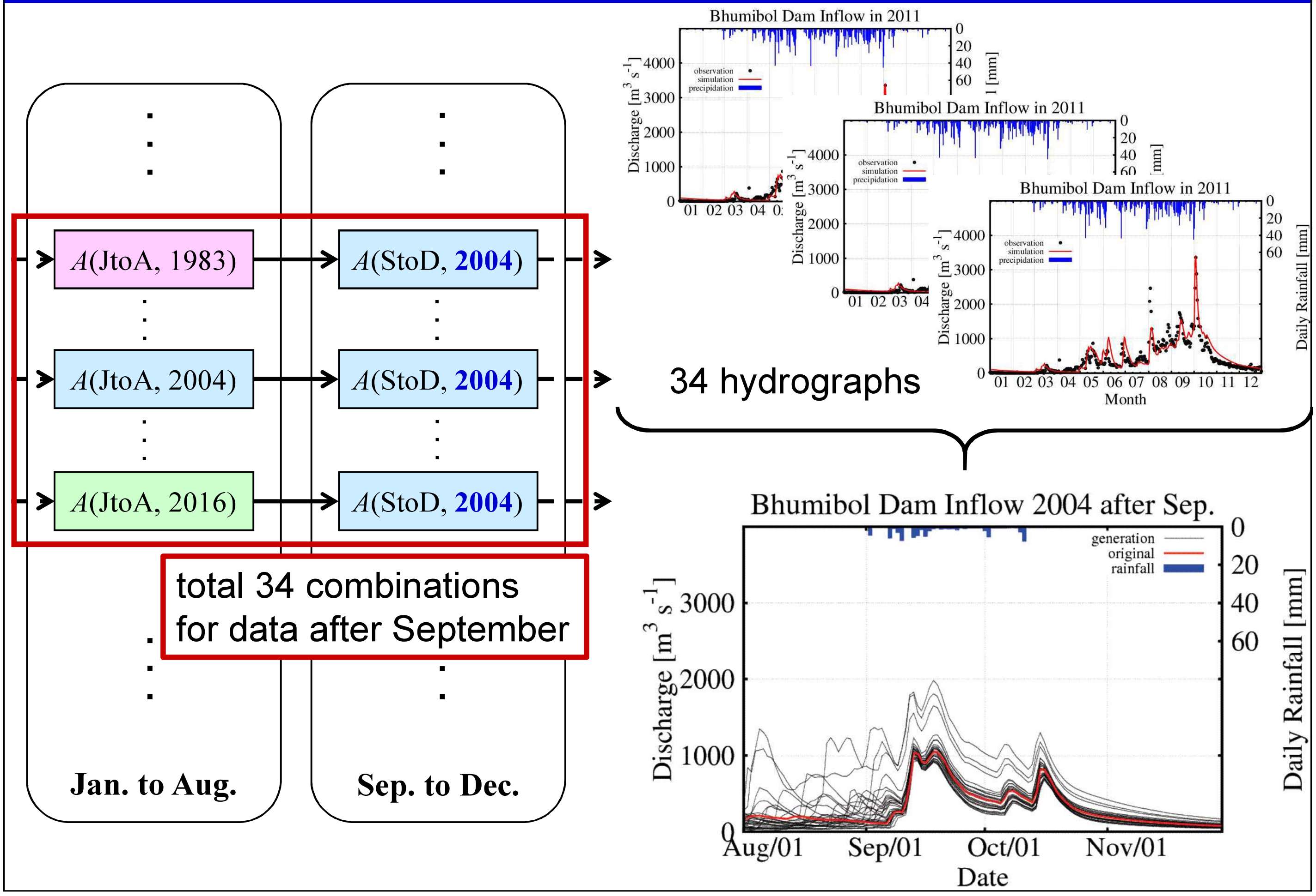
Caused by different rainfall pattern after September.

- Standard deviation of peak discharge values could show the impact of rainfall pattern.
- There are total 34 combinations for data before August.

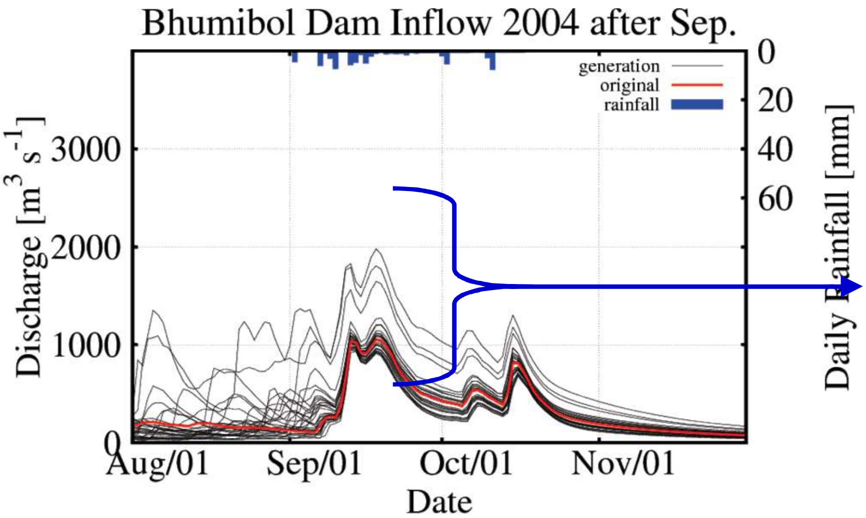
Impact of rainfall pattern:

Averaged standard deviation is **$718\ m^3\ s^{-1}$**

Sim. with Same Precipitation after Sep.



Impact of Soil Moisture



Caused by different soil moisture at the end of August.

- Standard deviation of peak discharge values could show the impact of initial soil moisture.
- There are total 34 combinations for data after September.

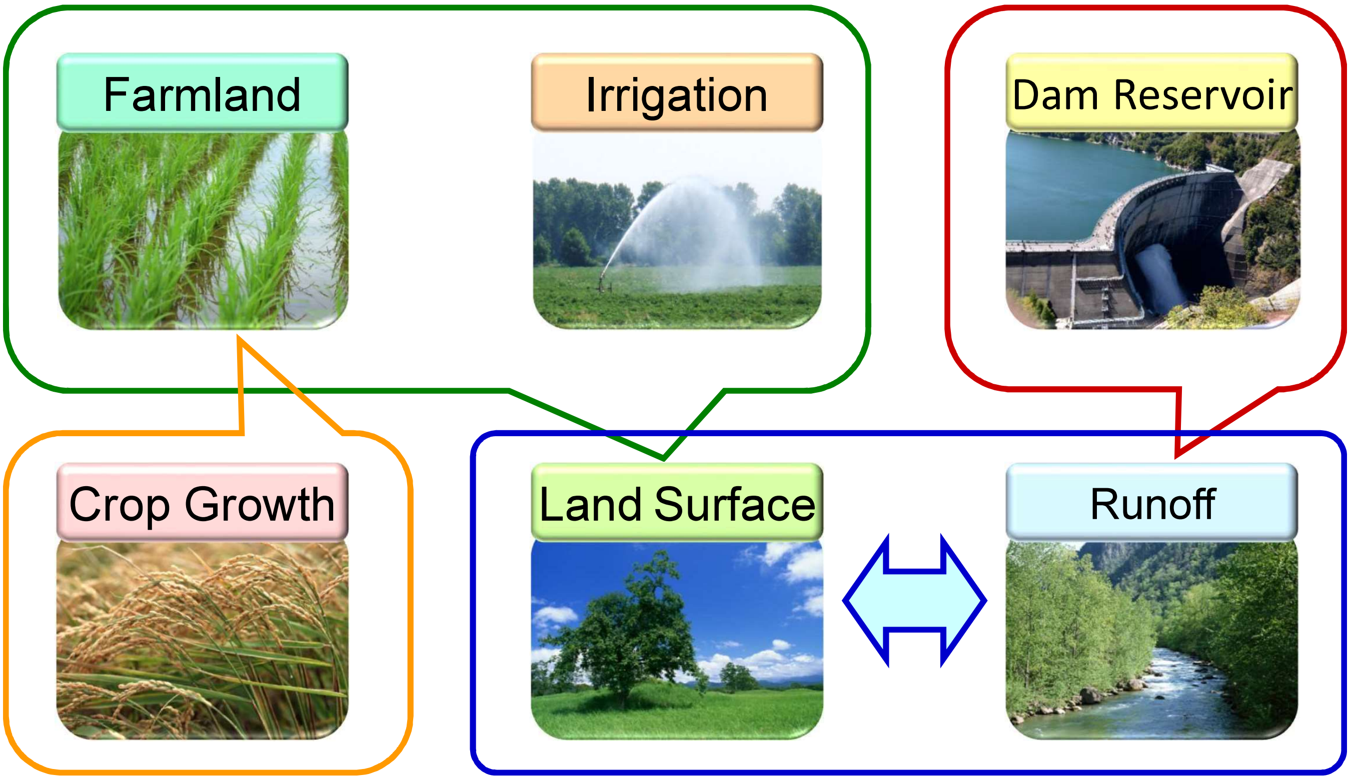
Impact of soil moisture:

Averaged standard deviation is **127 m^3 s^{-1}**

Conclusions

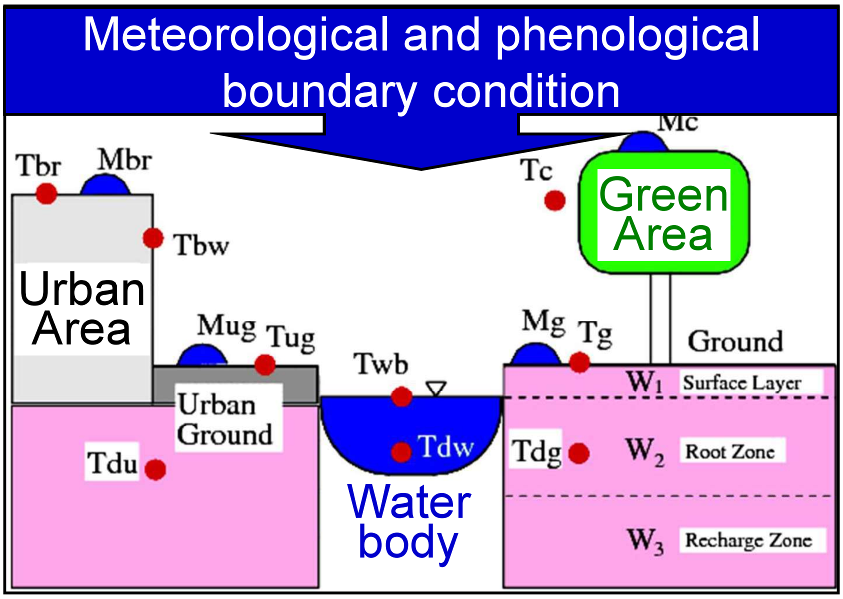
- A distributed hydrologic model was developed for upper part of Bhumibol dam catchment.
- By using recombined atmospheric data between August and September, pseudo-river discharge data was generated utilizing a distributed hydrologic model.
- Estimation of the **impact of rainfall pattern** on peak river discharge was **718** m^3 s^{-1}.
- Estimation of the **impact of soil moisture** on peak river discharge was **127** m^3 s^{-1}.
- **The soil moisture impact on river peak discharge is NOT negligible.**

Integrated Hydrologic Model



Land Surface Model

Simple Biosphere including Urban Canopy



Schematic image of SiBUC

Meteorological boundary: Rainf, Snowf, LWdown, SWdown, Tair, Qair, Psurf, Wind

Phenological boundary: Leaf Area Index

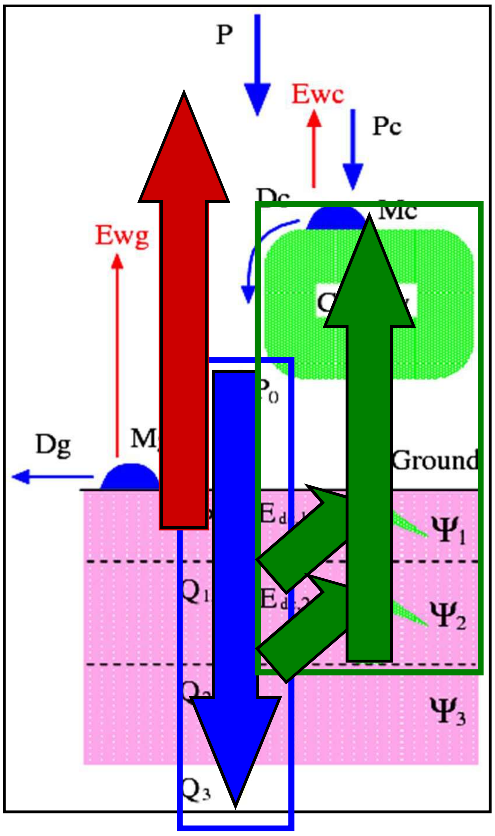
Prognostic Equation of Soil Moisture

$$\frac{dW_1}{dt} = \frac{1}{\theta_s D_1}\left[P_1 - Q_{1,2} - \frac{1}{\rho_w}\left(E_s + E_{dc,1}\right)\right]$$

$$\frac{dW_2}{dt} = \frac{1}{\theta_s D_2}\left[Q_{1,2} - Q_{2,3} - \frac{E_{dc,2}}{\rho_w}\right]$$

$$\frac{dW_3}{dt} = \frac{1}{\theta_s D_3}\left[Q_{2,3} - Q_3\right]$$

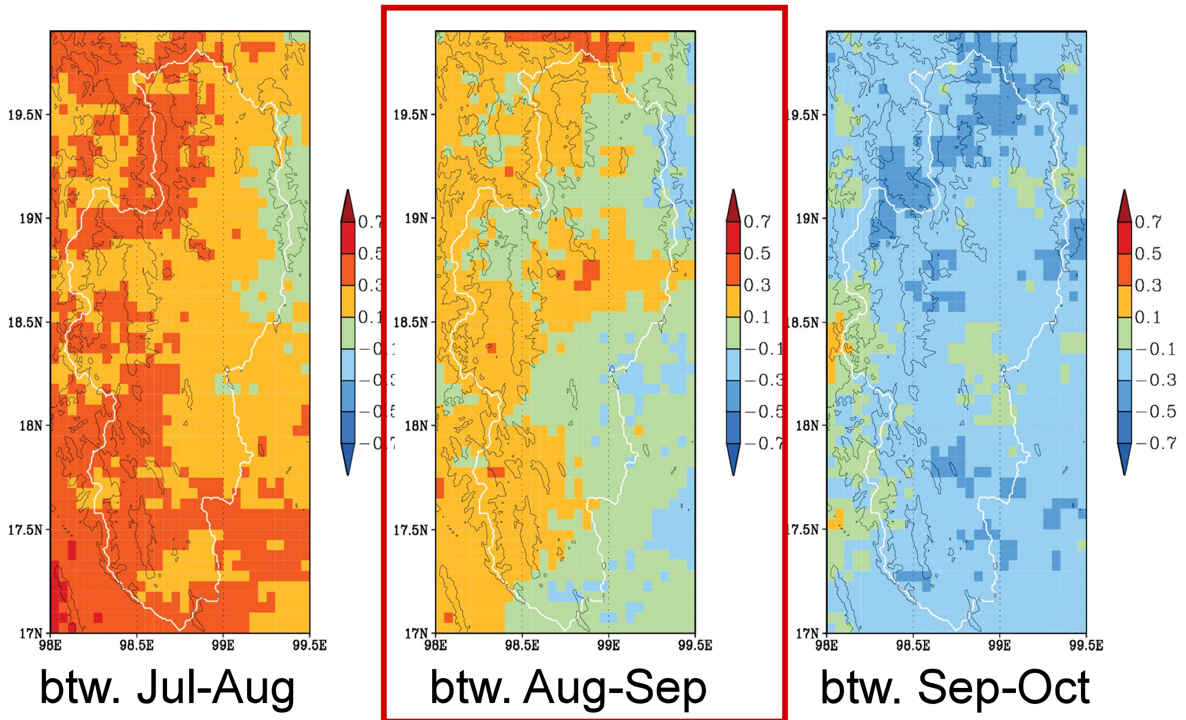
W_i : soil wetness of i th layer,
D_i : soil depth of i th layer,
θ_s : porosity, ρ_w : water density,
P_1, $Q_{i,\,i+1}$: infiltration,
E_s : evaporation,
$E_{dc,\,i}$: transpiration from i th layer



Water balance concept

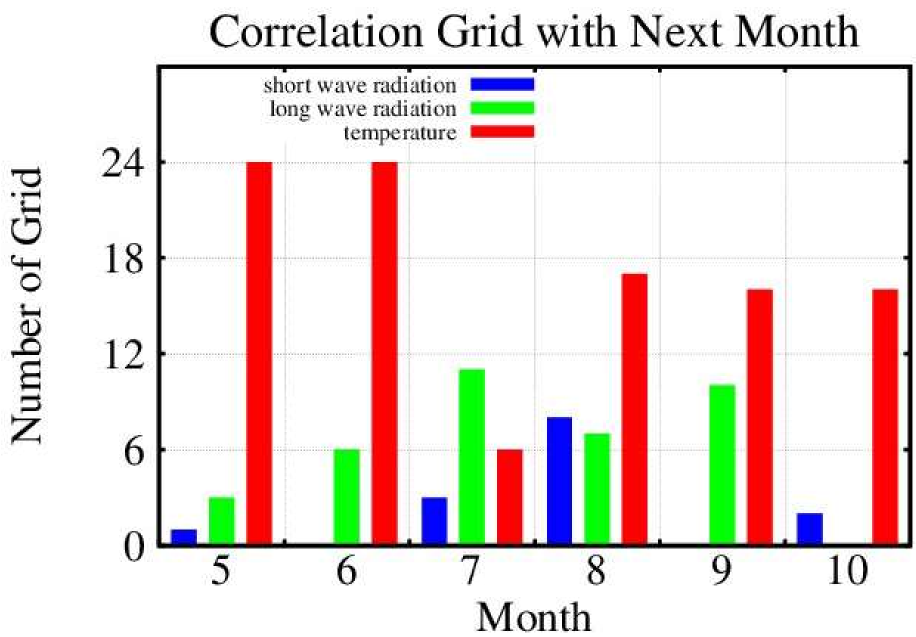
K. Tanaka, doctoral dissertation, 2005

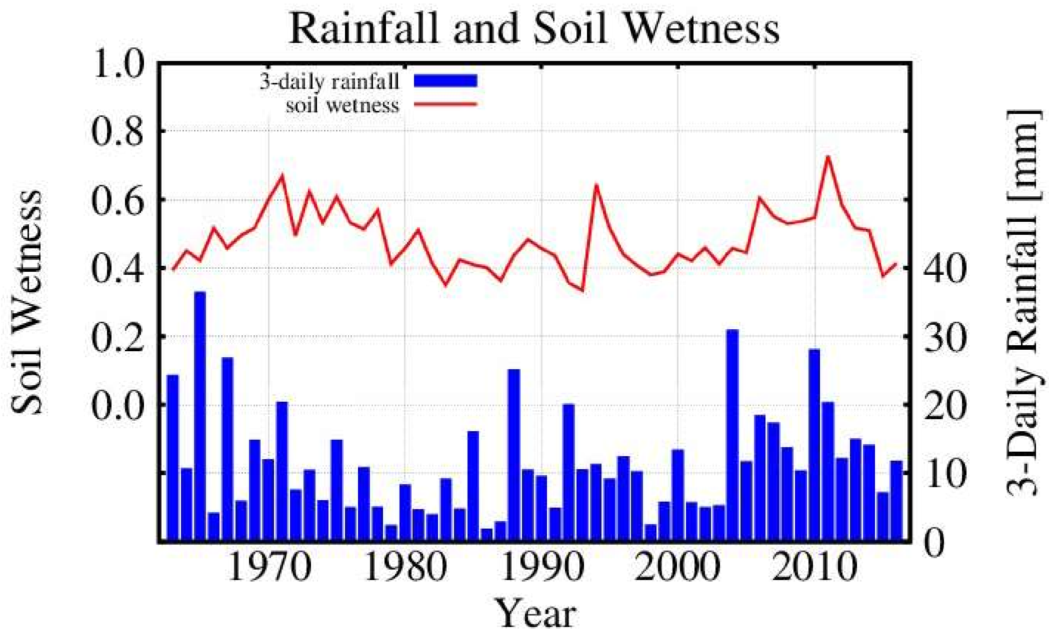
Monthly Rainfall Correlation

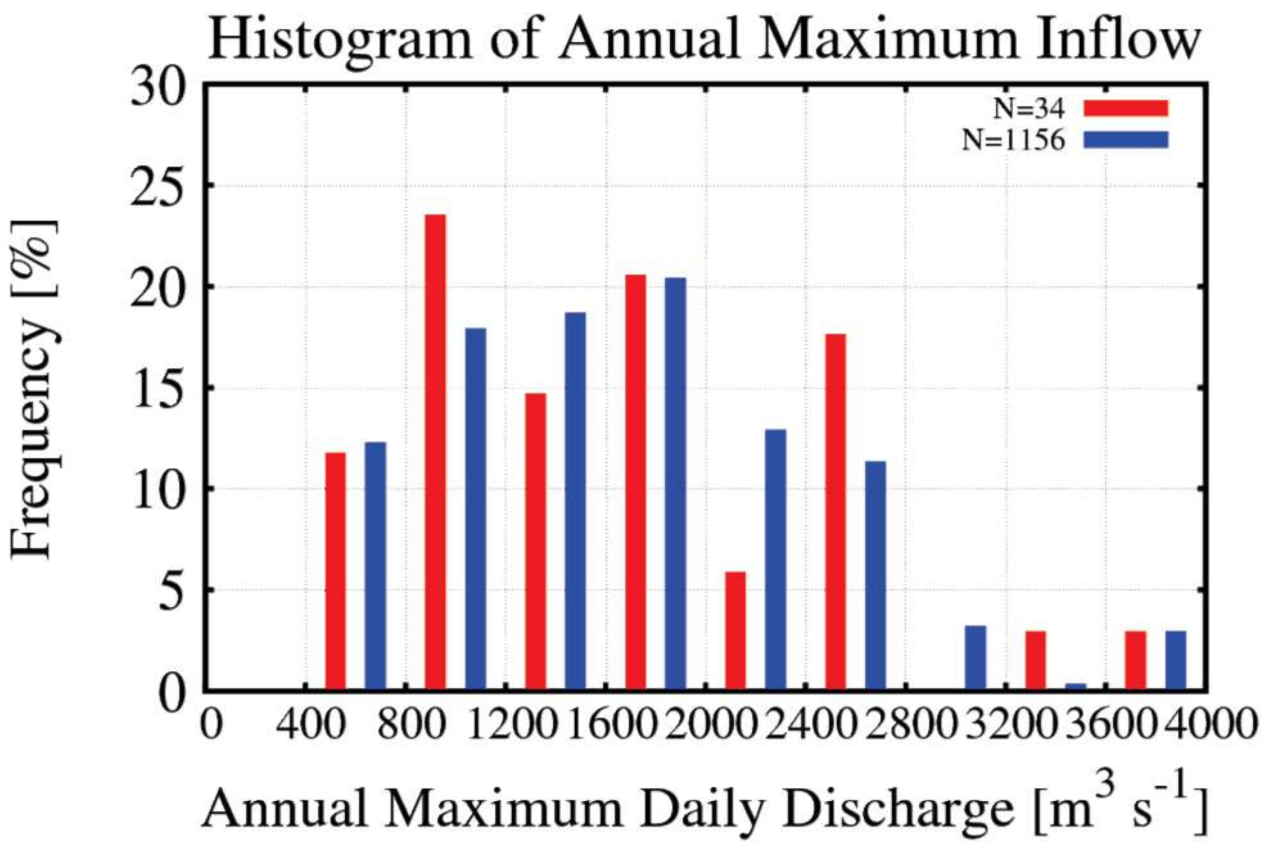


When did dam inflow record annual maximum?

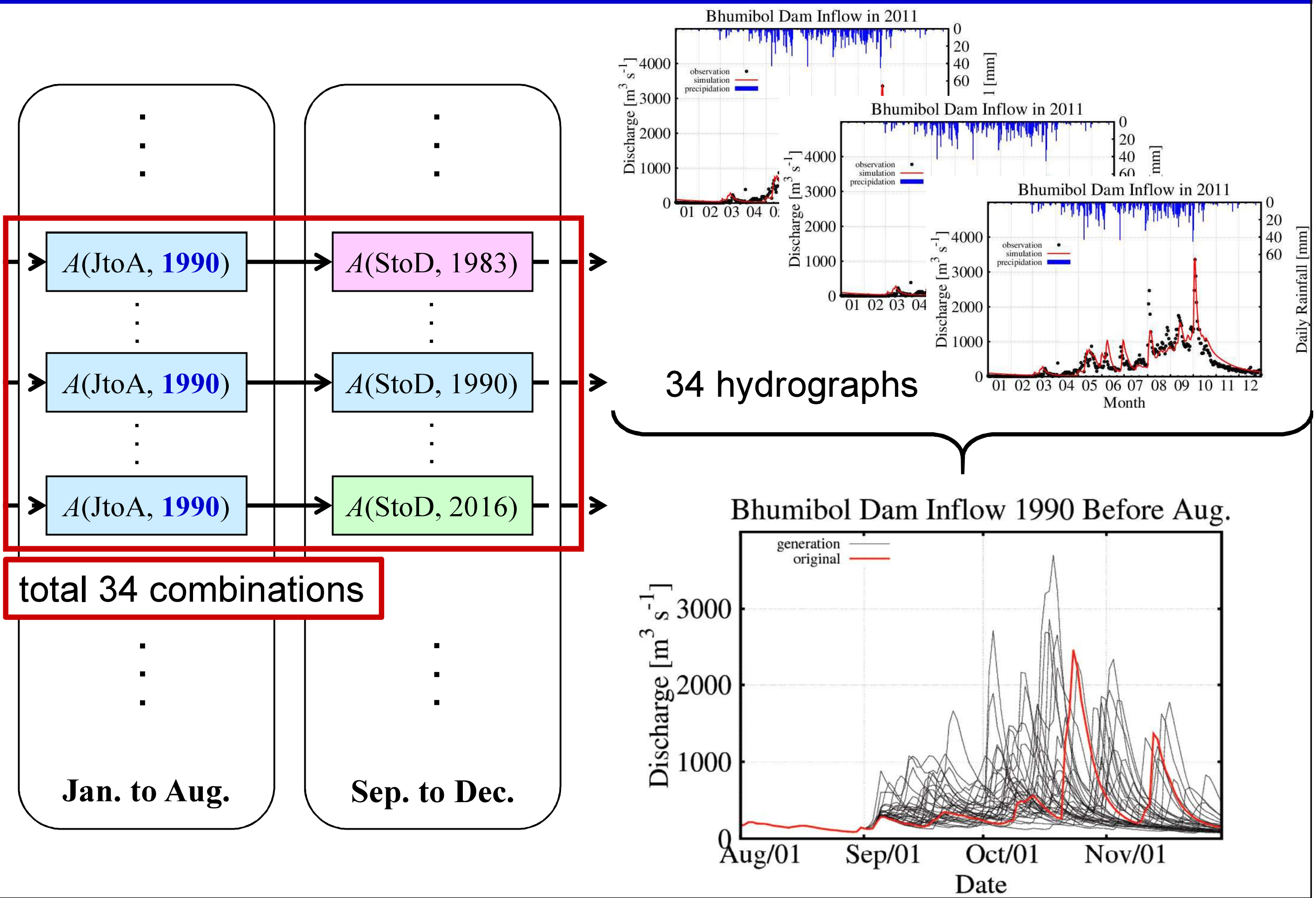
Jul.	Aug.	Sep.	Oct.	Nov.
0	4	26	18	4



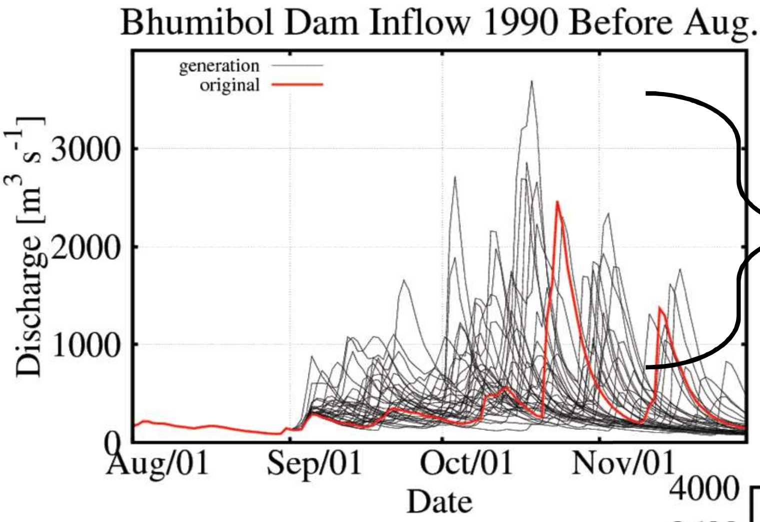

Rainfall and Soil Wetness
3-daily rainfall
soil wetness
Soil Wetness
3-Daily Rainfall [mm]
1.0
0.8
0.6
0.4
0.2
0.0
40
30
20
10
0
1970
1980
1990
2000
2010
Year


Histogram of Annual Maximum Inflow
N=34
N=1156
Frequency [%]
30
25
20
15
10
5
0
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
Annual Maximum Daily Discharge [m3 s-1]

Sim. with Same Initial Soil Moisture

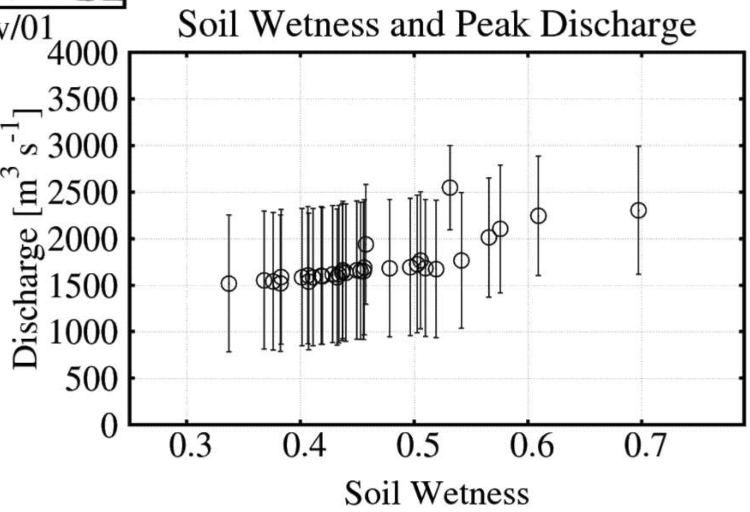


Impact of Rainfall Pattern



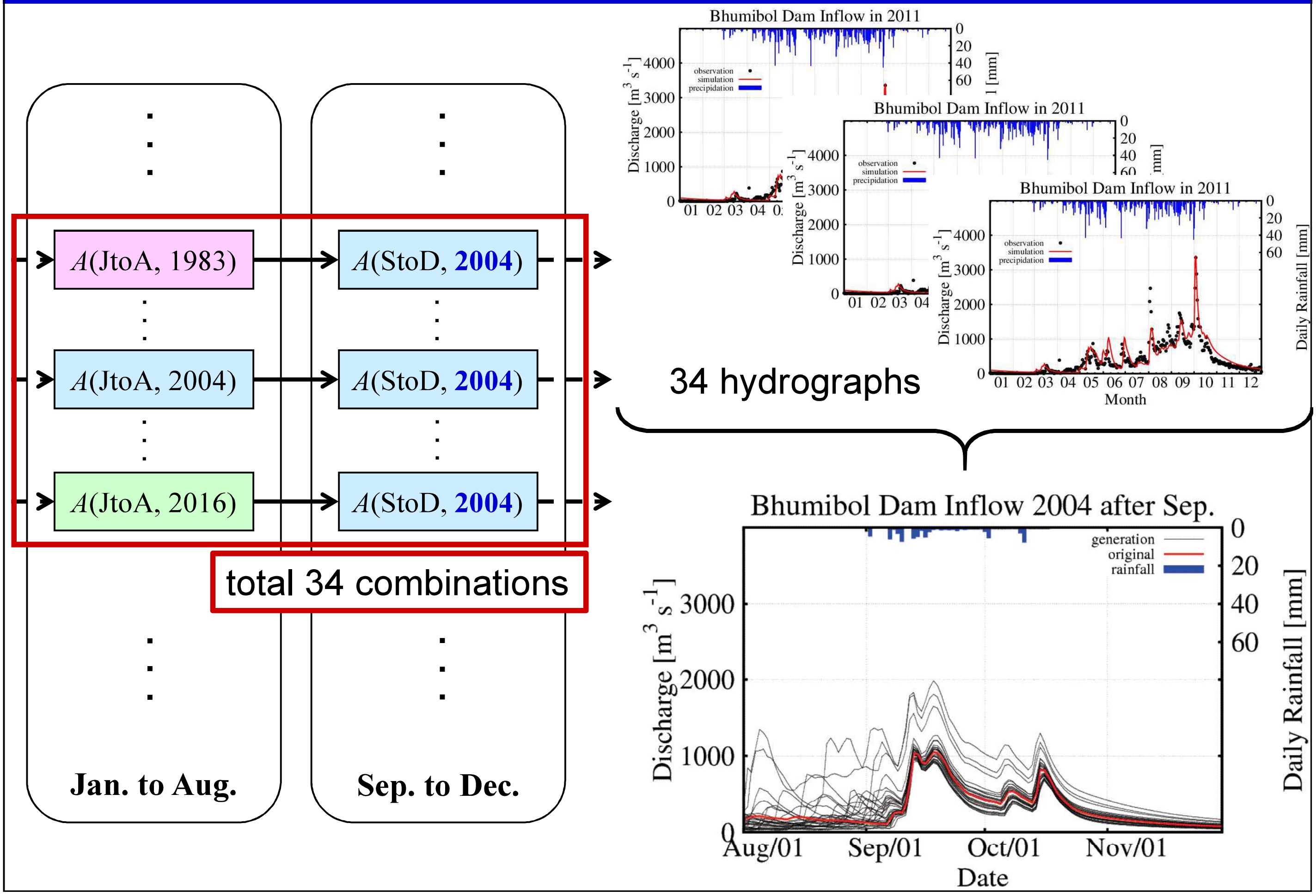
Peak discharge varies because of different rainfall pattern forcing

Mean and standard deviation

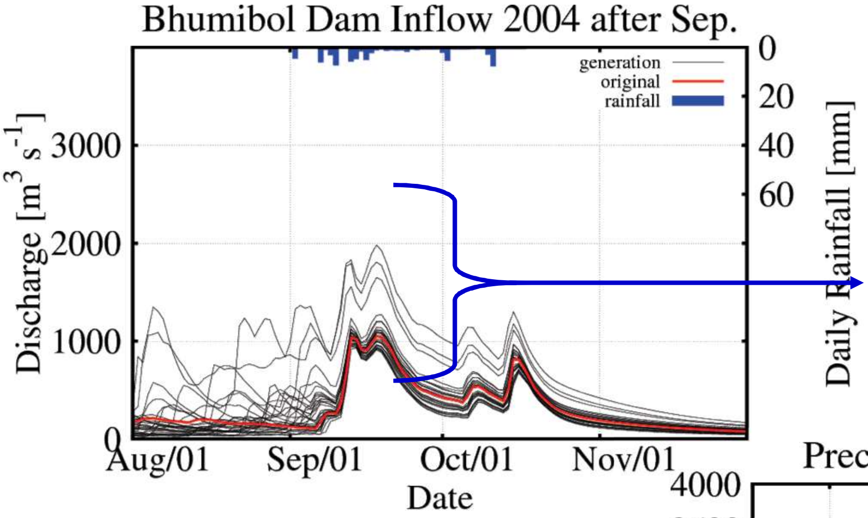


Impact of rainfall pattern:
Averaged standard deviation is **718 $m^3\ s^{-1}$**

Sim. with Same Precipitation after Sep.

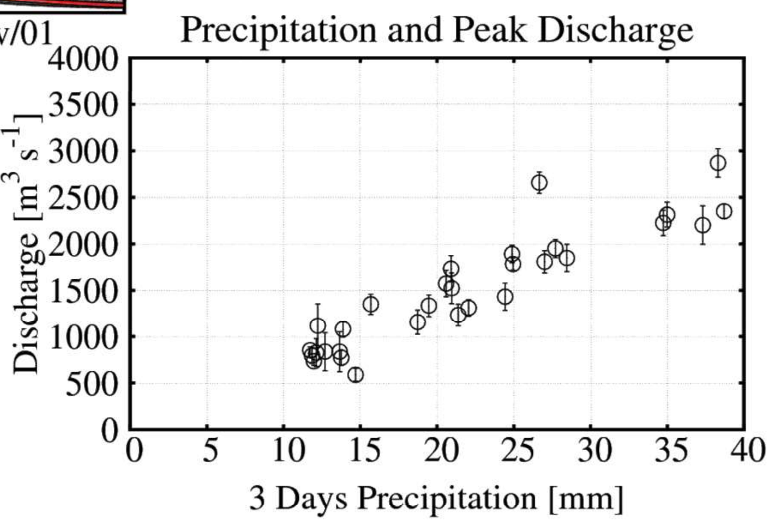


Impact of Soil Moisture



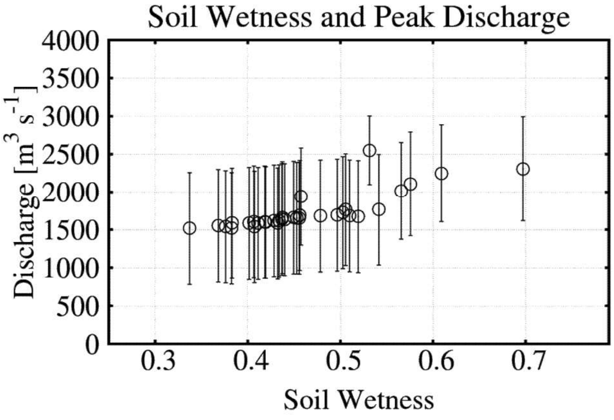
Peak discharge varies because of different soil moisture at the end of Aug.

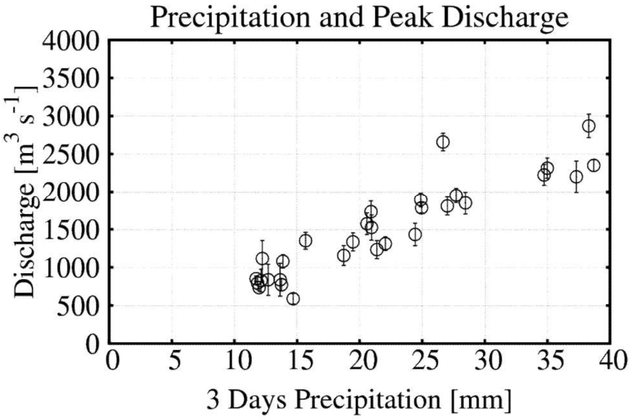
Mean and standard deviation



Impact of soil moisture: Averaged standard deviation is **127 m^3 s^{-1}**

Conclusions





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Impact of soil moisture:
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The soil moisture impact on river peak discharge is NOT negligible.