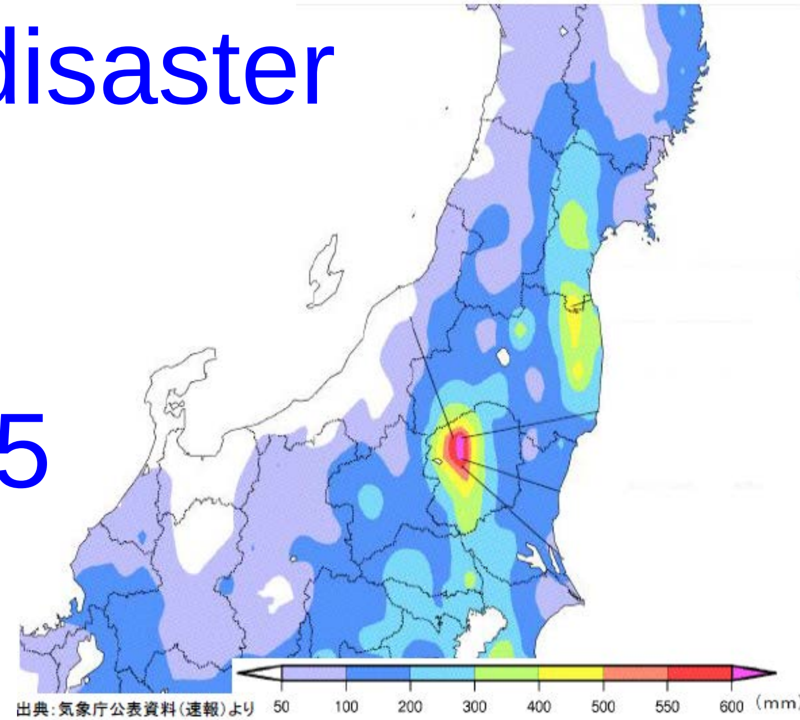
Extreme Flood Frequency Analysis and Risk Curve Development under a Changing Climate

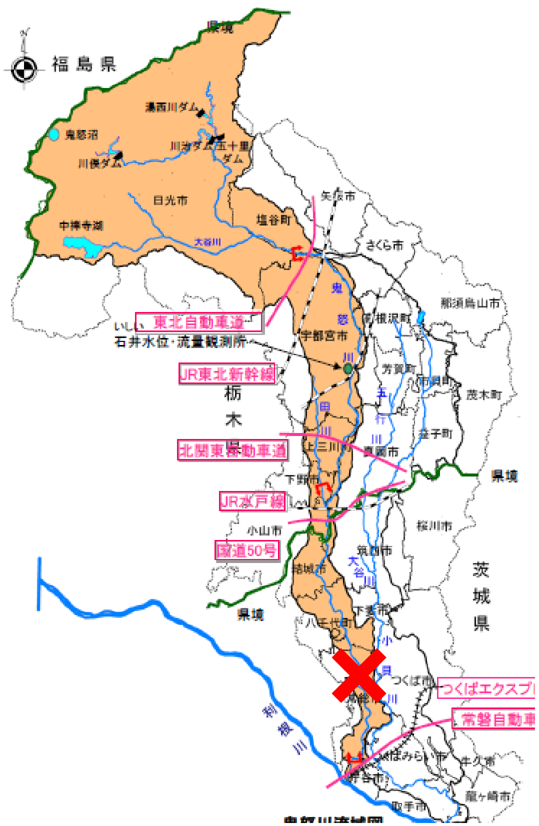
Yasuto TACHIKAWA

Hydrology and Water Resources Research Lab.
Dept. of Civil & Earth Resources Engineering, Kyoto University

Flood and inundation disaster in the Kinu River by Typhoon 18 on September 10, 2015



位置図



流域諸元

■水源　:栃木県と群馬県県境の鬼怒沼
■幹川流路延長 :176.7km
■全流路延長　:746.0km
■全流域面積　:1,761km²
■流域内人口　:約55万人

出典:平成21年度河川現況調査

After Construction Ministry of Japan

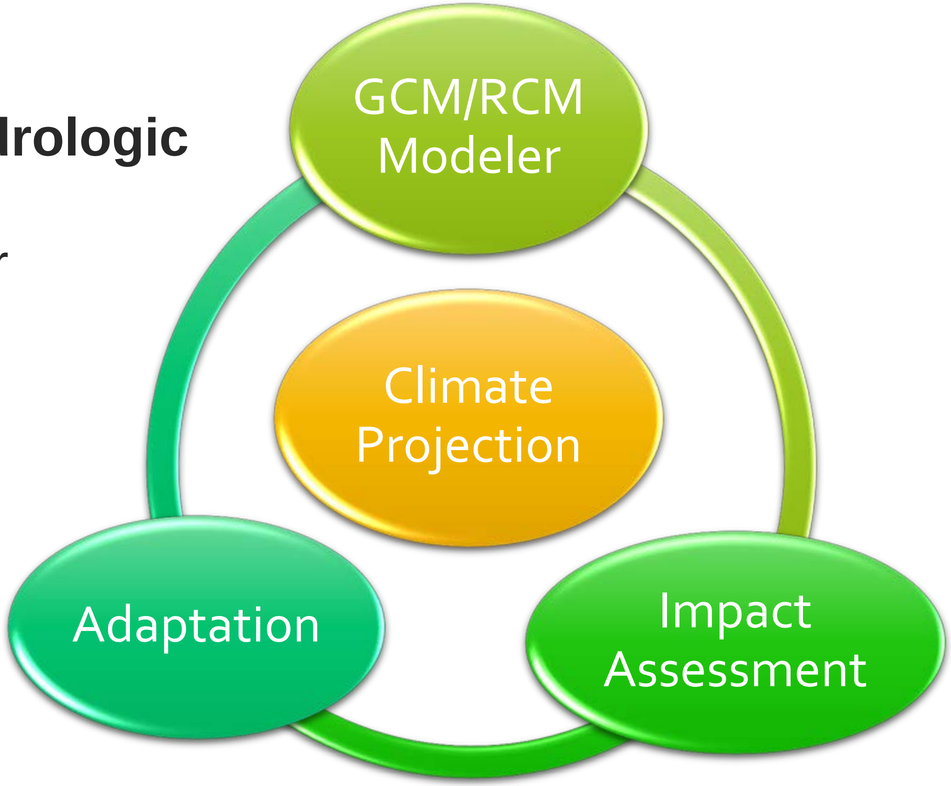
Impact assessment of climate change on water-related disasters and water resources

Input data : Future projection of hydrologic time series generated by

- General Circulation Models, and/or
- Regional Climate Models

Analysis models :

- Hydrologic models,
- Hydraulic models,
- Storm surge models,
- Risk assessment models



Assessment of hazard and risk change:

- Probabilistic analysis of extremes,
- Largest-class estimation of extremes, and
- Flood and inundation risk analysis.

Change of hazard and risk under global warming
Flood and Inundation

1. Probabilistic analysis to evaluate a change of extreme rainfall and flood characteristics using a stationary and non-stationary hydrologic frequency analysis method;

2. Largest-class estimation of probable largest-class floods due to typhoons; and

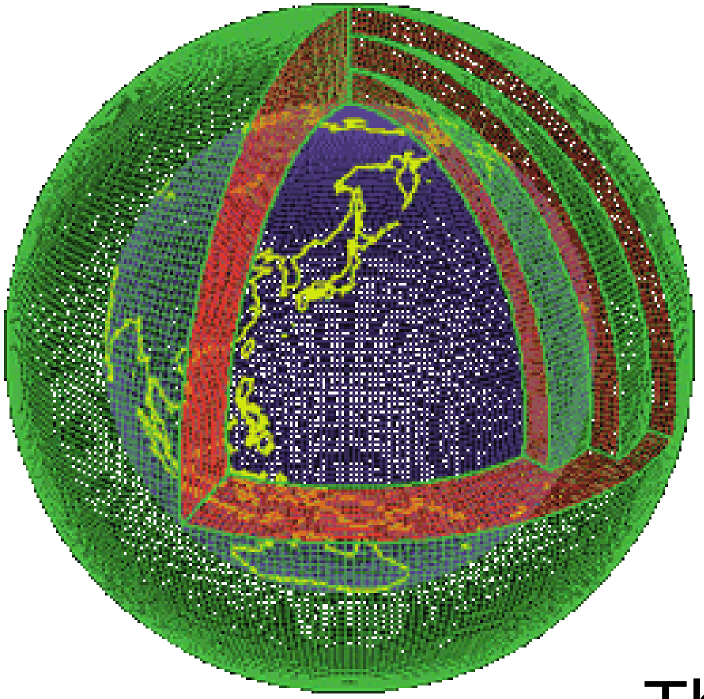
3. Flood risk analysis using a risk curve to evaluate economic loss.

* flood risk curve: probabilistic distribution of annual maximum economic loss due to flood and inundation

Evaluation of a change of extreme rainfall and flood characteristics in Japan using a stationary hydrologic frequency analysis method

Yasuto TACHIKAWA, Shohei TAKINO, Yuko FUJIOKA, Kazuaki YOROZU, and Sunmin KIM, JSCE, 67(1), 2011.

Future climate projection data using General Circulation Model, MRI-AGCM 3.1S developed by MRI, Japan



Present climate experiment:
1979-2004 (25years)

Near future climate experiment:
2015-2039 (25years)

The end of 21st century experiment:
2075-2099 (25years)

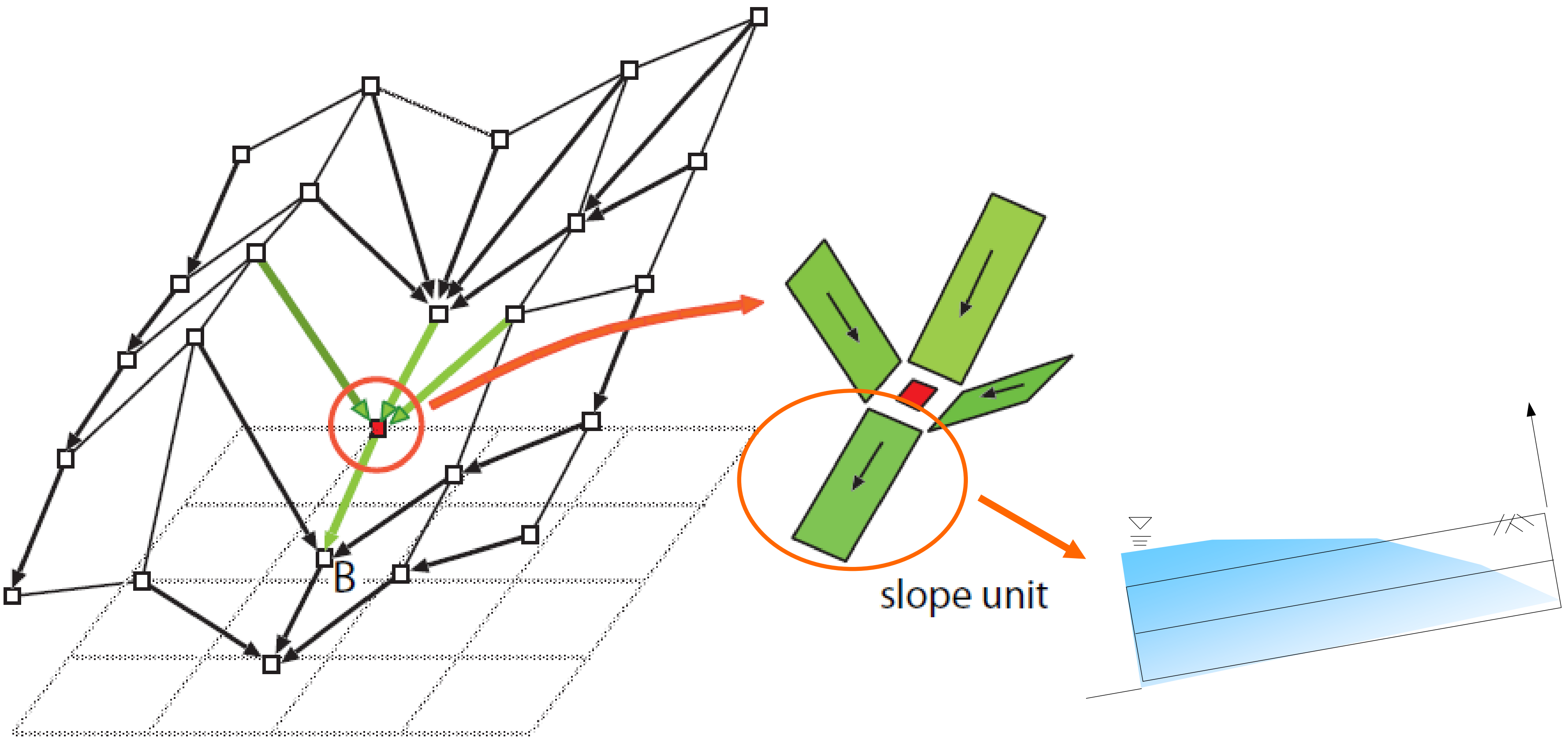
Method of Analysis

20km resolution GCM rainfall

1km resolution distributed hydrologic model for all Japanese catchments for 75 years runoff simulations

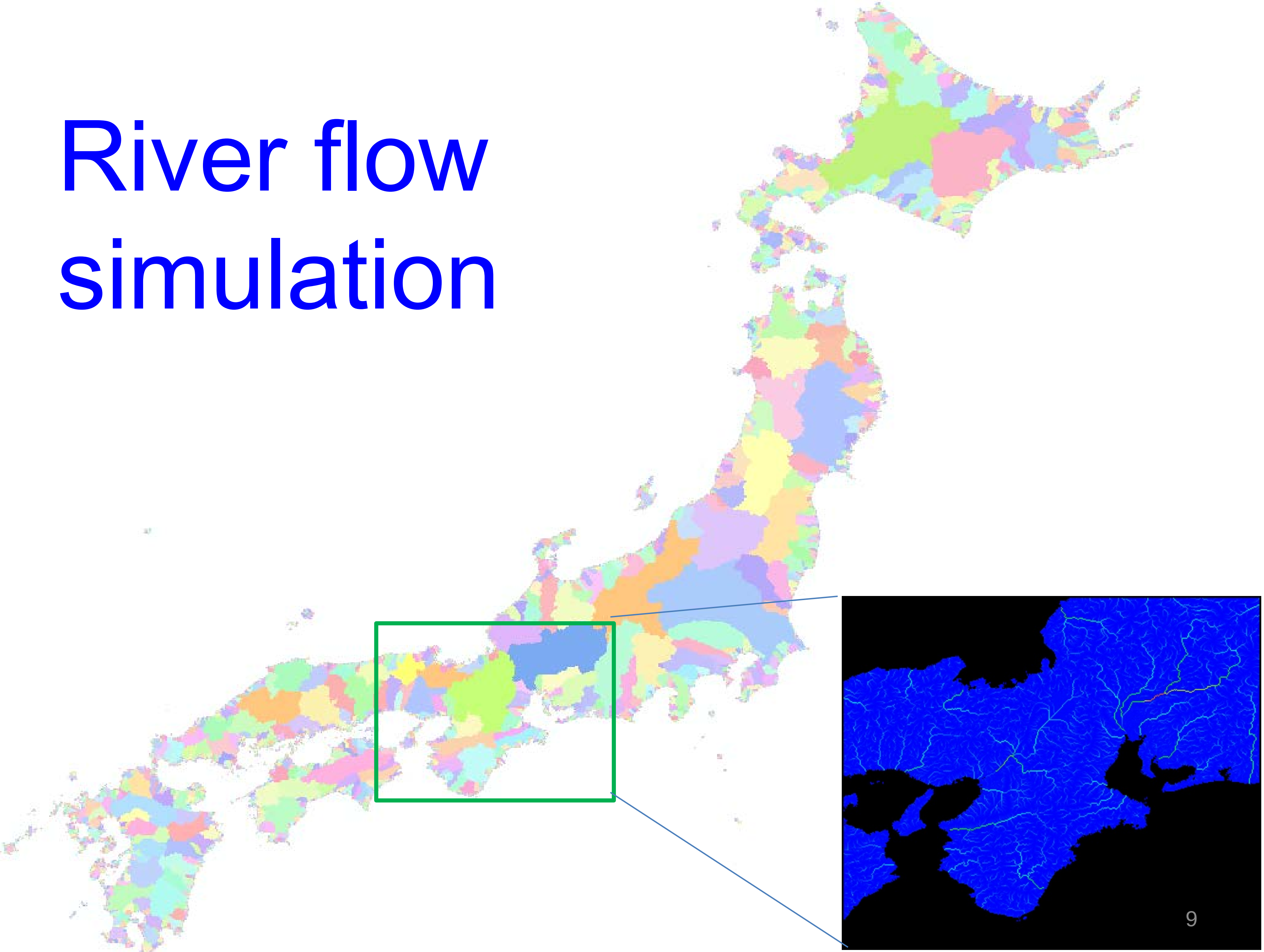
Examine the changes of extreme river discharge and duration curve to assess flood and drought risks.

Hydrologic Flow Modeling



A flow direction map with 1 km spatial resolution is developed. Then, runoff is routed according to the flow direction map using one dimensional kinematic wave flow model .

River flow simulation

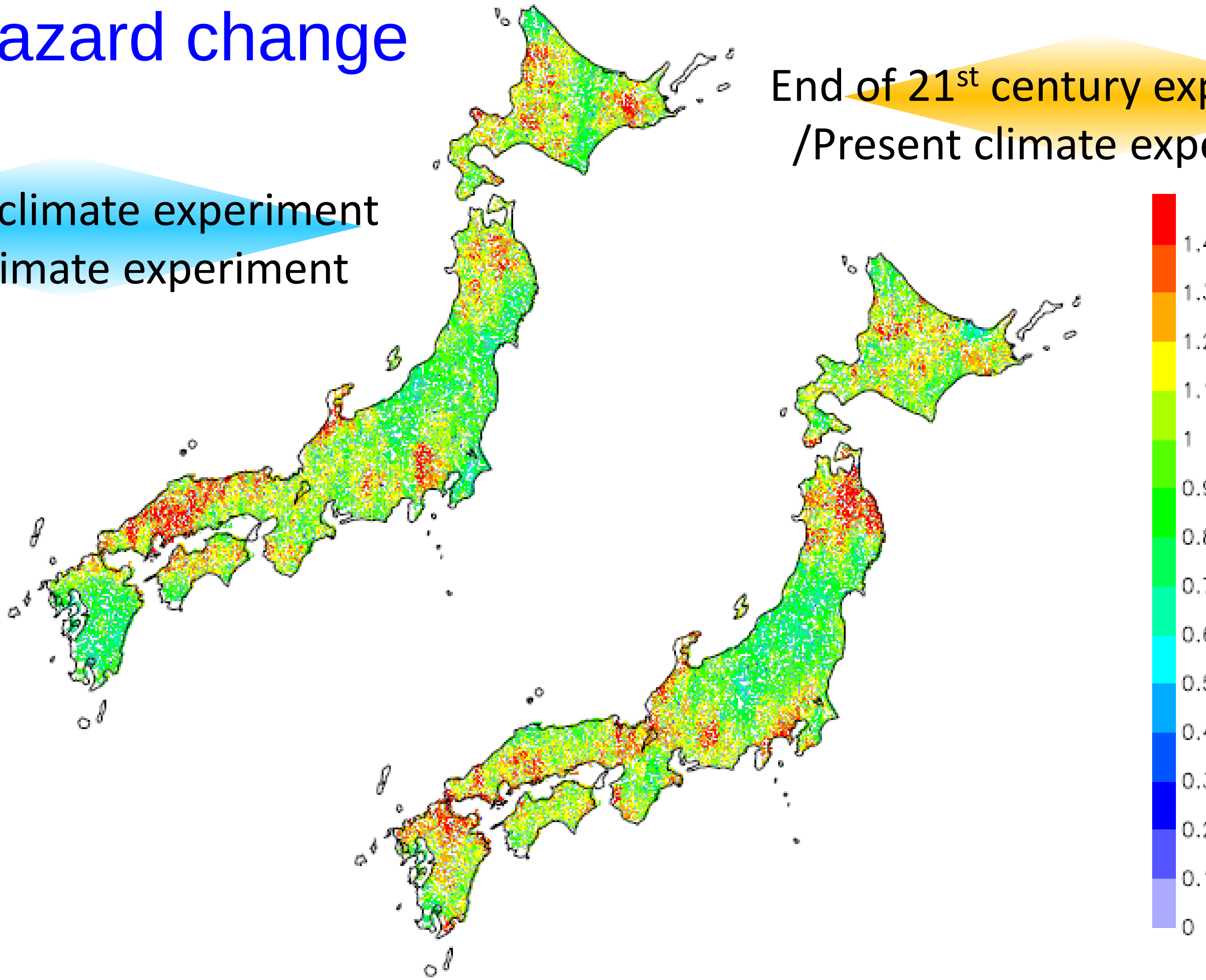


Change ratio of mean of annual maximum hourly discharge

Flood hazard change

Near future climate experiment
/Present climate experiment

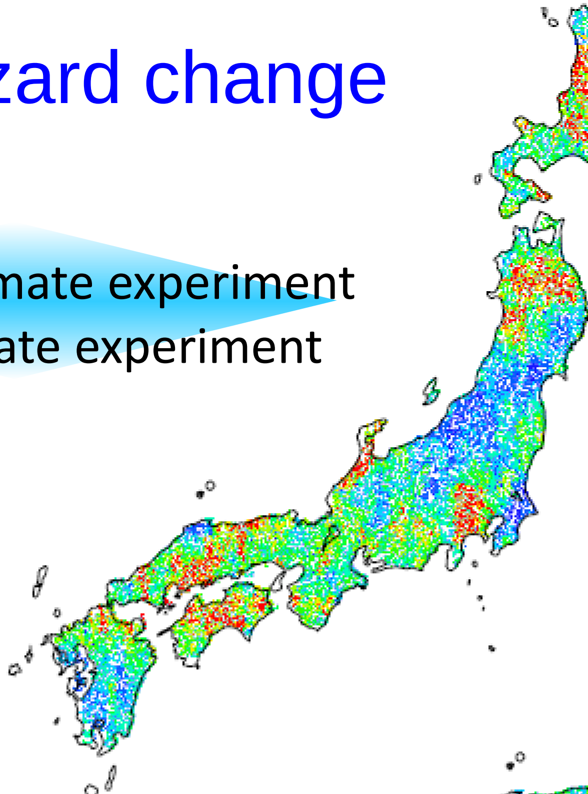
End of 21st century experiment
/Present climate experiment



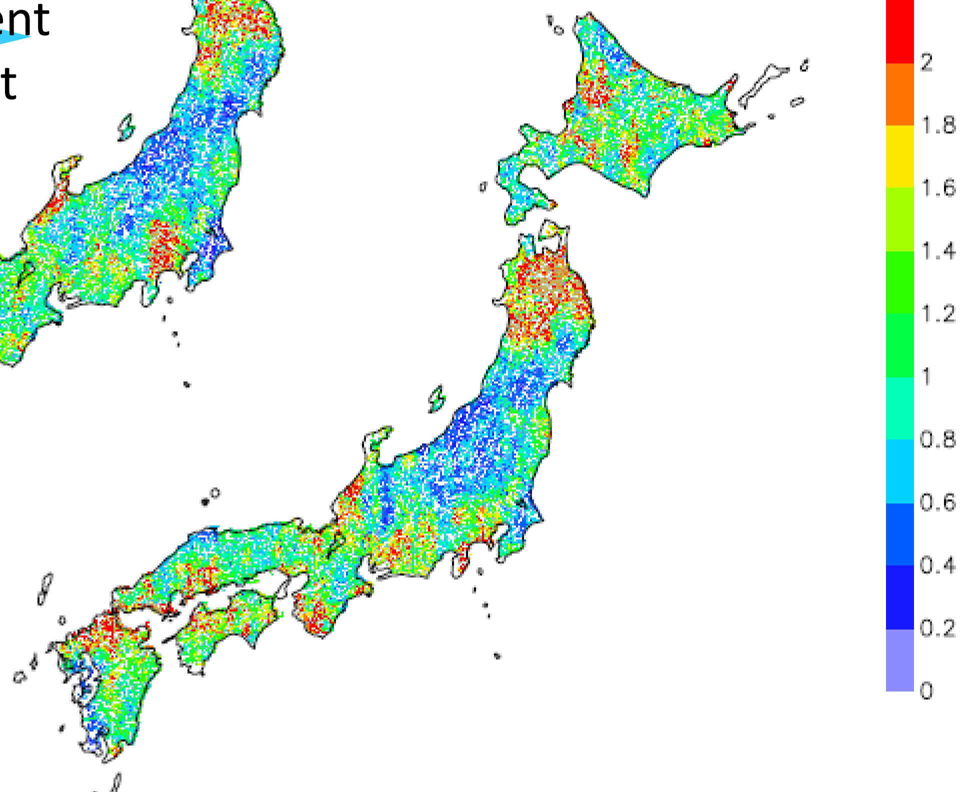
Change ratio of standard deviation of annual maximum hourly discharge

Flood hazard change

Near future climate experiment
/Present climate experiment



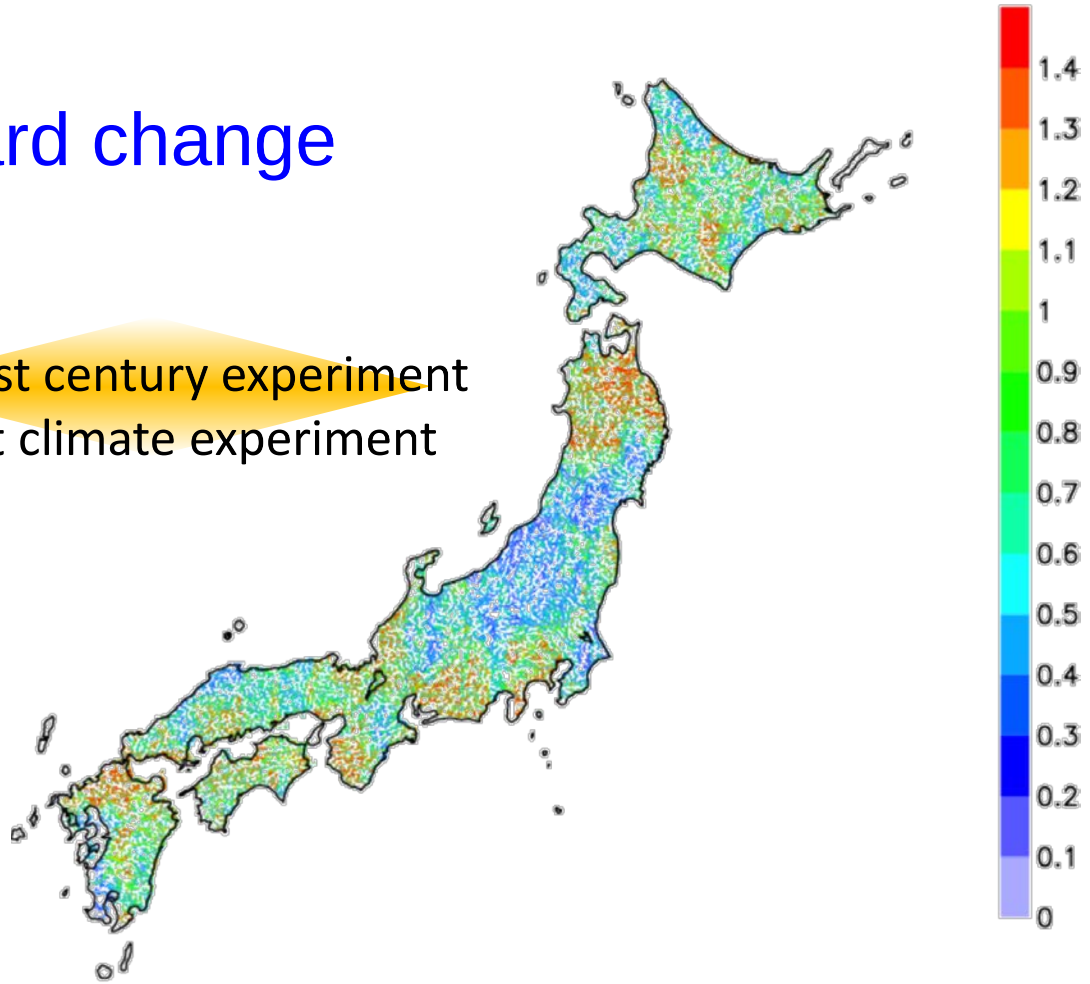
End of 21st century experiment
/Present climate experiment



Change ratio of the 100-year annual maximum hourly discharge

Flood hazard change

End of 21st century experiment
/Present climate experiment



A GEV distribution was fitted to each GCM grid for each 25 years annual maximum discharge series data.

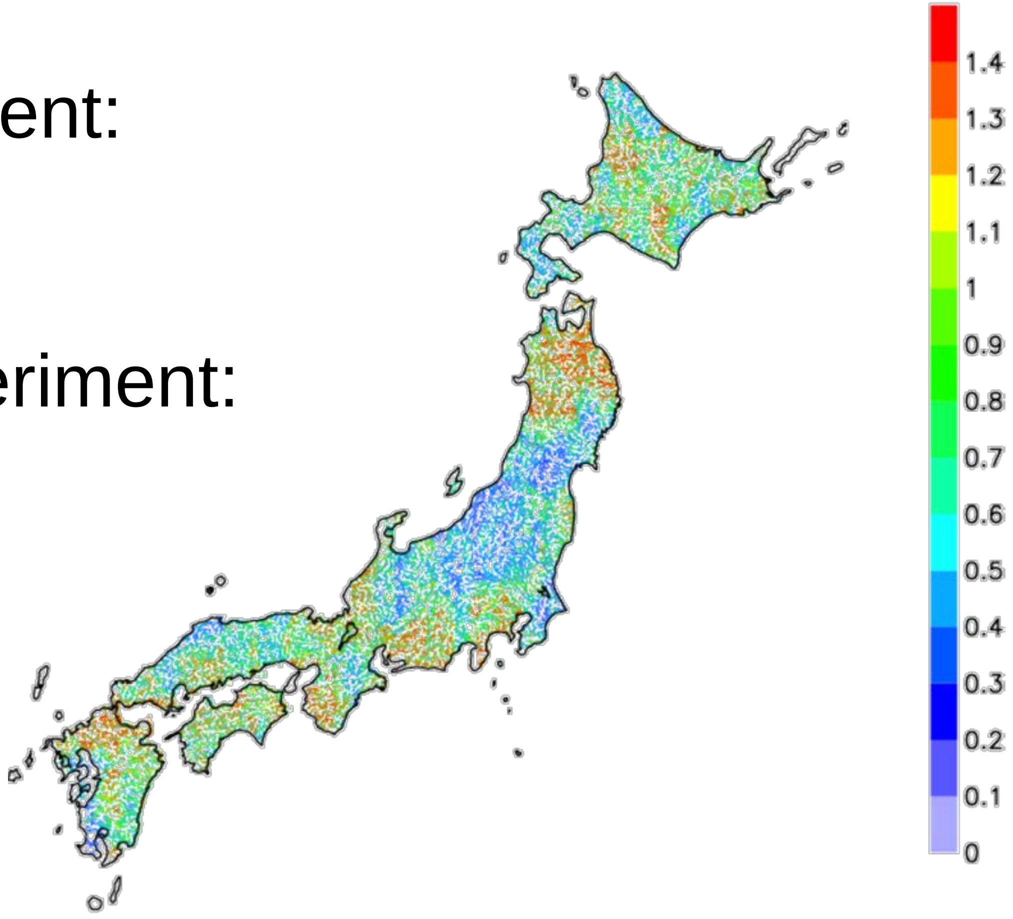
Change ratio of the 100-year annual maximum hourly discharge

GCM data used for runoff simulation

Present climate experiment:
1979-2004 (25years)

Near future climate experiment:
2015-2039 (25years)

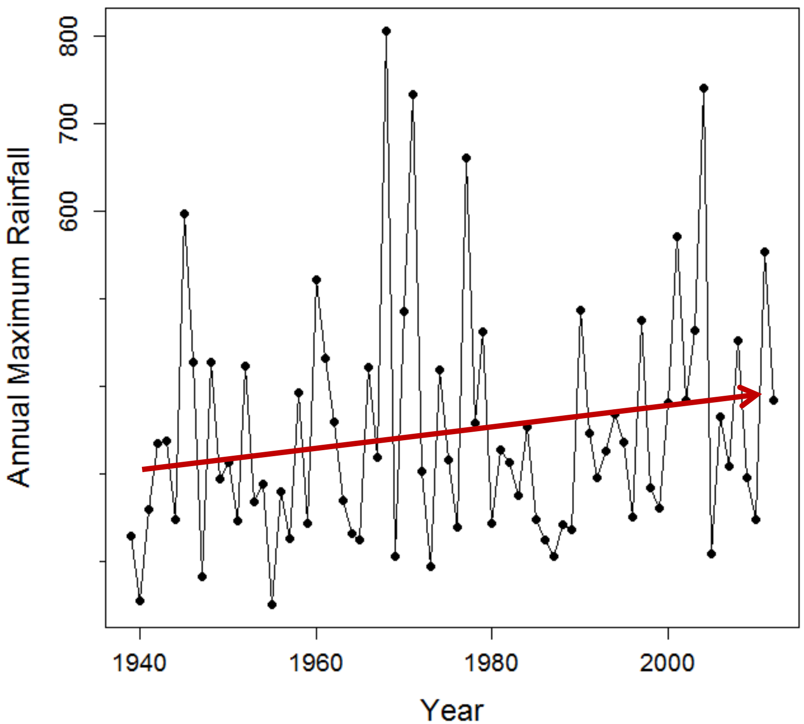
The end of 21st century experiment:
2075-2099 (25years)

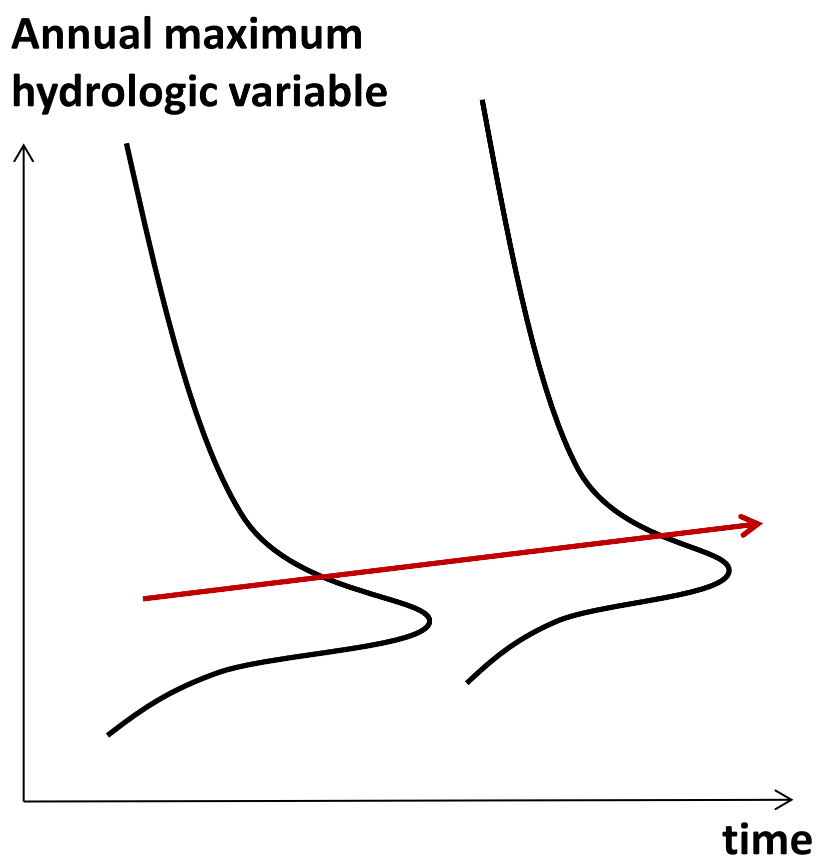


Evaluation of a change of extreme rainfall and flood characteristics using a non-stationary hydrologic frequency analysis method

Hiromasa HAYASHI, Yasuto TACHIKAWA, Michiharu SHIIBA, JSCE, 71(1), 2015.
Yasuto TACHIKAWA, Shinji MORI, Kazuaki YOROZU, and Sunmin KIM, JSCE, 71(4), 2015

Non-stationary frequency analysis





Annual maximum daily rainfall at Osase, Japan（1939 - 2012）

Characteristics of population change with time.

Non-stationary frequency analysis model

Non-stationary GEV distribution (Coles, 2001)

$$F(x_{t_i}|\boldsymbol{\theta}) = \exp\left\{-\left[1+\xi\left(\frac{x_{t_i}-\mu(t_i)}{e^{\sigma(t_i)}}\right)\right]^{-1/\xi}\right\}$$

$$\mu(t_i) = \sum_{k=0}^{p} \mu_k t_i^k \qquad \sigma(t_i) = \sum_{k=0}^{q} \sigma_k t_i^k$$

$$t_i = \frac{i}{n+1},\ i = 1, \cdots, n$$

- Location and scale parameters μ and σ are assumed to be a function of time and estimated using the method of likelihood.
- Shape parameter ξ is assumed to be constant.

Coles, S.: An introduction to statistical modeling of extreme values, Springer, 2001

Non-stationary Gumbel distribution

$$F(x_{t_i}|\boldsymbol{\theta}) = \exp\left[-\exp\left(-\frac{x_{t_i} - \mu(t_i)}{e^{\sigma(t_i)}}\right)\right]$$

$$\mu(t_i) = \sum_{k=0}^{p} \mu_k t_i^k, \ \sigma(t_i) = \sum_{k=0}^{q} \sigma_k t_i^k$$

Non-stationary SQRT-ET distribution

$$F(x_{t_i}|\boldsymbol{\theta}) = \exp\left[-e^{a(t_i)}\left(1 + \sqrt{e^{b(t_i)} x_{t_i}}\right) \times \exp\left(-\sqrt{e^{b(t_i)} x_{t_i}}\right)\right]$$

$$a(t_i) = \sum_{k=0}^{p} a_k t_i^k \quad b(t_i) = \sum_{k=0}^{q} b_k t_i^k$$

Non-stationary Lognormal distribution

$$f(x_{t_i}|\boldsymbol{\theta}) = \frac{1}{\sqrt{2\pi} e^{\sigma(t_i)} x} \exp\left[-\frac{1}{2}\left(\frac{\log x - \mu(t_i)}{e^{\sigma(t_i)}}\right)^2\right]$$

Selection of non-stationary model

- Four kinds of non-stationary model (GEV, Gumbel, SQRT-ET, Lognormal)
- Location and scale parameters are modeled as a constant, a linear function, and a quadratic function:

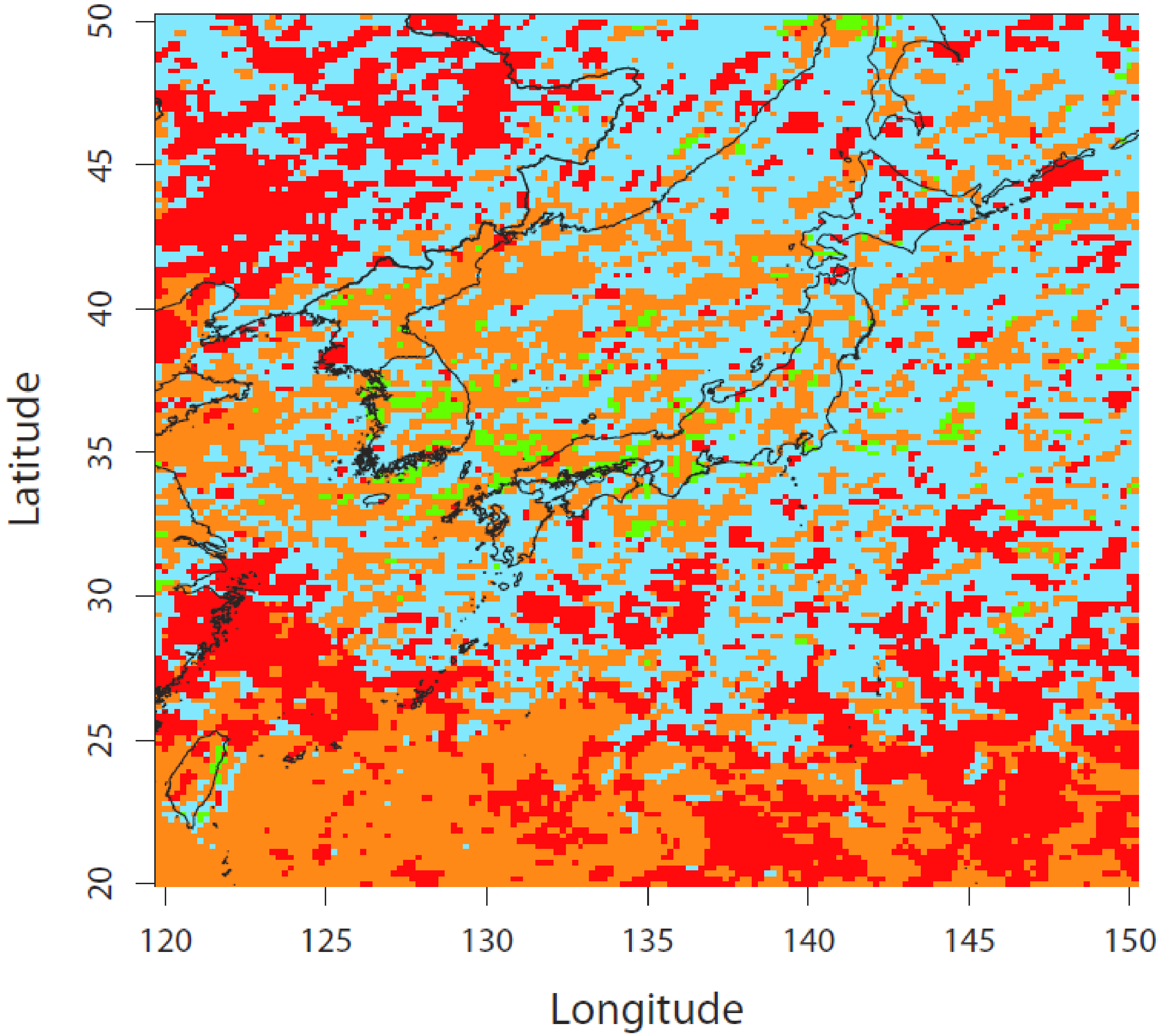
Location parameter $\mu(t_i) = \sum_{k=0}^{p} \mu_k t_i^k$, p = 0, 1, 2

Scale parameter $\sigma(t_i) = \sum_{k=0}^{q} \sigma_k t_i^k$, q = 0, 1, 2

- We tested total 36 models for each GCM grid precipitation.

- The parameter values were identified using the maximum likelihood method. AIC was used to select the best fitted model.

Spatial distribution of a selected model evaluated by AIC for annual maximum daily rainfall using MRI-AGCM 3.2

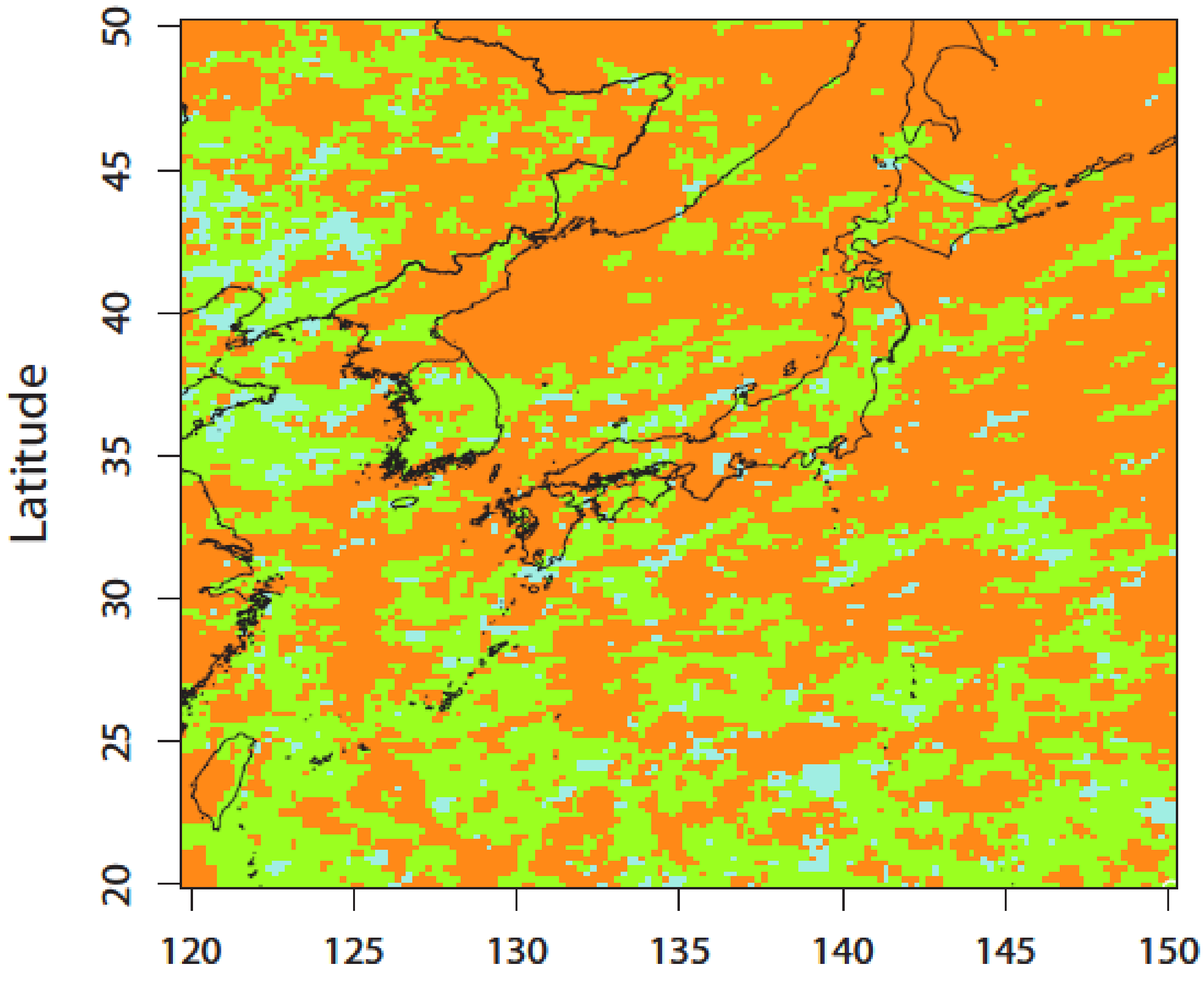


- Present climate experiment: 1979-2008
- Near future climate experiment: 2015-2044
- The end of 21st century experiment: 2075-2104

Total 90years data

Red: GEV distribution
Green: Gumbel
Right Blue SQRT-ET
Orange: Lognormal

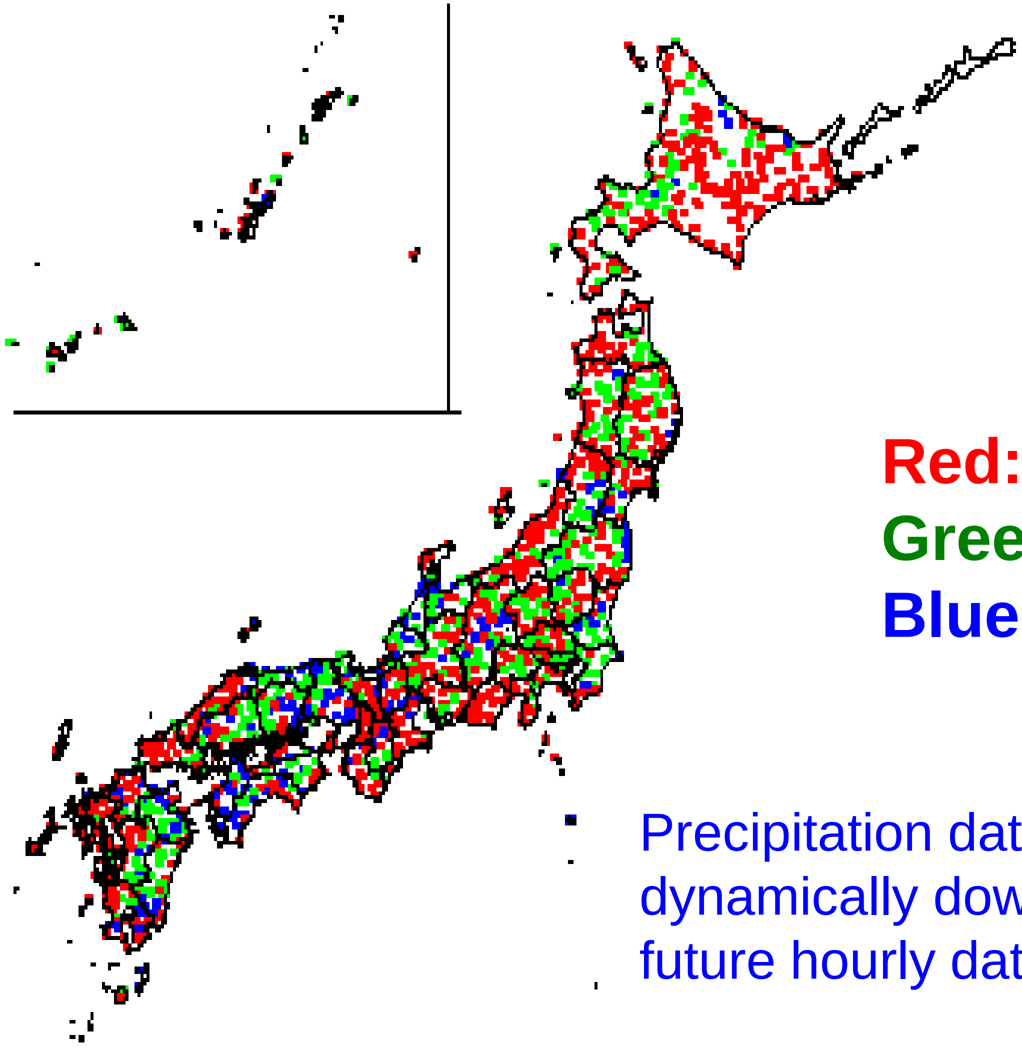
Spatial distribution of the change of 100-year annual maximum daily rainfall at 1993 and 2089



MRI-AGCM 3.2
SRES A1B scenario

Orange: Increase
Green: no change
Right Blue: Decrease

Spatial distribution of 100-year annual maximum 24 hours rainfall at 1990 and 2076 using dynamically downscaled and bias corrected rainfall data



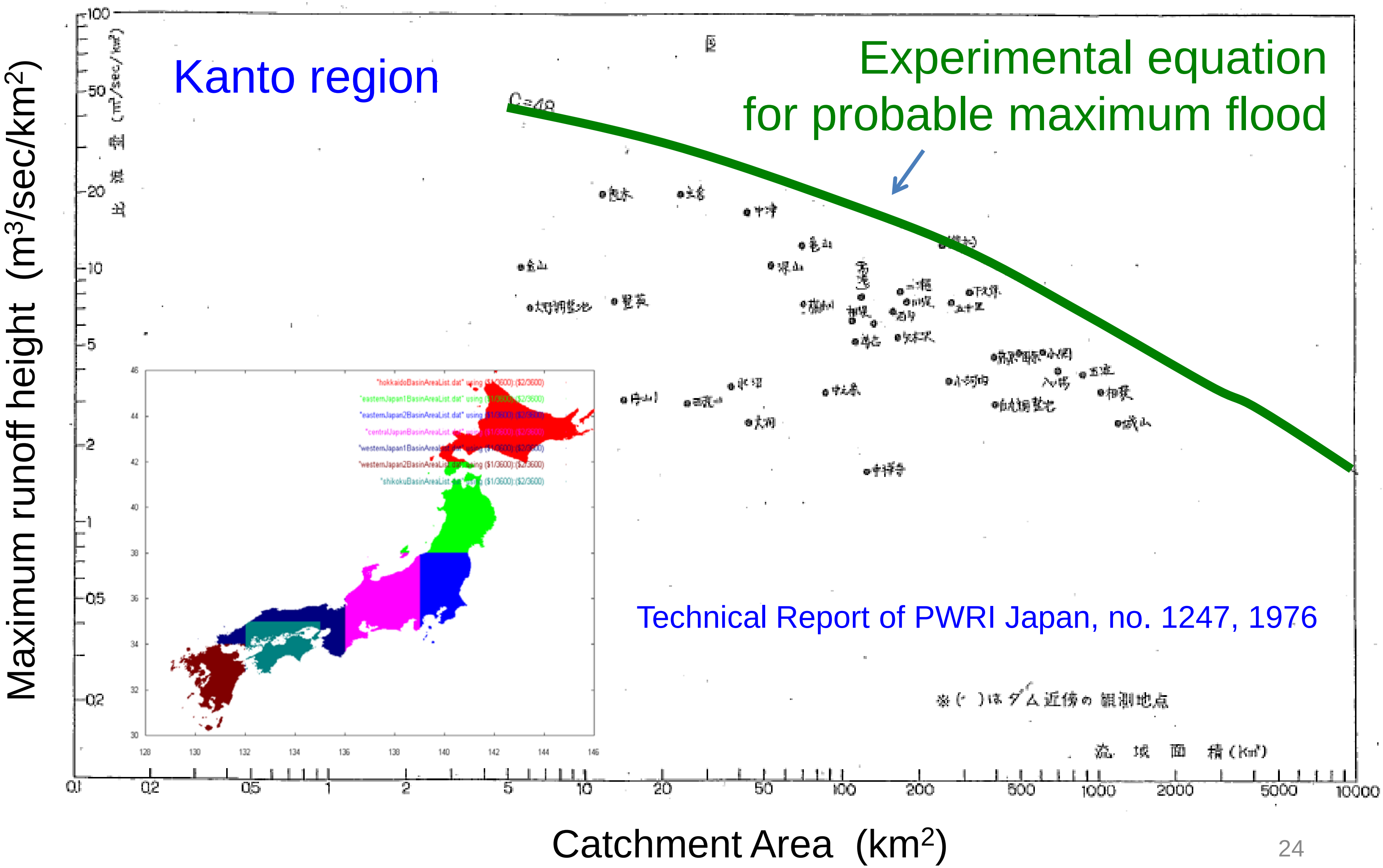
Red: Increase
Green: No change
Blue: Decrease

Precipitation data used is 5km resolution dynamically downscaled and bias corrected future hourly data based on MRI-AGCM 3.2.

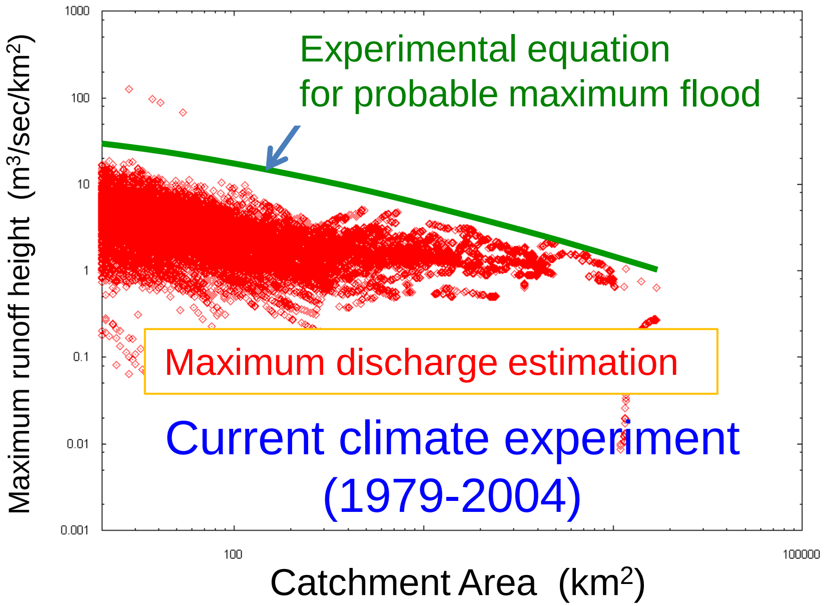
Estimation of probable largest-class floods by typhoons under a changing climate

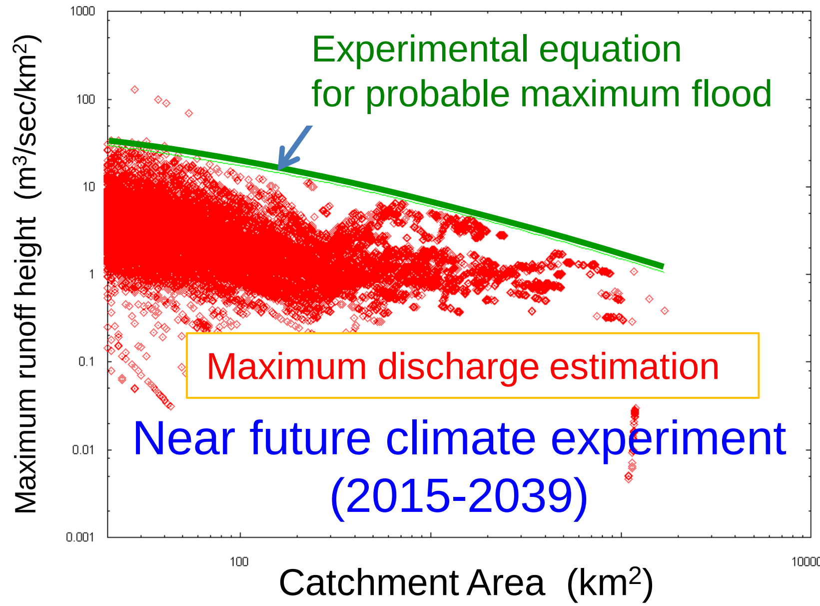
Kohei MIYAWAKI, Yasuto TACHIKAWA, Tomohiro TANAKA, Daiki ISHII, Yutaka ICHIKAWA, Kazuaki YOROZU, and Tetsuya TAKEMI,
JSCE, 72(4), 2016

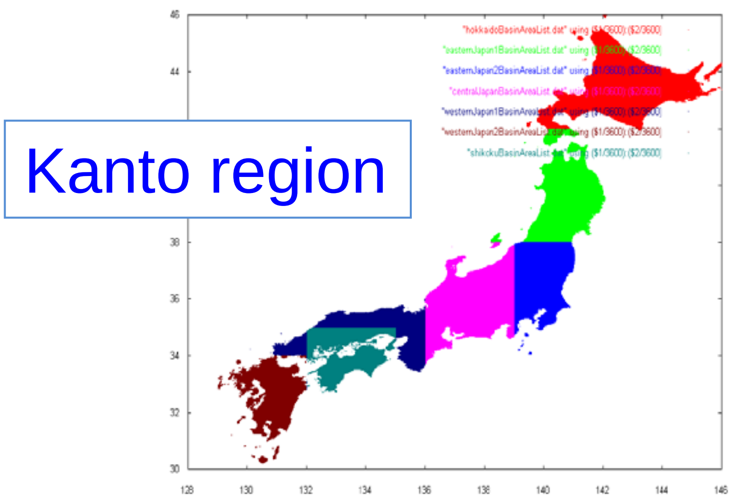
Design flood discharge for dam reservoir construction

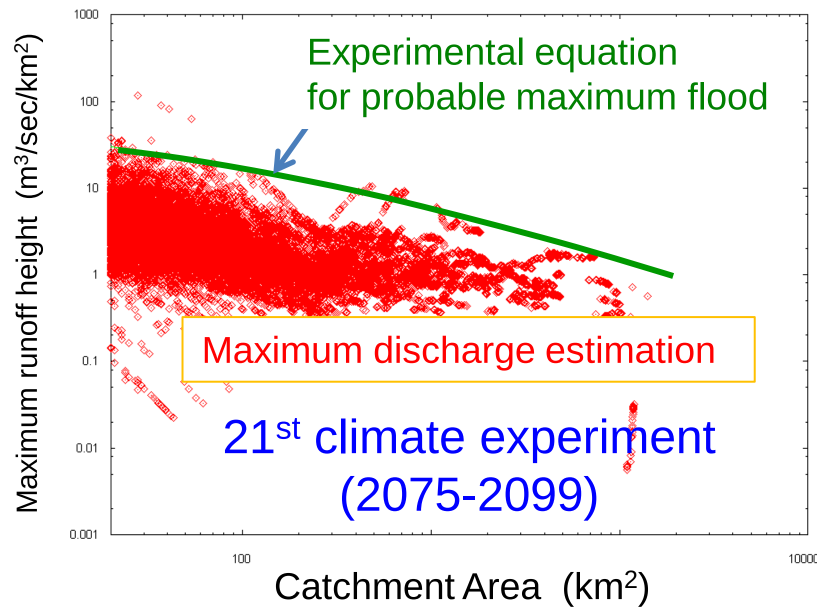


Maximum flood discharge at Kanto region estimated by a distributed hydrologic model with MRI-AGCM3.2S data

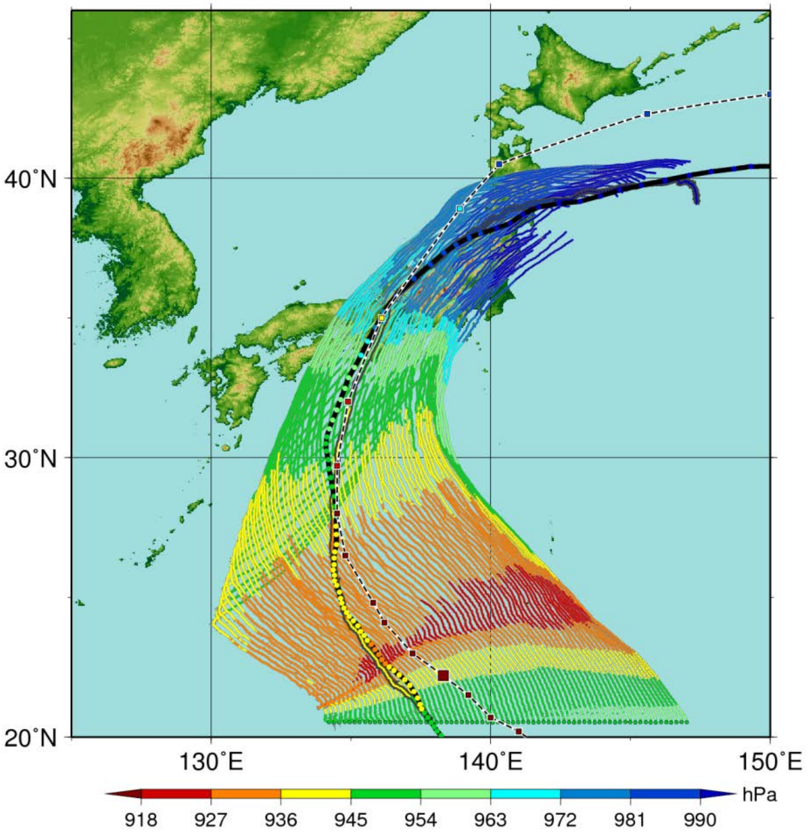




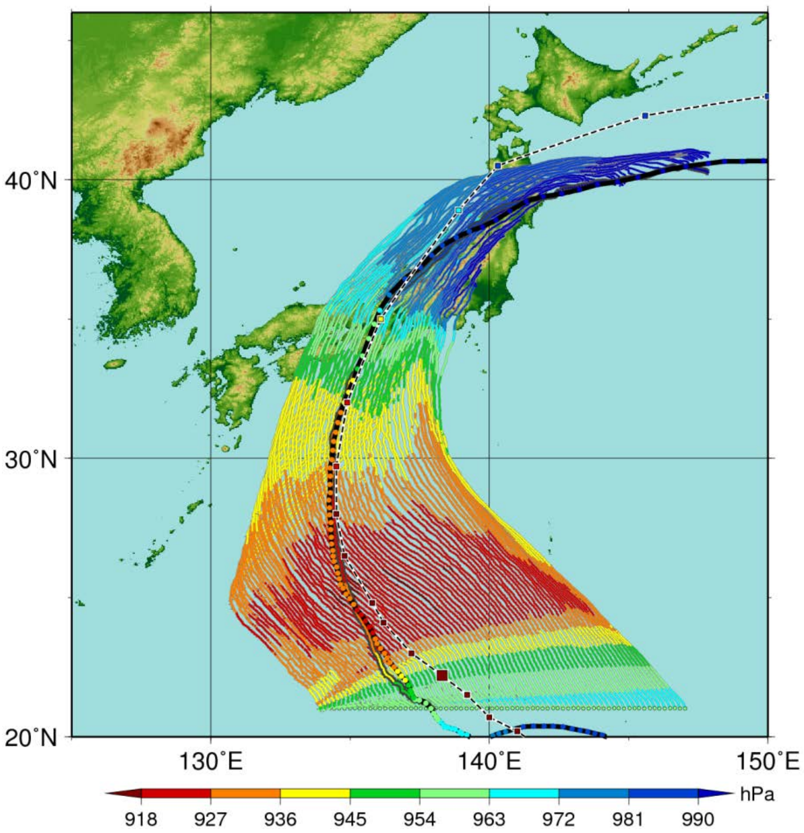




Virtual shifting of typhoon's initial position for the historical typhoon (Isewan Typhoon, 1959)



Control run



pseudo-global warming experiment

Takemi (DPRI, Kyoto Univ.), et al., 2013

Flood and inundation simulations under the largest-class typhoons

Various scenarios of the largest-class typhoons under a changing climate

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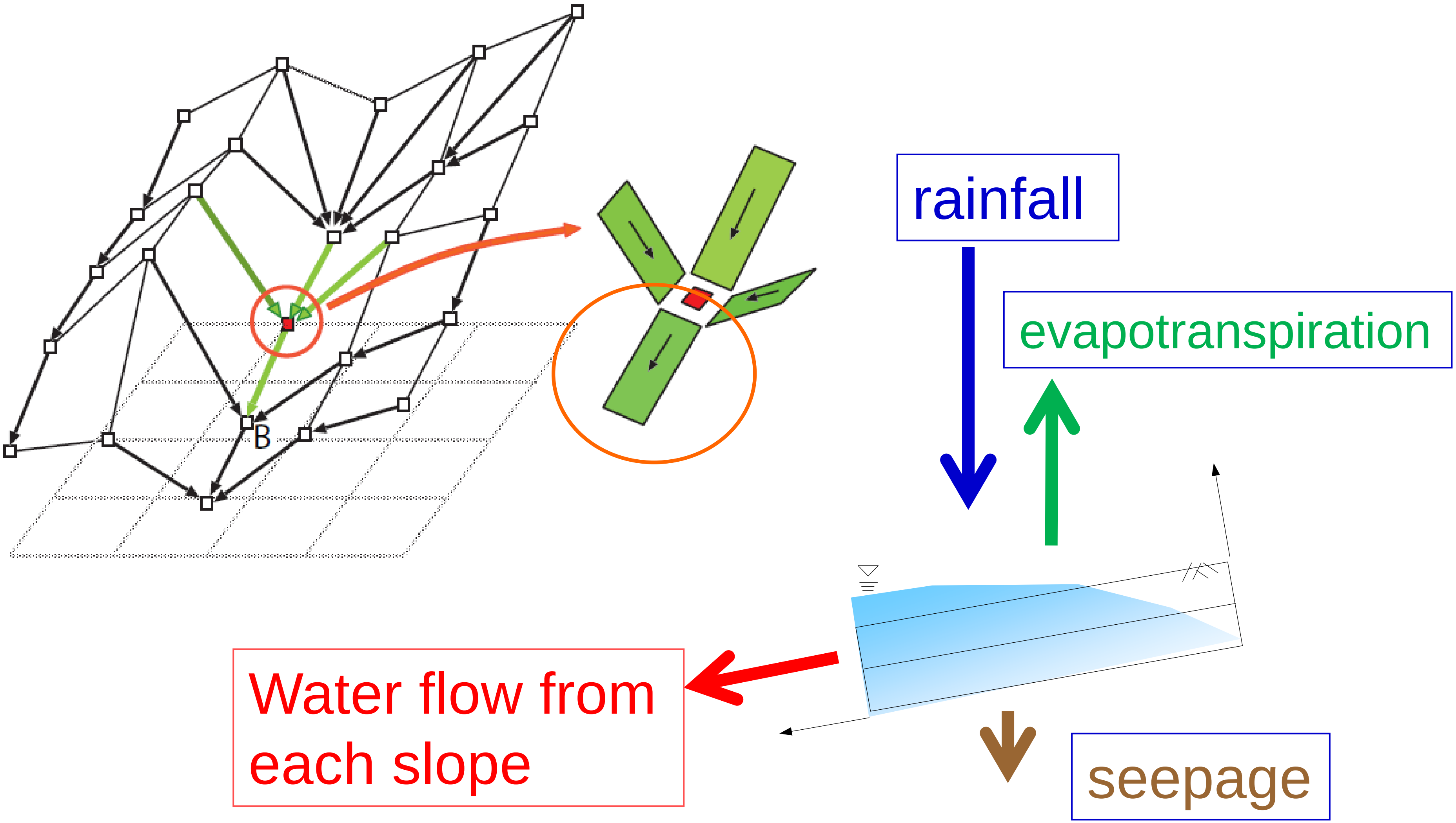
Flood and inundation simulations

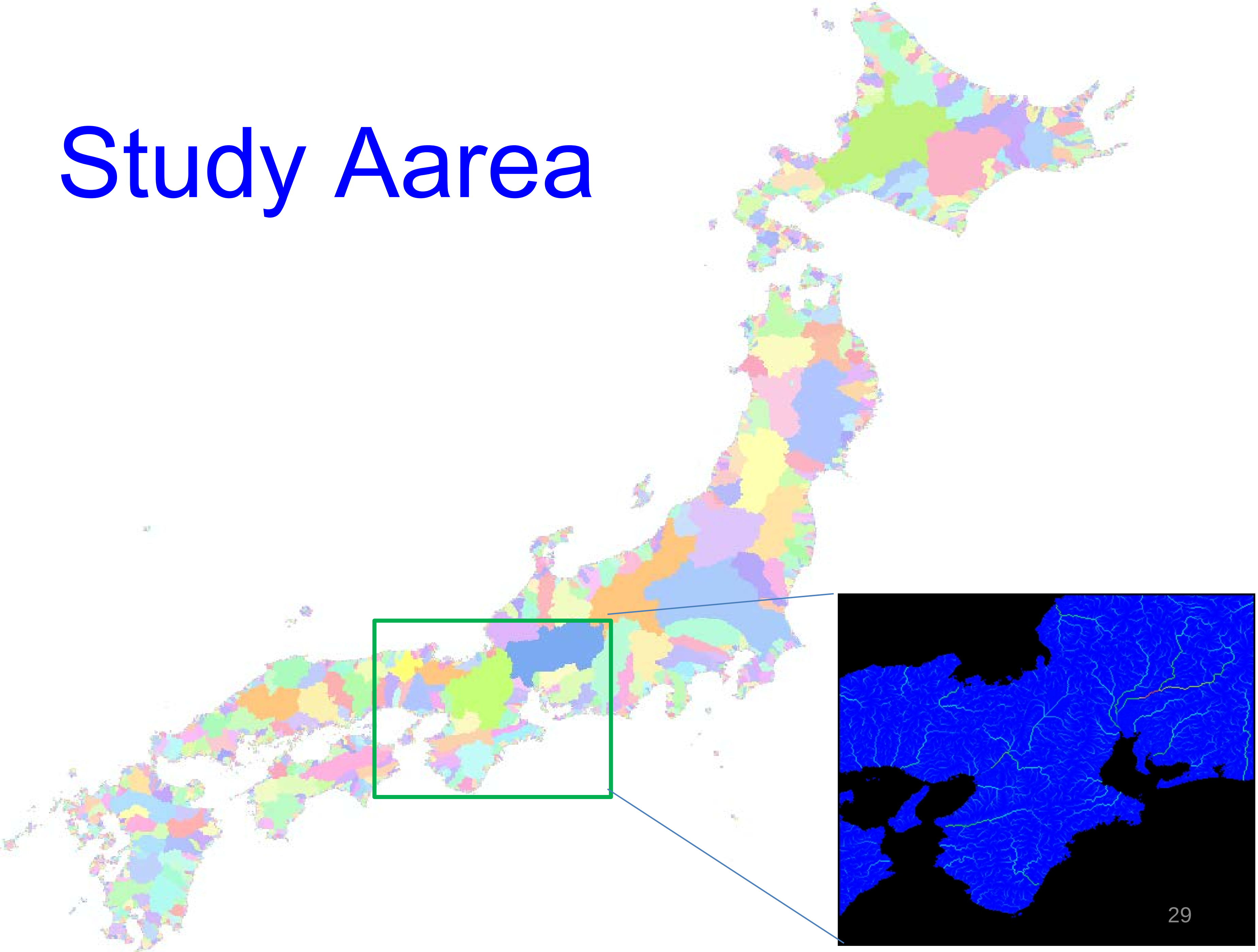
↓

The worst case impact assessment

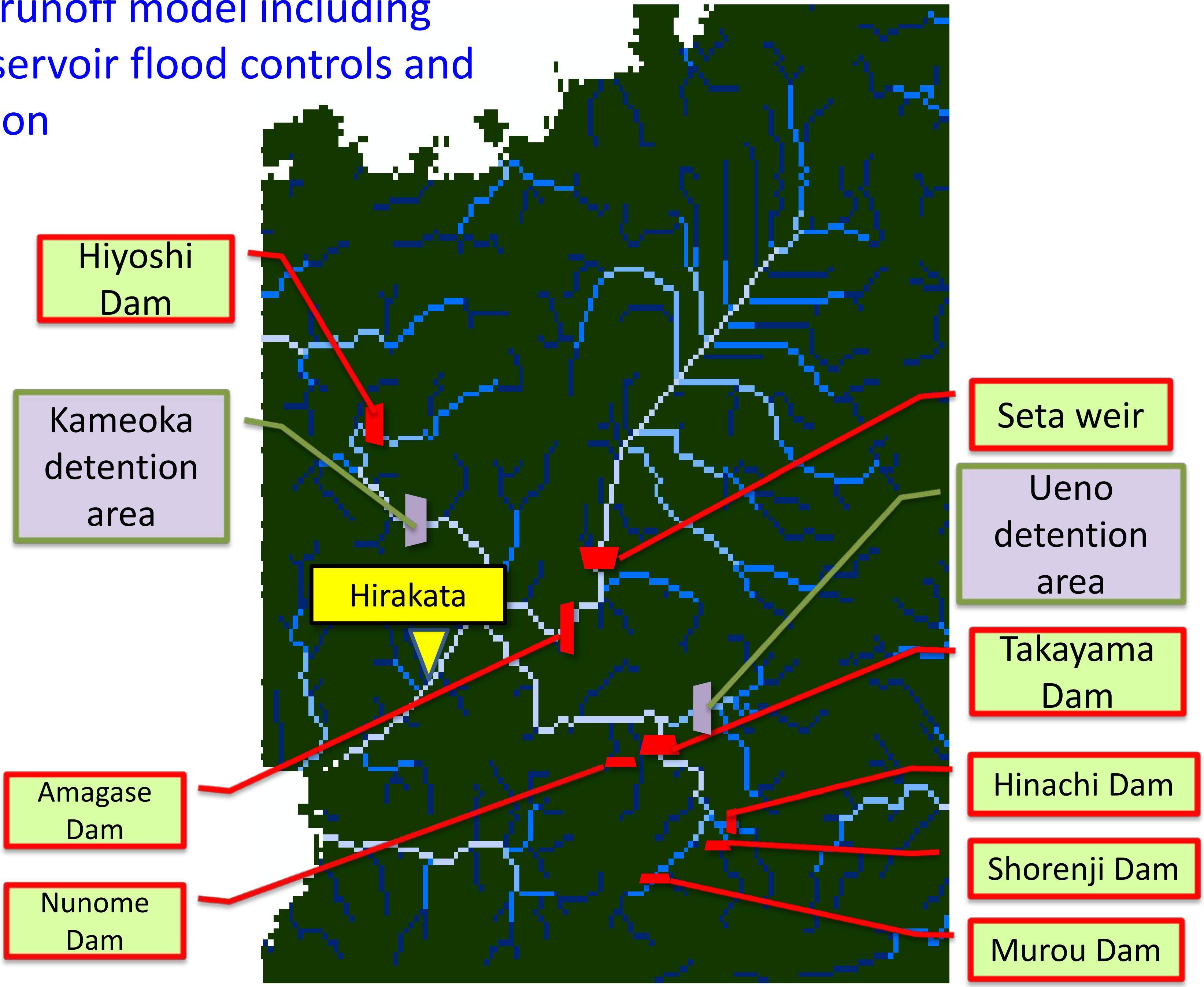
Rainfall-Runoff Model



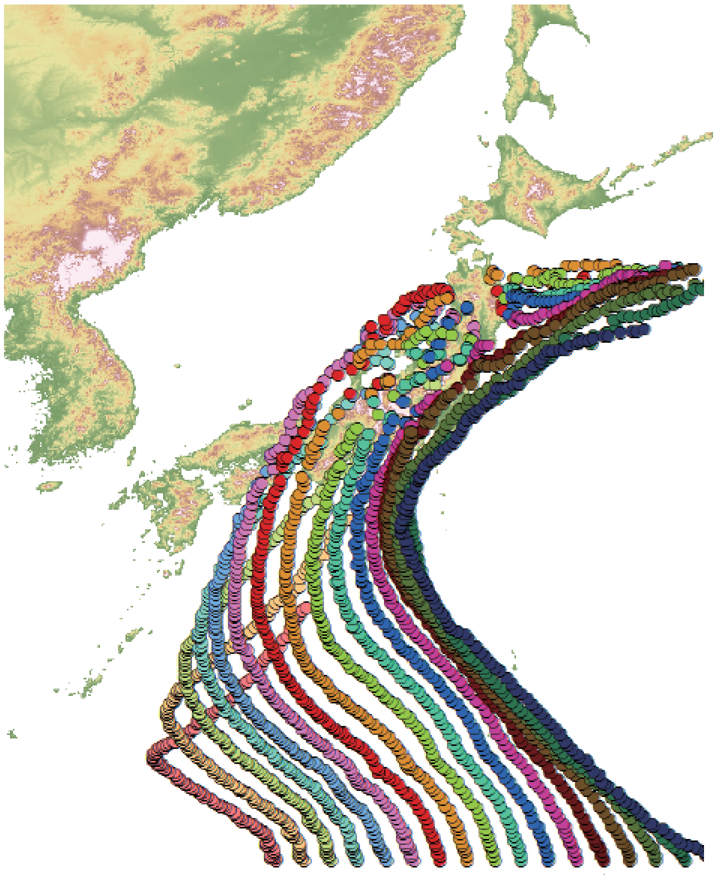
Study Aarea



Rainfall-runoff model including main reservoir flood controls and inundation

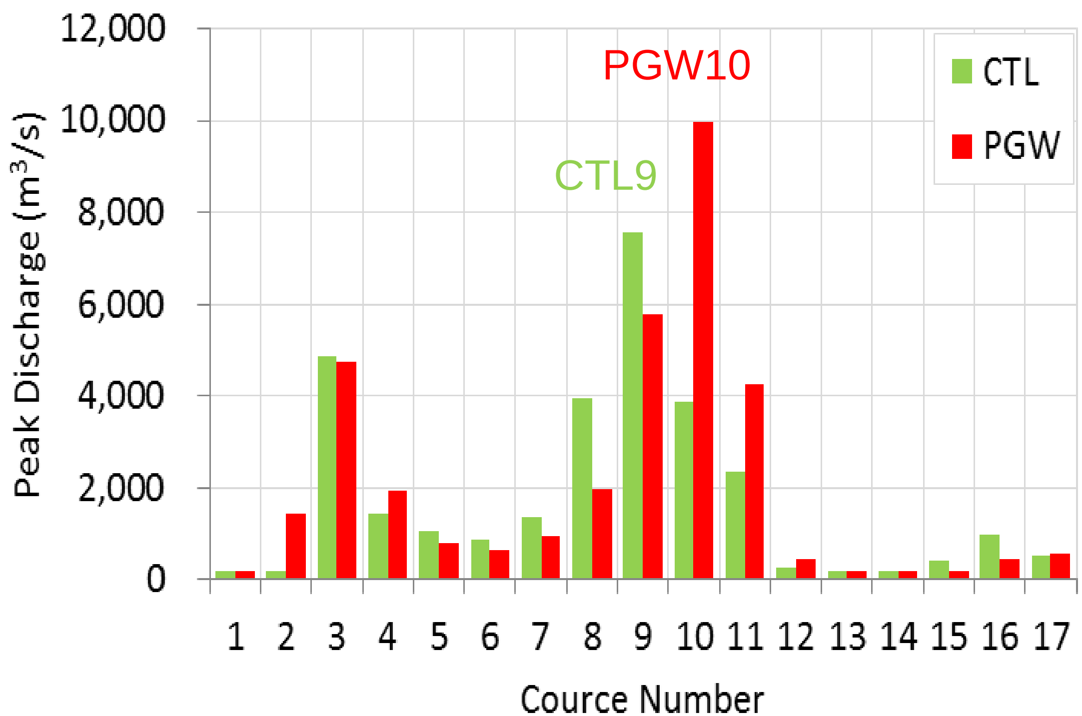


Typhoon Course Ensemble Simulations



Typhoon tracks

Peak discharge at Hirakata station
for different typhoon tracks



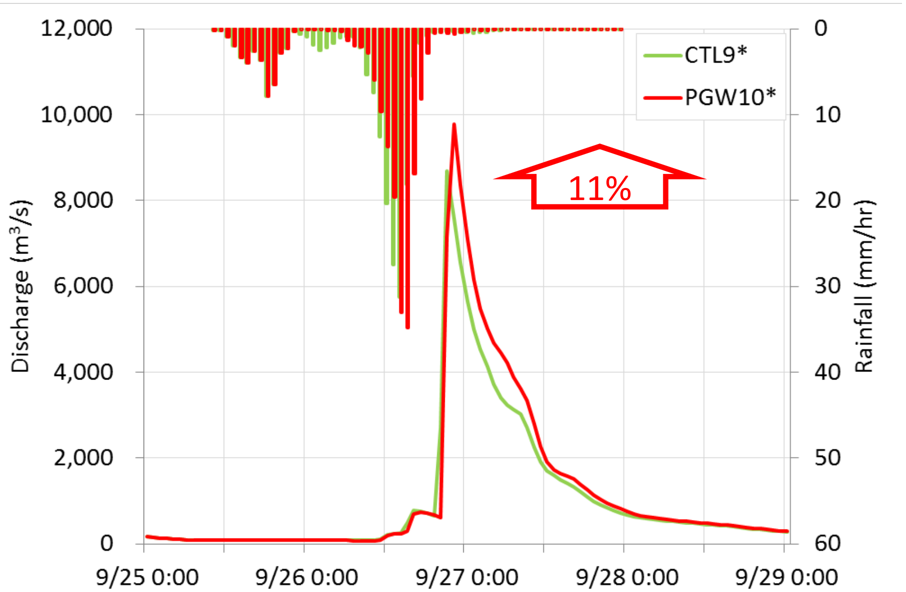
CTL: Control experiment (present climate)

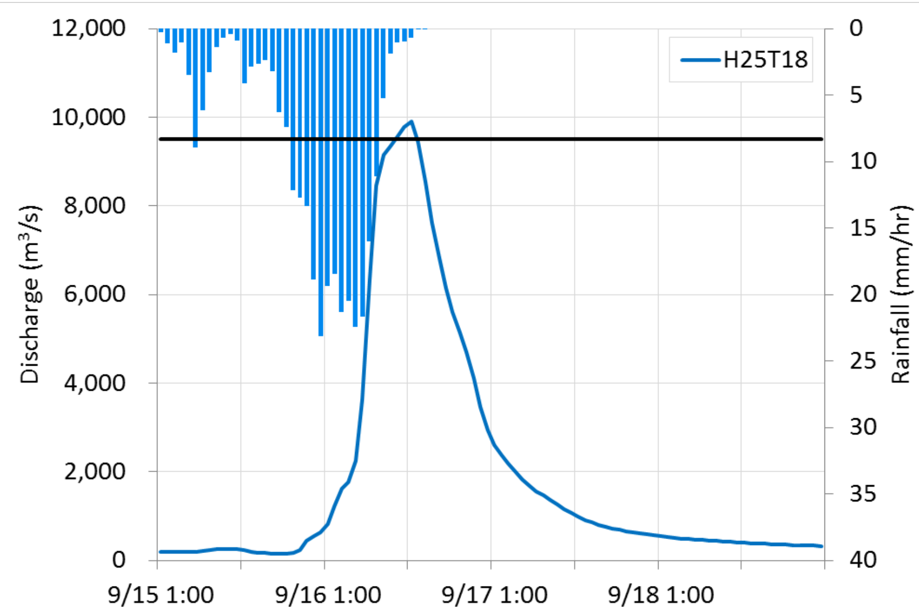
PGW: Pseudo Global Warming experiment

Climate change effect on peak discharge

Control run: track no. 9
PGW run: track no. 10

Observed discharge for
Typhoon No. 18 in 2013



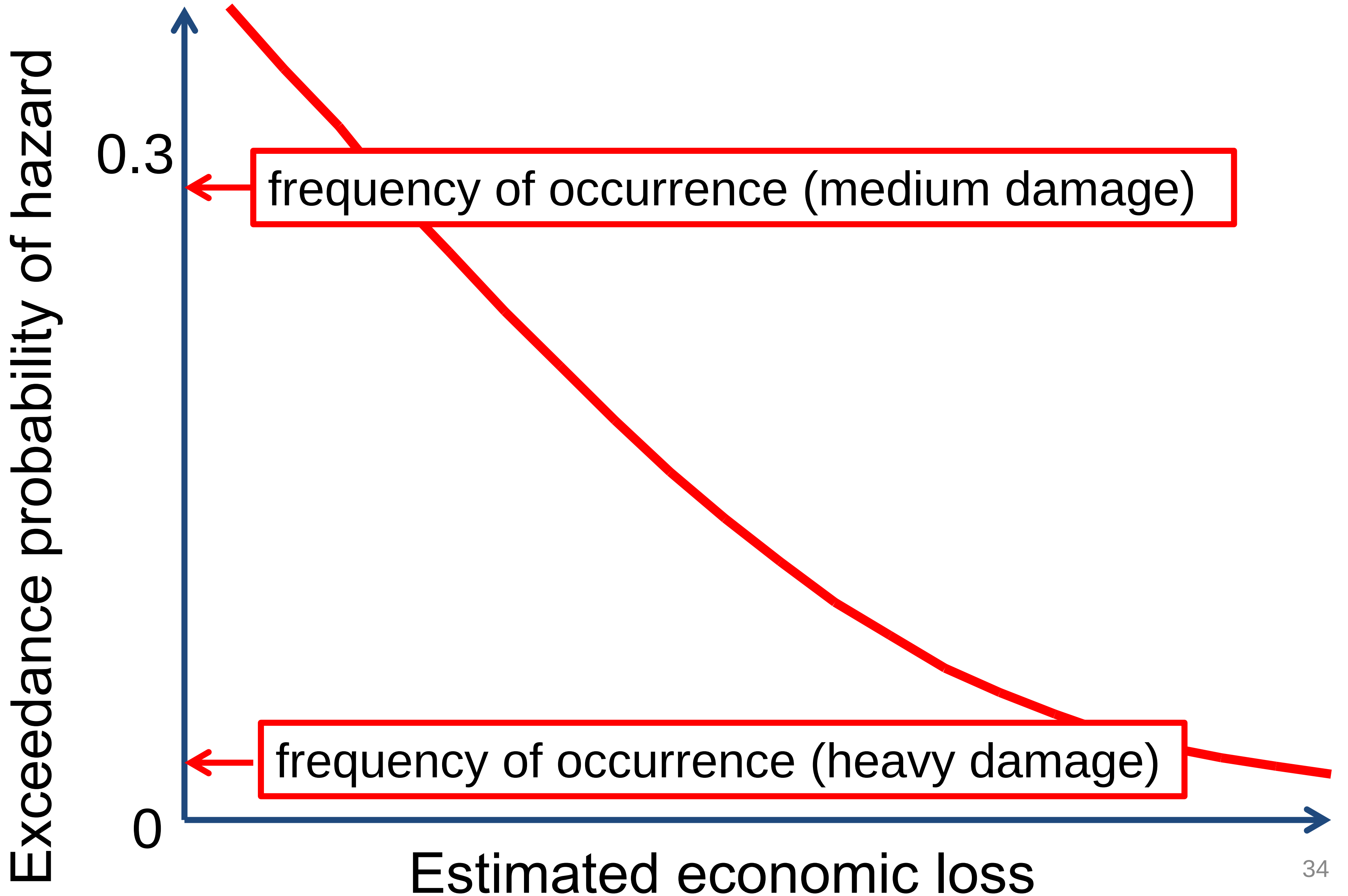


Change of Hazard → Change of Risk

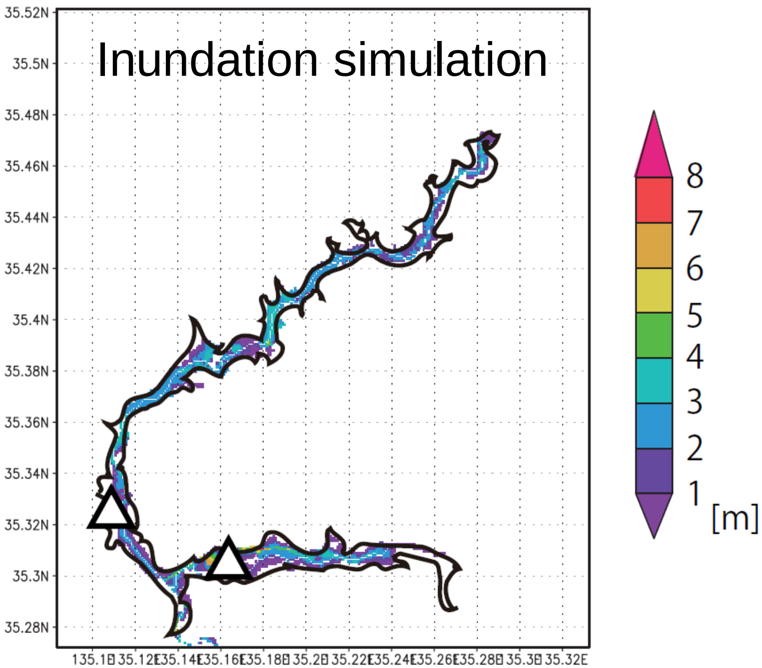
Flood risk analysis using a risk curve for flood hazard change

Tomohiro TANAKA, Yasuto TACHIKAWA, Yutaka ICHIKAWA, Kazuaki YOROZU, JSCE, 72(4), 2016.
Tomohiro TANAKA, Yasuto TACHIKAWA, Kazuaki YOROZU, JSCE, 71(4), 2015.

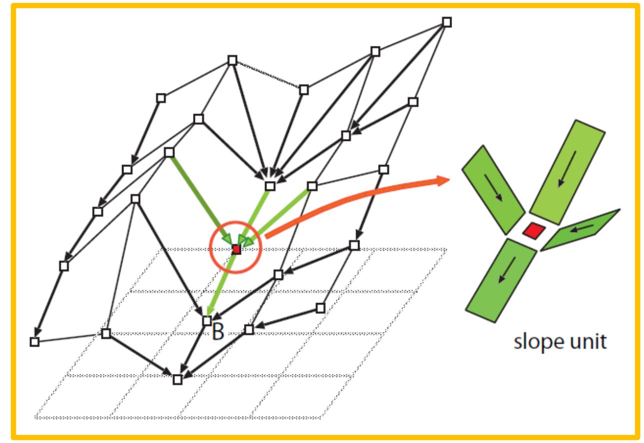
Flood risk curve: Probabilistic distribution of annual maximum economic loss due to flood and inundation



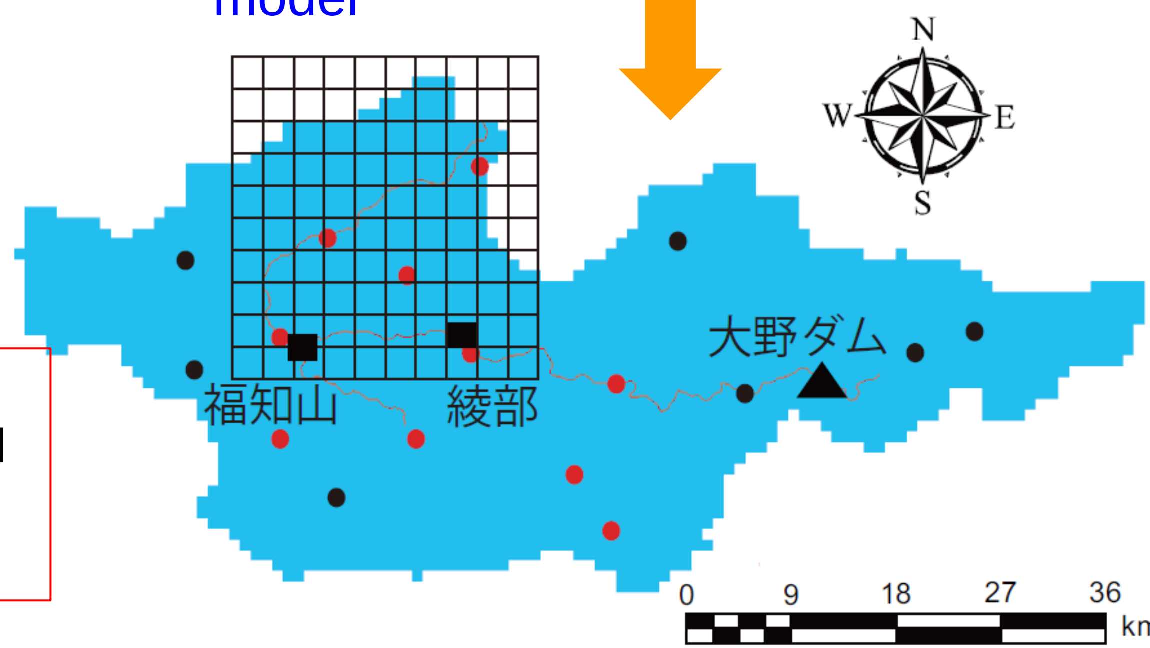
Evaluation of economic loss by inundation



Rainfall-runoff model



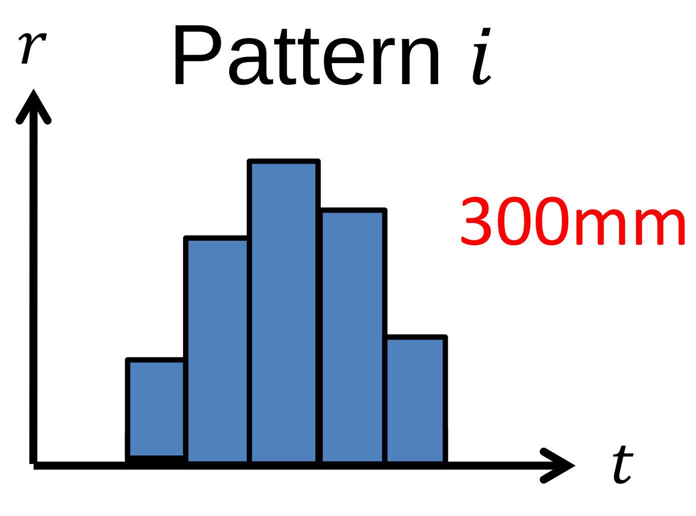
Inundation model

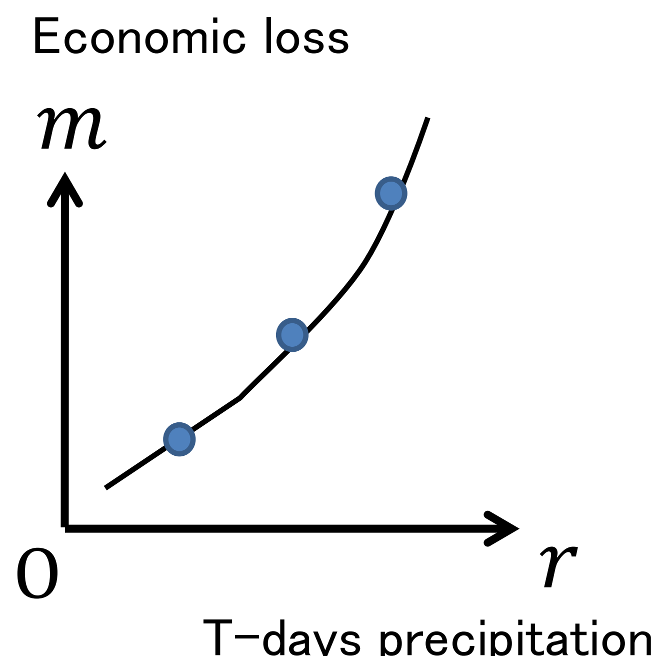


Economic loss due to inundation, which is estimated from a spatial distribution of maximum water depth.

Calculation procedure for flood risk curve

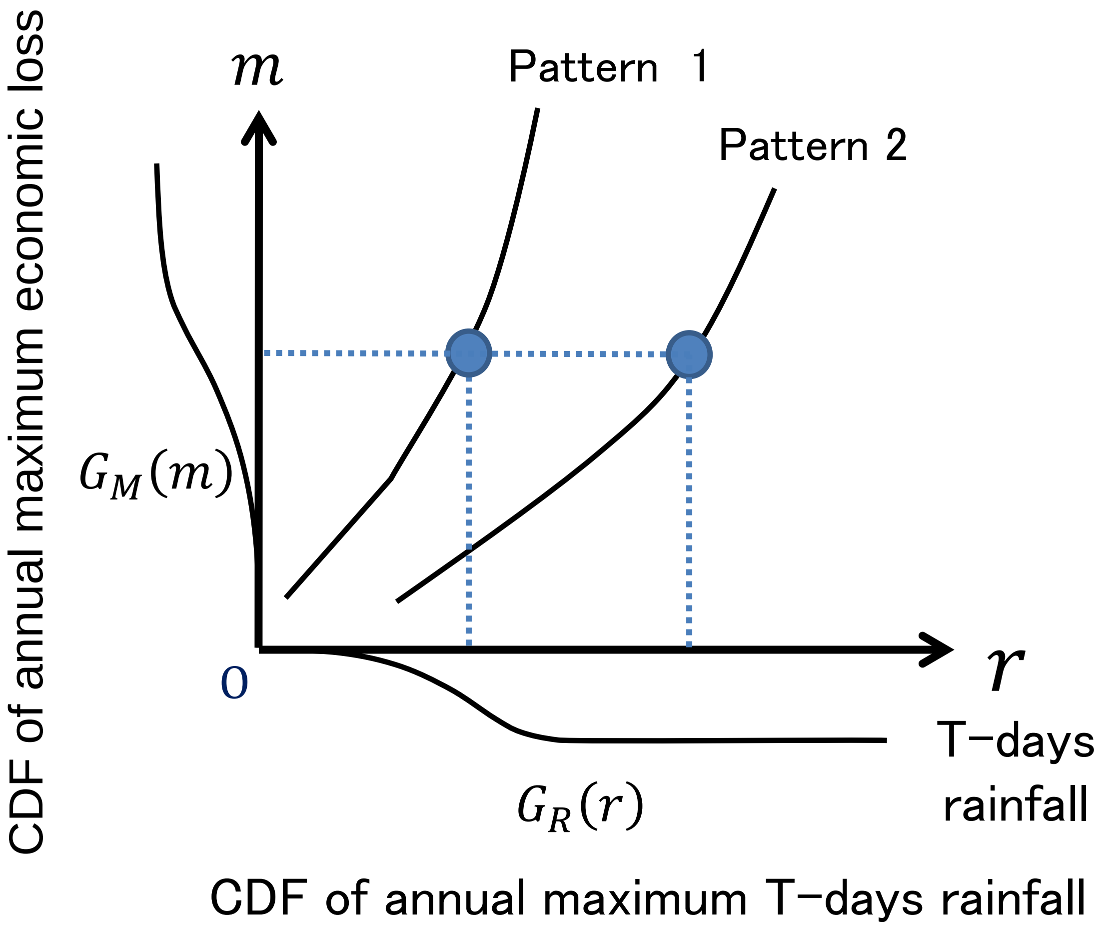
1. Prepare *N* rainfall events, which include typical time and space rainfall distributions for the study area.
2. Define a dominant rainfall duration for flood peaks, e.g. 24 hours for the study area.
3. Generate a rainfall time series with multiplying the original time series by a constant value.
4. Calculate runoff and inundation using a rainfall-runoff model and inundation model giving the generated rainfall series.
5. Estimate economic loss due to the flood.

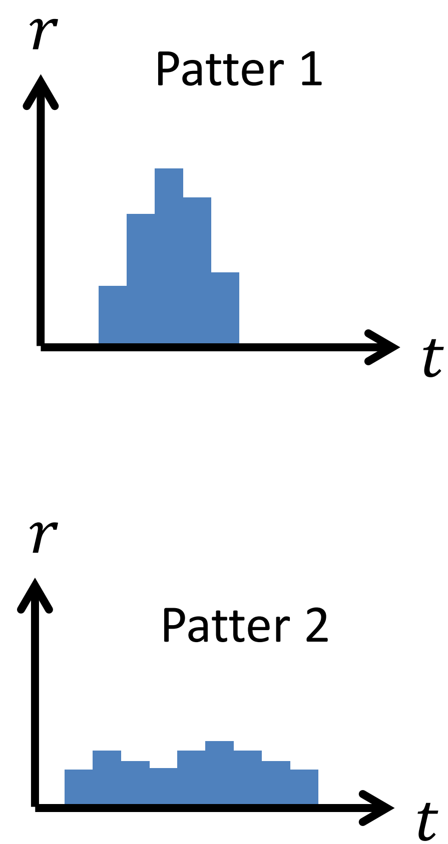




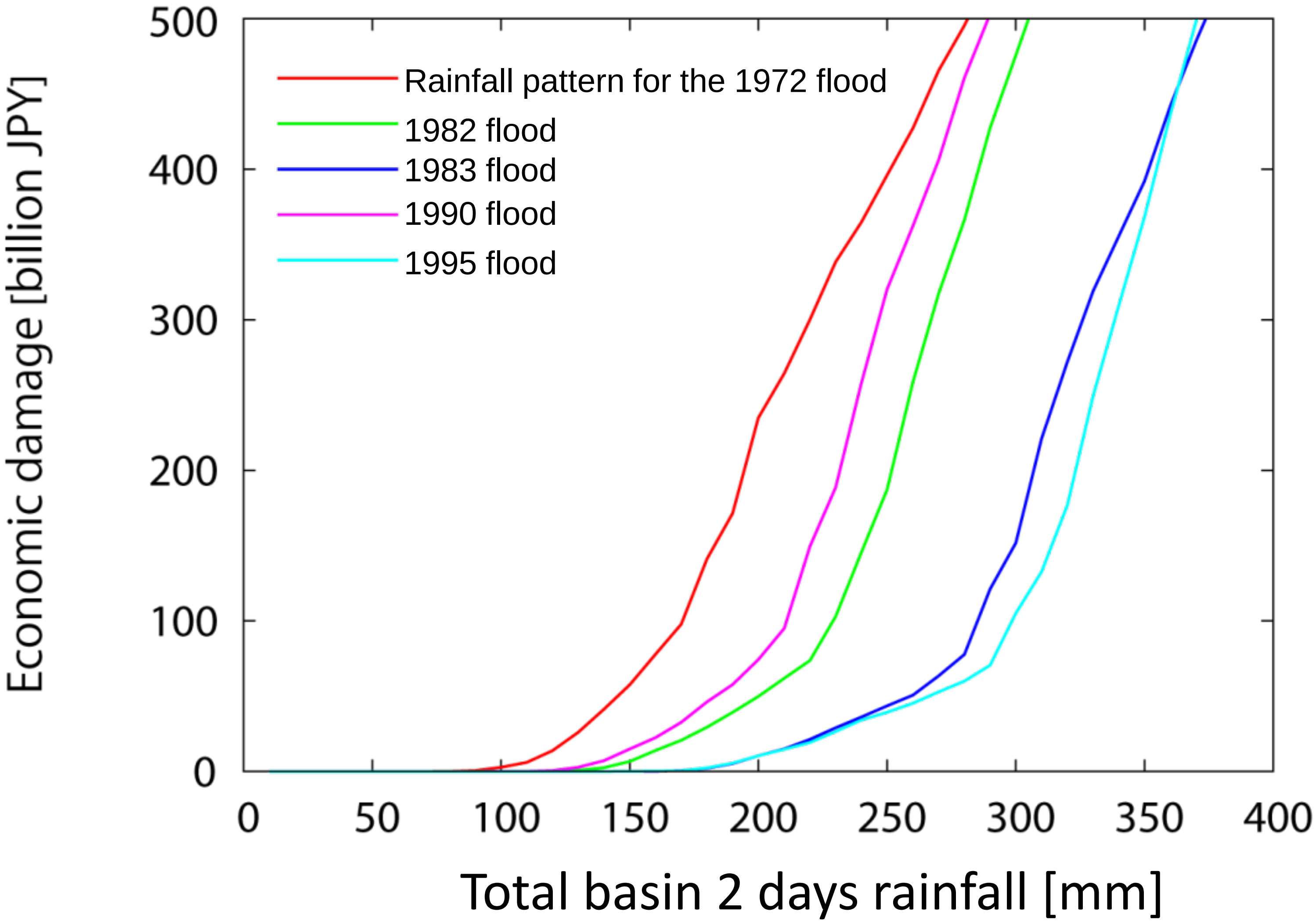
Calculation procedure for flood risk curve

Economic loss due to various rainfall patterns





2-day rainfall - economic loss relationships



Derivation of flood risk curve

$$F_M(m) = \prod_{i=1}^{N} F_{R_\mathrm{a}}(r_{\mathrm{a},i}(m))^{p_i} \simeq \sum_{i=1}^{N} p_i F_{R_\mathrm{a}}(r_{\mathrm{a},i}(m))$$

m : Economic loss

$F_M(m)$: CDF of annual maximum economic loss m due to flood inundation.

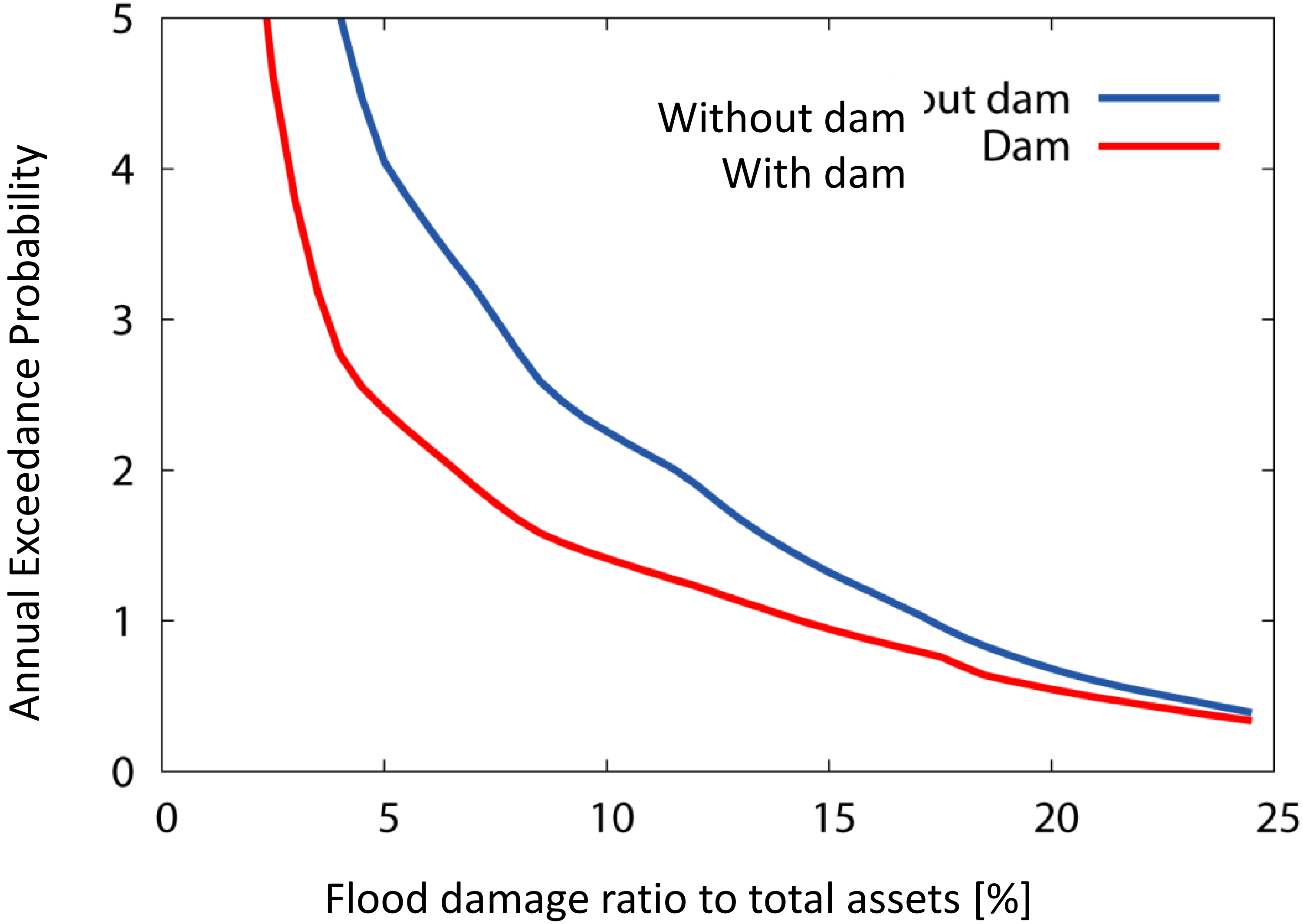
$F_{Ra}(r)$: CDF of annual maximum T-day rainfall.

$r_{a,i}(m)$: T-day rainfall amount that causes economic loss m for the rainfall pattern i.

N : Total number of rainfall patterns.

p_i : Probability of event occurrence for the i-th rainfall pattern.

Flood risk curves with/without dam operation



Quantitative flood risk assessment using risk curve

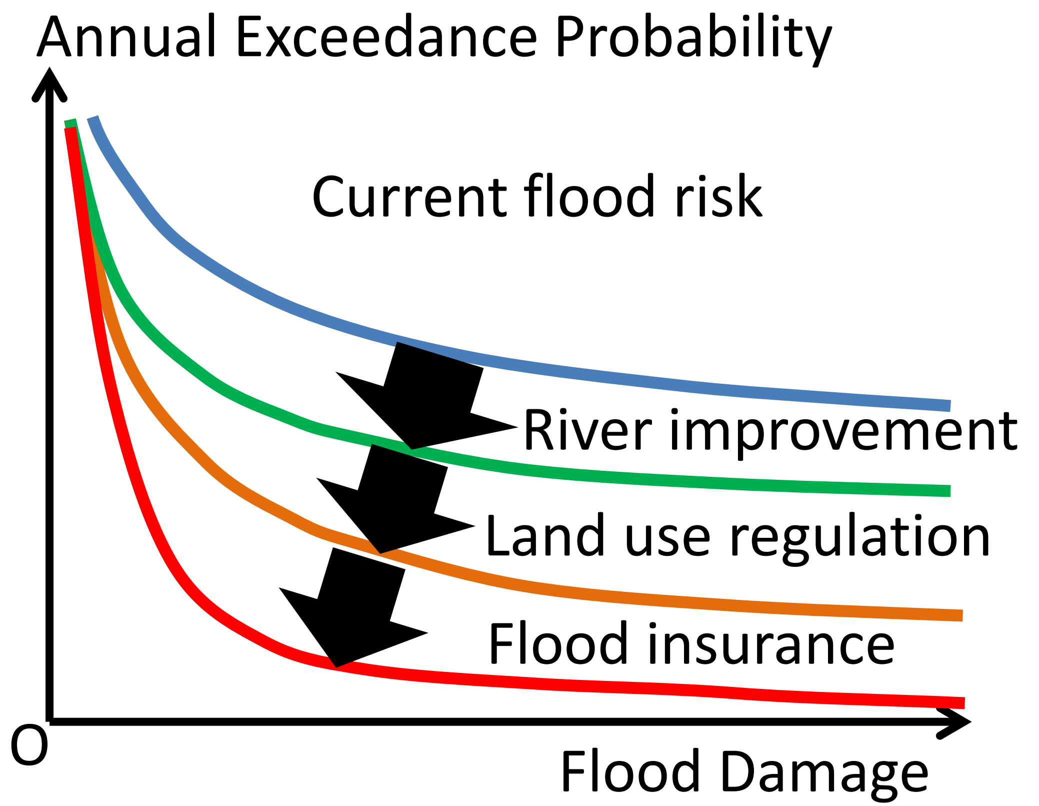
<u>Risk</u> = **<u>Probability of hazard</u>** X **<u>Associated damage</u>**

(Magnitude X Probability) (Exposure X Vulnerability)

Flood Risk Curve (FRC)

<u>=Annual exceedance probability of various flood damages:</u>

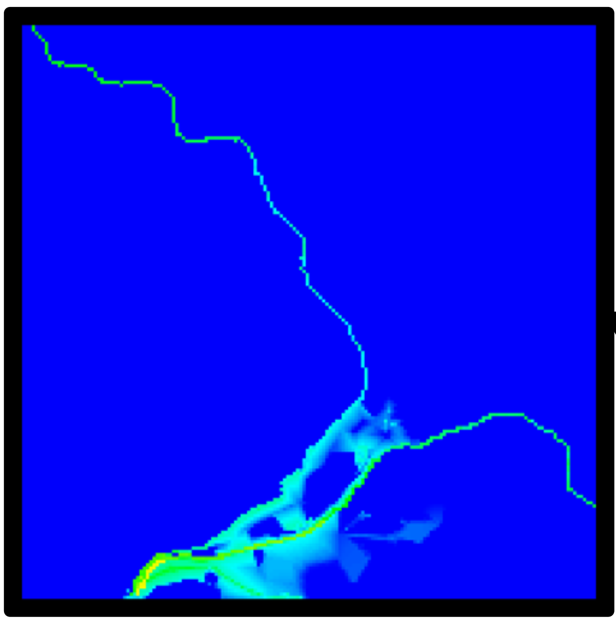
- Quantifies the current risk in the target area
- Describes the effect of various types of countermeasures
- Supports decision-making on risk management planning

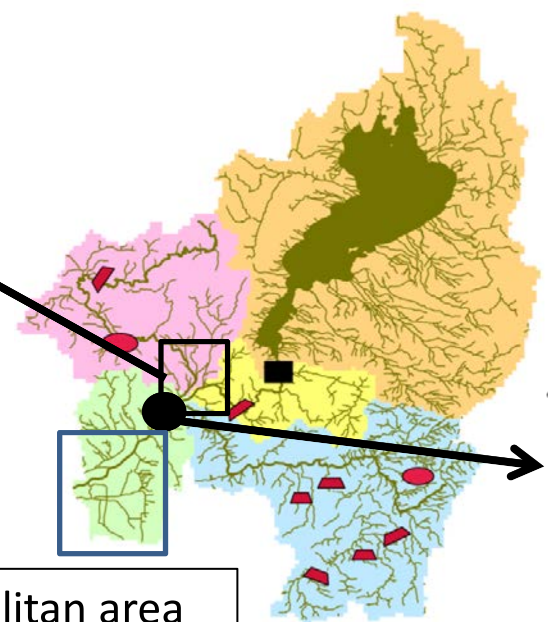


Application to the Yodo River basin, in Japan

Flood-inundation model
in the Kyoto City area

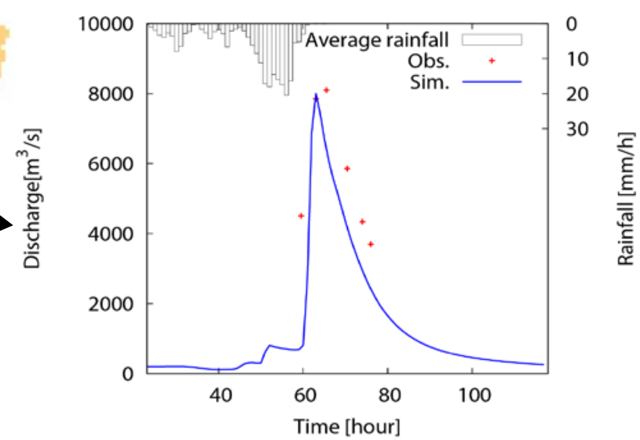
$$F_Q(Q) = \exp\left[\mu\Delta t \sum_{i=1}^{N} \frac{1}{N}\left(1 - G_{R|D}(\boldsymbol{r_i}(\boldsymbol{Q})|d_i)\right)\right]$$





Osaka Metropolitan area

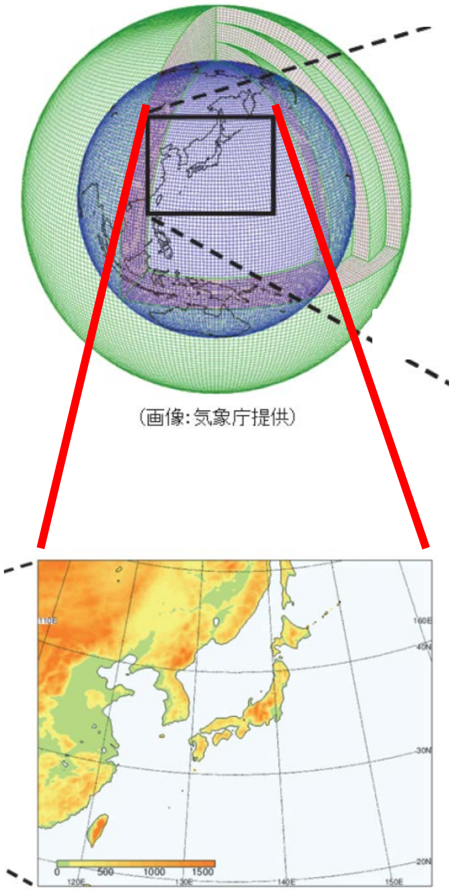
Validation of 1K-DHM
(Rainfall-runoff model)
at the Hirakata Station



Yodo River basin (8,240 km^2)

A new opportunity for extreme hydrologic prediction research using the database for Policy Decision making for Future climate change (d4PDF)

database for Policy Decision making for Future climate change (d4PDF)



MRI-AGCM 3.2H, 60km spatial resolution

■ Present Climate Experiments:
100 ensembles of 60 years climate simulation under different boundary conditions, which provides 6,000 years hydrologic time series data.

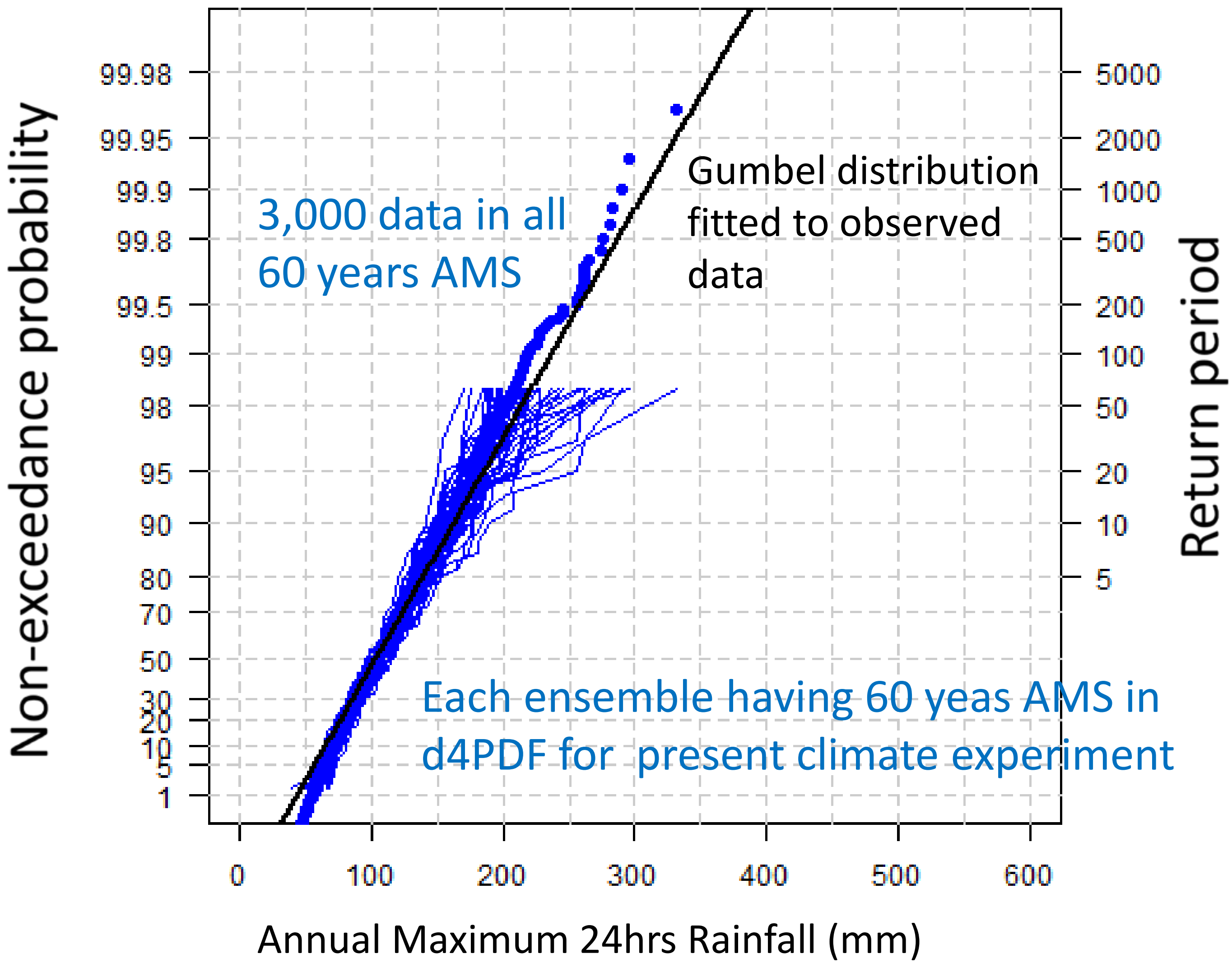
■ The End of 21st Century Climate Experiments (4 degree increase):
90 ensembles of 60 years climate simulation under different initial and boundary conditions, which provides 5,400 years hydrologic time series data.

MRI-NHRCM, 20km spatial resolution

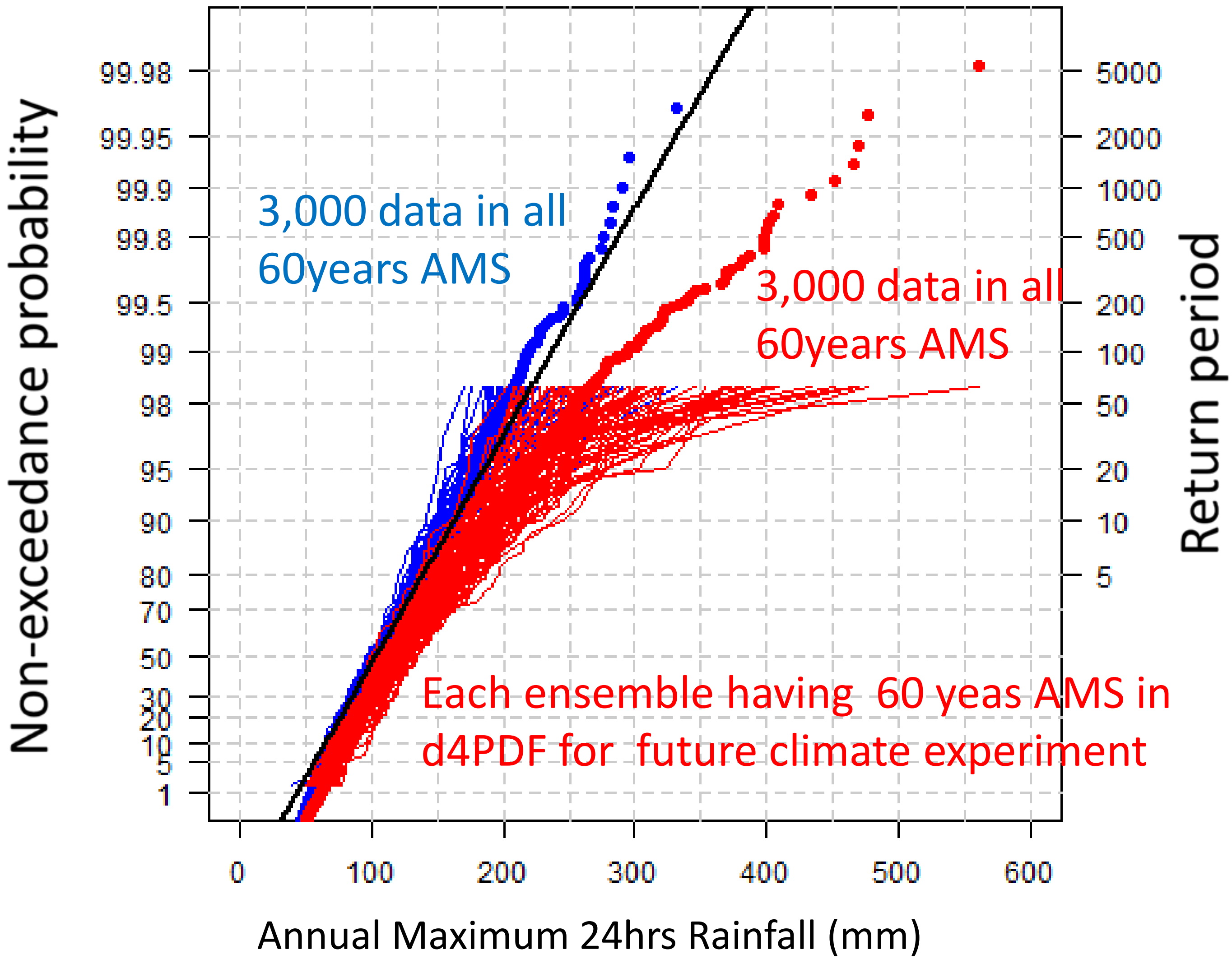
■ Present Climate Experiments:
50 ensembles of 60 years climate simulation under different boundary conditions, which provides 3,000 years hydrologic time series data.

■ The End of 21st Century Climate Experiments (4 degree increase):
90 ensembles of 60 years climate simulation under different initial and boundary conditions, which provides 5,400 years hydrologic time series data.

Probability Plot for Annual Maximum 24hrs Catchment Mean Rainfall at Yodo River Basin



Probability Plot for Annual Maximum 24hrs Catchment Mean Rainfall at Yodo River Basin



Change of hazard and risk under global warming
Flood and Inundation

1. Probabilistic analysis to evaluate a change of extreme rainfall and flood characteristics using a stationary and non-stationary hydrologic frequency analysis method;

2. Largest-class estimation of probable largest-class floods due to typhoons; and

3. Flood risk analysis using a risk curve to evaluate economic loss.

* flood risk curve: probabilistic distribution of annual maximum economic loss due to flood and inundation

Thank you very much for your attention