Flood risk assessment under a changing climate using a large ensemble climate data

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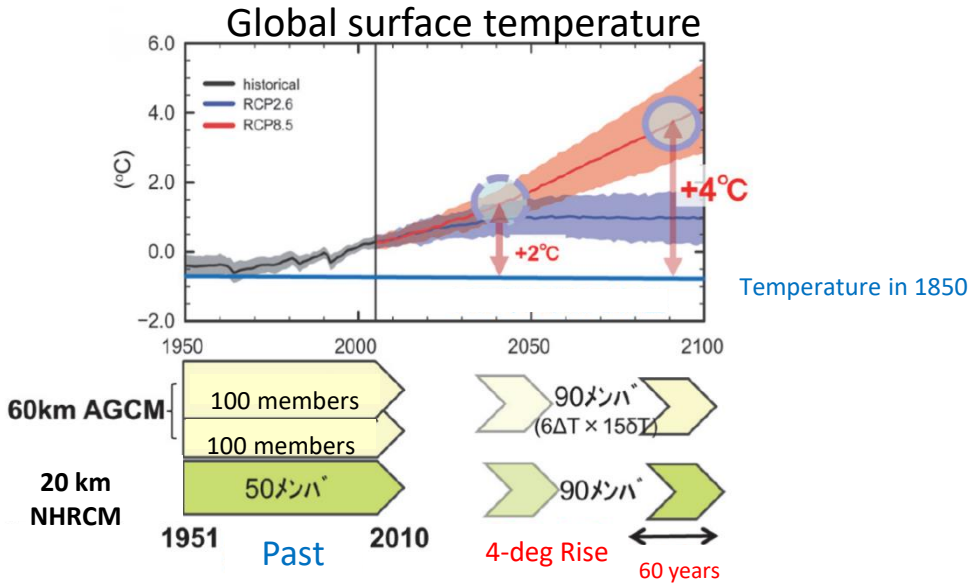
database for Policy Decision making for Future climate change (d4PDF)

Large ensemble of 20 km climate data around Japan (and 60 km over the world)



- Present Climate Experiments:
  100 ensembles × 60 years = 6,000 years hydrologic time series data.
- 4 Degree Increase Experiments:
  15 ensembles × 60 years × 6 future SST settings = 5,400years
  (= 900years times 6 SSTs) hydrologic time series data.

Mizuta et al. (2017, BAMS)
From d4PDF Users' manual
http://www.miroc-gcm.jp/~pub/d4PDF/index_en.html

Flood risk assessment using d4PDF

- Flood risk assessment
  →Statistical modelling of rainfall is needed
  - Frequencies of extreme events have high uncertainty
  - Combined events (e.g. pluvial/fluvial flooding) have larger uncertainty in frequencies

- d4PDF with large physical ensembles
  - Provides physically-based alternative of statistical modelling

Target area/phenomena for impact assessment

- How will these events be under the warmer world?

Extreme pluvial flooding in Nagoya, Japan

http://www.cbr.mlit.go.jp/shonai/tokai_gou_15yrs/photo_gallery/index.html

High dykes installed after devastating flood in 1971 in Hanoi, Vietnam

http://webun.jp/item/1089067

Presentation Topics

- Two case studies of flood risk assessment using d4PDF
  - Pluvial/Fluvial flood risk curve development in the Nagoya Metropolitan area, Japan

→ Compare different features at the present climate

  - Frequency analysis of extreme floods in Red River

→ Estimate frequency change of 1971 serious flood

Fluvial(River) v.s. pluvial(Rainfall) flooding

The Asahi Shinbun, 2019
https://webronza.asahi.com/politics/articles/2019101900002.html

BBC Japan, 2018
https://www.bbc.com/japanese/44761300

Kanagawa Shinbun
https://www.kanaloco.jp/article/entry-33628.html

Fluvial flooding is more focused than pluvial flooding in terms of devastating risk → How are they different actually?

Fluvial flooding

Pluvial flooding

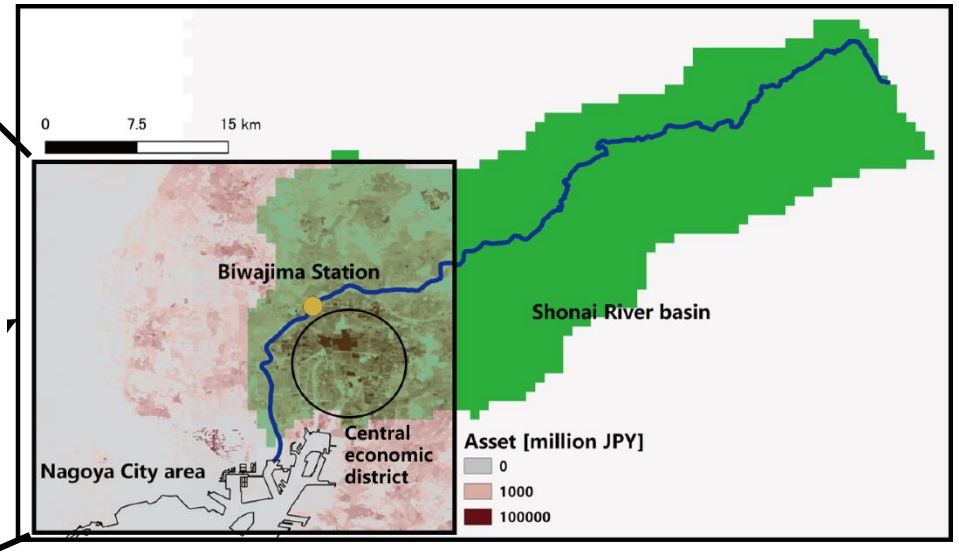
Study area: Nagoya City (in Shonai River basin)

- Area: 1010 [km^2]
- Population: 255.3 [million]
- Asset in floodplain area: 2.9 million USD
- Prone to pluvial flooding

Severe rain storm flood in 2000

http://www.cbr.mlit.go.jp/shonai/tokai_gou_15yrs/photo_gallery/index.html

Fluvial flood risk by Shonai River



Pluvial flood risk in low-lying area

Algorithm of pluvial/fluvial flood model

- River flow/Flood propagation are based on the local inertial equations (Bates et al., JoH, 2010)
- Infiltration rate is set from drainage pump discharge per drainage area

River module

Overflow

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q_{\mathrm{runoff}}-q_{\mathrm{o}}$$

$$\frac{\partial Q}{\partial t}+gA\frac{\partial h}{\partial x}+g\frac{n^2Q|Q|}{AR^{4/3}}=0$$

Floodplain module

Overflow

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=\max(r-i_{\mathrm{f}},0)+q_{\mathrm{o}}$$

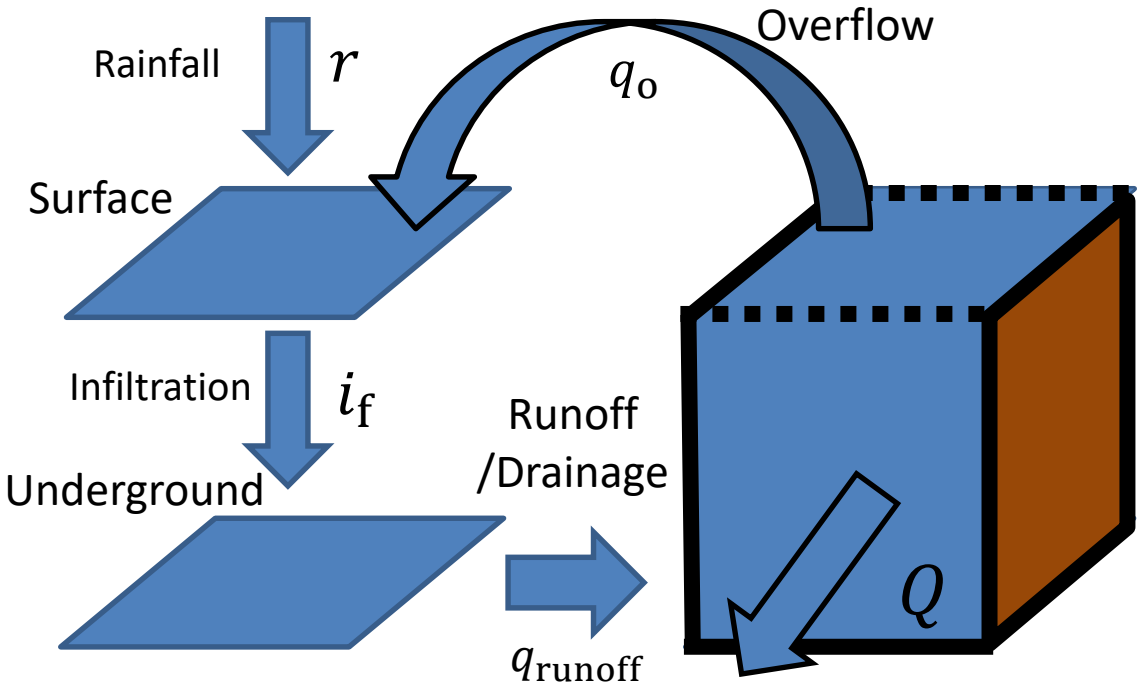
$$\frac{\partial q_x}{\partial t}+gh\frac{\partial h}{\partial x}+g\frac{n^2q_x|q_x|}{h^{7/3}}=0$$

$$\frac{\partial q_x}{\partial t}+gh\frac{\partial h}{\partial x}+g\frac{n^2q_x|q_x|}{h^{7/3}}=0$$

Sewage module

$$\frac{\partial h_{\mathrm{runoff}}}{\partial t}+\frac{\partial q_{\mathrm{runoff}}}{\partial x}=i_{\mathrm{f}}$$

$$q_{\mathrm{runoff}}=\alpha {h_{\mathrm{runoff}}}^{m}$$



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River module

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_{\mathrm{runoff}} - q_{\mathrm{o}}$$

$$\frac{\partial Q}{\partial t} + gA\frac{\partial h}{\partial x} + g\frac{n^2 Q|Q|}{AR^{4/3}} = 0$$

Floodplain module

Pluvial flood

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = \max(r - i_{\mathrm{f}}, 0) + q_{\mathrm{o}}$$

$$\frac{\partial q_x}{\partial t} + gh\frac{\partial h}{\partial x} + g\frac{n^2 q_x|q_x|}{h^{7/3}} = 0$$

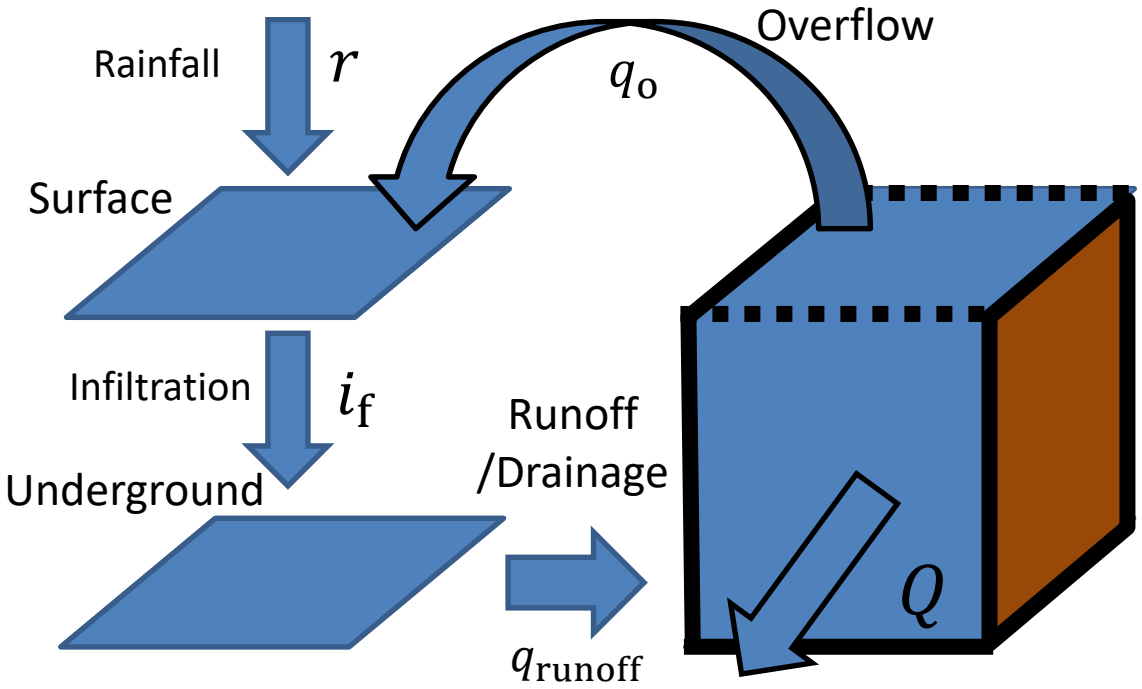
$$\frac{\partial q_x}{\partial t} + gh\frac{\partial h}{\partial x} + g\frac{n^2 q_x|q_x|}{h^{7/3}} = 0$$

Sewage module

Infiltration

$$\frac{\partial h_{\mathrm{runoff}}}{\partial t} + \frac{\partial q_{\mathrm{runoff}}}{\partial x} = i_{\mathrm{f}}$$

$$q_{\mathrm{runoff}} = \alpha h_{\mathrm{runoff}}{}^{m}$$



Algorithm of pluvial/fluvial flood model

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River module

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_{\mathrm{runoff}} - q_{\mathrm{o}}$$

Drainage

$$\frac{\partial Q}{\partial t} + gA\frac{\partial h}{\partial x} + g\frac{n^2 Q|Q|}{AR^{4/3}} = 0$$

Floodplain module

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = \max(r - i_{\mathrm{f}}, 0) + q_{\mathrm{o}}$$

$$\frac{\partial q_x}{\partial t} + gh\frac{\partial h}{\partial x} + g\frac{n^2 q_x|q_x|}{h^{7/3}} = 0$$

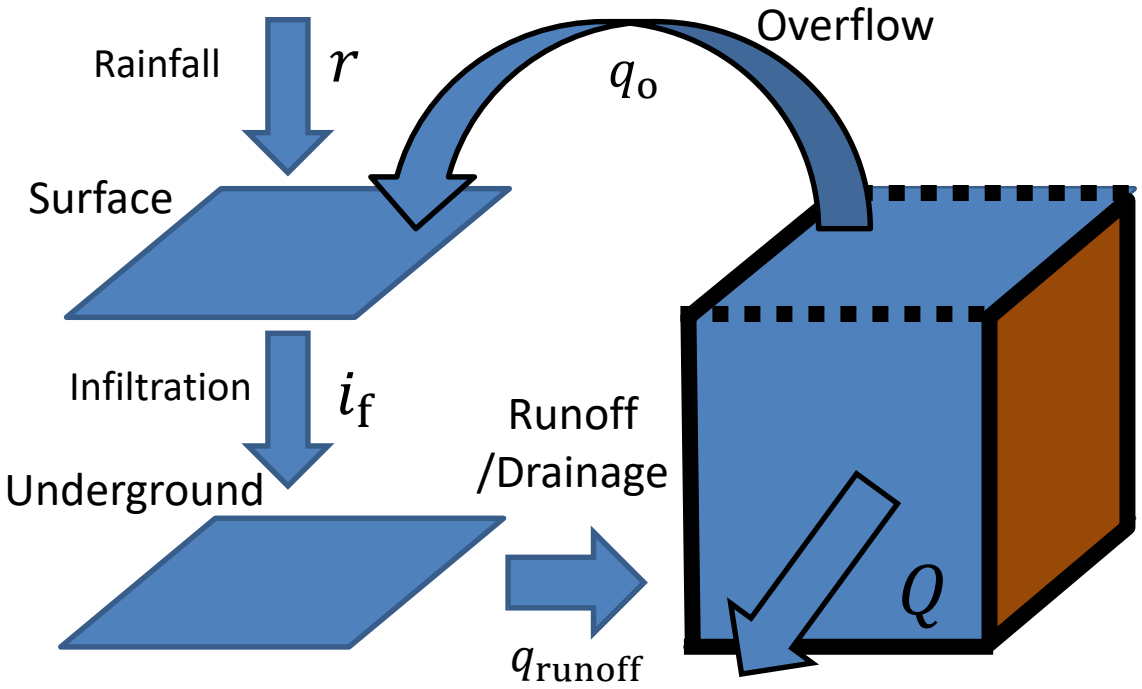
$$\frac{\partial q_x}{\partial t} + gh\frac{\partial h}{\partial x} + g\frac{n^2 q_x|q_x|}{h^{7/3}} = 0$$

Sewage module

$$\frac{\partial h_{\mathrm{runoff}}}{\partial t} + \frac{\partial q_{\mathrm{runoff}}}{\partial x} = i_{\mathrm{f}}$$

Drainage

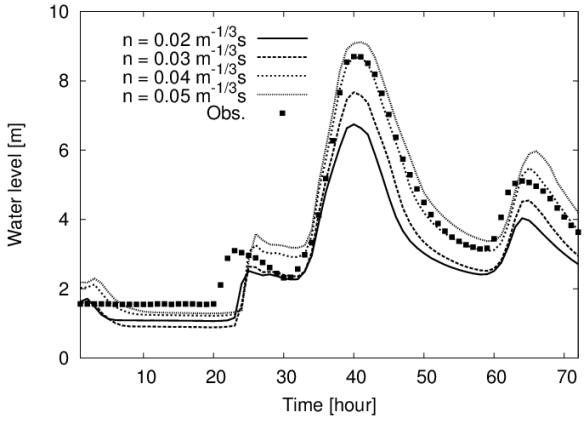
$$q_{\mathrm{runoff}} = \alpha {h_{\mathrm{runoff}}}^{m}$$



Validation of pluvial/fluvial flood model

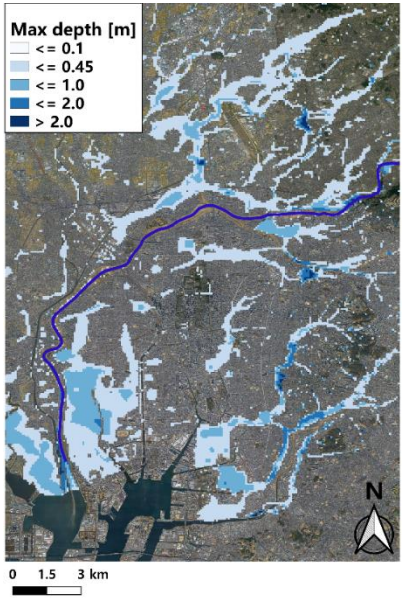
- River module was validated against the river water level on the Shonai River
- Floodplain module was validated for flood area in Tokai Heavy Rainfall

Water level simulated by
River module with different Manning's n

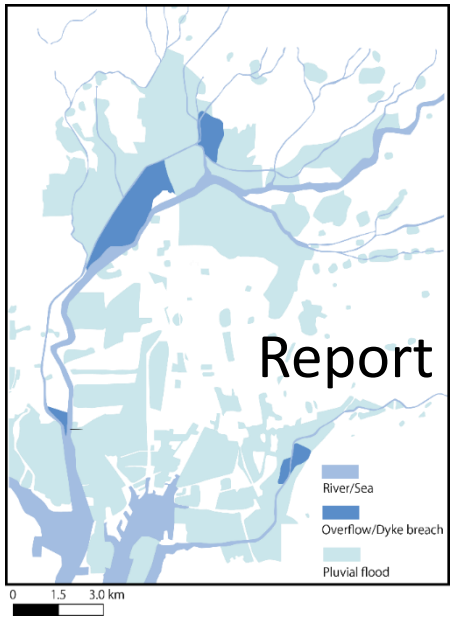


Pluvial flood area in Tokai Heavy Rainfall (2000)

Sim



Report



Flood damage validation

- Flood damage calculation
  - (Economic asset) X (damage ratio)
  - Damage ratio: function of max depth
    - House: Household: Office

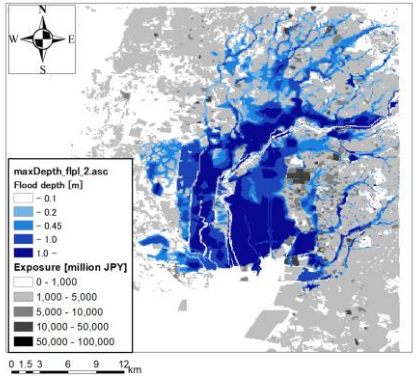
	Flooded houses (100 people)	Workers of flooded company (100 people)	Building/Household Damage (million USD)	Office Damage (million USD)	Total (million USD)
Sim	1,740	3,170	5,830 *including office	2,740	8,570
Survey*	656	3,546	1,850 *House only	3,300	5,150

* Flood damage survey for Aichi Prefecture by Fire and Disaster Management Agency, 2000.

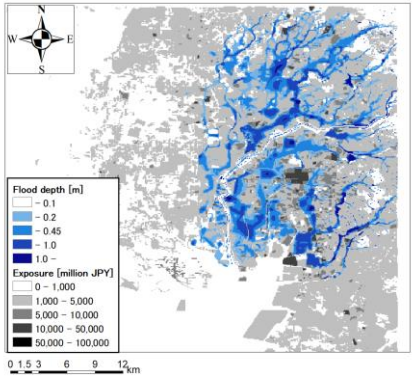
Approach to separating pluvial/fluvial flood depth

- Pluvial flood depth
  - Switch off river flow scheme
- Fluvial flood depth
  - Switch off drainage scheme? → Too much depth
  - $d_{\mathrm{Fmodel}} = d_{\mathrm{PFmodel}} - d_{\mathrm{Pmodel}}$

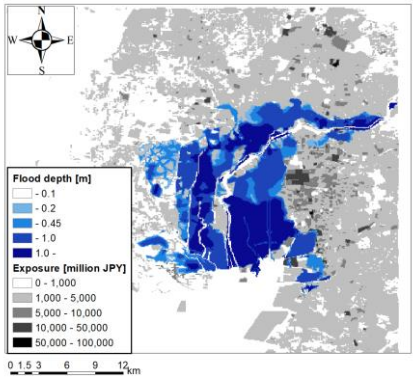
Max depth of FLPL Model



Max depth of PL Model



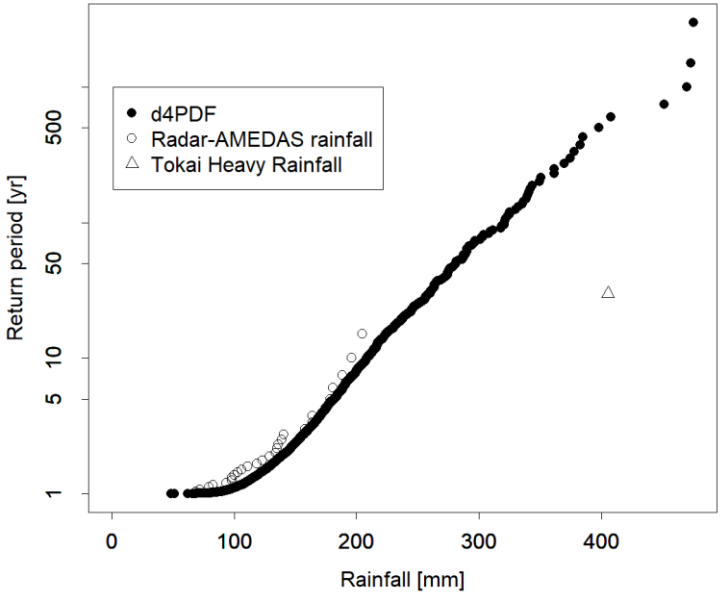
Max depth of FL Model



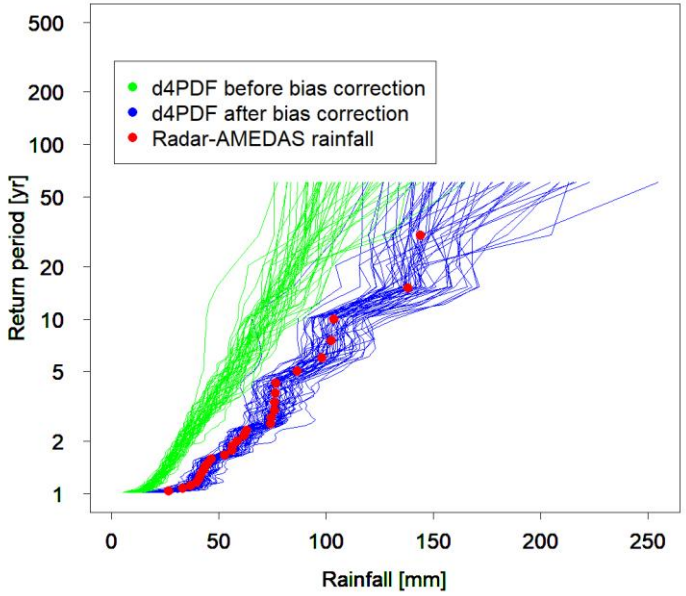
Bias identification of d4PDF rainfall - Large and Small space/time scales -

- Annual Max 24-hour basin rainfall: Not large bias → remained same
- Annual Max 3-hour Nagoya areal rainfall: Large bias → Bias corrected

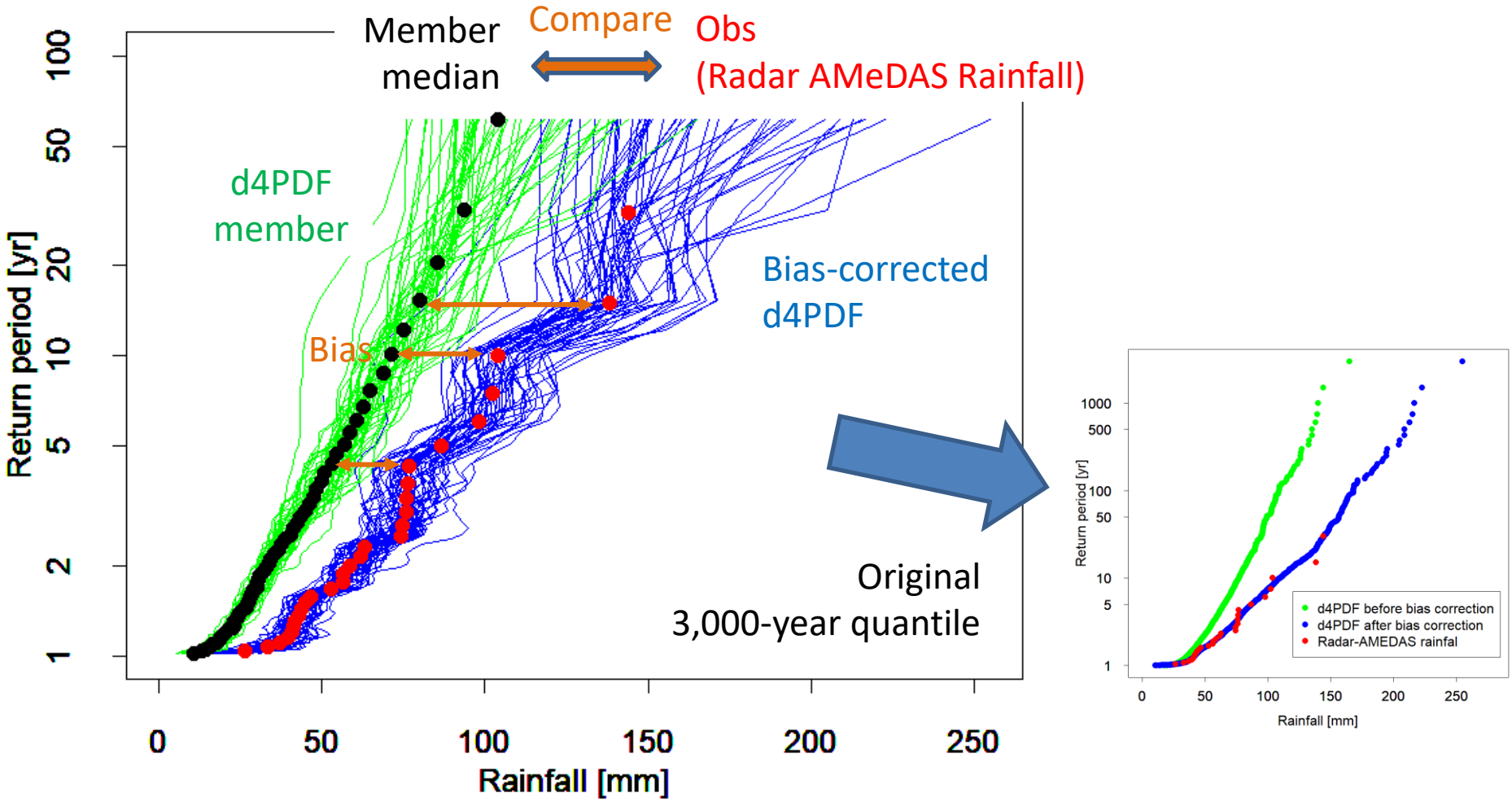
(For Fluvial flood)
Annual Max 24-hour basin rainfall



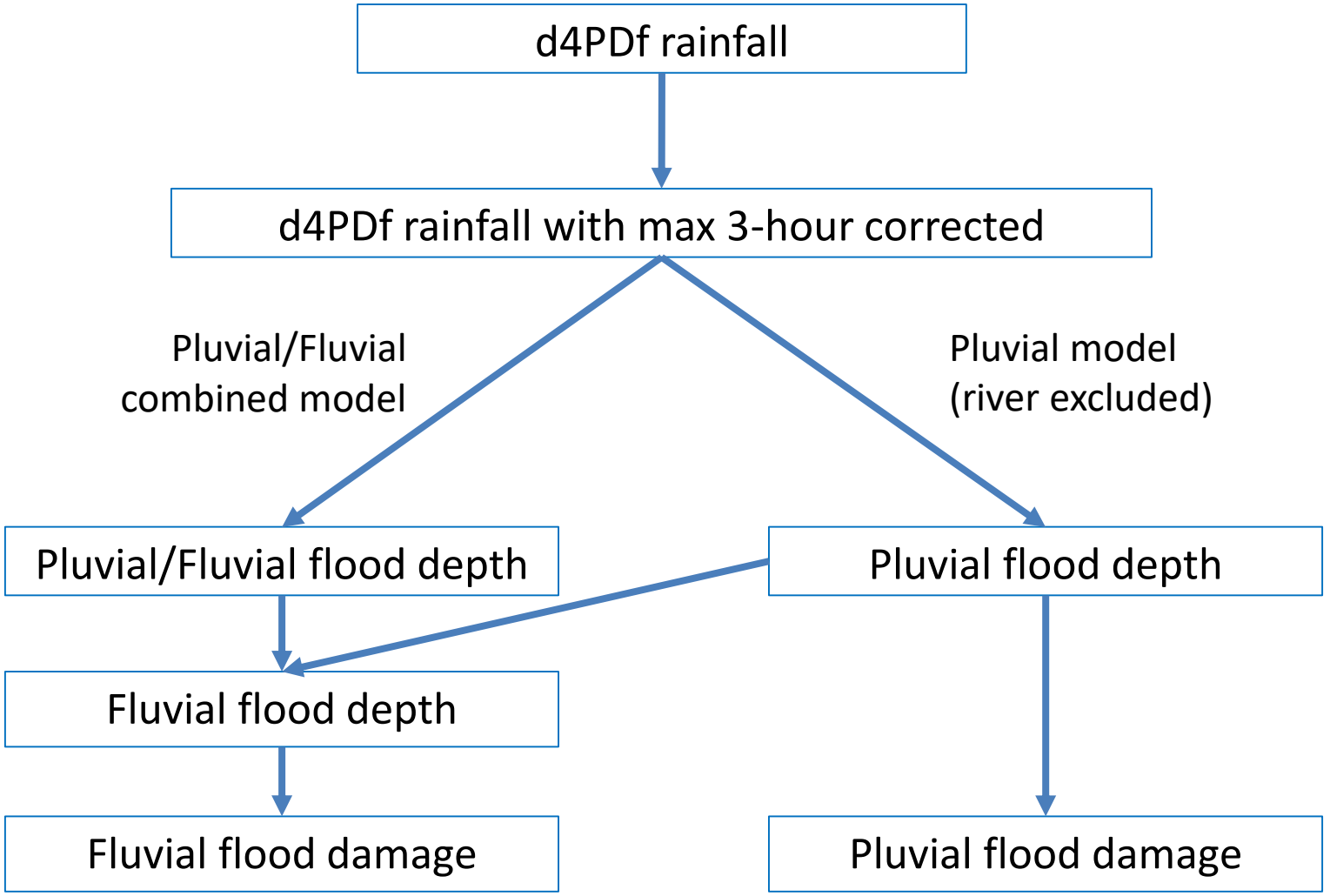
(For Pluvial flood)
Annual Max 3-hour Nagoya areal rainfall



Bias correction of annual max 3-hour Nagoya (small) areal rainfall for d4PDF

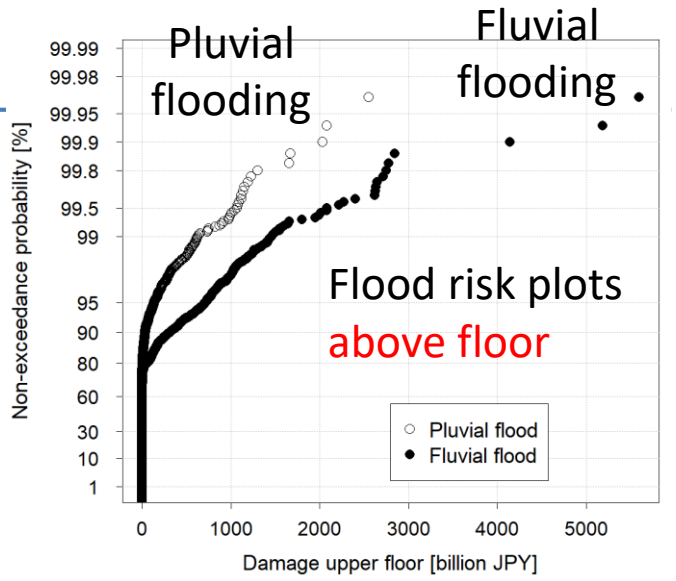


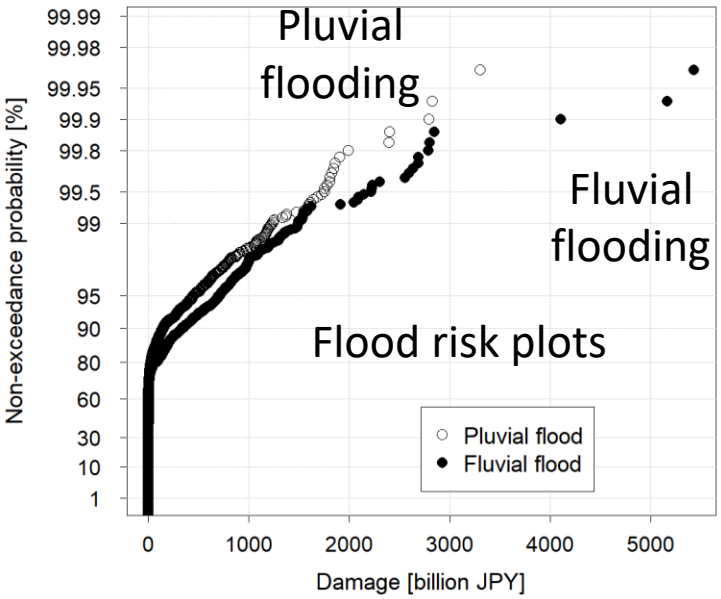
Simulation flowchart

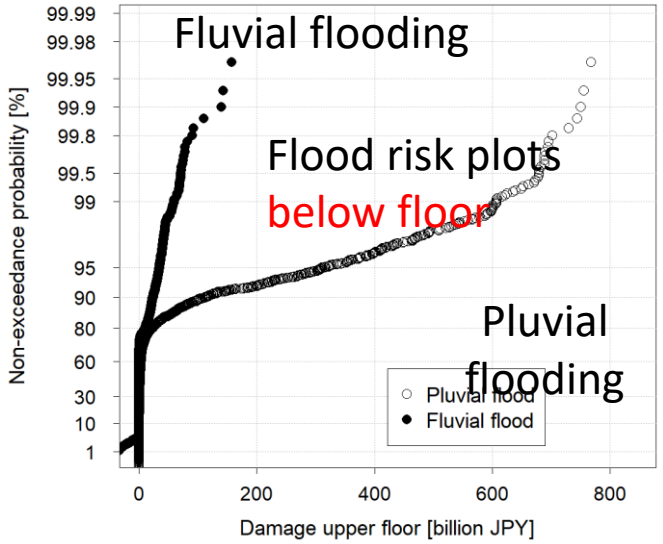


Pluvial/Fluvial flood risk curves in Nagoya City area

- Pluvial flood has similar economic risk as fluvial flood under around 100-year return period
- Large pluvial flood risk is caused by damage below the 1st floor of buildings
- Damage above floors is larger in fluvial flooding



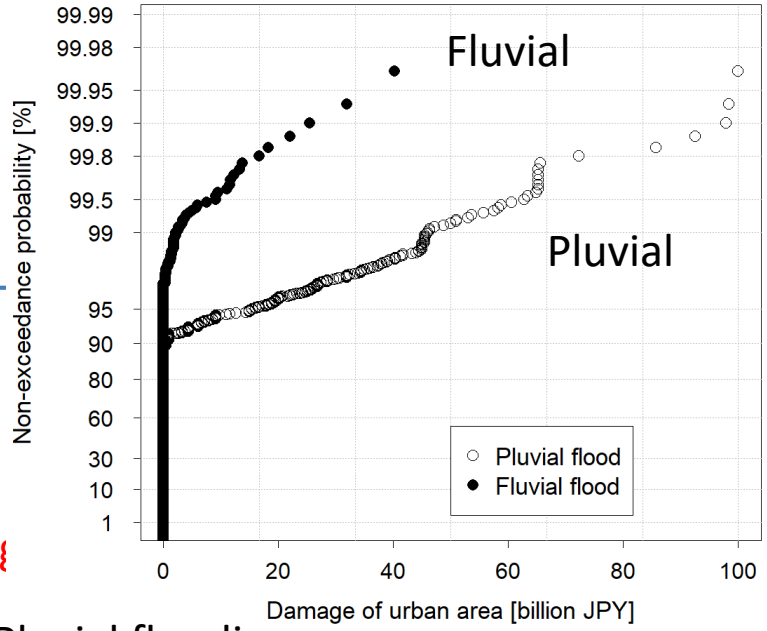




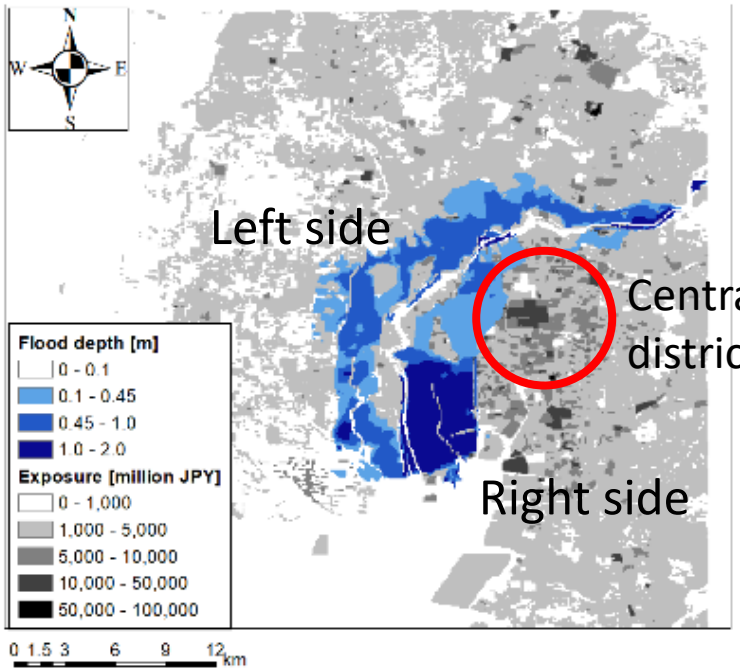
Pluvial flood risk is much higher than fluvial one in the central economic district

- City is around Nagoya Castle
  - Located in higher places
  - Dyke on right side is higher than left side

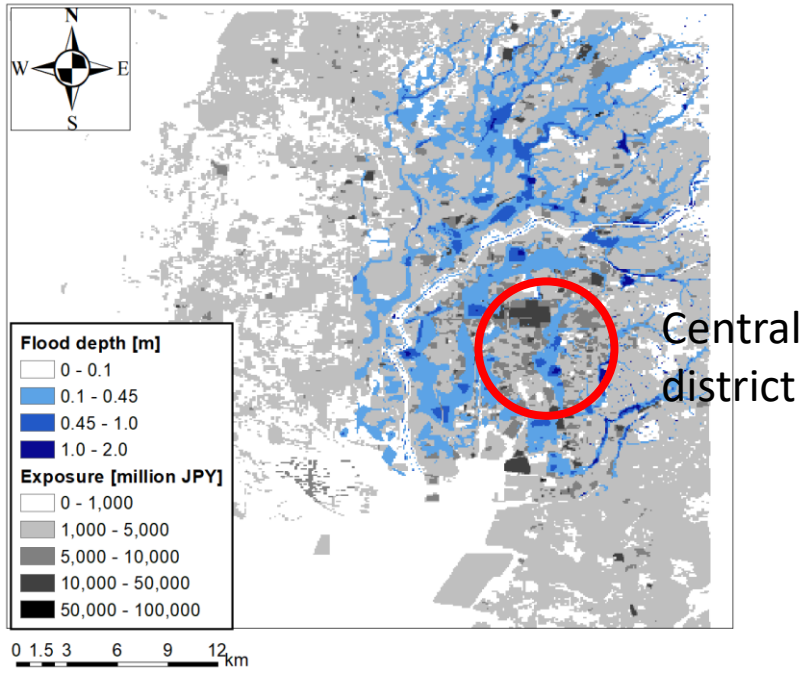
➢ Difference of topographic/economic characteristics are quantified as flood risk by using a large ensemble climate data



Fluvial flooding

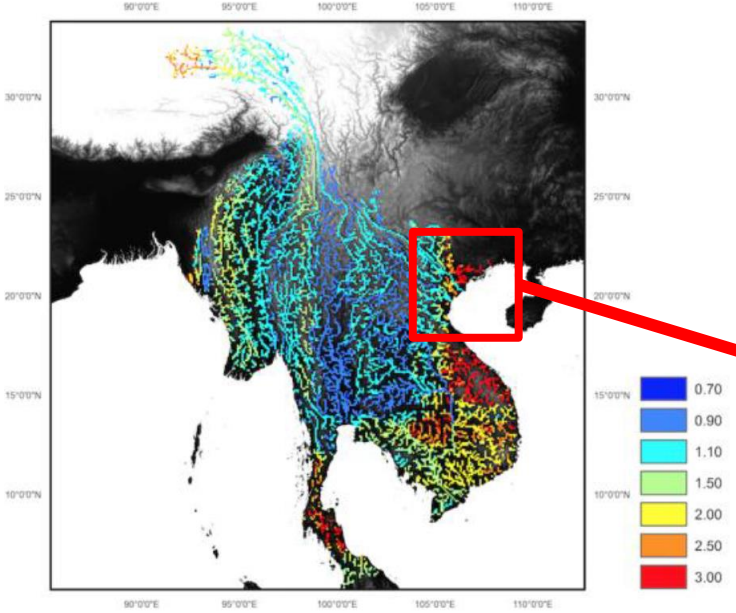


Pluvial flooding



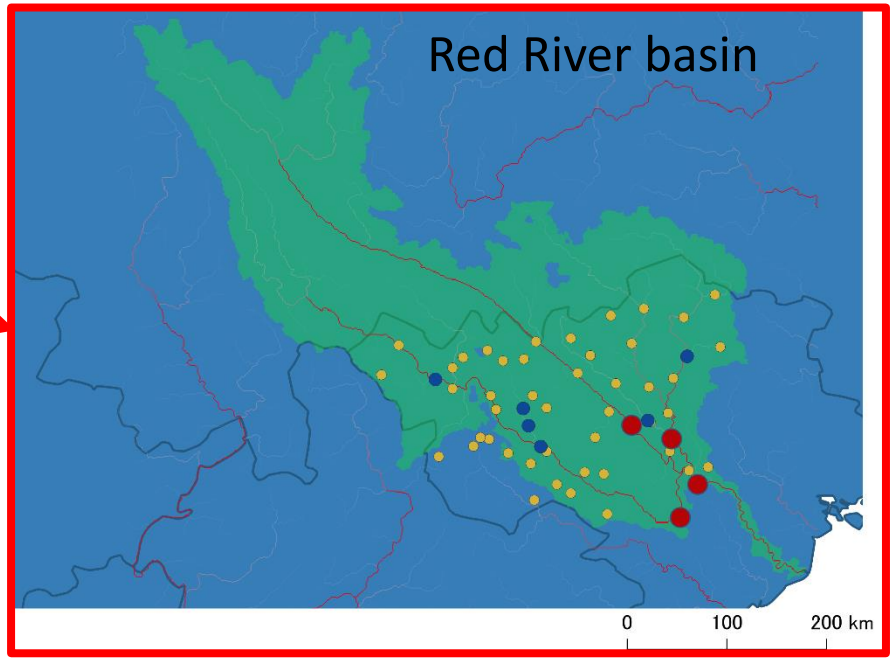
Future hotspots of flood risk in Indochina Peninsula

Ratio of future change in annual max discharge by MRI-AGCM based on SST in MRI-CGCM3 in d4PDF



Patinya et al., JSCE, 2017

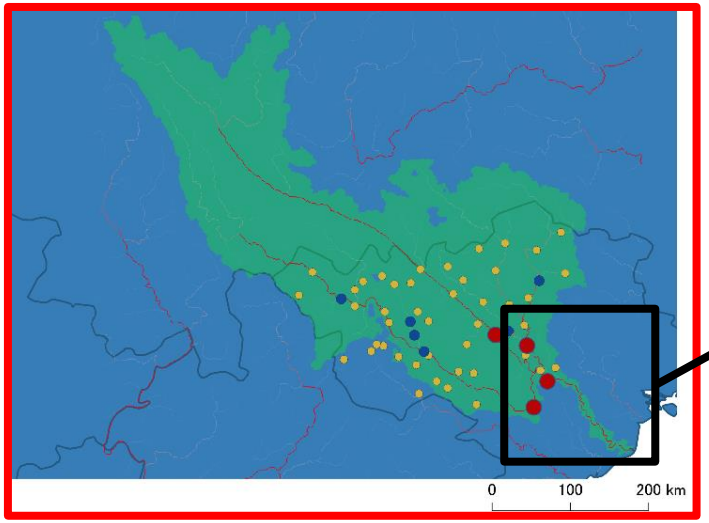
- ✓ Red River is one of hotspots of future flood risk change in Indochina Peninsula



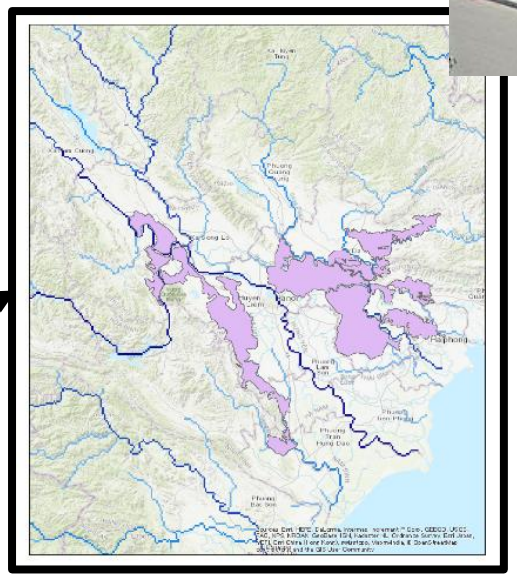
Flood characteristics in Red River basin

- ✓ Devastating flood occurred in 1971
- ✓ Large dams and high/long embankment
- ✓ No severer damage after 1971

http://webun.jp/item/1089067



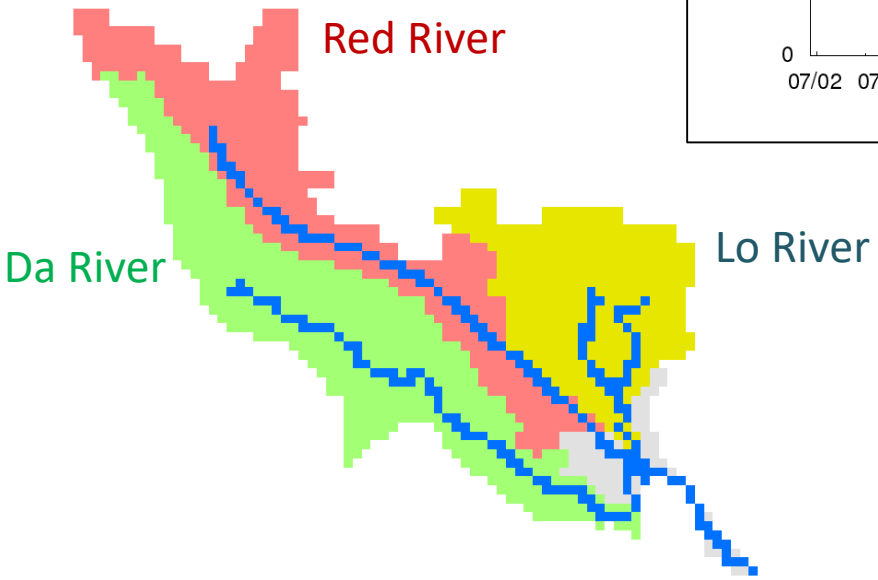
Large flood area in 1971 flood

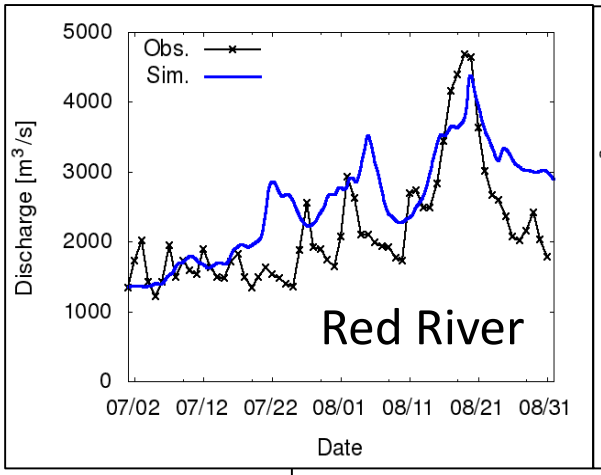


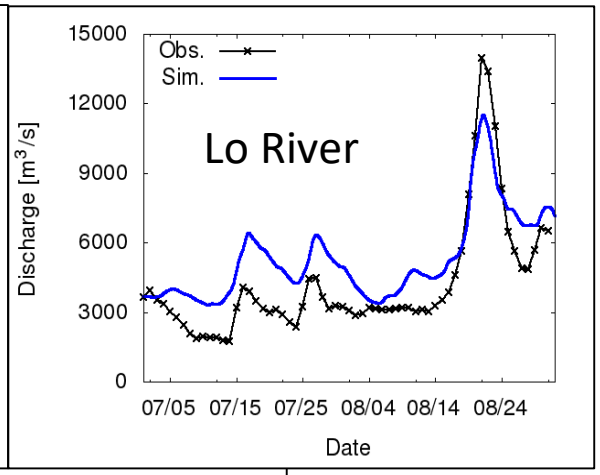
Embankment

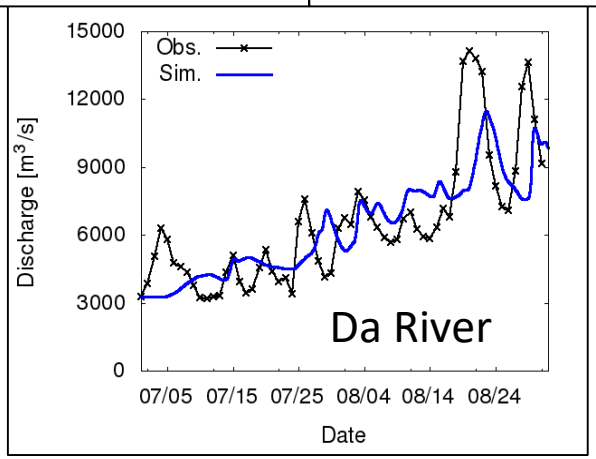
Calibration performance

- ✓ Calibrated on each river
- ✓ Results are satisfactory



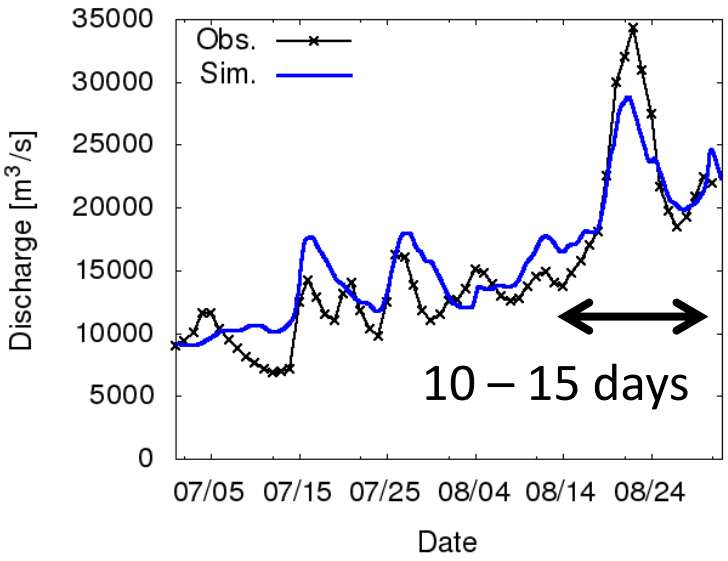


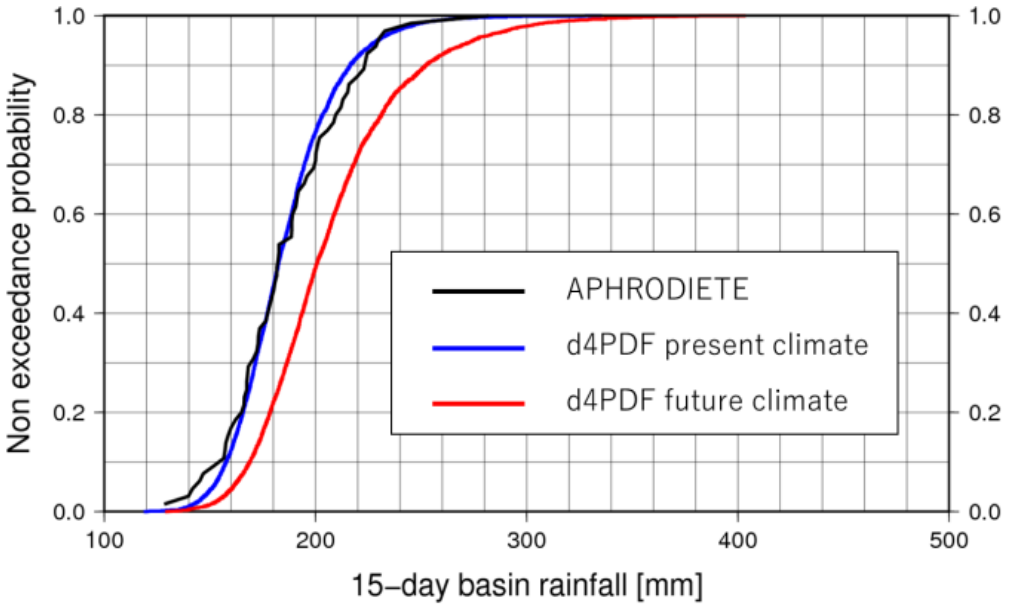




d4PDF rainfall data in Red River basin

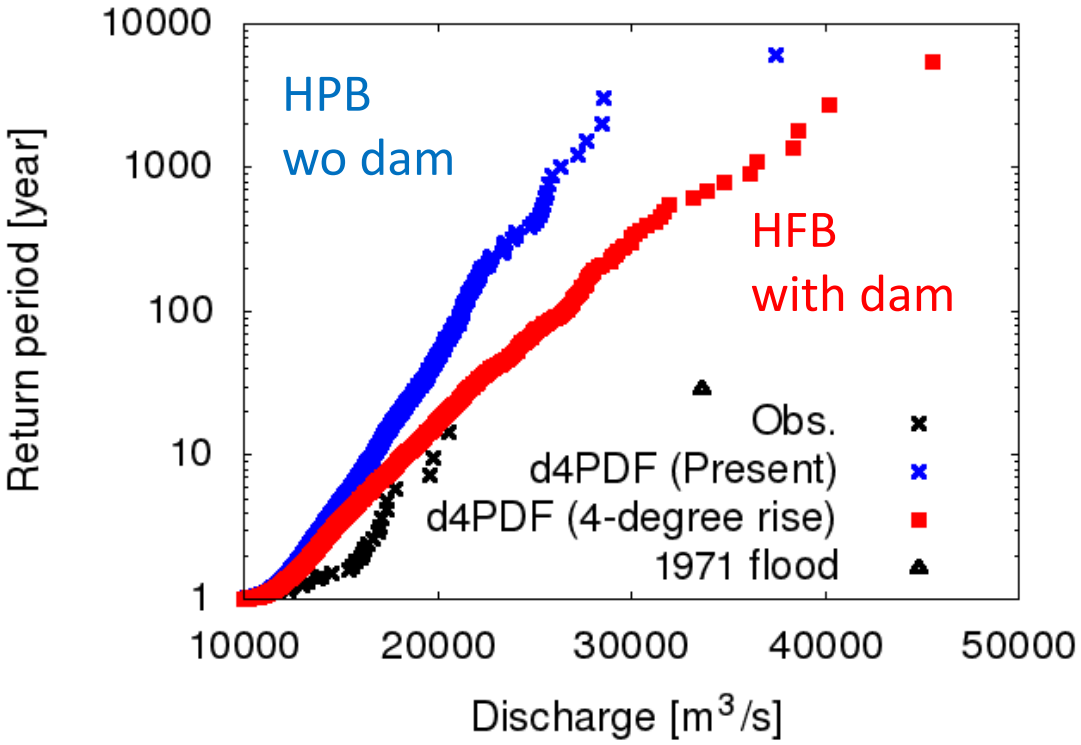
- ✓ Major flood period is around 15 days
- ✓ Annual max 15-day rainfall of present climate agree with APHRODITE
- ✓ Annual max 15-day rainfall will largely increase in future climate





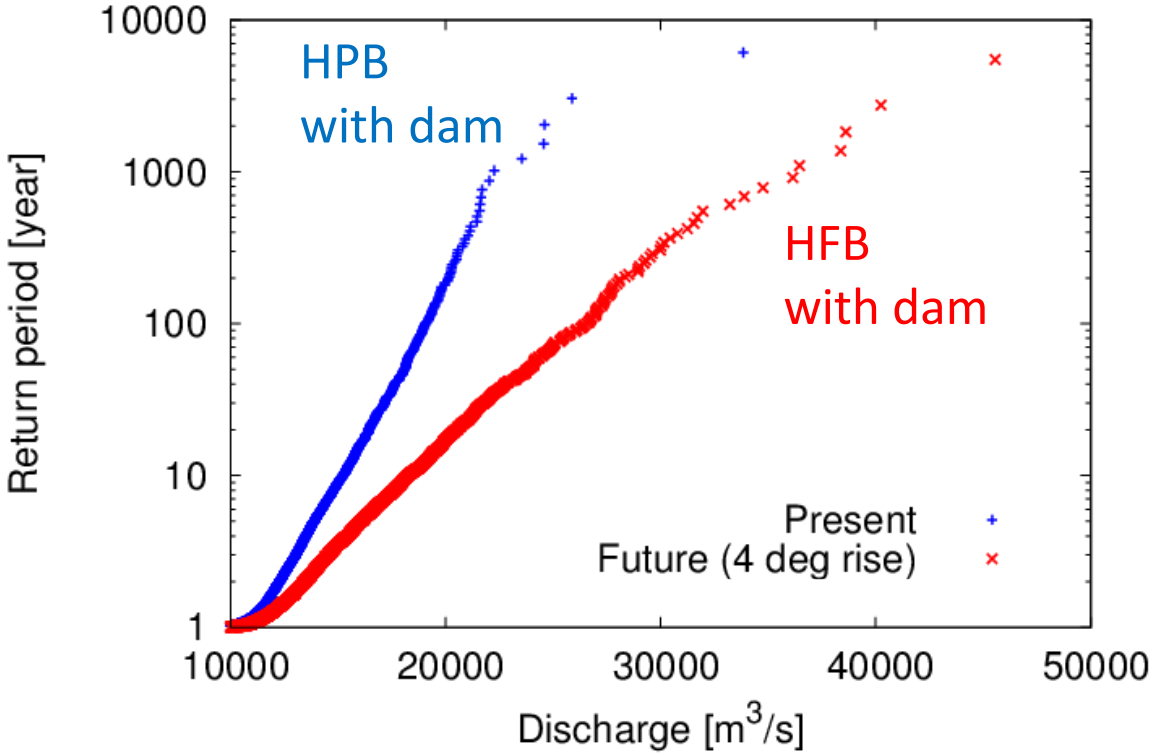
Flood frequency curves at Son Tay

- ✓ Huge ensemble data in d4PDF realized deriving flood frequency curves without parametric distribution



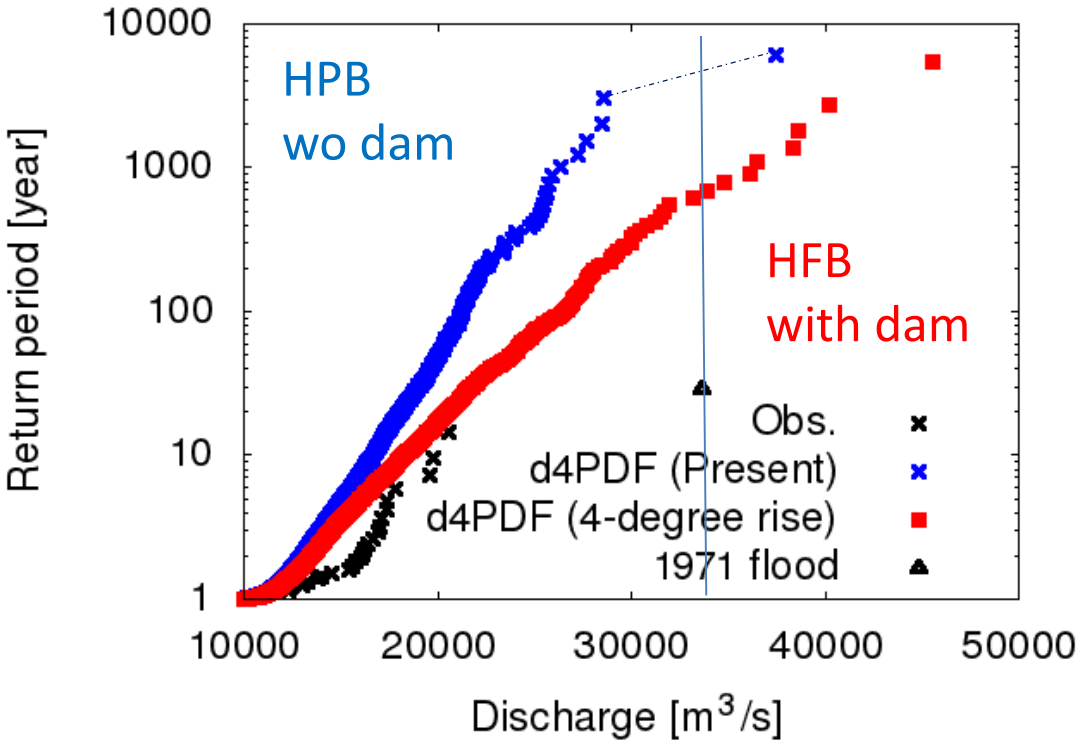
Future flood frequency change (with dam for both climates)

- ✓ Setting dam operation both in HPB and HFB, discharge clearly increases in 4 degree rise scenario (1.39 times at 100 years)



Return period of 1971 flood in present and future climates

- ✓ Return period of 1971 flood is over 1,000 years at present climate while around 700 years in future climate



Conclusions

- Pluvial/Fluvial flood risk in Metropolitan area
  - Pluvial flood has comparable risk as fluvial flooding
  - Metropolitan area has been protected by fluvial flooding but pluvial flood is expected
  - Qualitatively known facts are quantified as economic risk by using d4PDF

- Flood frequency analysis in Vietnam
  - The return period of the max historical record in 1971 corresponds to more than 1,000 years now
  - This event (used as design value) may happen at lower return period than 1,000 years under 4-degree rise scenario
  - Extreme flood frequencies were estimated using d4PDF

Acknowledgements

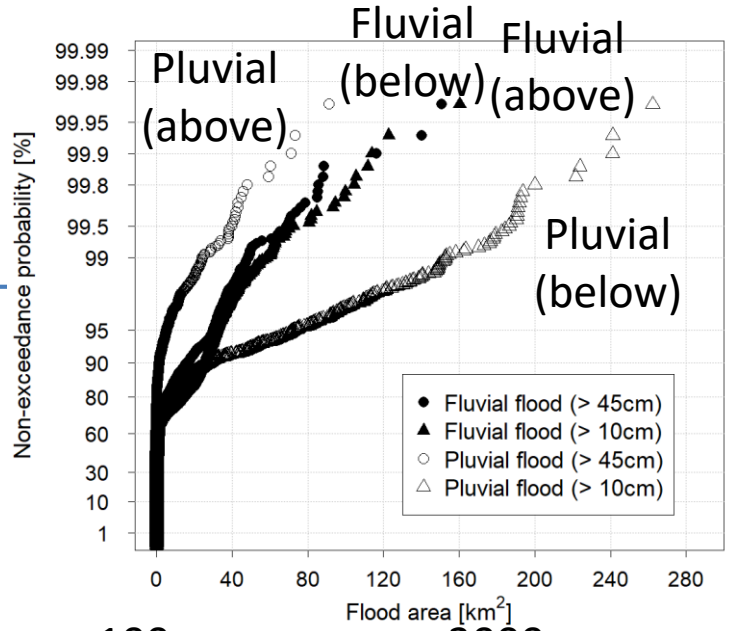
Research of pluvial and fluvial flood risk assessment was supported by JSPS KAKENHI Grant Numbers JP18K13837. River cross-section data were provided by Prof. Takeda at Chubu University. Drainage capacity data were provided by Nagoya City Waterworks & Sewage Bureau.

Research of flood frequency analysis in Red River was supported by Collaborative Research with Tokio Marine Research Institute. Observation data of rainfall and river discharge were provided by Thuyloi University, Vietnam

Thank you very much
for your kind attention!

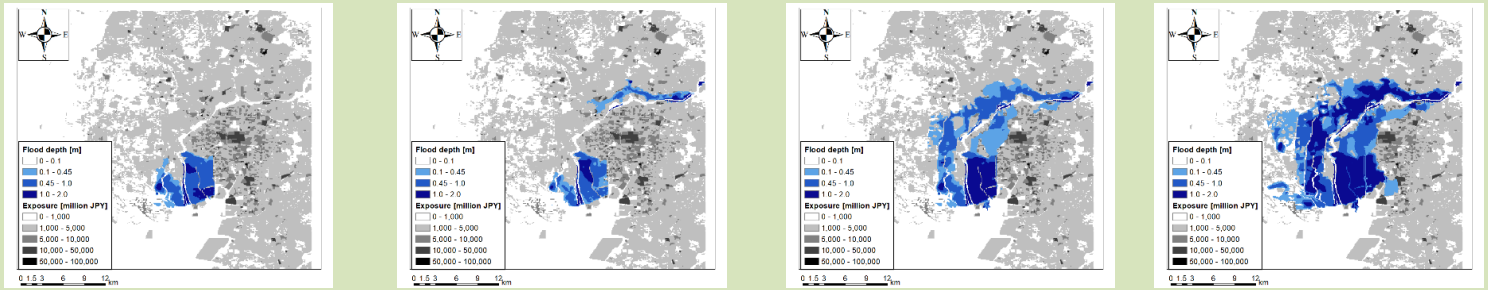
Inundation area characteristics

- Fluvial: below/above floor are equally flooded
- Pluvial: in most areas flood depth is below the 1st floor

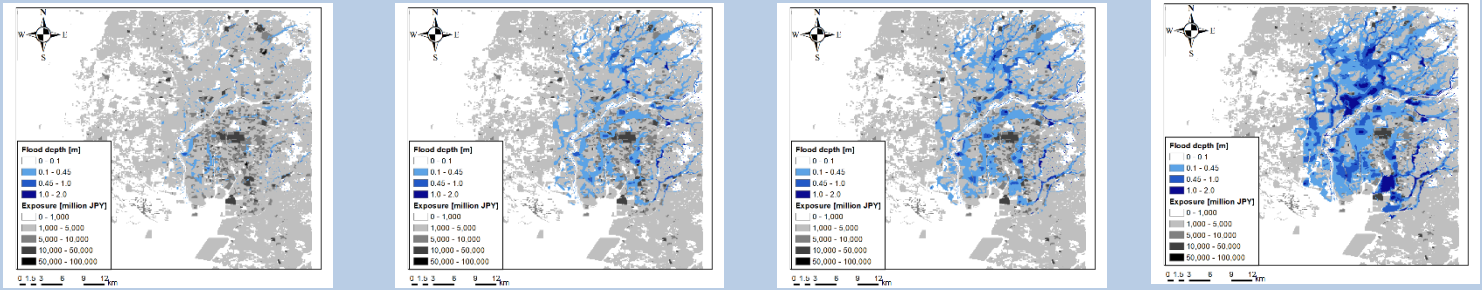


10 years | 50 years | 100 years | 3000 years

Fluvial flooding

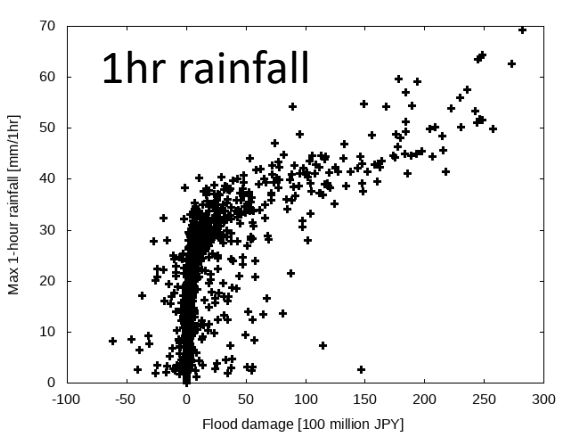


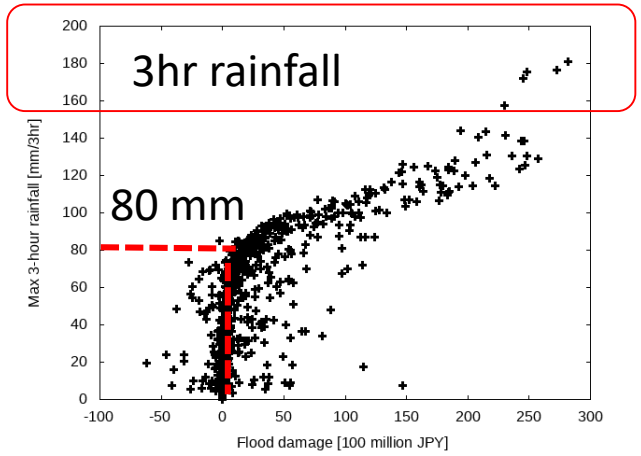
Pluvial flooding

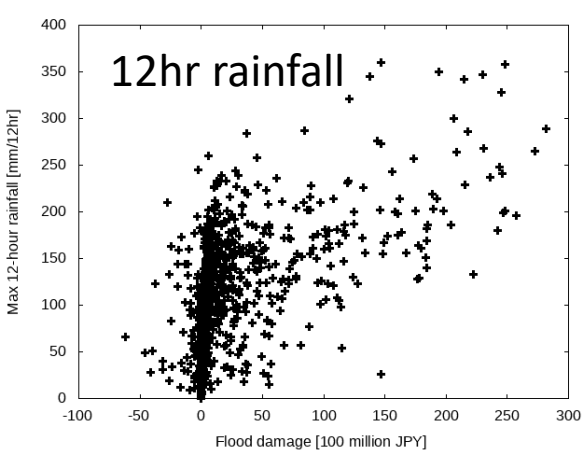


Dominant rainfall indentification

- Row 3,000 AMS of 24-hour rainfall of d4PDF was input to into pluvial flood model
- 3-hour rainfall determines pluvial flood damage
- Bias was corrected to max 3-hour AMS of 24-hour rainfall



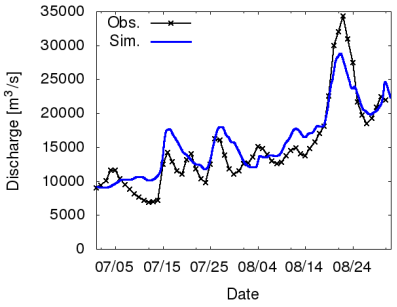




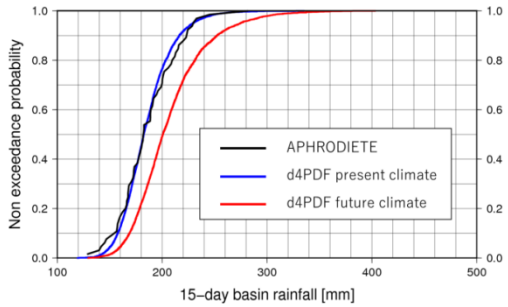
d4PDF rainfall to discharge

- ✓ 62 days causing annual max rainfall is set as simulation period
- ✓ Rainfall data were inputted directly without any bias correction
- ✓ Dam model was excluded in comparison with obs. (1971 - 1998)

62 days



No bias correction

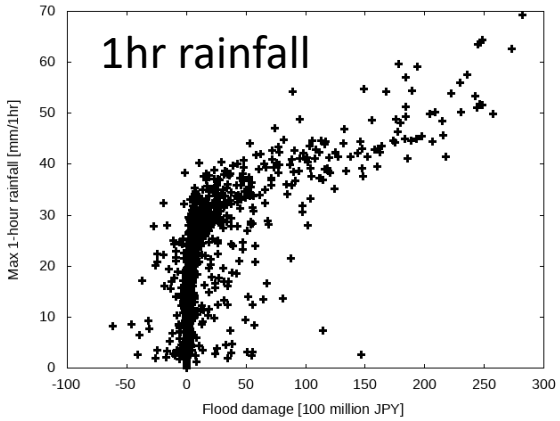


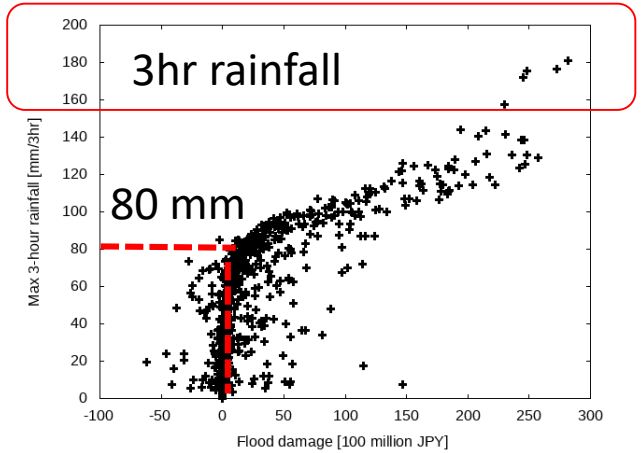
Only Thac Ba and Hoa Binh Dam constructed before 2000

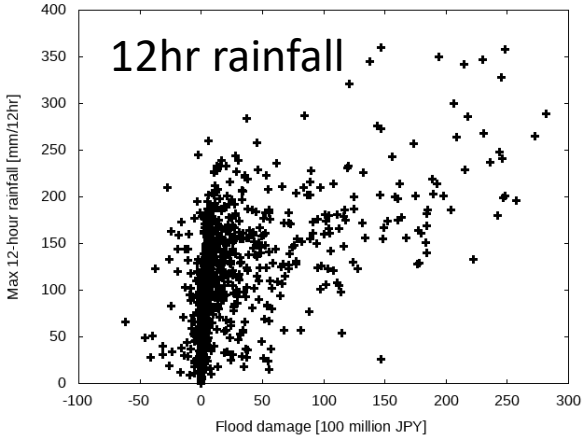
Dam	Son La	Hoa Binh	Thac Ba	Tuyen Quang
Year	2005	1979	1964	2002
Dam	Lai Chau	Ban Chat	Huoi Quang	
Year	2011	2009	2011	

Discussion: “Annual Max” event for Fluvial / Pluvial flooding

3-hour rainfall determines pluvial flood damage

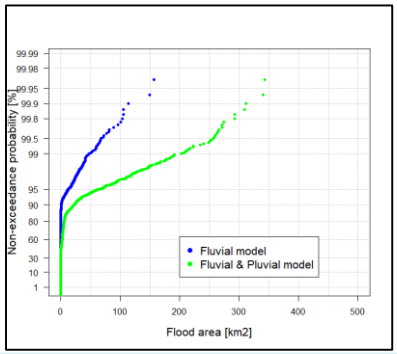




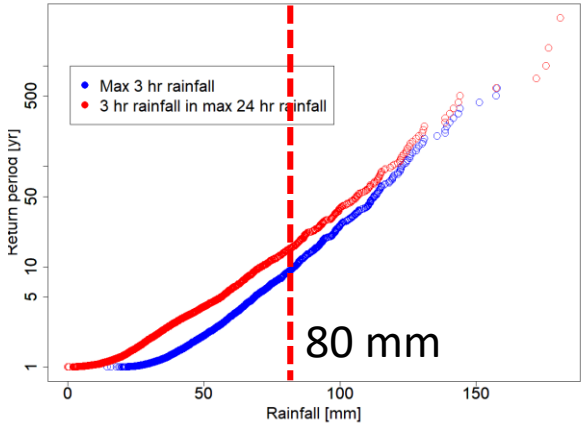


Annual Max 24 hr rainfall event was used in calculation

→ Different from AM 3hr rainfall?

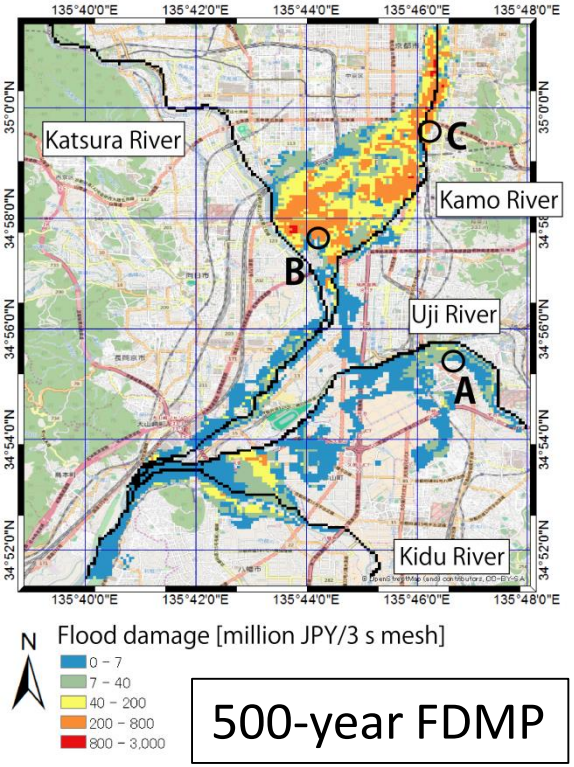


3 hr rainfall in AM 24hr rainfall and AM 3hr rainfall is similar

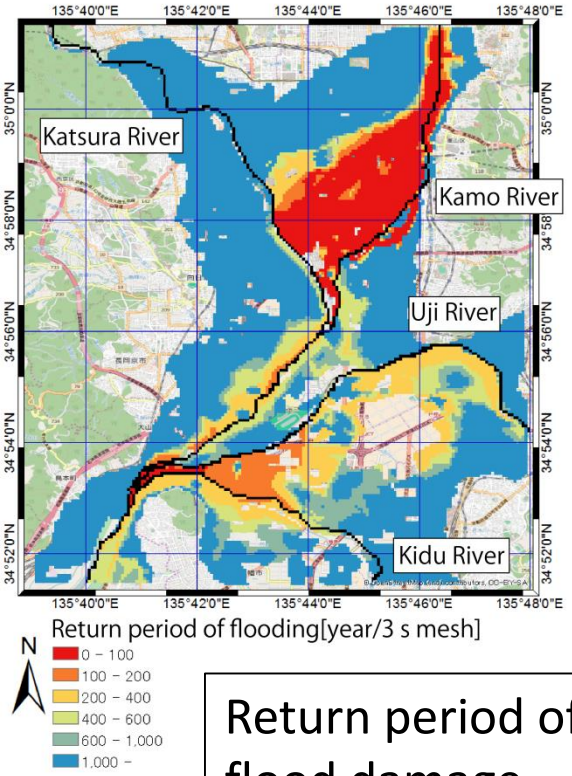


Flood Damage Probability Map (FDPM)

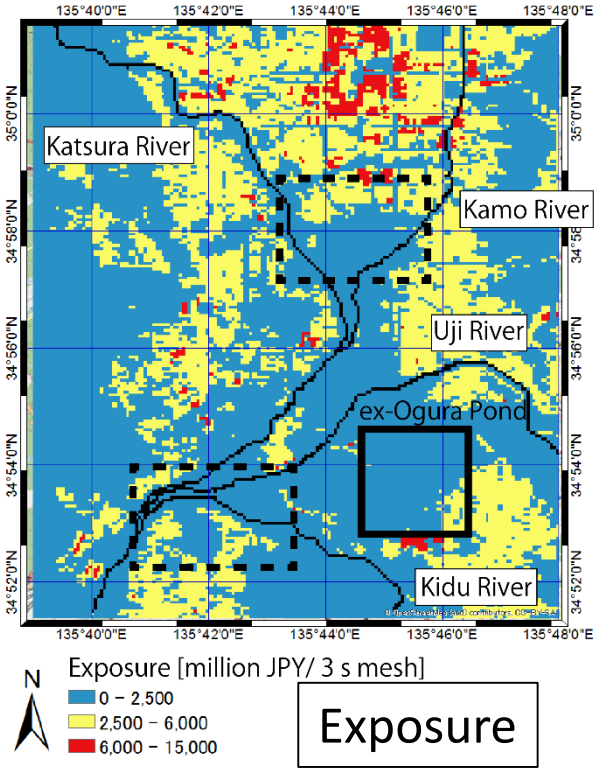
- The most populated area (red area in exposure) has lower risk
- Area at higher flood risk has smaller density of property
- Asset allocation of the Kyoto City area is harmonized with flood risk reduction



500-year FDMP



Return period of flood damage



Exposure