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THINK × ACT KANSAI UNIVERSITY

RISK ASSESSMENT OF AGGREGATE LOSS BY STORM SURGE INUNDATION IN ISE AND MIKAWA BAY

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Background

- **The risks of disaster are intertwined**
  - There is an occurrence possibility of simultaneous damage in multiple areas.
  - Nationwide companies have more risks of simultaneous damage in multiple areas by one disaster.

- **In this case when damage occurred…**
  - Company will need more money for recovery.
  - To make this money, making an insurance contact with insurance company in advance.

    (e.g. CAT bond)

Background

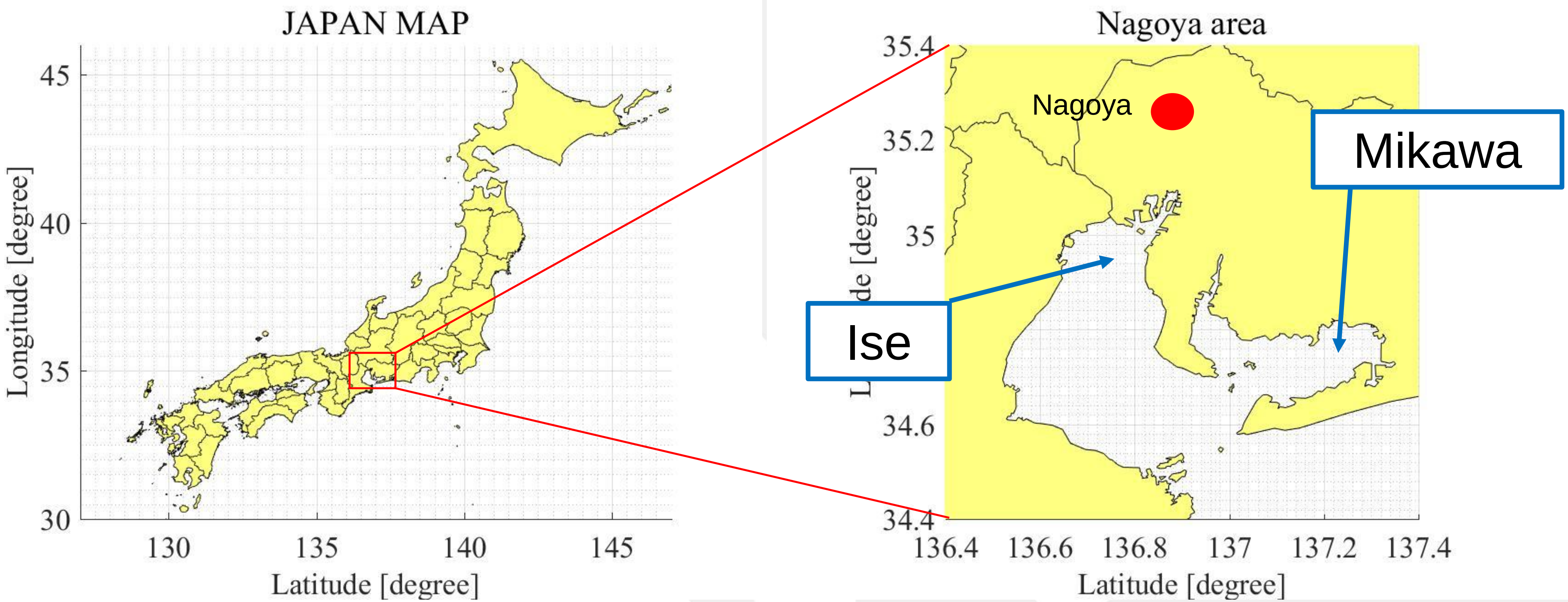
- **For the insurance company…**
  - Assess amount of insurance payout because to pay it for contracted companies quickly.
  - But, it is difficult to estimate total amount since there are few researches assessing aggregate loss caused by coastal disasters.

・Purpose of study

To propose a procedure of assessment of aggregate loss by storm surges in Ise and Mikawa Bay located in Nagoya area, in Japan.

About target areas

- **Ise Bay & Mikawa Bay**
  - Located in Nagoya area, in JAPAN.
  - The automobile industry is thriving. (e.g. TOYOTA etc.)
  - Economic loss will be large when the damage occurred in these areas.



Typhoon in Ise Bay in past

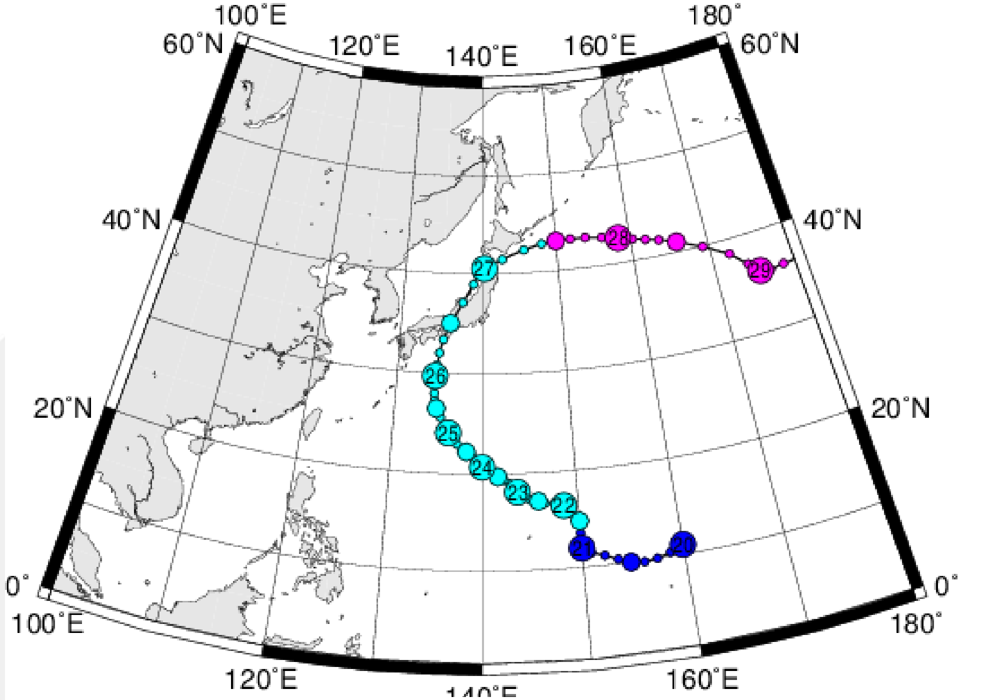
- **Vera (09/21/1959)**
  - Storm surge : 3.45m

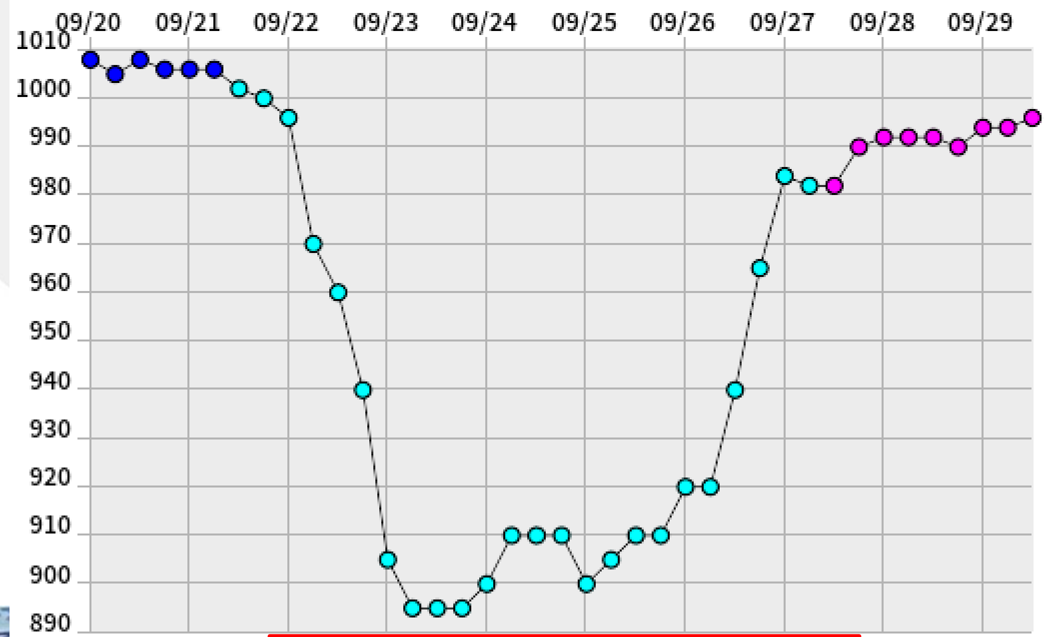
(in Ise Bay)

  - Dead : 3,168
  - Completely destroyed of house : 23,334
  - Partially destroyed of house : 97,049

(in Nagoya area)

- Vera is called Ise Bay typhoon in Japan.





Central pressure

Photo source : http://agora.ex.nii.ac.jp/digital-typhoon/summary/wnp/s/195915.html.ja

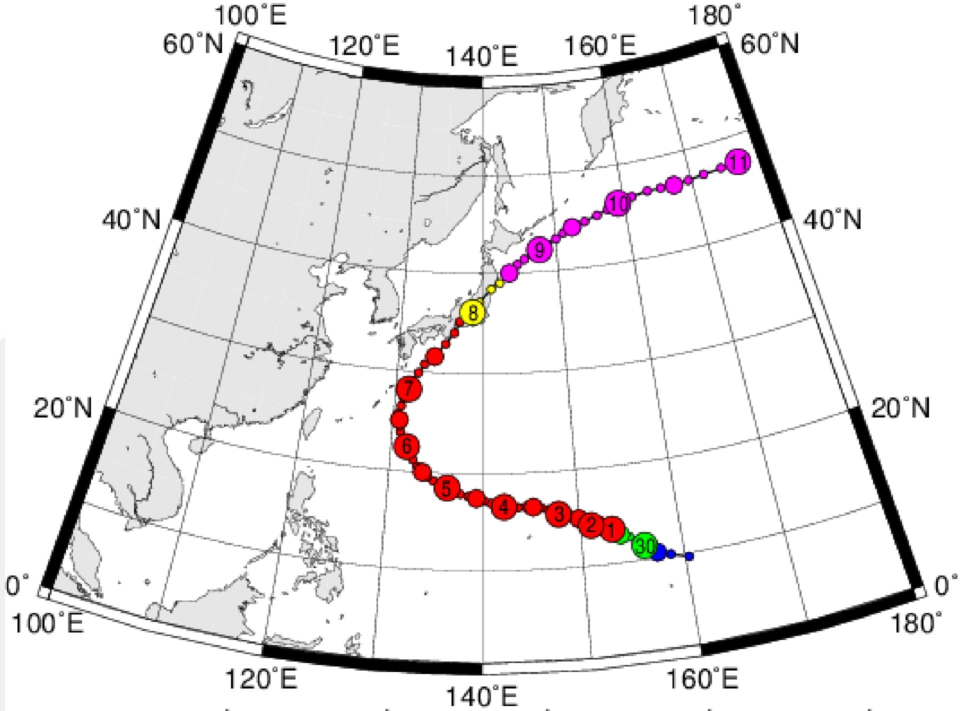
Typhoon in Mikawa Bay in past

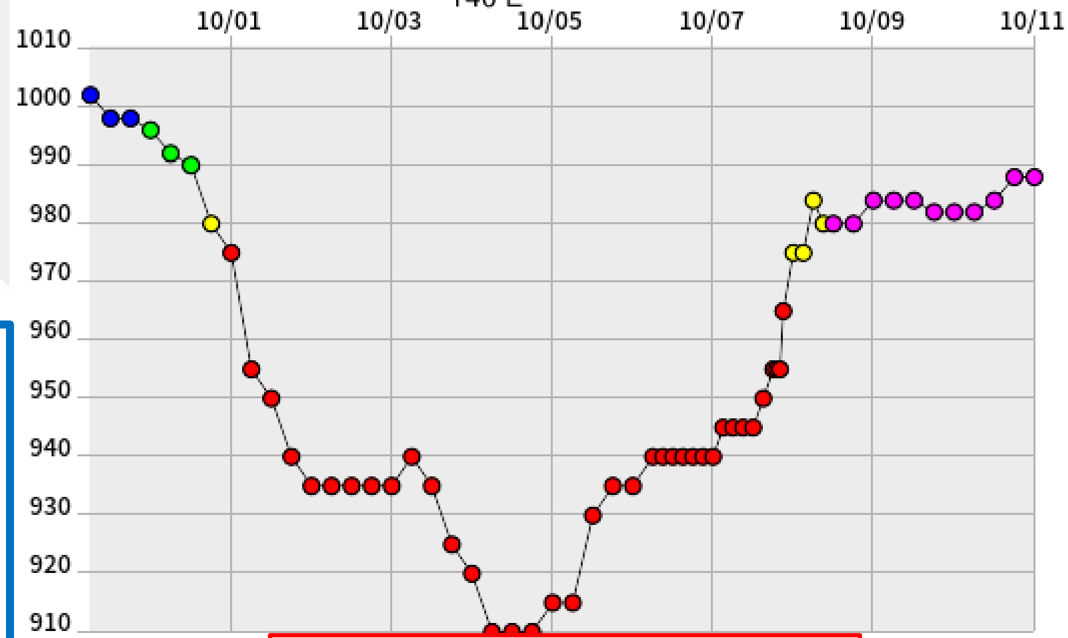
- **Melor (10/08/2009)**
  - Storm surge : 2.6m
  - Container damage : 136

(in Mikawa Bay)

  - Injured : 28
  - Completely destroyed of house : 6

(in Nagoya area)





Central pressure

Typhoons causing large damage have also occurred in Mikawa Bay, but it haven't been focused as much as Ise Bay typhoon.

Photo source : http://agora.ex.nii.ac.jp/digital-typhoon/summary/wnp/s/200918.html.ja

Method

Synthetic typhoon datasets for 1000 years made by the stochastic typhoon model

Confirmation of typhoon route

Both Ise and Mikawa Bay

- Storm surge analysis by SuWAT
- Inundation simulation by LISFLOOD-FP
- Calculation loss
- Making loss function

Only Ise Bay

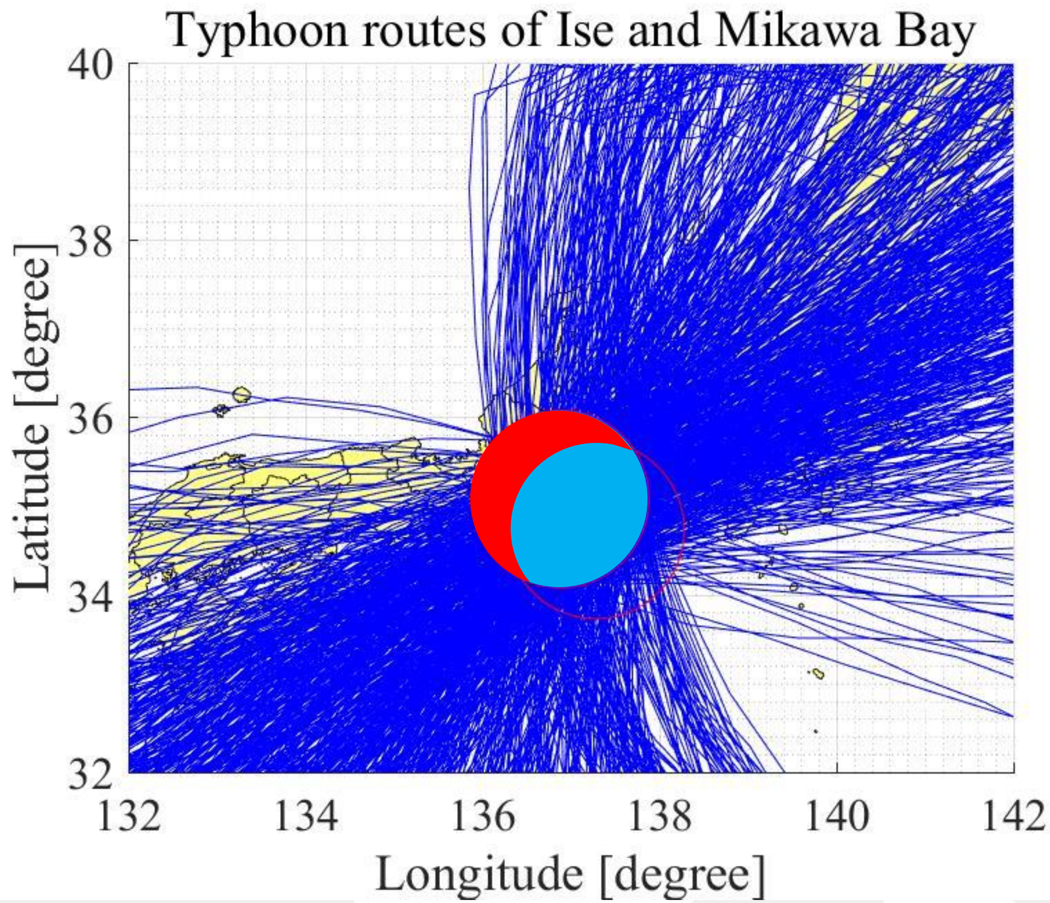
- Storm surge calculation by empirical formula of JMA

Calculation aggregate loss & expected loss

Aggregate risk assessment

Typhoon data

- **Synthetic typhoon datasets for 1000 years**
  - Made by the stochastic typhoon model by Nakajo et al.(2013)
- **Typhoon extraction area**
  - Ise Bay
  - Ise＆Mikawa Bay



Extraction Areas	Ise Bay	Mikawa Bay	The number of typhoons for 1000 years			
Center	Nagoya	Mikawa	WORLD	113193	Ise	192
Latitude	35.08	34.73	JAPAN	6923	Ise&Mikwa	805
Longitude	136.88	137.28			SUM	997

Storm surge calculation in Ise Bay

- Storm surges by typhoons which passed only Ise Bay were calculated by empirical formula by Japan Meteorological Agency till 1998.

$$h = a(1010 - P_m) + bU^2 \cos(\theta_0 - \theta)$$

- h:Maximum Storm Surge [cm]
- P_m:Minimum Central Pressure [hPa]
- U:Maximum Windspeed [m/s]
- θ_0:Main Wind Direction [°]
- θ:Maximum Windspeed Direction [°]
- a, b:Coefficients of each Bay

	Ise
$\boldsymbol{a}$	1.674
$\boldsymbol{b}$	0.165
$\boldsymbol{\theta_0}$	147

Quoted from Tide table(1991)

No coefficient of empirical formula in Mikawa Bay.

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Aggregate risk assessment

Storm surge analysis by SuWAT(Kim et al. 2007)

- Continuity equation

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0$$

- Equation of motion

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{d}\right) + \frac{\partial}{\partial y}\left(\frac{MN}{d}\right)$$
$$= -gd\frac{\partial \eta}{\partial x} - \frac{1}{\rho_w} d\frac{\partial P}{\partial x} + \frac{1}{\rho_w}(\tau_s^x - \tau_b^x + F_x) + A_h\left(\frac{\partial^2 M}{\partial_x^2} + \frac{\partial^2 M}{\partial_y^2}\right) + fN$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{d}\right) + \frac{\partial}{\partial y}\left(\frac{N^2}{d}\right)$$
$$= -gd\frac{\partial \eta}{\partial y} - \frac{1}{\rho_w} d\frac{\partial P}{\partial y} + \frac{1}{\rho_w}(\tau_s^y - \tau_b^y + F_y) + A_h\left(\frac{\partial^2 M}{\partial_x^2} + \frac{\partial^2 M}{\partial_y^2}\right) + fM$$

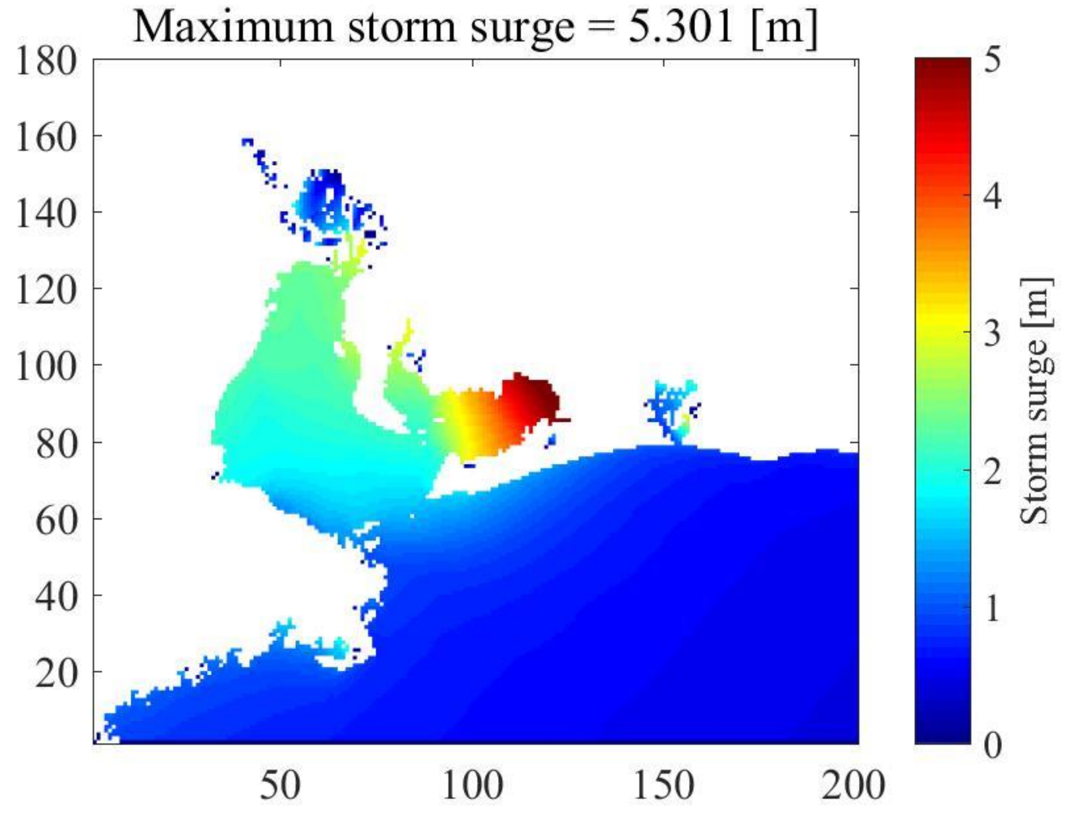
where
η : water level from still water level
d : total water depth
M, N: flux(for x and y direction)
f : Coriolis parameter
Fx, Fy : Radiation stress
τ_s, τ_b: friction force(Sea surface and Bottom surface)
A_h: horizontal eddy viscosity coefficient
P: atmospheric pressure
ρ_w: seawater density

Storm surge analysis by SuWAT(Kim et al. 2007)

- Storm Surge in Ise and Mikawa Bay were analyzed by nonlinear shallow water equation model, SuWAT by Kim et al.(2007).

Calculation conditions	
Time	Disappearance from occurrence of typhoon
Wave setup	No consideration
Flood・Runup calculation	No performance
Inflow of river water	No consideration
Domain size	200×180 (1grid = 810m)
The number of analysis	805

One example out of 805



Inundation simulation by LISFDLOOD -FP

- **LISFLOOD-FP (Bates et al. 2005)**
  – Flood plain inundation simulation model only on land quickly.
  – Inundation simulation in Ise Bay wasn't performed because of already done in previous study.(Tsujita et al. 2016)
- **Continuity equation and Equation of motion**

$$\frac{\partial A}{\partial x} + \frac{\partial Q_x}{\partial x} = 0$$

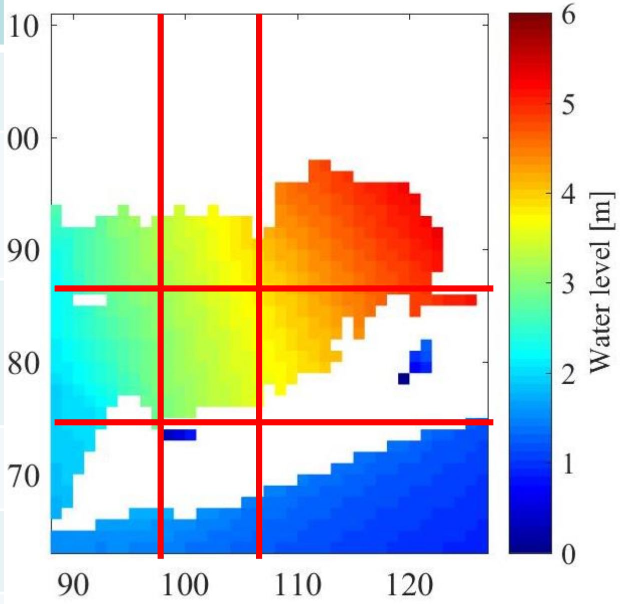
$$\frac{\partial Q_x}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q_x^2}{A}\right) + gA\frac{\partial (h+z)}{\partial x} + \frac{gn^2 Q_x^2}{R^{4/3}A} = 0$$

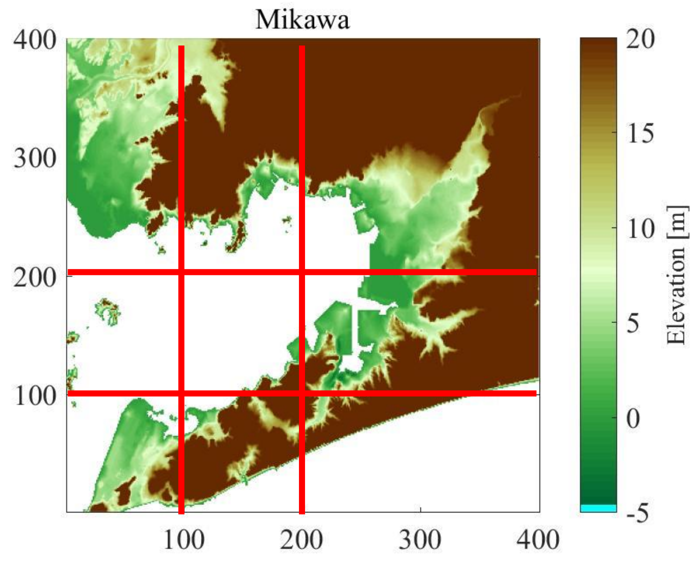
where
h : water depth
n : Manning's coefficient
t: time
z: height of bottom
A: sectional area of flow
R: hydraulic radius
Q_x: flow rate
x: distance for x direction

Inundation simulation by LISFDLOOD -FP

- LISFLOOD-FP (Bates et al. 2005)
  - Flood plain inundation simulation model only on land quickly.
  - Inundation simulation in Ise Bay wasn't performed because of already done in previous study.(Tsujita et al. 2016)

Calculation conditions	
Input water level	SuWAT
Calculation section	9(Right figures)
Domain size	400×400 (1grid = 100m)
Seawalls	No consideration
River	No consideration
The number of simulations	805





Results of Inundation simulation

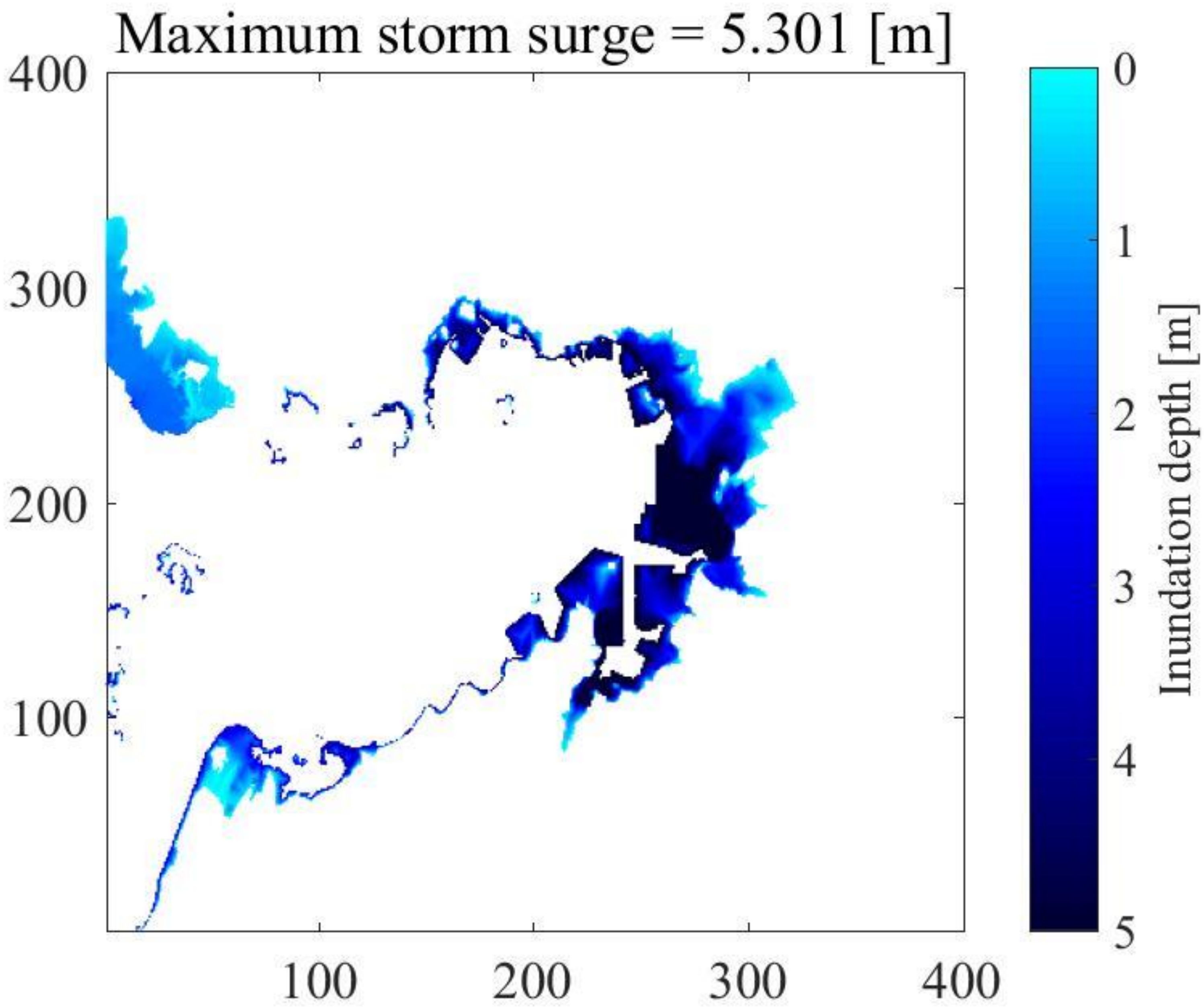
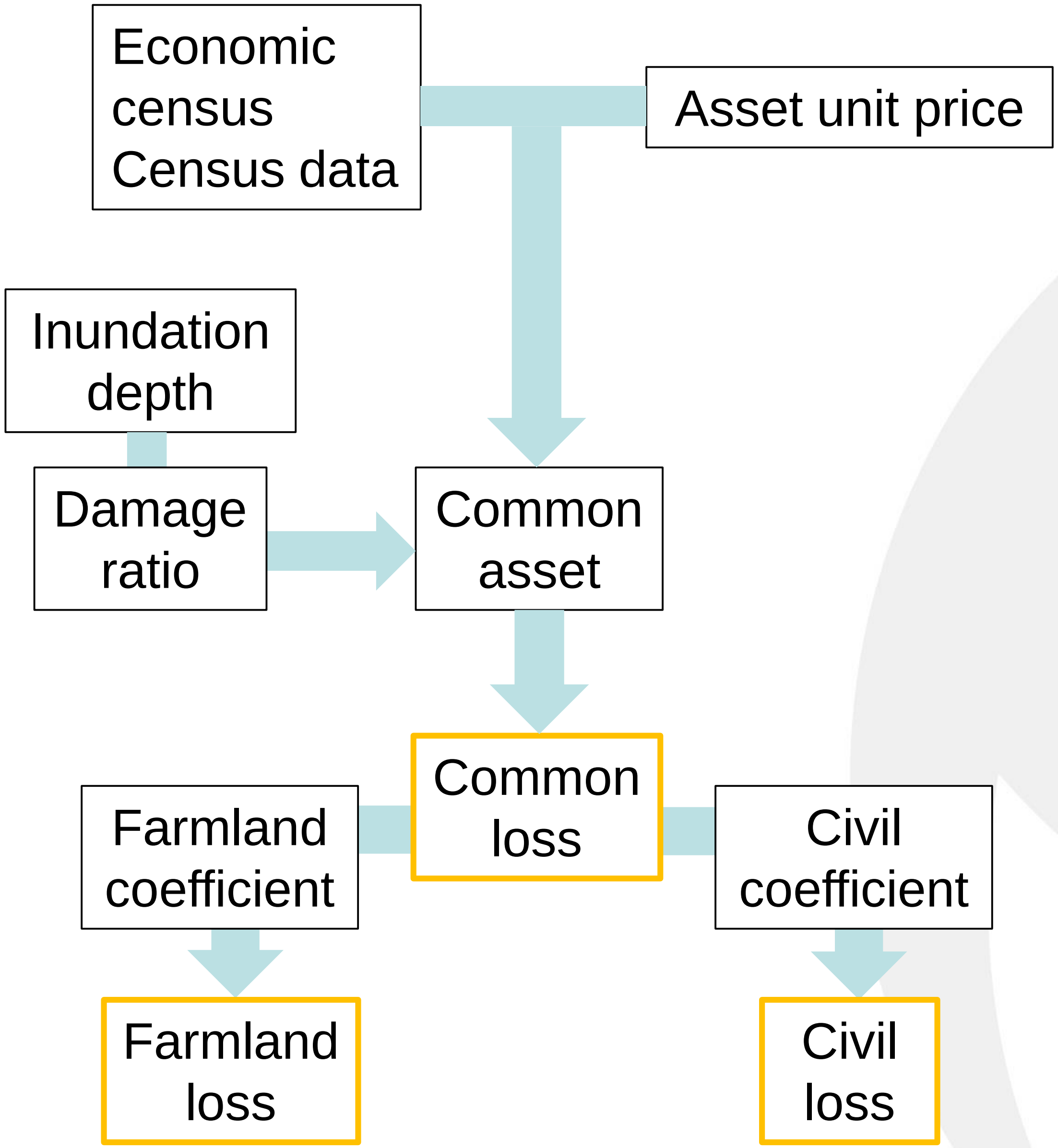


Figure shows when inundation area is the widest in the calculation time.

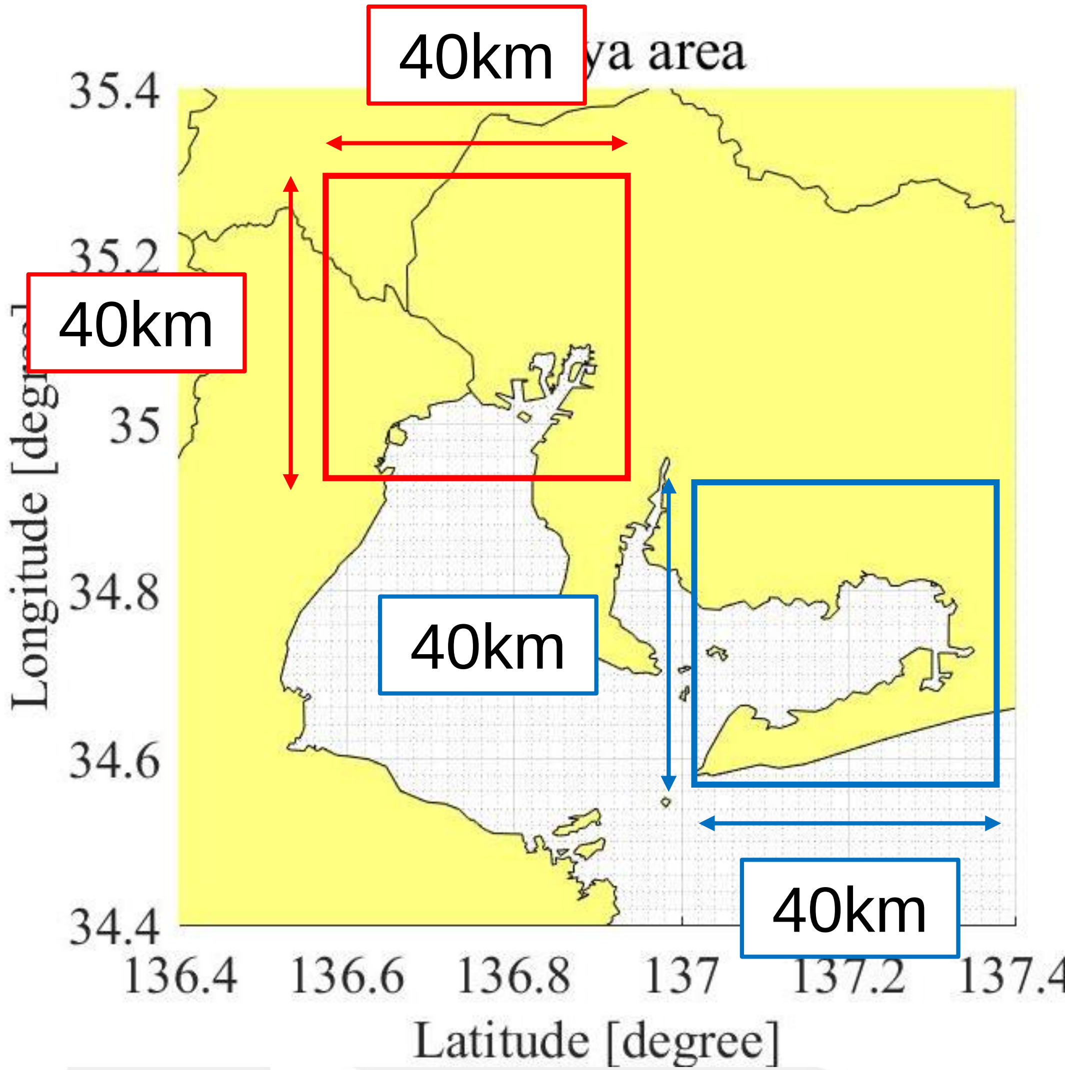
One figure shows one typhoon.

Not showing the time series of inundation by typhoon.

Process of making Loss function

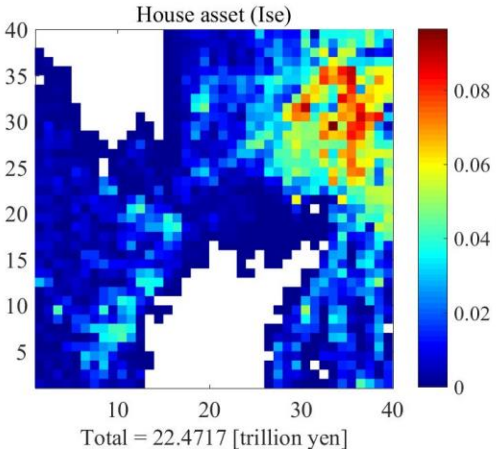


Areas of making assets

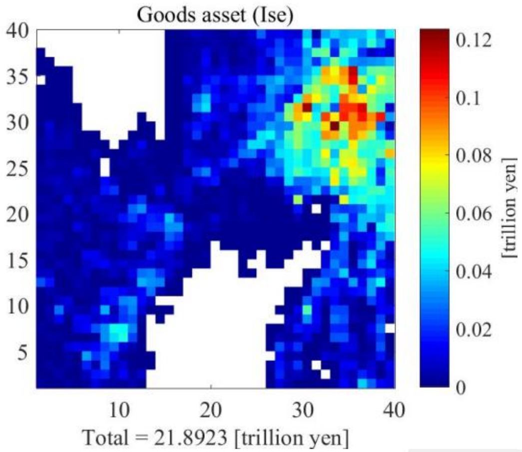


Common asset in Ise Bay

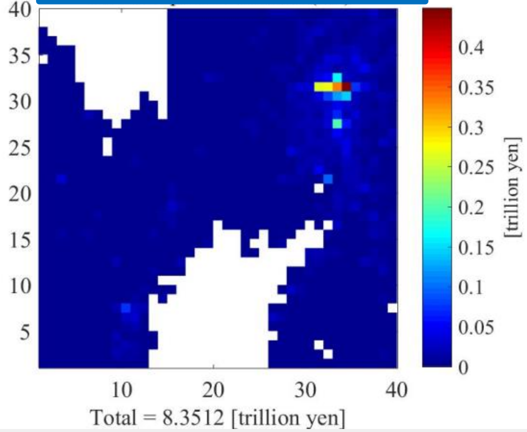
House



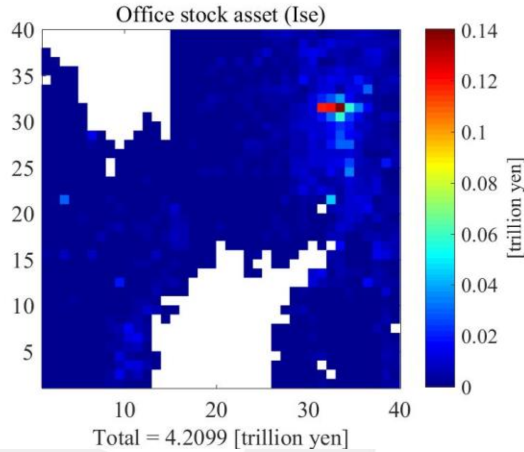
Goods



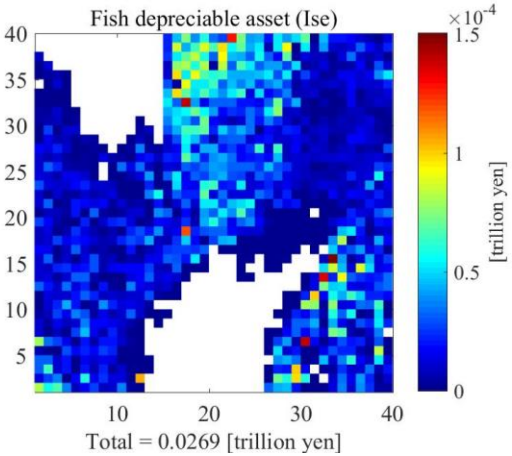
Office depreciable



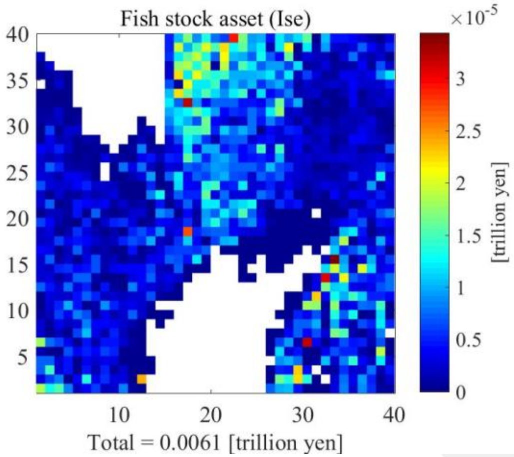
Office stock



Fish depreciable



Fish stock



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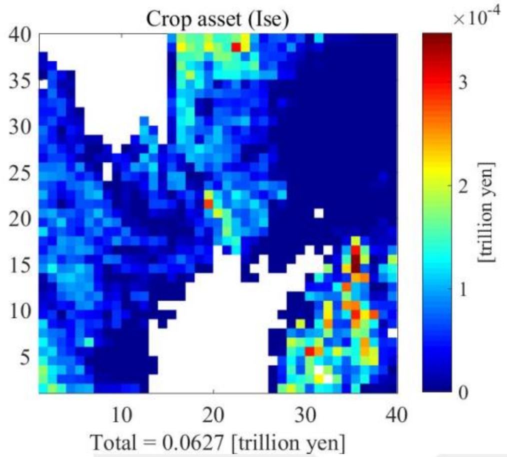
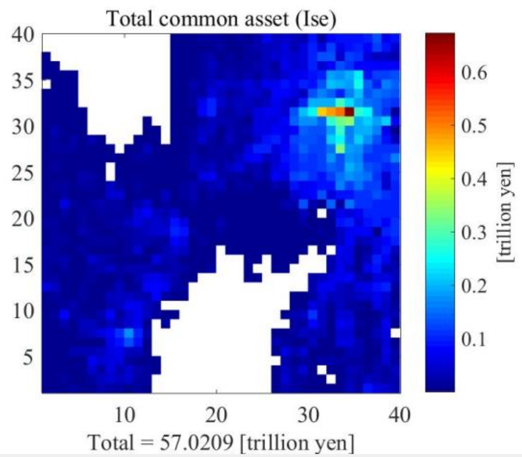


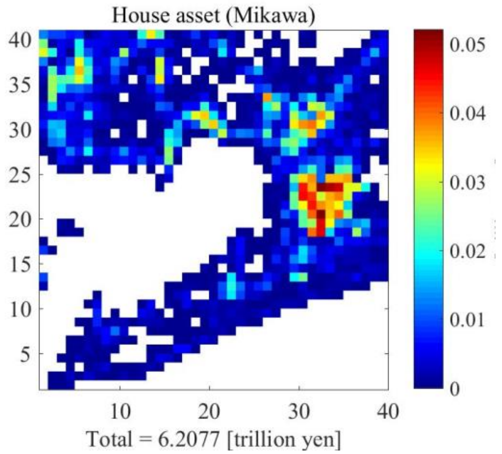
Total



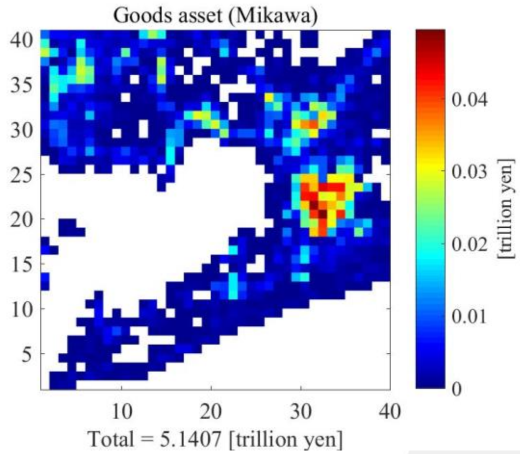
Total common assets = 57.0 trillion yen (514 billion US$)

Common asset in Mikawa Bay

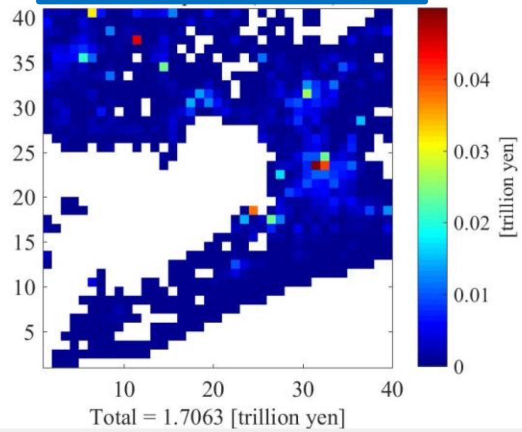
House



Goods



Office depreciable



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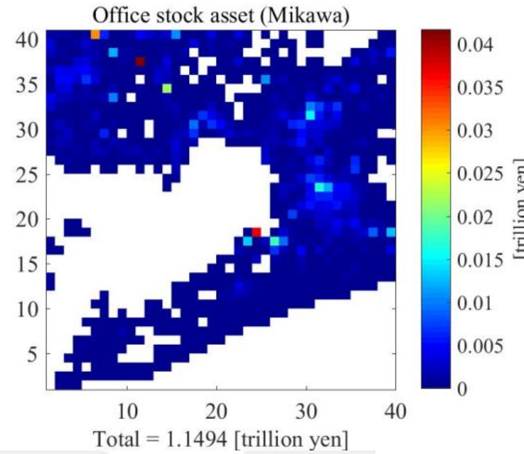
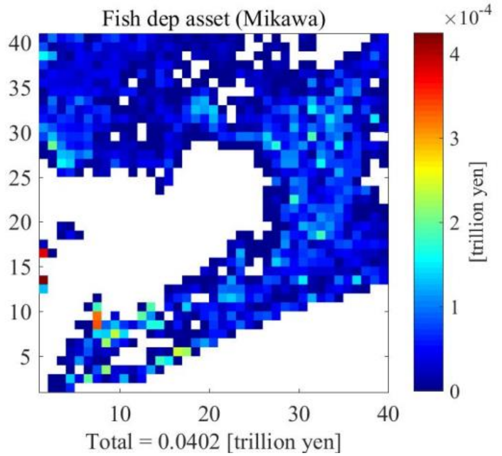
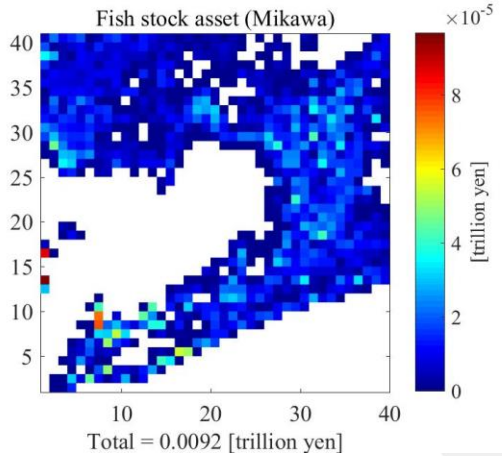


Fish depreciable



Fish stock



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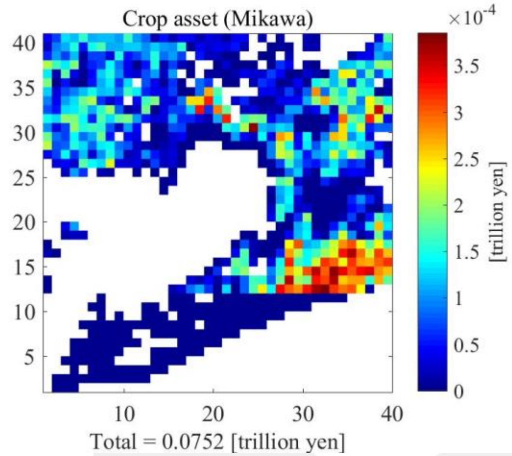
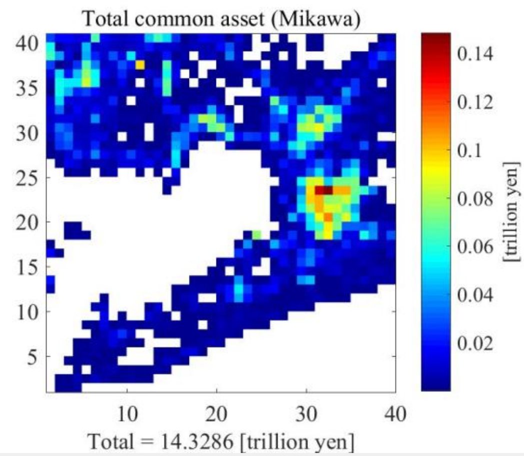
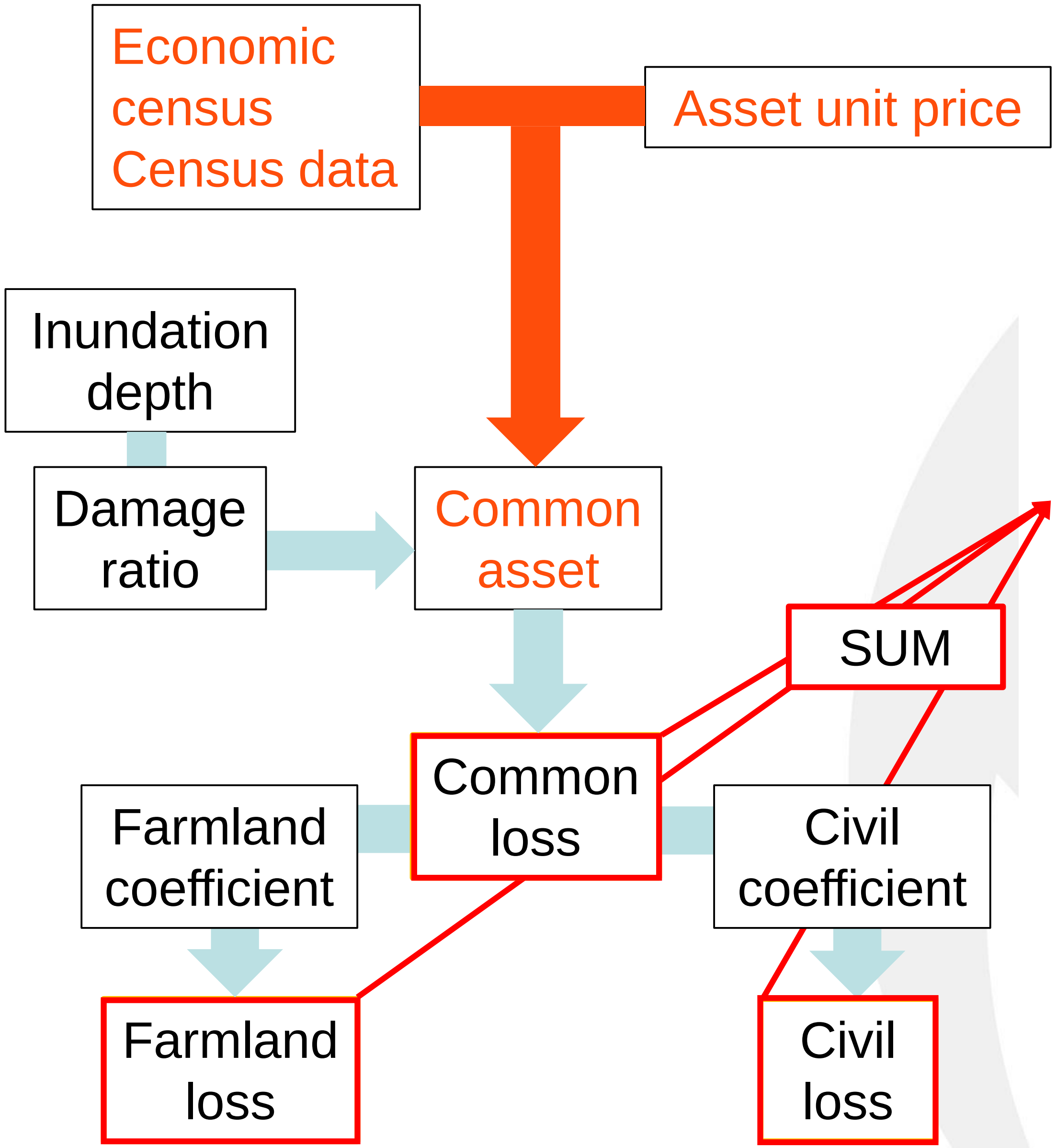


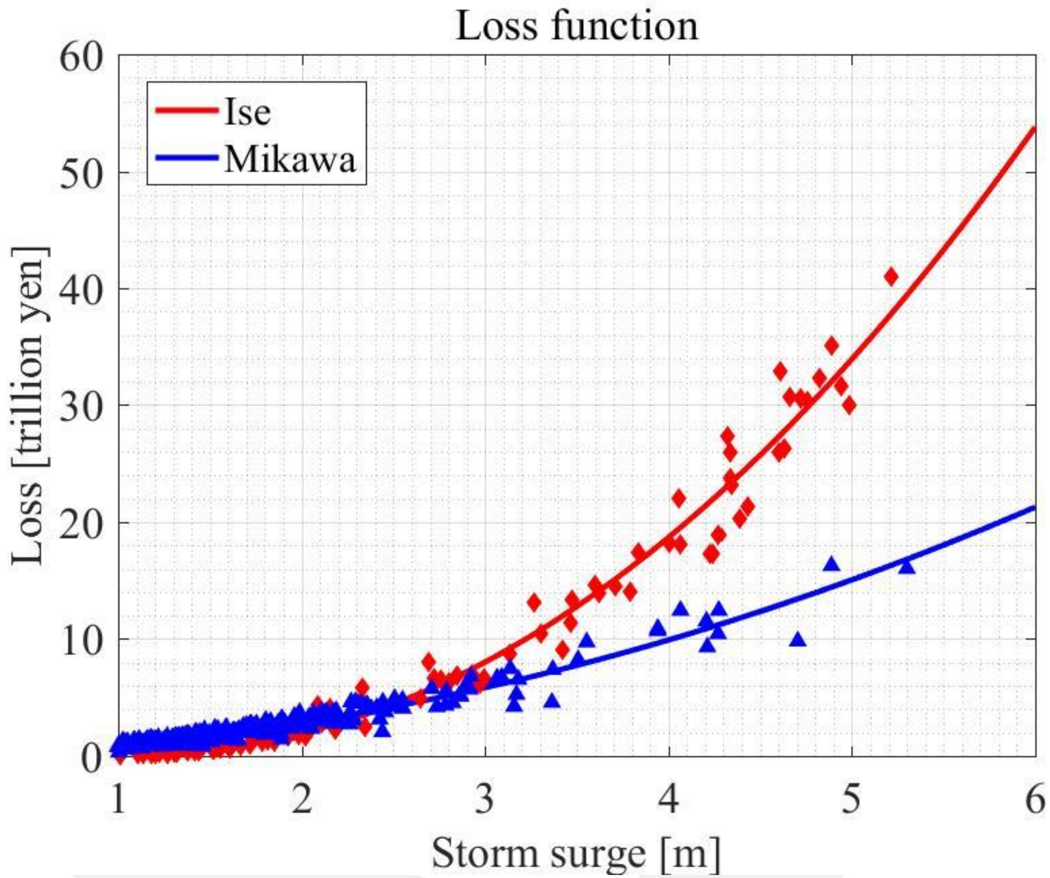
Total



Total common asset = 14.3 trillion yen (129 billion US$)

Loss function





Loss function in Ise bay was quoted from previous study, Tsujita et al.(2016)

Method

Synthetic typhoon datasets for 1000 years made by the stochastic typhoon model

↓

Confirmation of typhoon route

Both Ise and Mikawa Bay

- Storm surge analysis by SuWAT
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Only Ise Bay

- Storm surge calculation by empirical formula of JMA

↓

Calculation aggregate loss & expected loss

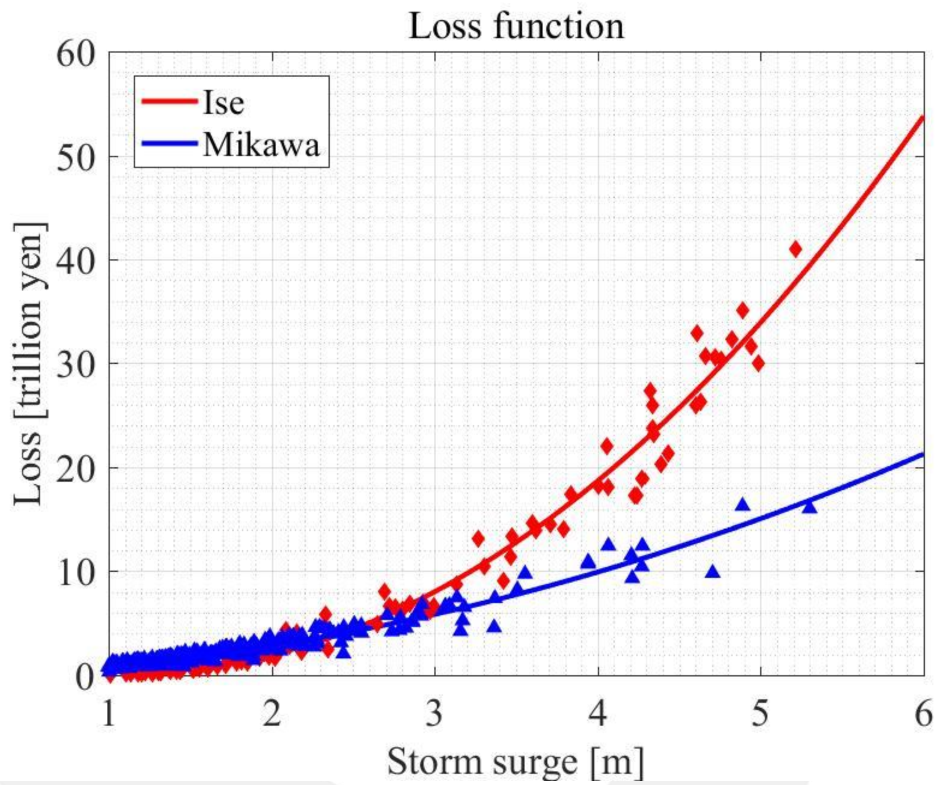
↓

Aggregate risk assessment

Aggregate loss calculation

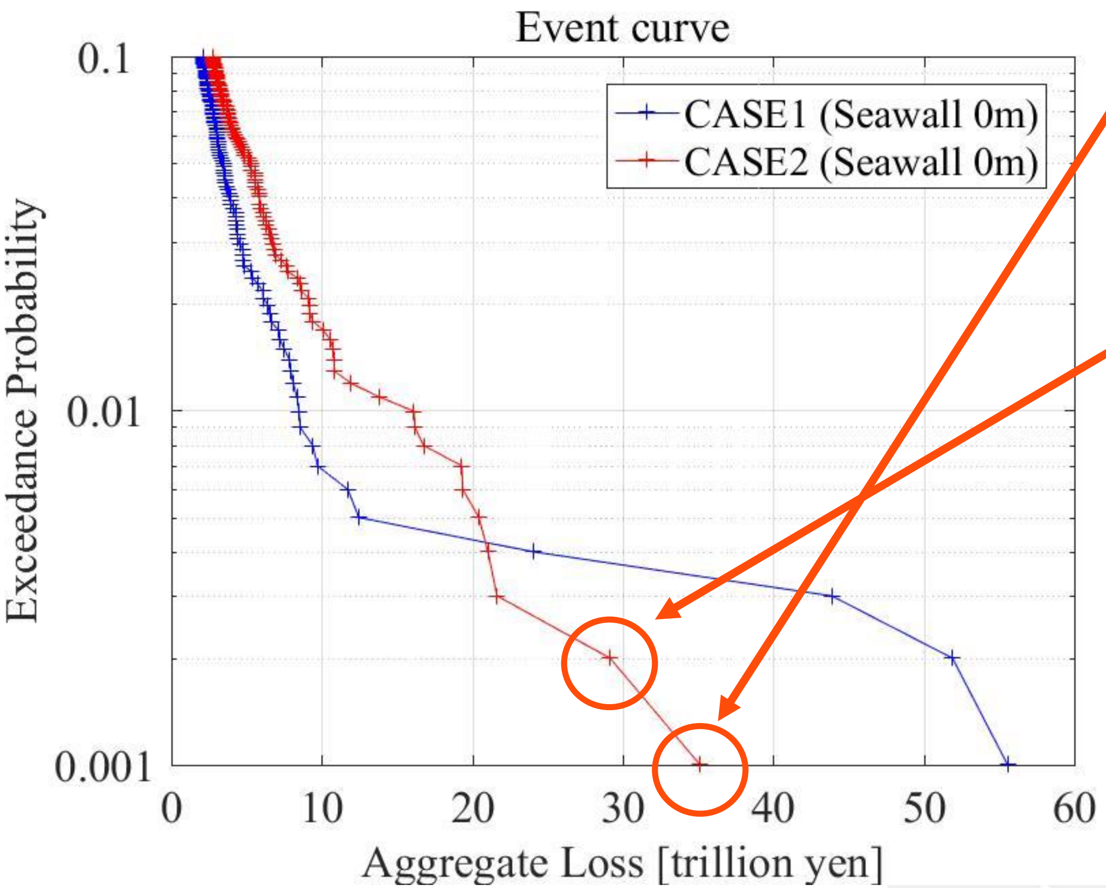
- All typhoon losses were calculated by loss functions and storm surges.

Passed Bay	Passed area	CASE1	CASE2
1Bay	Ise	Empirical formula	Empirical formula
2Bays	Ise	Empirical formula	SuWAT
	Mikawa	SuWAT	SuWAT



There are 2 results of storm surge in Ise Bay, empirical formula and SuWAT which typhoon passed both bays. Expected loss was compared in empirical formula with SuWAT to verify the accuracy of empirical formula.

Expected aggregate loss

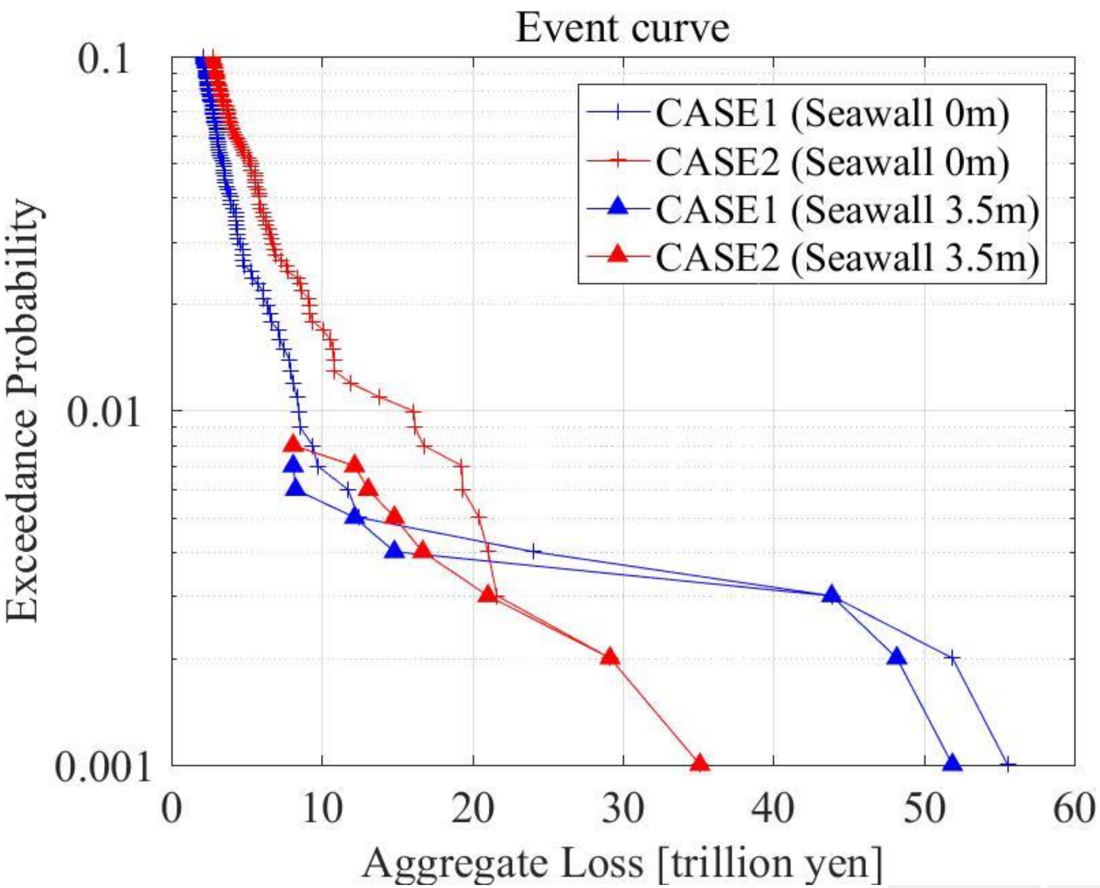


- Loss of over about 35 trillion yen (315 billion US$) occurs with the probability of once in 1000 years.
- Loss of over about 30 trillion yen (270 billion US$) occurs with the probability of twice in 1000 years.
- Expected loss = Σ(Aggregate Loss x Exceedance probability)

Passed Bay	Passed area	CASE1	CASE2
1Bay	Ise	Empirical formula	Empirical formula
2Bays	Ise	Empirical formula	SuWAT
	Mikawa	SuWAT	SuWAT

Expected loss [trillion yen ($)]	Seawall 0m	Seawall 2.5m	Seawall 3m	Seawall 3.5m
CASE1	0.87	0.23	0.19	0.15
CASE2	1.06	0.24	0.16	0.10

Seawalls are considered simply



- Conditions of seawall
  - Loss becomes 0 if storm surge height are smaller than seawall height.
  - Seawall is broken if storm surge is higher than seawall height.
- Expected loss = Σ(Aggregate Loss x Exceedance probability)

Passed Bay	Passed area	CASE1	CASE2
1Bay	Ise	Empirical formula	Empirical formula
2Bays	Ise	Empirical formula	SuWAT
	Mikawa	SuWAT	SuWAT

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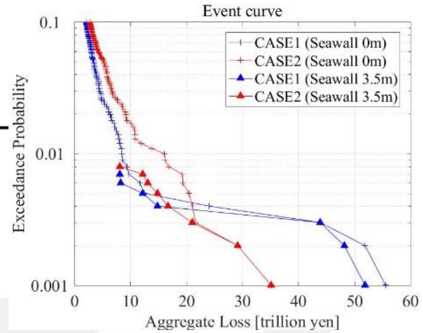
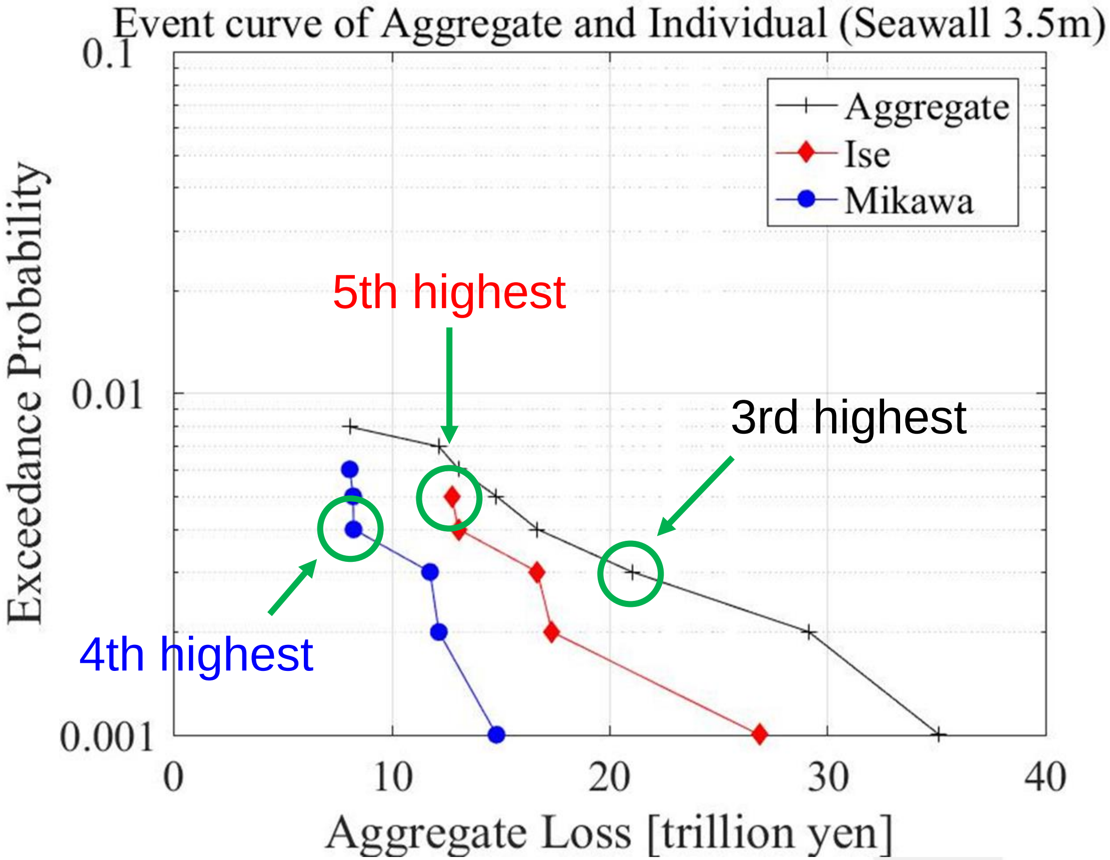
Aggregate risk assessment



- The details of losses in ▲ event curve.



Ise Loss (trillion yen)	Mikawa loss (trillion yen)	Aggregate loss (trillion yen)
26.9	8.3	35.1
17.4	11.8	29.2
12.8	8.3	21.0
16.7	0	16.7
0	14.8	14.8
13.1	0	13.1
0	12.2	12.2
0	8.1	8.1

Aggregate loss is larger than Individual loss.

Conclusion

- Process to calculate the aggregate loss by storm surge inundation in the multiple area is proposed.
- Expected aggregate loss in Ise and Mikawa Bay was estimated.
- To estimate losses in Ise and Mikawa Bay, aggregate loss is necessary to be considered rather than Individual losses.


Thank you for your attention