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The state of stochastic tsunami hazard assessment

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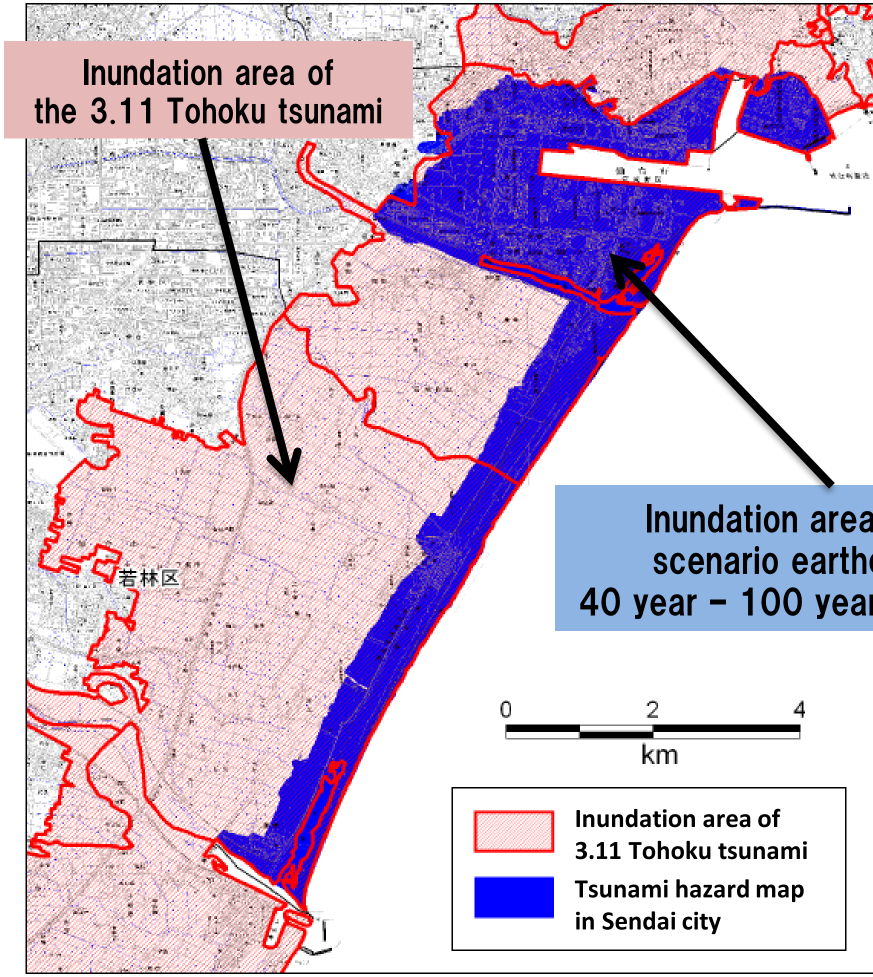
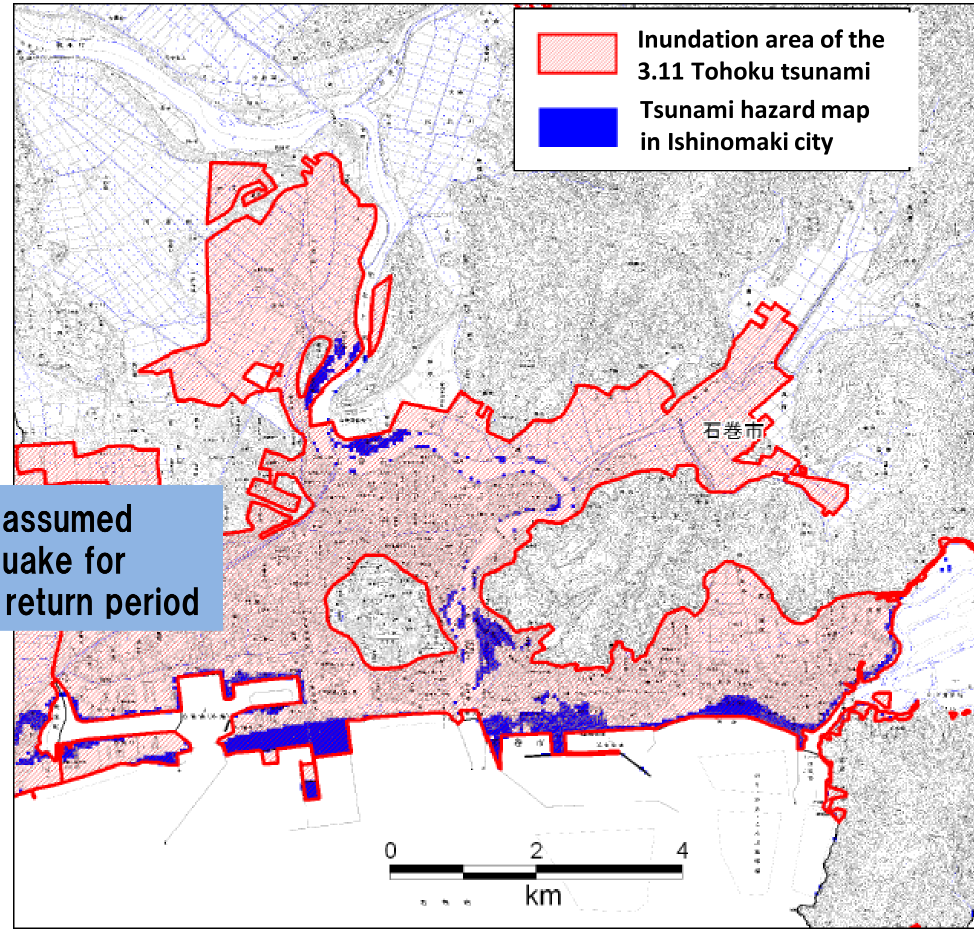
Necessity of stochastic tsunami hazard evaluation

Comparison between inundation area of the 3.11 Tohoku tsunami and tsunami hazard map





（出典）・東北地方太平洋沖地震浸水範囲：国土地理院資料より作図
・ハザードマップ：仙台市「仙台市津波ハザードマップ」、石巻市「石巻市津波ハザードマップ」

The tsunami hazard map (blue shade) is no more than deterministic map.
We need stochastic tsunami hazard map including information for uncertainty based on stochastic tsunami hazard assessment.

Tsunami hazard curve considering uncertainties

In order to develop the stochastic tsunami hazard map, first of all, we need to evaluate stochastic tsunami wave height by using tsunami hazard curve.

Coastal wave heights computed from tsunami numerical simulation

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Uncertainties of tsunami numerical simulation

There are two kinds of uncertainties that are known generally in the engineering field.

(Probability Concepts in Engineering (1975))

◆ Epistemic uncertainty

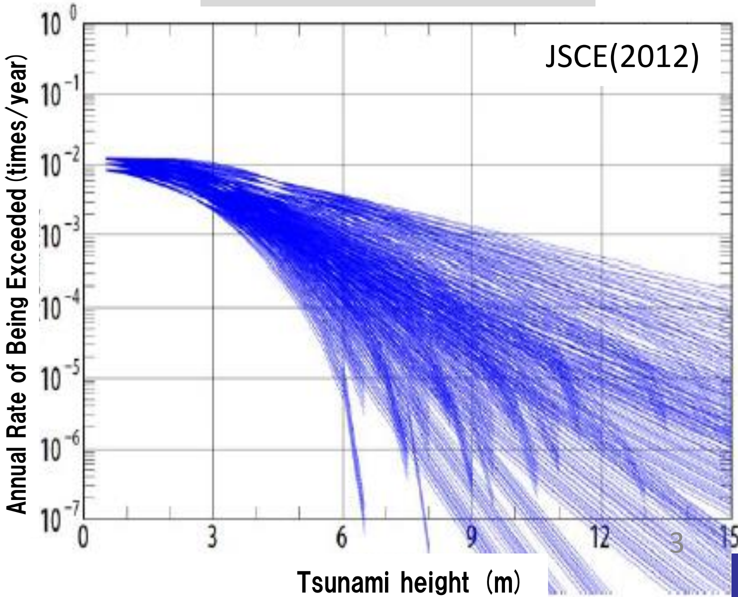
- This uncertainty arises from a lack of knowledge or data.
- Captured by logic trees with alternative credible models.

◆ Aleatory uncertainty

- Unexplained difference between a model prediction and observed data.
- It can only be estimated from validation exercises in which the predicted and observed tsunami wave heights are compared.

(Pacific Gas & Electric Company (2010))

Tsunami hazard curve



Evaluation for uncertainties

In this study, we included the lessons learned from the 3.11 Tohoku earthquake into both Epistemic uncertainty and Aleatory uncertainty

◆ Epistemic uncertainty

※ Lessons learned from the 3.11 Tohoku earthquake

※ We evaluated many possible fault models by using CRSP model (Liu et al.(2006)), which have not occurred so far.

※ Lessons learned from the 3.11 Tohoku earthquake about dislocation distribution by Ishii(2013) was used in evaluating the fault models.

◆ Aleatory uncertainty

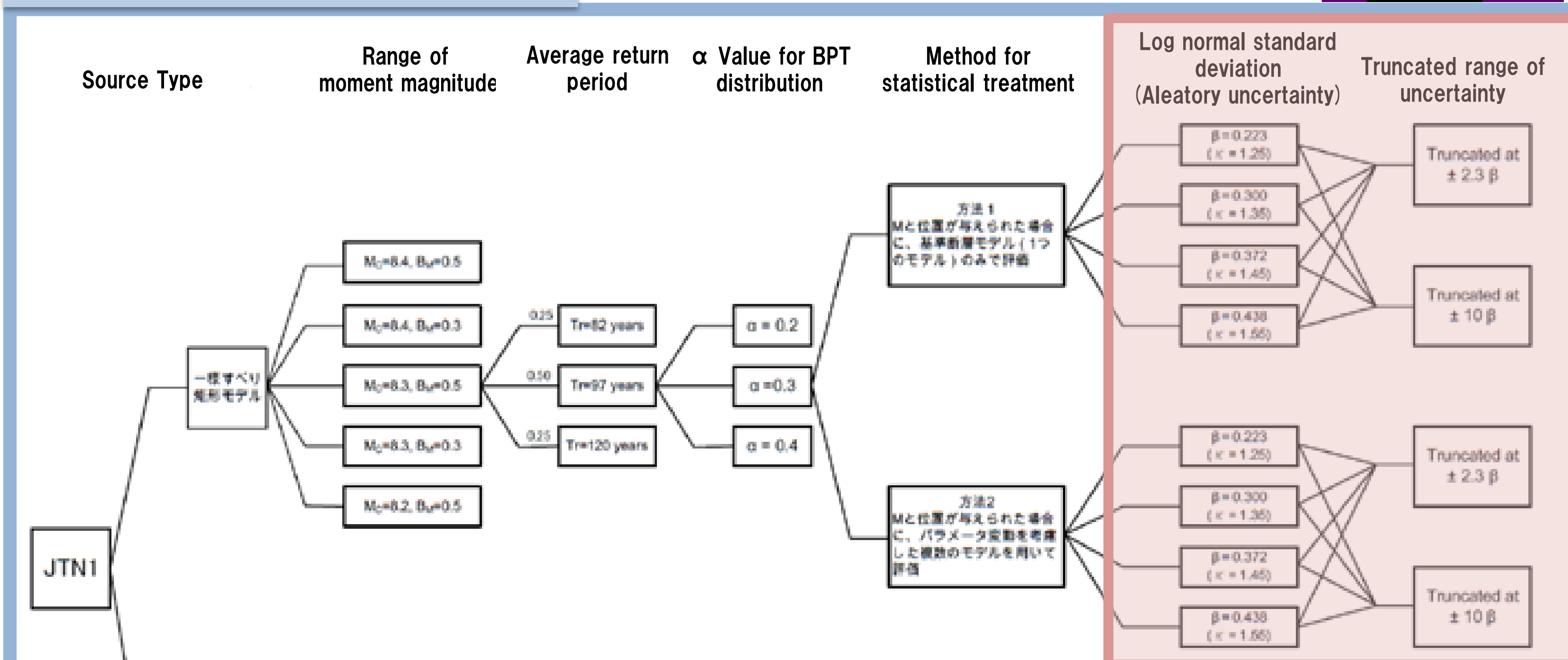
※ Validation exercises in which the predicted and observed tsunami wave heights in the 3.11 tsunami (JNES(2012)) was used.

※ Uncertainty due to dynamic fault rupture effect of huge fault was evaluated (Fukutani et al.(in prep))

Evaluation for uncertainties

Evaluation methods are different depending on kinds of uncertainties.

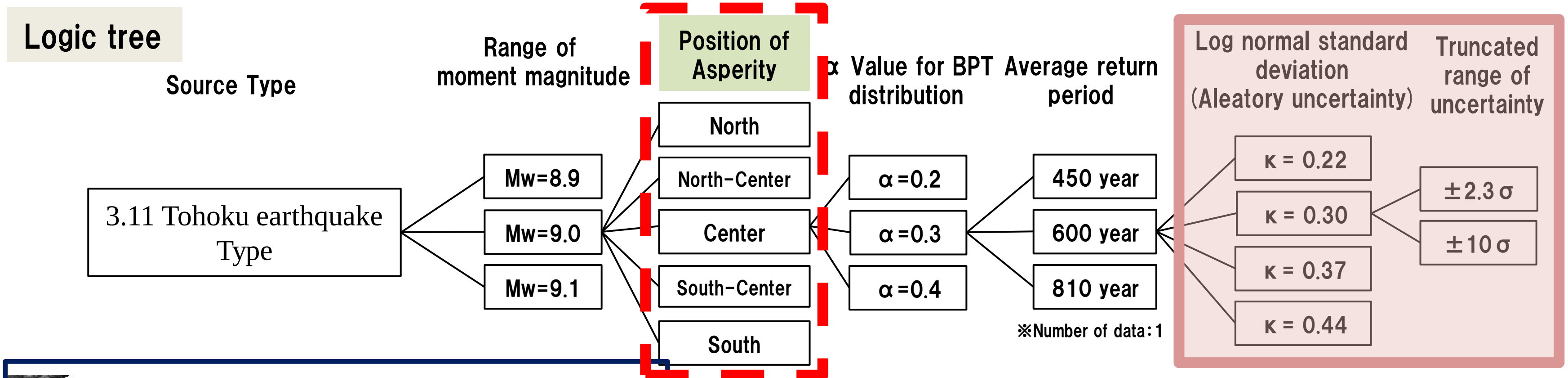
◆ Epistemic uncertainty



Information for aleatory uncertainty is incorporated into the logic tree.

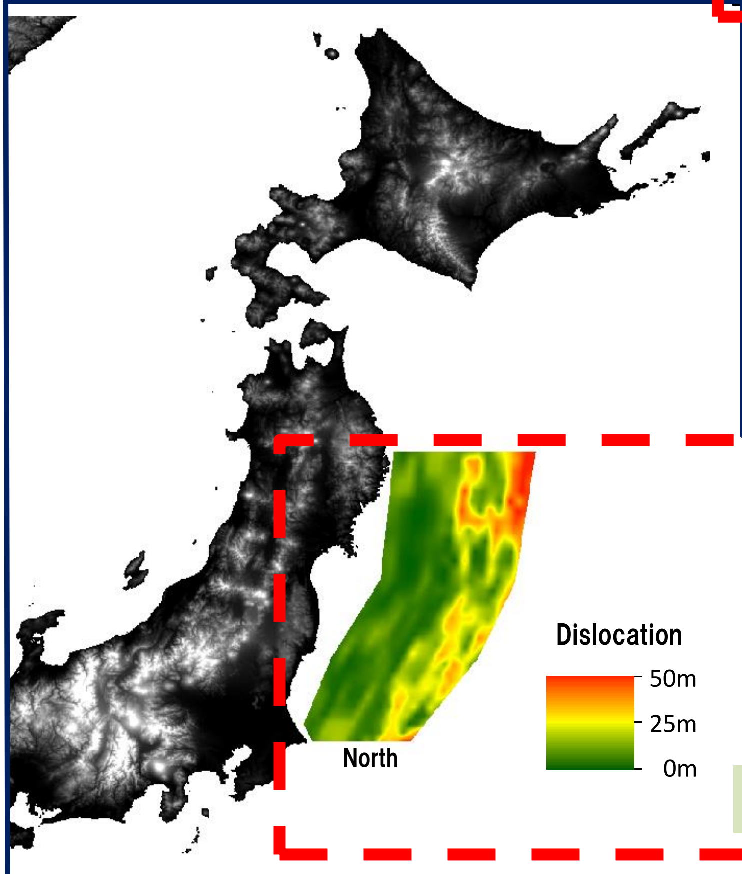
◆ Aleatory uncertainty

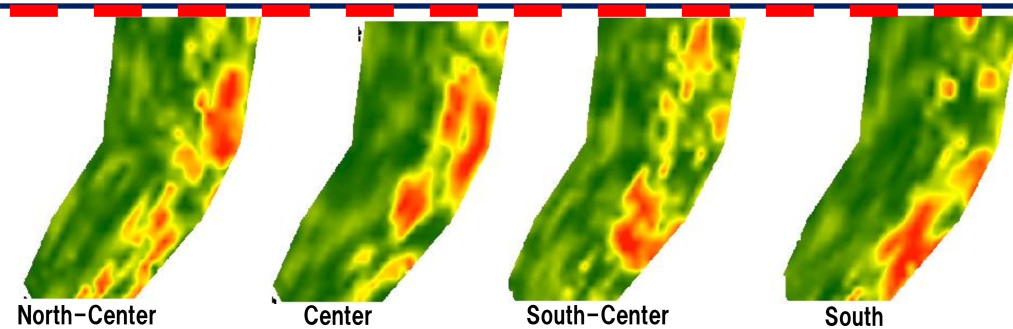
Example of stochastic tsunami hazard assessment



- Range of moment magnitude（3 cases）
- Position of asperity（5 cases : below figure）
- Variability of generation interval model（9 cases）
- Range of aleatory uncertainty（8 cases）

3×5×9×8＝1080 cases for hazard curve can be drawn.





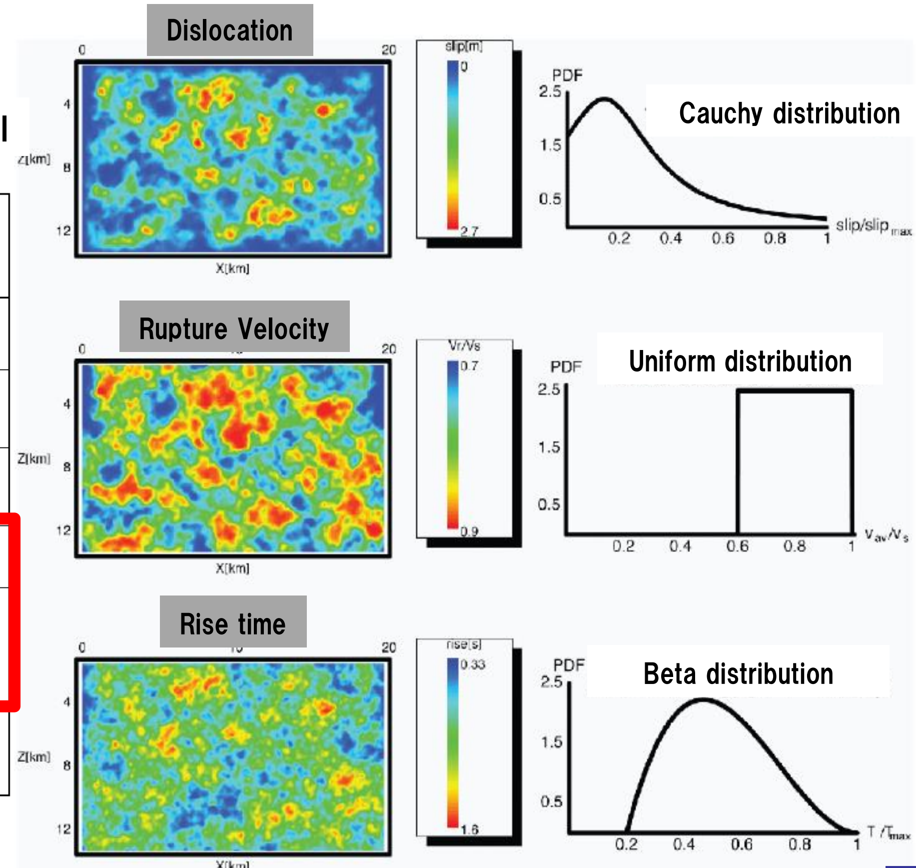
Distribution of dislocation generated from CRSP model

CRSP (Correlated Random Source Parameter) Model

◆One of kinematic fault model proposed by Liu et al. (2006)
◆We can obtain smooth distribution of dislocation on fault surface, also 2D correlation between dislocation and rupture velocity, dislocation and risetime.
◆Distribution of dislocation are generated from probabilistic density function calculated from statistical analysis for past distribution of dislocation.

Difference between Characteristic source model and CRSP model

	Characteristic source model	CRSP model
Earthquake Moment	not necessary	not necessary
Dislocation	set up in both asperity area and backgroud area	follow Cauchy distribution
Stress drop	set up in both asperity area and backgroud area	set up as average value of entire fault
Number of asperity	Empirical rule	not necessary
Position of asperity	The place where cumulative displacement is large or arbitrary	not necessary
Rupture velocity	Constant	Change on fault surface (Uniform distribution)



JNES(2008)

CRSP Model

Width and Length of fault (NIED(2013))

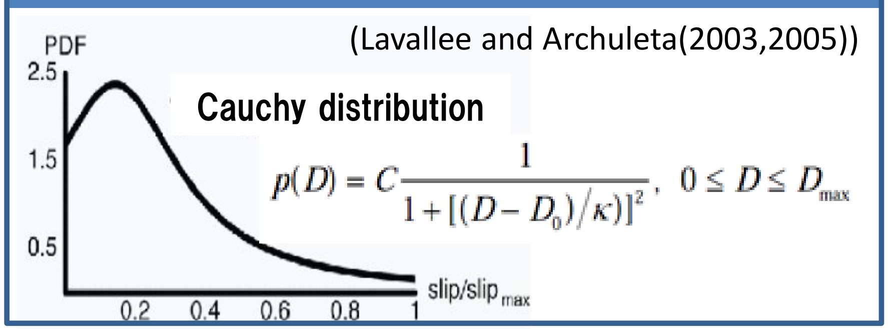
Definition of Mw(Moment Magnitude) (Uzu(2001))

Definition of average dislocation

Regarding huge subduction-zone earthquake, Dislocation proportion of deep area to shallow area is about **3 times**, which is calculated from data of the3.11 Tohoku earthquake **(Ishii(2013))**

Truncated-Cauchy distribution using in CRSP model

(Lavallee and Archuleta(2003,2005))

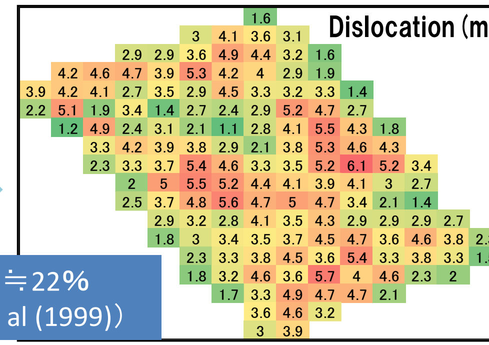


2D Gaussian distribution (perfectly random)

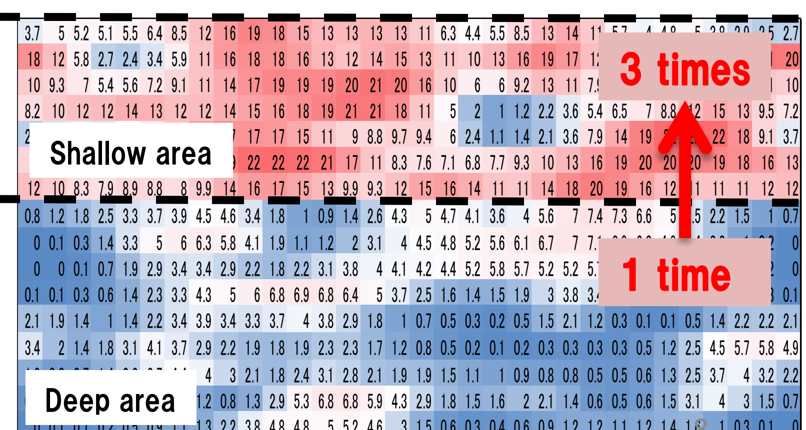
Multiplied by Fourier Spectrum in 2D Fourier space

$$F(k_x, k_y) = \left\{1 + \left[(k_x C_L)^2 + (k_y C_W)^2\right]\right\}^{-\nu/2}$$ (Mai and Beroza(2002))

Obtain modified 2D Gaussian distribution



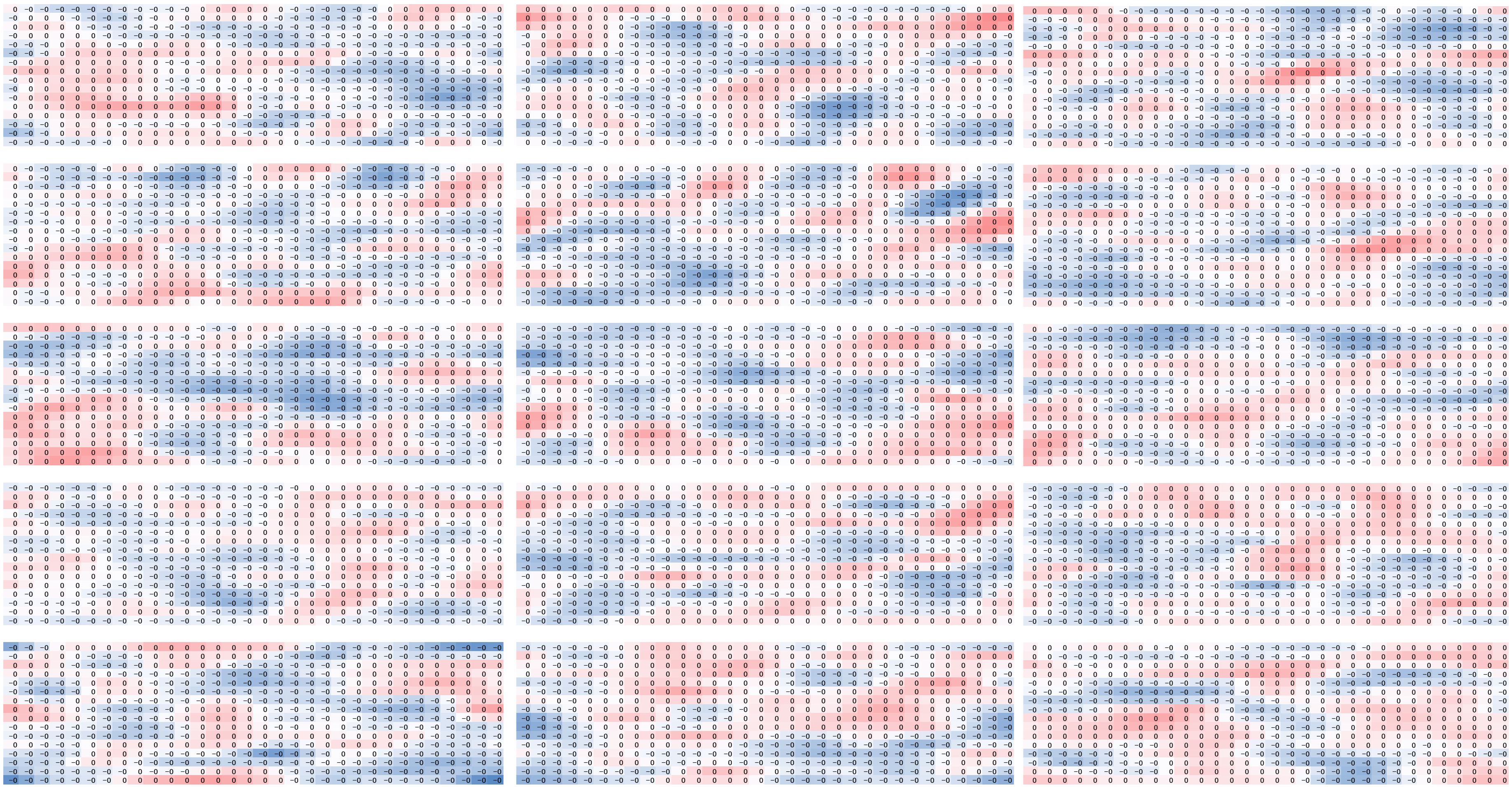
Asperity area≒22%
(Sommerville et al (1999))



Huge subduction-zone earthquake

Examples of dislocation distribution based on CRSP model

Distributions of slip（15 cases）



We can generate random slip distributions probabilisitically

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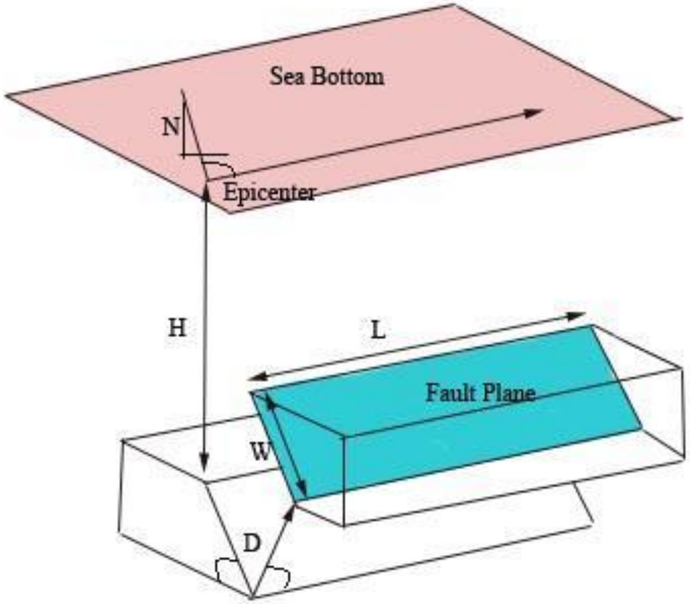
By using the distribution, tsunami numerical simulation are conducted

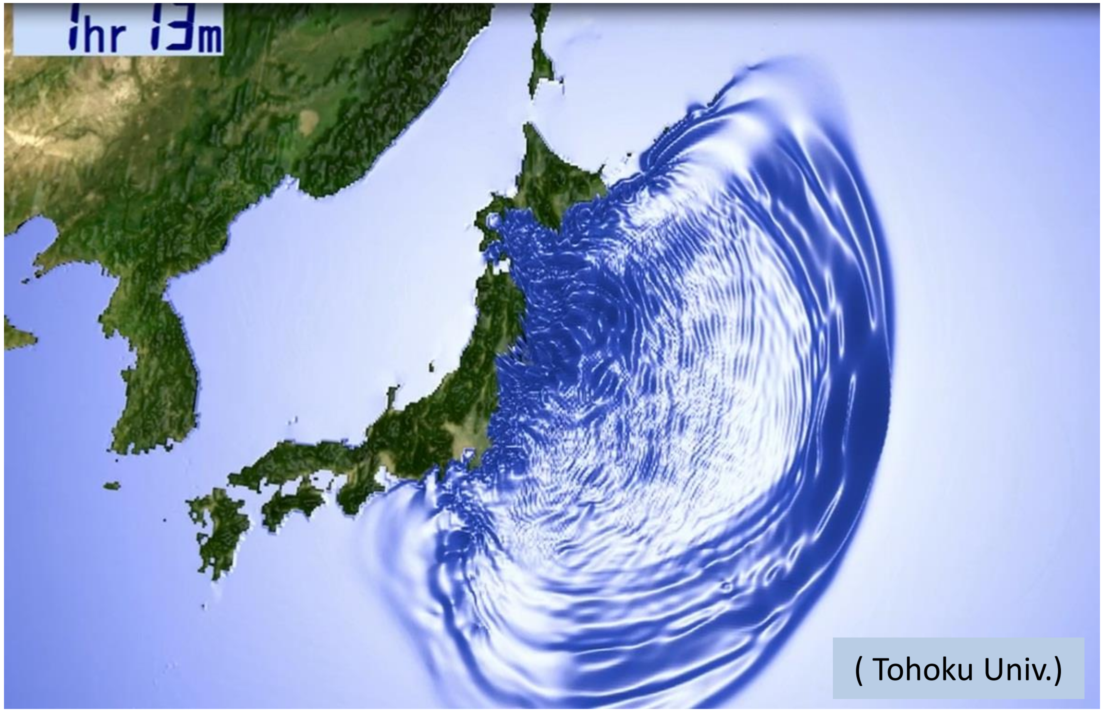
Fault parameters for tsunami numerical simulation

Outer fault parameter	Latitude	We used the parameters for developing Probabilistic Seismic Hazard Map published by NIED (National Research Institute for Earth Science and Disaster Prevention) in 2012
	Longitude	
	Length	
	Width	
	Depth	
	Dip	
	Strike	
	Rake	
	Dislocation	We evaluated through CRSP model

Position and shape of the fault



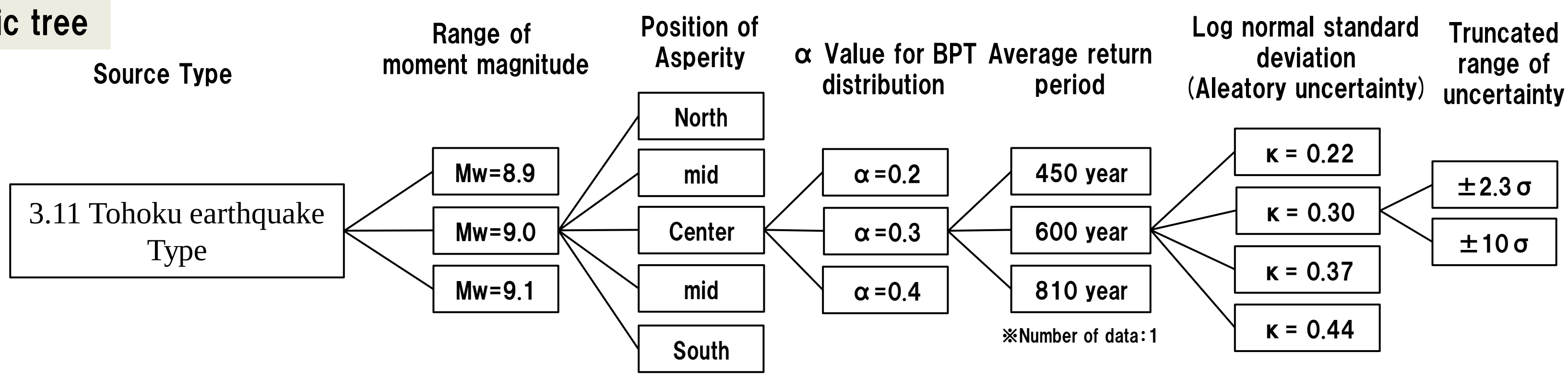
(UNESCO, 1997)

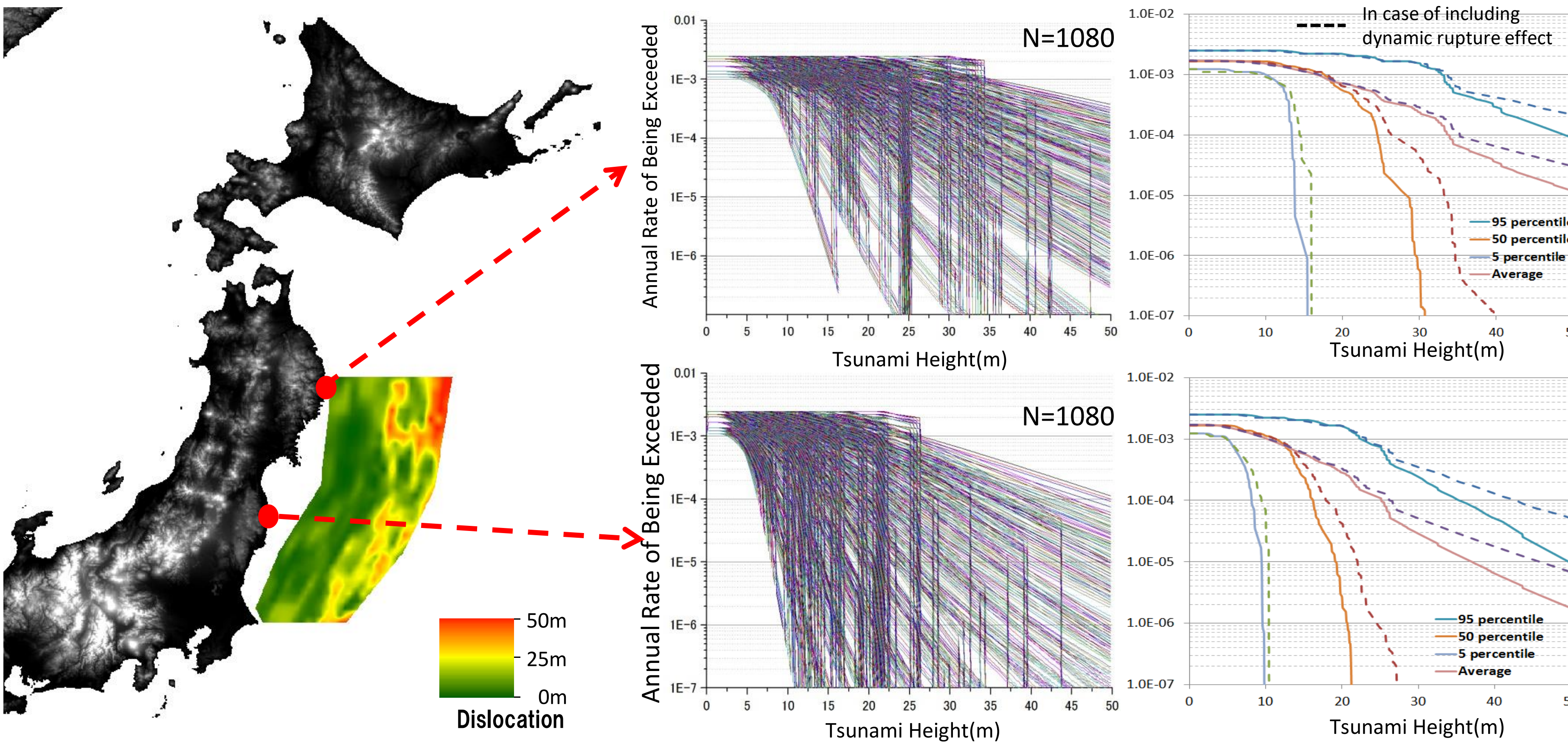


(Tohoku Univ.)

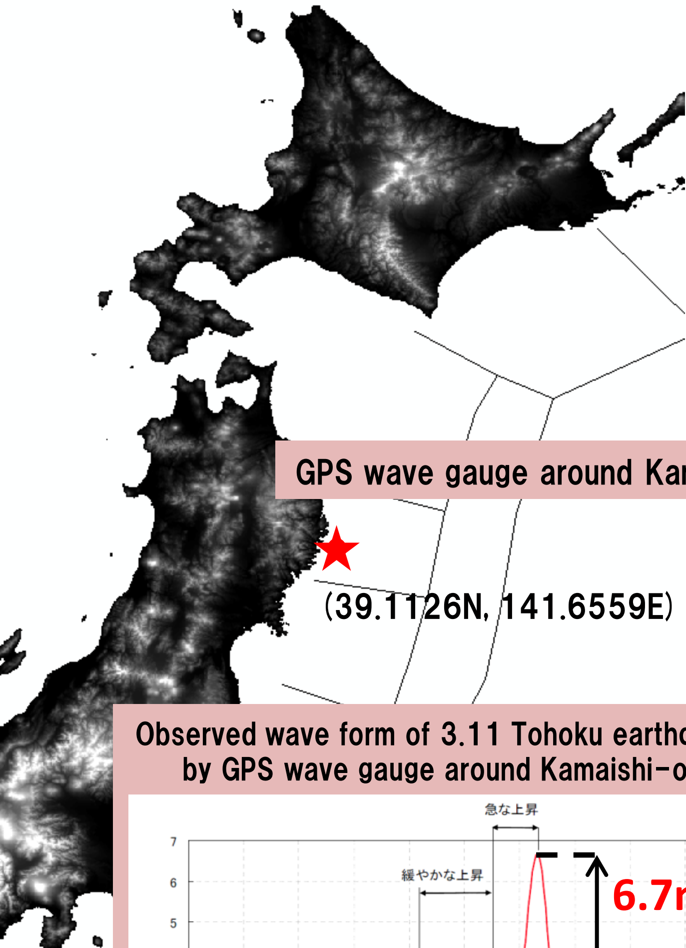
Example of stochastic tsunami hazard assessment

Logic tree

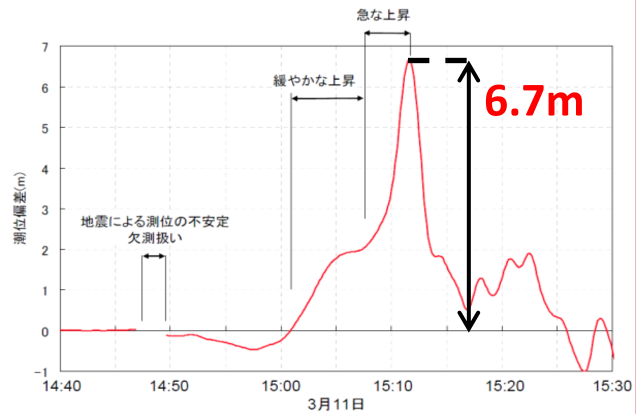




Comparison between 3.11 tsunami data and stochastic analysis

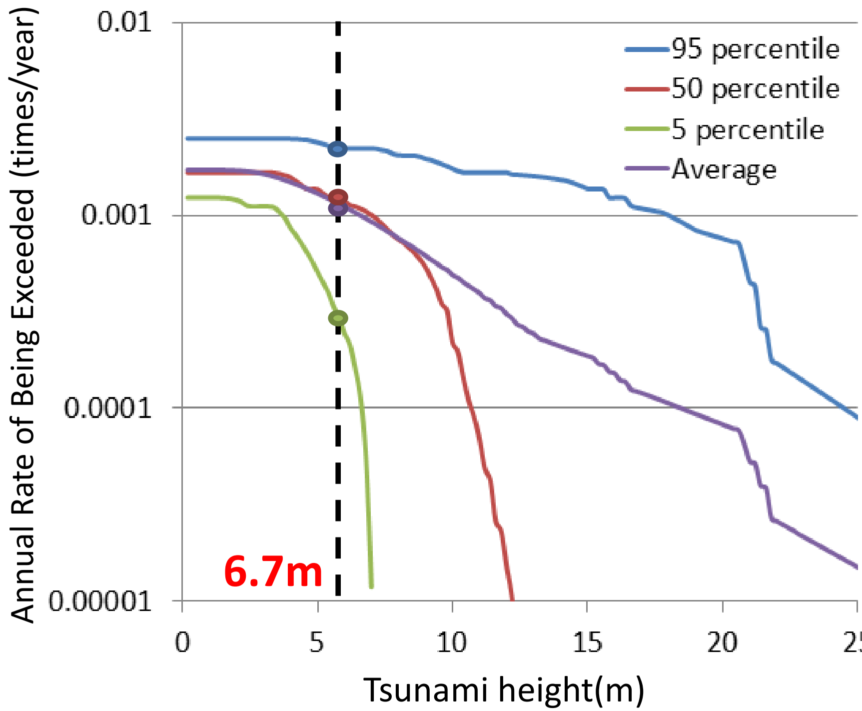


Observed wave form of 3.11 Tohoku earthquake by GPS wave gauge around Kamaishi-oki



図－２　岩手南部沖ＧＰＳ波浪計が捉えた津波の第１波

Hazard curve at GPS wave gauge

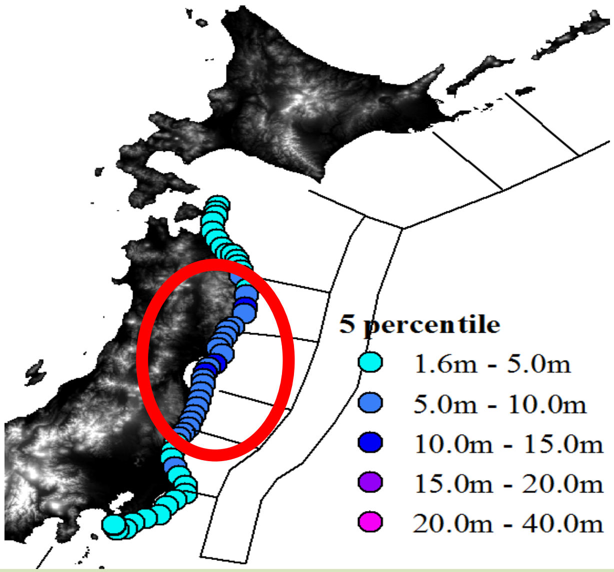


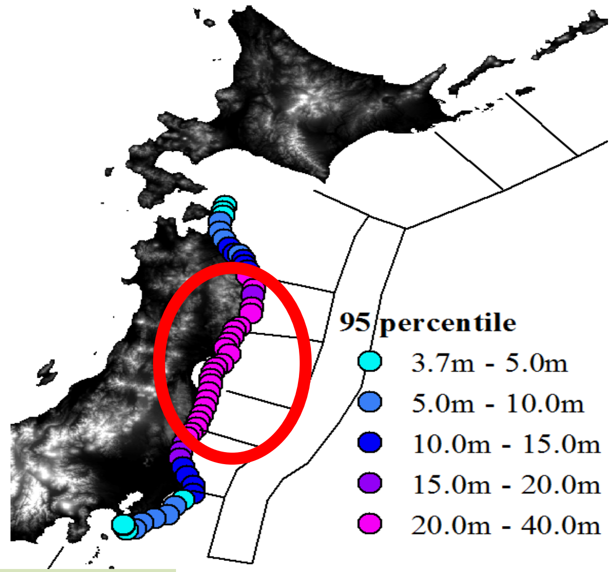
	5 percentile	Average	50 percentile	95 percentile
Annual Exceedance Probability (Times/Year)	0.0000834	0.000979	0.001064	0.002222
Return Period (Year)	12000	1022	940	450

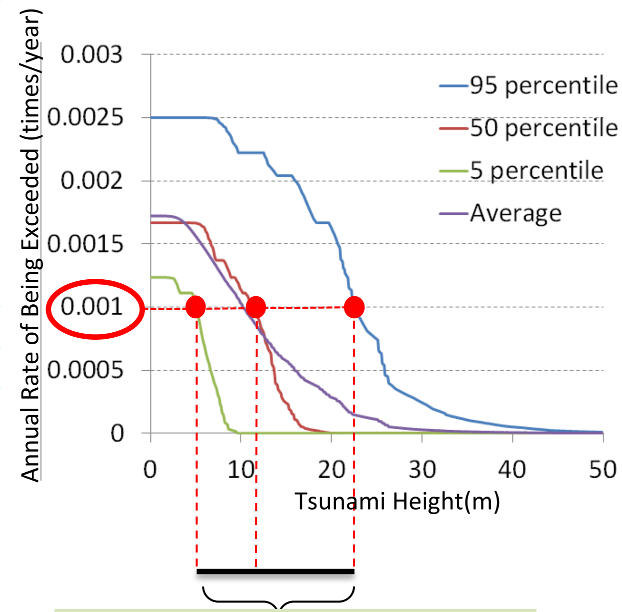
Tsunami height 6.7m corresponds to range of return period from 450 year to 12000 year (5 percentile～95 percentile).

Results of stochastic wave height and uncertainty

Wave height（1000 years return period）on 50 m off-shore point

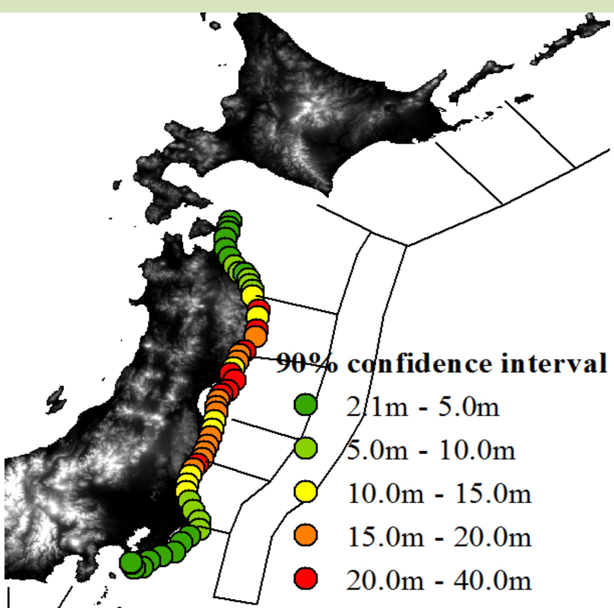


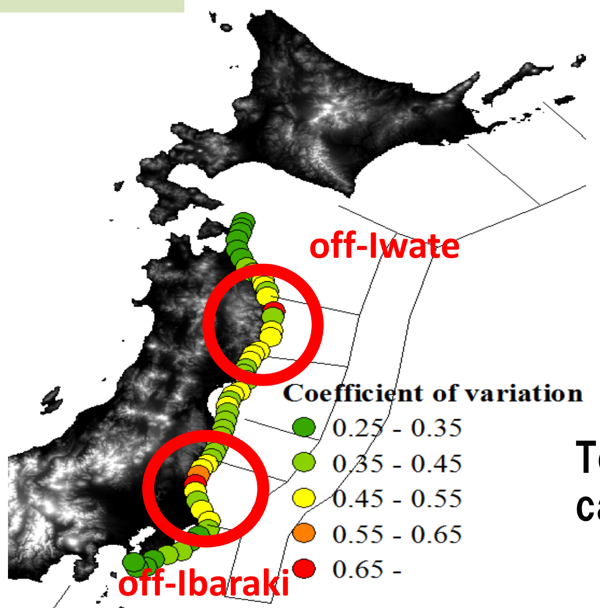




90% confidence interval

90% confidence interval and Coefficient of variation





Coefficient of variation
= Standard deviation / Average

To visualize uncertainty concretely
can be **useful for risk communication**

Conclusion & Future work

Conclusion

◆**We evaluated stochastic tsunami height based on the knowledge of the Tohoku tsunami.**

－We included four valuable lessons from the Tohoku earthquake into the assessment.

－In order to get slip variability of the fault, CRSP model (stochastic model) was used.

－Wave height in Tohoku tsunami corresponded to range of return period from 450 year to 12,000 year.

◆**We visualized regional difference of uncertainty**

－Coefficient of variation of wave height changes depending on the area.

－To visualize uncertainty concretely can be useful for risk communication.

Future work

◆**Evaluation of uncertainties due to tide variation**

－Astronomical tide

－Meteorological tide

－Sea level rise due to global warming (IPCC(2013))

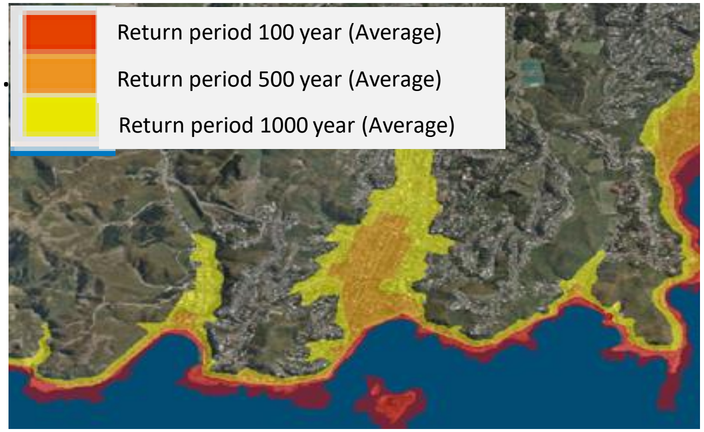
◆**Development of stochastic tsunami hazard map**

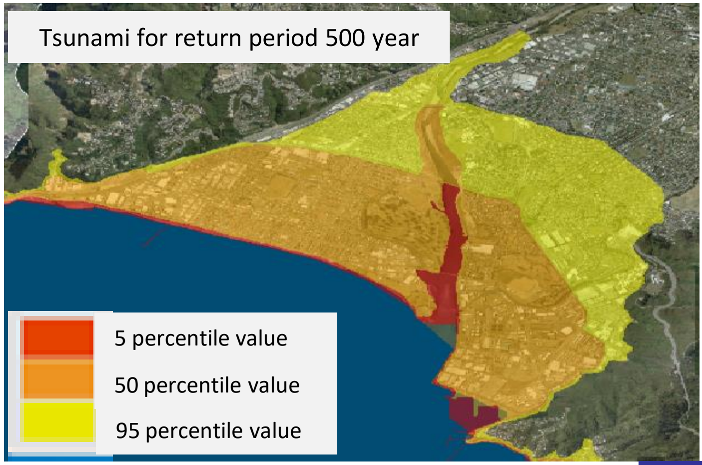
－100 year, 500 year, 1000 year

－5% tile value, 50% tile value, 95% tile value

◆**Combining hazard curve and fragility curve into quantitative evaluation for risk and uncertainty**

Example of stochastic tsunami hazard map





Adapted from Wellington city (2013)

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Thank you for your kind attention

TOKIO MARINE