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Stochastic analysis and uncertainty assessment of tsunami wave height using a random source parameter model

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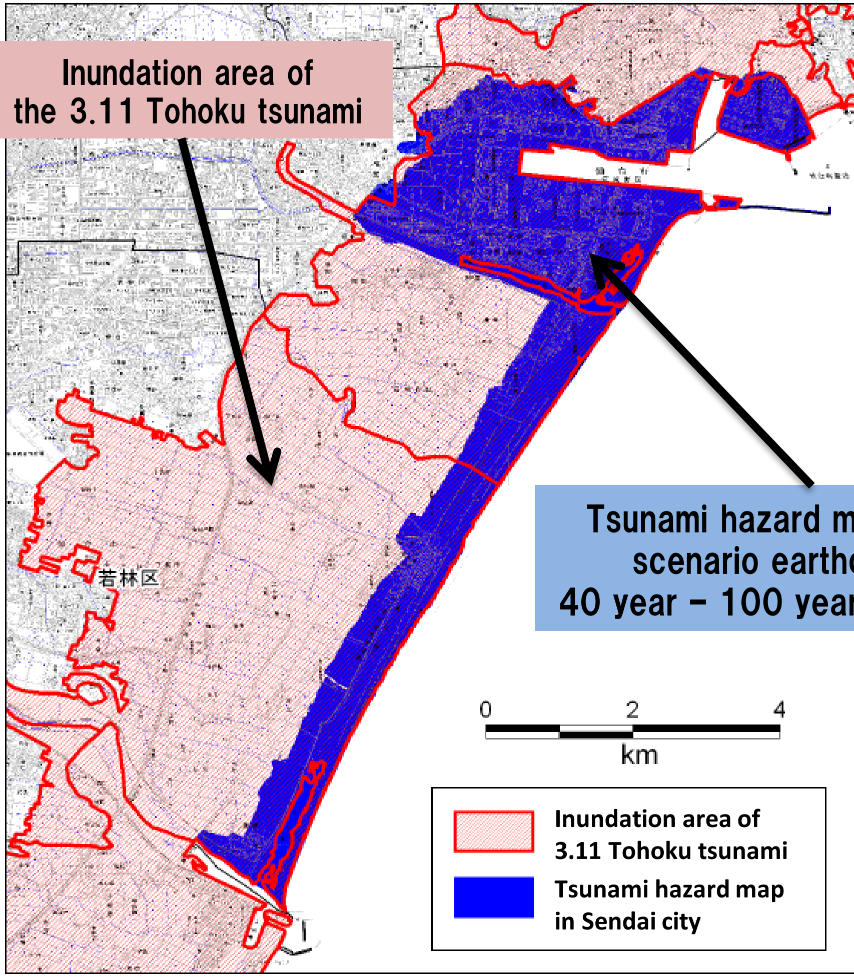
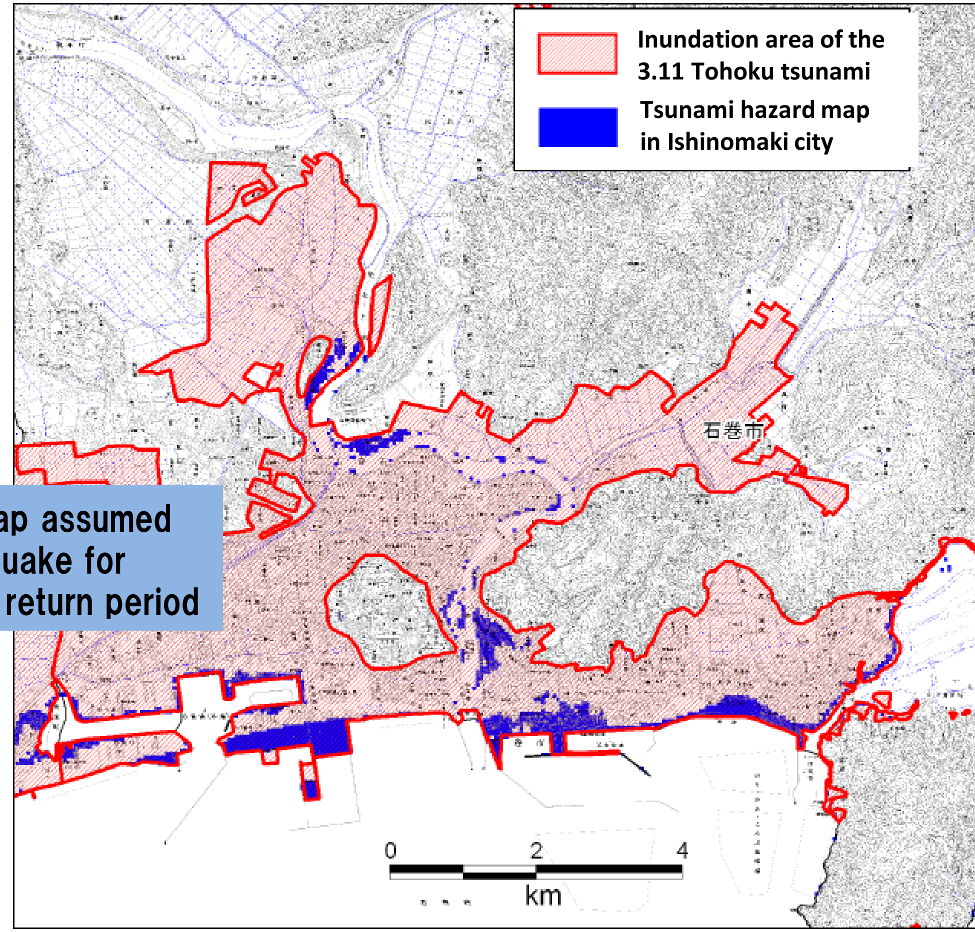
Tsunami hazard map before the 3.11 earthquake

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 based on an earthquake scenario. We need stochastic tsunami hazard map including information for uncertainty based on stochastic tsunami hazard assessment.

In order to quantify the uncertainty of estimated tsunami, we need to know the nature.

Uncertainties of tsunami simulation

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

(Probability Concepts in Engineering (1975))

◆ Epistemic uncertainty

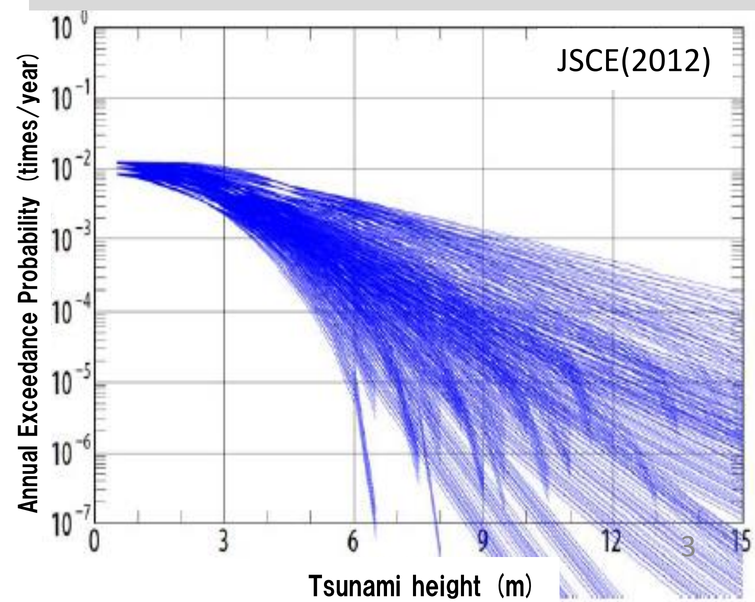
- This uncertainty arises from a lack of knowledge or data.
- Captured by logic trees with alternative credible models.

◆ Aleatory uncertainty

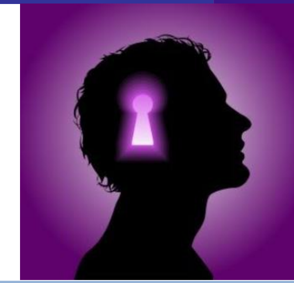
- Unexplained difference between a model prediction and observed data.
- It can only be estimated from validation exercises in which the predicted and observed tsunami wave heights are compared.

(Pacific Gas & Electric Company (2010))

Tsunami hazard curves including uncertainty

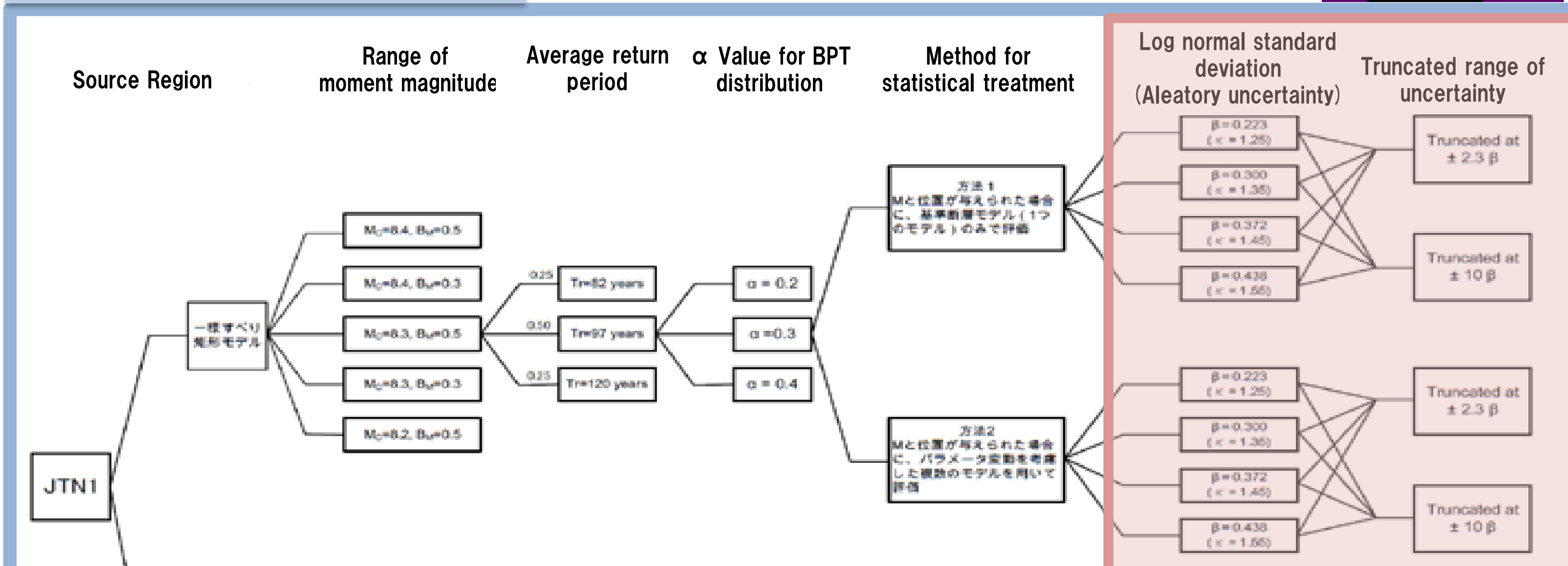


Evaluation methods differ due to the kind of uncertainties.



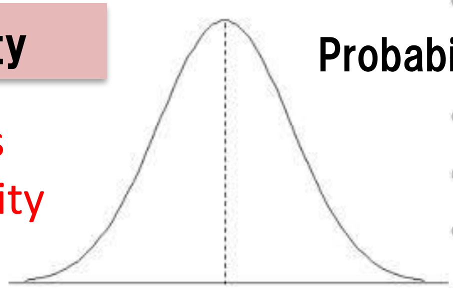
◆ Epistemic uncertainty

Alternative models are captured by logic tree.

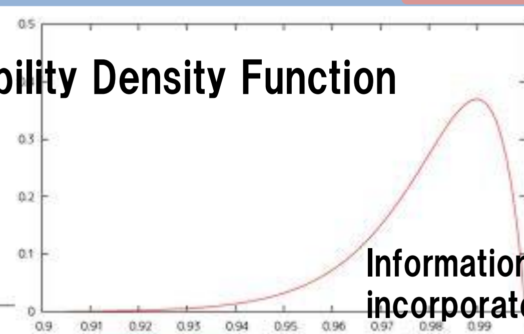


◆ Aleatory uncertainty

Aleatory uncertainty is quantified by probability density function.



Probability Density Function



Information for aleatory uncertainty is incorporated into the logic tree.

Evaluation methods for uncertainties

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

◆ Epistemic uncertainty

◆ Variability of slip distributions in earthquake fault

- To capture the uncertainty, we artificially generated many possible slip fault models by using CRSP model (Liu et al.(2006)), which have not occurred so far.
- Lessons learned fromthe 3.11 Tohoku earthquake about slip distribution by Ishii(2013) was used in evaluating the fault models.

◆ Aleatory uncertainty

◆ Difference between Variability of a Tohoku tsunami model and observed data

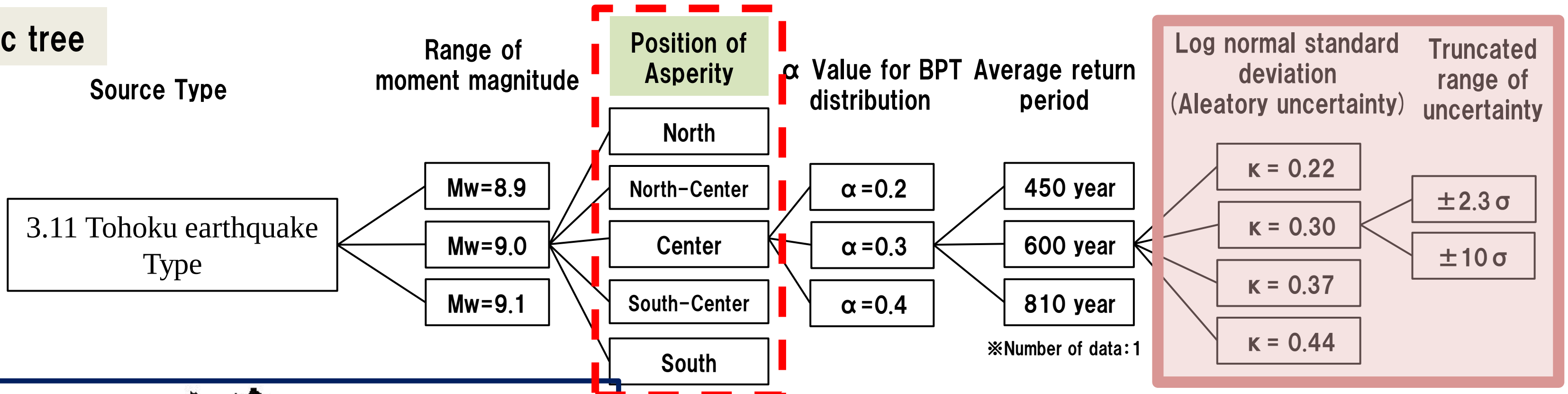
- Validation exercises in which the predicted and observed tsunami wave heights in the 3.11 tsunami (JNES：Japan Nuclear Energy Safety) was used.

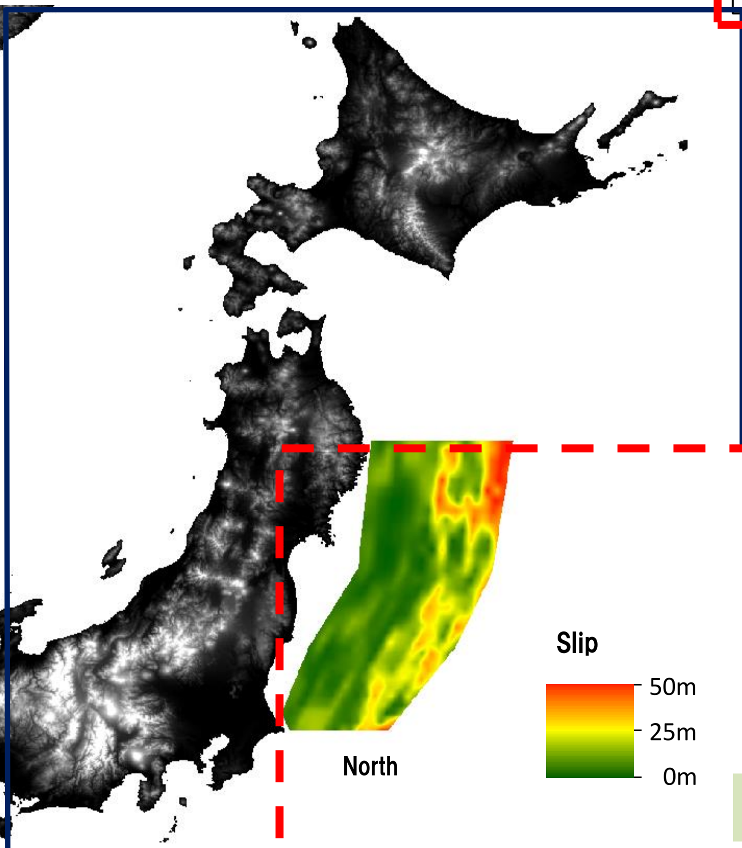
◆ Variability due to dynamic fault rupture effect

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

Example of stochastic tsunami hazard assessment

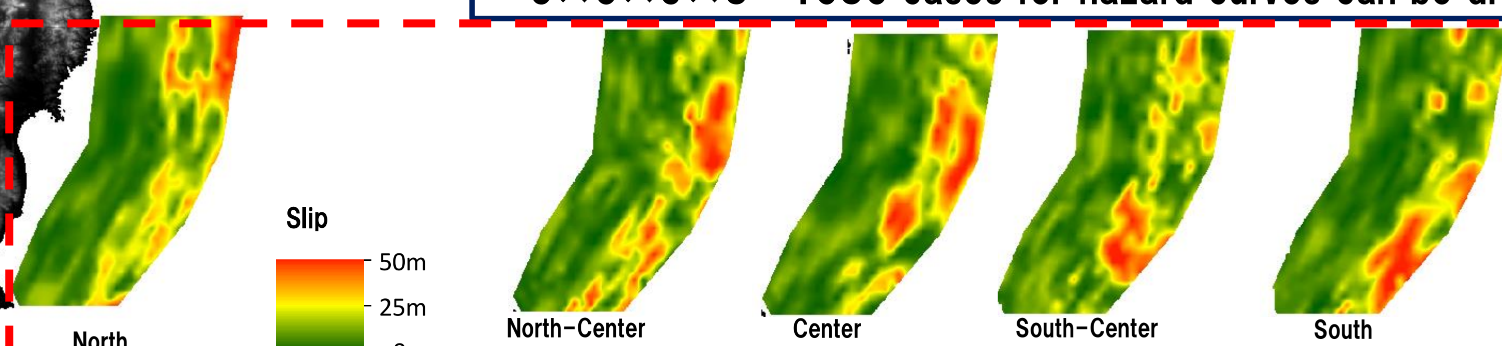
Logic tree





- Range of moment magnitude (3 cases)
- Position of asperity (5 cases: below figure)
- Variability of generation interval model (3×3 = 9 cases)
- Variability of aleatory uncertainty (4×2 = 8 cases)

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



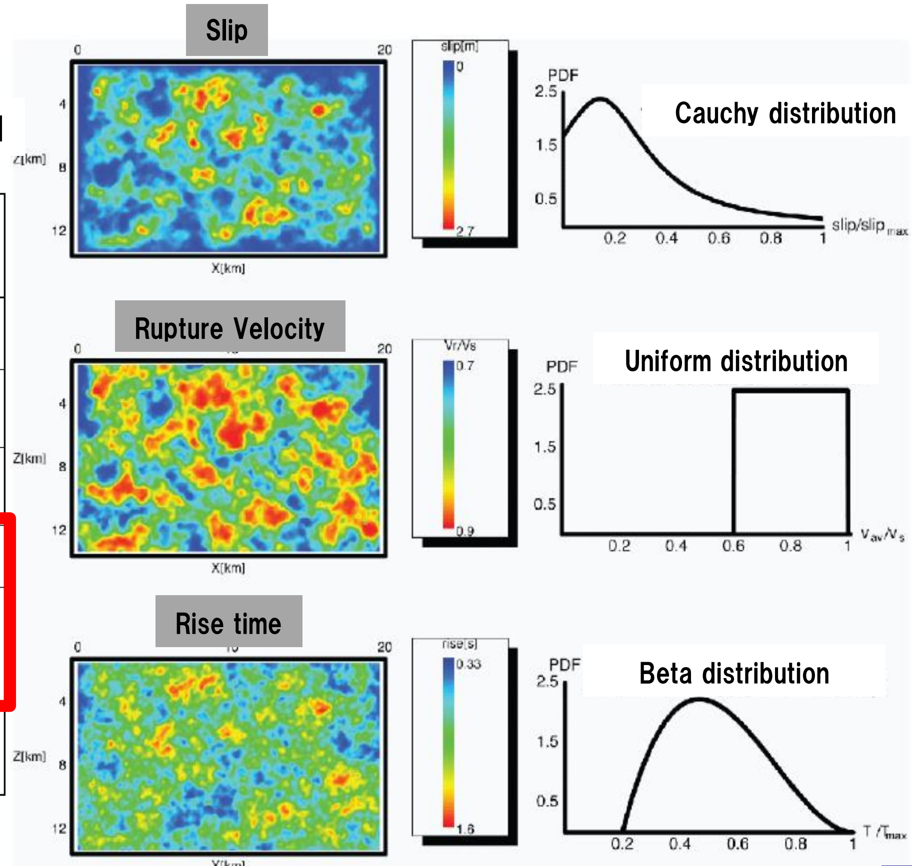
Slip distributions generated from CRSP model

CRSP（Correlated Random Source Parameter）Model

◆One of kinematic fault model proposed by Liu et al. (2006).
◆We can obtain smooth distribution of slip on fault surface, also 2D correlation between slip and rupture velocity, slip and risetime by using this model.
◆Asperities in the fault are probabilistically-generated based on past seismic data.

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))

↓

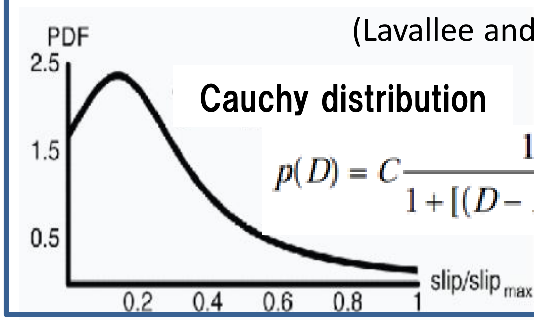
Definition of average slip

Regarding huge subduction-zone earthquake, slip rate between deep area and shallow area is about **3 times**, which is calculated from data of the 3.11 Tohoku earthquake **(Ishii(2013))**

↓

Truncated-Cauchy distribution using in CRSP model

(Lavallee and Archuleta(2003,2005))



$$p(D) = C\frac{1}{1+[(D-D_0)/\kappa)]^2},\quad 0 \le D \le D_{max}$$

2D Gaussian distribution (perfectly random)

↓

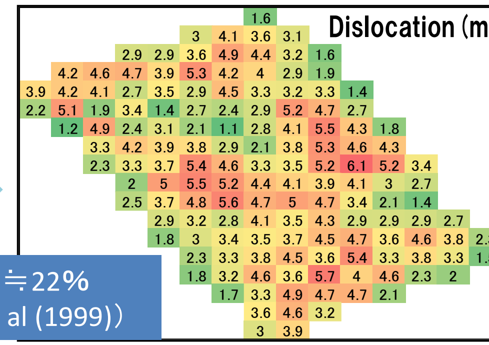
Multiplied by Fourier Spectrum in 2D Fourier space

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

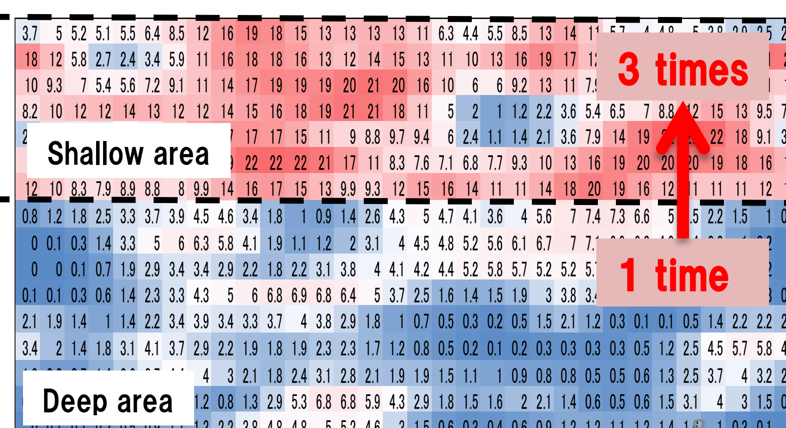
↓

Obtain modified 2D Gaussian distribution

→



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



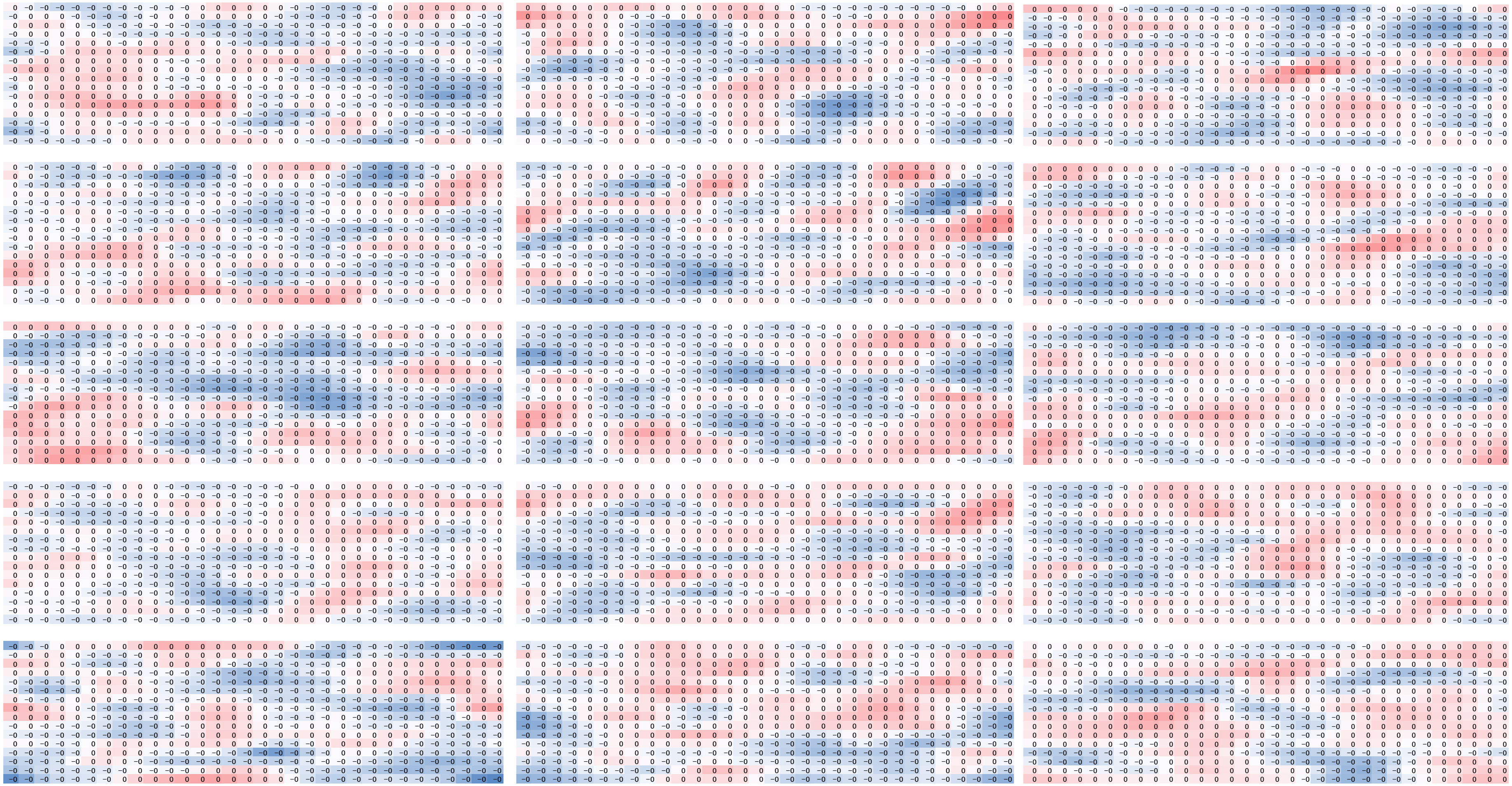
Huge subduction-zone earthquake

IRIDeS International Research Institute of Disaster Science 災害科学国際研究所

Examples of slip distributions using CRSP model

TOHOKU UNIVERSITY

Slip Distributions（15 cases）



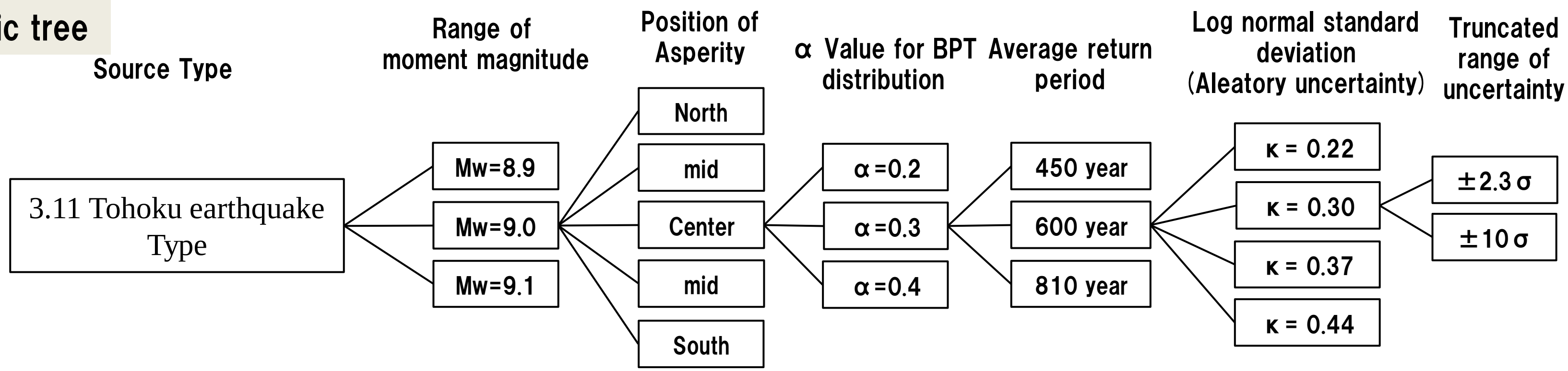
We can generate many slip distributions artificially using the CRSP model.

↓

By using the distributions, many tsunami numerical simulations are conducted.

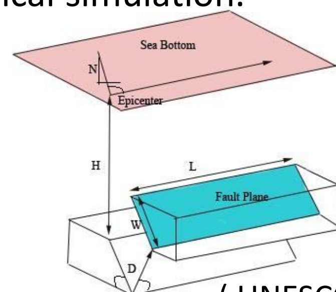
Fault parameters for tsunami numerical simulation

Logic tree



◆We generated earthquake parameters using the slip distribution and conditions based on the branches of the logic trees and conducted tsunami numerical simulation.

【Earthquake parameters】
Longtitude, Latitude, Length, Width, Dip, Rake, Slip, Depth, Strike (9 paremters)



(UNESCO, 1997)

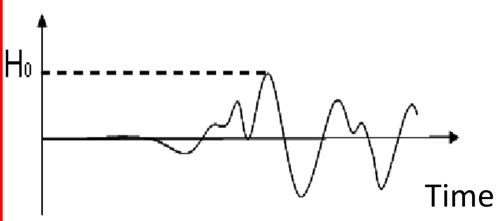
Governing equation	2D non-linear shallow water equation（Tohoku University TUNAMI model）
Coordination system	Lon-Lat coordination
Numerical integration method	Staggered leap-frog differential method
Mesh size	15 seconds（approximately 450m）
Time step	1.2 seconds
Ground displacement	Okada(1985) equation

Calculation condition


Calculation domain

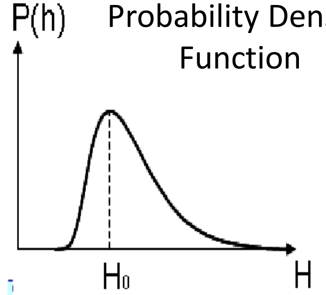
Calculating stochastic tsunami height using hazard curve

◆We can obtain tsunami hazard curve, which is relationship between tsunami height and annual exceedance probability, by applying the logarithm of standard deviation in the logic tree to calculated maximum tsunami height and converting it to exceedance probability distribution.



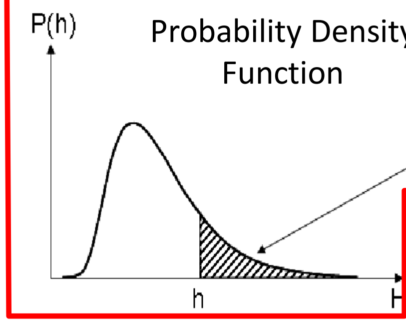
H0 Maximum tsunami height

A wave form and maximum tsunami height value for each mesh point



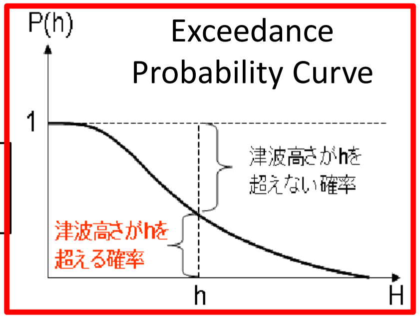
P(h) :

The function indicates that tsunami heights vary around "Ho".



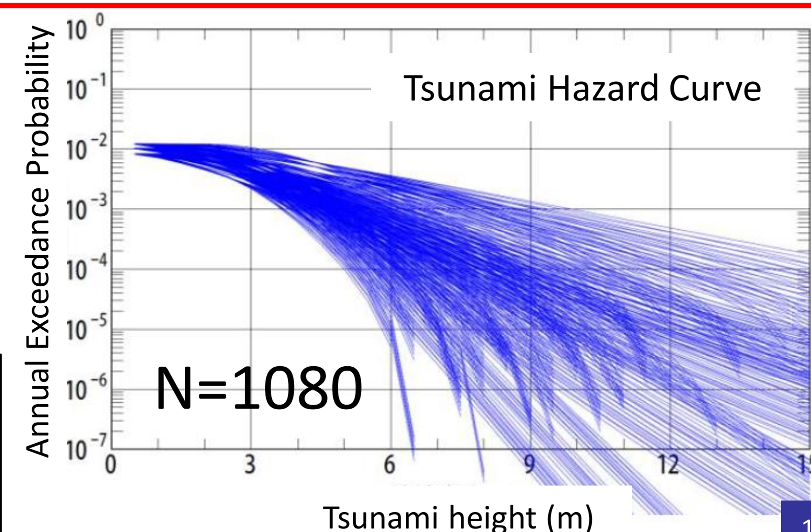
The slashed line area denotes exceedance probability at tsunami height "h".

Plot the slashed line area with changing "h"



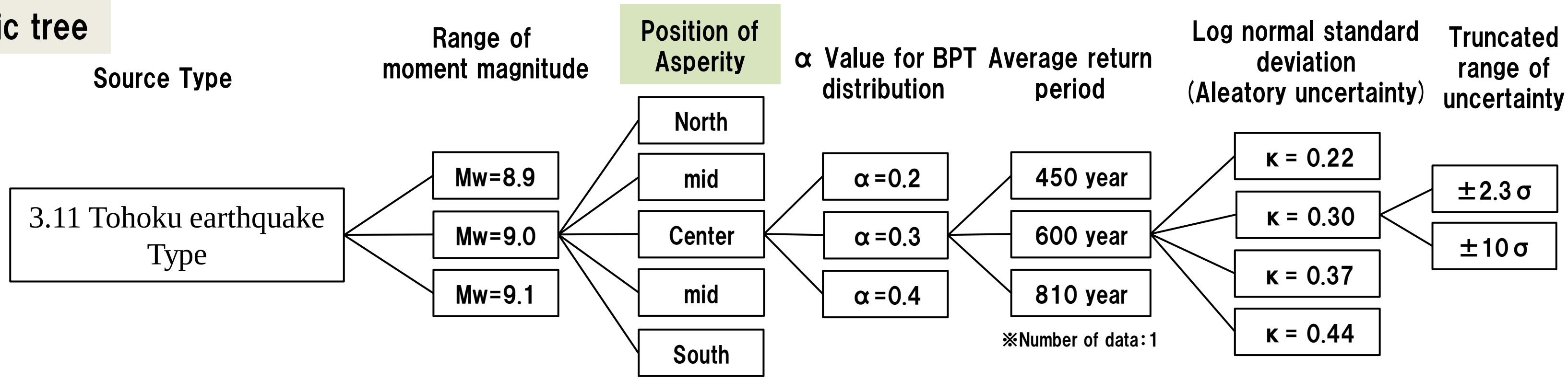
(The Japan Society of Civil Engineers (2012))
(Japan Nuclear Energy Safety Organization(2014))

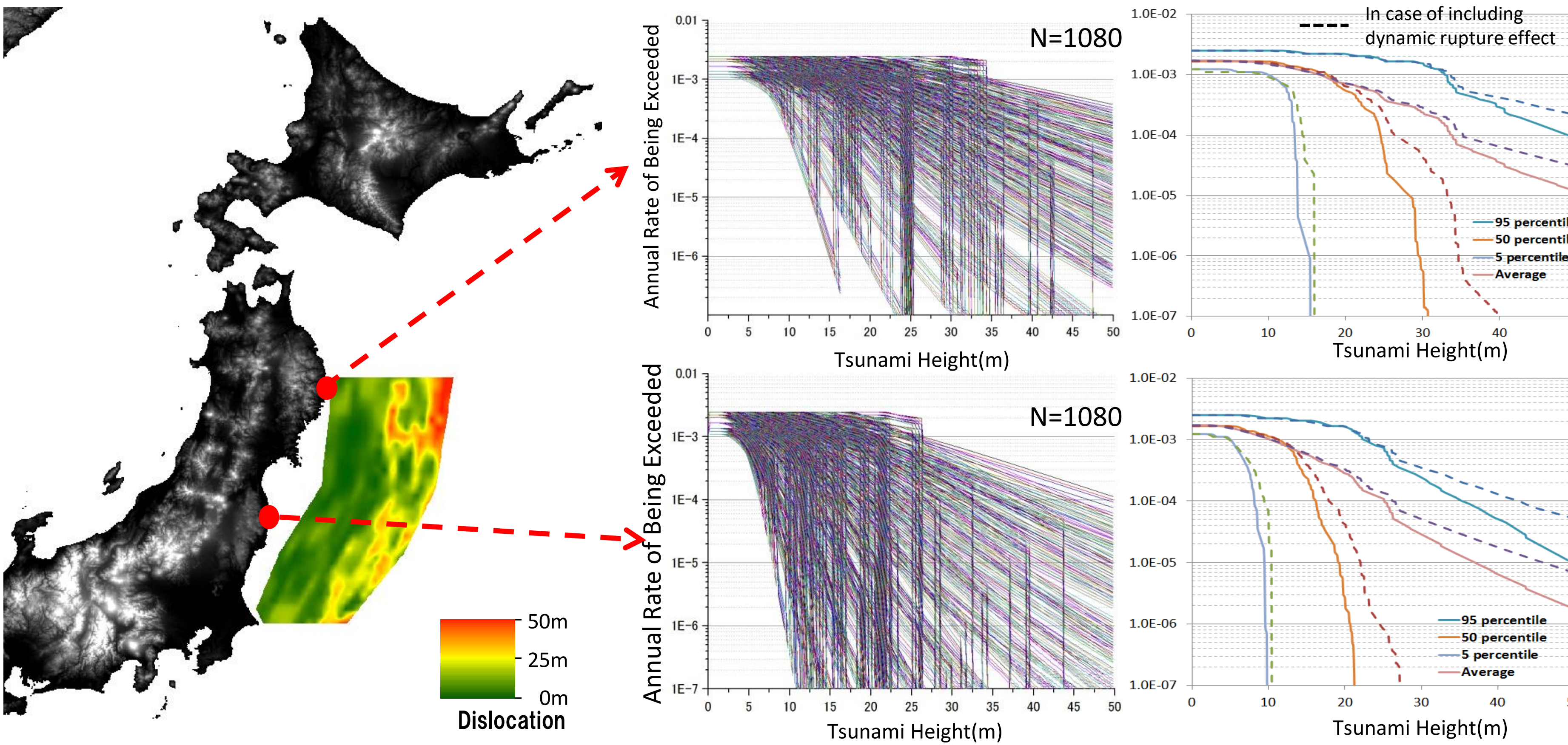
Tunami hazard curve by using the information for return period of target fault.



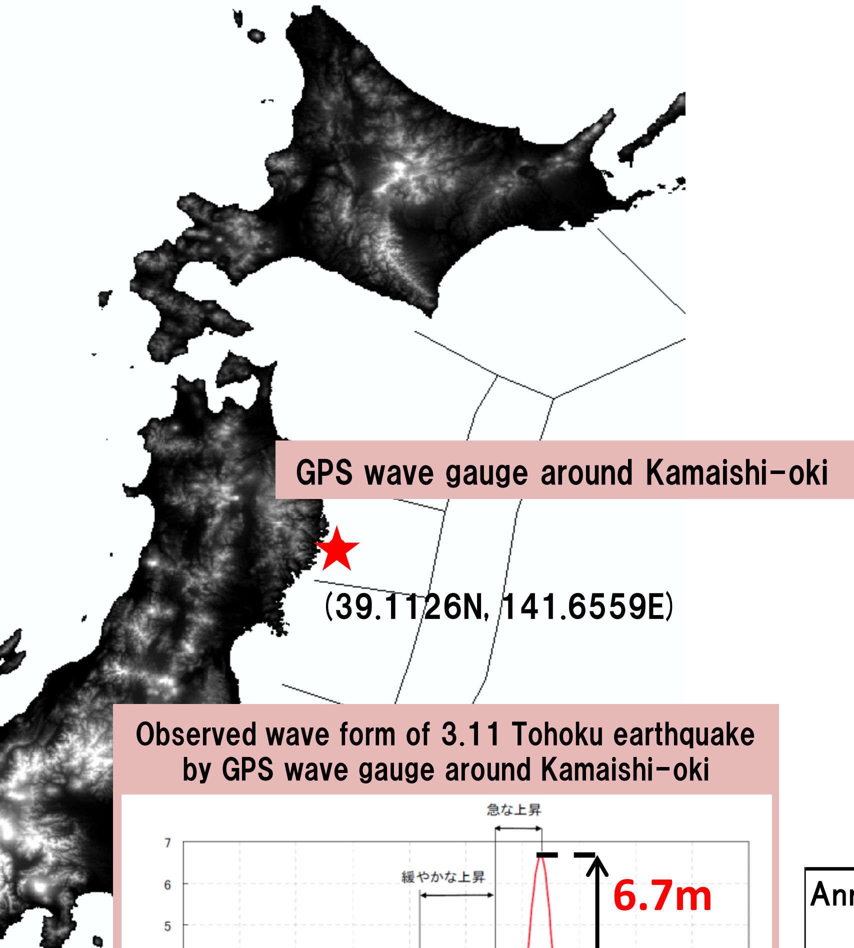
Example of stochastic tsunami hazard assessment

Logic tree

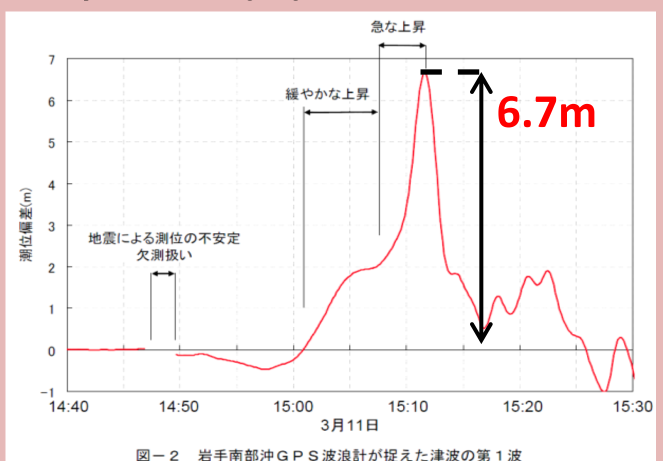




Comparison between the 3.11 tsunami data and stochastic analysis

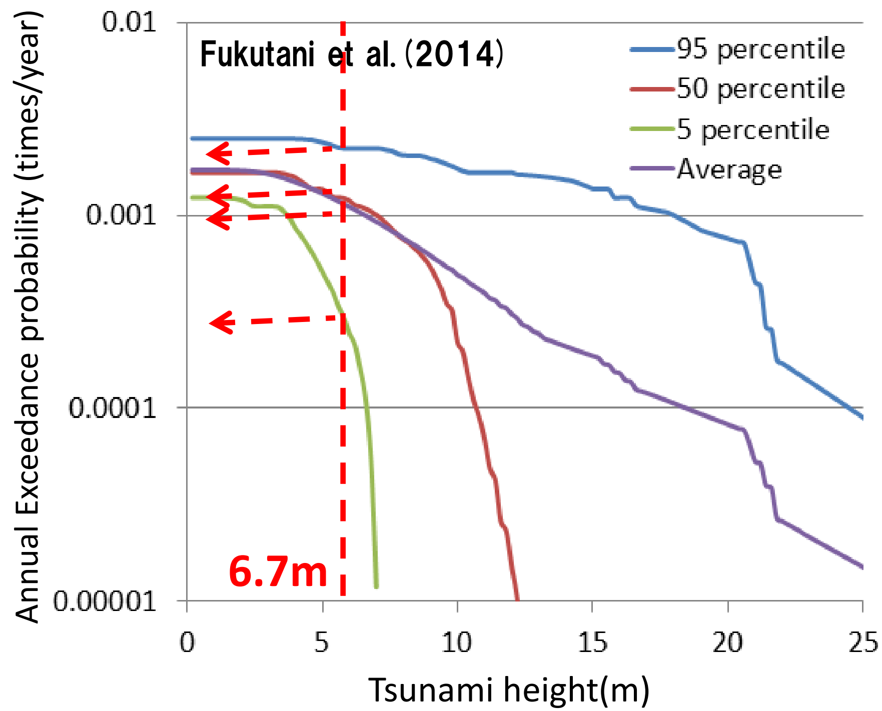


Observed wave form of 3.11 Tohoku earthquake by GPS wave gauge around Kamaishi-oki



図－２　岩手南部沖ＧＰＳ波浪計が捉えた津波の第１波

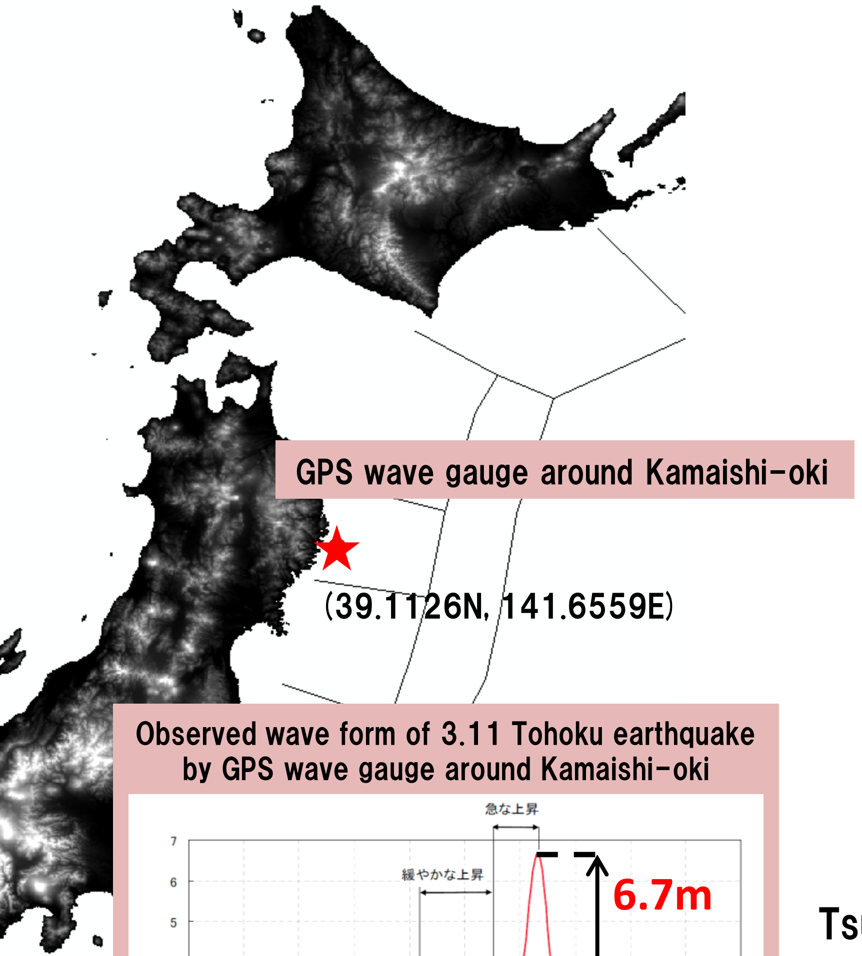
Hazard curve at GPS wave gauge



	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 heights have large uncertainty.
The tsunami height 6.7m corresponds to range of return period from 450 year to 12000 year (5 percentile～95 percentile).

Comparison between the 3.11 tsunami data and stochastic analysis



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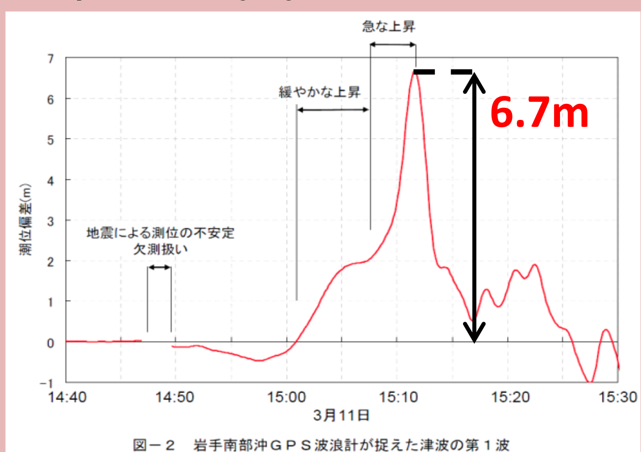

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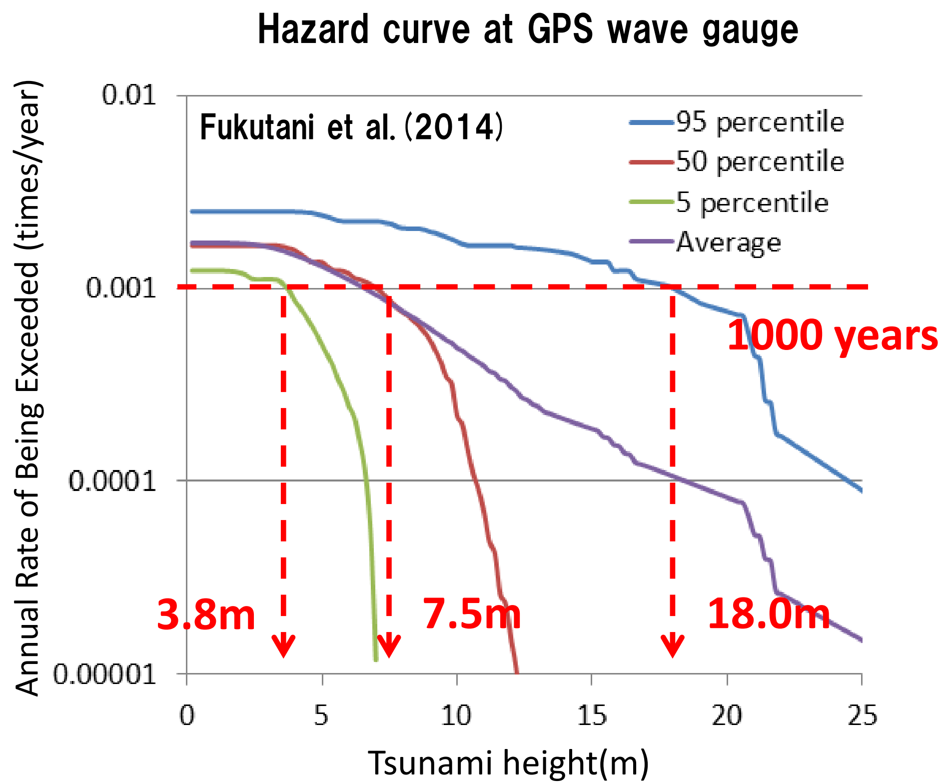
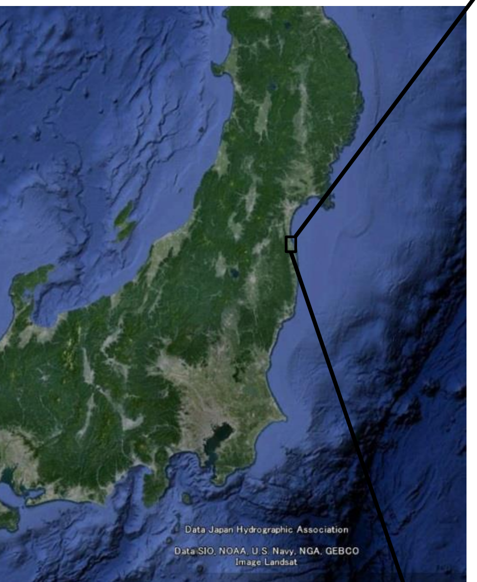


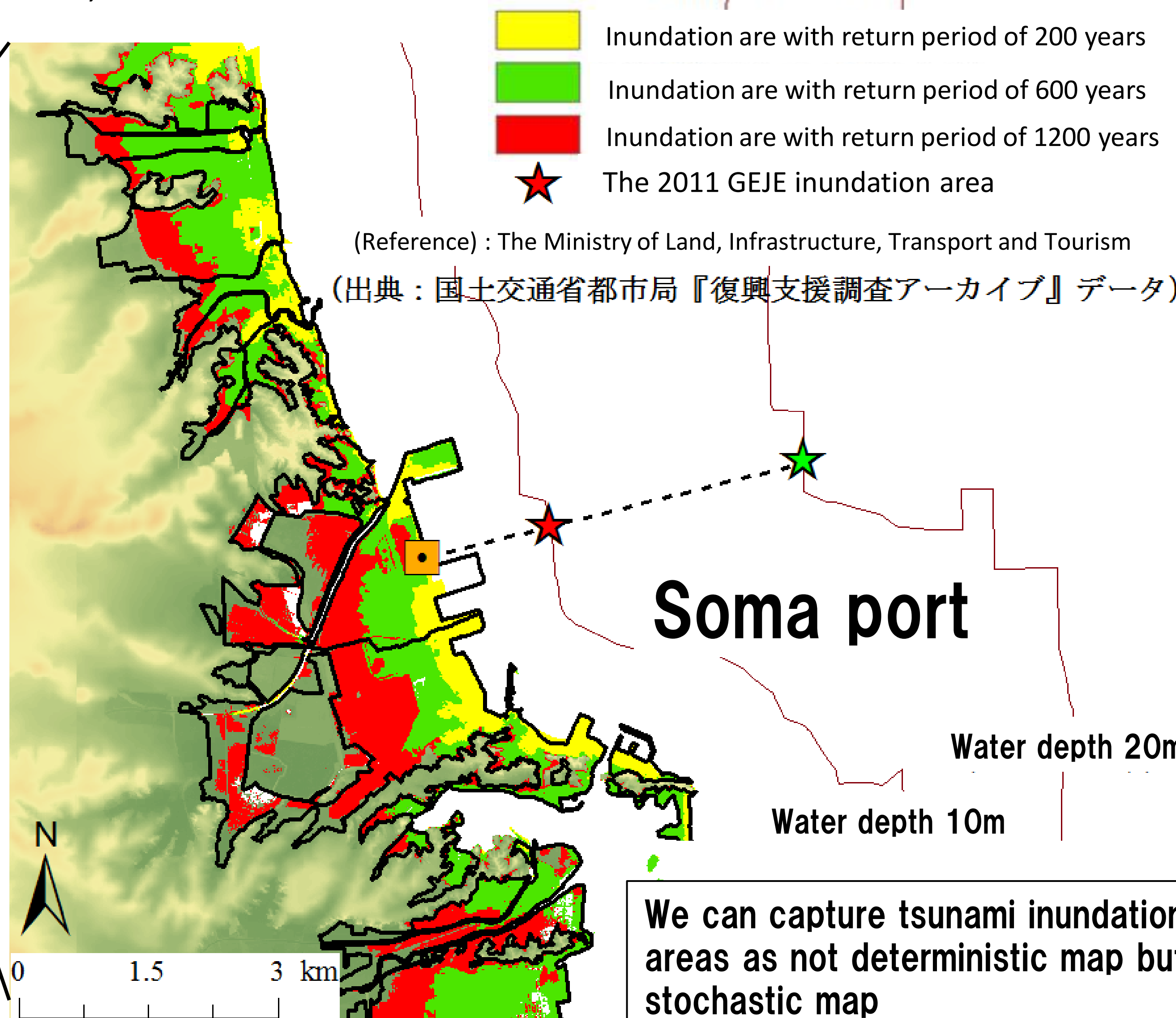
Tsunami heights for various return periods vary also widely.

Tsunami heights for return period 1000 years are the wave heights from 3.8m to 18.0m (5 percentile～95 percentile).

Stochastic tsunami hazard map

If we use the hazard curve data, we can estimate tsunami inundation area





We can capture tsunami inundation areas as not deterministic map but stochastic map

I will talk about this map at “2014 AGU fall meeting” to be held in Sanfrancisco in the next week.

An example of inundation map for Soma-city in Japan

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Thank you for your kind attention

TOKIO MARINE