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A Stochastic Analysis and an Uncertainty Assessment of Tsunami Wave Height Using a Random Source Parameter Model

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Research Background

As for stochastic analysis methods for tsunami height, a method considering epistemic uncertainty as logic trees and aleatory uncertainty as probabilistic distributions is general in Japan. In this study, we focused on variability of tsunami height in case that we deal with heterogeneous slip on a fault as epistemic uncertainty by using the logic trees. In addition, we quantitatively evaluated the uncertainty of tsunami height.

①Correlated Random Source Parameter Model

We used CRSP (Correlated Random Source Parameter) model developed by Liu et al. (2006)) in order to generate heterogeneous slip on a fault. If we use the model, we can generate hypothetical two dimensional slip distributions on the fault based on a probabilistic distribution of slip rate estimated from past seismic recording data.

An overview of the model is as follows. First, a two dimensional random Gaussian distribution is converted to wave number space by using 2 dimensional Fourier transform after multiplying below filter (Mai and Beroza (2002))

$$F(k_x,k_y)=\{1+[(k_xC_L)^2+(k_yC_W)^2]\}^{-\nu/2} \tag{1}$$

$$log_{10}(C_L)=-2.5+Mw/2 \tag{2}$$

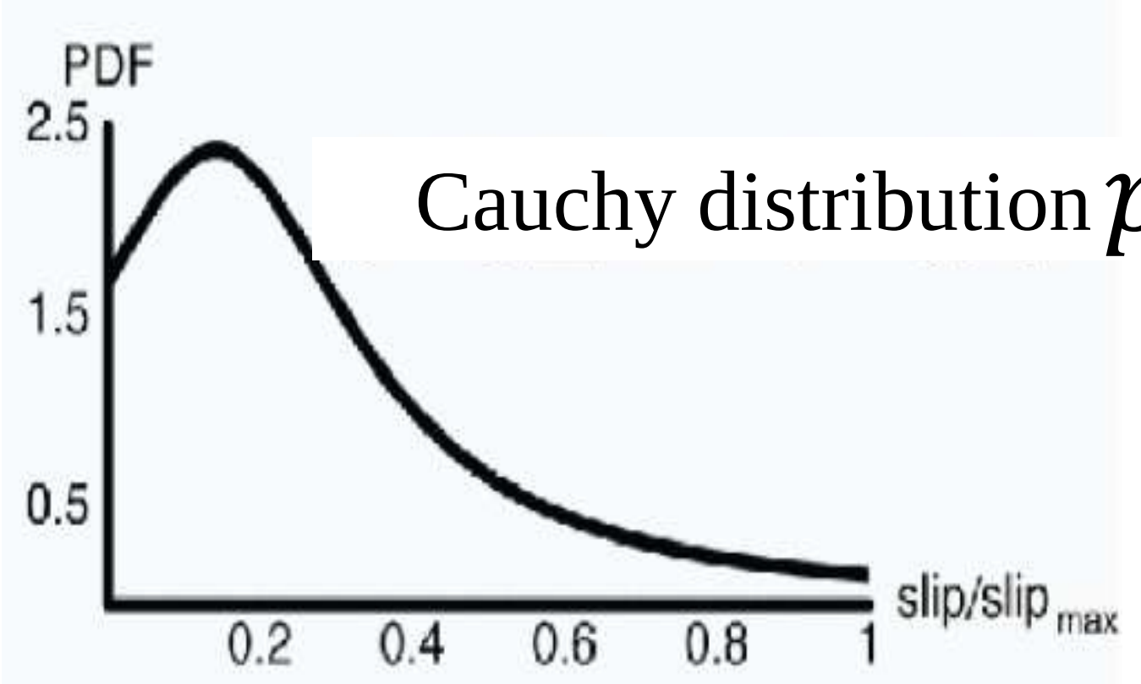
$$log_{10}(C_W)=-1.5+Mw/3 \tag{3}$$

Where, kx: wave number along fault strike, ky: wave number along fault dip, ν: fractal dimension, CL: correlated length along fault strike, Cw: correlated length along fault dip, Mw: moment magnitude

Next, after we apply Fourier inverse transform to the converted distribution, we can get random Gaussian distributions, which theirs amplitude in the wave number space attenuate following $k^{-\nu/2}$. Finally, we covert the distributions to a slip rate distributions using NORTA method (Cairo and Neilson (1997)) because the slip rate distribution follows Truncated-Cauchy Distribution (Fig.1). In this study, we divided the fault into shallow area and deep area, and apply the Truncated-Cauchy distribution to each area. We adopt three times by Ishii et al. (2013) as magnification factor of dislocation of shallow area and deep area. In each area, we use below value as average slip D_{ave} and maximum slip D_{max};

$$D_{max}=2.8*D_{ave} \tag{4}$$

We referenced slip rate value 2.8 of maximum slip and average slip in shallow area of the 3.11 Tohoku earthquake (Yoshida et al.(2013)).



Cauchy distribution $p(D)=C\dfrac{1}{1+[(D-Do/\kappa)]^2}$

C : regularization of probabilistic density function
D_o : location parameter of Cauchy distribution
κ : scale parameter of Cauchy distribution

Figure.1 Truncated-Cauchy Distribution

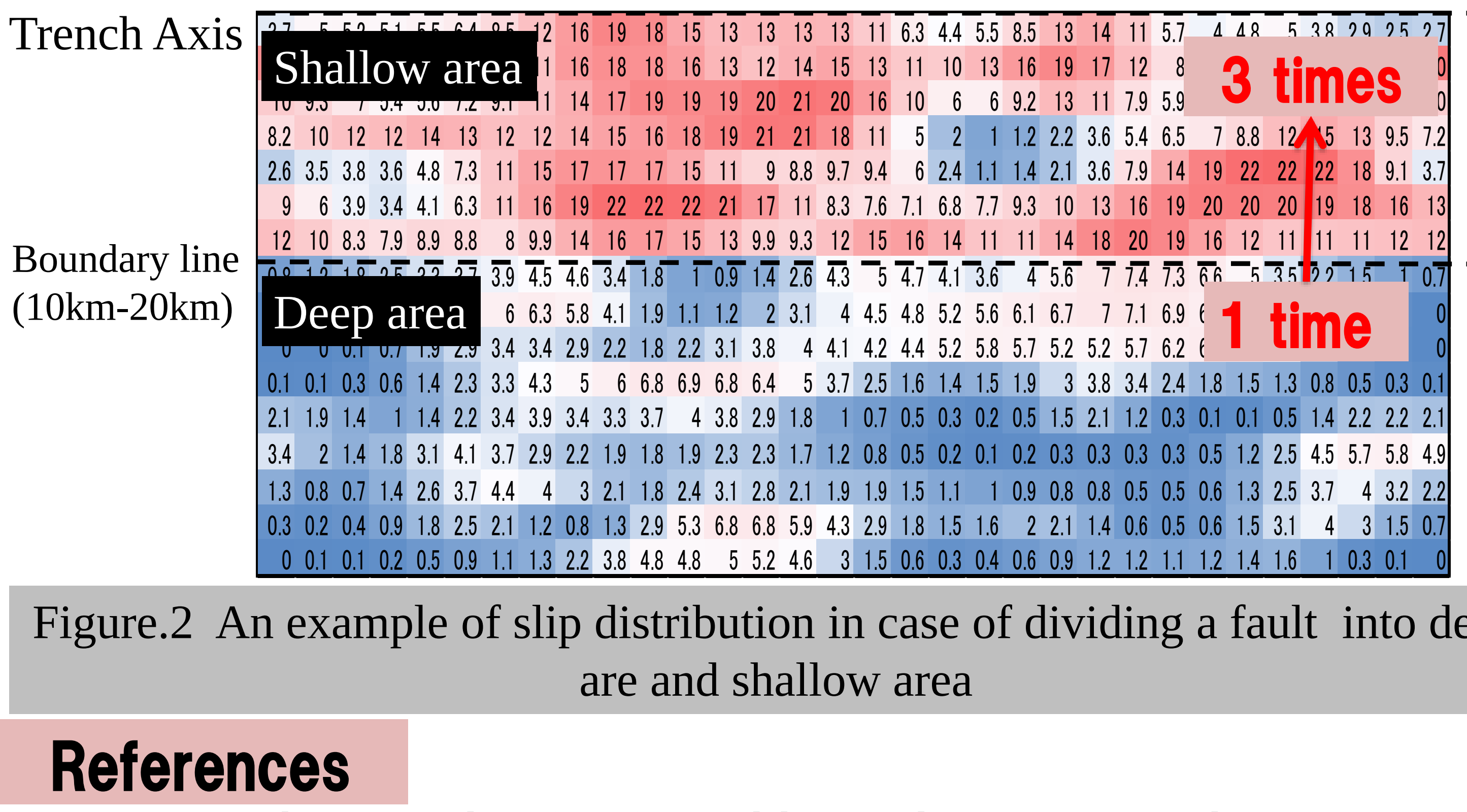


Figure.2 An example of slip distribution in case of dividing a fault into deep are and shallow area

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②Quantitative assessment for uncertainty of tsunami wave height

Fig.3 (a) shows examples of slip distributions for a type of the 3.11 Tohoku earthquake fault model using the CRSP model, and Fig.3 (b) shows a logic tree including these slip distributions as epistemic uncertainty.

Fig.4 shows tsunami hazard curves when the number of included slip distributions change to (a) 5 cases, (b) 3 cases and (c) 1 case. In case of 1 case, we can see that range of tsunami wave height for one return period is less than that of 3 cases and 5 cases.

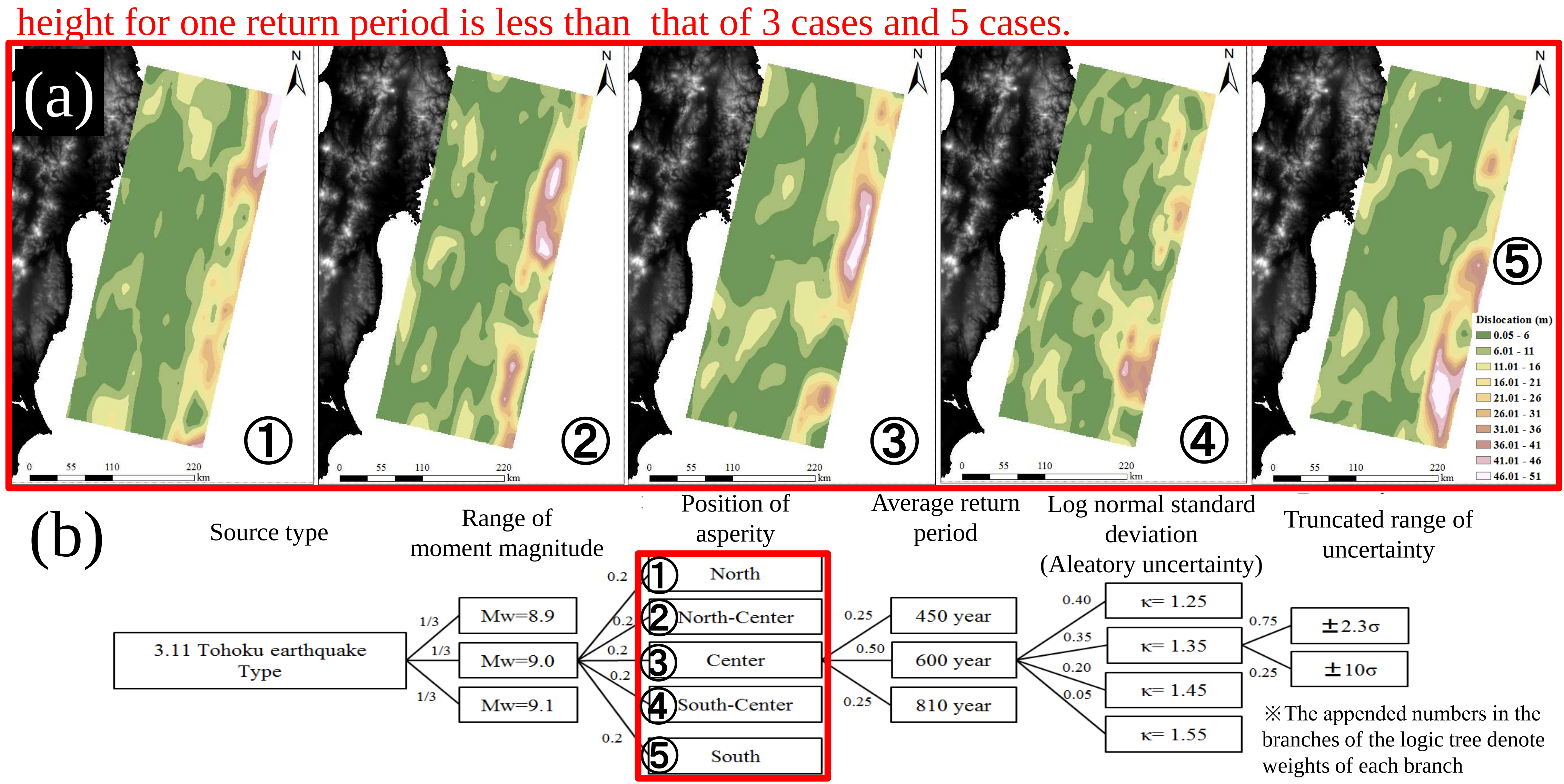

Figure.3 (a) Examples of slip distributions for the 3.11 Tohoku earthquake and (b) a logic tree

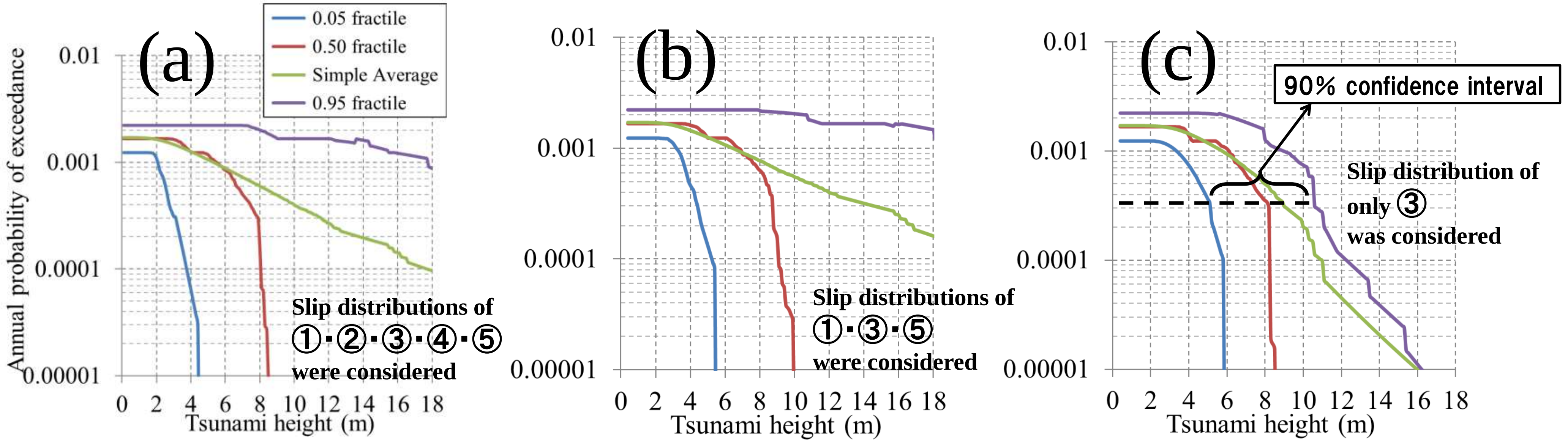

Figure.4 Hazard curves in case that (a) five, (b) three and (c) one slip distribution include the logic tree

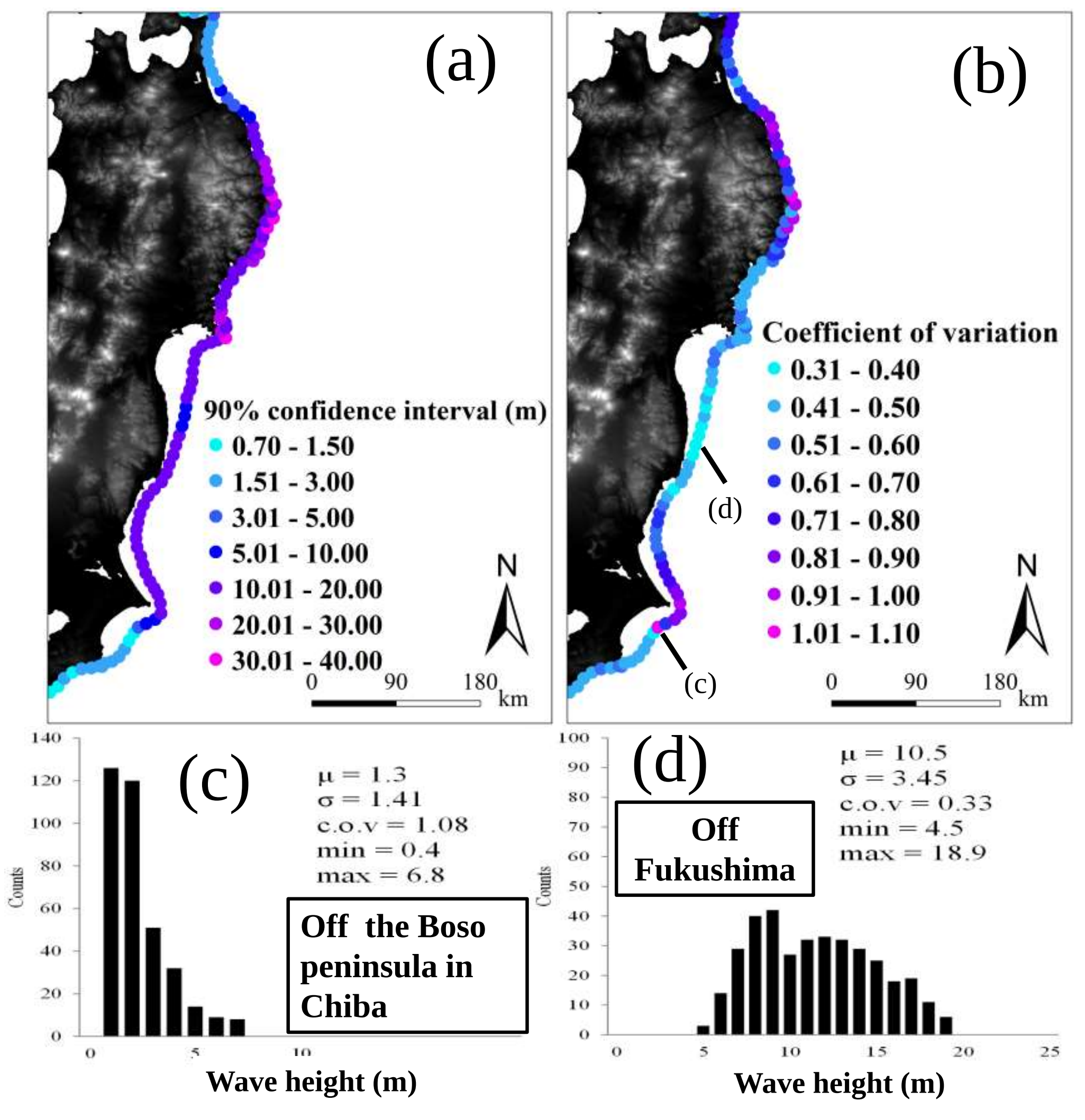

Figure.5 (a) 90% confidence interval of wave height, (b) Coefficient of variation, (c)・(d) Frequency distribution of wave height

Fig.5 shows (a) 90% confidence interval, (b) Coefficient of variation of stochastic wave height for 1,000 years return period along the Tohoku coastal area at the water depth of 50 m. The below figure of Fig.5 shows frequency distribution of stochastic wave height for 1,000 return period where the coefficient of variation is (c) maximum and (d) minimum.

Basically, the 90% confidence interval is high where the wave height of each fractile point is high. The values of coefficient of variation clearly indicate regional difference of wave height. Off the Boso peninsula in Chiba prefecture where the coefficient of variation is maximum, the variance of maximum wave height due to the difference of slip distribution on the fault greatly influence on the coefficient of variation. The spot where the coefficient of variation is minimum is off Fukushima prefecture. Fig.6 shows the results for rias coastal area in Iwate prefecture. In the rias area, the coefficient of variation is high off the edge point of the peninsula while the coefficient of variation is low inside the bay area.

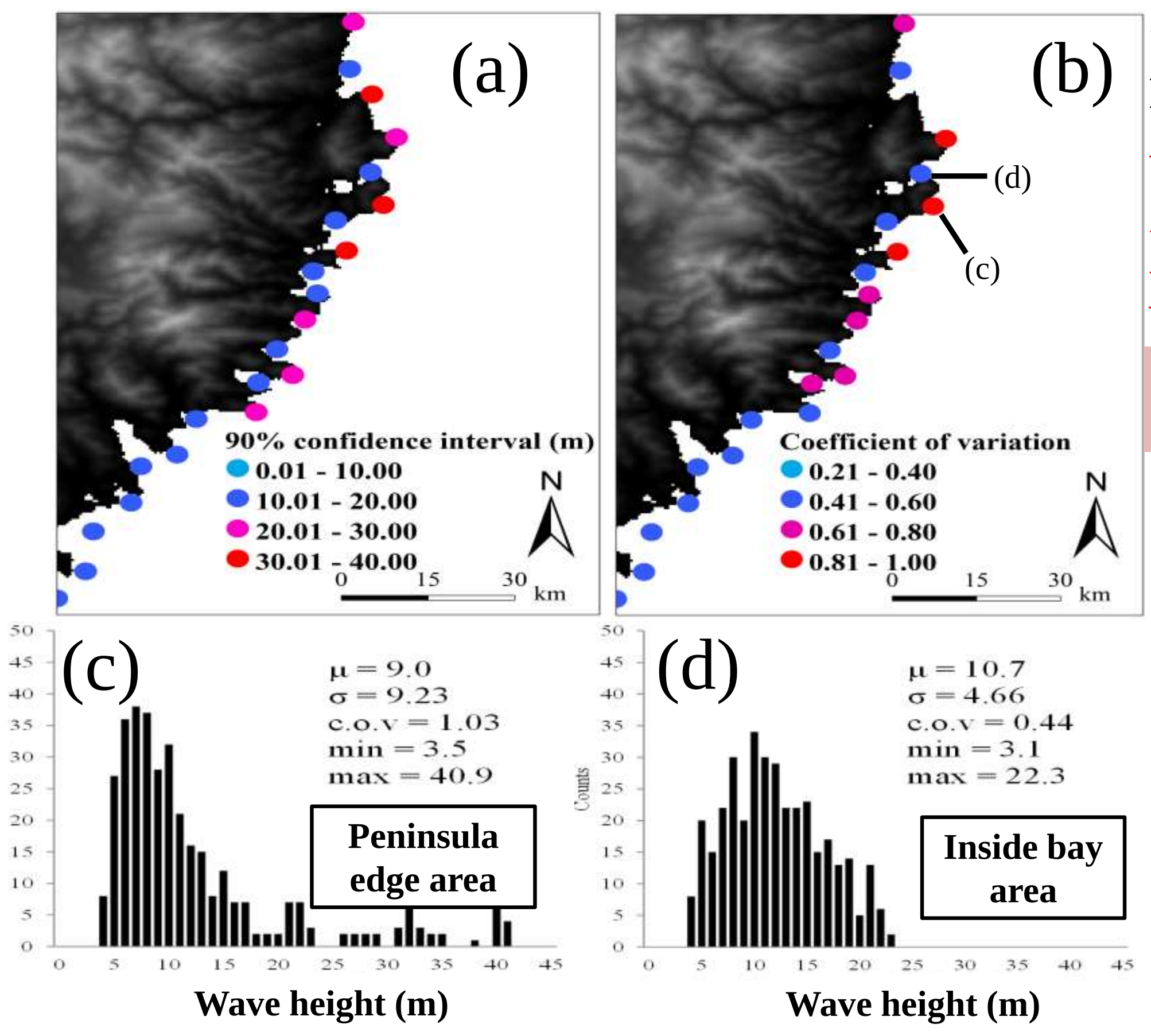

Figure.6 (a) 90% confidence interval of tsunami wave height, (b) Coefficient of variation, (c)・(d) Frequency distribution of wave height

③Conclusion

- ・We conducted the uncertainty assessment of tsunami wave height using CRSP model and the logic tree, then, we were able to obviously confirm the regional difference of wave height uncertainty.
- ・It is important for us to quantitatively assess the uncertainty of tsunami wave height and to visualize it on the topographic maps, because the uncertainty of stochastic tsunami wave height calculated from stochastic assessment might be higher than people expected.