ICCE 2018
36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018
Baltimore, Maryland | July 30 – August 3, 2018
The State of the Art and Science of Coastal Engineering

Probabilistic Tsunami Hazard Assessment in South China Sea with Consideration of Uncertain Earthquake Characteristics

Cornell University
School of Civil and Environmental Engineering

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INTRODUCTION

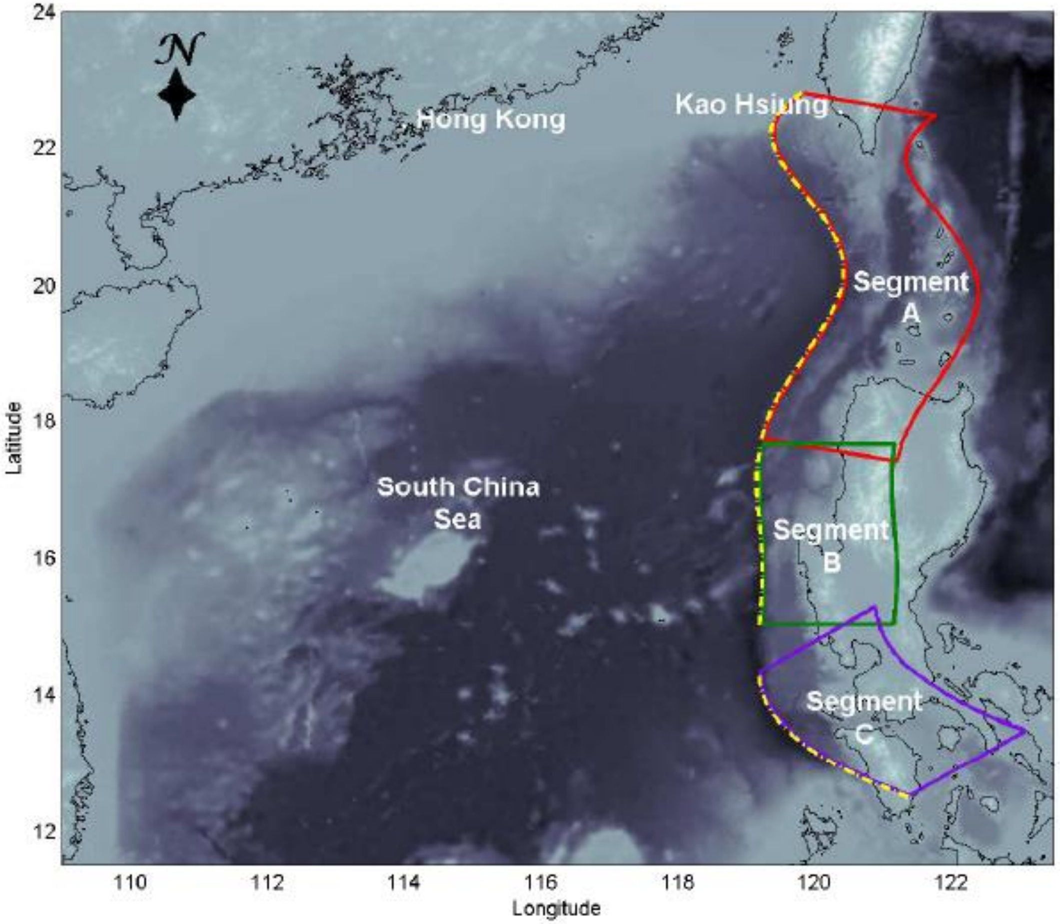
The assessment of tsunami events has often been done by means of numerical models using a deterministic approach based on scenarios. This approach leads to some questions such as which is the uncertainty of our inputs, or furthermore, how uncertainties propagate from model inputs to model outputs.

We conduct a **PTHA in Kao Hsiung and Hong Kong** due to tsunamis generated by earthquakes in the Manila Subduction Zone. We propose a **PTHA methodology which considers uncertain earthquake slip distributions and locations**.

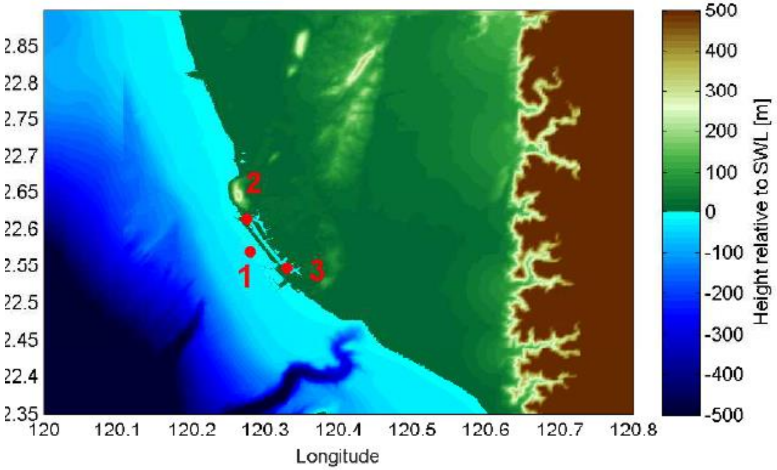
The PTHA uses input data and models subject to errors, which contributes with further uncertainties. The additional uncertainties analyzed in this study are associated with **the probability properties of earthquake slip and location and the earthquake recurrences.**

PROBLEM SETUP

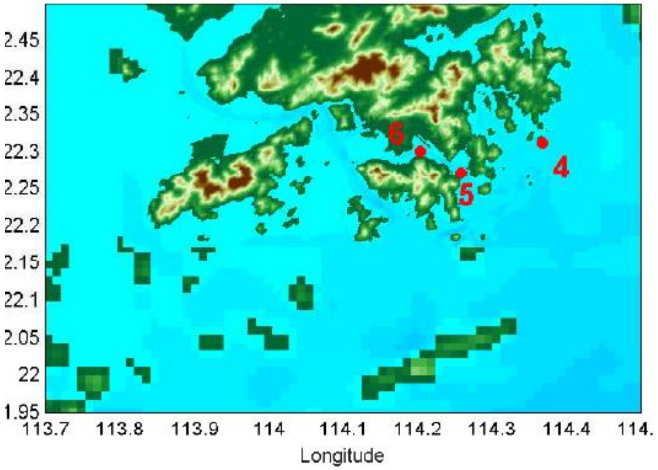
PTHA IN KAO-HSIUNG AND HONG KONG DUE TO EARTHQUAKES IN MANILA SUBDUCTION ZONE



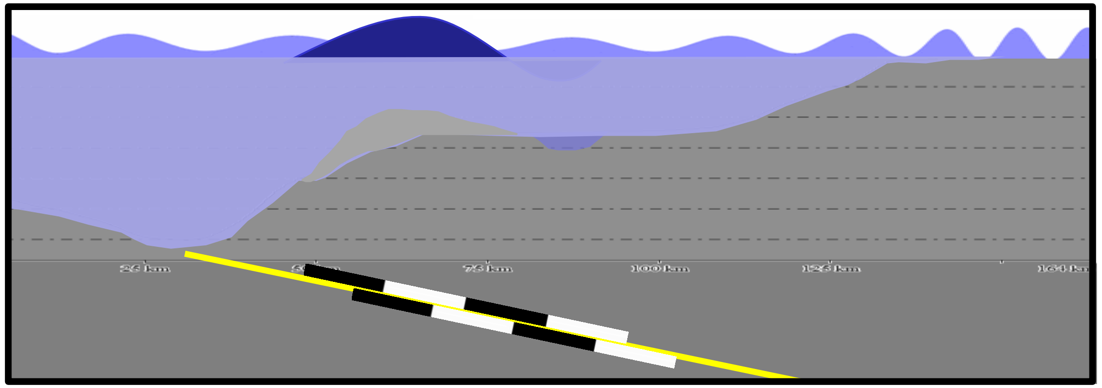
KAO-HSIUNG



HONG-KONG



SOURCES OF UNCERTAINTIES IN PTHA



INPUTS

BATHYMETRY
- Error in measurements
- Interpolation errors

EARTHQUAKE FOCAL PARAMETERS
- Uncertainty in estimations of location and slip distribution.

OTHER MODEL PARAMETERS
- Manning number
- Poisson value
- Etc.

TSUNAMI MODEL

Generation model
- Co-seismic deformation (e.g. Okada).
- Tsunami initial condition.

Propagation model
- Wave propagation model (e.g. SWE)
- Model configuration (e.g. grid resolution)

Outputs

Water elevation, current speeds, runup

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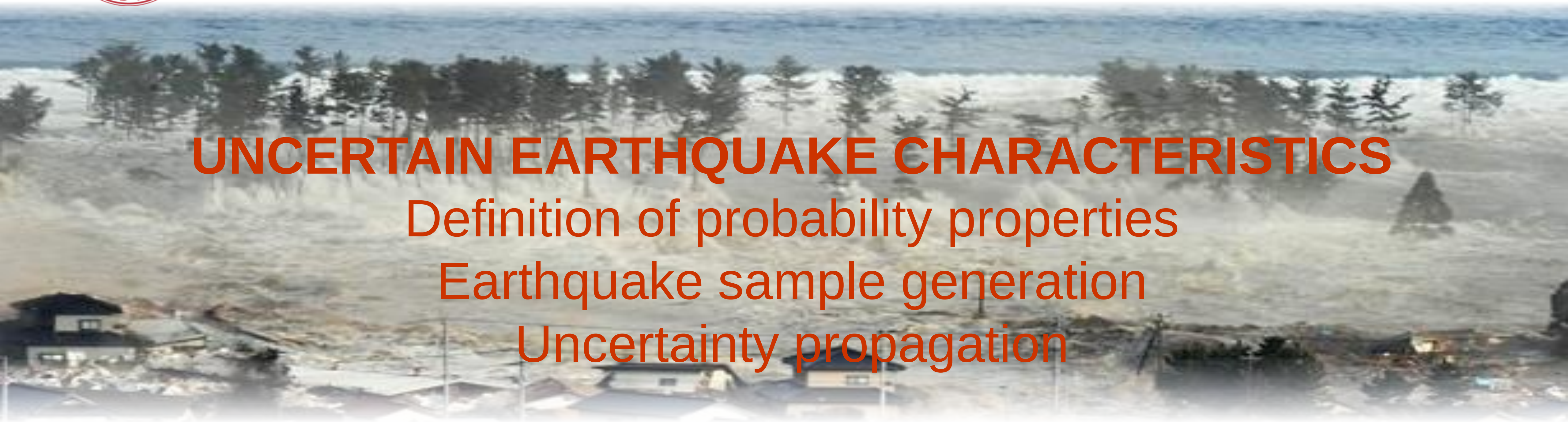


UNCERTAIN EARTHQUAKE CHARACTERISTICS

Definition of probability properties

Earthquake sample generation

Uncertainty propagation

UNCERTAIN EARTHQUAKE CHARACTERISTICS

STAGES OF UNCERTAINTY QUANTIFICATION (Sepulveda et. al., 2017)

1 Definition of probability properties

- Marginal distribution
- Covariance function

Definition of probability properties using **scaling relations of rupture area, correlation lengths and slip standard deviation.**

2 Input sample generation

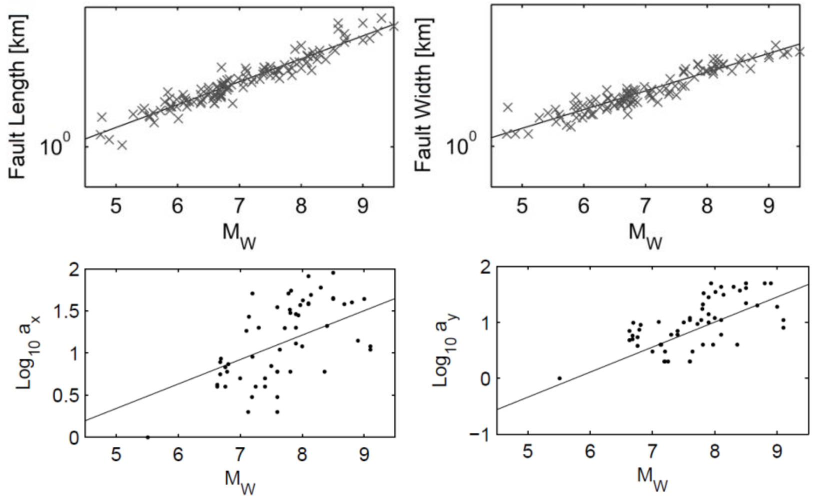
- Uncertain slip samples.
- Location samples.

Generation of samples using **a Karhunen-Loeve translation and translation model.** They consider any rupture geometry and slip marginal distribution.

3 Uncertainty propagation

- Selection of more efficient methods than Monte Carlo.

We use a **Stochastic Reduced Order Model** instead of a Monte Carlo simulation (less samples required).



Karhunen-Loeve expansion

$$G([x,y]) = \mu + \lim_{N \longrightarrow \infty} \sum_{k=1}^{N} \lambda_k^{1/2} Z_k \psi_k([x,y])$$

Translation model

$$S([x,y],\omega) = F^{-1} \circ \Phi(G([x,y],\omega))$$

$$\min_p \{e_t(p)\},$$

$$e_t(p) = \sum_{u \geq 1} \alpha_u e_u(p)$$

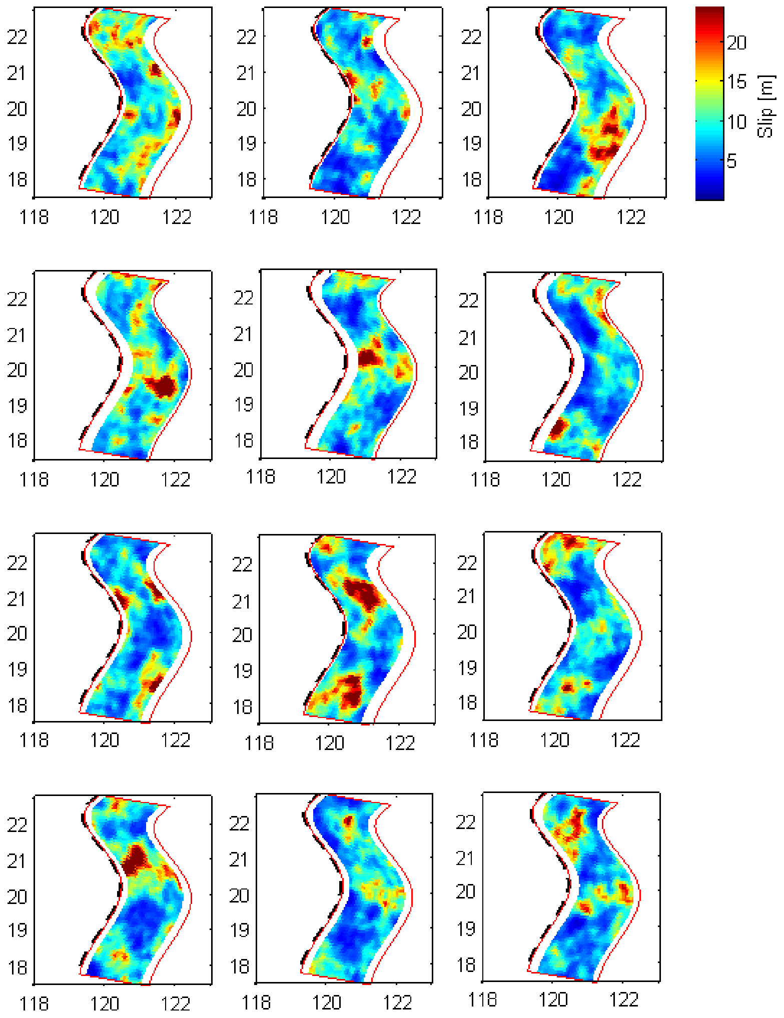
$$e_1(\tilde{Z},p) = \sum_i \int_{I_i} (\tilde{F}(x_i) - F(x_i))^2 dx_i$$

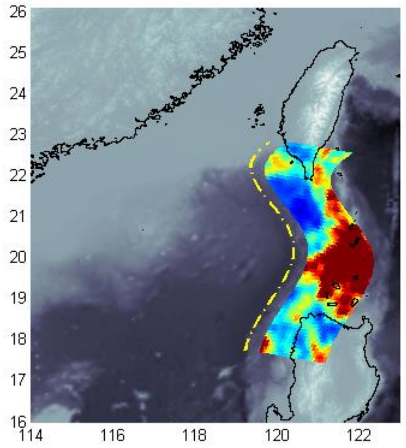
$$e_2(\tilde{Z},p) = \sum_i \sum_{q=1}^{4} (\tilde{\mu}_i^q - \mu_i^q)^2$$

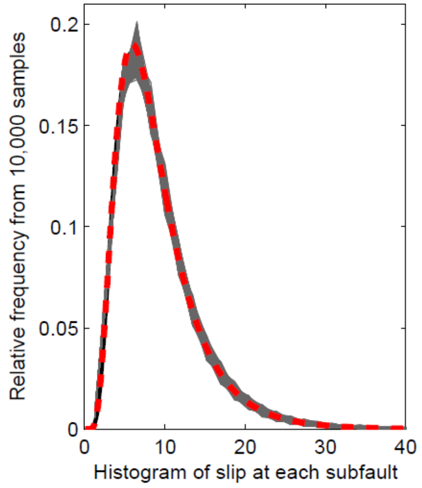
$$e_3(\tilde{Z},p) = \sum_{i,j;j>i} (\tilde{r}_{i,j} - r_{i,j})^2$$

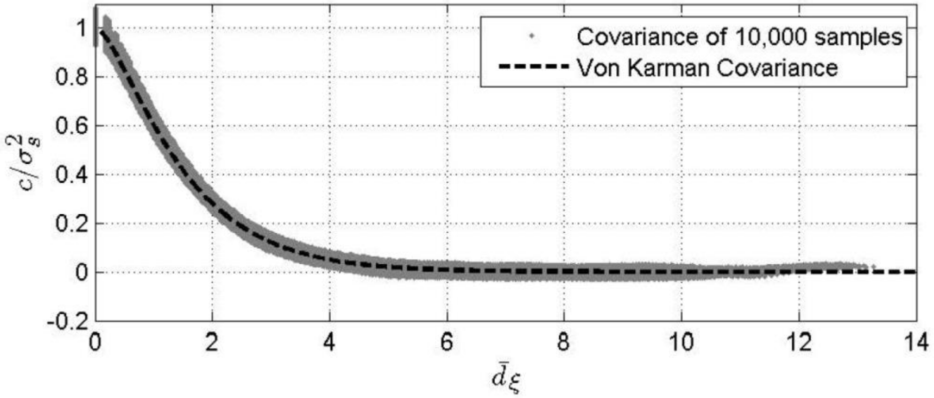
UNCERTAIN EARTHQUAKE CHARACTERISTICS

SAMPLES OF Mw 9.0 EARTHQUAKE WITH LOG-NORMAL DISTRIBUTION





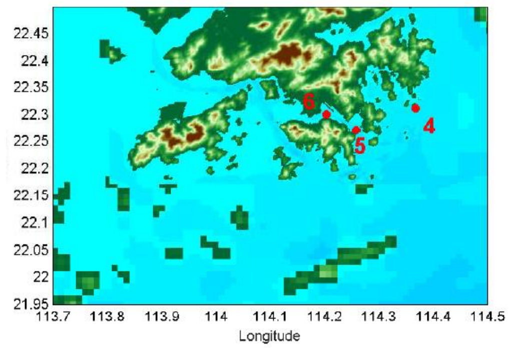




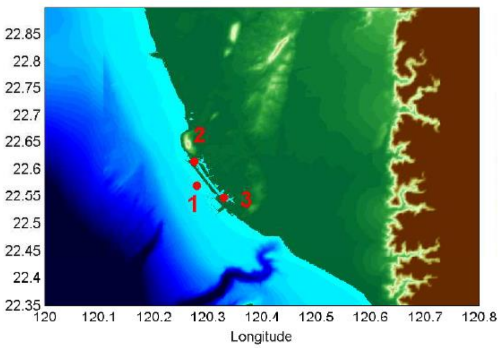
UNCERTAIN EARTHQUAKE CHARACTERISTICS

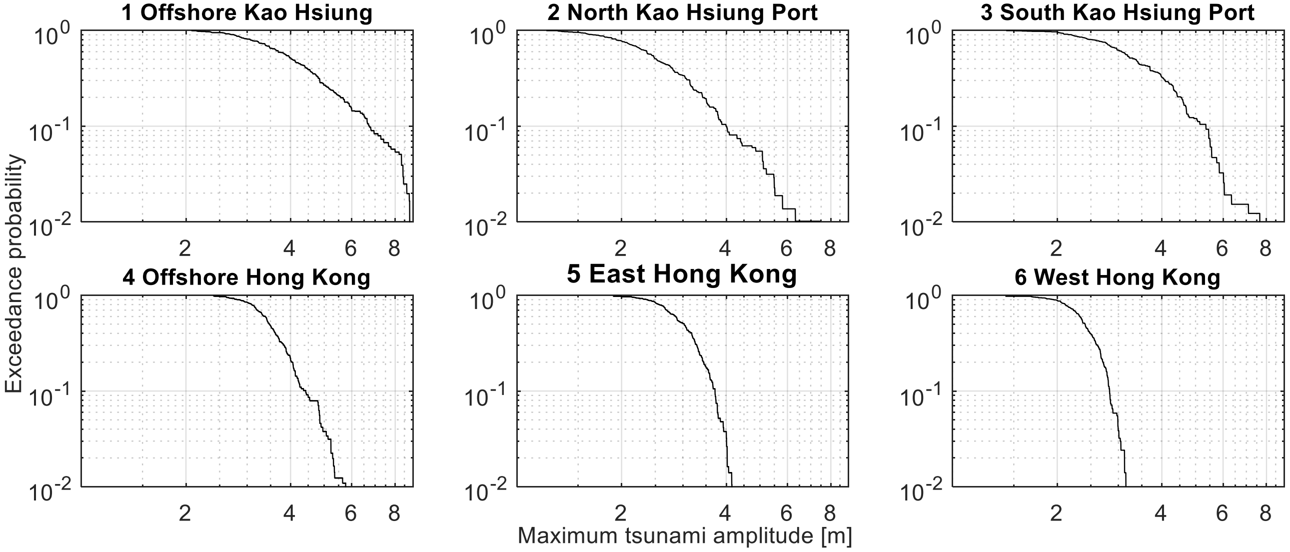
INUNDATION MAP DUE TO A Mw 9.0 EARTHQUAKE IN SEGMENT A

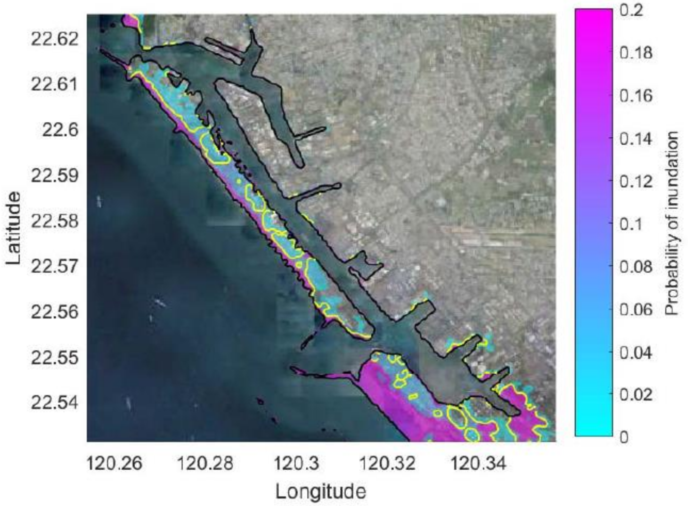
HONG-KONG

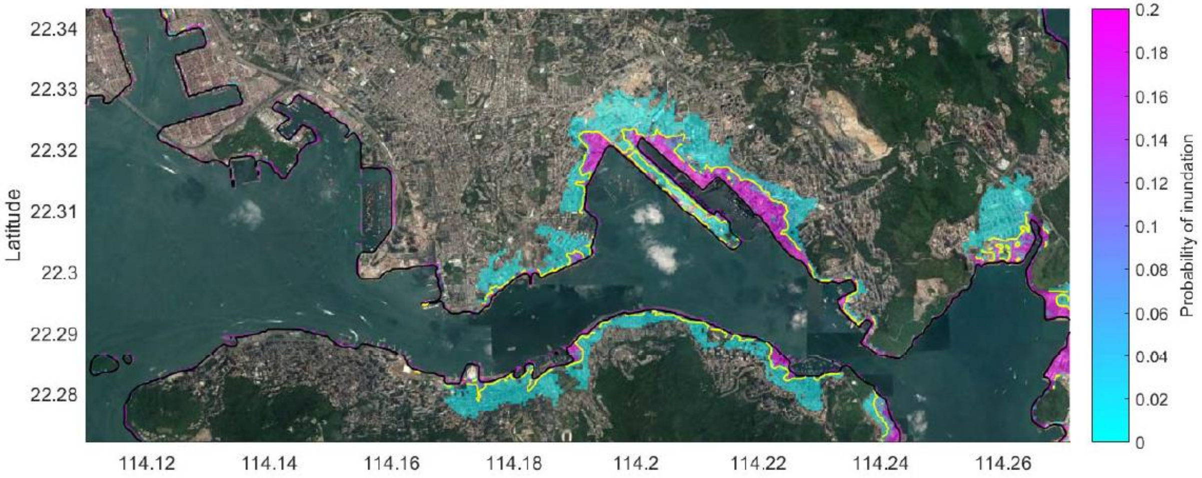


KAO-HSIUNG









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PROBABILISTIC TSUNAMI HAZARD ASSESSMENT
with consideration of uncertain earthquake characteristics

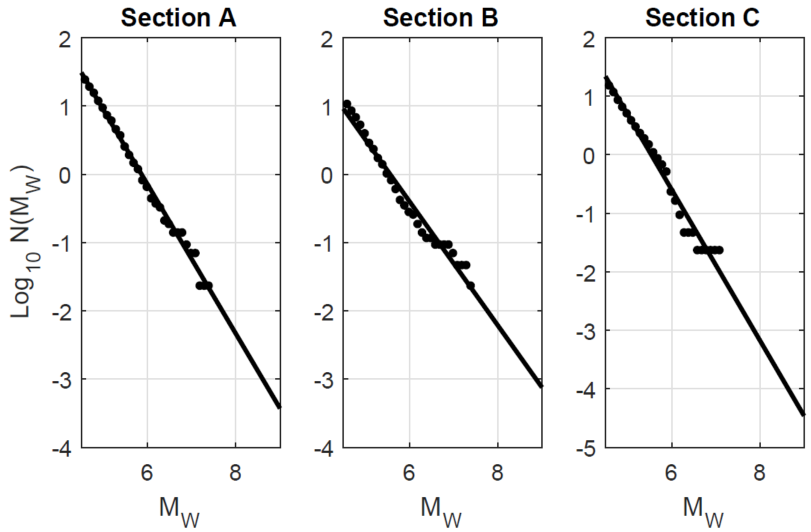
PTHA IN SOUTH CHINA SEA

PROBABILISTIC TSUNAMI HAZARD ASSESSMENT (PTHA)

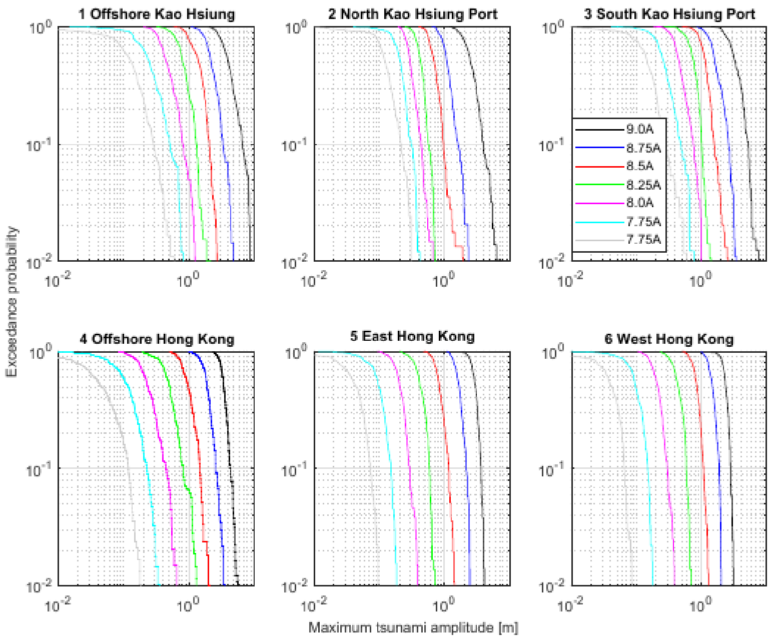
Assuming that earthquake occurrences are described by a Poisson process (memoryless events), we can determine an overall return period of a maximum tsunami amplitude,

$$T_R(h_{crit}) = \frac{1}{\sum_{M_W} \sum_{x_i} \lambda^{EQ}_{M_W,x_i} P_h(h > h_{crit} | M_W, x_i)}$$

Gutenberg-Richter Law



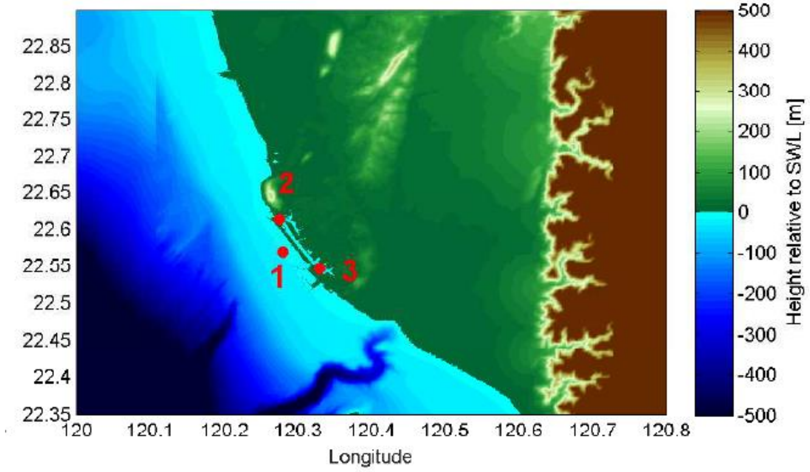
Proposed Stochastic approach



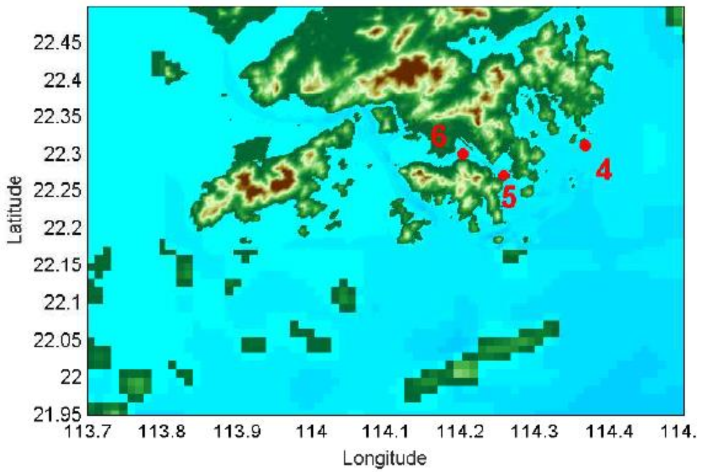
PTHA IN SOUTH CHINA SEA

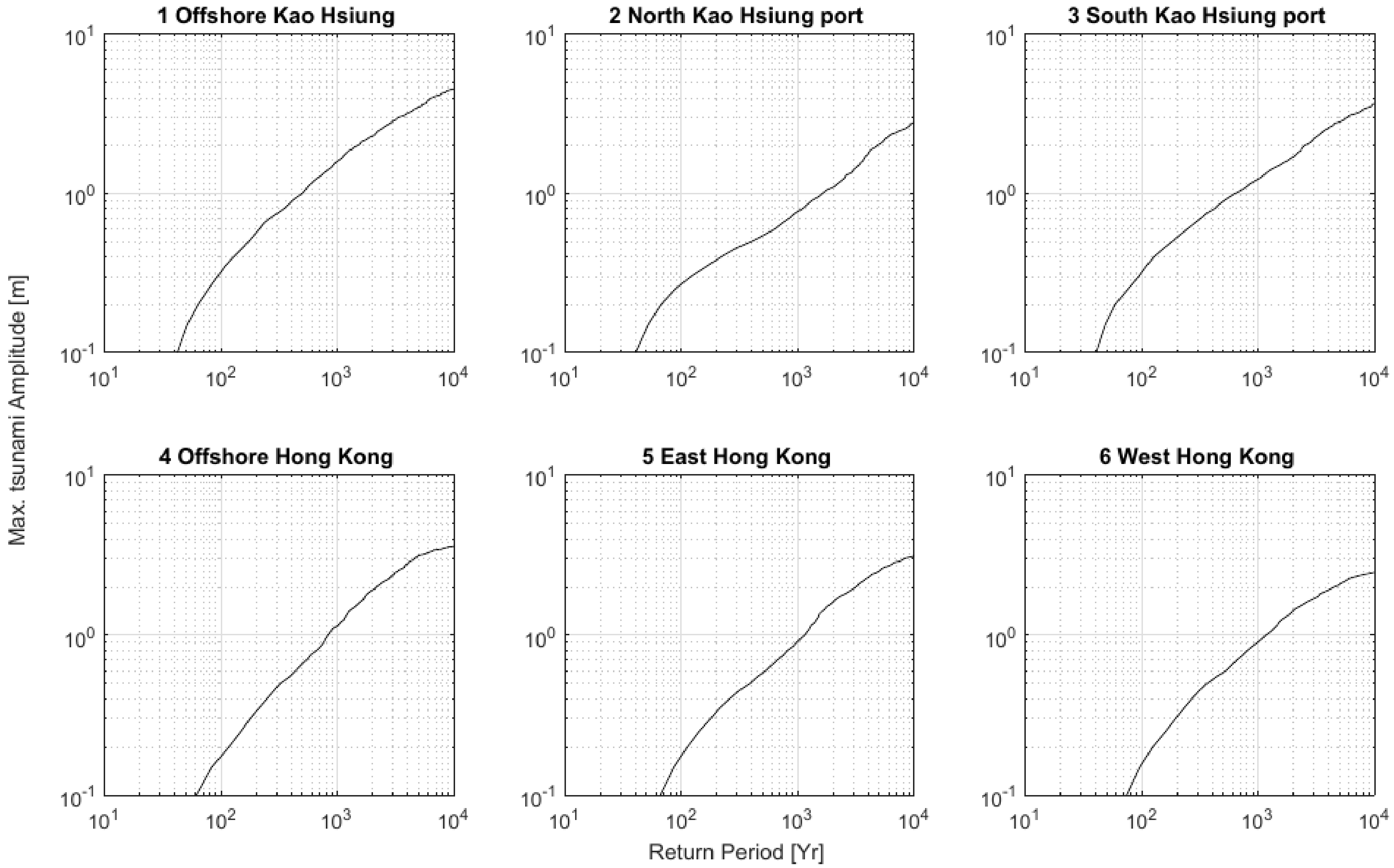
MAXIMUM TSUNAMI AMPLITUDE. APPLICATION CASE IN SOUTH CHINA SEA

KAO-HSIUNG



HONG-KONG

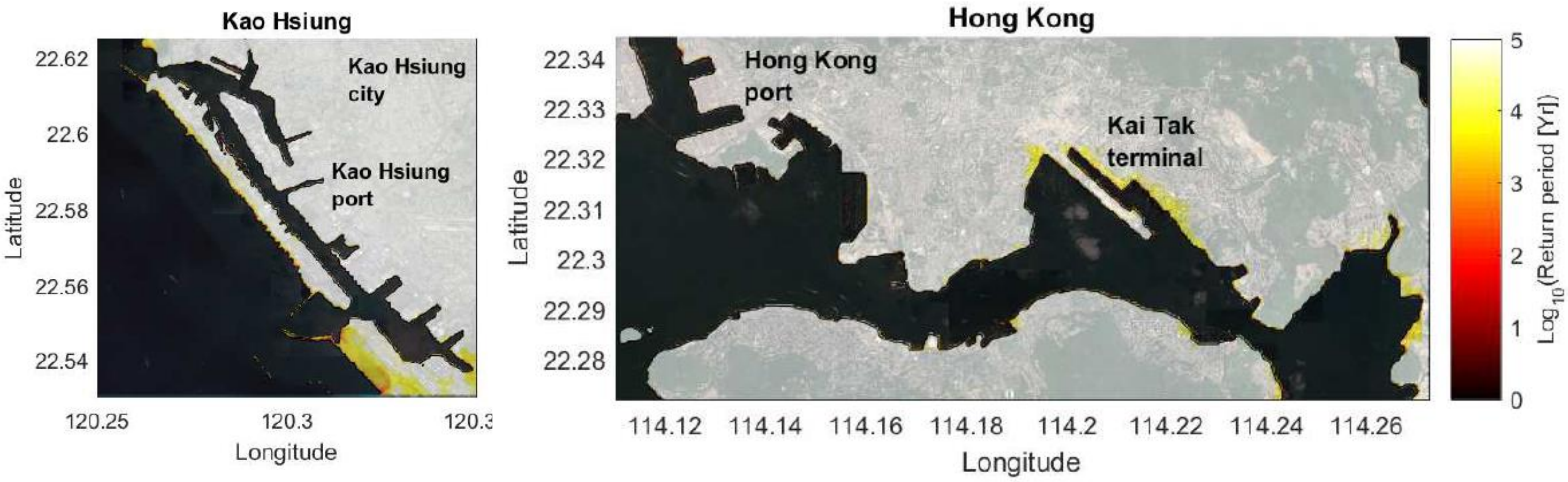




PTHA IN SOUTH CHINA SEA

INUNDATION MAPS. APPLICATION CASE IN SOUTH CHINA SEA

Recurrence periods of inundation (flow depth>0), given earthquakes in Manila subduction zone.



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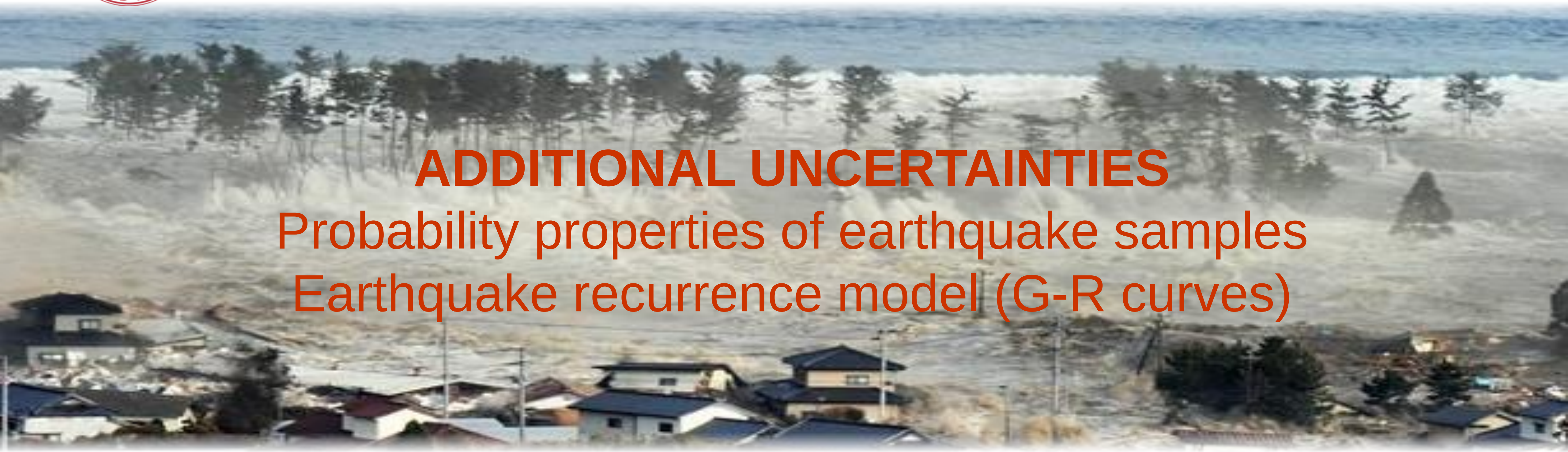


ADDITIONAL UNCERTAINTIES

Probability properties of earthquake samples

Earthquake recurrence model (G-R curves)

STOCHASTIC TSUNAMI MODEL

1) The stochastic model for the slip distribution and location employs observations and scaling relations calibrated with past earthquakes. Those observations are subject to errors, which constitutes a source of uncertainty.

2) The earthquake recurrence models, such as the Gutenberg-Richter Law, rely on many simplifications and data which is subject to errors. These aspects also constitute sources of uncertainty.

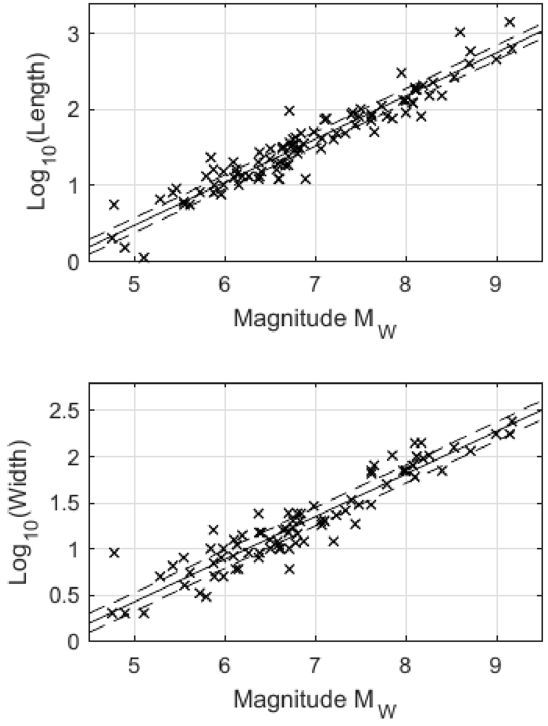
We aim to assess the relevance of these sources of uncertainty by adopting sensitivity analyses.

STOCHASTIC TSUNAMI MODEL

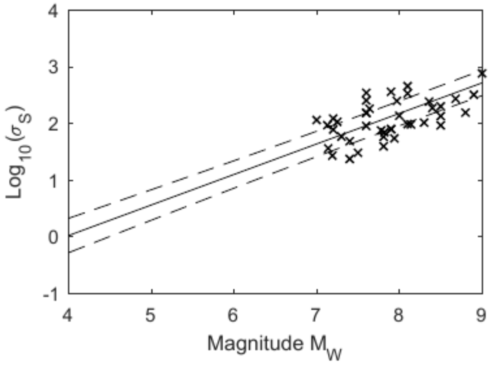
EARTHQUAKE PROBABILITY PROPERTIES

We identify relevant uncertainties in the properties observed from past earthquakes. The most relevant sources of uncertainty are the rupture area, the slip standard deviation and the slip marginal distribution.

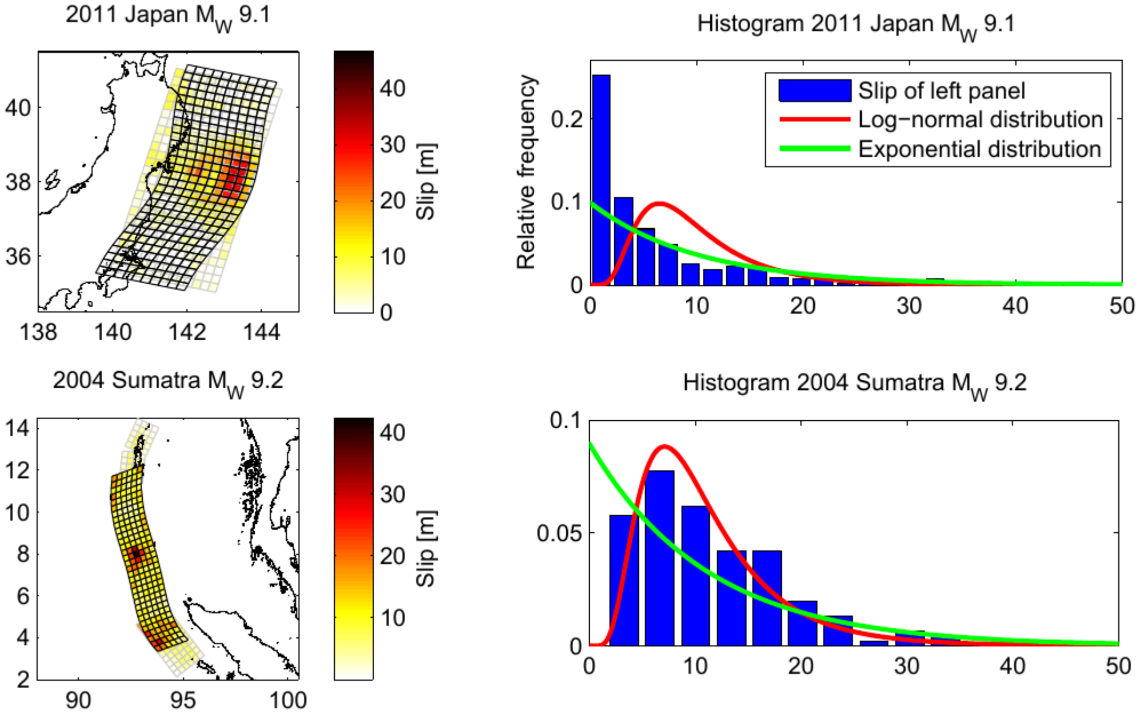
Rupture area



Standard deviation



Slip marginal distribution



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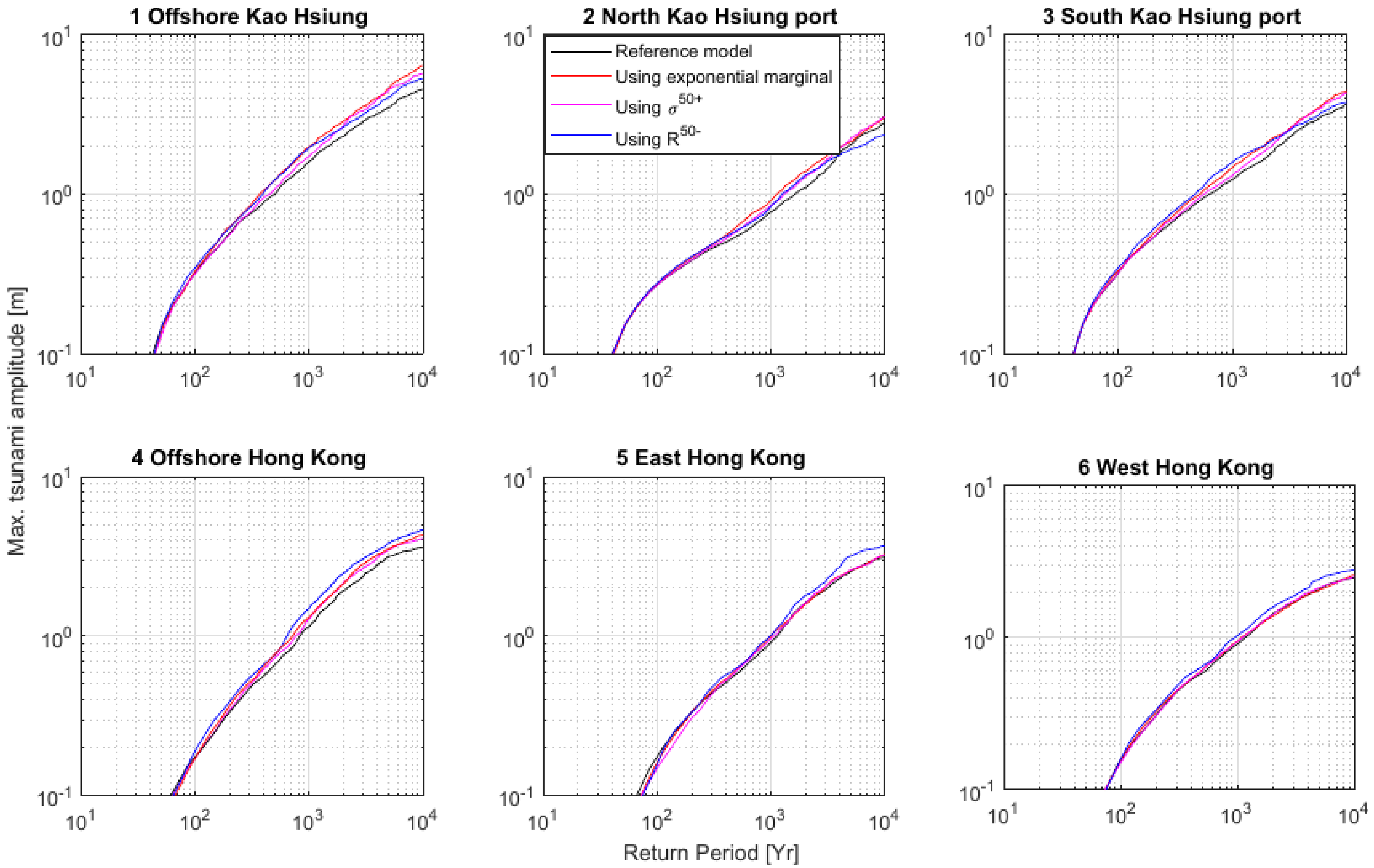


We generate 3 alternative Gutenberg-Richter curves using different input data. The earthquake annual recurrence (N) are obtained as following:

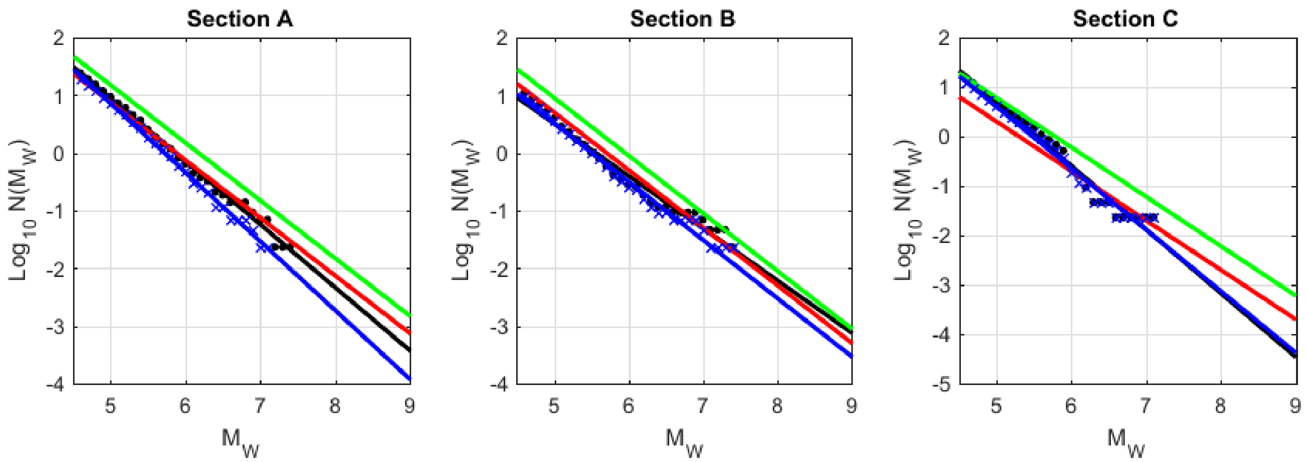
Recurrence model 1 (reference): Using NEIC catalog and seismogenic regions with sizes defined in this study. We used this model before.

Recurrence model 2: Using NEIC catalog and smaller seismogenic regions according to high coupled areas estimated in Hsu et al. (2012).

Recurrence model 3: Using the slip deficit rate estimated by Hsu et. al. (2012) and the formula of Ader et. al. (2012).

Recurrence model 4: Using the slip deficit rate estimated in “Model B” of Hsu et. al. (2016), which estimated larger slip deficit rates as compared to red curve.

Gutenberg-Richter curves for segments A, B and C

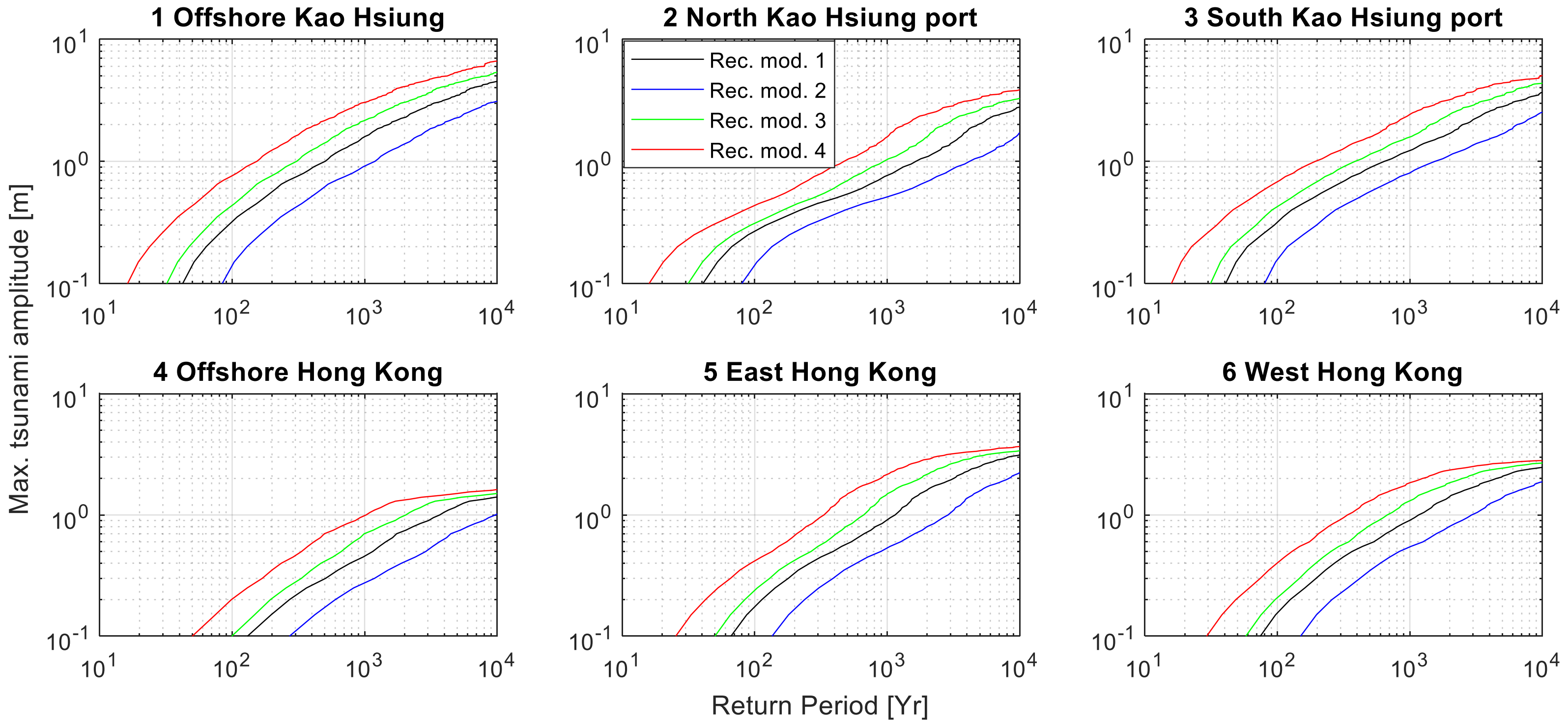


STOCHASTIC TSUNAMI MODEL

EARTHQUAKE RECURRENCE MODEL

We generate 3 alternative Gutenberg-Richter curves using different input data. The earthquake annual recurrence (N) are obtained as following.

Differences of PTHA using different earthquake recurrence models are significant.



STOCHASTIC TSUNAMI MODEL

WHAT ARE THE MOST RELEVANT EPISTEMIC UNCERTAINTIES?

We compare the reference PTHA with the new PTHA's. We compare the maximum tsunami amplitudes corresponding to the 100 and 1000 years return periods.

The most relevant uncertainty is associated with the earthquake recurrence model.

	Measure	St. 1	St. 2	St. 3	St. 4	St. 5	St. 6
Maximum tsunami amplitude of reference PTHA	$h_{crit(T_{100})}$	0.32 m	0.27 m	0.32 m	0.18 m	0.18 m	0.16 m
	$h_{crit(T_{1000})}$	1.59 m	0.77 m	1.23 m	1.14 m	0.91 m	0.90 m
Sensitized property	New maximum tsunami amplitudes and difference relative to reference PTHA (in parenthesis)						
Rupture area (R^{50-})	$h_{crit(T_{100})}$	0.34 m (8.1%)	0.28 m (4.1%)	0.35 m (7.9%)	0.20 m (9.1%)	0.16 m (-9.8%)	0.16 m (0.6%)
	$h_{crit(T_{1000})}$	1.93 m (21%)	0.88 m (14%)	1.56 m (27%)	1.45 m (27%)	1.02 m (12%)	1.00 m (12%)
Slip marg. distribution (Exponential)	$h_{crit(T_{100})}$	0.33 m (3.1%)	0.27 m (0.4%)	0.32 m (-0.6%)	0.17 m (-1.4%)	0.16 m (-8.6%)	0.15 m (-3.2%)
	$h_{crit(T_{1000})}$	1.96 m (23.3%)	0.90 m (16.9%)	1.46 m (18.7%)	1.31 m (14.9%)	0.99 m (8.8%)	0.94 m (4.4%)
Slip standard deviation (σ^{50+})	$h_{crit(T_{100})}$	0.32 m (-1.4%)	0.27 m (-0.9%)	0.32 m (-1.1%)	0.17 m (-1.4%)	0.15 m (-15%)	0.15 m (-3.9%)
	$h_{crit(T_{1000})}$	1.72 m (8.2%)	0.84 m (9.0%)	1.30 m (5.3%)	1.28 m (11.4%)	0.96 m (5.5%)	0.94 m (4.5%)
Earthquake recurrence (recurrence model 4)	$h_{crit(T_{100})}$	0.76 m (138%)	0.44 m (63.6%)	0.68 m (113%)	0.45 m (160%)	0.42 m (139%)	0.40 m (158%)
	$h_{crit(T_{1000})}$	3.04 m (91.2%)	1.59 m (107%)	2.40 m (95.1%)	2.61 m (128%)	2.16 m (137%)	1.85 m (105%)

CONCLUSION

RELEVANT ASPECTS

We have proposed a methodology to conduct PTHA with consideration of uncertain slip and location. The methodology is consistent, in the sense that the slip and location preserve their probability properties.

Kao Hsiung and Hong Kong are significantly impacted by large earthquakes in the Manila subduction zone (e.g. Mw 9.0). However, the return periods of such an earthquakes are very long. As a result, **the tsunami hazard is small in Kao Hsiung and Hong Kong.**

The earthquake recurrence model is a relevant source of uncertainty in the PTHA of Kao Hsiung and Hong Kong. The remaining property uncertainties play a secondary role. **Hence, a reduction of PTHA uncertainties in South China Sea would need a better understanding of the earthquake recurrence.**

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