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Tsunami Warning & Risk Prediction based on Inaccurate Earthquake Source Parameters - 2011 Tohoku Tsunami -

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2011 Tohoku Tsunami Warning

- The 11th March 2011 Great East-Japan earthquake and tsunami caused catastrophic damage to coastal cities and towns in the Tohoku region of Japan.
- The first estimate of the Japan Meteorological Agency (JMA) magnitude was Mj7.9 (3 minutes after the earthquake), significant underestimation due to saturation. This was updated by the JMA to Mj8.4 (74 minutes after the earthquake).
- A reasonable estimate of the moment magnitude (M_w) equal to 8.8 was reached 54 minutes after the earthquake.
- (On the other hand, the U.S. Geological Survey obtained an accurate estimate of M_w about 10 minutes after the earthquake.)
- Consequently, tsunami warnings issued by the JMA underestimated the observed tsunamis significantly (3 to 6 m versus 10+ m).

Motivation

- Tsunami early warning systems and hazard/evacuation maps are essential for mitigating the consequences of catastrophic tsunami disasters.
- Tsunami warning systems detect off-shore tsunami waves and issue updated warnings to residents in coastal communities based on observations and modified earthquake information.
- Prior to actual detection of tsunamis, warnings are issued based on earthquake information.
- Issuing accurate and prompt tsunami warnings to residents in coastal areas is critically important for mega-thrust tsunamigenic earthquakes.

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Objectives

- The effects of underestimation/errors of the earthquake source parameters are investigated in the context of tsunami early warning and tsunami hazard/risk assessment.
- A rigorous probabilistic tsunami loss estimation is carried out to quantify the tsunami loss of a building portfolio (about 86,000) in Miyagi Prefecture. The method takes into account the key uncertainties, such as slip distribution and tsunami fragility.
- The results are discussed from early warning perspectives:

  When the magnitude is in error (e.g. 0.5 units), what would be the impact in terms of tsunami loss prediction?

  What is the uncertainty of the predicted tsunami loss given a moment magnitude and hypocentre location? How does this compare with the bias in tsunami loss, caused by inaccurate earthquake information?

Probabilistic Tsunami Loss Estimation

- Scenarios -> Stochastic source models -> Monte Carlo tsunami simulation -> Building exposure data -> Tsunami fragility and damage assessment -> Tsunami loss estimation

Risk = Hazard × Exposure × Vulnerability

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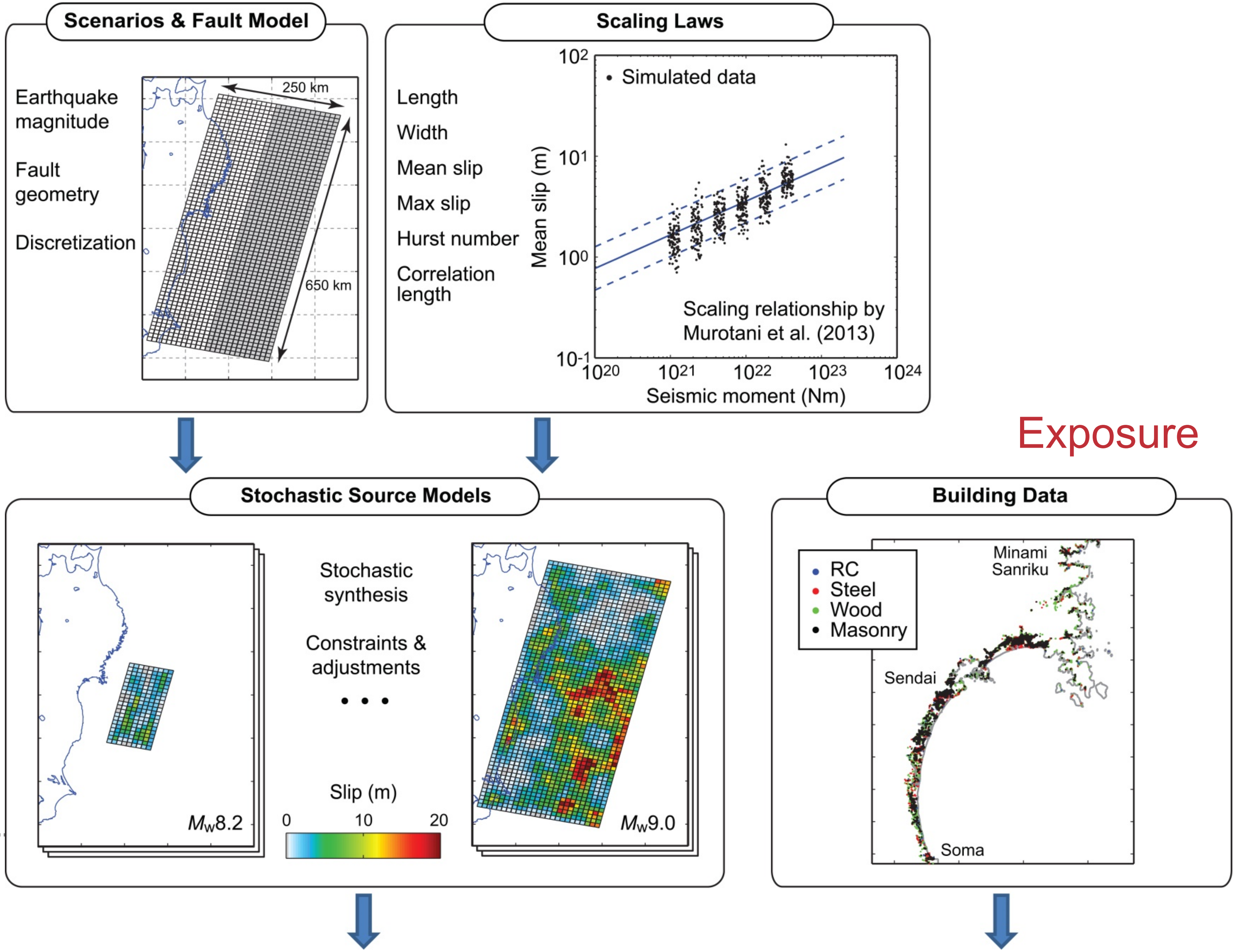
Tsunami Loss Estimation Method

Scenarios & source region characteristics

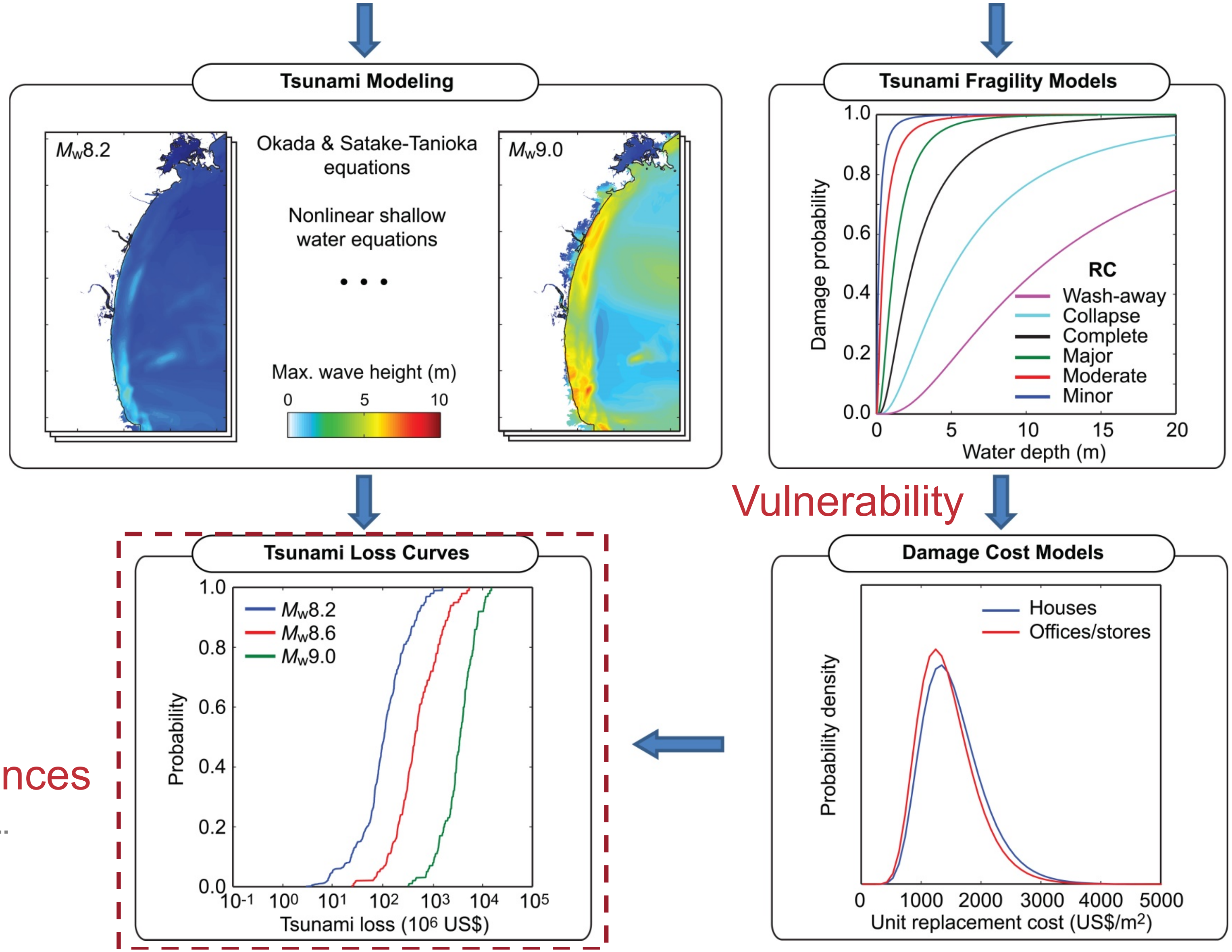
Scenario generation

Exposure



Tsunami Loss Estimation Method

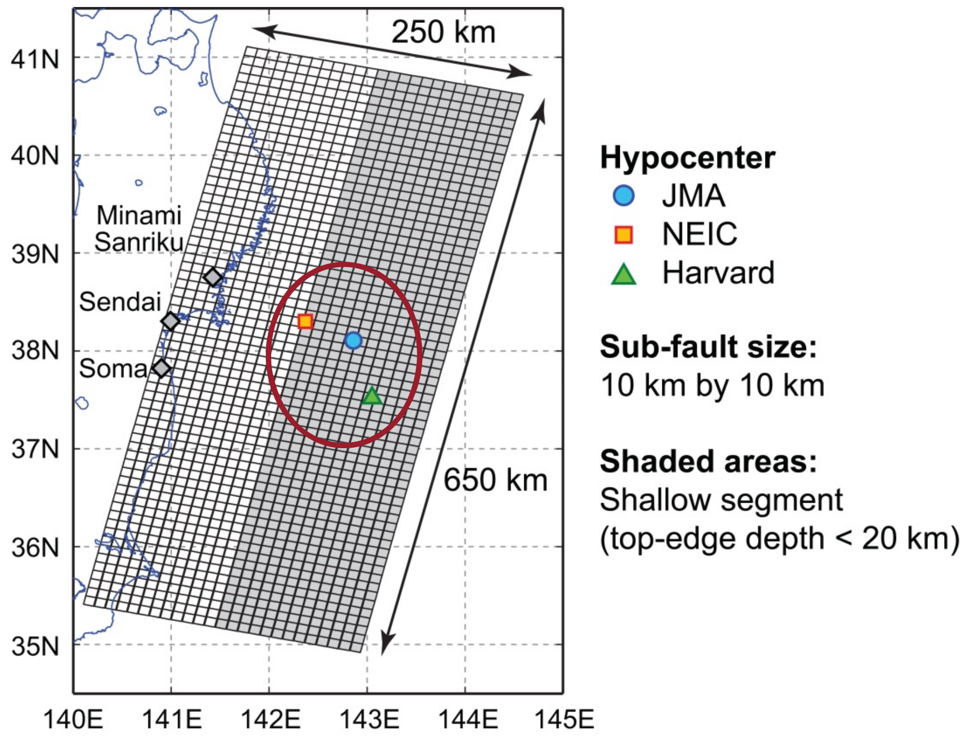
Hazard modeling



Consequences

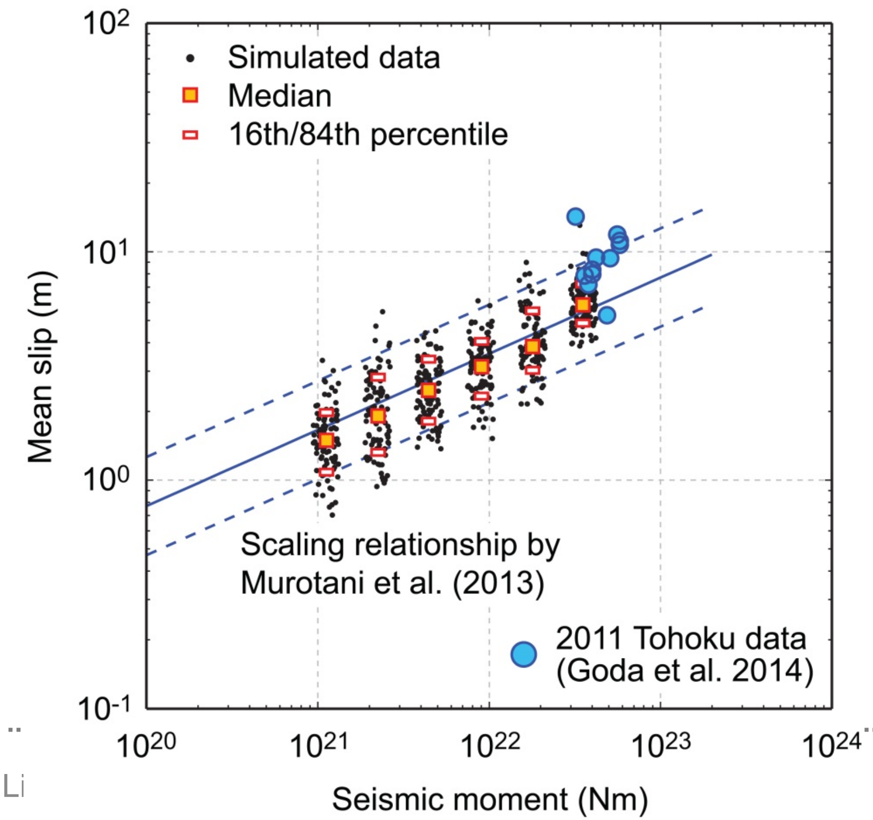
Fault Model

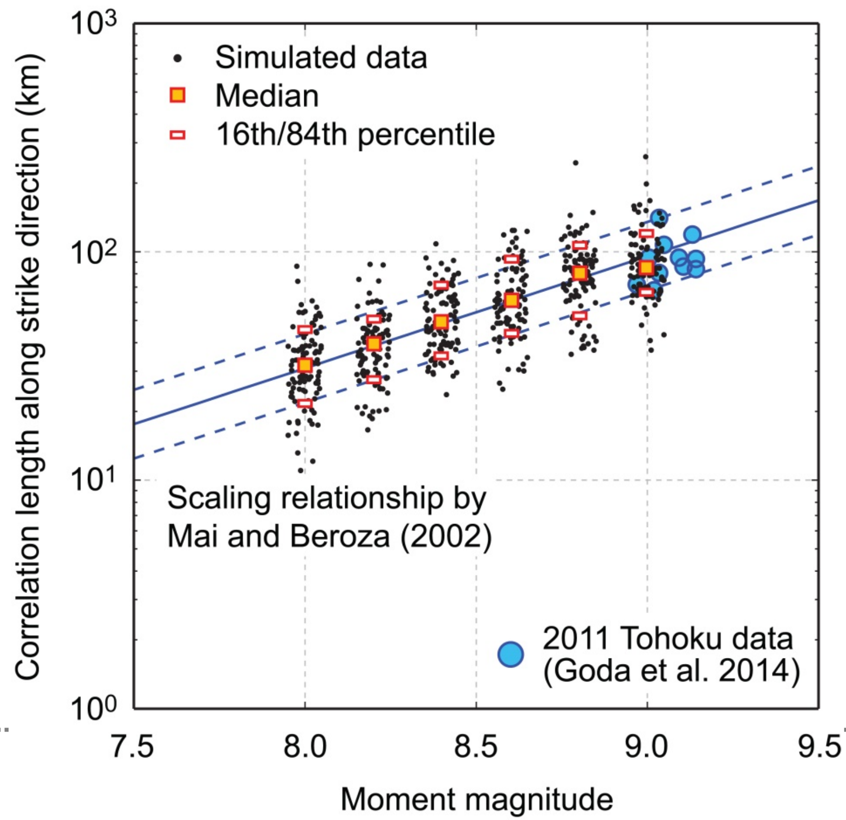
- A source region covers off-shore Tohoku region (650 km by 250 km). It can accommodate the earthquake size similar to the 2011 Tohoku earthquake.
- The region is discretized into 10 km by 10 km sub-faults.
- By assigning (suitable) slip values to the sub-faults, various earthquake scenarios can be created.
- The asperities tend to be in the shallow part of the fault plane.



Scaling Laws

- The empirical scaling laws can be used to determine parameters that are related to geometry, slip, and spatial distribution of the slip for different earthquake scenarios in terms of moment magnitude.





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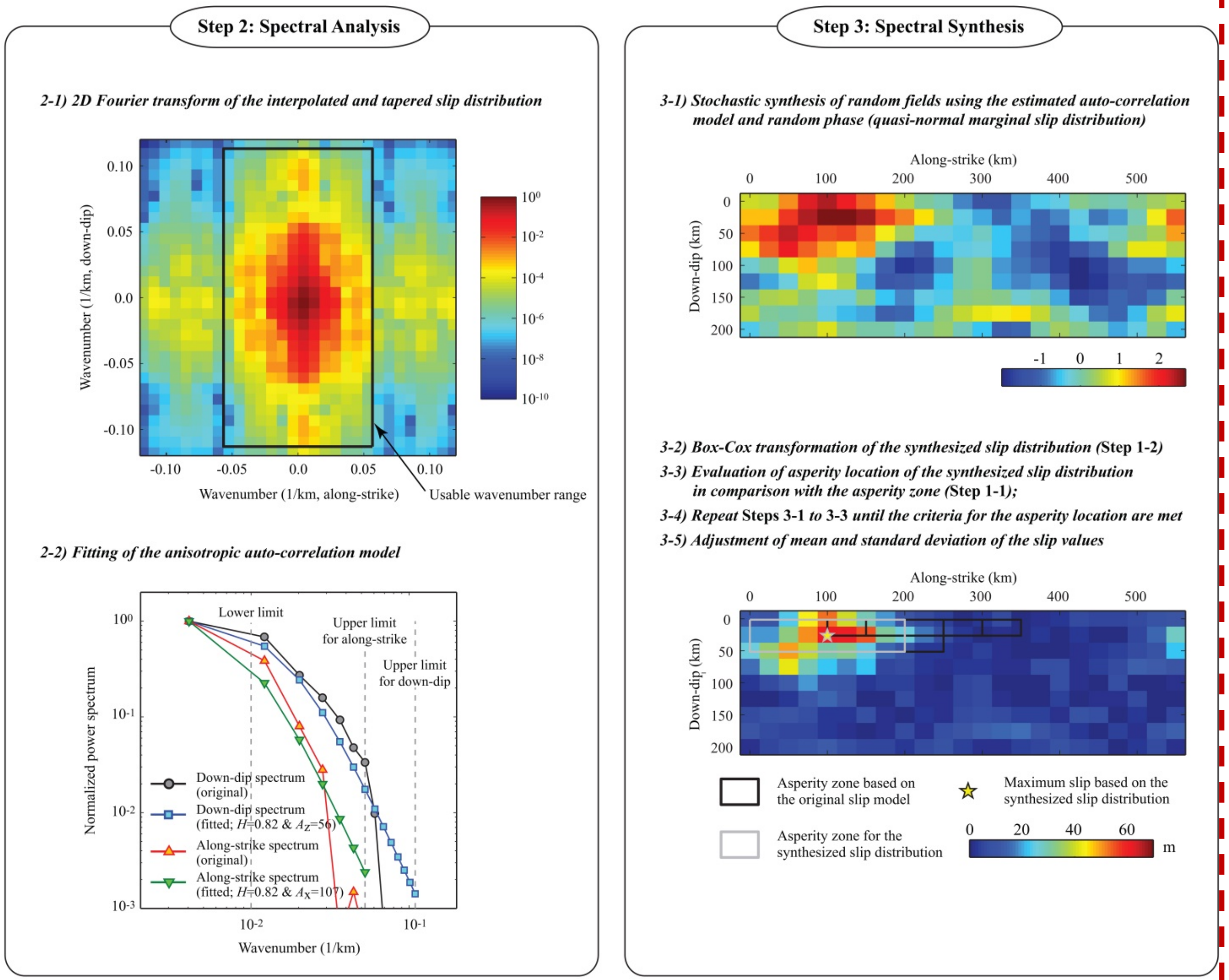
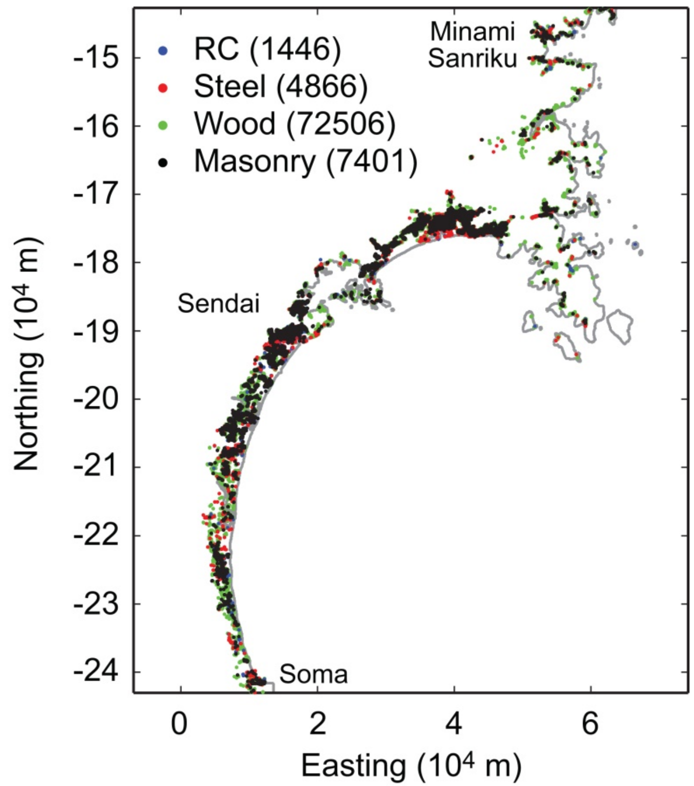
Spectral Synthesis of Slip Distribution

- Spatial feature of earthquake slip is modeled by a 2D wavenumber spectrum.
- Gaussian random-fields are generated.
- To represent the large asperities, Box-Cox transform is implemented.
- Various constraints are taken into account.



Building Data in Miyagi Prefecture

- The Ministry of Land, Infrastructure, and Transportation (MLIT) of Japanese Government developed an extensive tsunami damage database after the 2011 Tohoku tsunami.
- The database includes more than 250,000 damage data.
- Using the database, empirical tsunami fragility models have been developed (e.g. Suppasri et al. 2013).
- In this study, 86,219 buildings in Miyagi Prefecture are considered. The supplementary information on material and story number is available for these buildings.



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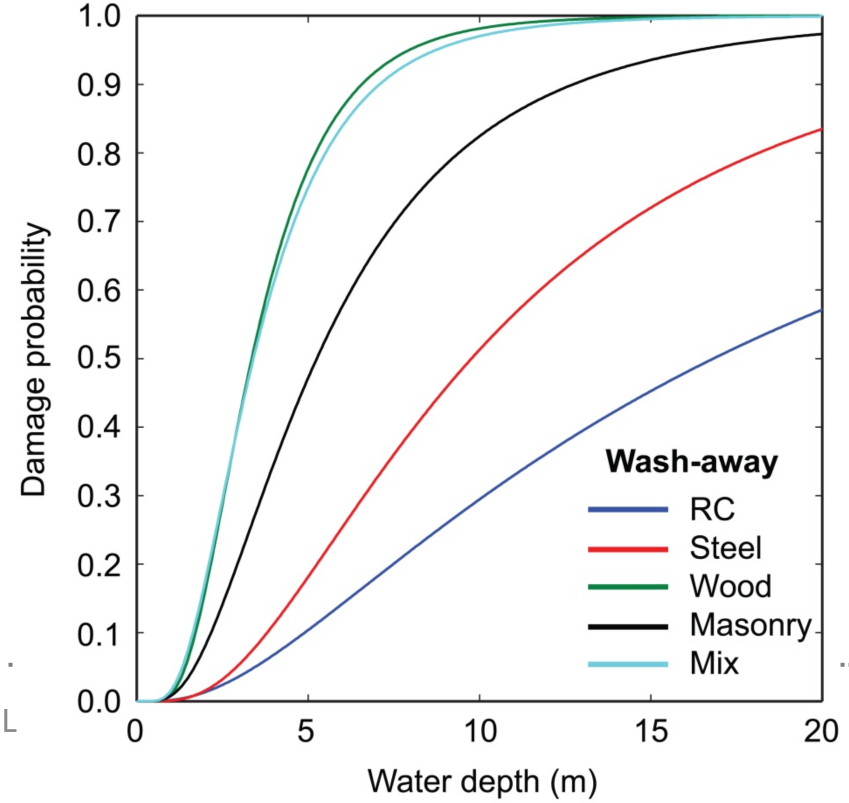
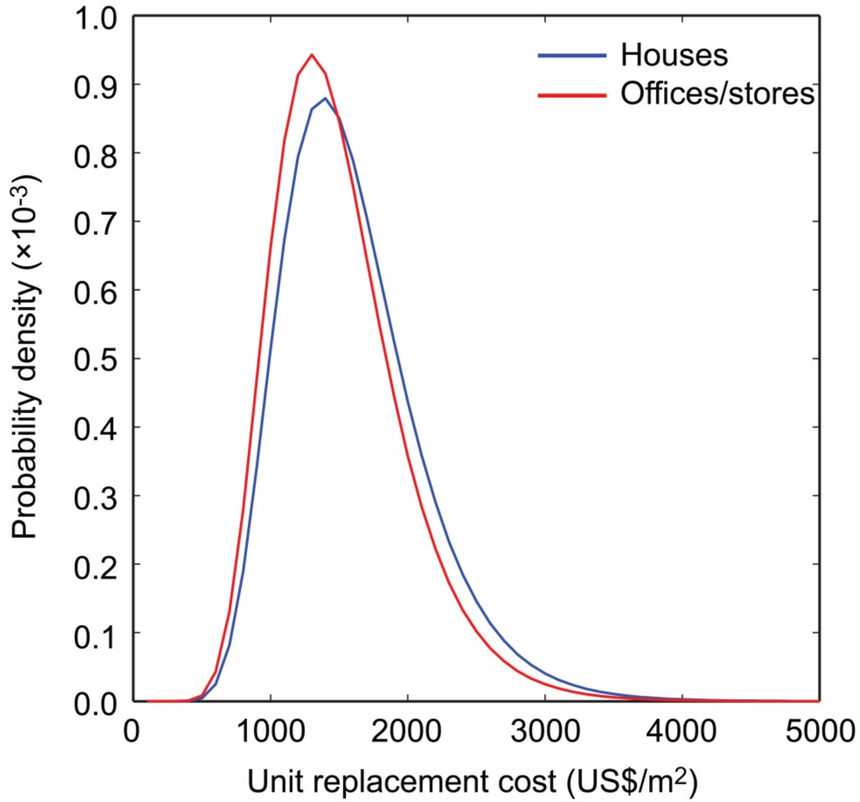
Tsunami Fragility & Cost Models

- The tsunami fragility models are based on the 2011 Tohoku damage data (Suppasri et al. 2013).
- The damage ratios are: 0.05, 0.2, 0.4, 0.6, and 1.0 for minor, moderate, major, complete, collapse/wash-away damage states, respectively.





Results

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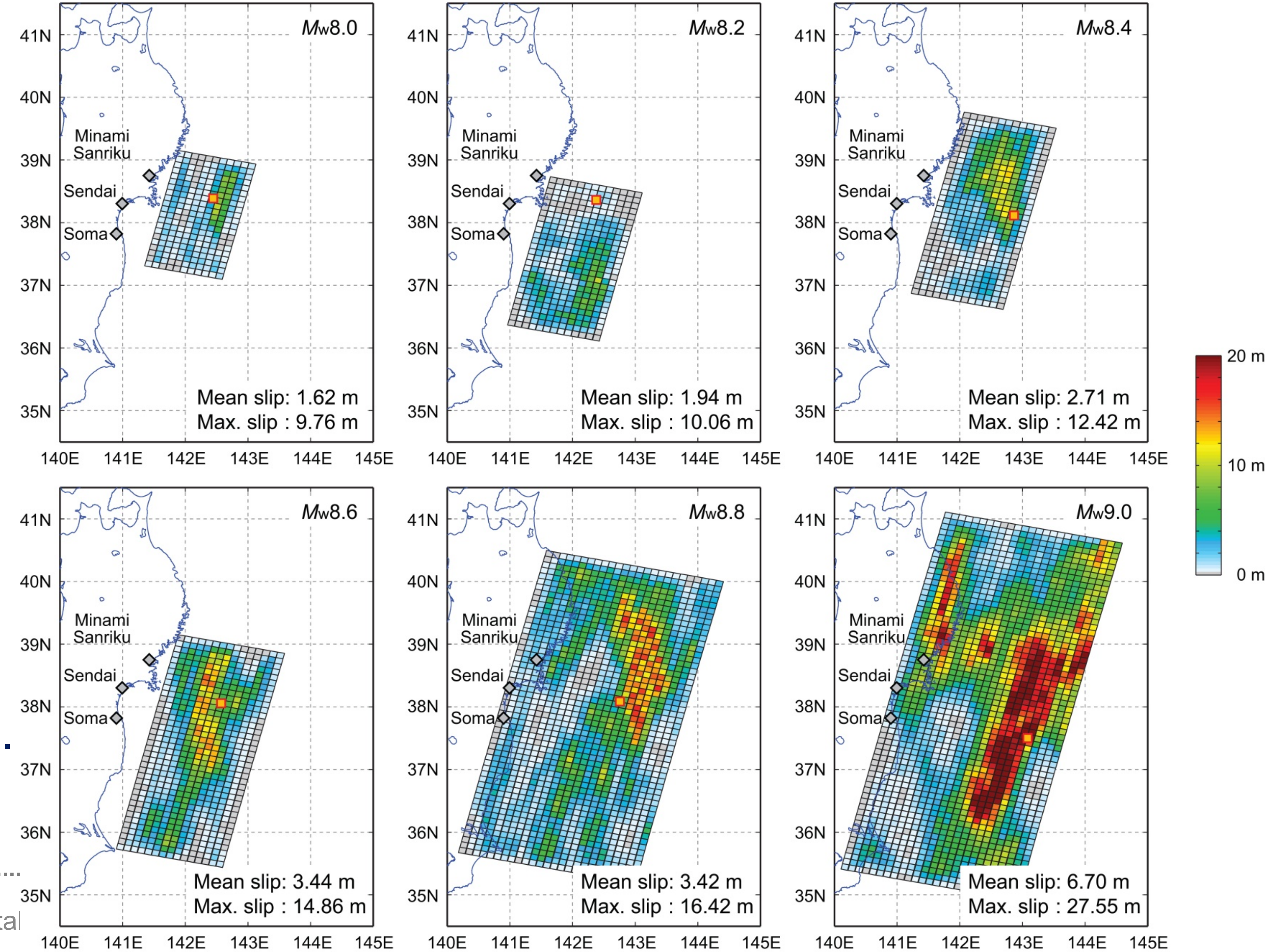
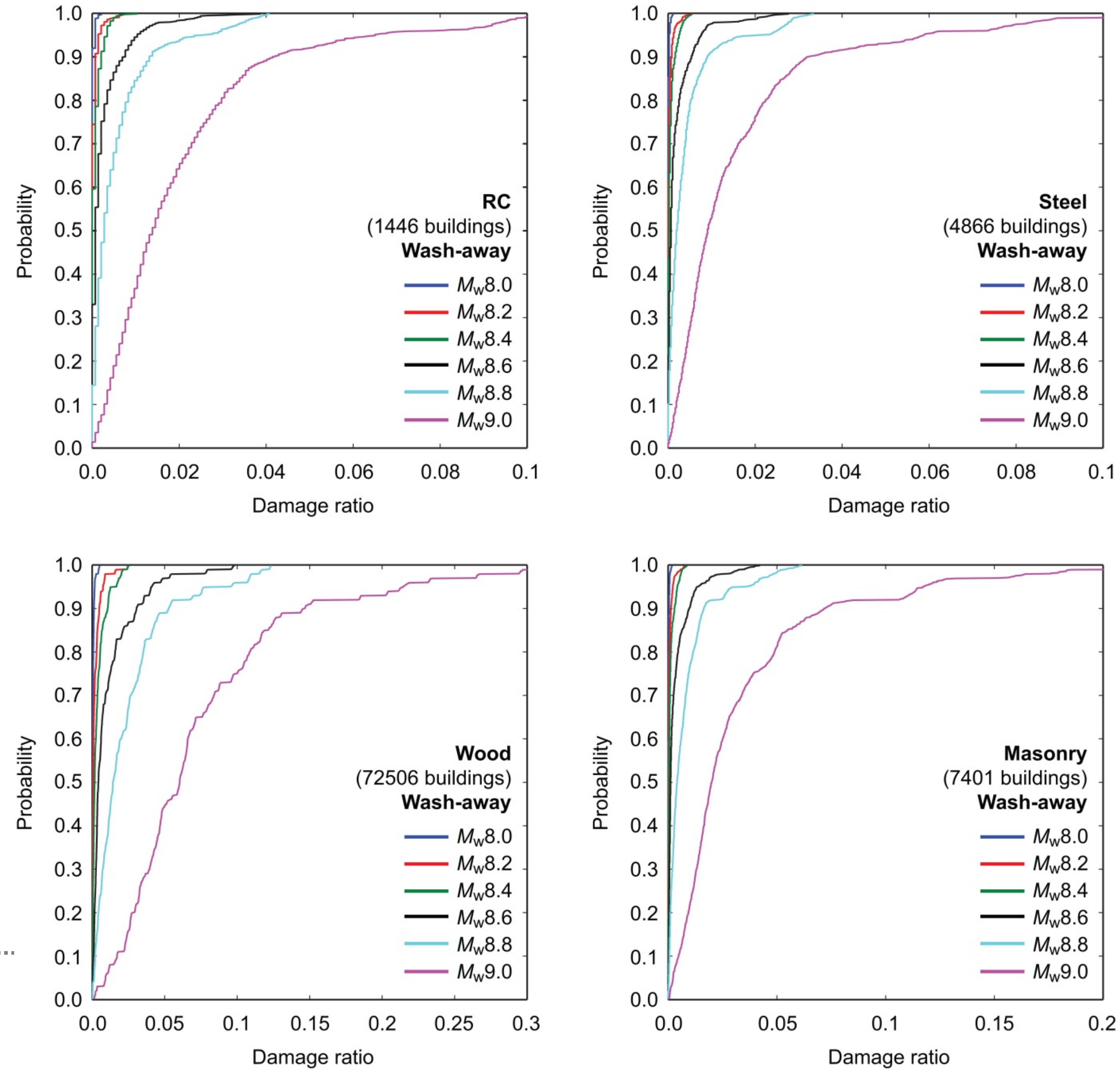
Synthesized Source Models

- Six moment magnitudes: 8.0 to 9.0.
- 100 source models per magnitude.
- All source models contain observed locations of hypocenters.



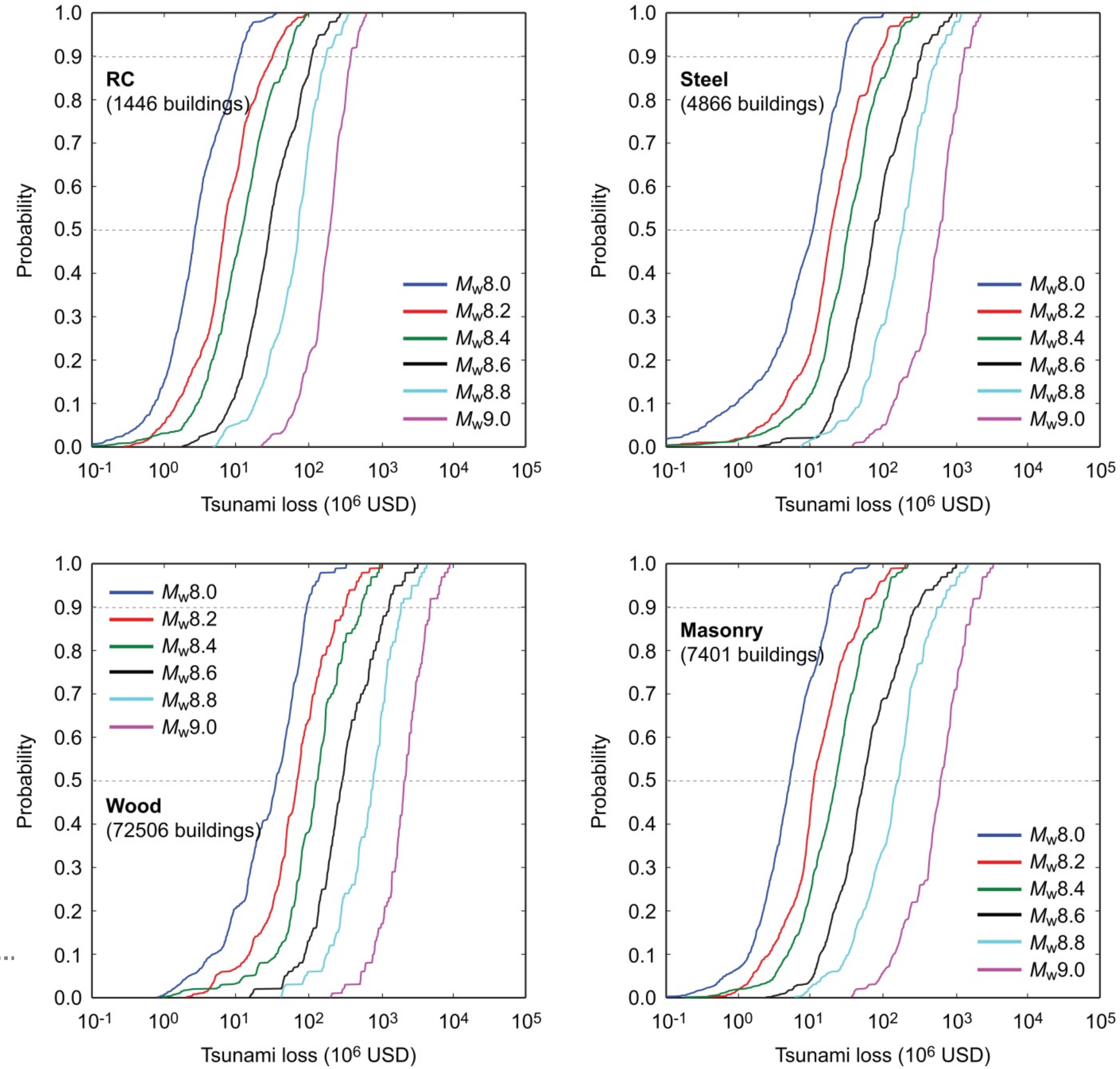
Tsunami Damage Curves

- For each source model, tsunami simulation is carried out to obtain inundation depths at individual building locations.
- Then, tsunami fragility models are applied to obtain the damage probabilities for different damage states.



Tsunami Loss Curves

- Further, information on damage states can be transformed into tsunami loss using damage ratios and building cost models.
- The tsunami loss curves for different building types and for different scenarios can be obtained.



Uncertainty of Tsunami Loss

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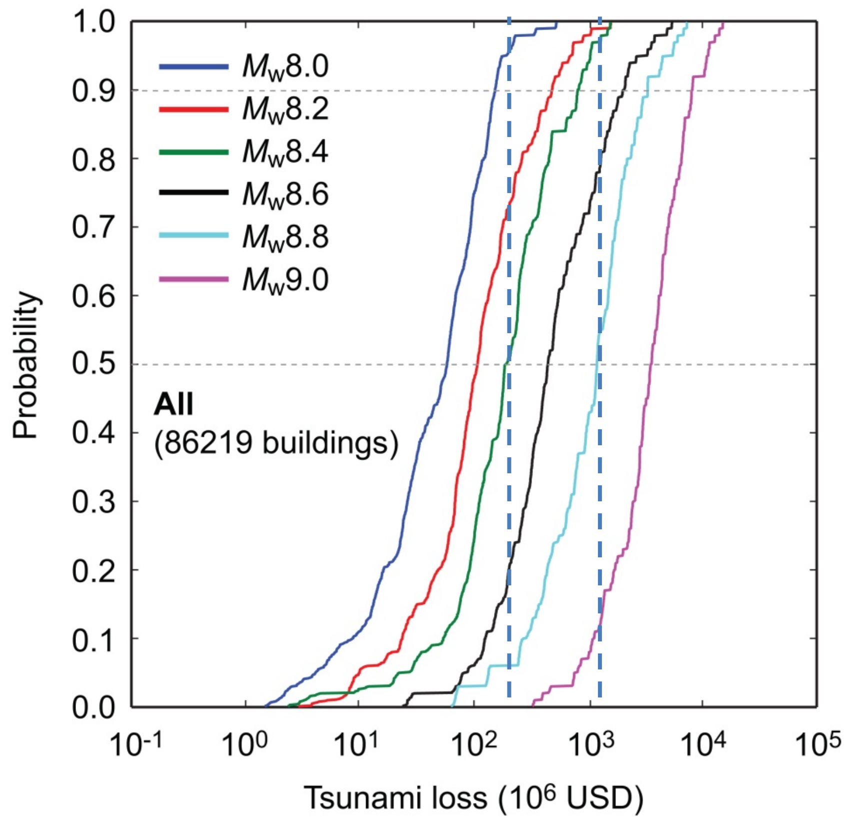
- The differences of the loss curves are the quantitative estimates of the errors due to scenario magnitudes.
- For a given scenario, the loss curve has large variability (a factor of 10 differences at 10th and 90th percentiles).
- The variability is caused by the uncertainty of the source characteristics (e.g. slip distribution).
- The within-scenario variability tends to decrease with magnitude.



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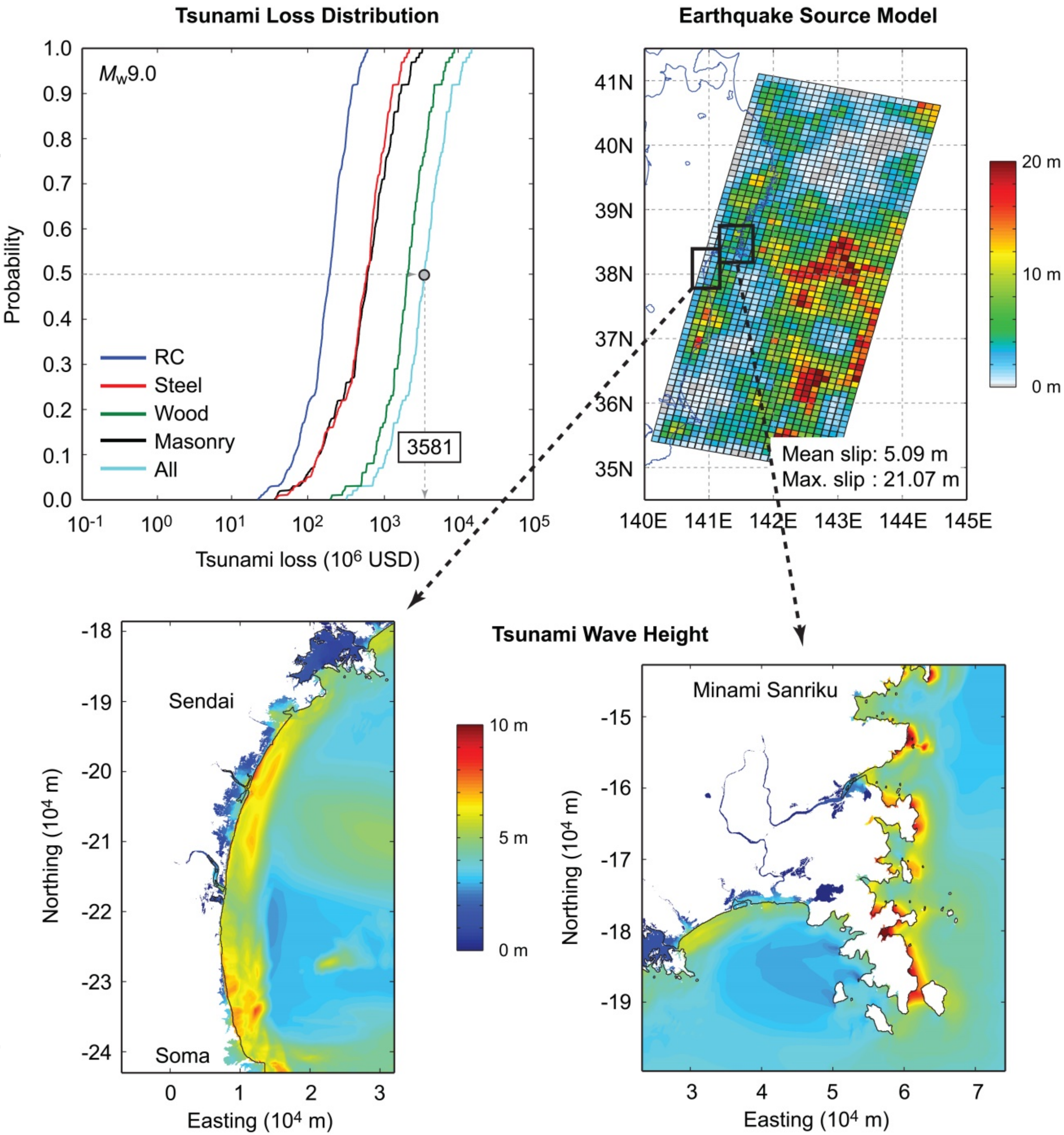
- Moreover, extensive tsunami hazard and risk assessments can provide a valuable integrated interpretation of the results.
- There is one-to-one relationship to interpret the tsunami loss result in terms of source and inundation information.



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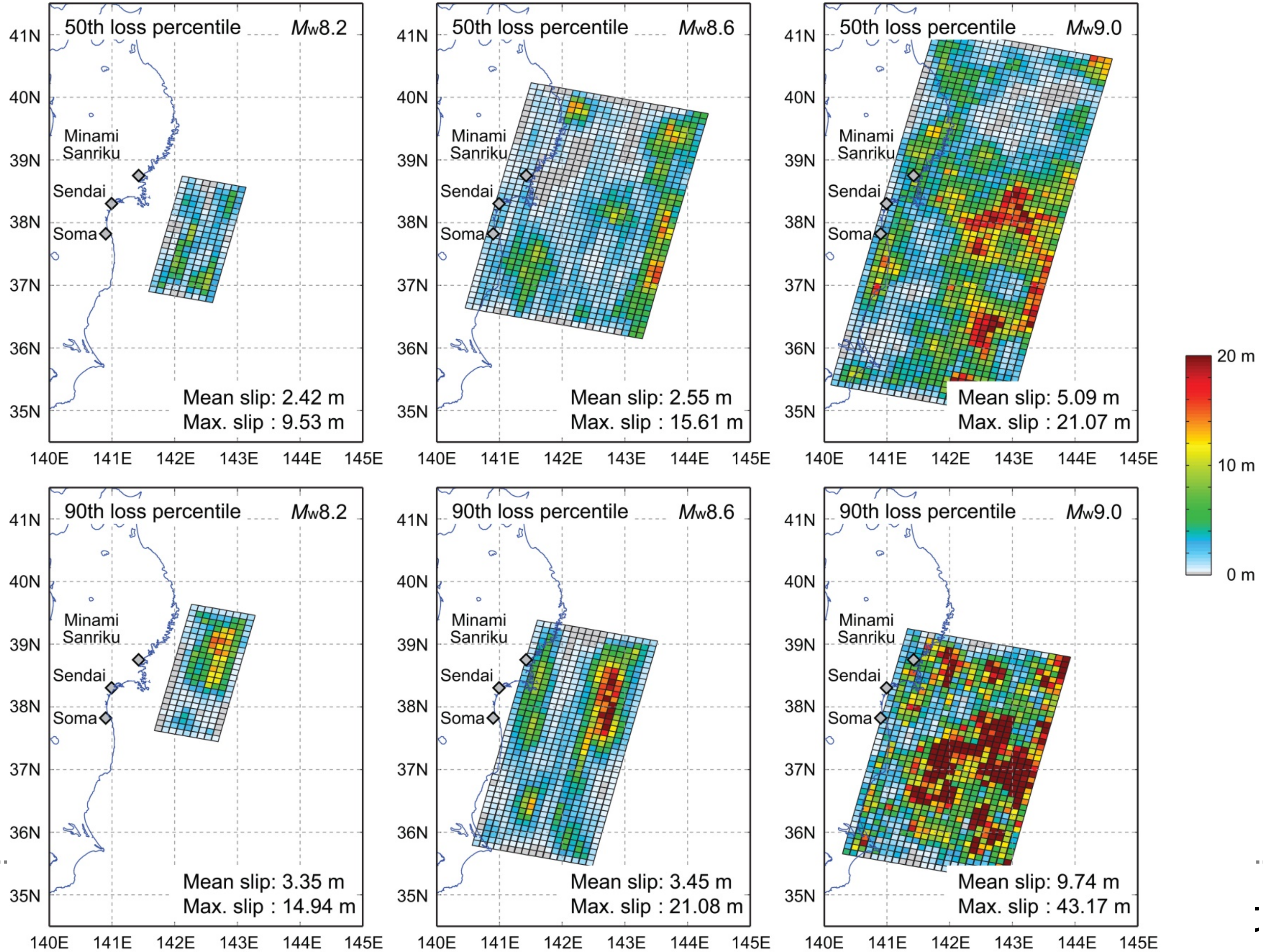
Source Models for Critical Loss Scenarios



Inundation Maps for Critical Loss Scenarios

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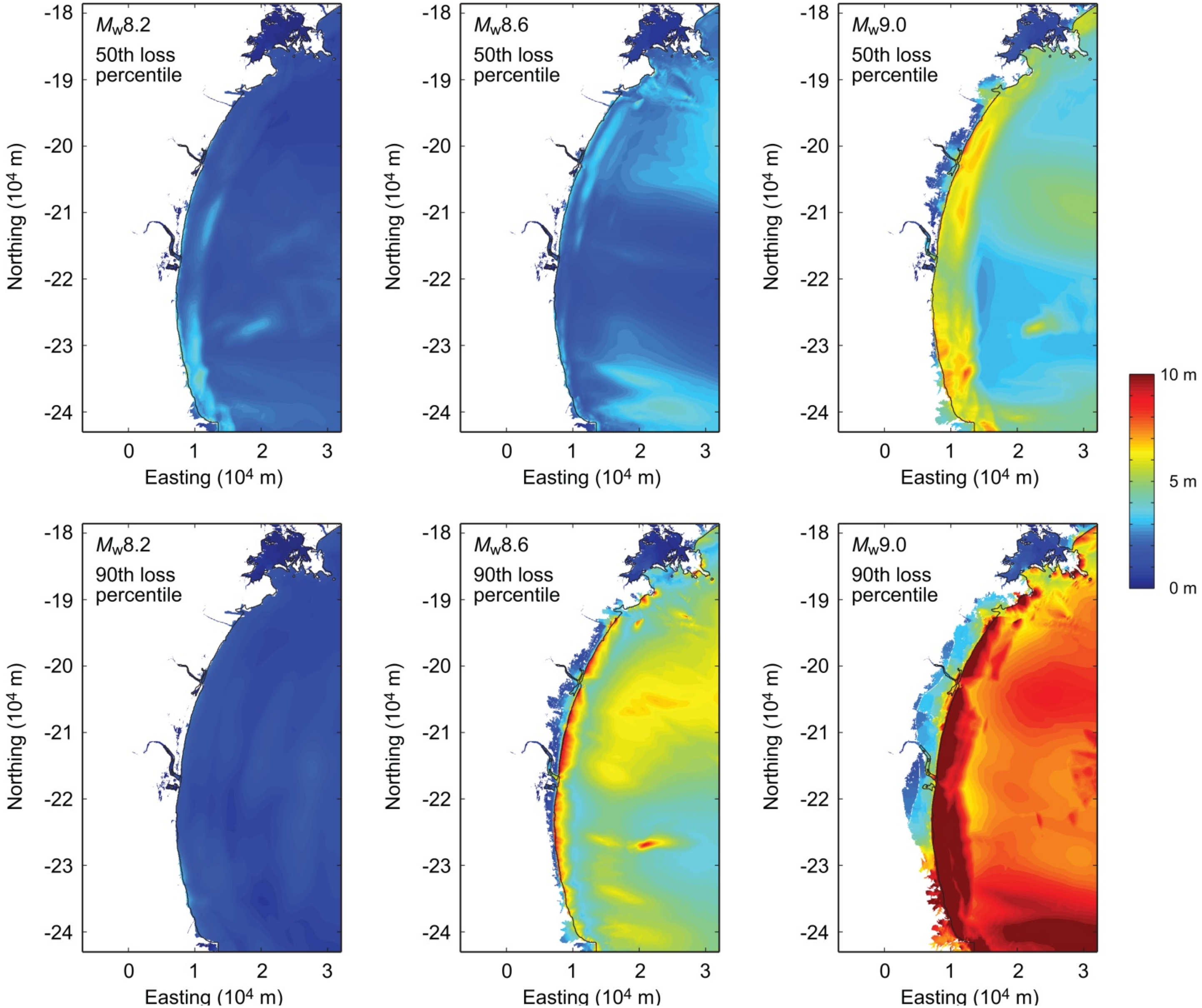
- These are useful decision-support tools for tsunami risk reduction.



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Summary & Conclusions

- A comprehensive probabilistic tsunami loss model has been developed and used for the investigations.
- The errors in earthquake source information (in the context of tsunami warning) can have major influence on the potential consequences of the tsunami event.
- In terms of regional tsunami loss, total tsunami loss increases logarithmically with scenario magnitude (e.g. a factor of 100 from M_w8.0 to M_w9.0). Such information should be useful for risk managers who decide to issue warnings and evacuation orders.
- For a given earthquake scenario, tsunami loss curves vary significantly. This variability is caused by the uncertainty of the source characteristics (not captured by the earthquake magnitude and hypocenter location).