Impact of inaccurate earthquake magnitude to tsunami loss estimation: A tsunami early warning perspective

The challenge

Tsunami warnings require a reliable estimation of key earthquake source characteristics, such as magnitude and location. The estimation of earthquake information is usually accurate and prompt, however, for very large earthquakes satisfactory performance may not be achieved during the early phase of evacuation.

This can be exemplified for the 2011 Tohoku tsunami case, where the first estimate of the magnitude was 7.9 (3 minutes after the earthquake) and the correct estimate of the magnitude of 9.0 was reached 134 minutes after the earthquake. Consequently, tsunami warnings issued by the Japan Meteorological Agency underestimated the observed tsunami significantly (3 to 6 m versus 10+ m).

This study investigated the effects due to underestimation of the earthquake source parameters in the context of tsunami early warning and tsunami risk assessment. For this purpose, a new comprehensive probabilistic tsunami loss model for large magnitude earthquakes in the Tohoku region of Japan was developed, generating a tsunami loss curve for a building portfolio by considering uncertainties in earthquake source parameters. By analysing the estimated tsunami loss for coastal cities and towns in Miyagi Prefecture (case study location), potential biases due to underestimation of earthquake magnitude were quantified. These results provided useful insights regarding the importance of deriving accurate seismic information and were compared with the effects due to uncertain source characteristics (e.g. geometry and spatial slip distribution) for given moment magnitudes, which is unavoidable in making risk predictions based on macroscopic earthquake parameters only.

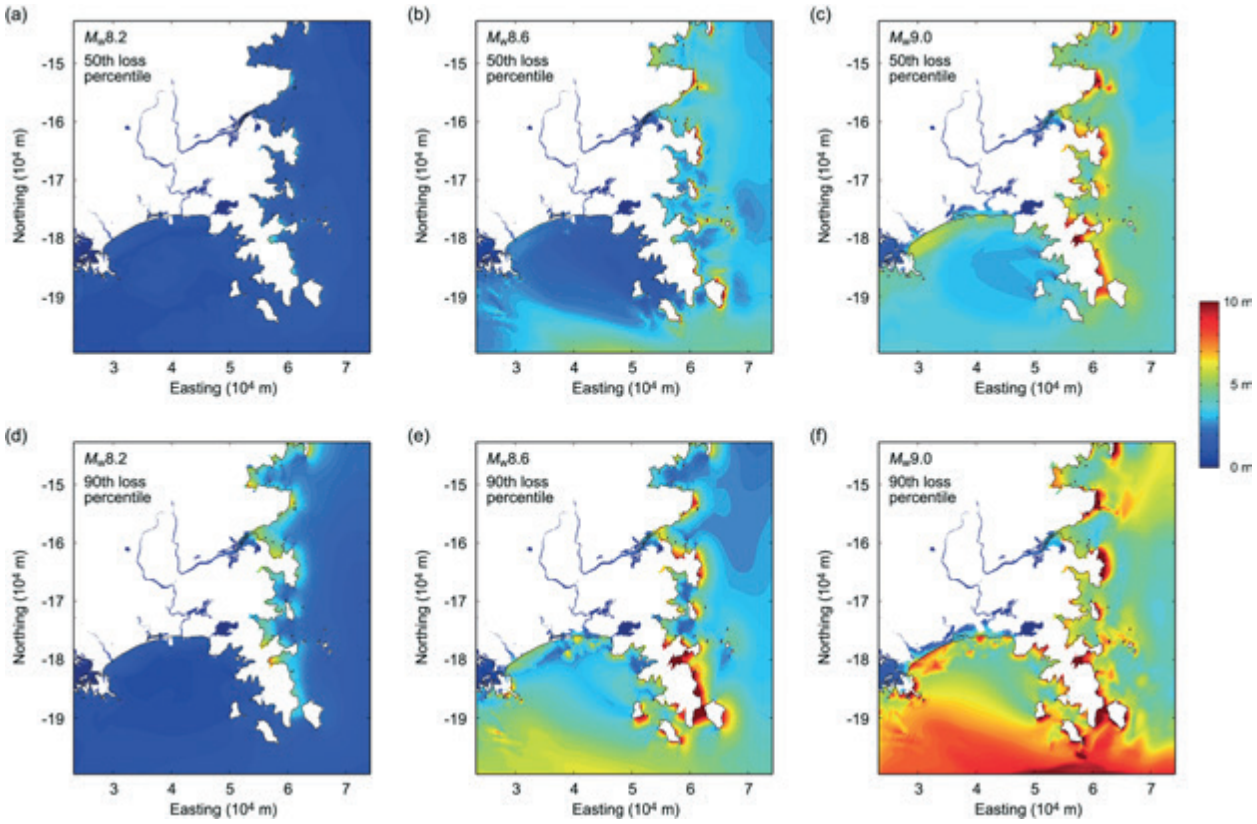
What was achieved

For the Tohoku tsunami case study, we found that the tsunami loss generation process is exponential with respect to earthquake magnitude. Therefore, biases/errors in earthquake source information (magnitude and hypocenter location) can have major influence on the potential consequences of the tsunami event in the context of tsunami early warning and risk prediction. At the median probability level, for instance, total tsunami loss increases by about a factor of 100 from M8.0 to M9.0 scenarios. We also quantified the variability of the tsunami loss curves due to uncertain earthquake rupture characteristics that were not captured by the macroscopic earthquake information. The within-scenario variability of tsunami loss was comparable with the tsunami loss differences caused by the biases in earthquake magnitude.

How we did it

The 2011 Tohoku earthquake was focused on as a case study to illustrate the significance of the effects of issuing inaccurate tsunami warnings on the tsunami risk predictions from a retrospective perspective. In the case study, a building portfolio consisting of about 86,000 buildings in Miyagi Prefecture was considered.

The problem was set up as follows. A tsunami event of M9.0 in the offshore areas of the Tohoku region was adopted as reference. The magnitude of this event may be underestimated significantly during the early stage of the disaster (as was the case for the 2011 tsunami). The underestimated scenarios were represented by a set of earthquake scenarios with lower moment magnitudes than the reference scenario. For each assumed scenario, stochastic source models were generated by



taking into account uncertainty of tsunami source characteristics. Using the multiple sets of tsunami source models corresponding to different moment magnitudes, probabilistic tsunami loss estimation was carried out. In total, six scenario magnitudes from M8.0 to M9.0 were considered, and for each magnitude 100 stochastic source models were generated to represent the within-scenario uncertainty of the earthquake rupture.

In the study, two questions were considered: (i) when the magnitude is in error, what would be the impact in terms of tsunami loss prediction? and (ii) what is the uncertainty of predicted tsunami loss given a moment magnitude and hypocentre location? The former is relevant when the warnings need to be given shortly after a very large seismic event, whereas the latter is always present in issuing tsunami early warnings.

To evaluate the economic consequences due to tsunami events with different scenario magnitudes, probability distributions of tsunami loss for the building portfolio were obtained for different magnitude values. The tsunami loss curves became more severe with increasing magnitude. Practically, this meant that the over-/underestimation of earthquake magnitude by certain units in the tsunami warning might correspond to very different situations in terms of potential consequences. On the other hand, the within-scenario variability of the tsunami loss curve was caused by the uncertainty associated with detailed earthquake slip characteristics that were not captured by the macroscopic earthquake information. This variability was found to be significant, and the main contributor of the variability was the spatial slip distribution, especially the location and extent of major asperities with respect to the building portfolio. Importantly, the within-scenario variability of tsunami loss was grossly comparable with the tsunami loss differences caused by the bias in earthquake magnitude.

References

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The team

Katsu Goda
katsu.goda@bristol.ac.uk

University of Bristol

Kamilla Abilova

University of Oxford (CREDIBLE summer research student)