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Natural Hazards and Earth System Sciences
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Discussions

Interactive comment on "Tsunami hazard warning and risk prediction based on inaccurate earthquake source parameters" *by* K. Goda and K. Abilova

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We thank Reviewer 2 for reading our manuscript carefully and providing us with comments that improve the clarity of the manuscript.

C1 Mention that new methods for the estimation of earthquake magnitude will contribute to the reduction of uncertainties associated with the estimation. R1 Agreed. We added the following sentence in Introduction by citing two suggested papers: 'It is important to point out that recent new developments for rapid and reliable estimation of earthquake magnitude will definitely contribute to the reduction of uncertainties associated with estimated magnitudes in the early phase of tsunami disasters (Kanamori

and Rivera 2008; Melgar et al. 2015)'.

C2 Comment on the stability of the loss results based on 100 realizations per magnitude. R2 The simulation run number (i.e. 100 cases) is selected based on the authors' previous experience on the stochastic simulation of earthquake slips for the 2011 Tohoku earthquake (Goda et al. 2014) and the computational requirement (to cover the entire Miyagi prefecture with sufficient grid resolutions). Ideally, we wanted to increase the simulation number to examine the sensitivity of the results to the simulation run. Although we have not conducted such investigations, we expect that the aggregate loss curves are stable if we perform simulation runs more than 100 or so. One reason is that although variability of tsunami inundation results and consequently tsunami damage at a specific location is more sensitive to subtle features of individual slip distributions, when the results are summed, we observed that the results are more stable. In the revised manuscript, we included the following sentence to clarify the rationale behind the simulation run of 100 times: 'Note that the sample size of 100 is selected based on the authors' previous experience in tsunami sensitivity analysis (Goda et al. 2014) and practical restrictions of computational resources.'

C3 Include the results for Dmax in Figure 3. R3 Agreed. In the revised manuscript, we included the results for Dmax (i.e. comparison of scaling laws and simulated samples). As can be observed from Figure 3c (in the revised manuscript; Fig1 in this reply), the constraints affect the final accepted values of Dmax, which tend to be greater than the average relationship by Thingbaijam and Mai (2016). Note that the model by Thingbaijam and Mai (2016) is for global earthquakes (not just for subduction earthquakes) and does not include source models for the 2011 Tohoku earthquake. On the other hand, the results by Goda et al. (2014), as shown in the figure, are significantly greater than the Thingbaijam-Mai model. In fact, the Thingbaijam-Mai model predicts Dmax/Da ratio of about 3.7 for a Mw9 earthquake (Da = 10 m or so), while the 11 source models for the 2011 Tohoku earthquake show the mean Dmax/Da ratios of about 5.6 (min ratio = 3.4 while max ratio = 9.7). Given the current limitation of the available scaling models, we considered that greater final Dmax values are acceptable. However, this should be improved in the future and we are developing new scaling relationships for subduction tsunami events for various source parameters for this purpose. We briefly mention this new development in our response below (R4). In the revised manuscript, we added a few sentences: 'The simulated maximum slip is generally greater than the empirical relationship by Thingbaijam and Mai (2016), noting that the maximum slip values from 11 source models for the 2011 Tohoku earthquake (Goda et al., 2014) are significantly larger than the Thingbaijam-Mai relationship. Note that the results shown in Figure 3c are the final accepted values, which are modified from originally sampled values of the maximum slip (see the explanations of constraints discussed in Section 2.3). In light of large differences of the maximum slip between the Thingbaijam-Mai model and the results for the 2011 Tohoku earthquake, the simulated maximum slip values are considered to be acceptable.'

C4 Comment on the important assumption that is adopted in the study that the scaling relationships by Mai and Beroza (2002) do not include Mw8+ subduction events. R4 Our justification for using Mai-Beroza models for correlation lengths was due to reasonable match between the extrapolated model predictions at Mw = 9 and the results from the 11 source models for the 2011 Tohoku earthquake (Goda et al. 2014). The results are shown in Figure 3. As rightly pointed out by the referee, the Mai-Beroza models were developed for mainly crustal earthquakes and did not include Mw+8 subduction events. The first author, in collaboration with Prof Mai, has been working on the development of new scaling relationships using the SRCMOD database (http://equake-rc.info/SRCMOD/). The analyses have been completed. However, we have not formally written up the results and have not yet prepared a journal manuscript. For this reason, this work is not available at the moment. The main motivation of the new scaling relationships is twofold: (i) the new models are based on extensive datasets of inverted source models (226 models from 158 earthquakes), which include mega-thrust subduction earthquakes around the world (i.e. 2004 Sumatra, 2010 Chile, 2011 Tohoku etc), and (ii) the models are developed for fault length, width, mean slip, max

slip, correlation lengths, Hurst number, and Box-Cox parameter, and their correlation is also evaluated. The second feature is particularly useful in simulating stochastic source models because various source parameters can be generated jointly. The results from the new study can confirm that the correlation length models by Mai and Beroza (2002) are consistent with the new data from the SRCMOD database. More specifically, the correlation length along strike showed very consistent result with the Mai-Beroza model, while the correlation length along dip show different behaviour for subduction events and non-subduction events; the overall trends are consistent with the Mai-Beroza model. The main reason for the different scaling relationships of the correlation length along dip for subduction and non-subduction events is the different geometry constraint for these two event types. The subduction events have shallow dip angles and thus the fault rupture can extend toward the down-dip direction. On the other hand, crustal earthquakes usually have steeper dip angles, resulting in saturation of fault width when the fault plane reaches the maximum extent of a seismogenic thickness of the crust.

C5 Clarify the meaning of 'further adjusted'. R5 Agreed. We meant that after the stochastic slip simulation, we applied the Box-Cox transform to make the slip values having positive skewness (which is observed in slip models for the 2011 Tohoku earthquake and other earthquakes). After this conversion, we adjusted the transformed slip distribution to achieve the target mean slip and non-excessive maximum slip (note: Box-Cox transform is a power transformation – this can generate unrealistically large slip value). We mentioned these as 'further adjustments'. In the revised manuscript, we removed 'further' and added 'Subsequently'.

C5 Comment on the sensitivity to the hypocentre variation. R5 The results are not particularly sensitive to the hypocentre locations. Although the variation of these estimates by three institutions is large, in comparison with overall rupture area, the variation is relatively minor. In the context of the analyses conducted in this study, these hypocentre locations constrain the locations of the fault rupture plane. Because the buildings that are considered in this study are near the hypocentre locations, the loss results are not so sensitive to this variation. Regarding the large variation of hypocentre locations, for usual cases, locations should be able to be determined more accurately.

C6 Do the candidate source models contain many instances where slip is concentrated near the trench? R6 The simulated slips do have relatively high concentration of slip along the Trench (shallower parts) – for example Figure 4e; for the referee's information, we show another set of simulated slip distributions for the six magnitude values (Fig2 in this reply). These features are controlled through the requirement that the slip concentration in the shallower part (shaded area in Figure 2) to be more than 60% and less than 75%. We tested several cases for these percentages; we finally selected the range between 60% and 75% because this set-up led to simulated slip distributions that match with our expectation for such events in light of our knowledge on the earthquake rupture that can cause large tsunamis. We recognize that this process is subjective.

C7 Comment on questions like 'How strongly does the within-scenario variability depend on the choice of wavenumber spectrum and the choices of the empirical relationships?' and 'Could this variability be reduced with improved knowledge about rupture processes?', and 'Would this variability be different in other subduction zones?' R7 Our short answer is that we do not know at the moment and cannot answer these questions. However, the development of a consistent set of scaling relationships for major source parameters (as mentioned in R4) will help answer these questions in the future. For example, the results we have obtained so far suggest that the von Karman spectral model is applicable to characterize the spatial slip distribution for a wide range of magnitudes (up to Mw9.0).

C8 Make corrections for the suggested typos. R8 Agreed. These changes are made in the revised manuscript.

Interactive comment on Nat. Hazards Earth Syst. Sci. Discuss., 3, 7487, 2015.

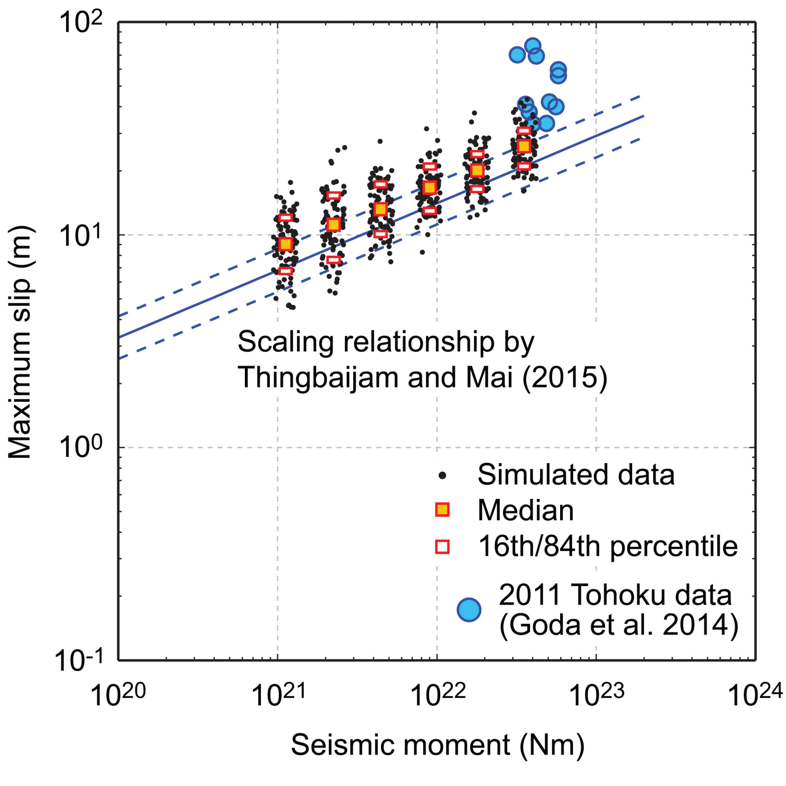

Fig. 1. Seismic moment versus maximum slip (Figure 3c in the revised manuscript)

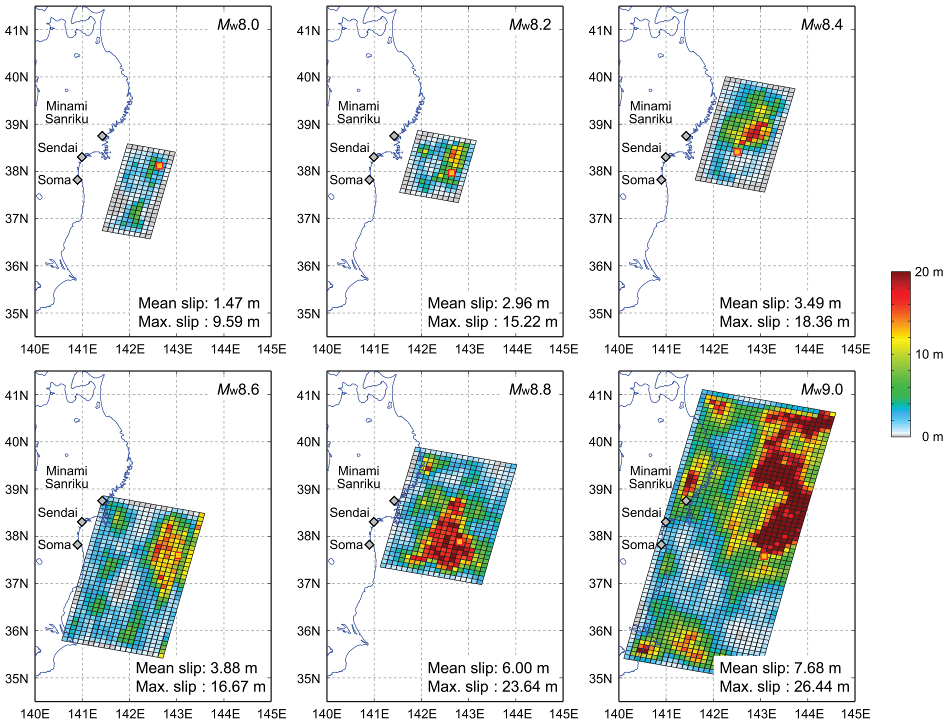

Fig. 2. Another set of simulated slip distributions for the six magnitude values