Tsunami height variations due to stochastic self-similar slip distributions on a non-planar fault for megathrust earthquakes

*Masaru Nakano[1], Shane Murphy[2], Ryoichiro Agata[1], Yasuhiko Igarashi[3], Masato Okada[3], Takane Hori[1]

1. Japan Agency for Marine-Earth Science and Technology, 2. Ifremer, France, 3. Graduate School of Frontier Sciences, The University of Tokyo

Megathrust earthquakes along the Nankai trough in southwest Japan, such as the 1944 Tonankai and 1946 Nankai events, have caused severe damage due to strong ground motion and the generation of large tsunamis. Since such devastating earthquakes have repeatedly occurred throughout history in this region, we should prepare for future large earthquakes. Tsunami early warning systems have been developed to mitigate such tsunami disasters. Two types of systems exist: (1) based on early estimations of earthquake and/or tsunami sources (e.g. Tatehata 1997; Tsushima et al. 2009), and (2) based on correlations of coastal tsunami heights from scenario earthquakes and offshore tsunami observations (e.g. Baba et al. 2014; Igarashi et al. 2016; Yamamoto et al. 2016). While the computation cost for early warning is relatively low in the latter method, its accuracy may depend on the variations of scenario earthquakes. To date, studies adopting method (2) compute the theoretical tsunamis using thousands of earthquake scenarios of various magnitude earthquakes with uniform slip distributions. However, actual earthquakes have heterogeneous slip distributions which affect coastal tsunami heights and distributions. One possible solution to resolve this issue is to create a set of scenario earthquakes based on a slip probability density function (SPDF, Murphy et al., 2016), in which heterogeneous slip distributions on the source fault are stochastically generated based on a given probability density function. The generated earthquake slip distributions differ from event to event, but their average over a large ensemble of models converges to a predefined SPDF.

In this study, we create a set of scenario earthquakes that contain self-similar slip distributions based on the composite source model (Herrero and Murphy, 2018) on the Nankai trough. In this set of scenario earthquakes fault slip is not tapered to zero at the free surface (i.e. surface rupture is considered). We assume the SPDF is similar to the slip deficit rate (SDR) obtained by Yokota et al. (2016), which may represent long-term average of slip on the target fault. Using this technique, 200 scenario earthquakes were generated for the expected Tonankai earthquake (Mw=8.2) and the ensuing tsunamis were computed using the JAGURS code (Baba et al. 2014). We then compared the peak nearshore tsunami amplitudes generated using these scenario earthquakes that incorporate slip heterogeneity with those from uniform slip distribution on the same fault area.

We found that the peak tsunami amplitudes along the coast facing the source region varies by as much as 3 to 10 times depending on the slip distribution of the scenario earthquakes. The peak tsunami amplitude distributions are well fitted by Gauss distribution with a mean and standard deviation depending on each site. Largest and/or smallest peak amplitudes are caused by a few extreme cases, and locations showing large variations might depend on the scenarios generated in this study. Increasing the number of scenario earthquakes might increase variations of peak tsunami amplitudes, especially locations showing relatively small variations obtained in this study.

Next, we compared the median heterogeneous-slip amplitudes with that due to an earthquake of uniform slip distribution. The median heterogeneous-slip amplitudes are larger compared with that from uniform

slip at most sites. This result indicates that consideration of heterogeneous slip for scenario earthquakes is crucial to accurately estimate peak tsunami amplitudes consequently improving the accuracy of tsunami early warning based on scenario earthquakes.

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