Seafloor Displacement along the Japan Trench Caused by the 2011 Tohoku-Oki Earthquake Examined by Repeated Bathymetric Surveys

*Toshiya Fujiwara[1,9], Shuichi Kodaira[1], Gou Fujie[1], Yuka Kaiho[1], Toshiya Kanamatsu[1], Takafumi Kasaya[2], Yasuyuki Nakamura[1], Tetsuo No[1], Tsutomu Takahashi[1], Takeshi Sato[3], Narumi Takahashi[4,1], Yoshiyuki Kaneda[5,1], Katharina Bachmann[6], Christian dos Santos Ferreira[6], Gerold Wefer[6], Michael Strasser[7], Tianhaozhe Sun[8]

1. Research Institute for Marine Geodynamics, Japan Agency for Marine-Earth Science and Technology, 2. Research Institute for Marine Resources Utilization, Japan Agency for Marine-Earth Science and Technology, 3. Sapporo Regional Headquarters, Japan Meteorological Agency, 4. National Research Institute for Earth Science and Disaster Resilience, 5. Kagawa University, 6. MARUM, University of Bremen, 7. Institute of Geology, University of Innsbruck, 8. Pacific Geoscience Centre, Geological Survey of Canada, 9. Kochi University

After the 11 March 2011 Tohoku-oki earthquake, we have conducted multibeam bathymetric surveys. The bathymetric data were collected along the same tracks obtained before the earthquake. These selected tracks were crossing the trench and extending from the landward to seaward trench slopes. We examined seafloor displacement on the landwardrelative to the seaward by means of the difference in multibeam bathymetry before and after theearthquake. Up until the present, we have evaluated several tracks from off-Fukushima to off-Sanriku, thus the seafloor displacement distributionalong the Japan Trench.

Along the off-Miyagi tracks near the epicenter, crossing the trench at 38˚05'N,the landward slope was largely elevated, the seafloor displacement extended to the trench, and there was sharp bathymetric changes at the trench axis [Fujiwara et al., Science 2011]. The conclusive result suggests fault rupture and slip extending to a shallow part of the subduction zone reached the trench axis. We estimated the coseismic horizontal displacement using the horizontal bathymetric offset. The horizontal displacement was very large about 50 m to the trenchward direction.

Notably, on the outermost landward slope, the 40 km wide area between the slope break and the trench axis, the seafloor was more than 10 m shallower on average. The observed seafloor elevation change on the outermost landward slope corresponds to a sum of vertical displacement and additional uplift for the sloping seafloor due to horizontal displacement. This uplift was likely an important factor contributing to the generation of the massive pulsating pattern of tsunami waves.

The method described in the Fujiwara et al. [2011] paper implicitly assumed the seafloor moved as a block unit. Sun et al. [Nat. Commun. 2017] evaluated the fault slip distribution over the most near-trench 40 km zone. The slip gently increased towards the trench and peaked at the trench axis. The slip was determined to be about 60 m.Quantitative information on the shallow slip is of critical importance to understand the rupture mechanism and the generation of the ensuring devastating tsunami.

Upward and downward changes in seafloor elevation of ±50 m are evident at the axial seafloorat 38˚05'N. Seismic data showed deformation of the sediment layer within the trench.The result is further evidence of the rupture propagation through the sediment layer [Kodaira et al., Nat. Geosci. 2012; Strasser et al., Geology 2013]. This bathymetric deformation is confined to an area extending 13 and 7 km along and across the trench directions, respectively. Currently, similar prominent bathymetric deformation is not found in any other places.

Large seafloor displacements suggesting coseismic slips to the trench were consistent in survey tracks in the off-Miyagi area, as far as the track at 38˚35'N. While, smaller seafloor displacements were observedalong the off-Fukushima track crossing the trench at 37˚25'N and along the off-Sanriku track crossing the trench at 39˚05'N, therefore the large coseismic slip to the trench is considered to be limited to the off-Miyagiarea near the epicenter.

We acquired three off-Sanriku survey trackscrossing the trench at 39˚10'N, 39˚20'N, and 39˚30'Nbecause maximum tsunami height caused by the earthquakewas observed at the coast of Sanriku.The evaluated seafloor displacements were relatively small, less than about 20 m in trenchward horizontal displacement and several meters in vertical displacement. Thus localized very large fault slip or very large submarine landslide is unlikely at least on the three survey tracks. There were coherent relative differences in the seafloor elevation on the landward trench slopes, which suggests the outermost lower slope was uplifted and the middle slope and the mid-slope terrace subsided along the trench axis [Fujiwara et al., GRL 2017].

Relatively small displacements less than 20 m in horizontal displacement and several meters in vertical displacement, these values are within ranges of error of the analysis [Fujiwara et al., MGR 2015]. Thus, quantitative discussion is rather difficult as values of the seafloor displacements are concerned about burying in the ranges of error. Additionally, in our analysis, data quality of the bathymetric data before the earthquake was major problem because the usage of repeated bathymetric survey for detection of seafloor displacement was not foreseen at that time. For the future, repeated acquisition of high resolution and accuracy bathymetric data using state-of-the-art technology at the present time of survey is important in the tectonically active regions.

Keywords: 2011 Tohoku-Oki Earthquake, Seafloor Displacement, Japan Trench, Multibeam Bathymetry, Tsunami

