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Evaluation of Seismic Rupture Models for the 2011 Tohoku-Oki Earthquake Using Tsunami Simulation

Ming-Da Chiou *, Emmy Tsui-Yu Chang, and Sen Jan

Institute of Oceanography, National Taiwan University, Taipei, Taiwan

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ABSTRACT

Developing a realistic, three-dimensional rupture model of the large offshore earthquake is difficult to accomplish directly through band-limited ground-motion observations. A potential indirect method is using a tsunami simulation to verify the rupture model in reverse because the initial conditions of the associated tsunamis are caused by a coseismic seafloor displacement correlating to the rupture pattern along the main faulting. In this study, five well-developed rupture models for the 2011 Tohoku-Oki earthquake were adopted to evaluate differences in simulated tsunamis and various rupture asperities. The leading wave of the simulated tsunamis triggered by the seafloor displacement in Yamazaki et al. (2011) model resulted in the smallest root-mean-squared difference (~0.082 m on average) from the records of the eight DART (Deep-ocean Assessment and Reporting of Tsunamis) stations. This indicates that the main seismic rupture during the 2011 Tohoku earthquake should occur in a large shallow slip in a narrow range adjacent to the Japan trench. This study also quantified the influences of ocean stratification and tides which are normally overlooked in tsunami simulations. The discrepancy between the simulations with and without stratification was less than 5% of the first peak wave height at the eight DART stations. The simulations, run with and without the presence of tides, resulted in a ~1% discrepancy in the height of the leading wave. Because simulations accounting for tides and stratification are time-consuming and their influences are negligible, particularly in the first tsunami wave, the two factors can be ignored in a tsunami prediction for practical purposes.

Key words: Seismic rupture model, Numerical tsunami simulation, Ocean stratification, Tides

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1. INTRODUCTION

On 11 March 2011, the M_w 9.0 Tohoku-Oki earthquake, with an epicenter close to the conjoint site of four tectonic plates (Fig. 1), caused considerable ground tremors and huge tsunami waves in and around northern Honshu, Japan. Based on over 100 years of seismic observations, the northern Honshu area is considered to be a relatively calm area compared to the active seismogenic zone of southern Honshu (e.g., Ando 1975). Hence, this catastrophic event, which caused extensive and severe structural damage in northeastern Japan, challenges the current understanding of seismotectonics for plate convergence around Japan. The findings from the Global Centroid Moment Tensor Solutions indicate that the mainshock of the 2011 Tohoku earthquakes was characterized as a reverse fault with a compression axis in the WNW-ESE direction (Nettles et al. 2011). Most of the aftershocks occurred in areas of persistent background seismicity, but were clearly subject to the Pacific Plate subducts under the Okhotsk Plate and were distributed in an approximately 200-km wide and 500-km long area (cf. the seismic catalogue of Japan Meteorological Agency - JMA website http://www.jma.go.jp).

To study the deformation processes of this earthquake, many rupture models of the mainshock have already been created using teleseismic and regional seismometer records, GPS observations, and tsunami wave height records (e.g., Ammon et al. 2011; Fujii et al. 2011; Ide et al. 2011; Lay et al. 2011a, b; Lee et al. 2011; Maeda et al. 2011; Ozawa et al. 2011; Simons et al. 2011; Tsushima et al. 2011; Yamazaki et al. 2011; Yue and Lay 2011; Zhao et al. 2011). All of these studies explain the faulting of the mainshock in different

* *Corresponding author*
E-mail: mdchiou@ntu.edu.tw