Modeling of the Tohoku-oki 2011 tsunami generation and coastal impact: a mixed co-seismic and SMF source

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The devastating coastal impact of the 2011 Tohoku-oki tsunami cannot at present be fully explained from a co-seismic source alone, because resulting tsunami simulations do not reproduce the elevated tsunami runup heights of up to 40 m along the (Sanriku) coast of northern Honshu, nor the higher frequency wave periods (3-4 min.) recorded at offshore buoys (both GPS and DART). Here, we model the tsunami generated from the combination of: (i) a new co-seismic source based on a detailed three-dimensional (3D) Finite Element Modeling (FEM) of the heterogeneous subduction zone, with geodetic data assimilation (Grilli et al., 2012a,b; Masterlark 2003, Masterlark and Hugue, 2008); and (ii) an additional tsunami source from a submarine mass failure (SMF) triggered north of the main rupture with a time delay. We show that the multi-source tsunami agrees well with all the available field observations, both offshore and onshore.

Both co-seismic and SMF sources are first modeled for 300 s in a 1km mesh regional grid, using the 3D non-hydrostatic (sigma-level) model NHWAVE (Ma et al., 2012), as a time- and space-varying bottom boundary condition (Fig. 1). Results are then re-interpolated into the fully nonlinear and dispersive Boussinesq model FUNWAVE-TVD, for modeling in a series of nested grids, in the near-field in Cartesian coordinates (Shi et al., 2012), and in the far-field in spherical coordinates (Kirby et al., 2012). Various bathymetry/topography data bases are from ETOPO1 in deep water to 50 m accurate data (and model grids) nearshore and onshore. Simulations are compared to GPS and DART buoy time series (Fig. 2) and maximum runup (Fig. 3).

Although there are no direct geological observations of the proposed SMF, its location and kinematics can be identified and validated by travel-time analysis of higher-frequency waves recorded at GPS and DART buoys, and additional more accurate SMF tsunami simulations. Additionally the proposed SMF source can be justified from both the known geology of the Japan trench (Cadet et al., 1987; Tsuru et al., 2002), and the tsunami runups and inundation limits recorded during post-tsunami field surveys (e.g., Fujiwara et al., 2011; Kawamura et al., 2012).

References

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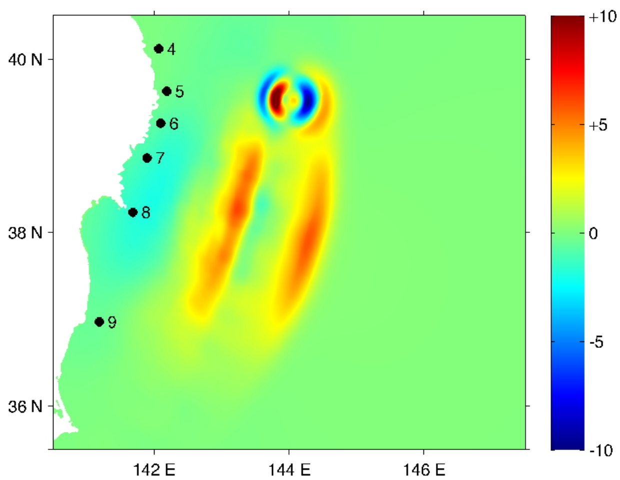

Fig. 1: Instantaneous surface elevation computed at t =300 s with NHWAVE, after the triggering of the UA co-seismic source at t = 0 and of the SMF at t = 135 s. Numbered dots indicate locations of GPS buoys (black; #1-9)

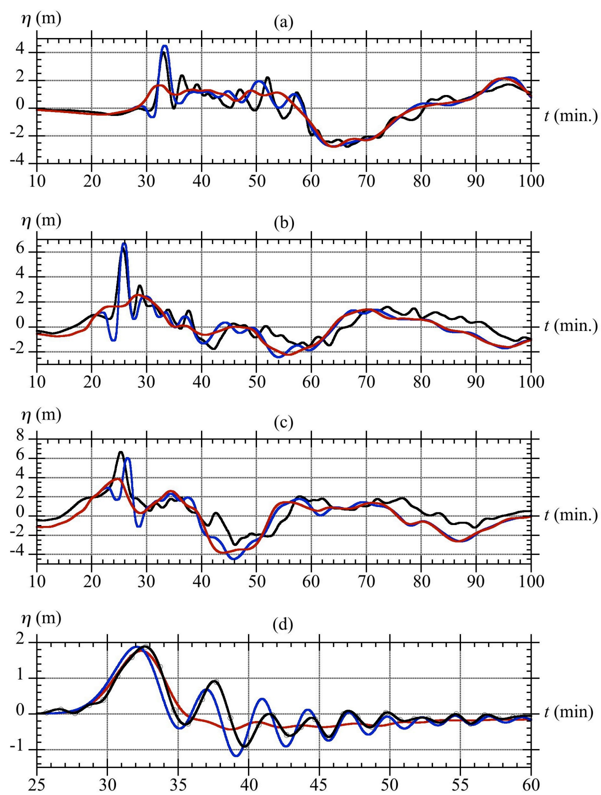

Fig. 2: Surface elevations at buoys near Japan as a function of time, for 4th-6th GPS stations (marked in Fig. 1): (a) North Iwate; (b) Central Iwate; (c) South Iwate; and (d) DART #21418. Field measurements (black), and computations for the co-seismic source (red) and the latter plus the SMF (blue). The abscissa is duration in minutes from the start of earthquake rupture.

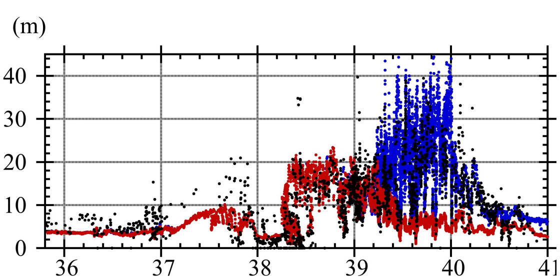

Fig. 3: Runup along the Japanese coast: measured in field surveys (black dots); simulated with the coseismic source alone (red dots); and with the combined coseismic and SMF sources (blue dots).