The effect of earthquake rupture propagation on regional tsunami amplitude

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Existing tsunami forecast/warning systems stand on the assumption that tsunami sources are built up instantaneously over the whole source region, since the effect of earthquake rupture propagation on tsunami generation and propagation is considered to be usually minor [Imamura et al., 1987, Proc.Coast.Engin.; Goto et al., 1988, Zisin]. For multi-segment great earthquakes with a fault length of 1000 km or so such as the 2004 Sumatra-Andaman earthquake, however, finite rupture propagation speeds reasonably affect travel times of the first tsunami waves [Neetsu et al., 2005, Science; Fine et al., 2005,GRL]; tsunamis generated from rupture propagation fault models have to arrive later at some regions than those from instantaneous fault models but do not arrive faster everywhere.

On the other hand, the effect of earthquake rupture propagation on tsunami amplitude has scarcely investigated based on real bathymetry, although it had studied under flat ocean assumption [Aida, 1969,BERI; Yamashita and Sato, 1974, JPE]. We investigated it for regional tsunamis (travel distance between 5deg and 30 deg) by using real bathymetry in terms of numerical simulation.

We focus on uni-lateral rupture propagation cases. We placed 14 rectangular subfaults along the Sumatra-Nicobar-Andaman Trench. Each of the subfaults starts to slip at the time that rupture front reaches there. Final tsunami waveforms are represented by a time-lagged, linear combination of tsunami Greens functions, calculated from each subfault. We calculated tsunami Greens functions at hypothetical points 50 km ~100 km offshore along the coasts of Bay of Bengal, Andaman Sea, and Indian Ocean, by solving linear-long wave equations with finite-difference algorithm on staggered grid system [Satake, 1995, PAGEOPH]. The grid size is 3 minutes of arc, interpolated from ETOPO2 [Smith and Sandwell, 1997, Science]. A constant amount of slip was given on each subfault. Other subfault parameters are the same as Hirata et al.[2006,EPS].

Effect on the first upward wave amplitudes of offshore tsunamis is summarized as follows;
(1) Tsunamis traveling in the rupture propagation direction tend to be larger in amplitude than those in the opposite direction. This observation is similar to theoretical and numerical consideration under a flat ocean assumption.
(2) However, amplification in tsunami amplitude seems to be larger in the direction of the minor axis of the tsunami source rather than in the rupture propagation direction. This observation does not agree with the consideration under a flat ocean assumption.
(3) In general, change in tsunami amplitude is larger for 500 km-long fault than 1400 km-long fault. This indicates that the shorter the fault length, the larger the effect of rupture propagation on tsunami amplitude.
(4) A general trend such that the slower the rupture propagation speed, the larger the change in tsunami amplitude is seen. This observation is similar to the consideration under a flat ocean assumption. In particular, for 500 km-long fault with rupture propagation speeds slower than 1.5 km/sec, tsunami amplitudes increase, at many regions, 1.1 to more than 1.3 times as large as those generated from instantaneous rupture. This means importance of rupture propagation effect for tsunamis generated by slow earthquakes.
(5) For 1400 km-long fault with finite rupture propagation speeds, tsunami amplitudes increase along the northeast coast of India (17degN-20degN) and the east coast of Sri Lanka (6degN-9degN), while those decrease along the east coast of India (11degN-15degN). Tsunami source geometry, tsunami source-to-receiver configuration, and refraction due to bathymetry may be responsible for this phenomenon.