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Cause of travel-time difference between observed and synthetic waveforms of distant tsunami

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It has been reported that the observed tsunami waveforms from distant tsunami are delayed by several to a few tens of minutes from synthetic waveforms based on linear long-wave theory. Tsunami waveforms recorded on pressure gauges in deep oceans from the 2011 Tohoku-Oki earthquake and the 2010 Chilean earthquake. The cause of this delay may include the effect of bathymetry data and parameters for numerical computation (e.g., Kusumoto et al., 2011) or the effects of elasticity of the earth, compressibility of seawater and gravity potential change that are not included in the present numerical computation (e.g., Watada et al., 2011). The contributions of these effects to travel-time delay of the observed tsunami waveforms are studied.

The travel-time delay increases as a function of travel time. Travel-time delay for the Tohoku-Oki earthquake monotonically increases with travel time, and becomes near 15 minutes at travel time of 1200 minutes. Travel-time delay for the Chilean earthquake is almost zero up to travel time of 600 minutes, then rapidly increases with travel time, and reaches more than 10 minutes at travel time of 1200 minutes.

Three different kinds of bathymetry data, ETOPO5, ETOPO1 and GEBCO are examined. They all produce similar travel-time differences, but the travel-time differences for ETOPO5 are 1-3 minutes larger than the others.

The gravity and the earth's radius are usually assumed as constant for present numerical computation. However, these should be treated as variables because the real earth is spheroid. When these are treated as variables that depend on only colatitude, travel-time difference hardly changes until travel time of 400 minutes, but decreases by 1-2 minutes over the travel time of 600 minutes.

Phase velocity of the observed waveforms are measured, and normalized for a constant (4 km) deep ocean. The normalized phase velocity is compared with theoretical dispersion curves of linear gravity wave and of the PREM model, which includes the effects of the elasticity of the earth, compressibility of seawater and gravity potential change. Phase velocity of the normalized observed waveforms is slower by more than 1 % than that of the linear gravity wave at a period range more than 2,000 seconds, and these match with the dispersion curve of PREM.

The main cause of the travel-time difference is thus inferred as wave dispersion of longer period due to the effect of elasticity of the earth, compressibility of seawater and gravity potential change. Moreover, gravity and the earth's radius should be treated as variables when tsunami propagates for a long time in equatorial regions.

Finally, to include the effects of the above main causes, i.e., elasticity of the earth, compressibility of seawater and gravity potential change, into the current simulation method, phase delay of the theoretical dispersion curves was applied to the simulated waveforms. Comparison with the observed tsunami waveforms shows that the travel-time difference became less than 5 minutes for both earthquakes.

Keywords: tsunami propagation, travel-time differences, Deep-Ocean Assessment and Reporting of Tsunamis, the 2011 Tohoku-Oki earthquake, 2010 Chilean earthquake