Retrieval of tsunamis by the interferometry of deep ocean pressure records

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Over the last 10 years, seismic waveform interferometry became a popular technique for studies of earth's subsurface. It enables to retrieve virtual seismic waveforms propagating between two stations without earthquake sources by stacking of the cross-correlation of continuous records of ground motions. We applied waveform interferometry to the records from deep ocean pressure gauges to retrieve tsunami waveforms without tsunamis sources.

Continuous pressure records for the year 2011-2015 from three DART stations (21418, 21413, 52401), located along the western boundary of the Pacific at the depth of 5500-5900 m were used for the tsunami interferometry. Distance between stations ranges from 956 to 2265 km. De-tided data in a common four or eight hour-long data window were pre-processed: removal of the long-period trend by 6th-order polynomial fit, time domain one-bit amplitude normalization, and frequency domain amplitude spectrum whitening. Cross-correlated waveforms of multiple time windows with a half timewindow overlap for three years were stacked. The stacked waveforms showed gradual amplitude increase toward the arrival time of virtual tsunami propagating between two stations. A sharp transition from positive to negative amplitude was observed at the expected arrival time.

This characteristic waveform reflects the fact that the long-wave tsunami at the deep ocean is nearly non-dispersive for a broad wave-period range. In theory the cross-correlation of 2D isotropic non-dispersive wavefield coming from large distance shows gradual increase of amplitude before the expected arrival time of the virtual waves traveling between two points because; the time lag of an incoming plane wave to the two points with a slant angle is less than the traveltime between the two points, and interference of plane waves coming from all azimuth will result in the maximum amplitude of the cross-correlation in the azimuth connecting two points. No plane wave arrives at two points with a time lag larger than the traveltime between the two points, corresponding to the abrupt amplitude decrease of cross-correlated waveforms. In reality dispersive surface gravity waves propagate at the speed slower than the long-wave and appear later than the virtual tsunami.

The extracted virtual tsunami waveforms were then analyzed for the phase velocities of tsunamis between two points. Subtracting the initial phase from the measured phase by assuming cylindrical 2D waves, we succeeded to measure the phase velocity of virtual tsunamis for the period range from 300 to 3000 s. The measurements were in good agreement with the tsunami phase velocities expected from the ocean depth. A clear reduction of phase velocity from long-wave speed, as predicted from the surface gravity wave theory, was detected for wave periods toward 300 s.

Keywords: tsunami waveform interferometry, DART, tsunami waveform, phase velocity of tsunami, dispersive tsunami, cross-correlation of ocean bottom pressure

