Real-Time Tsunami Detection Based on Ensemble Empirical Mode Decomposition

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Offshore bottom pressure gauges (OBPGs) are useful in tsunami early warning because they are able to detect tsunami in real time. A reliable tsunami detection algorithm for OBPGs should be able to identify the tsunami signals and characterize the tsunami amplitude accurately, at a small computational cost. Traditional methods, like the DART algorithm adopted by the National Oceanic and Atmospheric Administration (NOAA), have to rely on the prediction of the tides and other lower frequency signals. These algorithms can detect a tsunami by subtracting predicted pressures from the observation, but they cannot properly identify its waveform. And they are unable to capture the feature of the background sea noise.
In our research, we propose a method of real-time tsunami detection based on Ensemble Empirical Mode Decomposition (EEMD). EEMD decomposes the time series into a set of intrinsic mode functions (IMFs) (Huang et al., 1998; Wu, 2005). Unlike Fast Fourier Transform or wavelet analysis, it does not need a priori basis. Instead, it adaptively determines the natural oscillatory modes embedded in the original signal. Therefore, it is applicable to nonlinear, non-stationary data like tsunami signals. In our practice, we use the series of the OBPG record of the past three hours, and then we conduct EEMD and obtain the IMFs. The tsunami signals can be separated from the tide signals, seismic signals, as well as background noise. By comparing the value with a threshold of 2 cm, we could decide whether the tsunami has arrived.
We apply our method to the tsunami record of OBPGs of the 2016 Fukushima earthquake, Japan (M7.4; Gusman et al., 2017). Five OBPGs owned and operated by the Earthquake Research Institute recorded the tsunami generated by the earthquake. We retroactively conduct EEMD to the data. Our method automatically extracts tsunami-signals from the low-frequency components (e.g. tide) and the high-frequency components (e.g. seismic waves). The tsunami arrival is easily determined by setting the threshold. We compare our algorithm with STA/LTA (Short Time Average over Long Time Average) method (Allen, 1982). Our method is less influenced by the tide signals and is able to estimate the tsunami amplitude after detection. We also apply our method to the extremely large case of the 2011 Tohoku earthquake (M9.0), and the extremely small case of the 1998 off Sanriku earthquake (M6.1). The EEMD algorithm is able to detect and characterize the tsunami of the extremely large case, but it could not work for the extremely small case.

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