Performance evaluation of methods to estimate temporal changes in attenuation property using active sources

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We compare the ability of two methods which are developed for estimating temporal changes in attenuation using signals generated by an artificial seismic source, ACROSS.

Temporal changes in attenuation have not been studied well, probably due to lack of useful methods to detect the change. A lot of studies are reported on temporal changes in travel time all over the world and some of the proposed mechanisms have been suggested on attenuation change. Thus, development of a suitable method on temporal changes in attenuation will contribute to the related study all over the world.

We used an artificial seismic source, ACROSS, to detect temporal changes in attenuation. To find the temporal change in attenuation of a medium, stability of the source is necessary to avoid fake change due to the source instability. ACROSS can excite same signals continuously because it generates seismic waves by rotating eccentric mass under precise phase control. Temporal changes in noise level should also be considered because it may cause fake changes in amplitude. In the ACROSS measurement, noise level is also measurable because frequencies of exciting signals are known. The noise level can be used for estimating the amplitude variation in the following processes.

We developed two methods to estimate temporal changes in attenuation using ACROSS. One method is "simultaneous estimation" (Tsuji et al, 2019, JpGU Meeting), and the other is a method based on wave energy of the signals, named “energy-based estimation”. The simultaneous estimation is a method to estimate variation in travel time and amplitude simultaneously by fitting transfer functions with a specific model in a complex plane. The best-fit parameters are looked for with maximum likelihood method so that minimize square of the length in the complex plane. The energy-based method calculates deviation of energy of transfer functions by reducing the noise energy that is estimated simply by the signal design of ACROSS system.

To assess the performance of the two methods, we applied the methods to a synthetic data in which Gaussian noise of various amplitudes is added to a signal. We compared amplitudes that are estimated with the two methods for the synthetic data. As a result, the simultaneous estimation could estimate smaller variations in amplitude than the energy-based method under a condition of a constant noise level. However, a bias due to noise level is found for the simultaneous estimation. This means results with the simultaneous estimation may contain fake change due to changes in noise level.

Next, we applied the two methods for in-situ data and compared the results. We test the data observed in an ACROSS experiment at Awaji Island that was conducted between January 2000 and April 2001 (Ikuta et al., 2002; Ikuta and Yamaoka, 2004). The previous studies reported sudden delays in travel time in P and S phases at the time of the earthquakes. The amplitude also dropped at the earthquake with a difference between the two methods. The variation with the simultaneous estimation is smaller than that with the energy-based estimation (blue dots of figure) for 1700m borehole seismometer. It may be caused by a difference in noise level between 800m and 1700m sensors. Based on the synthetic test, the simultaneous estimation could work stably in noisy conditions though a bias appears.

Considering the results, the simultaneous estimation is better if the bias due to noise could estimate. Now we are updating the simultaneous estimation by developing a method to estimate the bias. We will show the result in our poster.

Figure Caption:
Variation in amplitude with the simultaneous estimation (left sides) and the energy-based estimation (right sides). Each figure shows one week before and after the occurrence of the 2000 Western Tottori earthquake. Each row shows UD (top), NS (middle) and EW (bottom) component of the sensors at 800m (red) and 1700m (blue) deep.

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