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Characteristics of the CCF of coda waves: dependence on the angle between the station pair and the source

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Coda of earthquakes consists of scattered waves and the late coda can be regarded as a diffuse field. The diffuse wave field is necessary for the seismic interferometry. Campillo & Paul (2003) showed that we can extract the Green's function from field-to-field correlation of coda waves. Different from the noise field, scattered waves around the source region are included in the coda. We analyze the cross-correlation functions (CCF) of coda of earthquakes occurred around the source region of the 2011 Tohoku-oki earthquake and examine the fluctuation of them.

We use the earthquakes with magnitude larger than 5 occurred from 2008 to 2011 and about 74 Hi-net stations located in the east coast of northeastern Japan. We apply the band-pass filter (0.1 - 0.2Hz) and divide the coda window into 300s-long segments from 200s after the origin time until 700s with an interval of overlap of 100s. By stacking the CCFs, we detect the Rayleigh wave with the propagation velocity of 3.2km/s. We examine the dependence on the source location by using the angle between the source and the station pair. The CCFs with angles less than 45 degrees are asymmetry. On the other hand, the CCFs with the angles larger than 45 degrees are more symmetric. This feature was also reported in Paul et al. (2005). This observation indicates that the energy coming from the source is still dominant in the late coda.

We calculate the fractional travel-time change, dt/t, by applying the stretching method to the coda of the CCF and analyze the fluctuation of it. The dt/t shows the strong fluctuation and the RMS of it is about a few percent. This fluctuation is not systematic. The fluctuation of the dt/t measurement based on the stretching method due to the random fluctuation of the waveform is theoretically estimated by Weaver et al (2011). When we apply their theory to our measurement, the predicted fluctuation and the observed fluctuation are the same order of magnitude. This result indicate that the observed fluctuation of dt/t is not reflected the uniform change of the medium. Because the diffuse field of coda is not isotropic, we can't obtain the stable CCF from the coda. We also calculate the CCF of noise field in the same region and calculate the dt/t due to the 2011 Tohoku-oki earthquake by applying the stretching method. We observe the co-seismic change of dt/t. The dt/t increases by about 0.2 % after the earthquake. This is one order of magnitude smaller than the fluctuation of dt/t derived from the CCF of coda. Therefore we can't detect the change due to the earthquake from the CCF of coda. In order to improve the stability of the CCF of coda, we apply the curvelet denoising filter (Stehly et al 2011). By the denoising, the correlation coefficient between each CCF and the stretched reference CCF increases and the fluctuation of the dt/t decreases. However, the fluctuation is still too large to detect the co-seismic change.

Finally, we mention about the signal to noise ratio (SNR) of the CCF. The SNR of the CCF of noise is about 3 times larger than that of the CCF of coda. The ratio of the square root of the length of the time window of the noise used to calculate the one-day CCF to that of the coda is about 14. Therefore, in terms of the length of the time window, the CCF of the coda is efficient to extract the Green's function compared with the noise.

Keywords: Coda wave, Seismic interferometry