Passive seismic imaging of crustal structures: numerical study on acoustic and elastic reverse time migration

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Introduction

To image crustal structures from passive seismic data, we propose a reverse-time method using reflection signals in the observed records. We adopted reverse time migration (RTM), which is a powerful technique to image complex structures in active-source seismic imaging, to passive seismic observation. In addition to an acoustic RTM method based on P wave propagation, we developed an elastic RTM method using both P and S waves (Watanabe and Shiraishi, 2019, SEGJ). We conducted numerical study with a regional crustal structure model in SW Japan. The proposed method may become a useful technique for imaging crustal structures and monitoring their conditions from huge amounts of passive seismic data recorded with land-based and offshore seismic station networks and high-dense observation of optic fiber sensing.

Method

We assume a passive observation of seismic waves in the ground: the seismic waves excited at an underground source reflect downward after arriving at one receiver location on the surface, and then reflect upward at the subsurface boundary and arrive at another receiver location. In imaging process from such passive seismic data, we simulate two wavefields, forward in time from one receiver and backward in time from another receiver location, and calculate temporal integration after correlation of the two wavefields of every time step. Stacking the integral results from many records of different sources, we can obtain subsurface images directly from the passive seismic records with undefined source information. In a general acoustic-RTM based on the acoustic wave equation, we deal with only P wave propagation. By adopting elastic wave modeling, we can deal with both P and S wave information in an elastic-RTM. Furthermore, we can obtain two images from P and S waves by means of potential field representation from divergence and rotation computation of the simulated elastic wavefields.

Numerical study

We conducted a numerical study of the proposed method using synthetic data generated with a two-dimensional regional structure model, which was extracted from a plate and crust structure model in SW Japan (Nakanishi et al., 2018). We set a 400-km virtual survey line from Nankai trough off Kumano to Tango Peninsula. We randomly extracted 100 actual sources of local earthquakes from the JMA unified catalog within 35-km range from the survey line, and projected them on the vertical section along the line. We generated synthetic seismic records with 1-Hz dominant frequency using a finite difference method. We compared two observation conditions: ideal dense observation with 400 receivers at 1km intervals, and sparse observation with projected 48 stations to the survey line from Hi-net/F-net/DONET seismic stations within 35-km range from the survey line.

To image the model structures, we applied the acoustic-RTM using only vertical component of the synthetic seismic records and the elastic-RTM using both vertical and horizontal components. In the ideal dense observation, both the acoustic-RTM and elastic-RTM methods can image the subsurface structures. The result from the acoustic RTM, however, shows a degraded image due to S waves in the synthetic records. The elastic RTM with potential representation can overcome this problem by dealing with both P and S waves, and shorter wavelength of S waves than that of P waves is useful for better resolution image in some parts. In the quasi-actual sparse observation, it is difficult to obtain subsurface images by the present direct imaging approach. In addition to possible illumination improvement by increasing seismic records from different sources, application of compressive sensing may be useful to improve the subsurface images from the actual sparse observation condition.

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