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A subsurface random inhomogeneity inferred from the spatial autocorrelation of the travel time residual in cross-well tomography

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We tried to estimate subsurface small-scale random inhomogeneity by investigating the spatial autocorrelation function of the travel-time residuals at the stations of cross-well seismic velocity tomography, which has an advantage that all sources and receivers are deployed in an equally-spaced interval. Tomographic images are usually insensitive to subsurface small-scale inhomogeneity because of the model truncation in inversion algorithms based on the trade-off between resolution and uncertainty of solution. We consider that the residuals between the observed and calculated travel times are coming from the model truncation in the inversion; namely eliminating the small-scale inhomogeneity. The travel-time residuals are not coming from the random noise but reflecting small-scale velocity fluctuations along the seismic ray paths. In this light, subsurface heterogeneity consists of the large- (long wavelength) and the small-scale (short wavelength) inhomogeneities. The small-scale random inhomogeneity is characterized by the intensity (e2) and the characteristic distance of random heterogeneity (a). The small-scale random inhomogeneity is added to the tomographic image, or truncated model. This heterogeneous structure model having both large- and small-scale inhomogeneity is regarded as one of the candidates for realistic subsurface structure. We referred to it as a broadband model. The travel times of the truncated model and the broadband model are obtained by numerically simulating the wavefield in the truncated and the broadband models, respectively. Travel-time residuals in the numerical model are the differences of the travel times in the truncated and the broadband models. The spatial autocorrelation function of travel-time residual is obtained from the residuals at each observation points. Repeating generation of the small-scale random inhomogeneity and modifying the broad-band models, we conducted wave-field simulations for several times, and obtain autocorrelation of the travel time residuals for each stochastic realization. By comparing the observed autocorrelation function and the statistical distribution of the simulated auto correlation functions for different e2 and a, we can find plausible values for the parameters e2 and a that explain the observed autocorrelation function. We found that the small-scale random inhomogeneity characterized by e2 ˜0.01, and a = 20 m explains an observed autocorrelation function obtained from a cross-well tomography at the Yutsubo geothermal site, Oita, Japan.