Geophysical Research Abstracts
Vol. 18, EGU2016-9066-1, 2016
EGU General Assembly 2016

Double-Difference Adjoint Tomography

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We introduce a double-difference method for the inversion of seismic wavespeed structure by adjoint tomography. Differences between seismic observations and model-based predictions at individual stations may arise from factors other than structural heterogeneity, such as errors in the assumed source-time function, inaccurate timings, and systematic uncertainties. To alleviate the corresponding nonuniqueness in the inverse problem, we construct differential measurements between stations, thereby largely canceling out the source signature and systematic errors. We minimize the discrepancy between observations and simulations in terms of differential measurements made on station pairs. We show how to implement the double-difference concept in adjoint tomography, both theoretically and in practice. We compare the sensitivities of absolute and differential measurements. The former provide absolute information on structure along the ray paths between stations and sources, whereas the latter explain relative (and thus higher-resolution) structural variations in areas close to the stations. Whereas in conventional tomography, a measurement made on a single earthquake-station pair provides very limited structural information, in double-difference tomography, one earthquake can actually resolve significant details of the structure. The double-difference methodology can be incorporated into the usual adjoint tomography workflow by simply pairing up all conventional measurements; the computational cost of the necessary adjoint simulations is largely unaffected. Rather than adding to the computational burden, the inversion of double-difference measurements merely modifies the construction of the adjoint sources for data assimilation.