TESTING THE LIMITS OF TRAVEL-TIME PICKING, FREQUENCY EFFECTS, AND NOISE UPON THE RESOLUTION OF TRAVEL TIME TOMOGRAPHY

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Ray theory represents the most common basis for the study of seismic wave transmission and works well for describing the structure of a medium along the trajectory of energy propagation. Travel time tomography routinely uses ray theory to invert observed travel times for velocity structure of the medium. This theory is an infinite-frequency approximation. It fails to consider the influence of structures near the ray that affect the amplitude of realistic data at finite frequencies. The volume about the ray which affects the first half-cycle of the wavelet is called the first Fresnel zone. Its size is a function of the velocity and structure of the medium and the frequency of the wave. The Fresnel zone associated with the dominant frequency is commonly cited in the literature as the resolution limit of travel time tomography. Objects smaller than a Fresnel zone are hidden due to healing of wavefronts that have diffracted around the object.

This study investigates to what extent travel-time tomography can or cannot be used to resolve anomalous objects smaller than a Fresnel zone. Causal wavelets were used because they represent realistic physical sources and allow optimum picking of first arrivals, the most commonly used energy for tomography. A variety of auto-picking schemes were used to consistently pick the first arrival traveltimes. For noise-free data, accurate travel times could be picked for objects much smaller than the dominant-frequency Fresnel zone. Objects many times smaller than the Fresnel zone were detectable by times that were unequal to those with the object absent. Tomographic inversion of these travel times successfully recovered velocity anomalies for objects much smaller than the Fresnel zone. When realistic noise is introduced in the seismic data, the picking of individual traces becomes less accurate and may render small objects undetectable. These noisy picks are centered on the noise-free time, not the time that would have been observed in the absence of the object. This allows for statistical detection of smaller objects. Stacking of many traces prior to picking and averaging the picks of the individual traces both improve the picking accuracy and thus the ability to resolve or detect small objects. Tomography also performs an averaging of travel-times through the overlap of ray paths, so we anticipate an improvement in detection of small objects beyond that from a single seismic trace.

We have shown that tomography resolvability and detectability of small objects is better than the Fresnel zone. This is because travel times are more accurate then a half-period of the dominant frequency and can be improved in accuracy by data redundancy. Signal-to-noise ratio and ray coverage are the limiting factors of travel-time tomography. Full-wavefield tomography can improve resolution by including more information in the inversion.

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