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Petascale computing and adjoint methods in global seismic tomography

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Improving the resolution of tomographic images is crucial to answer important questions on the nature of the Earth's mantle. To develop higher-resolution tomographic images, inverting seismic observations at relatively long periods, we must use descriptions of seismic wave propagation more accurate than ray theory. As commonly used, ray-theoretical schemes rely on a high-frequency approximation and this inherently limits their resolution.

Finite-frequency theory is now becoming usable for global seismic tomography thanks to high-performance computing. The computation of numerical sensitivity kernels is by far the most expensive step of any finite-frequency tomography algorithm. A partial remedy consists of the adjoint method, recently proposed also for global inverse problems. The adjoint method has two major advantages: first, sensitivity kernels are fully determined after two simulations only, one forward and one time-reversed integration. Second, the adjoint method can be conducted for any arbitrarily heterogeneous Earth, making it relatively simple to find a non-linear solution iteratively. In contrast, analytically derived kernels are limited to a spherically symmetric Earth. Still, the availability of petascale hardware will be integral to the implementation of numerical finite-frequency tomography at increasingly high resolution.

We will show a benchmark of numerical finite-frequency tomography solved for the two-dimensional problem of determining the Earth's surface-wave phase-velocity distribution at intermediate to long periods. The resolution limit for ray-theoretical and finite-frequency tomographic schemes is clearly shown by our synthetic tests. In order to further improve the resolution, the three-dimensional problem of relating the sensitivity of observations to seismic velocities directly must be solved. We evaluate the performance of the widely used, efficient software package SPECFEM and compare its results with those derived in a normal-mode approach. We see that finite-frequency tomography will be a rewarding application of petascale computing.