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Benchmarking tomographic techniques with SPICE synthetic datasets and the validation and testing of the Automated Multimode Inversion (AMI)

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In the practice of seismic tomography, we define seismic observables, perform measurements on numerous seismograms, and use large collections of measurements to refine Earth models. Ideally, we wish to extract as much structural information as possible from each seismogram and to use as many relevant seismograms as possible. At the same time, we need to make sure that our assumptions on wave propagation and, more specifically, on structural sensitivity of our observables are valid as applied in the tomographic procedures. Benchmarking mantle-tomography techniques using inversions of synthetic data computed nearly exactly with the spectral element method (SEM) allows us—for the first time—to test simultaneously the resolving power of methods, the accuracy of their implementation, and the validity of approximations they rely on.

The Automated Multimode Inversion (AMI) (Lebedev et al. GJI 2005) uses as observables complete seismic waveforms, including fundamental-mode surface waves and S and multiple S waves. An elaborate scheme of filtering, windowing and weighting enables a highly complete and balanced use of structural information from seismic recordings. To ensure the validity of the JWKB approximation assumed, structural constraints are extracted only from waveforms within specially selected time-frequency windows, such that observed waveforms in all of them can be matched with JWKB synthetics simultaneously and nearly exactly. The application of the method to a global dataset has yielded a model with a high lateral resolution (a few hundred km, varying with data sampling); correct mapping of the structure known to be in the mantle (e.g., the seismic expression of subduction zones and other tectonic boundaries) suggests that the imaging is accurate.

AMI has now also been tested in an inversion of the first, benchmark-of-the-benchmark SPICE data set, computed with the SEM assuming a (relatively simple) laterally heterogeneous model (Qin et al. AGU 2005). The model has been reconstructed accurately, which validates the AMI procedure and the approximations applied in it. With this result in mind, one may wonder: do we need computationally expensive modelling—such as that with SEM—at all? or is (surface-wave) ray theory a sufficient basis for further and further increases in mantle-imaging resolution?

The validity of the JWKB approximation is not warranted in the presence of high heterogeneity, and for a large proportion of wavetrains recorded on seismograms it does not represent wave propagation accurately. Even if a tomography method (such as AMI) is successful in avoiding the signal for which the method's approximations are not valid, rejection of a large portion of the data may by itself affect the resolving power of the imaging. Testing of tomographic techniques using synthetic datasets computed with SEM assuming realistic synthetic models will help us determine true limits of the resolution achievable with this or that set of approximations and, perhaps, to formulate more effectively new approaches, based on numerical wave-propagation modelling and aimed at qualitative increases in imaging accuracy. I shall discuss the results of AMI processing of the new SPICE dataset (Qin et al. EOS 2006) computed with a new, realistic heterogeneous global model.