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Full Waveform Inversion Using Waveform Sensitivity Kernels

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We present a full waveform inversion concept for applications ranging from seismological to enineering contexts, in which the steps of forward simulation, computation of sensitivity kernels, and the actual inversion are kept separate of each other. We derive waveform sensitivity kernels from Born scattering theory, which for unit material perturbations are identical to the Born integrand for the considered path between source and receiver. The evaluation of such a kernel requires the calculation of Green functions and their strains for single forces at the receiver position, as well as displacement fields and strains originating at the seismic source. We compute these quantities in the frequency domain using the 3D spectral element code SPECFEM3D (Tromp, Komatitsch and Liu, 2008) and the 1D semi-analytical code GEMINI (Friederich and Dalkolmo, 1995) in both, Cartesian and spherical framework.

We developed and implemented the modularized software package ASKI (Analysis of Sensitivity and Kernel Inversion) to compute waveform sensitivity kernels from wavefields generated by any of the above methods (support for more methods is planned), where some examples will be shown. As the kernels can be computed independently from any data values, this approach allows to do a sensitivity and resolution analysis first without inverting any data. In the context of active seismic experiments, this property may be used to investigate optimal acquisition geometry and expectable resolution before actually collecting any data, assuming the background model is known sufficiently well. The actual inversion step then, can be repeated at relatively low costs with different (sub)sets of data, adding different smoothing conditions.

Using the sensitivity kernels, we expect the waveform inversion to have better convergence properties compared with strategies that use gradients of a misfit function.
Also the propagation of the forward wavefield and the backward propagation from the receiver into the medium (here realized by Green functions) can be done independently of each other. In comparison with the adjoint method, this can reduce the necessary number of wave propagation simulations, depending on the number of involved sources and receivers.
One challenge, however, is that in order to calculate the kernels in the volume of interest, wavefields and strains have to be stored throughout that volume, which typically demands a large amount of storage capacity.