Full-waveform inversion for signal enhancement of weak amplitude phases using beamforming and adjoint methods

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In this study, we develop a new adjoint- and full-waveform inversion approach for low-amplitude seismic phases that are typically below noise in individual recordings. The methodology aims at enhancing weak signals from body wave phases, which can be used in full-waveform inversion for inferring structural and boundary parameters in the earth. The new approach is based on the formulation of misfit functionals and corresponding adjoint sources for stacks of suitably time-shifted recordings.

To tackle this problem, we compute synthetic waveforms using spectral-elements for models with and without topographic variations along mantle discontinuities. We focus on global underside reflections which are reportedly almost always undetectable in real seismograms due to their low amplitudes and are considerably affected by topography. We enforce phase alignment on a chosen reference seismogram recorded at an average distance among the selected stations. A time shift towards the reference is applied to all seismograms according to their epicentral distance calculated by 1-D ray tracing. A set of time shifts is calculated by cross-correlation in time windows around predicted traveltimes of the desired phase. Using this set of time shifts, we sum the waveforms creating the main stack for each model.

We use the two linear stacks as observed and synthetic (with and without topography, respectively) and develop a least-squares misfit measurement which gives rise to an adjoint source determined by the time shift between stacks. The expectation is that computing the traveltime Fréchet kernel with respect to volumetric and boundary model parameters will show the exact sensitivity of the enhanced signal and save time from computing each station kernel separately. Upon achieving signal enhancement of the desired phases, we can ensure that these can be used for better informing updates of the initial model given the higher quality measurement of the observable.

This method once fully developed will allow us to leverage information of many recordings by reducing incoherent signal and enhancing weak seismic phases. The computation of sensitivity kernels in our study has a twofold importance. Firstly, it helps us realise whether the stacking technique indeed enhances the desired signal and whether it is ideal for precursor waves. Secondly, the exact sensitivity kernels show us the way of incorporating finite-frequency effects of weak but informative phases and introducing non-linear inversion for improving imaging while reducing some computational cost.