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Fully probabilistic earthquake source inversion on teleseismic scales

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Seismic source inversion is a non-linear problem in seismology where not just the earthquake parameters but also estimates of their uncertainties are of great practical importance. We have developed a method of fully Bayesian inference for source parameters, based on measurements of waveform cross-correlation between broadband, teleseismic body-wave observations and their modelled counterparts. This approach yields not only depth and moment tensor estimates but also source time functions. These unknowns are parameterised efficiently by harnessing as prior knowledge solutions from a large number of non-Bayesian inversions.

The source time function is expressed as a weighted sum of a small number of empirical orthogonal functions, which were derived from a catalogue of >1000 source time functions (STFs) by a principal component analysis. We use a likelihood model based on the cross-correlation misfit between observed and predicted waveforms. The resulting ensemble of solutions provides full uncertainty and covariance information for the source parameters, and permits propagating these source uncertainties into travel time estimates used for seismic tomography. The computational effort is such that routine, global estimation of earthquake mechanisms and source time functions from teleseismic broadband waveforms is feasible.

A prerequisite for Bayesian inference is the proper characterisation of the noise afflicting the measurements. We show that, for realistic broadband body-wave seismograms, the systematic error due to an incomplete physical model affects waveform misfits more strongly than random, ambient background noise. In this situation, the waveform cross-correlation coefficient CC, or rather its decorrelation $D = 1 - CC$, performs more robustly as a misfit criterion than ℓp norms, more commonly used as sample-by-sample measures of misfit based on distances between individual time samples.

From a set of over 900 user-supervised, deterministic earthquake source solutions treated as a quality-controlled reference, we derive the noise distribution on signal decorrelation D of the broadband seismogram fits between observed and modelled waveforms. The noise on D is found to approximately follow a log-normal distribution, a fortunate fact that readily accommodates the formulation of an empirical likelihood function for D for our multivariate problem. The first and second moments of this multivariate distribution are shown to depend mostly on the signal-to-noise ratio (SNR) of the CC measurements and on the back-azimuthal distances of seismic stations.

References:

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