Overview

Correlation detection using recorded waveforms has been highly successful in detecting recurrent seismicity, often achieving an order of magnitude reduction in detection thresholds over power (STA/LTA) detectors at a given false alarm rate. With the availability of increasingly accurate models of the seismic medium (e.g. from adjoint tomography), it seems reasonable to ask if waveform templates derived from forward propagation through models can be used to detect events in regions lacking prior observations. Simple waveform templates derived from deterministic models require earth models with unrealistically high fidelity for this approach to succeed, particularly at short periods. This study looks at the possibility that the requirement of model fidelity might be relaxed by using subspace (multi-dimensional) templates derived from stochastic extensions of an earth model [Rodgers et al., 2006]. In this approach model uncertainty maps to signal-space uncertainty by superimposing stochastic heterogeneity onto a deterministic base model. Forward calculations through a large number of stochastic realizations produce a sampling of the signal space uncertainty, that may be described with a waveform basis derived from a singular value decomposition of the sample waveforms.

In this simplified analysis, 2-D membrane-wave propagation is studied on the sphere using a uniform \( v = 3.9 \text{ km/sec} \) base velocity model. To simulate stochastic heterogeneity, the uniform velocity is perturbed by superimposing a homogeneous random field, represented with a spherical Karhunen-Loeve expansion [Lang and Schwab, 2014]. The basis functions in the K-L expansion are spherical harmonics (1 - 4 upper right). The coefficients in the expansion are statistically independent, with variance described by the angular spectrum distribution of (5). Forward calculations are performed with a purpose-built spherical spectral-element code. Two realizations of the random field are shown in (6) and (7).

The simulation scenario is shown in map (8), consisting of a source at the site of the 2012 Queen Charlotte Islands EQ and an array of 80 receivers distributed across the continental U.S. A snapshot of the wavefield at 2000 seconds through the uniform base model \( (3.9 \text{ km/sec}) \) is shown in (9) with a source time history consisting of an integrated Gaussian pulse filtered with a 5-pole Butterworth filter 0.015-0.030 Hz. The two wavefields generated through perturbed models (6) and (7) are shown in (A) and (B) respectively.

The question being asked in this study is: can processing gain be improved with knowledge of the statistics of the medium? To examine this question, one target realization was generated with the statistical structure of (5) and an additional 101 realizations were drawn from the same distribution. The computations required about 110 hours on 16-core Xeon servers and were carried out in the Google Cloud. Waveforms from the uniform medium model are compared with the waveforms from the target realization in (C). A data matrix was formed by concatenating the 80 waveforms as column vectors for each of the 101 sample realizations, then an SVD was performed to generate a basis for the collection of waveforms. The cumulative energy in the singular values is shown in (D). 25 singular values contain 90\% of the wavefield energy. A subspace of dimension 25 was selected to construct a subspace detector for comparison against the a correlator based on the uniform medium wavefield.

A test of detector sensitivity was performed with a purpose-built spherical spectral-element code. Two realizations of the random field are shown in (A) and (B). Forward calculations through a large number of stochastic realizations produce a sampling of the signal space uncertainty, that may be described with a waveform basis derived from a singular value decomposition of the sample waveforms.

The tradeoff works slightly in the subspace favor for the waveform energy; a subspace of dimension 25 was selected to construct a subspace detector for comparison against the correlator based on the uniform medium wavefield (9). A subspace of dimension 25 was selected to construct a subspace detector for comparison against the correlator based on the uniform medium wavefield.

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