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Direct probabilistic inversion of shear-wave data for anisotropy

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Seismic anisotropy (the variation of seismic wavespeed with direction) is a primary source of information about many dynamic processes in the Earth. It is an indicator of long range order in a seismic medium, through the alignment of crystals or grains, or larger scale features such as cracks, fractures or layering. As such, measurement of seismic anisotropy can provide a detectable signature to processes such as deformation which are invisible to other techniques. The most direct evidence of the effect of anisotropy on seismic body waves is the observation of shear-wave splitting.

Well-established techniques exist for measuring shear-wave splitting in a single (three component seismogram) and more recently these have been extended to treat shear-wave splitting in a tomographic fashion (Abt and Fischer, GJI, 2008): determining nonuniform anisotropic models using large datasets of splitting measurements. Here, I present an extension to this methodology which incorporates the data analysis into the inversion itself. This uses a non-linear Neighbourhood Algorithm (Sambridge, GJI, 1999) inversion to explore the parameter space defined by an anisotropic model consisting of a number of uniform domains, described by a base stiffness tensor, a strength parameter, and a set of rotation angles. Each candidate model is assessed by applying the splitting it predicts to the entire dataset. The elastic model can be composed of one, several or many domains, depending on the problem.

This scheme has several advantages. Prior knowledge of the anisotropy can be incorporated to reduce the size of the parameter space searched and the uncertainties in the data are directly incorporated in the inversion. Data which shows null splitting (a relatively common occurrence in SWS studies, even when the presence of anisotropy is certain) can be included with no special treatment. Finally, stacking methodologies are also inherently included, without a need to correct for polarisation. This approach is computationally expensive, but is highly amenable to parallelisation for deployment on large clusters, allowing even very large numbers of traces to be used on a sufficiently large machine.

I apply the methodology to several simple synthetic cases to demonstrate the utility of the method. Finally, I apply the approach to the problem of inferring two layer anisotropy from SKS splitting, which is a commonly attempted problem in global seismology. The example taken is station EKTN in Northern Canada. This station has been studied by Snyder and Bruneton (GJI, 2006), who infer a two layer solution based on the variation of SKS splitting as a function of backazimuth. I analyse a similar dataset, and am able to reproduce their results, however the tomographic approach highlights some inherent trade-offs and limitations in such SKS studies. These can be diagnosed and constrained by the method presented, and mitigated by incorporating extra information in the inversion. This method is applicable to shear wave anisotropy analysis in a broad range of settings from global to reservoir scale.