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Self-Adaptive Tomography With the Reversible Jump Algorithm

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The information obtained in seismic tomography is strongly dependent on the location of seismic sources and positions of receivers, which often results in some regions traversed by many seismic rays and other regions left with poor ray coverage. It is known that fixed grid optimization schemes that use regularization procedures give limited results in such situations. The grid size required to resolve densely sampled areas may introduce small-scale artefacts in regions where the velocity field is much less constrained. This effect is avoided by adding non data-driven constraints on the model. However, smoothing and damping procedures are global and while averaging over large areas, they make resolvable small-scale details difficult to see, or even hide them. Sharp discontinuities present in the data and which could be imaged are blurred into gradual transitions.

In order to deal with the irregular spatial distribution of the information, some seismologists have used irregular meshes. However, most of these studies have a fixed number of unknowns decided before hand, for example, the number of layers or cells. Another assumption that is made is the knowledge of data uncertainty, which is often poorly constrained in travel time tomography. The two questions of "how well to fit the data?" and "how many unknowns to include in the model?" are ubiquitous in inference problems. They are also related, since it is well known that the data can be fit better by introducing more degrees of freedom (or unknowns) into the model.

We present a general methodology for seismic travel time tomography where the number, size and shape of the cells defining the velocity model, as well as the level of data noise, are not fixed in advance but treated as actual unknowns in the inversion process. The inverse problem is tackled within a Bayesian framework and global damping procedures, controlled by an optimal regularization parameter, are avoided. Our ensemble inference approach generates many potential solutions with variable numbers of cells. Information is extracted from the ensemble as a whole using Monte Carlo integration to produce the expected Earth model. We find that the single expected model has some particular beneficial features, i.e. it tends to remove artefacts caused by uneven ray paths while allowing well constrained features to remain through a form of constructive interference. The ensemble of models can also be used to produce velocity uncertainty estimates and experiments with synthetic data suggest they represent actual uncertainty surprisingly well.

The methodology is illustrated with a problem with multiple scale, i.e. where the spatial sampling of the velocity field provided by the data is highly heterogeneous. The different data sets are obtained from cross correlation of ambient noise where little is known about the size of the errors associated with the travel times. A tomographic image of Rayleigh wave group velocity for the Australian continent is constructed together with uncertainty estimates.