Geophysical Research Abstracts
Vol. 16, EGU2014-6997-1, 2014
EGU General Assembly 2014

Bayesian seismic tomography by parallel interacting Markov chains

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The velocity field estimated by first arrival traveltime tomography is commonly used as a starting point for further seismological, mineralogical, tectonic or similar analysis. In order to interpret quantitatively the results, the tomography uncertainty values as well as their spatial distribution are required.
The estimated velocity model is obtained through inverse modeling by minimizing an objective function that compares observed and computed traveltimes. This step is often performed by gradient-based optimization algorithms. The major drawback of such local optimization schemes, beyond the possibility of being trapped in a local minimum, is that they do not account for the multiple possible solutions of the inverse problem. They are therefore unable to assess the uncertainties linked to the solution.
Within a Bayesian (probabilistic) framework, solving the tomography inverse problem aims at estimating the posterior probability density function of velocity model using a global sampling algorithm. Markov chains Monte-Carlo (MCMC) methods are known to produce samples of virtually any distribution. In such a Bayesian inversion, the total number of simulations we can afford is highly related to the computational cost of the forward model. Although fast algorithms have been recently developed for computing first arrival traveltimes of seismic waves, the complete browsing of the posterior distribution of velocity model is hardly performed, especially when it is high dimensional and/or multimodal. In the latter case, the chain may even stay stuck in one of the modes.
In order to improve the mixing properties of classical single MCMC, we propose to make interact several Markov chains at different temperatures. This method can make efficient use of large CPU clusters, without increasing the global computational cost with respect to classical MCMC and is therefore particularly suited for Bayesian inversion. The exchanges between the chains allow a precise sampling of the high probability zones of the model space while avoiding the chains to end stuck in a probability maximum. This approach supplies thus a robust way to analyze the tomography imaging uncertainties.
The interacting MCMC approach is illustrated on two synthetic examples of tomography of calibration shots such as encountered in induced microseismic studies. On the second application, a wavelet based model parameterization is presented that allows to significantly reduce the dimension of the problem, making thus the algorithm efficient even for a complex velocity model.