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Local Earthquake Tomography by trans-dimensional Monte Carlo sampling

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In the last decade, due to the growing availability of huge, high-performance computer clusters, Monte Carlo sampling algorithms have been widely applied to solve many different geophysical inverse problems. Recently, such methods have been applied to seismic tomography, a highly non-linear and non-unique inverse problem. The Reversible Jump Markov Chain Monte Carlo (Rj-MCMC) method is a trans-dimensional approach of parameters estimation in which the number of unknowns is treated as one of the unknowns. We developed a trans-dimensional algorithm to solve the non-linear inverse problem of the determination of hypocentral paramenters and 3D velocity structure from traveltime data.

In this preliminary study, we investigate the effectiveness of the Rj-MCMC in overcoming major limitations of the standard linearized inversion methods used in local earthquake tomography (LET). For instance, the optimum parameterization of the Earth structure depends on both the ray-paths distribution and the velocity heterogeneities; being the velocity model unknown, any choices about the discretization of the velocity field are subjective and may affect the solution quality. With the trans-dimensional method, the velocity field is discretized by Voronoi cells with geometry and position treated as unknowns in the parameter estimation procedure. In this case, the optimum parameterization of the Earth structure is directly determined by the seismological observables, with very weak a-priori constraints. This method doesn't require any global regularization of model parameters in order to stabilize the matrix inversion or to prevent the propagation of data noise into the solution. The use of a fully non-linear method overcomes the problem of the strong dependence of tomographic results on the starting model. In addition, as a result of the lack of parameterization and regularization constraints, the amplitude and shape of the velocity heterogeneities are better resolved and the estimate of the model uncertainty is unbiased.

We illustrate our new algorithm applied to synthetic and field measurements collected in the Alto Tiberina fault zone (northern Apennines, Italy). We discuss the recipe of sampling the target posterior density distribution, i.e. the combination of choices that guides the generation of samples from the posterior probability density. Although the choice of the recipe doesn't affect the final solution, it may strongly affect the effectiveness and speediness of the sampling. We show that the choice of a good recipe is crucial, especially in the case of simultaneous recovery of earthquake location and velocity structure. By comparing the results with those obtained with the SIMULPS13 code, we argue that some important improvements in local earthquake tomography can be obtained by the use of the Rj-MCMC method.