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Time-evolution of subsurface elastic properties revealed by full 4D seismic tomography: an application to the 2009 L'Aquila earthquake sequence

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Data about temporal evolutions of Earth's parameters are widely used to study the processes which take place both on its surface and deep interior. In seismology, temporal variations of the Earth's elastic properties have been hypothesized in some models of earthquake nucleation. Unfortunately, few observations were consistent with the theory for two main reasons. First, such phenomena are intrinsically unpredictable, and therefore elusive. Second, the classical methods applied to investigate the subsurface seismic structure (e.g. seismic tomography) are more suited to produce "static", 3D images of the Earth's seismic properties, rather than point out the temporal variation of such properties.

In the last years, some research groups developed new data-mining technologies which exploit at best the network and computer resources accumulated in the last decade. One of these techniques, Monte Carlo sampling of the model space, has proven useful to address non-linear inverse problems. Monte Carlo (MC) sampling does not need any linearization of the inverse problem, which is often implied in the solution of a non-linear problem. The MC sampling only needs some kind of (possibly) loose prior information. Repeated solution of the forward model (i.e. predict arrival times given an elastic model) drives the sampling in "Markov chain Monte Carlo (McMC)" algorithms. Reversible jump McMC (RjMcMC) is a variation of McMC sampling that involves trans-dimensional sampling where the number of unknown parameters is an unknown itself. In practice, RjMcMC makes use of an adaptive grid of nodes in the model space, so that the number of elastic nodes varies along the McMC sampling. As a consequence, model resolution is directly dictated by the data, and not imposed by the user, e.g. via subjective smoothing of the solution. Also, posterior and prior information can be directly compared to assess robustness of the results. Seismic tomography using RjMcMC has been recently developed for a simple 2D case.

Here, we develop a RjMcMC algorithm to solve the full four-dimensional tomographic inverse problem in seismology. This algorithm is a key to tackle the temporal variations of subsurface elastic properties. Using this algorithm, we analysed the foreshock sequence of the 2009 L'Aquila earthquake (Central Italy). Evidences for the temporal evolution of the subsurface seismic properties, in the area of the main shock, have been recently found in the seismic records of the stations deployed in the region. Our algorithm exploits such information to investigate the volume where such variations occurred. Preliminary results indicate a complex evolution of the seismic velocities near the fault plane in the two months before the main shock.