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Towards 3D multi-scale teleseismic and gravity data inversion using hybrid DSM/SPECFEM technique : application to the Pyrenees

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We describe here a method of inversion applied to seismic data sets constrained by gravity data at the regional scale. This will allow us to obtain robust models of P and S wave velocities but also of density, providing key constraints on the composition and thermal state of the lithosphere.

Our approach relies on teleseimic waves, which illuminate the medium from below. We have developped a hybrid method in which a wave propagation method at the global scale (DSM/Direct solution method) is coupled with a spectral element method at the regional scale (Monteiller et al. 2013). With the spectral element method, we are able to model the 3D wave propagation effects in a computational domain of 400km long x 400km wide and 200 km deep, for an incident teleseismic wavefront introduced at the boundaries of this domain with periods as short as 2 s. The DSM global method allows to compute this incident field for a spherical Earth model. We use a multi-scale joint inversion of both gravity and seismic waveform data, accounting for the long wavelengths of the gravity field taken from a global model.
In terms of inversion technique, we have validated an adjoint method for the inversion of seismic waveforms. An optimized BFGS inversion technique is used to minimize the difference between observed and computed full waveforms. The gradient of the misfit function gives the direction over which the model must be perturbed to minimize this difference. At each step of the inversion procedure we choose an optimal step length that accelerates the minimization. This is the crucial ingredient that allows us to build an efficient iterative full waveform inversion.

We have extended this method by incorporating gravity data provided by the BGI/Bureau Gravimétrique International into the inversion. If the waveforms allow us to constrain the seismic velocities, they are less sensitive to the structure in density, which gives independent and crucial information to constrain the nature of rocks. The idea is to constrain the densities and the wave speeds simultaneously by a joint inversion of seismic waveforms and gravity data. The novelty of the approach is to improve tomographic images by using a full waveform inversion which provides finely resolved images of lithospheric structures, including the geometry of the main seismic interfaces such as the Moho. We take the spectral finite element SPECFEM3D package to model the wave propagation at the regional scale and we use MPI-based PRACE parallel platforms.

This new tomographic approach has been applied to the Pyrenees, which thanks to the PYROPE and IBERARRAY experiments, has been densely covered by seismological probes. The gravimetric data come from the BGI. In this region, strong Bouguer gravity anomalies and strong constrasts in first P wave arrival time delays are observed. We have been able to identify, through reverse-time migration and also some first full waveform inversions using the adjoint theory, that strong Moho jumps from 25 down 60 kms depths can be detected at different locations around the France-Spain border.