Geophysical Research Abstracts
Vol. 21, EGU2019-7129, 2019
EGU General Assembly 2019

Constructing a crustal 3-D shear-wave velocity model based on converted waves: from model to inversion

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Here we develop a new tool in which teleseismic P-to-S converted waves are used to construct a fully 3-D shear-wave velocity model of the crust. Our method is fundamentally different from ambient noise and local earthquake tomography, as it uses sub-vertical rays. This approach is based on receiver functions (RF) and requires a dense seismological network to investigate the less-studied S-wave velocities.
For the benchmark study we focus on the Central Alps, performing the analysis of RFs using a dataset composed of the last 20 years of high-quality data from permanent stations as well as temporary AlpArray stations, in order to get a homogeneous coverage of our zone.
For the forward model, we implement an accurate ray-propagator which respects Snell's law in 3-D at any interface geometry. This approach can be summarized in 3 steps:
1. An existing ray-shooting tool (Knapmeyer, 2004) computes P-ray geometry in a global velocity model (iasp91) to arrive at the station.
2. Considering the true local dip, a shear-wave is shot from the piercing point at the local Moho to the surface. This S-wave usually arrives several km away from the station.
3. We adjust the ray-parameter to make the corresponding crustal S-wave arrive at the station.
For the Alps case, using a local 3-D velocity structure (Diehl et al., 2009) and a complex Moho geometry (Spada et al., 2013), the mean distance between the arriving S-wave and the station is about 150 m (median ca. 40 m).
Based on the ray coverage of the actual dataset (almost 300'000 traces), we parameterize the model grid using square cells in X and Y directions, typically 25x25 km. In depth, we parameterize a multi-layer model defining an S-wave velocity above and below each discontinuity. The introduction of this flexibility allows accommodating a velocity gradient within each layer and investigate velocity jumps between them. The individual velocity model corresponding to each RF is extracted from the 3-D initial model along its ray path and the velocity structure is updated using a weighted mean at the enclosing mesh nodes.
We envisage to manage the inversion process by the stochastic Neighbourhood Algorithm approach (Sambridge, 1999), looking at the ensemble of models that sample the good data-fitting model for a multidimensional parameter space. We first plan to create and test a 2-layer Vs model (Moho and intra-crustal discontinuity) for the Central Alpine region. Later, we plan to extend our dataset to the entire Alpine domain, and apply this tool to other areas with a dense network of broadband seismometers.