A new inversion method to construct a 3-D crustal shear-wave velocity model from P-to-S converted waves and application to the Central Alps

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We developed a new method where teleseismic P-to-S converted waves are used to construct a fully 3-D shear-wave velocity model of the crust. The method differs from ambient noise and local earthquake tomography in its ray-paths being closer to vertical. Our approach requires a dense seismological network, and we first focus on the Central Alps considering the available permanent and temporary station datasets (e.g., Hetényi et al., 2018, Surv. Geophys.).

We implemented an accurate ray-propagator which respects Snell’s law in 3-D at any interface geometry. Following a teleseismic P ray propagator (Knapmeyer, 2004) from event to station which uses a 1-D global velocity model (iasp91), P-to-S conversion at the Moho is calculated for the crustal S ray considering the true local dip. The corresponding arrival to the surface is typically several km away from the station, which we then adjust by changing the ray-parameter. In the Central Alps, using the 3-D P-velocity structure of Diehl et al. (2009) and the local Moho geometry of Spada et al. (2013), the mean distance between the arriving S-wave and the station is about 150 m (median ca. 40 m).

For our approach we adopt a new model parameterization of velocities. It is rectangular in map view (nodes at 25x25 km in the Alps), while in depth we define a 2-layer model with separate velocities above and below each discontinuity. The introduction of this flexibility allows us to accommodate a velocity gradient within each layer and investigate velocity jumps across discontinuities.

The inversion proceeds iteratively, by visiting every node of the map following a Travelling Salesman Path. At each node, receiver function rays in the surrounding volume are considered for inversion, and bundled into sub-blocks and ranges of back-azimuth (5x5 km size, 45° or 60° bins for the Central Alps). The velocity model at the given node is inverted using the technique of Simulated Annealing, followed by a pattern search algorithm to avoid falling in a local minimum. During iterations of the Simulated Annealing, individual velocity model corresponding to each receiver function is extracted from the 3-D model along its ray path.

The inversion proceeds for 4 or 5 independent parameters: Moho and a hypothetical intra-crustal discontinuity depth, Vp/Vs ratio (either full crust, or separately for upper and lower crust) and the
P-wave velocity jump at the intra-crustal discontinuity. Finally, the velocity structure is updated with the result obtained at the given node. We observe that a few rounds of Travelling Salesman Paths improve the overall misfit.

First results on the Central Alps show that the Moho depth generally reflects well the roots of the Alpine orogen. Resolving crustal Vp/Vs ratio is more stable when considering the full crust, instead of two separate layers. The Conrad discontinuity remains difficult to resolve. The obtained velocity structure is compared along profiles to recent Vs results from 3-D ambient noise tomography (Lu et al., 2018).