Surface Wavefield Tomography of the Alpine Region to Constrain Slab Geometries, Lithospheric Deformation and Asthenospheric Flow

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Surface waves radiated by teleseismic earthquakes are ideally suited to constrain isotropic and anisotropic elastic properties of the upper mantle down to about 300 km depth beneath dense networks of broad-band stations. Rayleigh wave phase velocities were automatically determined in a broad period range from 8 s to 300 s and a very strict quality control was applied. This resulted in a data set of more than 200,000 inter-station phase velocity curves. Local dispersion curves, extracted from phase velocity maps were inverted for a 3D shear-wave velocity model (MeRE2020) using a newly developed stochastic inversion algorithm based on particle swarm optimization. It was shown that the presence of small and highly segmented slabs can be resolved by surface wave tomography in case of a high station density.

In the western Alps, a short Eurasian slab was imaged down to about 150 km depth, whereas at larger depths a pronounced low velocity anomaly indicates slab break-off. In the northern Apennines, a nearly vertical south-dipping slab connected to the Adriatic mantle lithosphere beneath the Po Basin is observed. In the central Alps, the presence of Eurasian mantle lithosphere is found down to the bottom of the model at 300 km depth. Whereas in the eastern Alps, a short Eurasian nearly vertical dipping slab is found down to only 150 km depth. The presence of a short slab consisting of Adriatic mantle lithosphere is also indicated beneath the northern Dinarides extending towards the Alps east of the Giudicarie fault.

Anisotropic phase velocity maps show at 25 s period (lower crustal depth) mostly fast orogen parallel directions, whereas in the western Alps azimuthal anisotropy is more inclined with respect to the Alpine arc. At 100 s period, azimuthal anisotropy beneath the western Alps indicates asthenospheric flow towards the Ligurian Sea and beneath the northern Dinarides towards the Pannonian Basin through slab gaps.

Moreover, seismic wavefields were analysed using AlpArray and Swath-D data. Wavefield animations illustrate the considerable spatio-temporal variability of the wavefield's properties at a lateral resolution down to about 100km. Within denser station distributions like those provided by Swath-D, even shorter period body and surface wave features can be recovered. Considerable amplifications of the Rayleigh wave in the Alpine area are observed for several earthquakes. To analyse Rayleigh wave quantitatively, an algorithm has been developed to extract their phase and amplitude fields using cross correlation between synthetic waveforms and recordings of a dense array. Phase fields are unwrapped by solving a linear system of equations. Phase and amplitude fields are quality controlled and interpolated to determine structural phase velocity fields using Helmholtz tomography. It is shown that the observed amplitude fields depend heavily on lateral heterogeneity outside the array. Often, linear amplifications in the propagation direction are observed. In order to model the observed wavefields, the AxiSEM-SPECFEM Coupling algorithm has been improved and adapted concerning flexibility and efficiency, reducing the necessary wavefield interpolation significantly and allowing topography as well as existing 3D Models of the Alpine region to be easily implemented.