Surface wavefield tomography of the Alpine region to constrain slab geometries, lithospheric deformation and asthenospheric flow

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In this tomographic study AlpArray data are analysed to resolve the shear-wave velocity structure of the crust and upper most mantle in the Alpine region. Specifically, surface wave tomography is optimized and applied to earthquake data recorded by a regional array in order to constrain the highly complex isotropic and anisotropic elastic properties of the Alpine orogen down to about 300 km depth. The evolution of the Alpine region is characterized by creation, subduction, and collision of rather small and mobile microplates caught between the larger Eurasian and African plates that are slowly converging since about 85 Ma. This configuration results in a high variability of subduction and collision in time and space compared e.g. to Pacific subduction zones and the Himalayan continental collision zone as evident already from the small dimensions and the strong curvature of the Alps. Reversals in the subduction direction along strike, the presence of slab gaps, horizontal slab tearing and subduction of oceanic as well as of conti-nental lithosphere have been invoked to explain the evolution of the Alpine orogen. These structures require particularly high imaging resolution. Such resolution can be provided by the wavefield tomography, able to extract highly complete structural information from data recorded by a large-aperture, dense array.

Recordings of the AlpArray Seismic Network, including its marine part, as well as recordings of Swath D are studied to image the local frequency dependent propagation of teleseismic Rayleigh and Love waves. Rayleigh and Love phases and amplitudes are measured to image the curvature, amplitude variations, and directionality of the surface wavefields caused by the Alpine deep structure. The usage of amplitudes is however also sensitive to errors in the amplitude response of the sensors. Quality control of the resulting amplitude measurements will be essential. In order to cope with the large amount of recordings, automated measurement methods will be developed. Helmholtz and eikonal tomography will be applied to obtain isotropic and anisotropic phase velocity maps.

In a first step, phase velocity maps will be inverted for an isotropic shear-wave velocity model of the Alpine region embedded into a regional model. Secondly, the inversion of anisotropic phase velocity maps will constrain radial and azimuthal anisotropy. A particle swarm optimization technique will be developed to obtain optimal models and to quantify uncertainties.

Tools for efficient numerical forward modelling of the interaction of teleseismic surface waves with the deep structure of the Alps based on discontinuous Galerkin methods will be developed. The influence of the surface and Moho topographies on the surface wavefields will be studied. Moreover, the propagation of teleseismic Rayleigh and Love will be modelled numerically for a suite of hypothetical models. The resulting synthetic wavefields will be compared to the observed ones and the validity of approximations applied in the tomographic inversions will be tested.

The resulting shear-wave velocity model for the Earth's upper 300 km will image the subducting Adriatic and Eurasian mantle lithospheres. It will resolve the slab geometry in the regions of polarity switches (SW Alps – Apennines, western - eastern Alps), of slab gaps (central Alps), of slab break-off (SW Alps), and in the transition from the eastern Alps towards the Dinarides. Conversion into density anomalies will enable us to estimate slab-pull and buoyancy forces in the Alpine region and quantify the contribution of endogenous forces to surface uplift and subsidence.

Seismic anisotropy reveals imprints of recent and past deformation on the lithosphere as well as mantle flow in the asthenosphere. We will compute a 3D model of seismic anisotropy within the lithosphere and the asthenosphere, offering evidence on the deformation of the crust and on the coupling/decoupling between the curst and mantle and between plate motion and mantle flow. It will further serve as observational evidence to evaluate predictions by numerical modelling for different evolution scenarios.

Apart from the PIs, two PhDs (M. Tesch, M. Ditz) are involved in this project. They are placed at University Kiel and Ruhr-University Bochum and will focus on the observational and modelling parts, respectively. Besides collaborations within the SPP we actively participate in the AlpArray working group "Surface waves, ambient noise and full waveform inversion". Moreover, we will co-operate with groups at ETH Zürich, UPMC Paris, DIAS, Irland, and Delft University.