Imaging structure and geometry of Alpine slabs by full waveform inversion of teleseismic body waves

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Seismic body waves from distant earthquakes (Fig. 1) recorded by the extraordinarily dense and large-aperture AlpArray Seismic Network (AASN) are inverted for the 3D distribution of seismic wave speeds in the lithosphere and sublithospheric mantle beneath the greater Alpine region (activity fields A, B, C and D and research themes 1 and 4). The resulting image is expected to resolve the internal structure and geometry of lithospheric slabs beneath the Alps down to the transition zone. It will give new insights into heavily debated issues such as subduction polarity switches and provide further detail on possible detachments of the Alpine slabs from the lower crust, on their connection to high-velocity material in the transition zone attributed to Late Cretaceous to Early Paleogene subduction of the Alpine Tethys, and finally on the amount of subducted material accumulated in the transition zone (research theme 1). The 3D image will constitute essential input for geodynamic models of lithospheric deformation and mantle flow as well as plate tectonic reconstructions (research themes 2, 3 and 4).

Iterative Gauss-Newton full waveform inversion based on waveform sensitivity kernels and adapted to the teleseismic imaging problem is employed to construct the 3D model of P and S wave speeds beneath the Alpine mountain belt. Numerical simulation of teleseismic wave propagation is performed in a hybrid way where either a 3D spectral element or a 3D discontinuous Galerkin method are used to model wave propagation in the target region. For the rest of the Earth, a fast and efficient solver valid for spherically symmetric earth models is employed. Initial wave speed models are obtained by classical tomographic inversion of automatically determined and quality-ranked travel times of P and S phases (Fig.

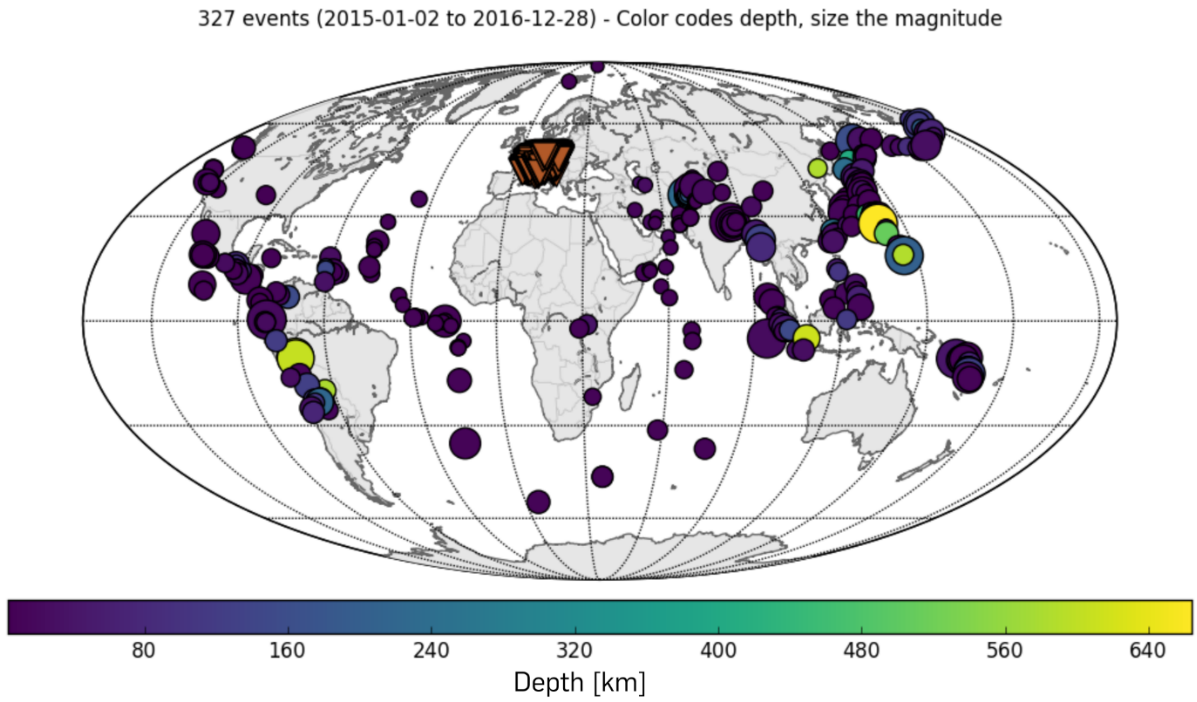

Figure 1: An exemplary distribution of tectonic events between 2015 and 2017 that will be used for teleseismic body wave tomography. Colour corresponds to depth and circle radii to earthquake magnitude. Note that the average magnitude of qualified events increases with distance to the AlpArray Seismic Network.

2). The latter also enter the full waveform inversion as additional constraints to stabilize the inversion against cycle-skipping. Effects of heterogeneities outside the target volume are minimized by inverting linear combinations of the data whose sensitivity is focused on the target region. The approach should permit inversions of body wave records up to periods of a few seconds implying a resolution length of about 20 km.

The current picture of the deep structure of the Alps that can be drawn from former seismological results looks as follows: The crust is characterized by stacking and wedging of tectonic units of European and Adriatic provenience to accommodate crustal shortening during collision. The Moho is discontinuous with gaps as well as vertical offsets between European and Adriatic Moho. The mantle below is pervaded by distorted, corrugated and torn slab segments of presumably continental origin whose dip apparently flips from SE in the western to central parts to NE in the eastern part of the Alps. This polarity flip is a unique feature of Alpine orogeny and has not been observed elsewhere in the world.

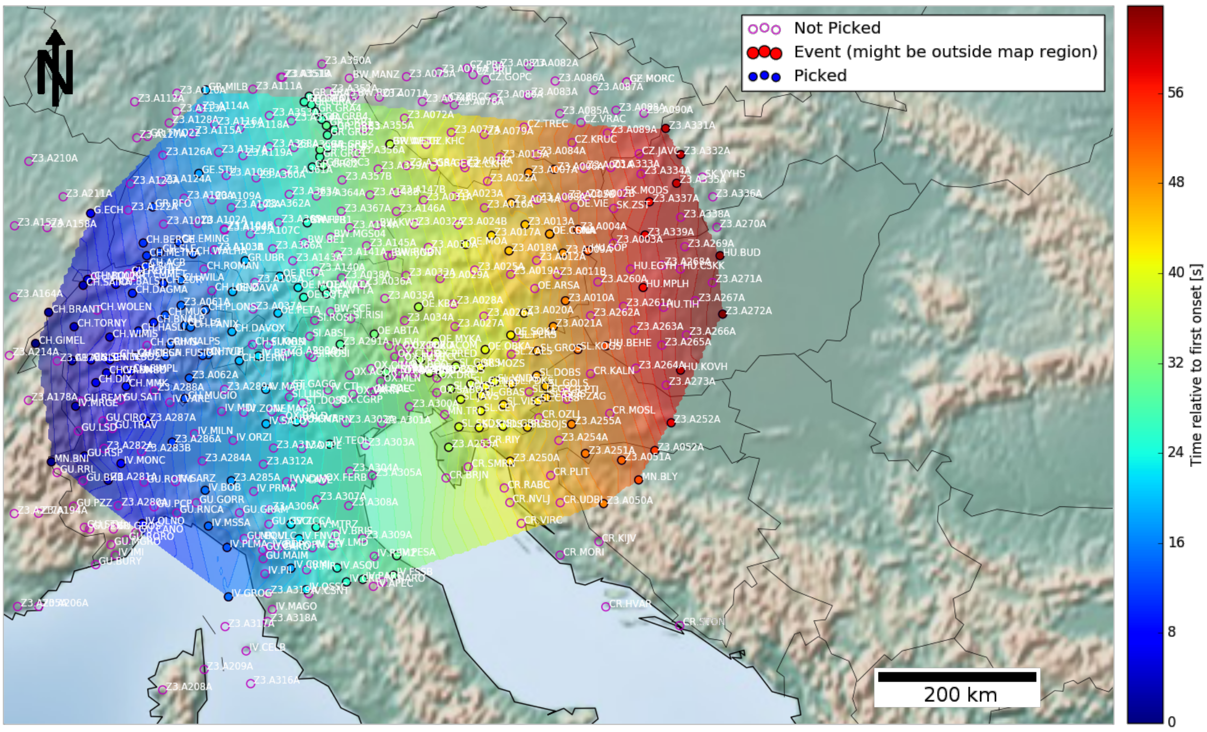

Figure 2: Manually determined P arrival times at the AlpArray Seismic Network used to tune the automatic picking algorithms. Colour corresponds to the arrival time and is interpolated in the area between the stations.

Further east, in the northern Dinarides, a slab seems to be entirely missing.

Despite the successes of Alpine geophysical research, the current state of knowledge on the deep structure of the Alps cannot be considered as satisfactory given major open questions and new opportunities of seismological observation and imaging.

Our research addresses the controversial images of oppositely dipping slab segments, open questions regarding the internal structure, outer boundaries and provenance of subducted material and their connections to surrounding lithosphere and asthenosphere beneath the Alps, as well as an analysis of lateral variations of attenuation and shear-wave velocity of the Alpine mantle.