Constraining the dynamics of the present-day Alps with 3D geodynamic inverse models

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There have been numerous geophysical and geological surveys, assembling GPS-velocities, Gravity anomaly data, seismological tomographic studies and many more in order to investigate the structure and tectonic history of the Alps. However, the physical, geodynamical behavior of the Alpine orogen is still not fully understood since the rheological parameters of the rock phases are not known. Even the geometry of the Alpine orogen is not clear, because different studies suggest different numbers and shapes of subducting slabs (e.g. Lippitsch et al. (2003), Handy et al. (2015)).

There are 2D geodynamic models that study Alpine dynamics on geological timescales (e.g. Bauville and Schmalholz (2015)), and 3D folding of the Helvetic Nappes (von Tscharner et al., 2016), but there is currently no published study that uses geodynamic models to simulate the lithospheric and upper-mantle scale evolution of the Alps evolution in 3D. Especially, effects of polarity switches in the subduction cannot be studied in 2D. We will perform high resolution 3D numerical models of the present day structure of the alpine orogen using different seismological studies as inspiration for geometrical endmembers. Our models will show whether slab breakoff, slab tearing and switches in the polarity of the sub-alpine slabs cause testable differences in the geophysical data, and which of the models are consistent with the geophysical data. Additionally, the models will give insights in the links between crustal and mantle deformation and seismic anisotropy and on how the large scale structure and rheology of the lithosphere affects the stress-state of the crust. Furthermore, we will constrain the rheology of the lithosphere, and show how deformation at depth and erosion affects surface uplift and exhumation rates in an automated manner by using inverse methods. Hence, the main goal of our project is to fit 3D geodynamic flow models of the Alpine region to geophysical observables in a fully automated manner, and to use these to constrain both the rheology and the dynamics of the present-day lithosphere. Performing the geodynamic inverse models will require building a consistent, 3D, geometric model of the Alpine (and wider Mediterranean) region, creating new tools to compute geological and geophysical predictions from the 3D geodynamic models that can be compared with data, and the implementation of the inverse modelling framework itself.

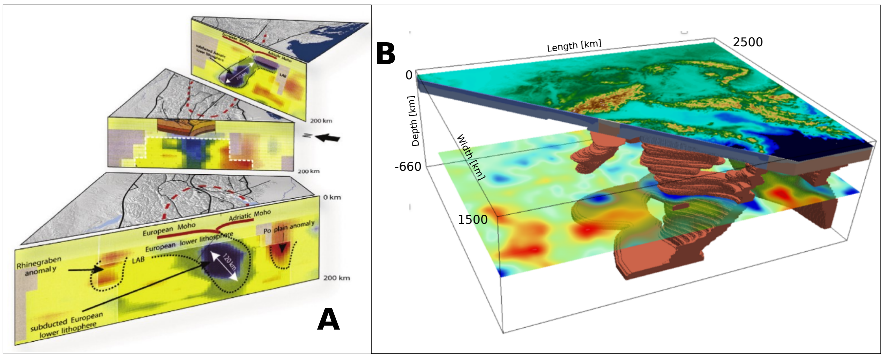

Figure 1: A) Vertical sections through tomographic image of Lippitsch et al. (2003). Subduction polarity flips from NW-SE in the western to central part of the Alps to SW-NE in the eastern Alps. Central section shows mantle beneath the TRANSALP profile where no clear subduction polarity is recognizable. B) Model geometry, with seismic tomography shown in the background.

The data that will be acquired by the working groups of the 4D-MB and AlpArray project and co-workers will build the base of the inversion approach:

- Gravity anomaly data taken by the GOCE satellite, which are currently being processed by the ESA gravity working group with the first 3D Earth model scheduled for public release in mid 2017.
- Digital topographic maps which will be compared to the dynamic topography resulting from simulations
- Moho geometry to build the consistent 3D model of the Alps
- 3D seismic anisotropy data of the mantle, will be compared to computed anisotropy by tracking of the finite strain tensor
- GPS surface velocities form an important constraint for my geodynamic models, and will be compared to modeled surface velocities.
- Cooling ages and calculated erosion rates will be computed synthetically and compared to laboratory measurements
- Aseismic and seismic areas in my models will be produced by zones of plastic failure and can be compared to tectonic settings in the Alps and their foreland.
- Analysis of moment tensors can be compared with principal stress directions from our simulations.
- Seismic tomography will be used to create and improve the 3D model setup

References

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