General Assembly, Vienna , Austria
4-8 May 2020

UNIL | Université de Lausanne
Institut des sciences de la Terre

FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
FONDO NAZIONALE SVIZZERO
SWISS NATIONAL SCIENCE FOUNDATION

This presentation participates in OSPP
Outstanding Student Poster & PICO Contest

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

Contact: leonardo.colavitti@unil.ch
Group website: http://wp.unil.ch/orog3ny
AlpArray website: http://www.alparray.ethz.ch

Leonardo Colavitti [(1)], György Hetényi [(1)] & AlpArray Working Group

[(1)] Institute of Earth Sciences, University of Lausanne, Lausanne, Switzerland

MOTIVATION

We develop a new tool where P-to-S converted waves are exploited in order to construct a fully 3-D shear-wave velocity model of the crust.
This method is based on receiver functions (RFs) and does not require local earthquakes (LET), nor a large aperture seismic network (ANT), but a dense array of 3-D component sensors with a spacing similar to the expected crustal thickness.

DATASET AND METHOD

As study area we focus on the Central Alps, using both permanent and AlpArray stations (Hetényi et al., 2018) in order to get a homogeneous coverage of our zone (**Figure 1**).
Our dataset is composed of the last 20 years' of high-quality data (**Figure 2**).

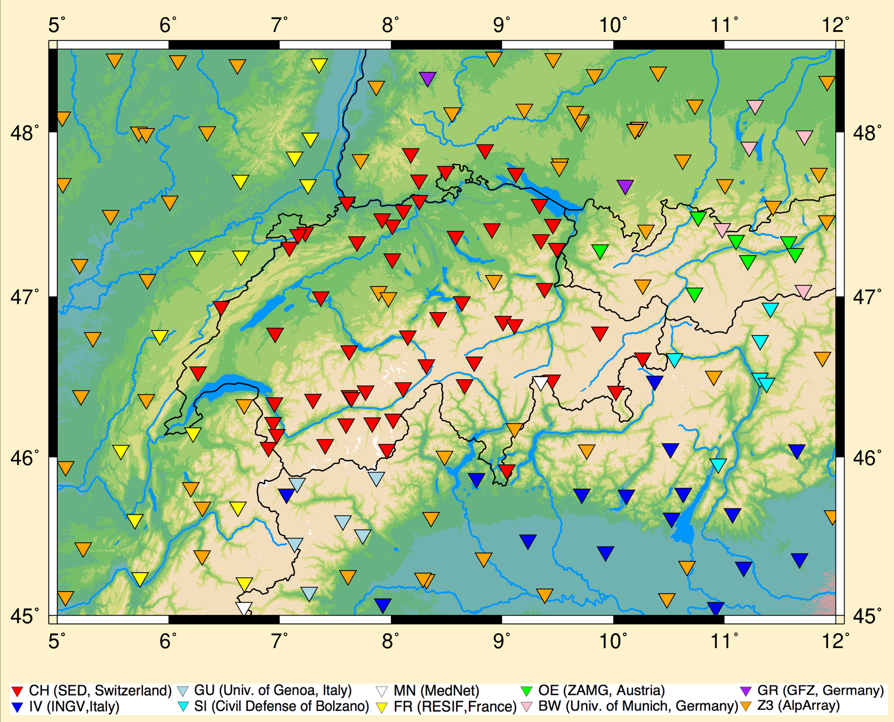

Figure 1 Seismic stations available in the Central Alps.

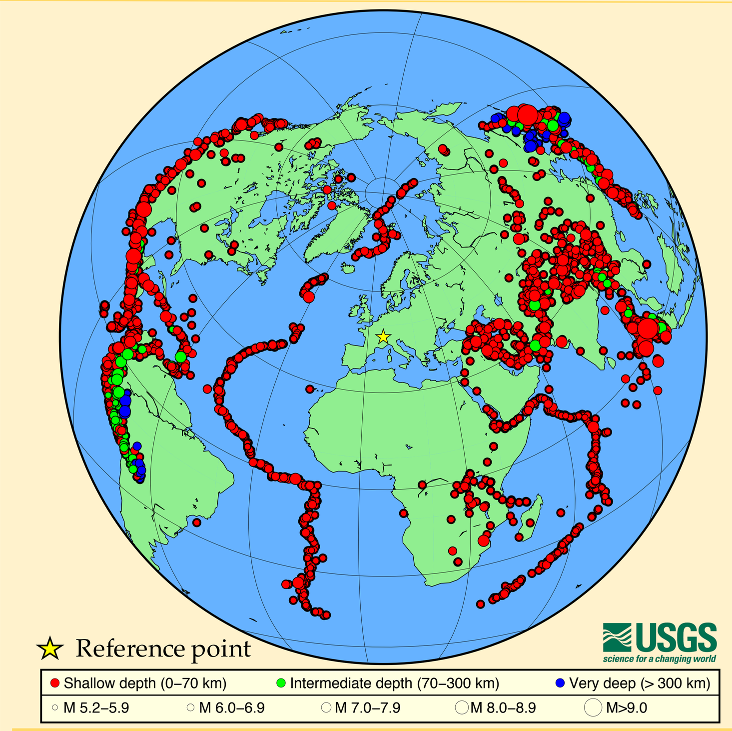

Figure 2 Earthquakes used for receiver functions.

We compute RFs to map Earth discontinuities at depth. The difference in travel time between the converted S-wave and direct P-wave contains information about the depth to the boundary and velocity relations.

N. Stations:	150
N. Events:	6450
Ep. Distance:	25° – 95°
Magnitude:	≥ 5.2
Frequency:	0.125-0.5 Hz
Deconvolution	Ligorría and
Algorithm:	Ammon (1999)

MODEL PARAMETERIZATION

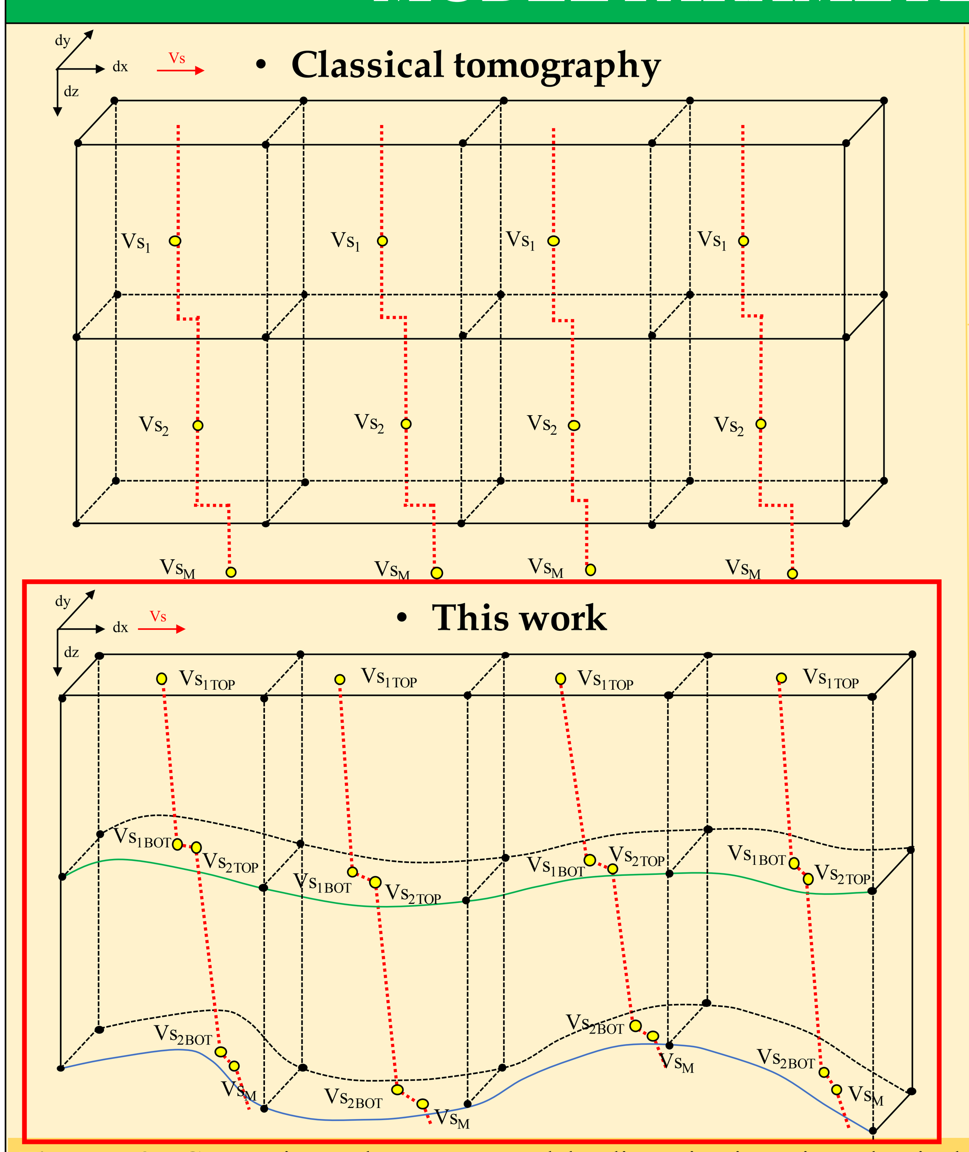

Figure 3 Comparison between model discretization in classical tomography and the parameterization used in this work.

We adopt a new model parameterization, considering that a discontinuity is laterally variable in depth and also that the velocity profile per layer can be a gradient (**Figure 3**).

The introduction of this flexibility in the discontinuity (given by 2 velocity for each node, above and below) allows us to investigate the velocity jump between neighbouring layers.

We first plan to test a 2-layer Vs model for the Alpine region.

RAY TRACING IMPLEMENTATION IN 3D

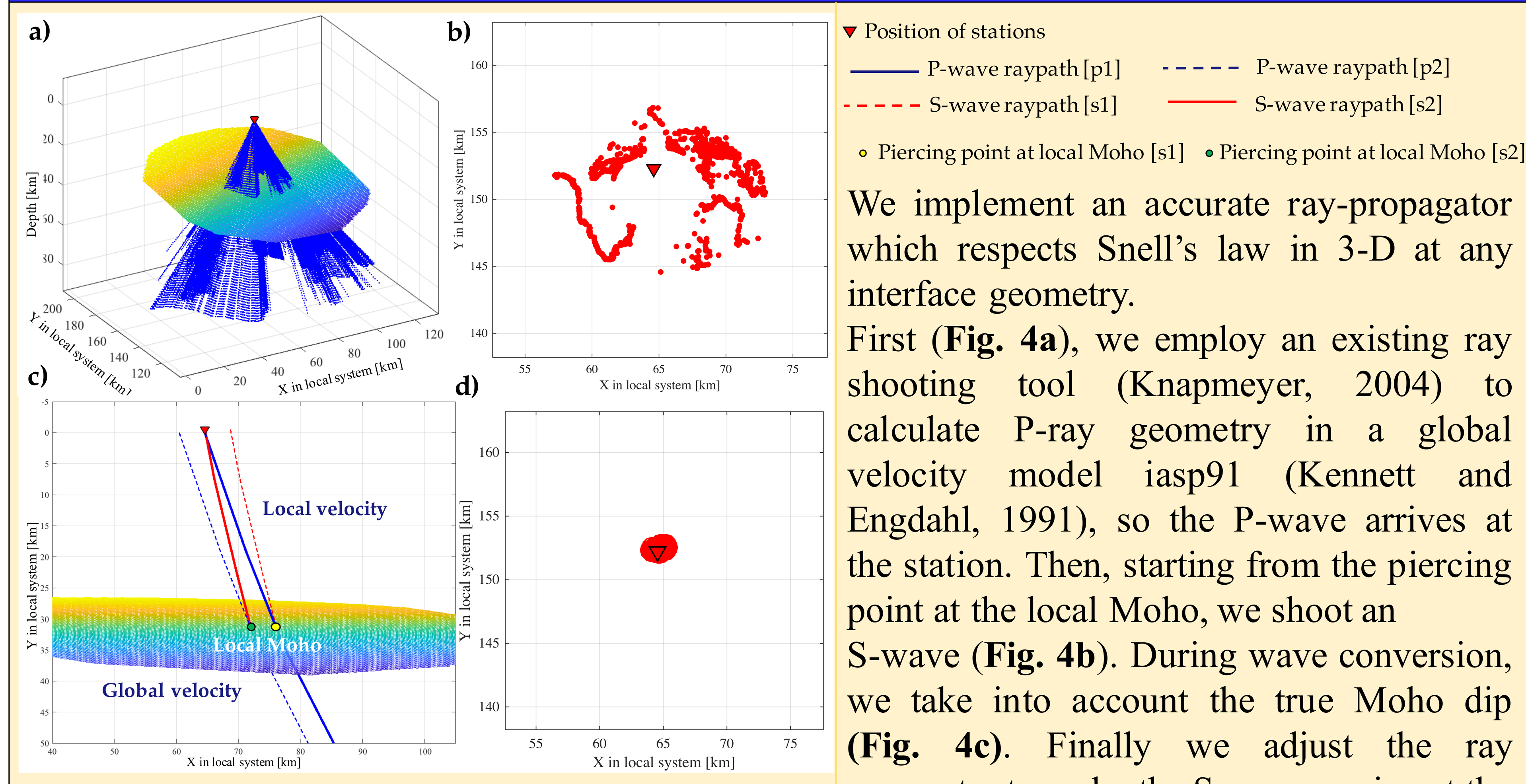

Figure 4
a) P-wave raypath in a global velocity model.
b) S-wave arrival points to the station at the surface before correction.
c) Example of a correct shooting.
d) S-wave arrival to the station after 2nd shooting.

We implement an accurate ray-propagator which respects Snell's law in 3-D at any interface geometry.
First (**Fig. 4a**), we employ an existing ray shooting tool (Knapmeyer, 2004) to calculate P-ray geometry in a global velocity model iasp91 (Kennett and Engdahl, 1991), so the P-wave arrives at the station. Then, starting from the piercing point at the local Moho, we shoot an S-wave (**Fig. 4b**). During wave conversion, we take into account the true Moho dip (**Fig. 4c**). Finally we adjust the ray parameter to make the S-waves arrive at the station (**Fig.4d**).
The mean of the distance between arrivals and the stations locations is around 60 m.

DEPTH AND VELOCITY MAPS

The inversion proceeds iteratively, by visiting every node of the map following a Travelling Salesman Path (TSP). 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, 60º bins). The velocity model at a given node is inverted using a technique of Simulated Annealing, followed by a pattern search algorithm to avoid falling in a local minimum.
We observed that a few rounds of TSP improve the overall misfit.

Generally the crustal thickness (**Fig. 5a**) reflects well the roots of the Alpine orogen, and its jump between the European and Adriatic plates, including the Ivrea Geophysical Body (**Figure 5**).
The Conrad depth reflects a similar pattern, despite it is less well resolved (**Fig. 5b**).
Average crustal Vp/Vs ratios (**Fig. 5c**) are relatively higher beneath the orogen.
Results of P-wave velocity jump across the Conrad (**Fig. 5d**) are not easy to interpret and may suffer from the limitation of how ΔVp_{Conrad} was implemented.

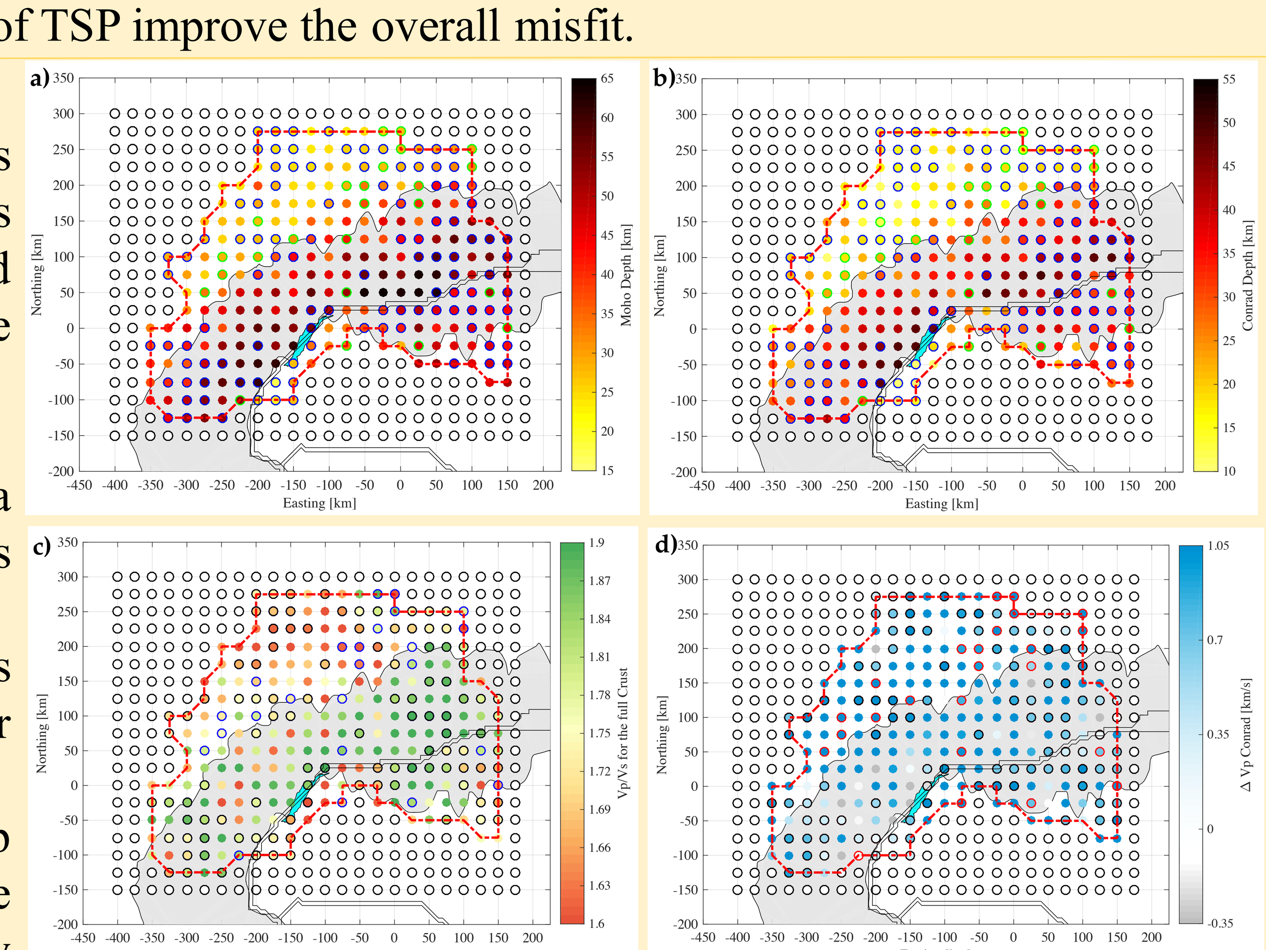

Figure 5
a) Conrad depth map; **b)** Moho depth map; **c)** Average Vp/Vs map for the full crust; **d)** P-wave velocity jump across the Conrad. Filled grey area shows the Alpine arc's smoothed 800 m altitude line. Thin double line indicates the plate boundary, red dashed contours the study area.

Vs CROSS SECTIONS

Shear-wave velocities cross-sections represent the ultimate goal of our converted-wave tomography method.
The sections are selected in the more reliably resolved areas, those crossed by a higher amount of rays (**Figure 6**).
Our results are similar to those found by 3-D ambient noise tomography in the area (**Figure 7**). The new method inherently performs better at localizing discontinuities, and less well at imaging bulk anomalies.
Future developments can incorporate joint inversions with gravity or other seismological tomography methods.

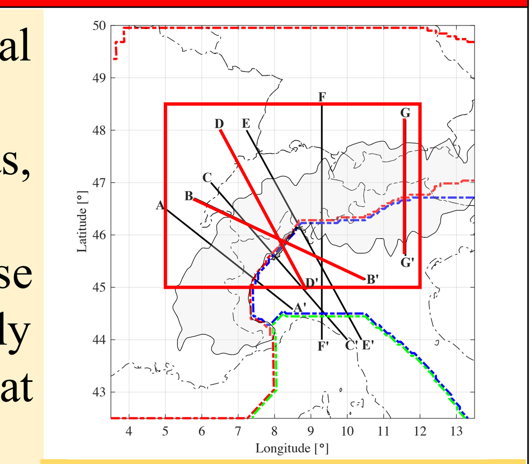

Figure 6
Map of the cross-sections; red box is the study area, red solid lines are the sections showed in Figure 7.

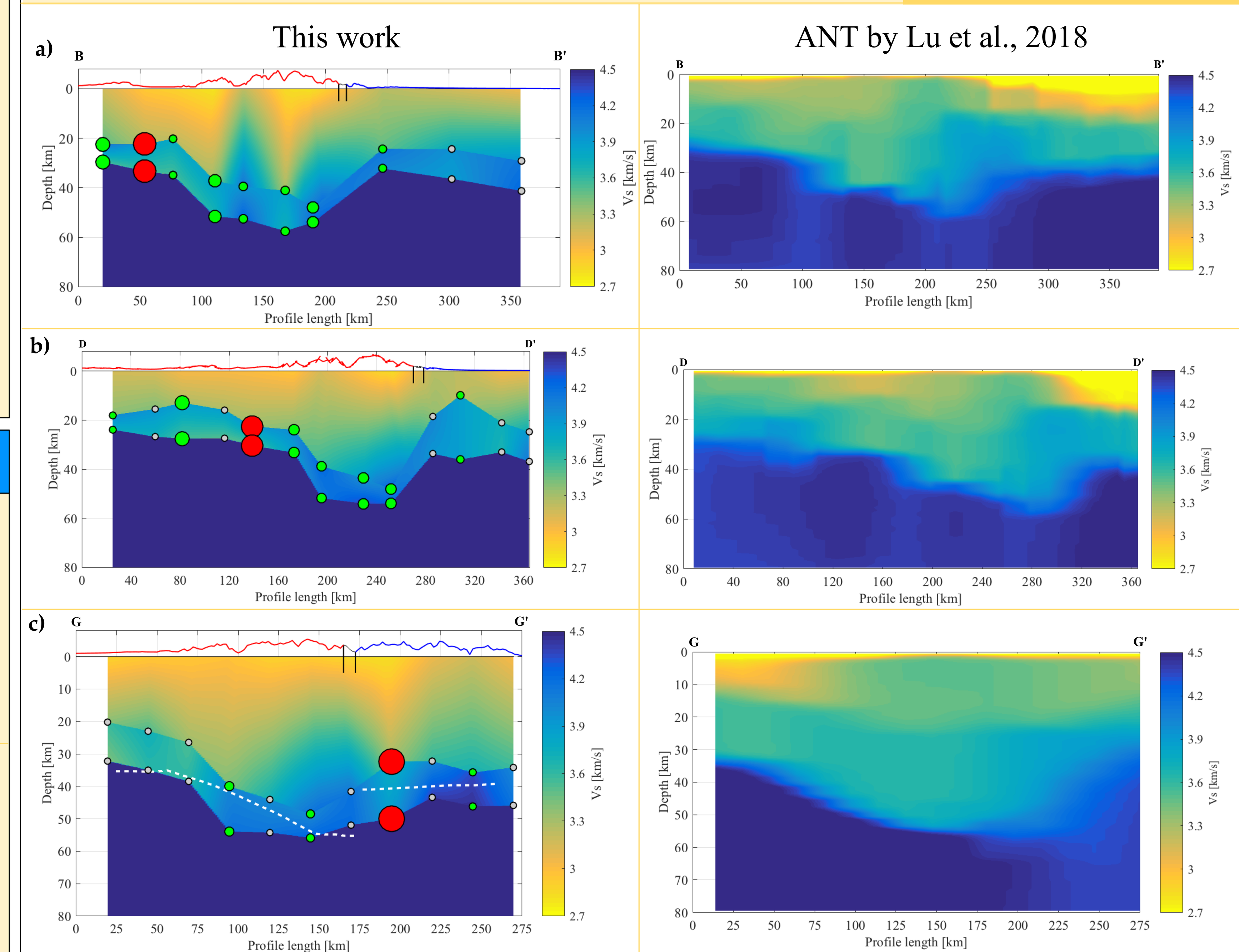

Figure 7 a) B-B' Vs cross-section: Jura mountains-Po plain; **b)** D-D' Vs cross-section: Vosges-West Po basin; **c)** G-G' Vs cross-section: TRANSALP, where white dashed line is the Moho from Kummerow et al. (2004). Left, results of this work, right, ANT performed by Lu et al., 2018. Background velocities represent the result of the inversion, where dots show the projection of the model nodes. Grey points are those not resolved directly by the inversion, green and red points are those accepted or discarded after performing the quality control and the size of the circle is proportional to the absolute misfit. Vertical exaggeration is 2:1.

GEODYNAMIC INTERPRETATION

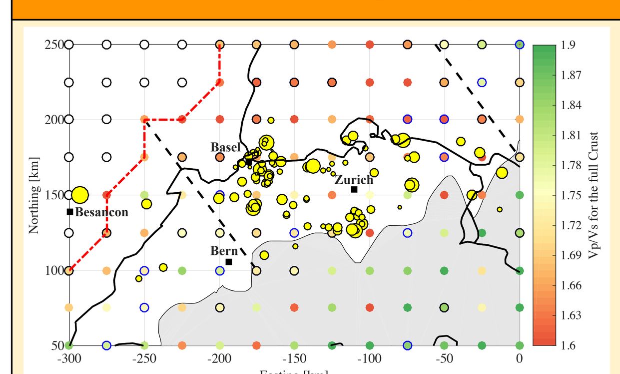

Figure 7 Vp/Vs map to which is superimposed with yellow dots the lower crustal seismicity.

While the majority of the Alpine domain shows high Vp/Vs values, the European foreland has a contiguous area with low Vp/Vs ratios (<1.70).
This zone correlates with lower crustal seismicity reported by Singer et al., 2014 (**Figure 7**), which we interpret as mechanical differences in rock properties, most likely inherited.

REFERENCES

- Diehl, T. et al., 2009. *Geophys. J. Int*. **179**, 1133-1147.
- Hetényi, G. et al., 2018. *Surv. Geophys*. **39**, 1009-1033.
- Kennett, B. L. N. and Engdahl, E. R., 1991. *Geophys. J. Int*. **105,** 429-465.
- Knapmeyer, M., 2004. *Seismol. Res. Lett*. **75(6)**, 723-726.
- Kummerow, J. et al., 2004. *Earth. Planet. Sc. Lett*., **225**, 115-129.
- Lu, Y. et al., 2018. *Geophys. J. Int*. **214**, 1136-1150.
- Singer, J. et al., 2014. *Earth. Planet. Sc. Lett*., **397**, 42-56.
- Spada, M. et al. 2013. *Geophys. J. Int*., **194(2)**, 1050-1068.

ACKNOWLEDGEMENTS

We are very grateful to the Swiss Seismological Service, Istituto Nazionale di Geofisica e Vulcanologia in Italy, University of Genova, Civil Defense of Bolzano, Mediterranean Network, Réseau simologique et géodésique français, Zentralanstalt für Meteorologie und Geodynamic in Austria, University of Münich, German Research Centre for Geosciences and AlpArray project for collecting and sharing seismological data.
We also say thanks to Prof. N. Linde (Institute of Earth Sciences in Lausanne, Switzerland), Dr. T. Bodin (Laboratoire de Géologie de Lyon, France) and the researchers of AlpArray RF Working Group for their fruitful advice during this research and Dr. T. Diehl (Swiss Seismological Service, Zürich, Switzerland for making the 3-D P-velocity model of the Alps available. This research is supported by the Swiss National Science Foundation grant number PP00P2_157627.