Shear-Wave Splitting in the Alpine Region

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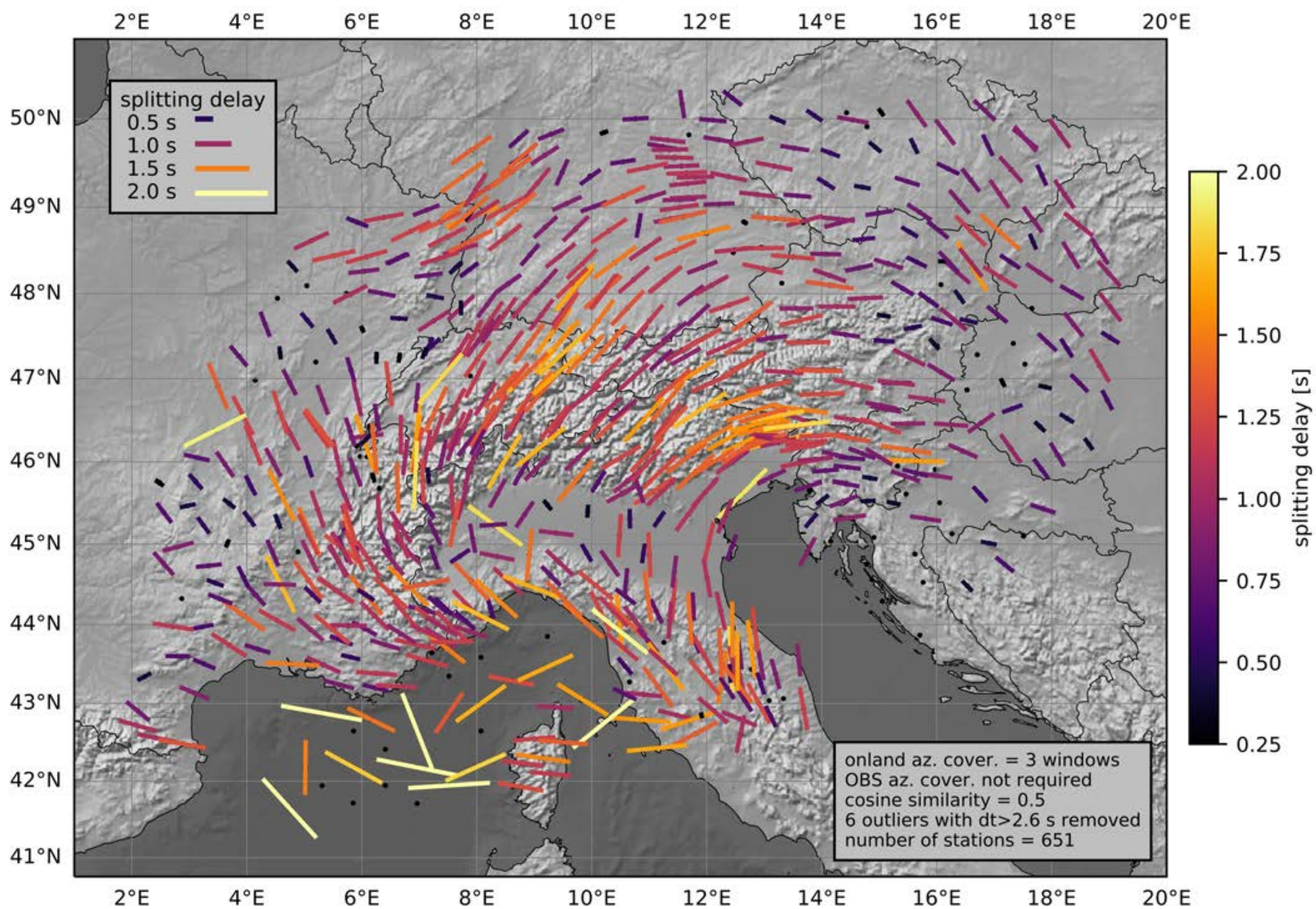
Automatic technique based on **splitting intensity**, with stabilization criteria.

Map shows single-layer parameters (**fast orientations and splitting delay**).

Fast orientations: more detail than before; enigmatic coherent large-scale features.

Splitting delays: show interesting new features.

Methodological issues: Noise decreases apparent splitting delays (bias)



Different criteria for on- and offshore stations!

The Splitting Intensity Technique: Strength and Weakness

Split SKS shear waves have a radial component that is similar to the incident waveform
$R(t) \approx w(t)$, and the traverse component that shows its derivative
$T(t) \approx -1/2\,(\delta t \sin 2\beta)\, w'(t)$,

This gives
$T(t) \approx -1/2\, s\, R'(t)$, with the splitting intensity s.

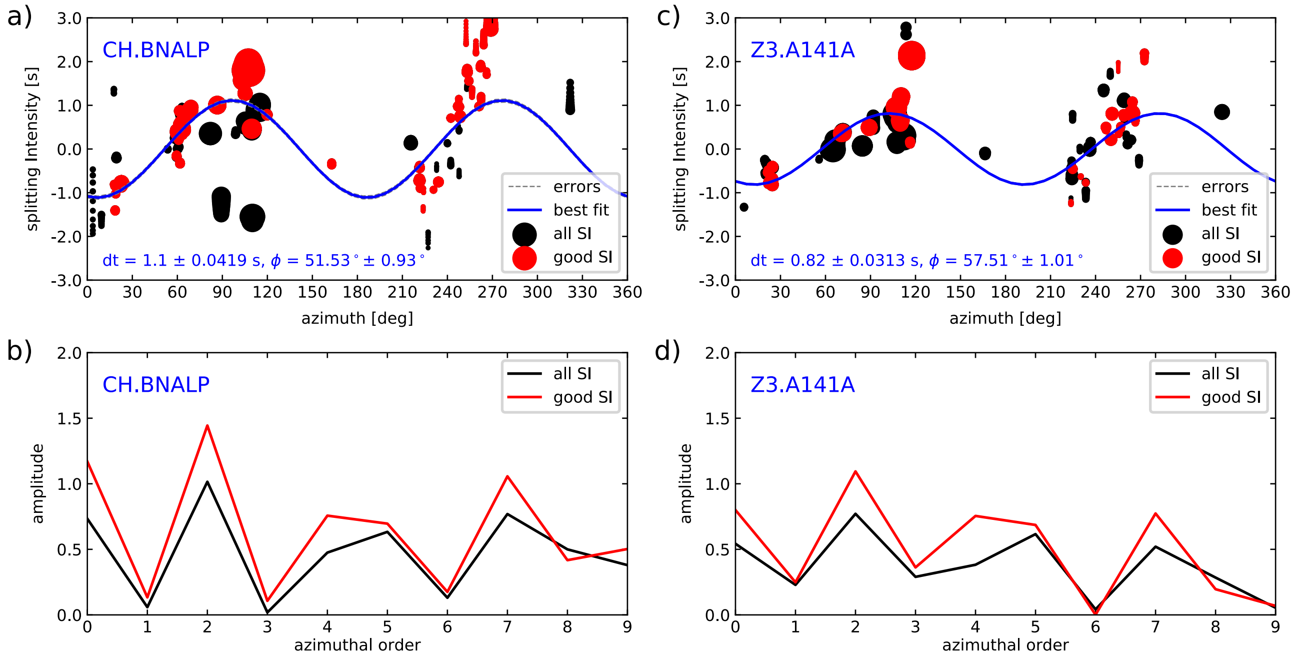
The splitting intensity technique of Chevrot (2000) assumes a waveform model
$T = -1/2\, s \otimes r + N$, with the derivative of the noise-free radial-component waveform r.

This accounts for additive noise N on the transverse component, but not on the radial components.
One can show that this leads to a noise-dependent bias in the apparent splitting delays δt^*,
$\delta t^* = \delta t/(1 + x)$, with x increasing with radial noise.
The presence of radial noise creates a bias to lower apparent splitting delay[1].

There is a tradeoff between bias and measurement instability - controlled by the degree of (accepted) noise level.

[1] The bias is still present after partial noise-reduction by Wiener-filtering. In principle, it may be adjusted explicitly using this formula.

Splitting Intensities and Angular Spectrum



To ensure high quality, we impose two criteria:

a) a cosine similarity criterion for R´ and T for individual measurements, and

b) an azimuthal gap criterion for stations (at least three 15°-windows need to be covered).

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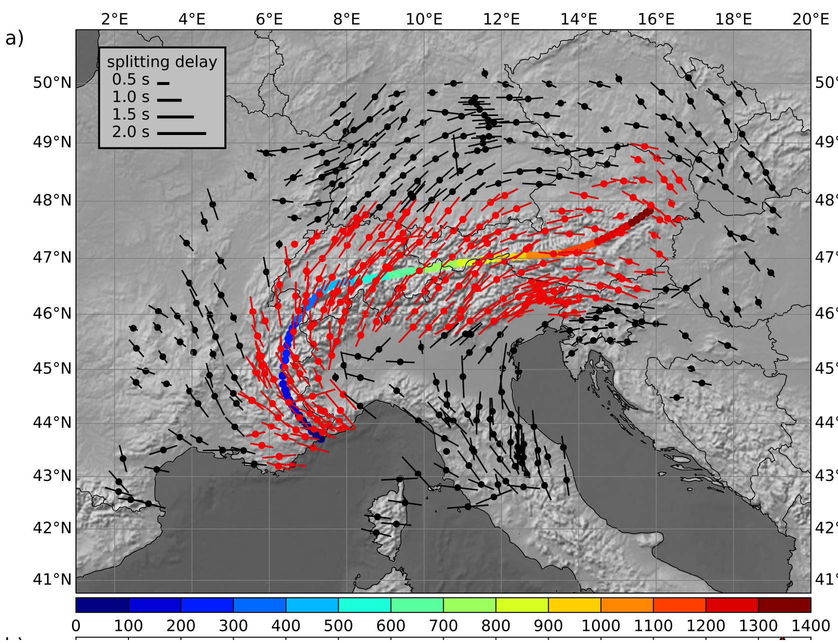
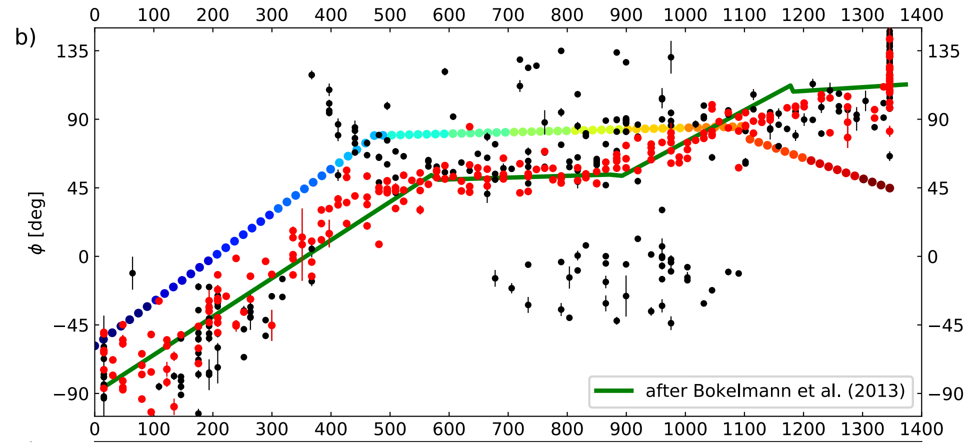
Variation of Splitting Parameters along the Alps



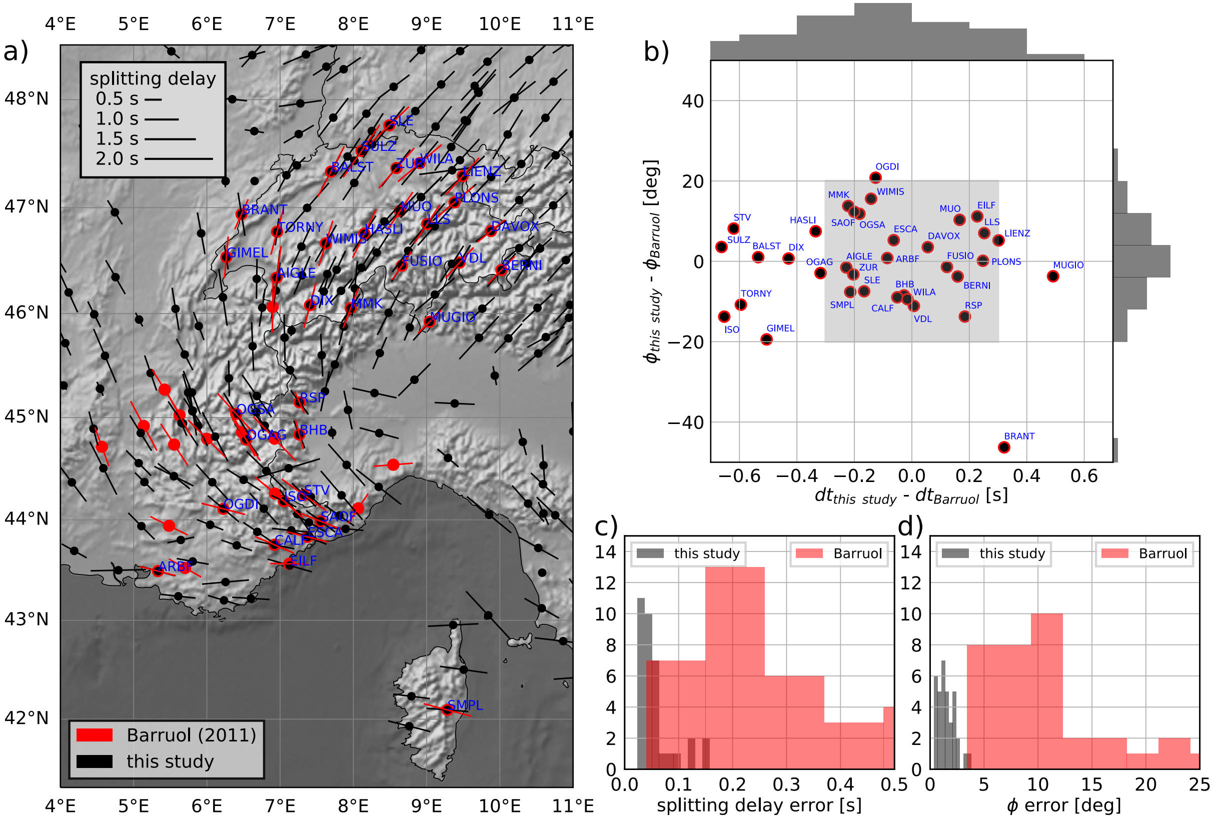
The colored line shows distance along the “Alpine axis” that connects the “centers of gravity” of topographic profiles.



The observed variation along the Alps agrees largely with earlier studies, e.g., it matches the green line that was proposed earlier by Bokelmann et al. (2013).

Note the nearly-constant offset of fast orientations from the orientation of the Alpine axis though.

Comparison with Barruol et al. (2011): Western Alps



Stations that were used in this study and in Barruol et al. (2011) show similar results:

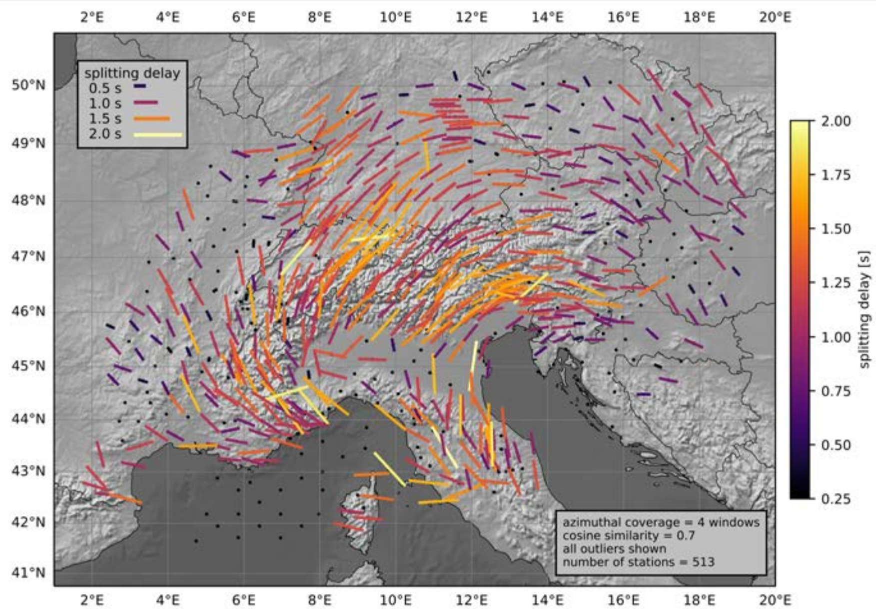
- For splitting intensity (here) and transverse minimization technique,
- For automatic application (here) and manual.

This shows that automatic measurements can achieve high stability.

Deviations are consistent with formal uncertainties, yet the SI-technique has somewhat optimistic formal uncertainties from unmodeled effects (e.g., bias).

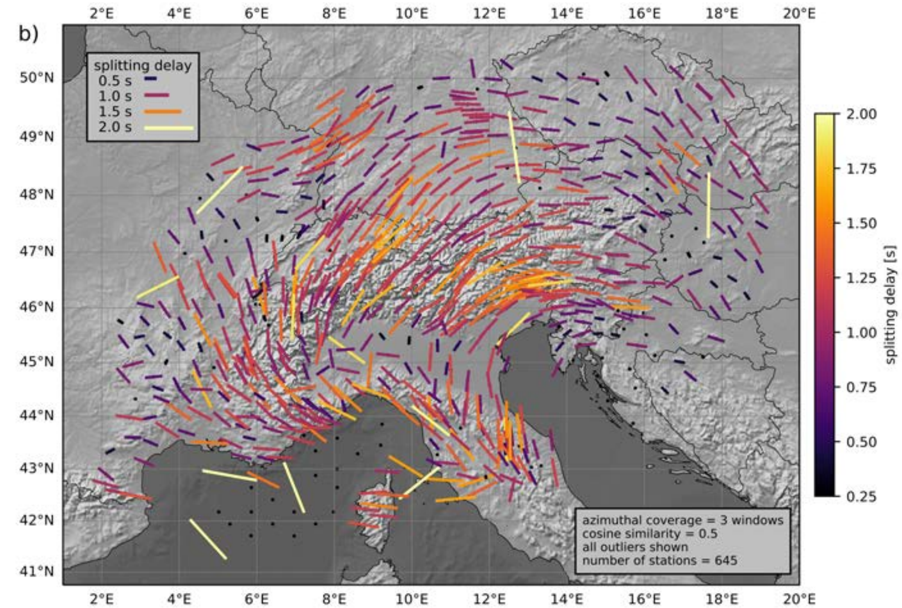
Dependence of Results on Cosine Similarity Criterion

More restrictive (> 0.7; 4 windows)



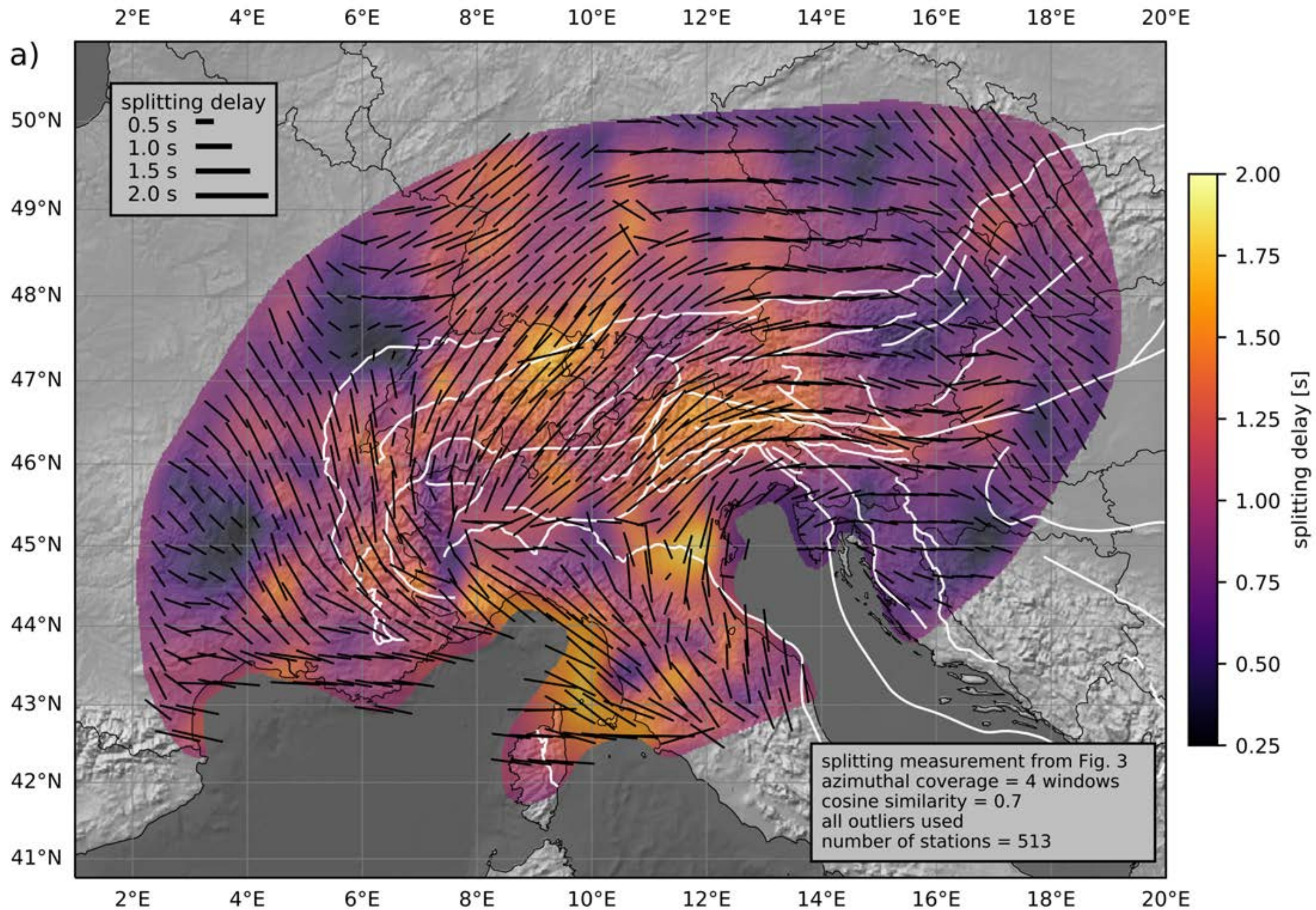
Tradeoff between minimum bias versus maximum measurement stability - controlled by the degree of (accepted) noise level.

Less restrictive (> 0.5; 3 windows)



More noise: slightly weaker splitting delays. More stations become acceptable, e.g. for the Ligurian Sea stations.

Interpolated Splitting Map

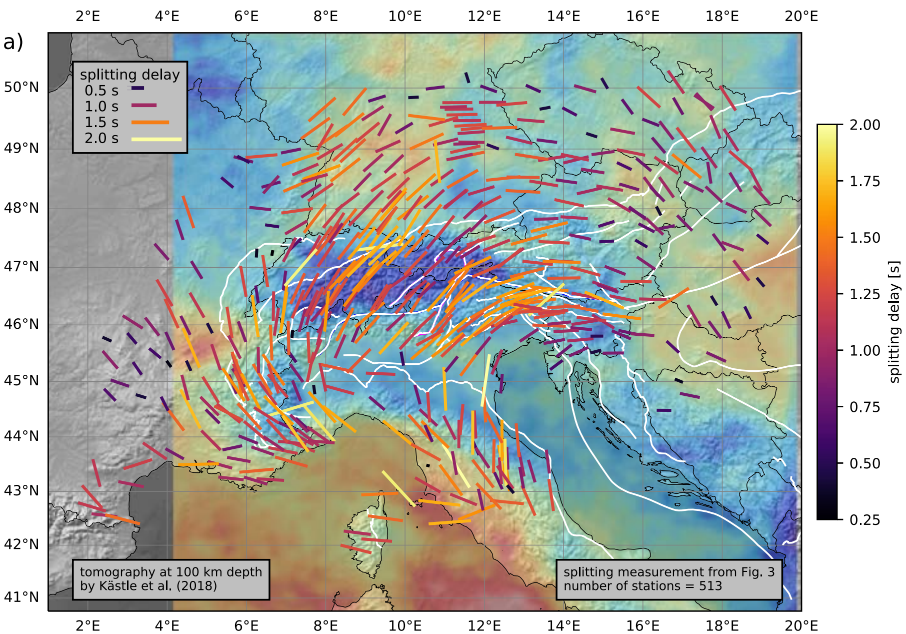


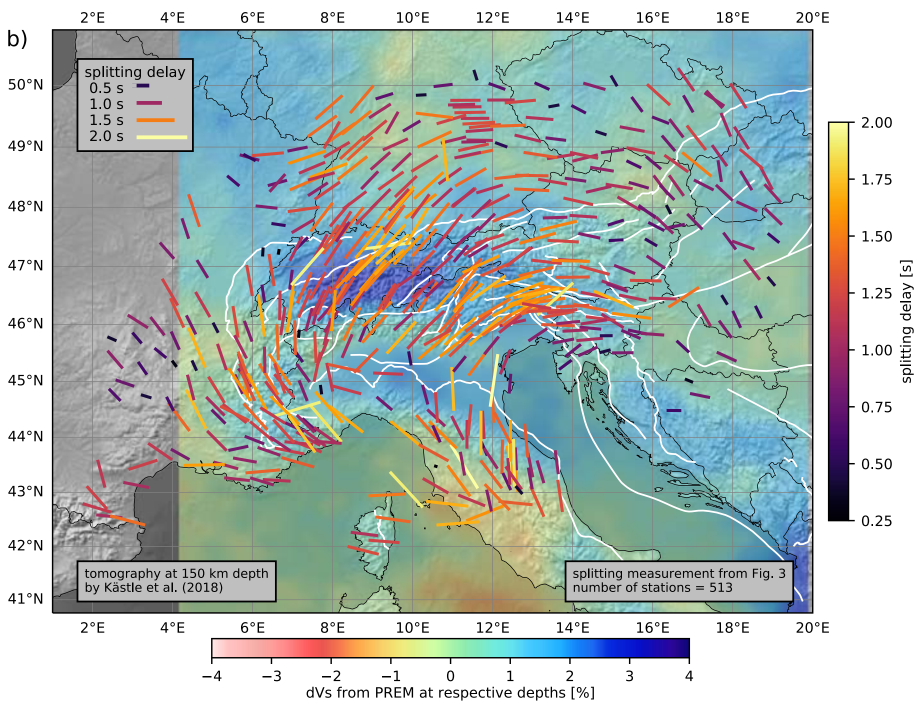
Comparison with Tomography (Geodynamic Interpretation)

Comparison with tomographic model (Kästle et al., 2018):

At 100 km depth

At 150 km depth





See Hein et al. (2021)

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Abstract:

To constrain seismic anisotropy under and around the Alps in Europe, we study SKS shear-wave splitting from the region densely covered by the AlpArray seismic network. We apply a technique based on measuring the splitting intensity, constraining well both the fast orientation and the splitting delay. 4 years of teleseismic earthquake data were processed automatically (without human intervention), from 724 temporary and permanent broadband stations of the AlpArray deployment including ocean-bottom seismometers. We have obtained an objective image of anisotropic structure in and around the Alpine region, at a spatial resolution that is unprecedented. As in earlier studies, we observe a coherent rotation of fast axes in the western part of the Alpine chain, and a region of homogeneous fast orientation in the central Alps. The spatial variation of splitting delay times is particularly interesting. On one hand, there is a clear positive correlation with Alpine topography, suggesting that part of the seismic anisotropy (deformation) is caused by the Alpine orogeny. On the other hand, anisotropic strength around the mountain chain shows a distinct contrast between western and eastern Alps. This difference is best explained by the more active mantle flow around the Western Alps. We discuss earlier concepts of Alpine geodynamics in the light of these new observational constraints.

References:

- Barruol, G., Deschamps, A., & Coutant, O., 2004, Mapping upper mantle anisotropy beneath SE France by SKS splitting indicates Neogene asthenospheric flow induced by Apenninic slab roll-back and deflected by the deep Alpine roots,Tectonophysics, 394(1), 125 – 138
- Bokelmann, G., Qorbani, E., & Bianchi, I., 2013, Seismic anisotropy and large-scale deformation of the Eastern Alps, Earth and Plan. Sc. Let.,383, 1–6
- Chevrot, S., 2000, Multichannel analysis of shear wave splitting, Journal of Geophysical Research: Solid Earth,105(B9), 21579–21590
- Hein, G., Kolinsky, P., Bianchi, I., Bokelmann, G., 2021, Shear-wave splitting in the Alpine Region, Geophys. J. Int., in review