Azimuthal Anisotropy in the Eastern Alpine Crust from Ambient Noise Tomography

E.D. Kästle (Freie Universität Berlin) and the AlpArray Working Group

EGU 2023

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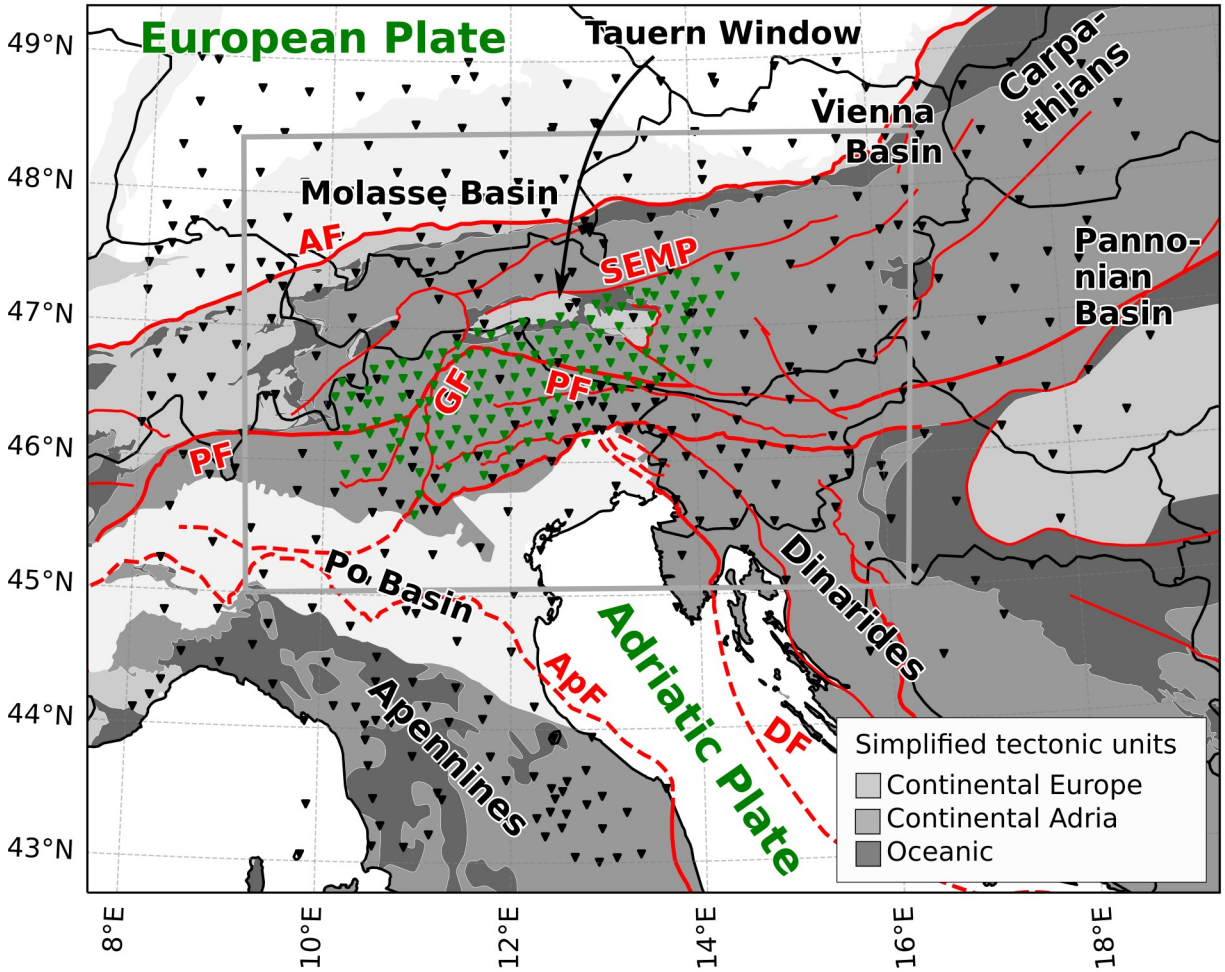
Tectonic setting



- station
- SwathD station

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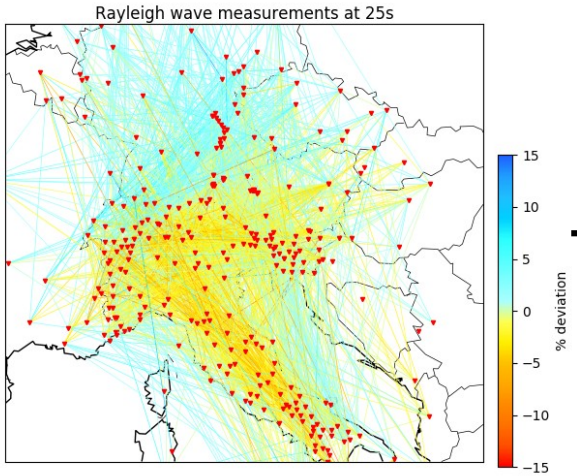
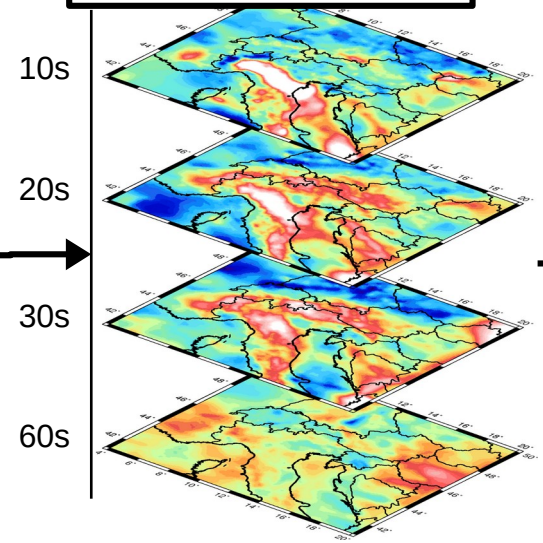
Ambient noise tomography

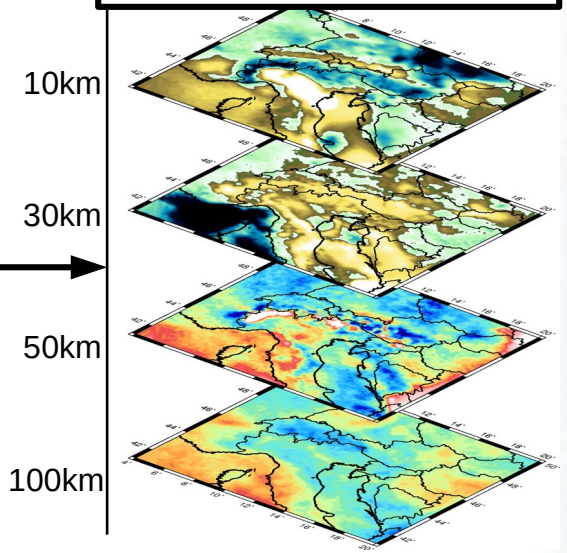
Phase-velocity measurements.



Phase-velocity maps.



3D shear-velocity model.



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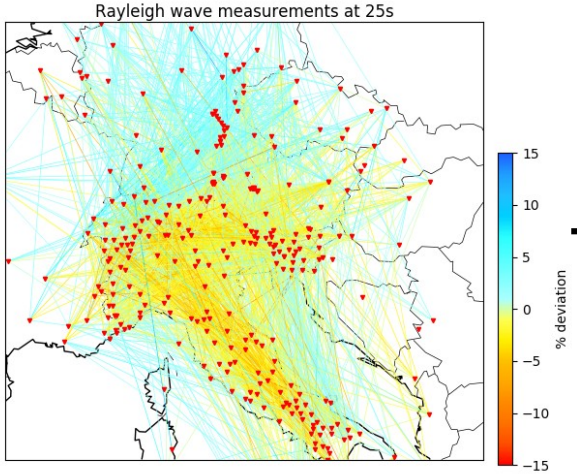

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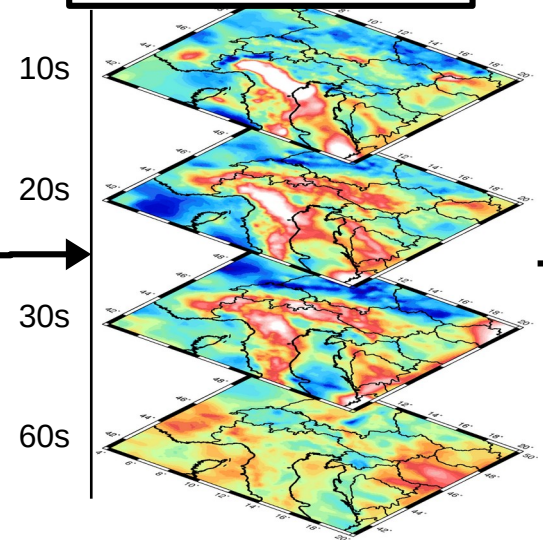

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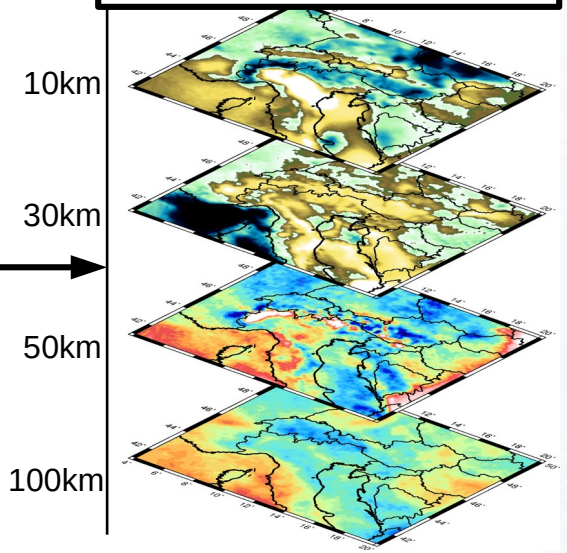


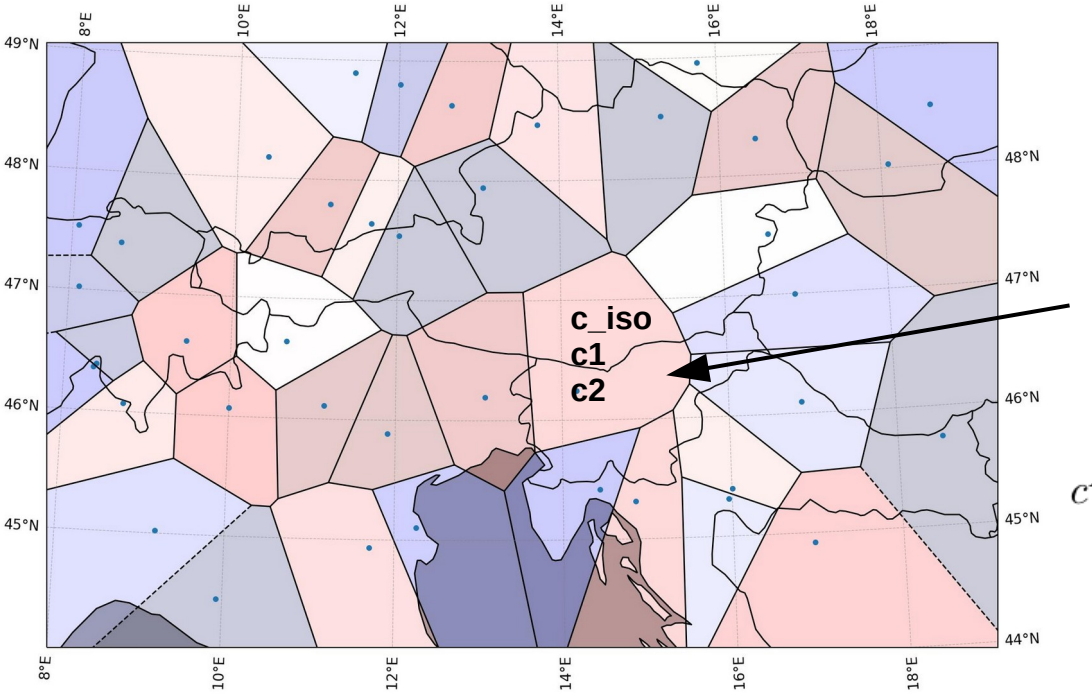
Inversion step 1 (rjMcMC)
Azimuthally anisotropic

Inversion step 2 (rjMcMC)
Azimuthally anisotropic

rjMcMC tomography

Reversible jump Markov Chain Monte Carlo
→ model search to find a probability distribution of models that fit the data

Simple Voronoi parameterization



Each Voronoi cell has 3 parameters: **one isotropic** (c_iso) Rayleigh phase velocity and **two anisotropic** (c1,c2) parameters.

$$c^{AA} = c^{iso}\left[1 + c_1\cos(2\Phi) + c_2\sin(2\Phi)\right]$$

rjMcMC tomography

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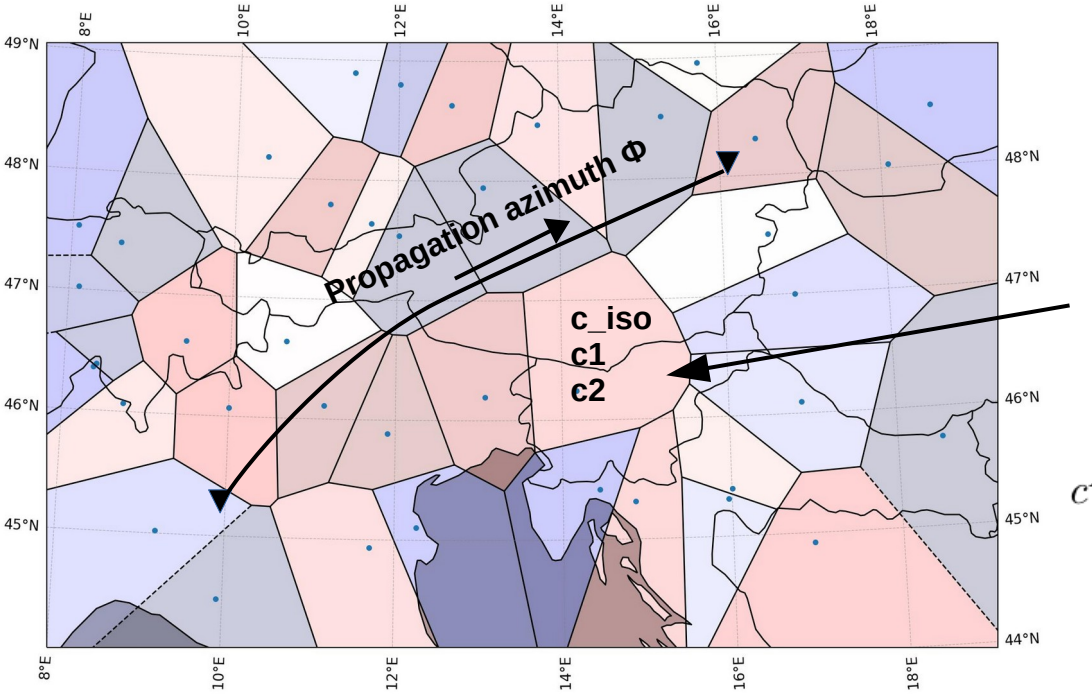

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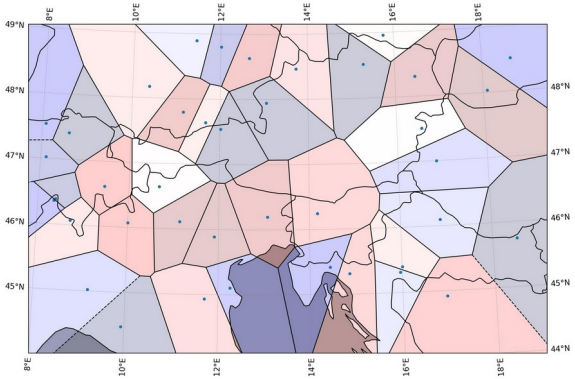
rjMcMC tomography



repeat

optional: re-calculate ray paths

Propose new model
- Change cell parameters
- Add cell
- Remove cell
- Move cell

Forward model
- Calculate synthetic phase travel times

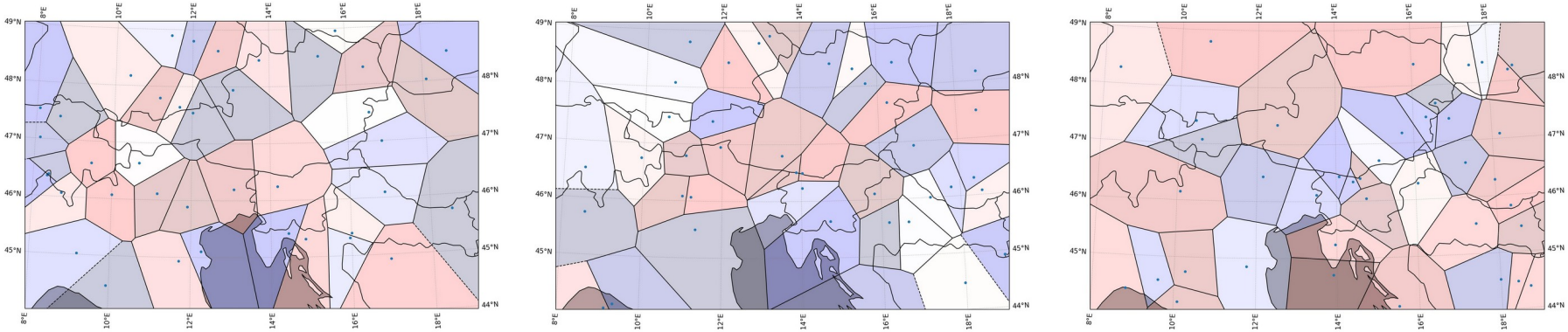
Calculate likelihood

accept/ reject new model

rjMcMC tomography

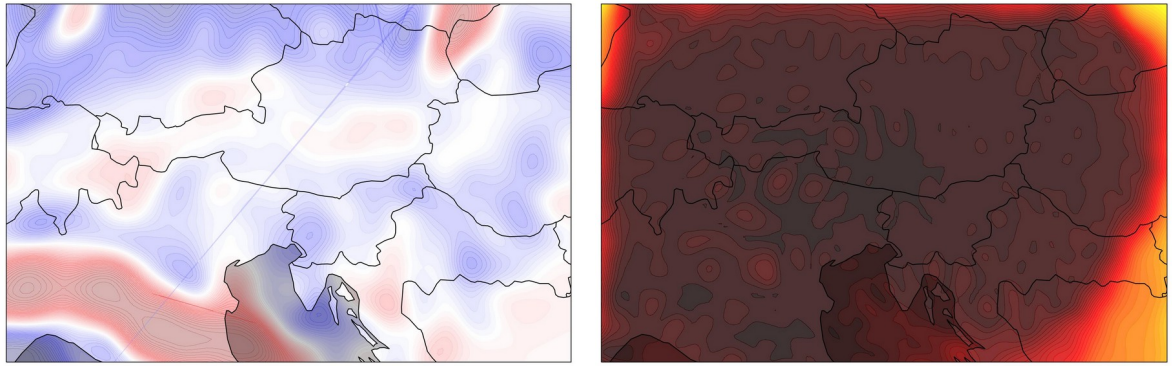
Reversible jump Markov Chain Monte Carlo

→ model search to find a probability distribution of models that fit the data



Alternative models that fit the data equally well

Average model and model standard deviation



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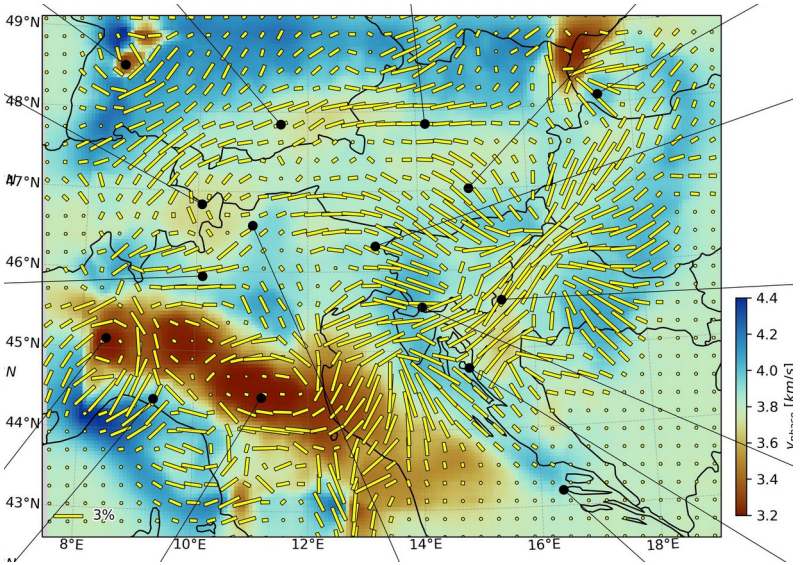
Azimuthal anisotropy

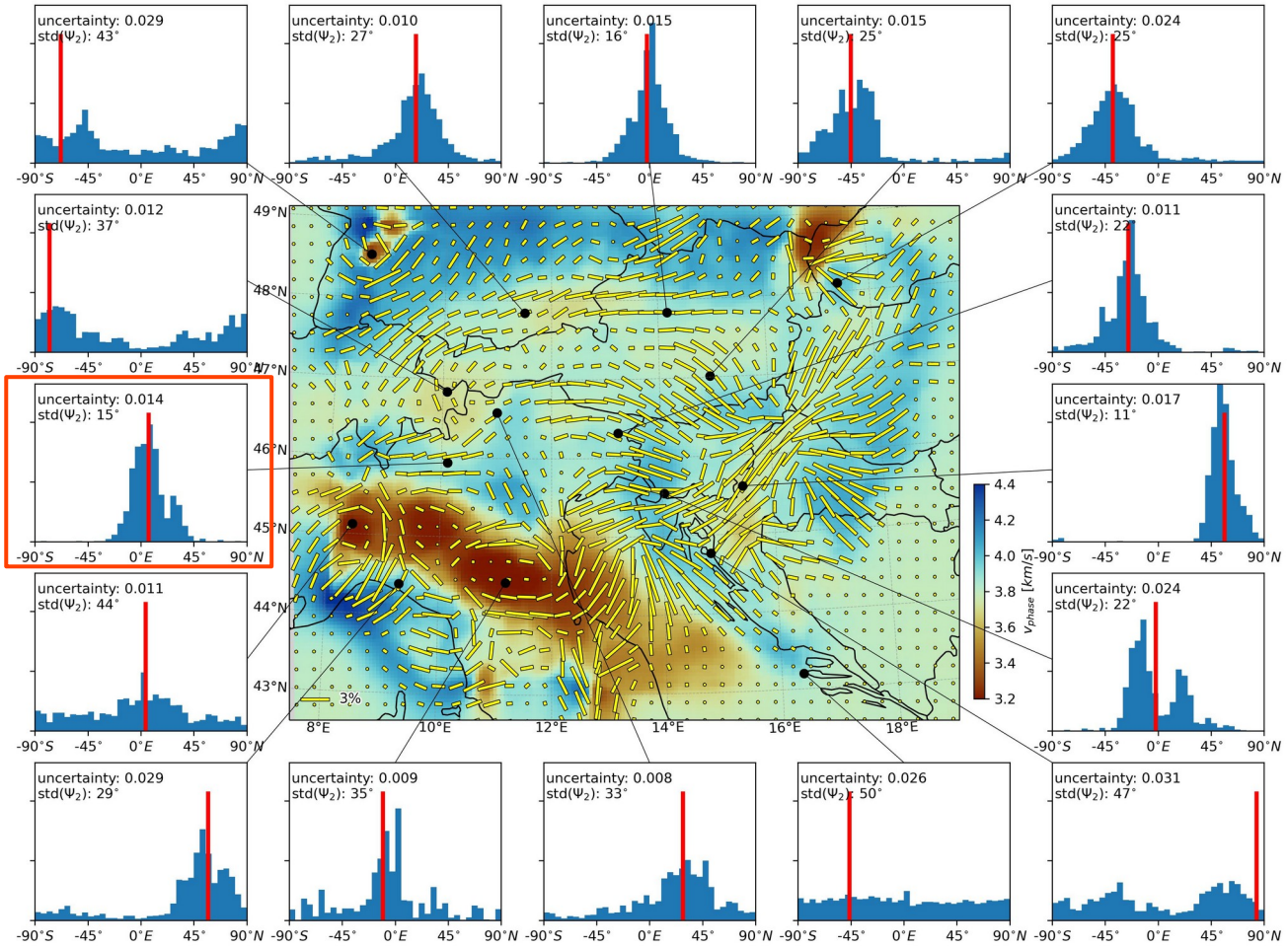
Rayleigh phase velocity at 15s



Anisotropic fast axis

Azimuthal anisotropy

Rayleigh phase velocity at 15s



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Ambient noise tomography

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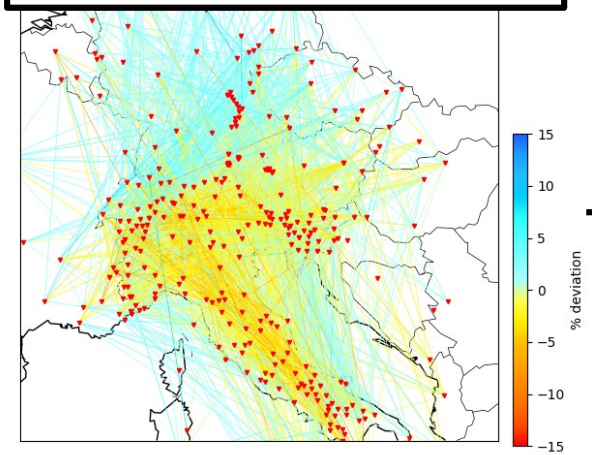

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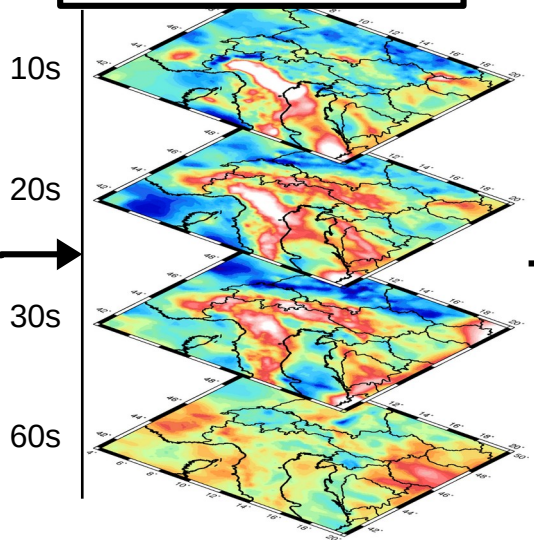

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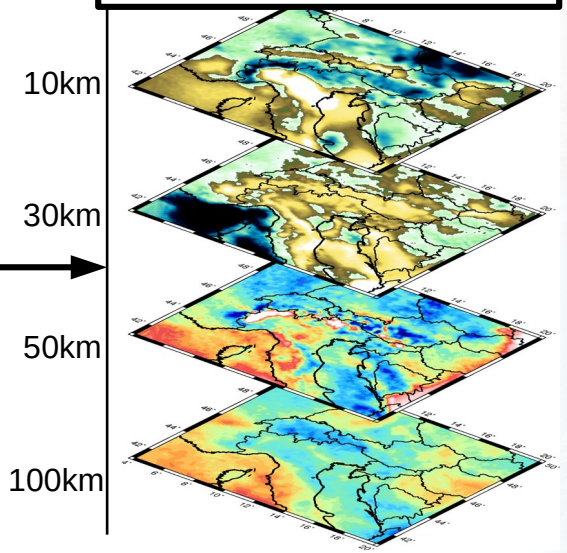

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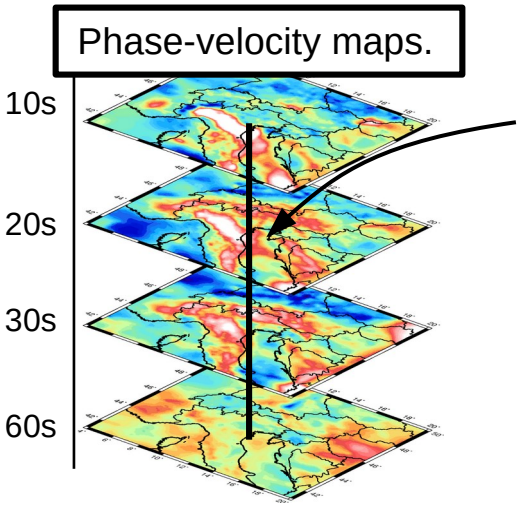
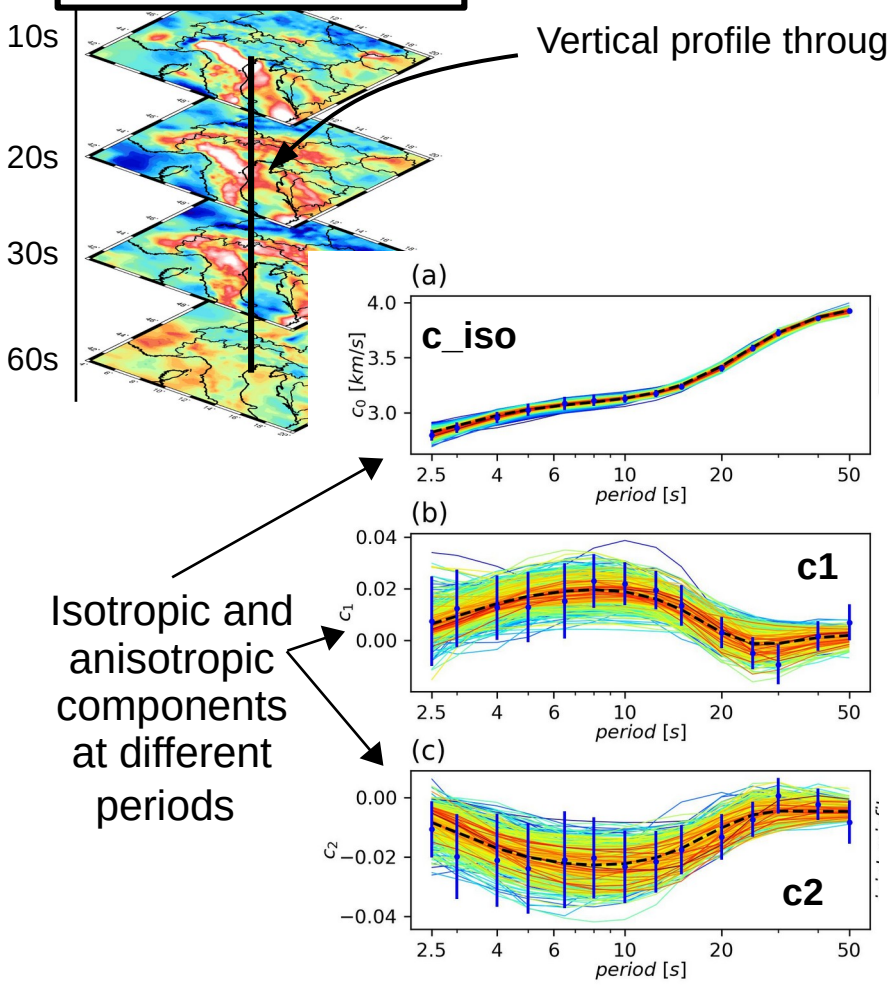
Depth inversion



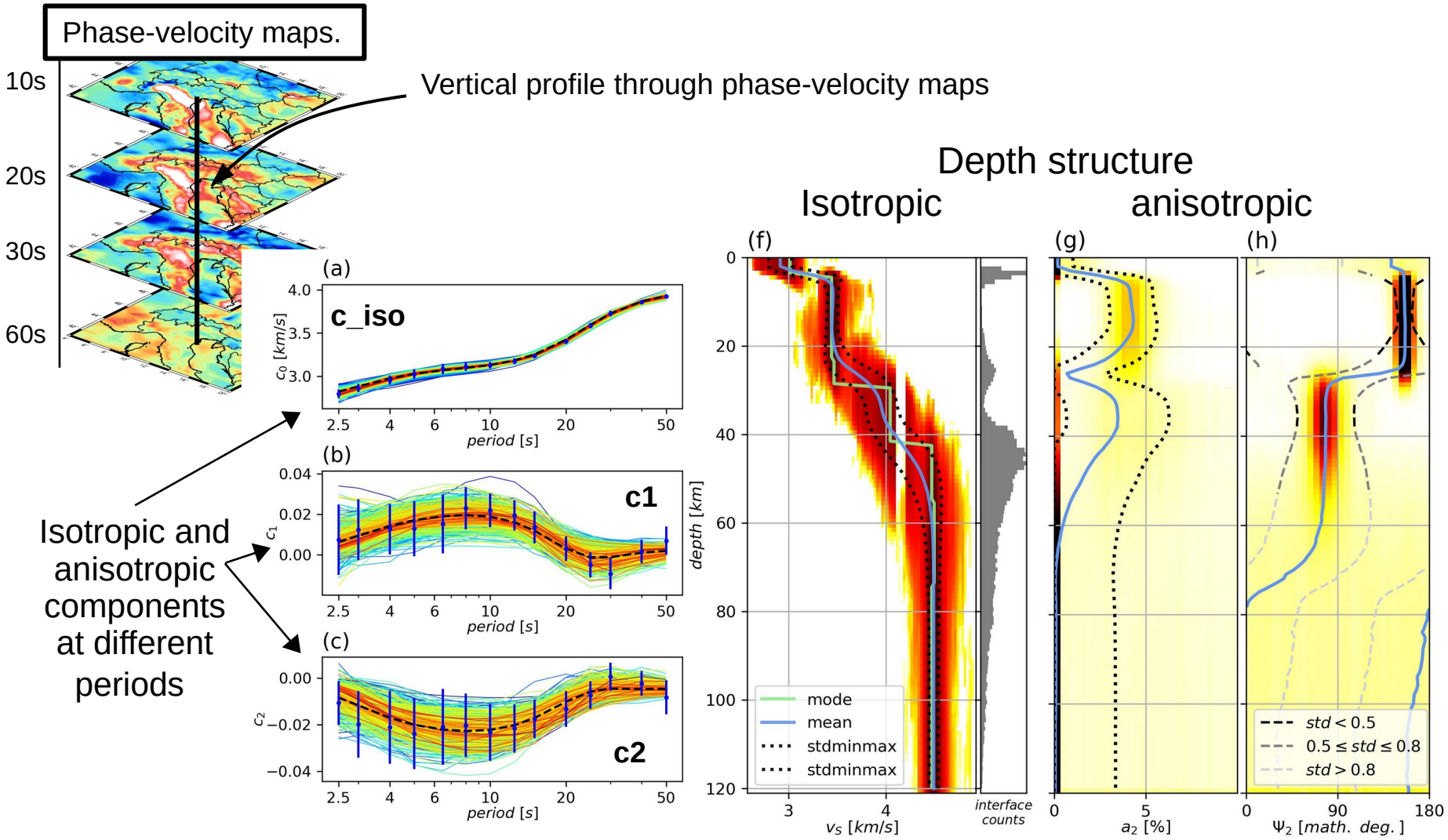
Vertical profile through phase-velocity maps

Depth inversion

Phase-velocity maps.



Depth inversion



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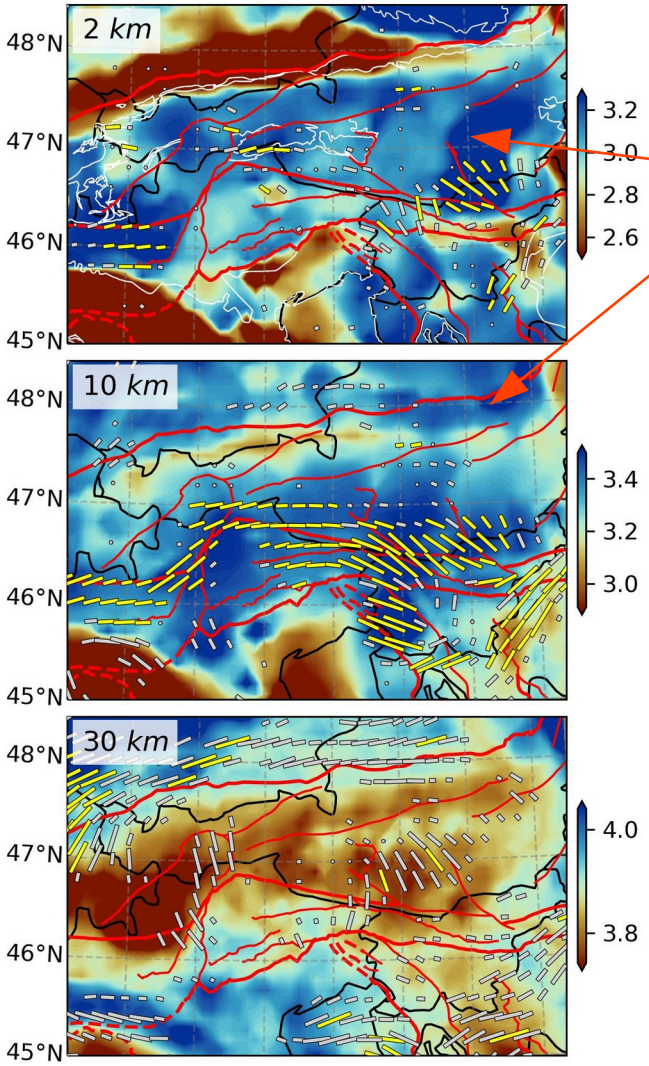
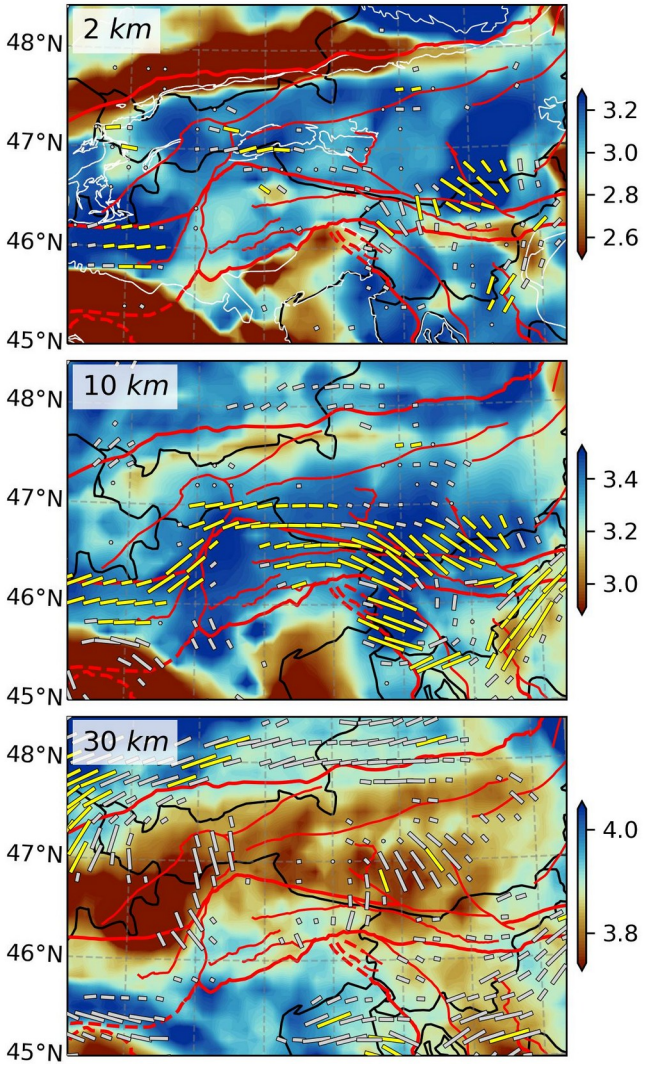
Results

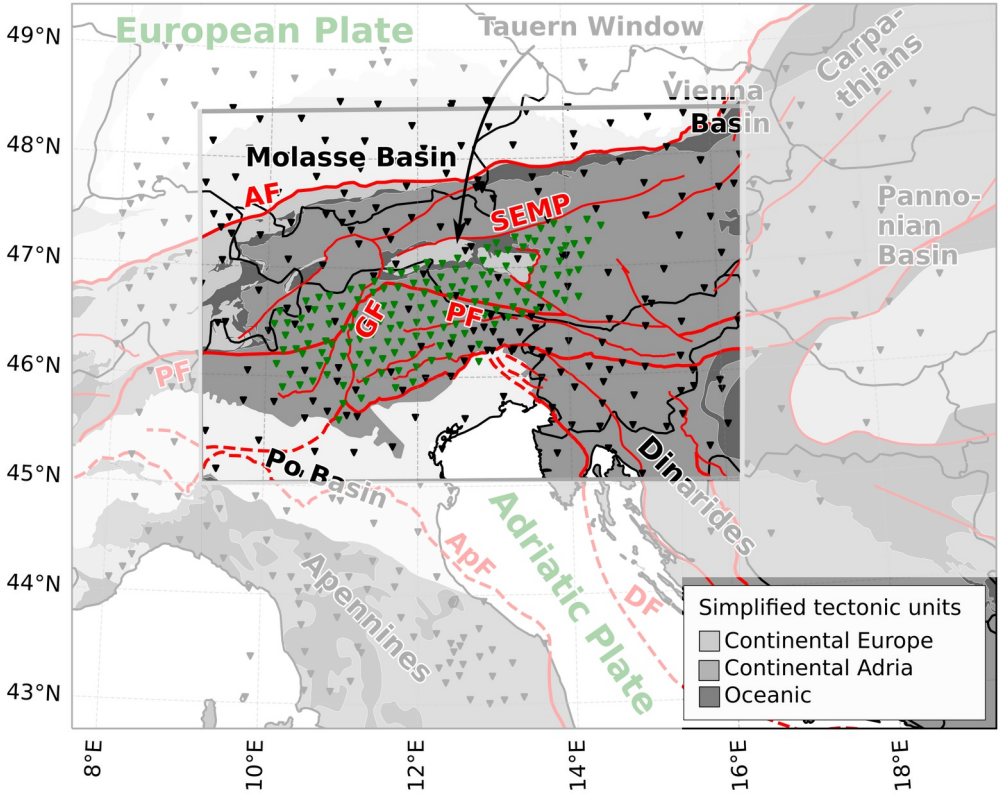
Results



Regions with high uncertainty in the anisotropy / no anisotropy

Results





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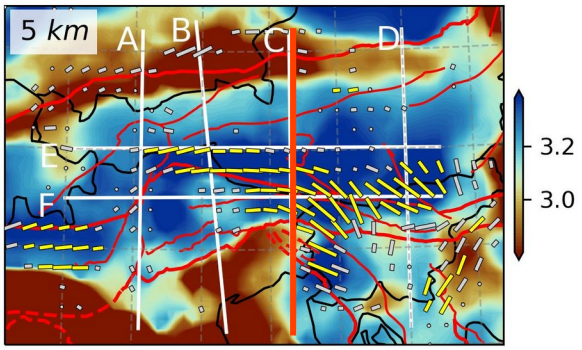

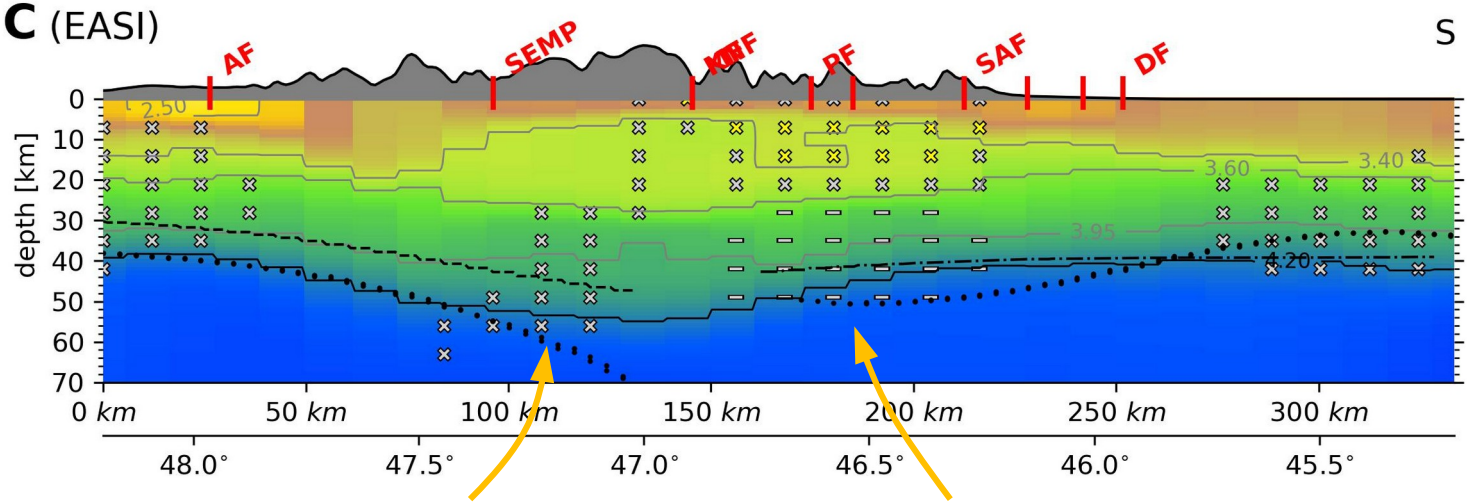

Anisotropic fast axis **perpendicular** to cross section strike

Anisotropic fast axis **parallel** to cross section strike

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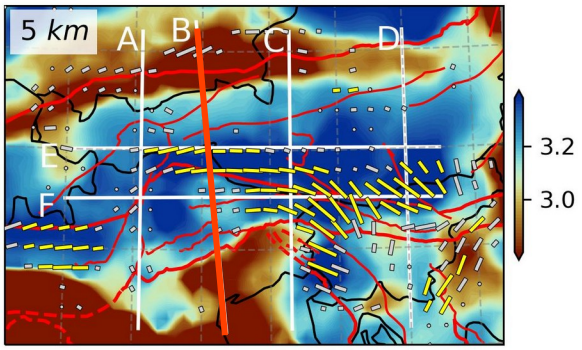
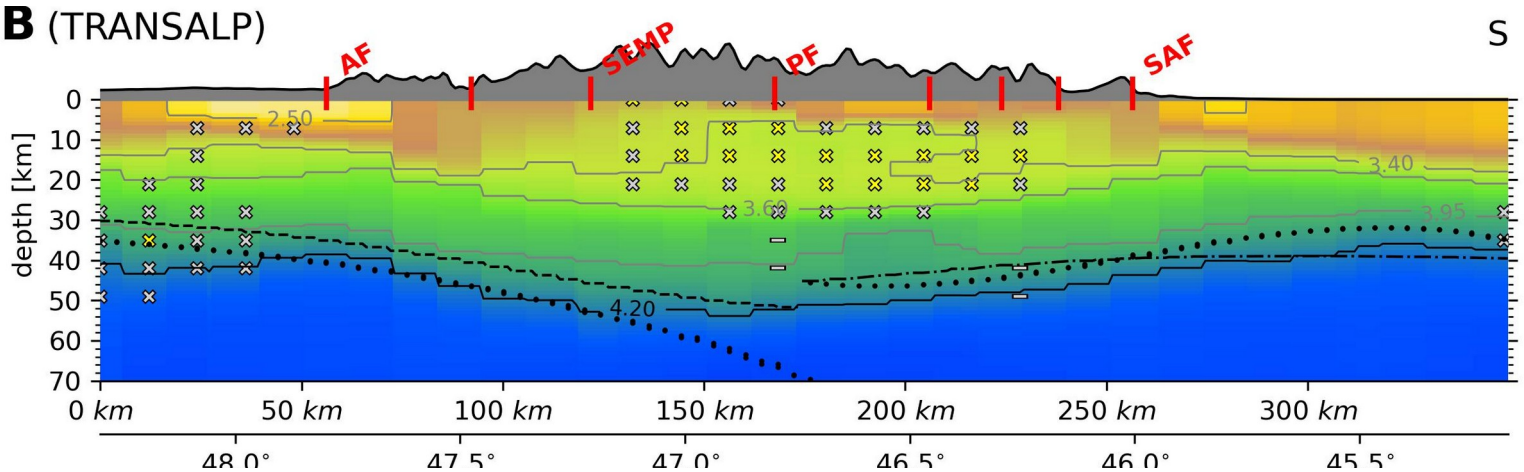
Results





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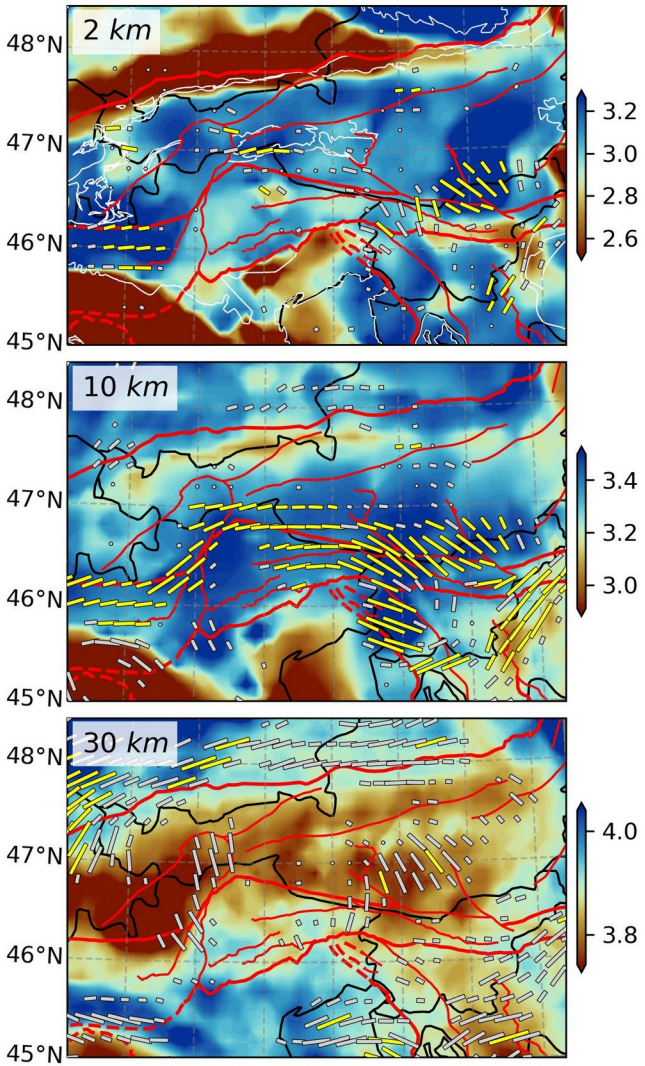
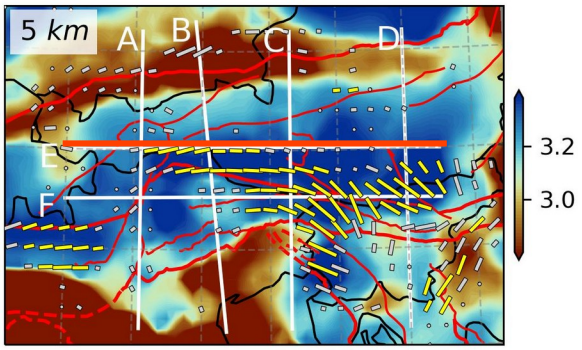
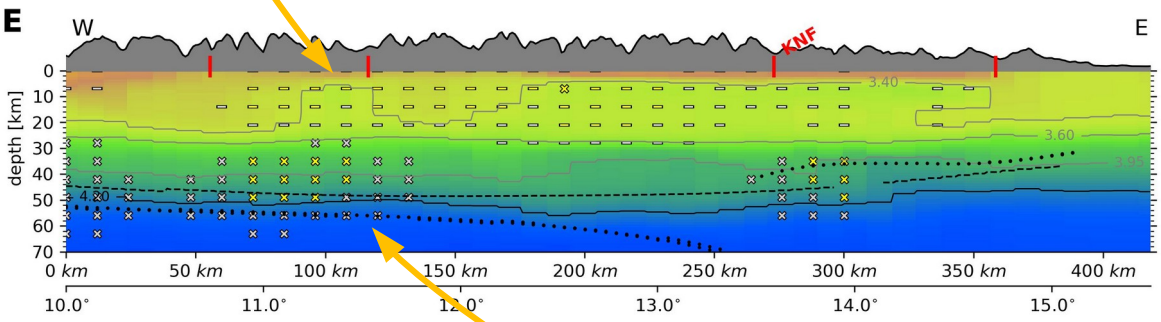


Upper crustal layer orogen parallel



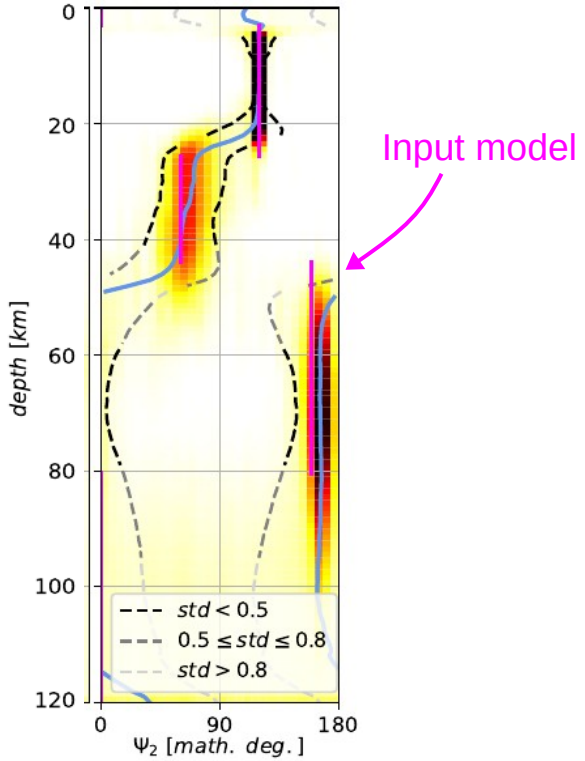


lower crustal / mantle layer orogen perpendicular

Resolution tests

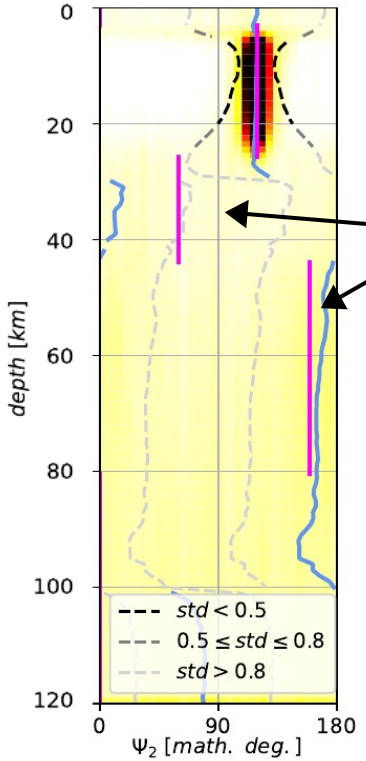
3-layer model of anisotropy – synthetic test

Low data uncertainty



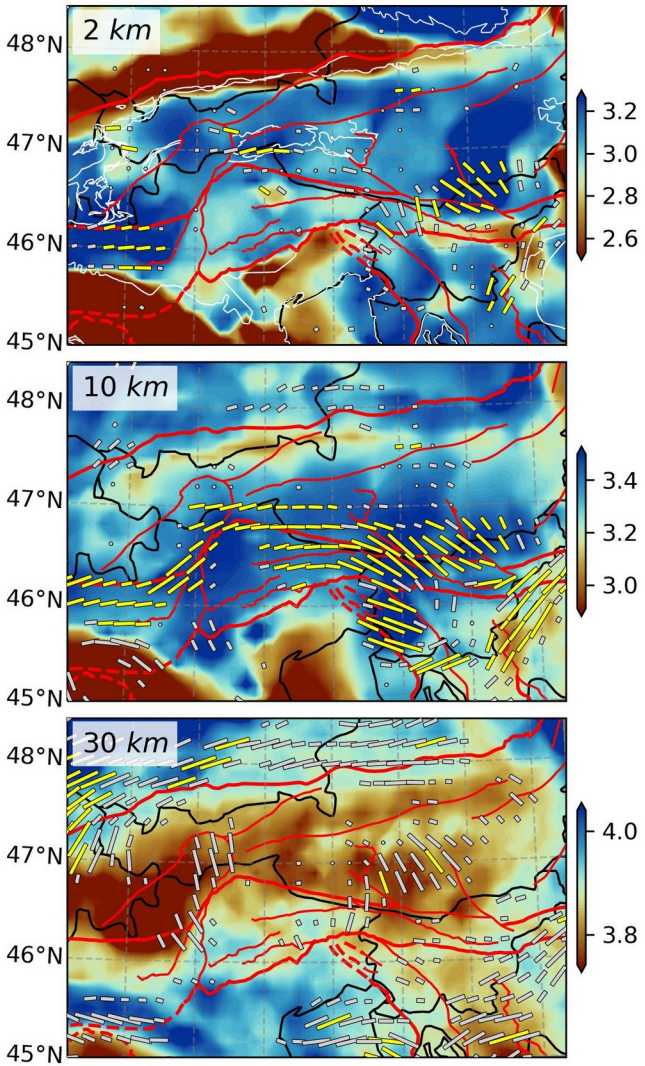
Input model

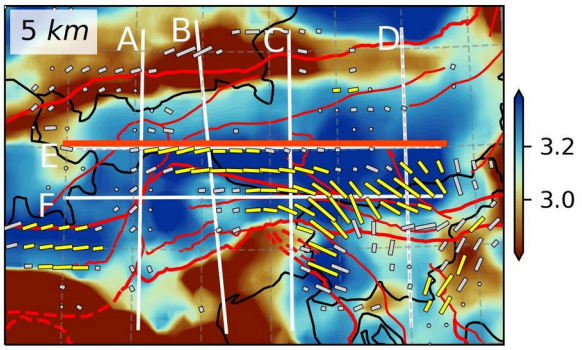
Realistic data uncertainty



Layer 2 and 3 with perpendicular fast axis directions cancel out

Results





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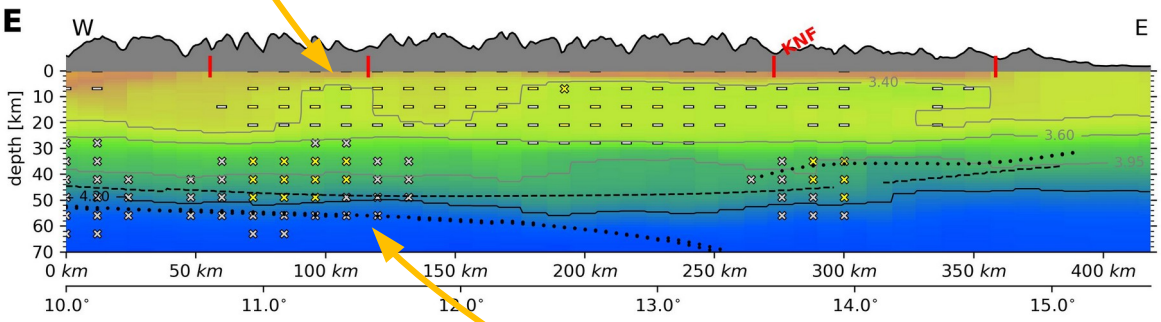

lower crustal / mantle layer orogen perpendicular

→ two layer anisotropy (at least).
→ more complex patterns cannot be resolved.

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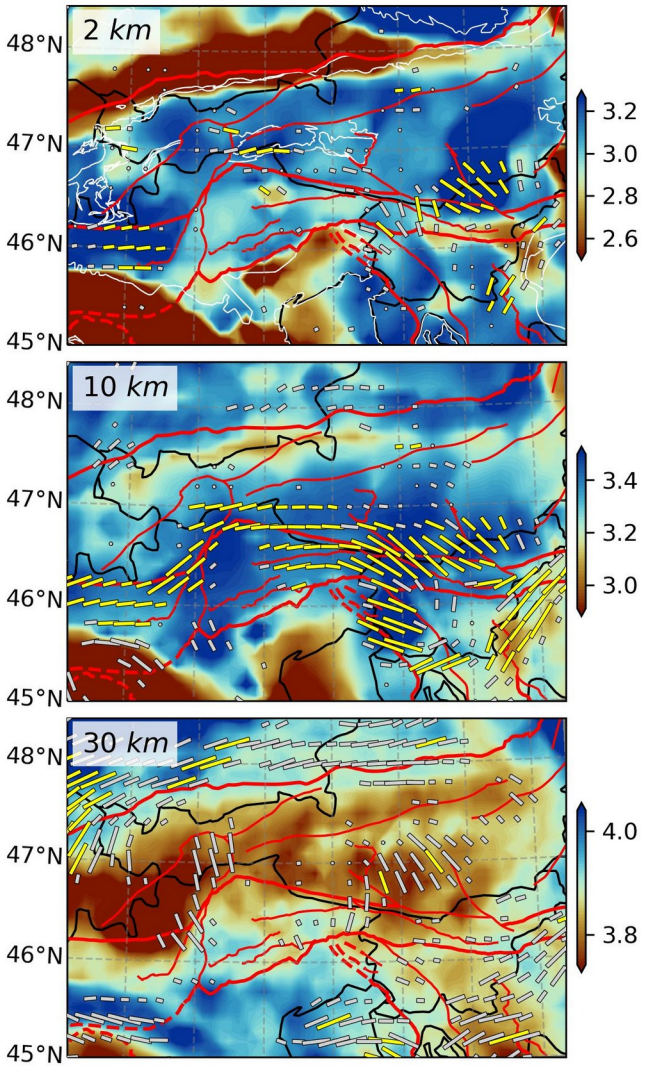
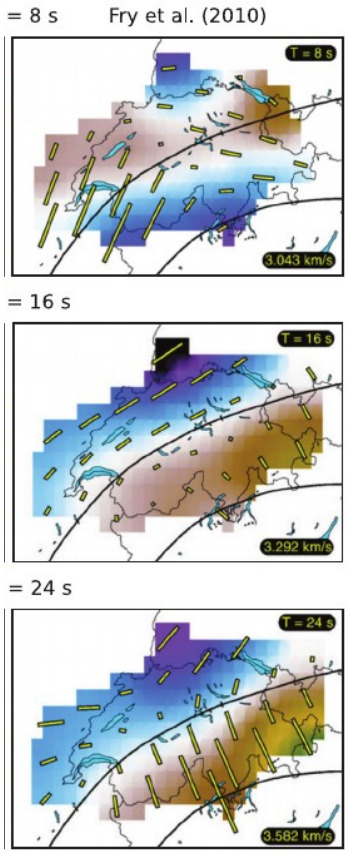
Comparison to previous works



Fry et al. 2010
(ambient noise,
linearized inversion)



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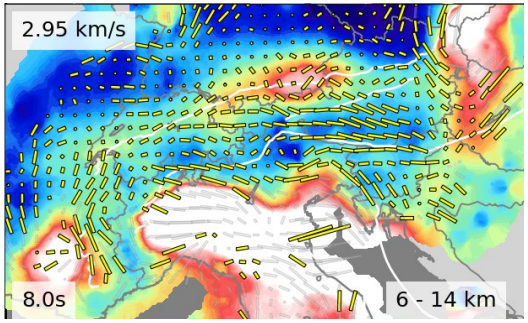

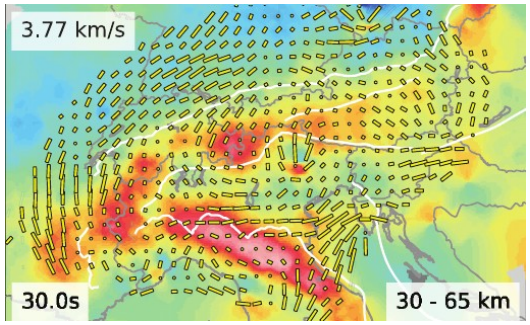

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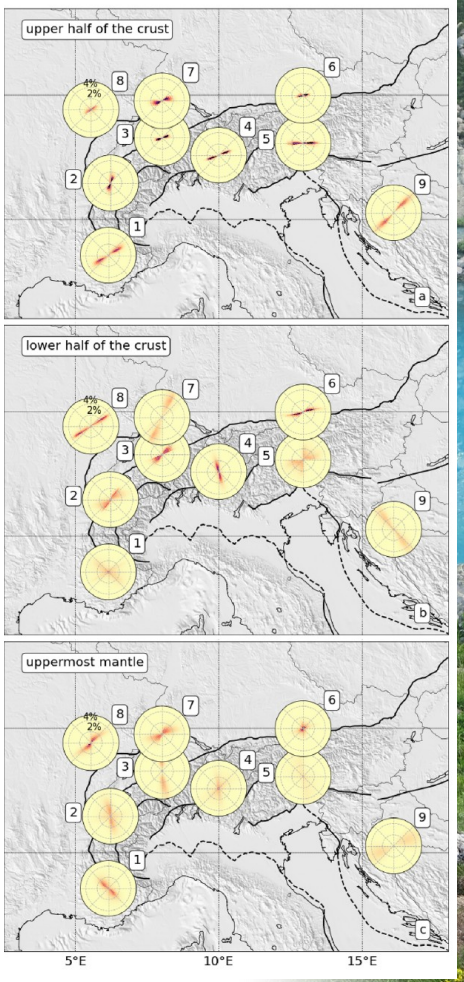

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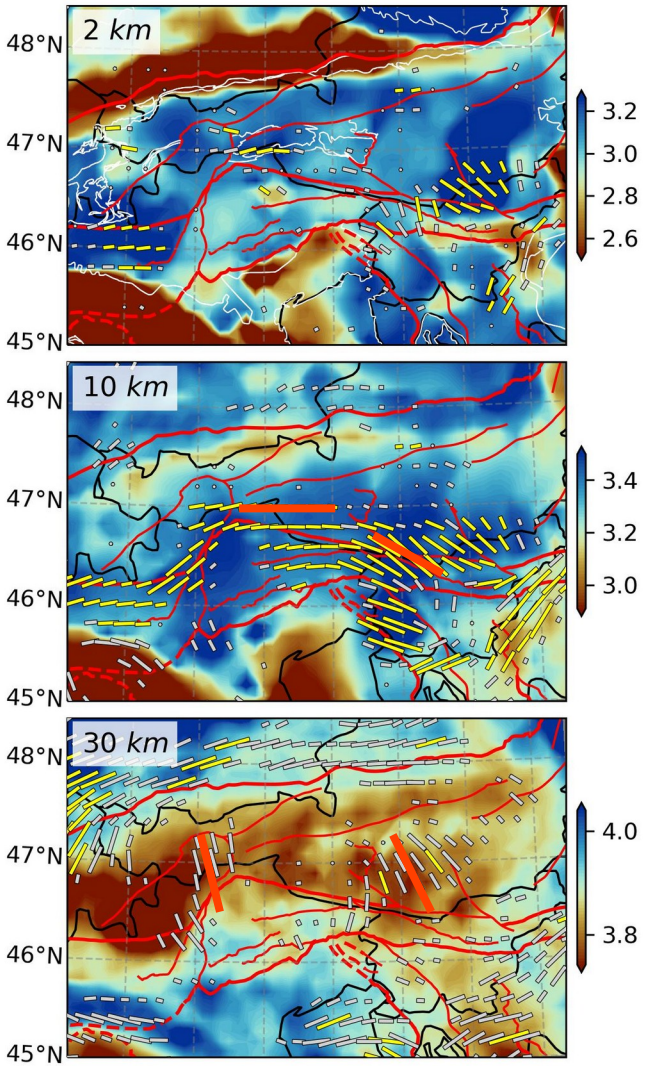

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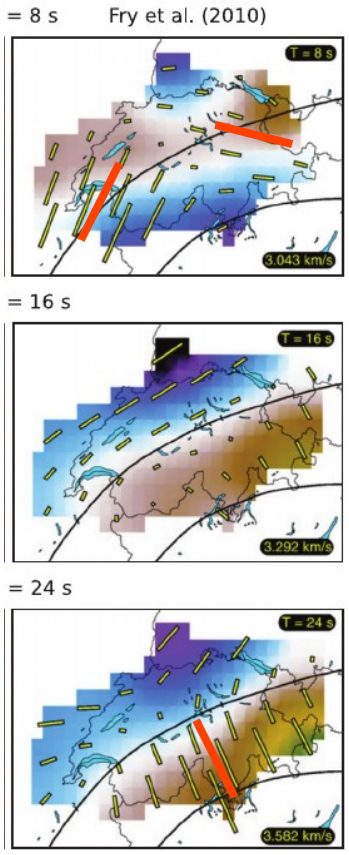

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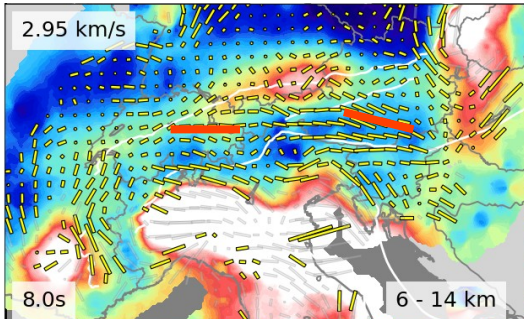

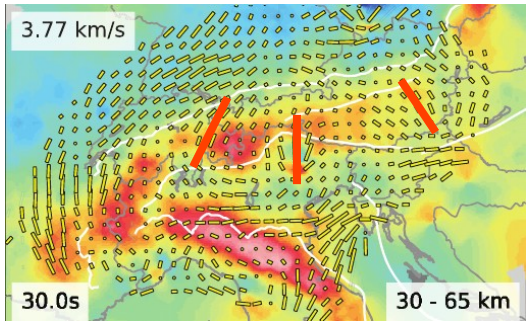

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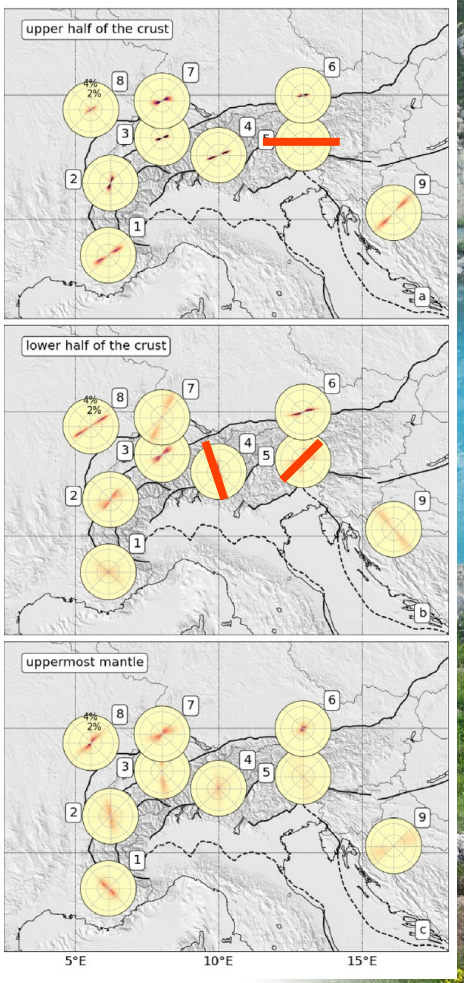

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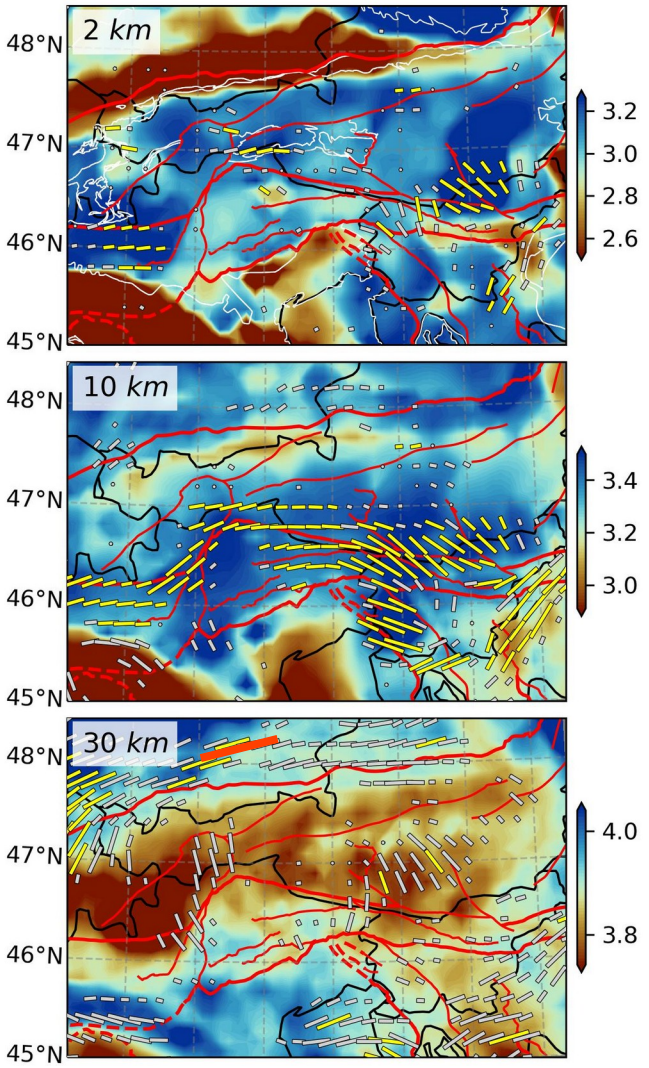

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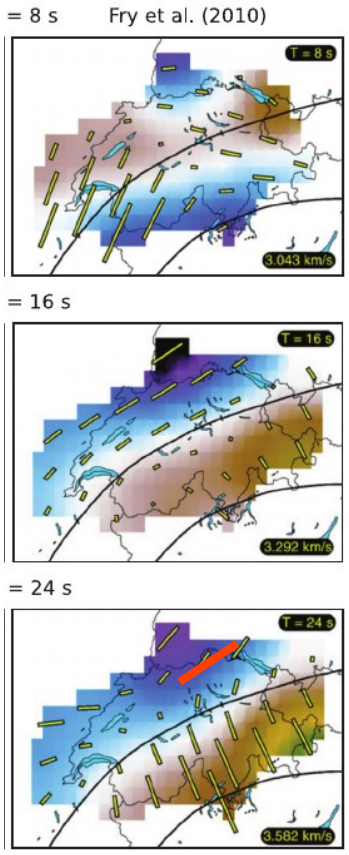

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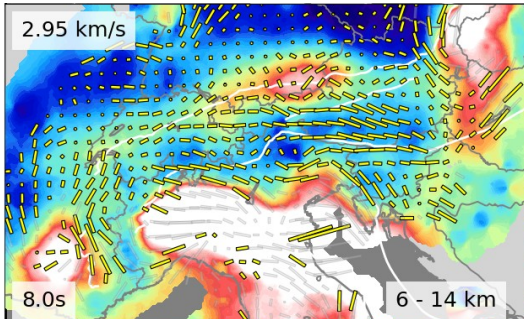

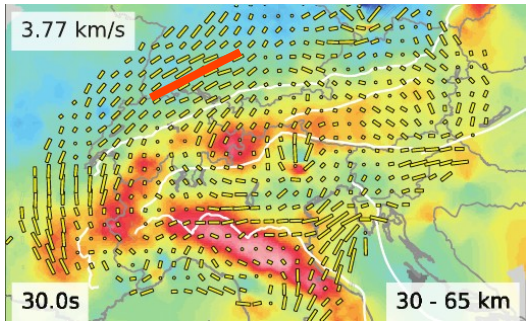

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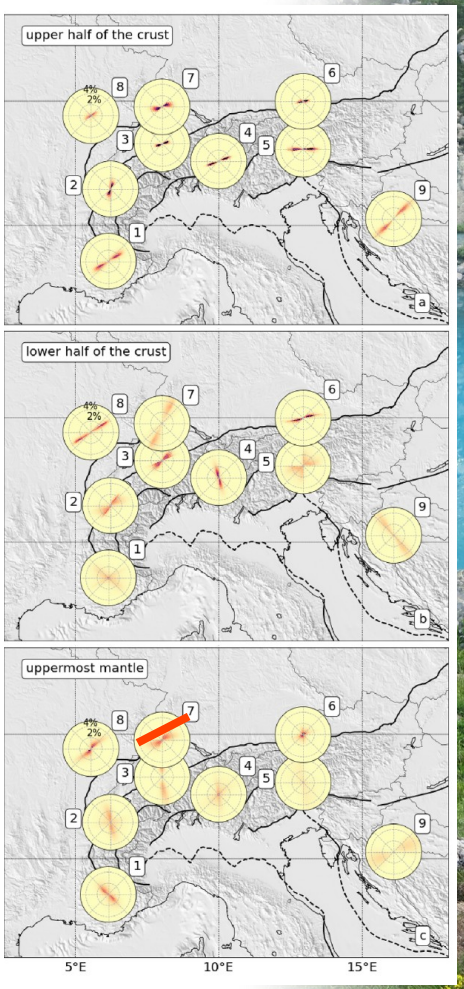

→ similar orientation as in SKS results

Sources of anisotropy

Intrinsic anisotropy

- Lattice-preferred orientation (LPO) / crystallographic preferred orientation (CPO) of minerals
- Fast axis typically parallel to main strain direction (olivine, amphibole, mica, ...)
- Some exceptions (e.g. pyroxene)

Apparent anisotropy

- Shape-preferred orientation (SPO) of grains
- (fluid filled) microcracks
- Layering
- Faults
- Foliation
- General: chemical & structural heterogeneities

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➢ For any effective anisotropic medium, a finely layered, purely isotropic counterpart can be found (Fichtner et al., 2013).

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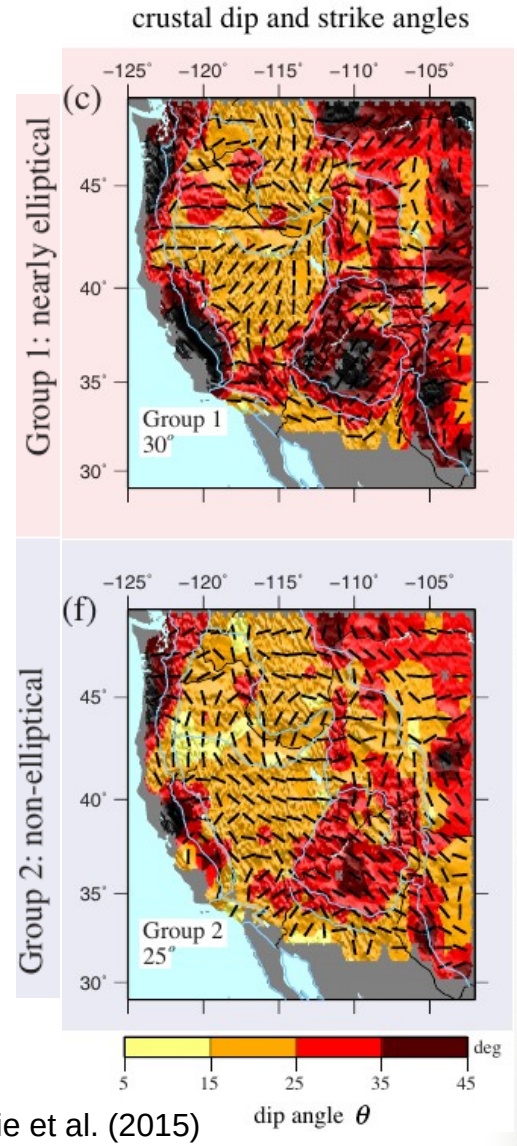
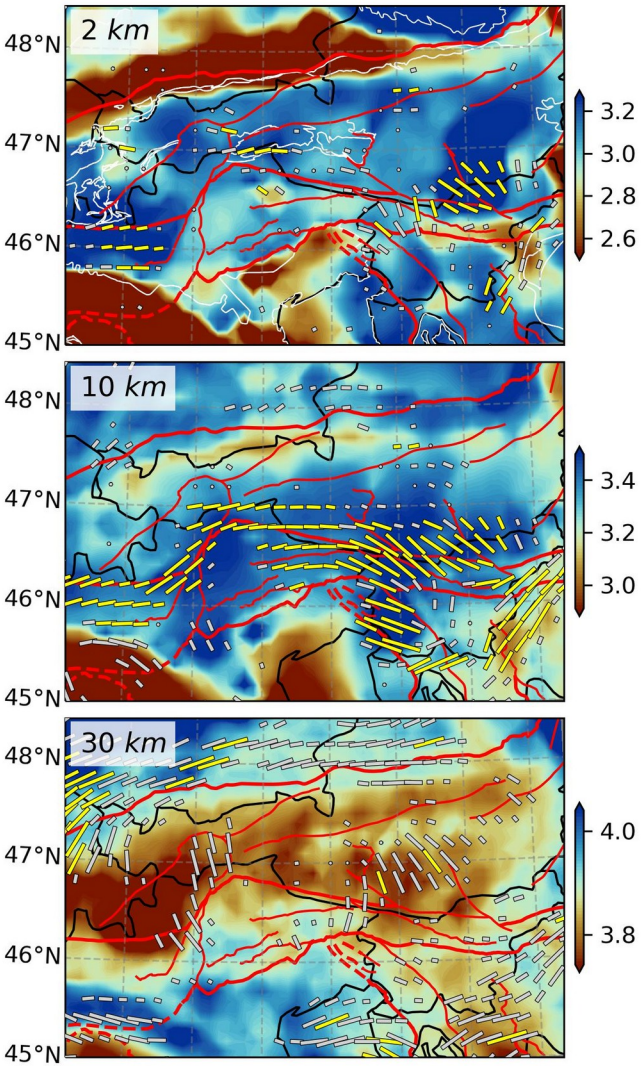
- For any effective anisotropic medium, a finely layered, purely isotropic counterpart can be found (Fichtner et al., 2013).
- 90° ambiguity for surface-wave anisotropy for some media (Xie et al., 2015).



Xie et al. (2015)

Conclusions



- At least two layers of anisotropy in the eastern Alps.
- Orogen parallel flow north of the Alps in the lowermost crust / uppermost mantle.
- Upper crustal anisotropy may be strain parallel (eastward extrusion).
- Anisotropy tends to align with the main fault structures.
- A combination of methods may be able to resolve some of the ambiguities (surface-waves and receiver functions).

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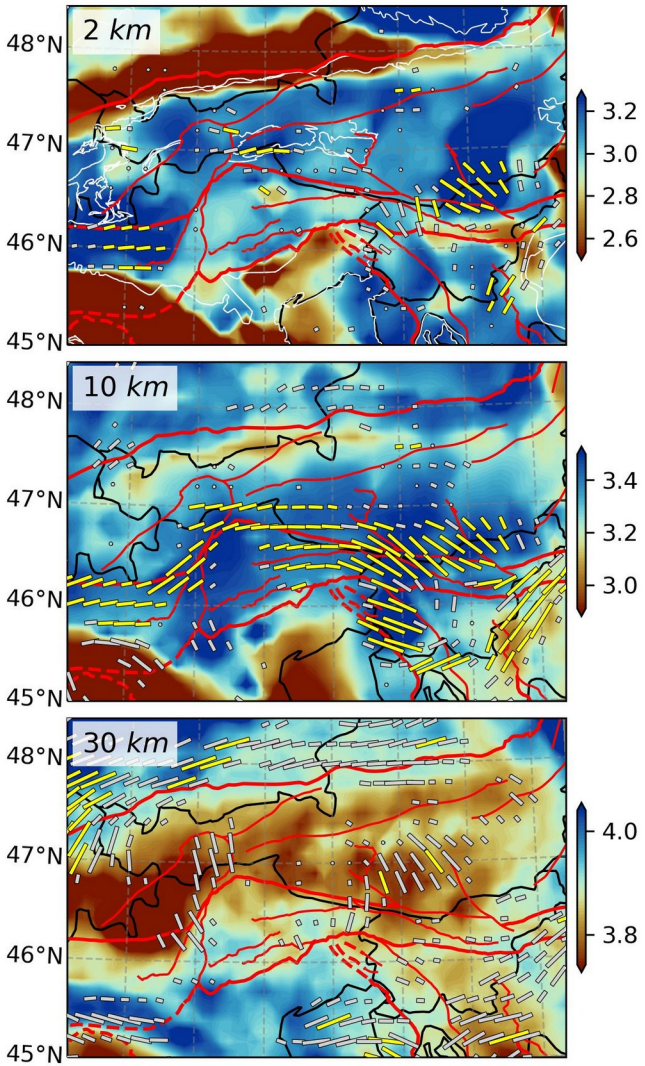

Thank you for your attention

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Anisotropic dispersion curve calculations:

https://github.com/ekaestle/pysurf96aa