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On the anisotropy of seismic waves in the Carpathian region

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Introduction

Seismic anisotropy: sign between Vsh and Vsv?

Love and Rayleigh dispersion curves cannot be satisfied by a single S-wave velocity-depth section:

Harkrider et al. 1962; Anderson 1966; Mitchell 1984; Nishimura and Forsyth 1989

Oceanic paths

Information was based mainly on data obtained along oceanic paths (Vsh>Vsv):

Forsyth, 1974; Schlue J. and Knopoff L., 1977; Yu G. and Mitchell B.J., 1979

PREM Model

A difference between SH and SV velocities resulted from radial anisotropy as a property of the Earth's material was included in the PREM model: Vsh>Vsv up to 220 km:

Dziewonski A.M. and Anderson D.L., 1981

Continental areas:

Asia:

Yanovskaya and Kozhevnikov 2006, Chen et al, 2009; Guo et al. 2012 and so on:

European region:

Shapiro and Ritzwoller, 2002; Kustowski et al., 2008; Chang et al., 2010; Schivardi and Morelli, 2011

Information on anisotropy under continental areas is extremely scarce Vsh>Vsv, Vsh<Vsv that is probably **due to significant variations in the structure of the crust and upper mantle** of the continents as compared to the oceanic areas.

Anisotropy coefficient

$$\alpha = (V_{SH}^2 - V_{SV}^2)/V_{SV}^2$$

Studying seismic anisotropy: what for?

It characterizes the properties of the Earth’s material, as well as the history of the tectonic structures and modern dynamic processes.

Surface Wave Tomography

Data in – $C(\varphi_i^{(1)}, \lambda_i^{(1)}, \varphi_i^{(2)}, \lambda_i^{(2)}; T_k)$ **Data out** – $V_S(\varphi, \lambda, z)$

Variational formula

For T_i and **r**(x,y)

$$\delta c(r,T) = \int_0^\infty G(z,T)\delta V_s(z,r)dz$$

$$V_s(z,r) = V_{s0}(z,r) + \delta V_s(z,r)$$

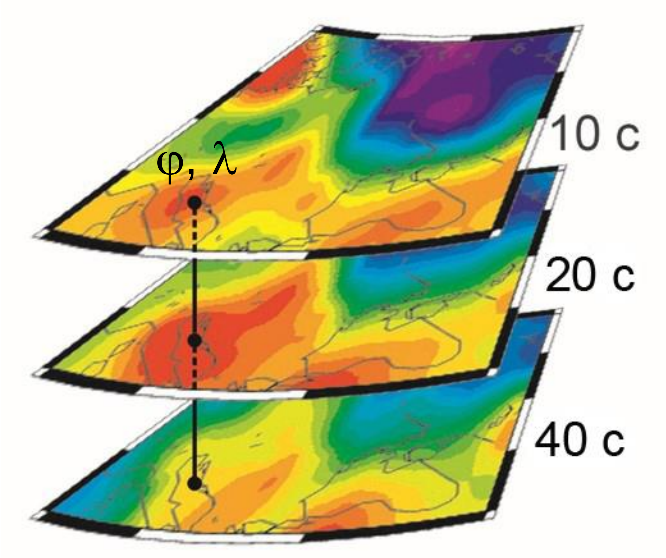
Traditional approach

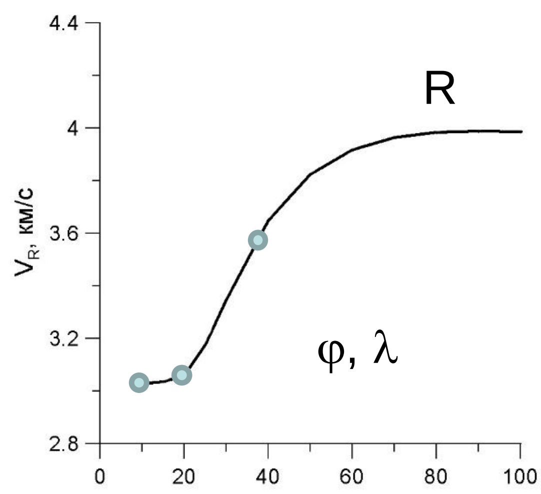
Data – $C(\varphi_i^{(1)},\lambda_i^{(1)},\varphi_i^{(2)},\lambda_i^{(2)};T_k)$ **need to be found** – $V_S(\varphi,\lambda,z)$

The 1st approach (traditional): **3D->2D+1D**

2D: $c(\varphi_i^{(1)},\lambda_i^{(1)},\varphi_i^{(2)},\lambda_i^{(2)};T_k)->c(\varphi,\lambda;T_k)$

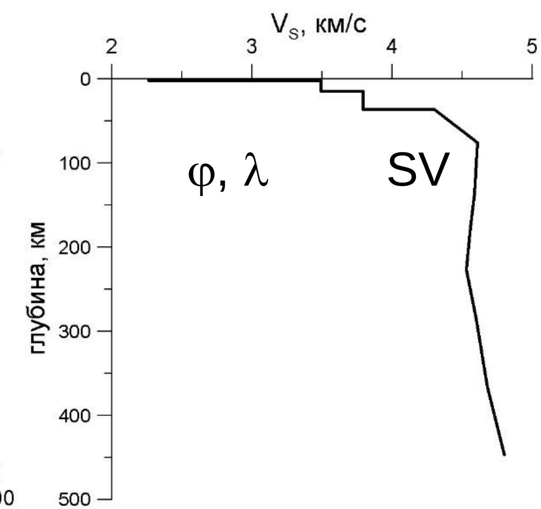
1D: $c(\varphi,\lambda;T_k)->V_S(\varphi,\lambda,z)$





local dispersion curve

local velocity section



$$C_R(\varphi_i^{(1)}, \lambda_i^{(1)}, \varphi_i^{(2)}, \lambda_i^{(2)}; T_k) \Longrightarrow V_{SV}(\varphi, \lambda, z)$$

$$C_L(\varphi_i^{(1)}, \lambda_i^{(1)}, \varphi_i^{(2)}, \lambda_i^{(2)}; T_k) \Longrightarrow V_{SH}(\varphi, \lambda, z)$$

$$\Longrightarrow \alpha(\varphi, \lambda, z)$$

Problems:

- Different number of traces for LQ and LR

$$\Downarrow$$

- Different **size** and **shape** of smoothing regions

$$\Downarrow$$

- Different **degree of smoothing** of velocity sections

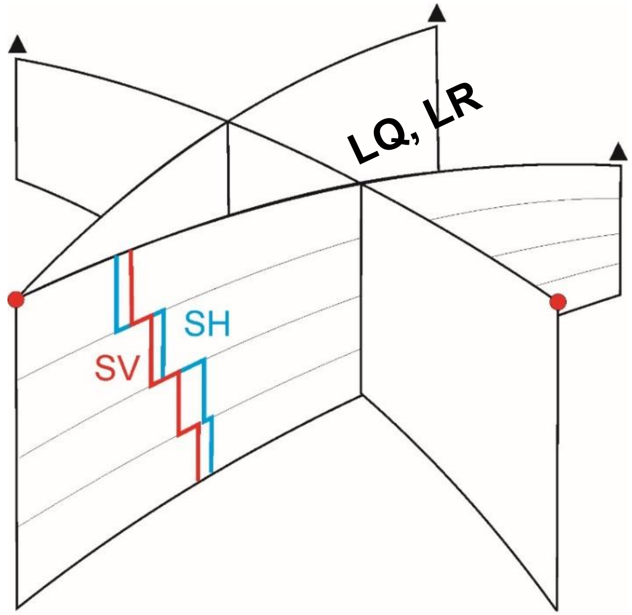
Ritzwoller, A.L. Levshin, J. Geophys. Res., **103**, 4839–4878 (1998)
Yanovskaya, L.M. Antonova, V.M. Kozhevnikov, Phys. Earth and Planet. Int., **122**,19–32 (2000)
Yanovskaya, V.M. Kozhevnikov, Phys. Earth and Planet. Int., **138**, 263–278 (2003)
Kozhevnikov, A.I. Seredkina, O.A. Solovei, Russ. Geol. Geophys., **55**, 1239-1247 (2014).
Yanovskaya, T. Koroleva, E. Lyskova, Geophys. J. Int., **205**, 1208–1220 (2016)
Seredkina, O.A. Solovei, Geodynamics & Tectonophysics, **9**(2), 427-437 (2018). and so on

An alternative approach:

3D->1D+2D

1D:

$$c(\varphi_i^{(1)},\lambda_i^{(1)},\varphi_i^{(2)},\lambda_i^{(2)};T_k) -> V_S(\varphi_i^{(1)},\lambda_i^{(1)},\varphi_i^{(2)},\lambda_i^{(2)};z)$$



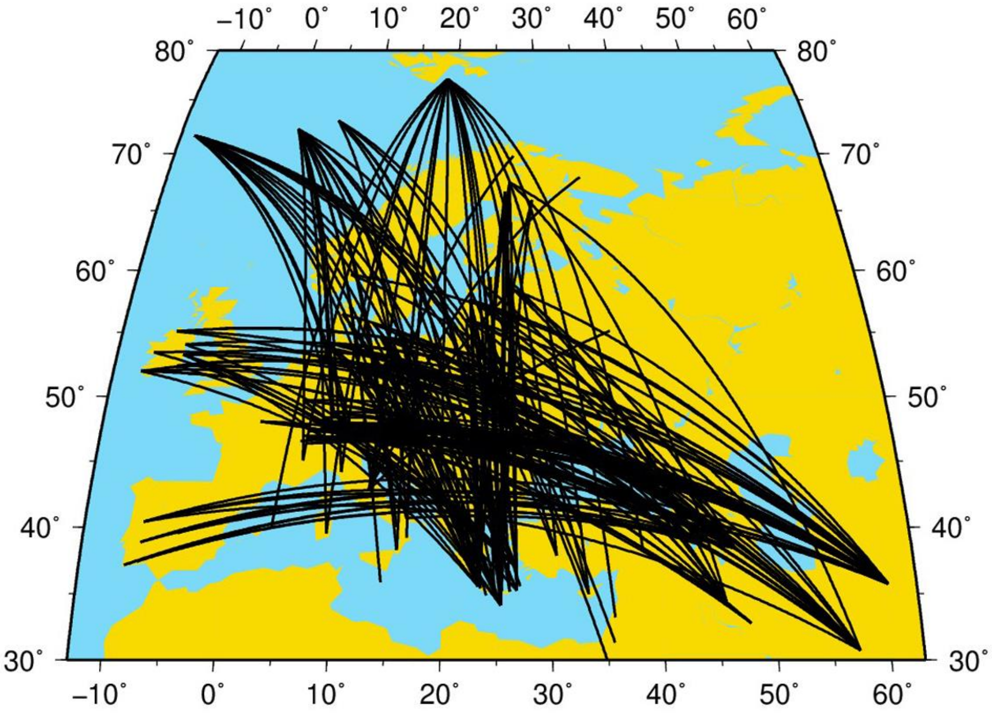
2D: At the 2nd stage the 2D tomographic technique is applied to the data of ‘path’ anisotropy coefficients at different depths

Yanovskaya et al., Izv. Phys. Solid Earth, 55(2), 195–204 (2019)

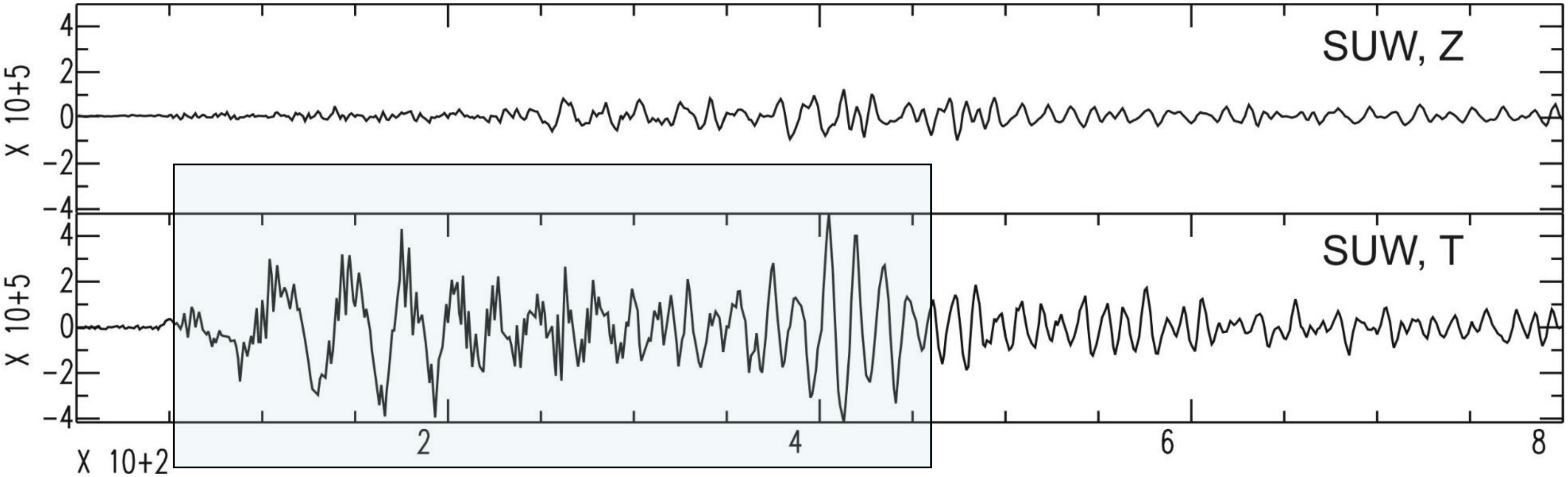
Data

Upper mantle: T=10 --100 sec --- long traces

Data centers: IRIS (https://www.iris.edu/hq) and GEOFON (https://geofon.gfz-potsdam.de), **LH-channel**

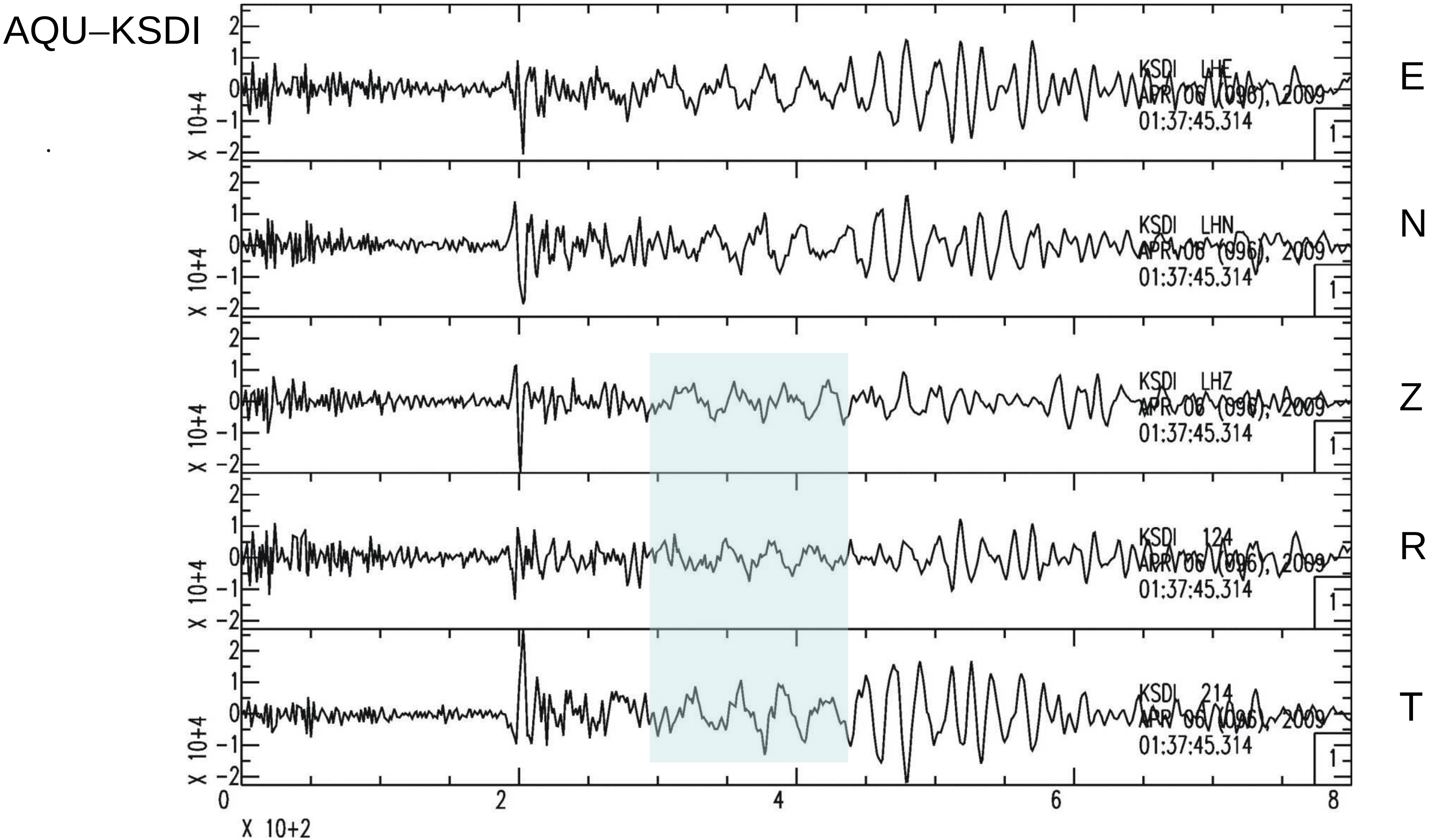


Focal mechanism

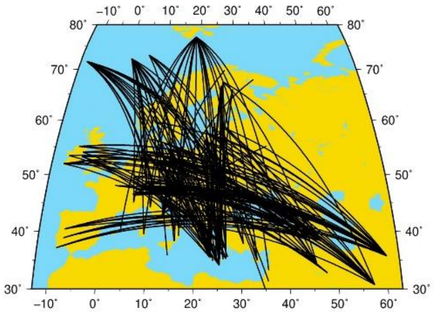


Earthquake in Turkey (12-11-1999, Mw7.2). At the SUW station (Poland) a strong Love wave (T-component) was recorded, while the Rayleigh wave (Z-component) turned out to be much weaker.

The closeness of the Love and Rayleigh wave velocities can be additionally aggravated by the fact that these waves arrive at the station along different paths.



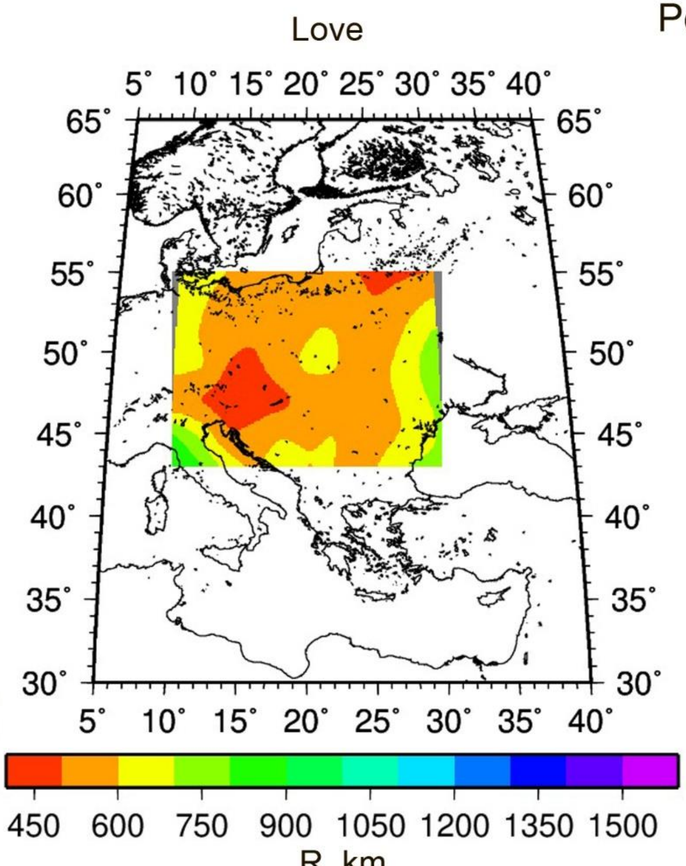
This effect can be eliminated using polarization analysis.

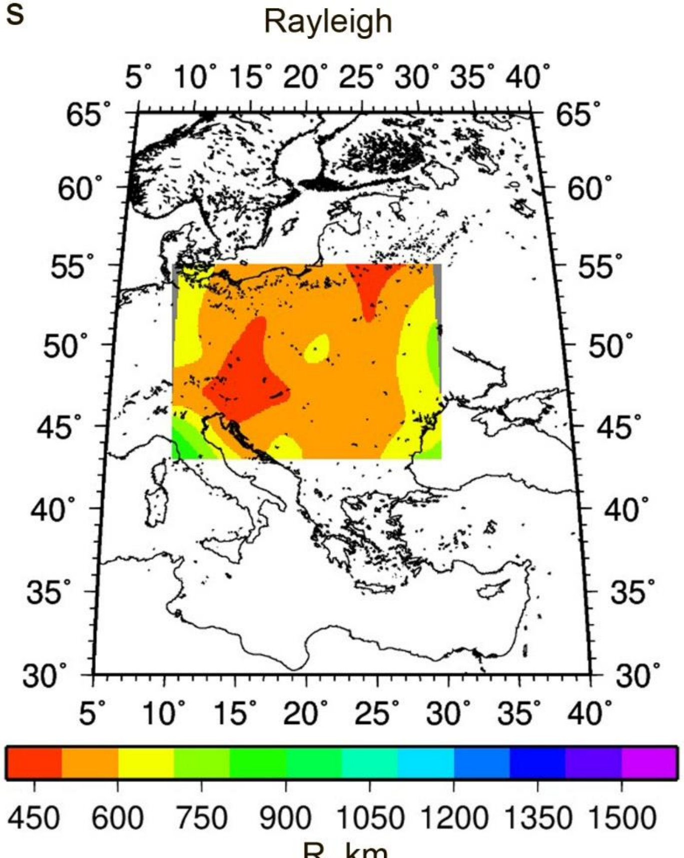


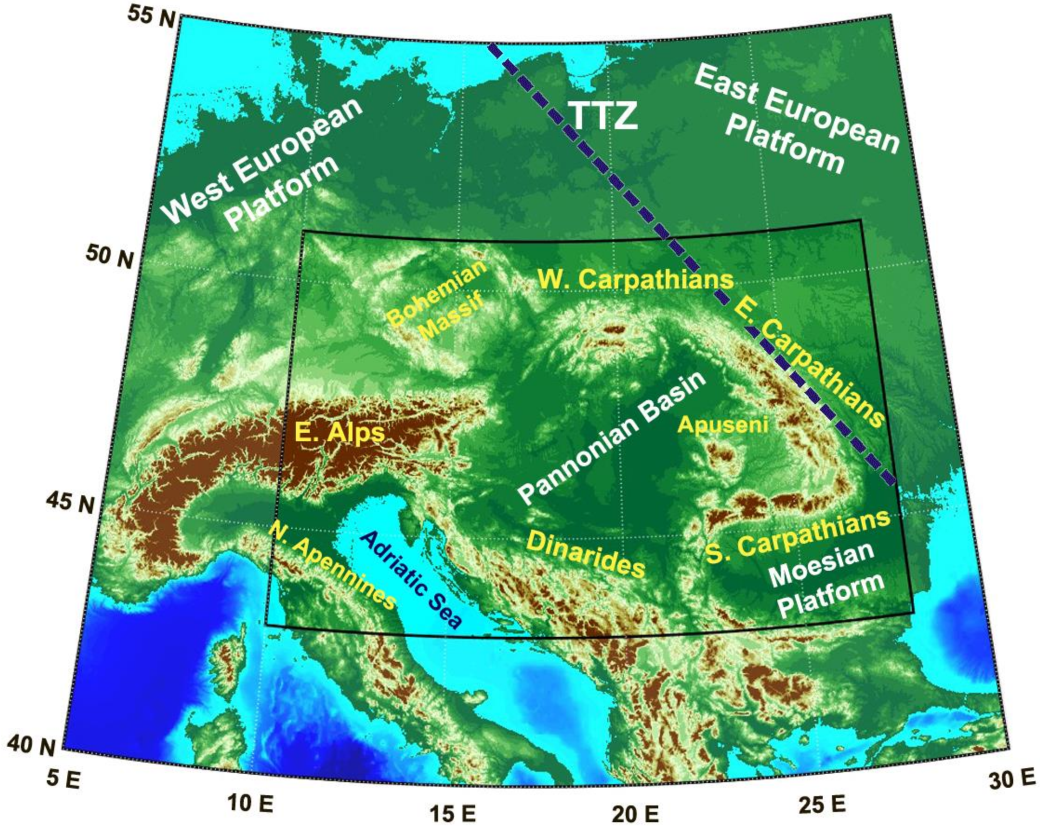
T.B. Yanovskaya, P.G. Ditmar, Geophys. J. Int., **102**(1), 63–72 (1990)

Distribution of the radius R of the effective smoothing area

Period 60 s

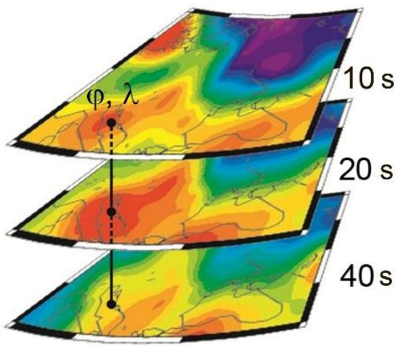


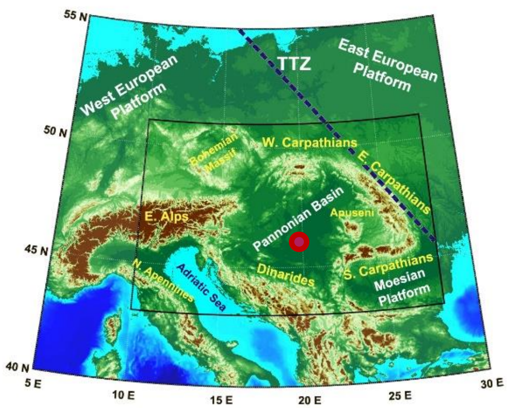


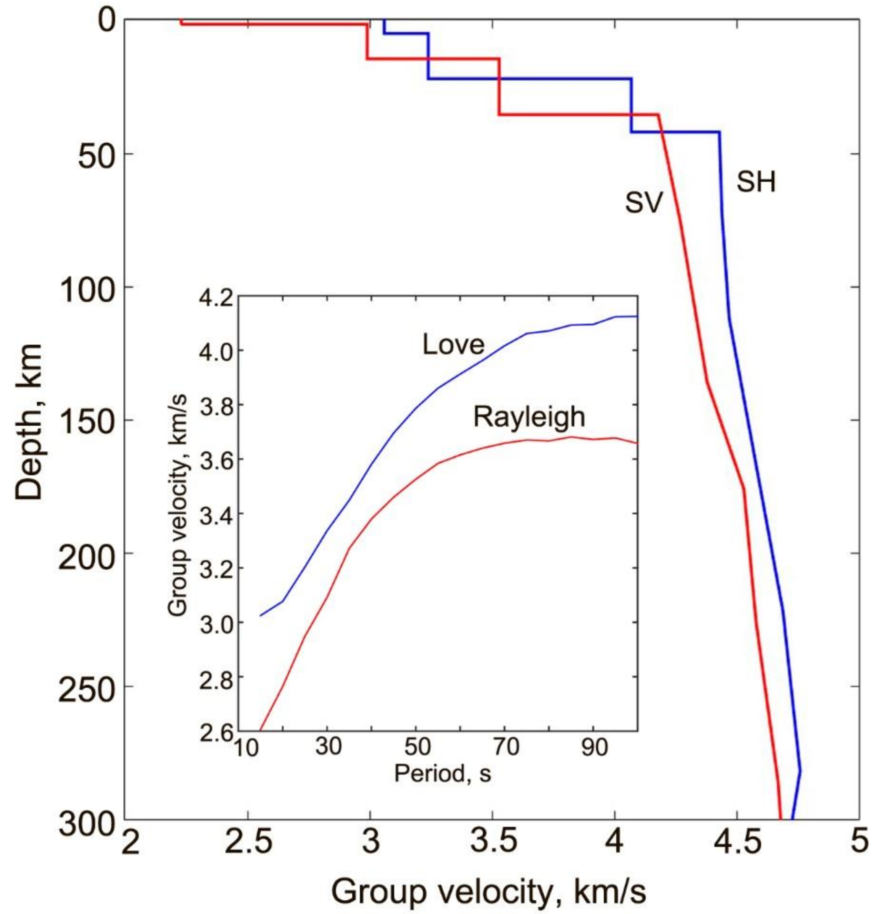


Topographic map of the Carpathian–Pannonian system with surface structural features. Area of the acceptable resolution is delineated by black. Tornquist–Teisseyre Zone (TTZ) is marked by blue dashed line.

An example of inversion of a group velocity dispersion curves to local velocity sections at the point ϕ = 46°N, λ = 20°E in the Pannonian Basin

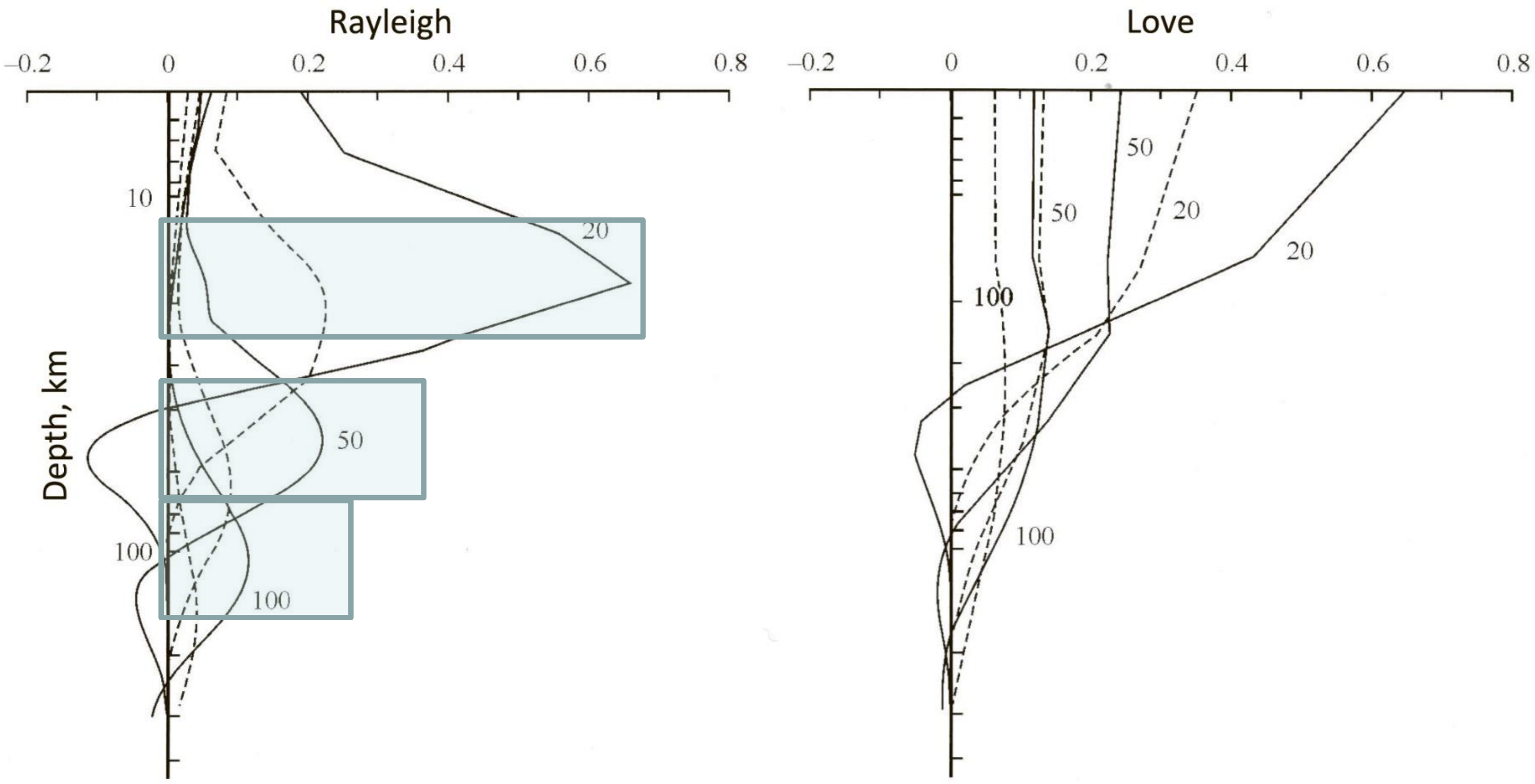




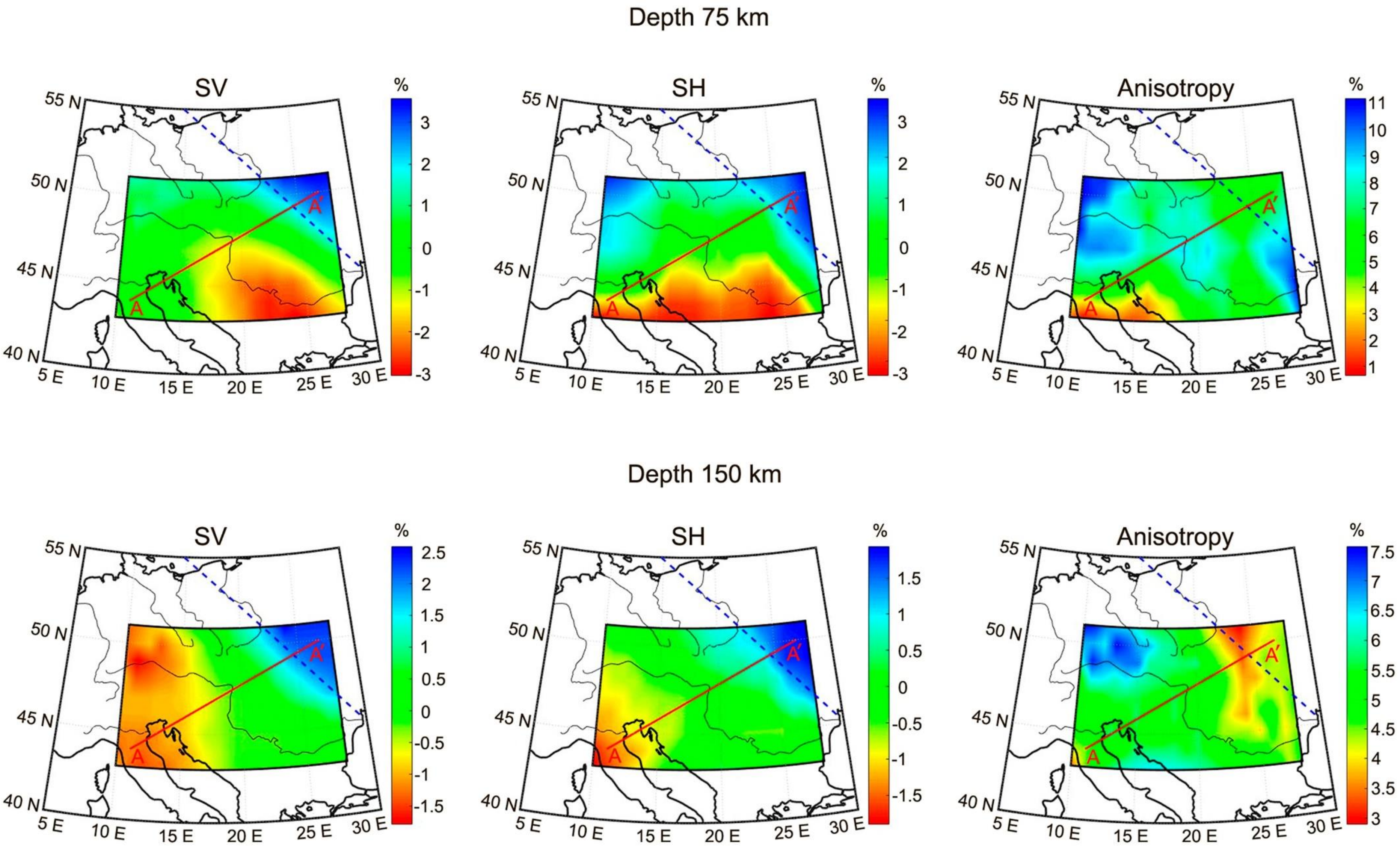


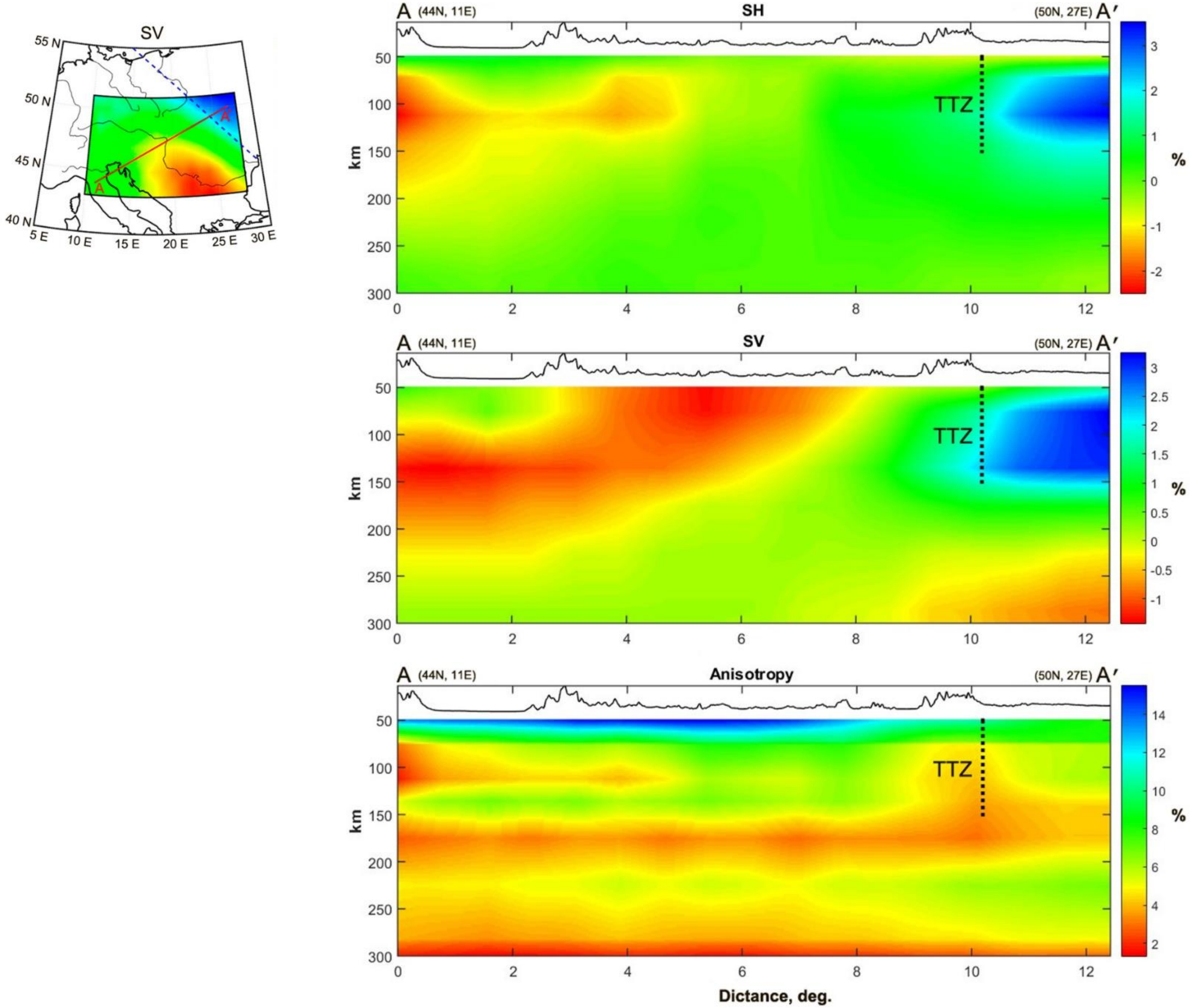
T.B. Yanovskaya, Poverkhnostno-volnovaya tomografiya v seysmicheskikh issledovaniyakh (Surface Wave Tomography in Seismic Studies) (Nauka, St.-Petersburg, 2015)

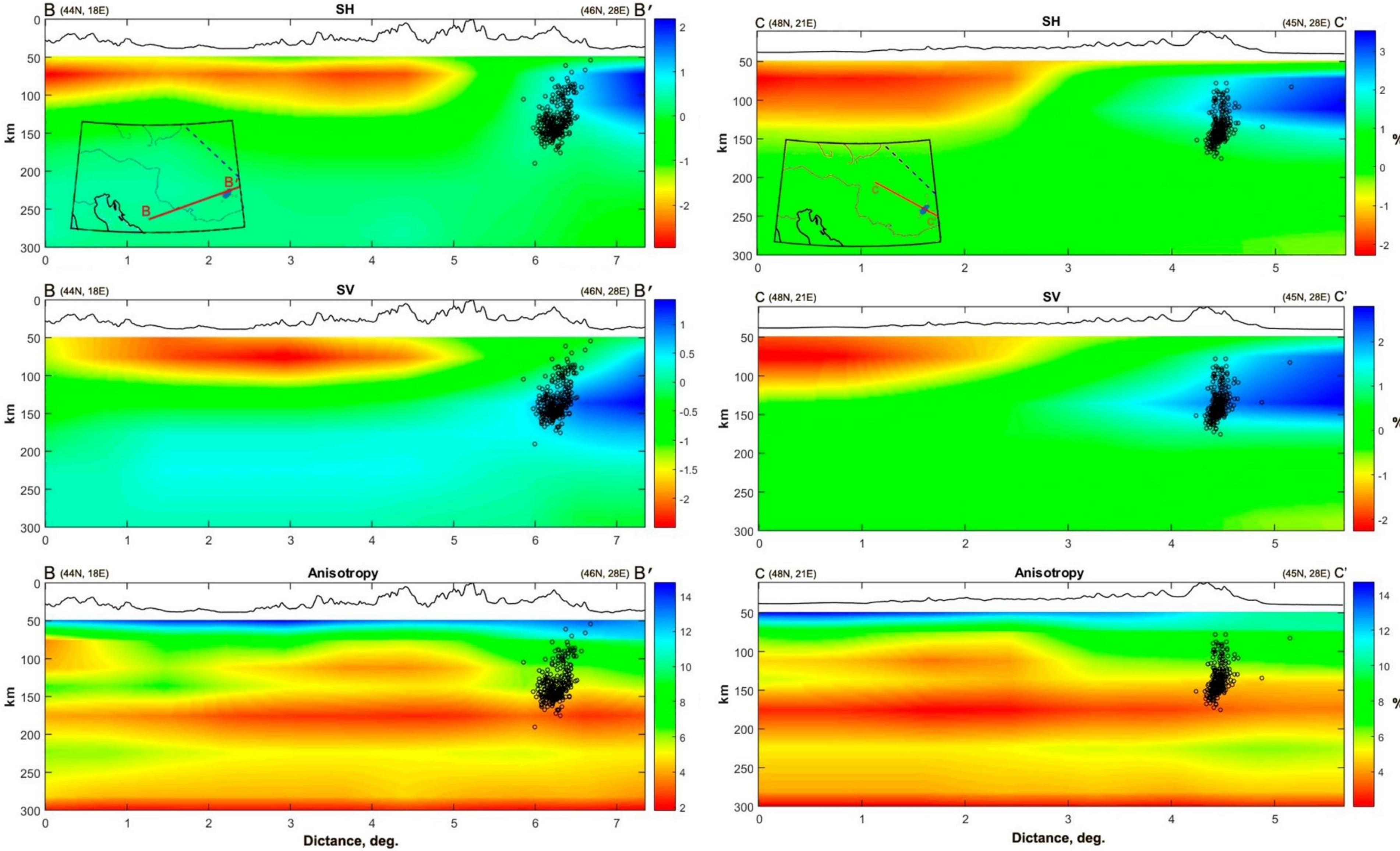
Sensitivity functions of dispersion curves to velocity section



Variations of SV- and SH-wave velocities and anisotropy coefficient distributions at depths 75 and 150 km in the mantle




SV
55 N
50 N
45 N
40 N
5 E
10 E
15 E
20 E
25 E
30 E
A
A'
A (44N, 11E)
SH
(50N, 27E) A′
km
TTZ
%
A (44N, 11E)
SV
(50N, 27E) A′
km
TTZ
%
A (44N, 11E)
Anisotropy
(50N, 27E) A′
km
TTZ
%
Dictance, deg.


B (44N, 18E)
SH
(46N, 28E) B′
C (48N, 21E)
SH
(45N, 28E) C'
SV
Anisotropy
km
%
Dictance, deg.

Conclusion

The results obtained confirm that the **Tornquist-Teisseyre Zone** divides the structures of the ancient East European Platform and orogenic zones of Western Europe: the upper mantle throughout EEP is characterized by high velocities, whereas velocities throughout WE are markedly lower
Yanovskaya et al., Geophys. J. Int., 205, 1208–1220 (2016)

According to the research results [**Dando et al, Geophys. J. Int., 186, 11–31 (2011); Ren et al., Earth planet. Sci. Lett., 349–350, 139–152 (2012)**], one should expect that in the rear of the Eastern Carpathians, low velocities should prevail in comparison with higher velocities in the north east of the arc. Low velocity anomalies prevail under **Pannonian Basin** and Transylvania. The Pannonian Basin, according to [**Tari et al., Geological Society of London, 156, 215–250 (1999)**], is characterized by anomalously high heat flow values.

The distribution of the anisotropy coefficient shown on the vertical sections along the AA', BB' and CC' profiles demonstrates an extended layer of low values of the anisotropy coefficient at depths 150–200 km. Above this layer, velocity distributions reveal the block structure of the lithosphere. This circumstance allows us to conclude that this layer is close in its properties to the asthenosphere – for the asthenosphere the difference in the values of SH- and SV-wave velocities should decrease, and hence the anisotropy coefficient will also decrease.

As noted above, earthquake sources in the Vrancea zone fall into the transition zone from the high-velocity mantle under the EEP to the low-velocity mantle under the WE. From vertical sections it follows that below the layer at a depth of 150-200 km, which we consider as asthenospheric, earthquakes do not occur.