Inversion of P-wave multiazimuthal VSP data for local anisotropy

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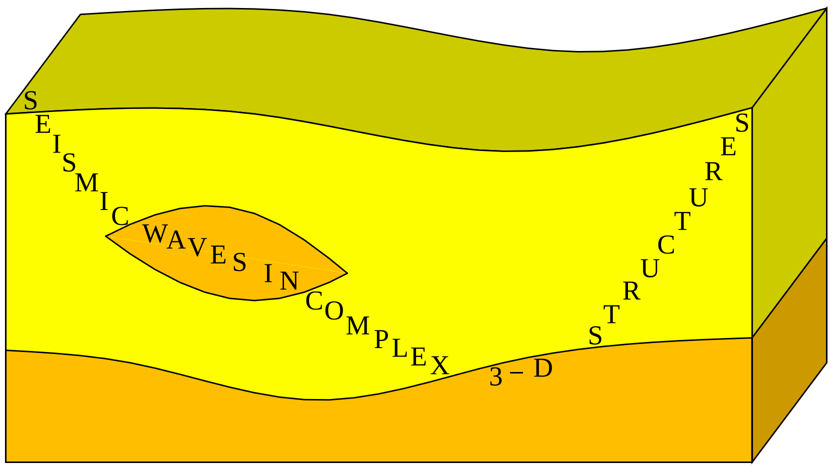


Outline:

Motivation

Algorithm

Results of numerical experiments

Plans

Conclusions

Motivation

- estimate of limits of the method based on P waves

Goals

- study of the dependence on

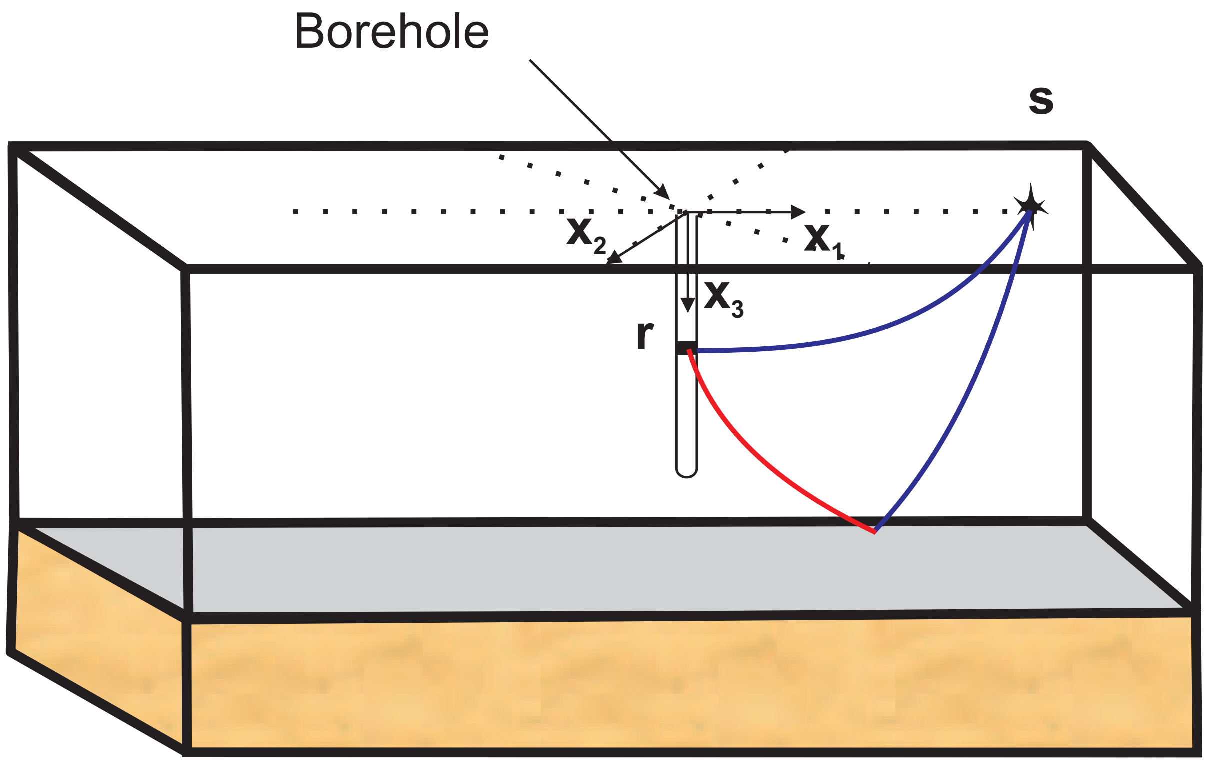
  the number and distribution of profiles
  with sources

  the number of used waves

  the level of the noise

Algorithm

Configuration



Algorithm

Data

- z-component of slowness vector and polarization vector of a P wave

computed by ANRAY in the borehole and generated along surface profiles

Inversion formula

Perturbation formula relating data to WA parameters

for each source-receiver pair $(D = \sqrt{n_1^2 + n_2^2})$

$$(\alpha^2 - \beta^2)^{-1} B_{13}(\epsilon) D - \frac{1}{2}\alpha^{-2} B_{33}(\epsilon) n_3 + \frac{1}{2} n_3 = D e_i^{(1)} g_i + \alpha \Delta\eta$$

Algorithm

Known quantities

α, β P- and S-wave reference velocities

For each source-receiver pair:

$\mathbf{n}$ unit vector parallel to reference slowness vector

$\mathbf{e}^{(1)}$ unit vector perpendicular to $\mathbf{n}$, situated in vertical plane

$\Delta\eta$ $z-$ component of difference of observed and reference slowness vector

$\mathbf{g}$ observed polarization vector

Sought quantities

ϵ 15 P-wave WA parameters linearly combined in $B_{mn} = B_{mn}(\epsilon)$

$\mathbf{B}$ weak-anisotropy matrix

Algorithm

Determination of reference quantities

reference medium (α, β): $\alpha p_z = g_z$ (LSQ for all sources)

$$\beta^2 = \alpha^2/3$$

direction $\mathbf{n} \parallel \mathbf{p}$: $\mathbf{n} = \mathbf{g} \quad \Rightarrow \quad \mathbf{g} \cdot \mathbf{e}^{(1)} = 0$

Determination of WA parameters

LSQ of system of perturbation formulae for each source

Algorithm

Numerical experiments

- **p** and **g** generated by ANRAY
- upto 5 profiles with 18 sources upto 0.9 km
  symmetrically wrt borehole
- receivers in the borehole between 0.1 and 0.7 km
- random noise separately on **p** and **g**,
  separately on down- and upgoing waves
- maximum standard deviation specified
- generation of 100 sets of noisy data to be inverted

Algorithm

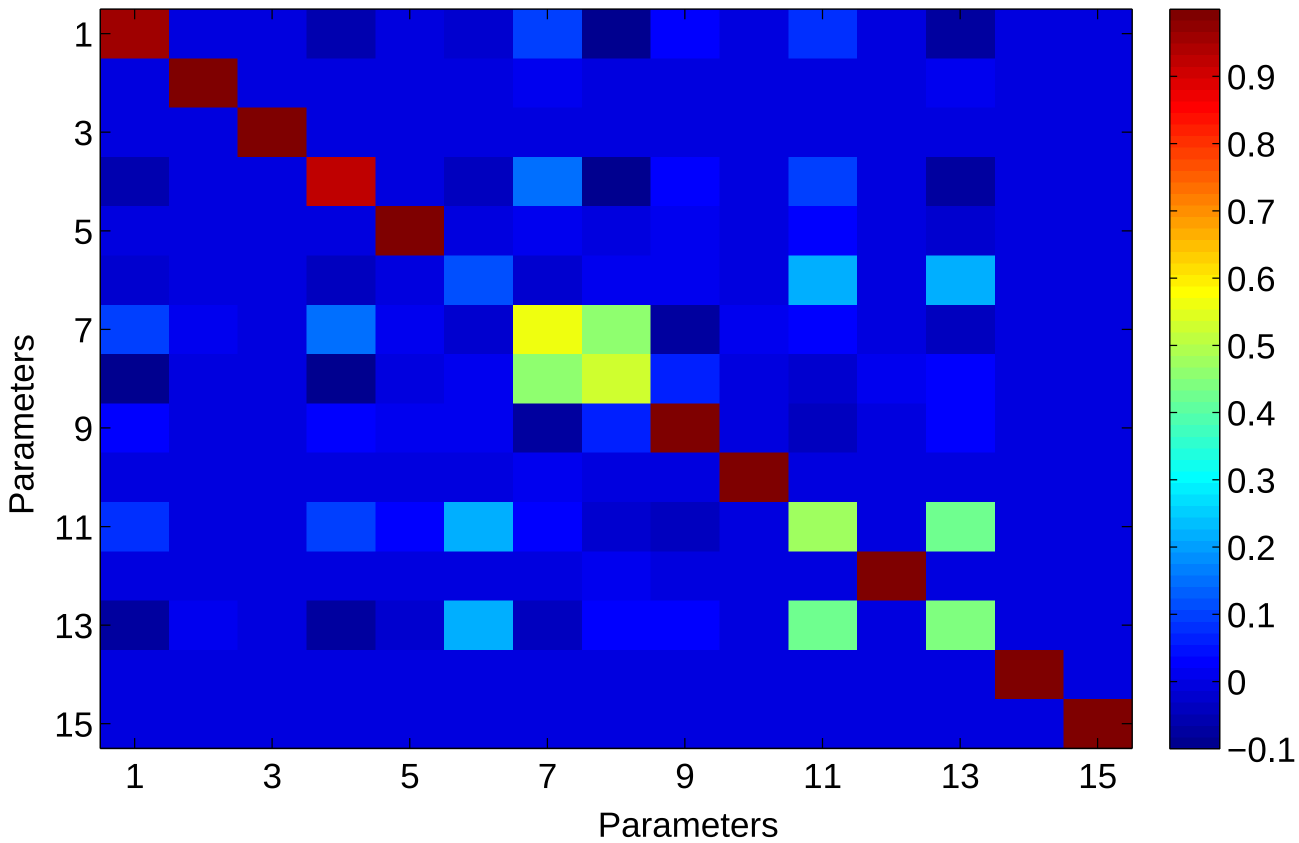
WA parameters

$$1 = \epsilon_x, \quad 2 = \epsilon_y, \quad 3 = \epsilon_z, \quad 4 = \delta_x, \quad 5 = \delta_y, \quad 6 = \delta_z,$$
$$7 = \chi_x, \quad 8 = \chi_y, \quad 9 = \chi_z, \quad 10 = \epsilon_{15}, \quad 11 = \epsilon_{16}, \quad 12 = \epsilon_{24},$$
$$13 = \epsilon_{26}, \quad 14 = \epsilon_{34}, \quad 15 = \epsilon_{35}$$

$$\epsilon_x = \frac{A_{11}-\alpha^2}{2\alpha^2}, \quad \epsilon_y = \frac{A_{22}-\alpha^2}{2\alpha^2}, \quad \epsilon_z = \frac{A_{33}-\alpha^2}{2\alpha^2},$$
$$\delta_x = \frac{A_{13}+2A_{55}-\alpha^2}{\alpha^2}, \quad \delta_y = \frac{A_{23}+2A_{44}-\alpha^2}{\alpha^2}, \quad \delta_z = \frac{A_{12}+2A_{66}-\alpha^2}{\alpha^2},$$
$$\chi_x = \frac{A_{14}+2A_{56}}{\alpha^2}, \quad \chi_y = \frac{A_{25}+2A_{46}}{\alpha^2}, \quad \chi_z = \frac{A_{36}+2A_{45}}{\alpha^2}$$

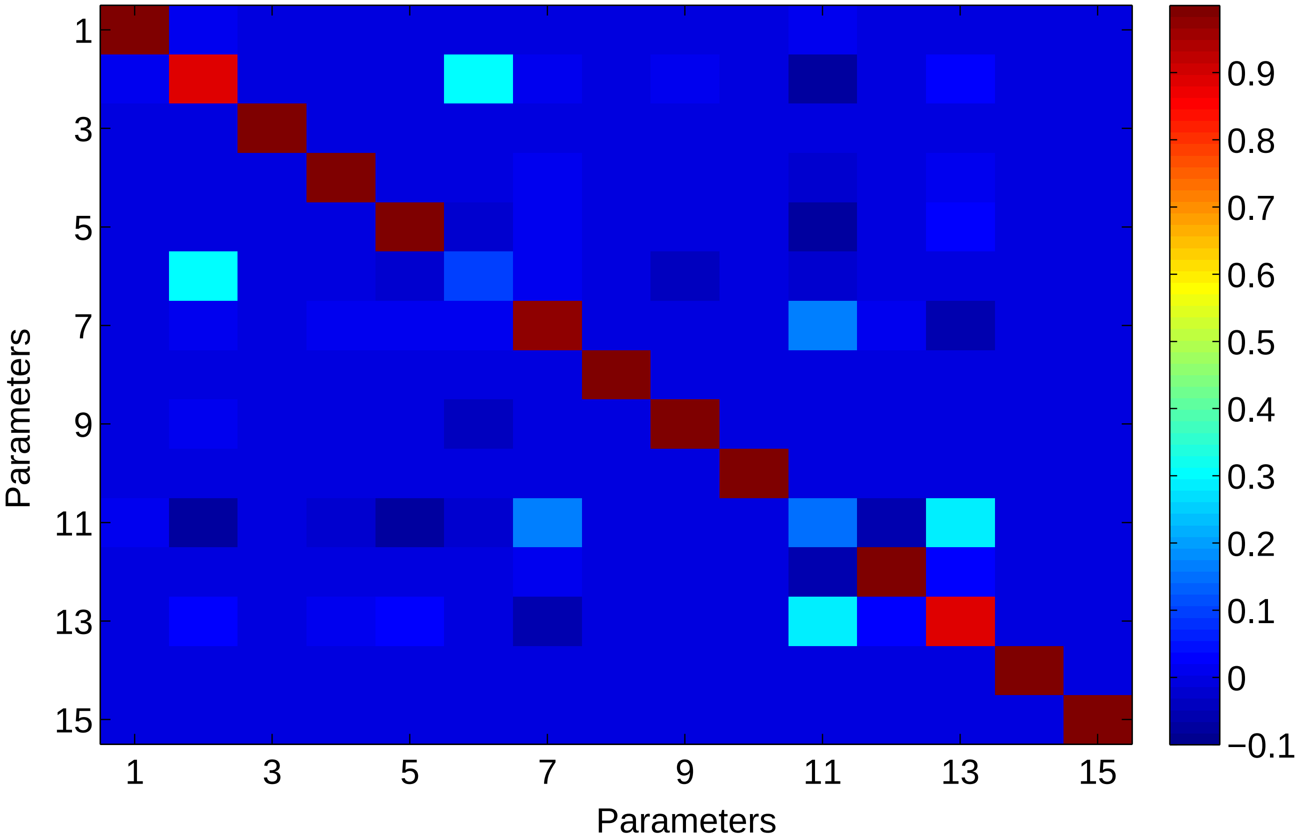
Results of numerical experiments

Resolution matrix for 3 profiles $0^0, 45^0, 90^0$



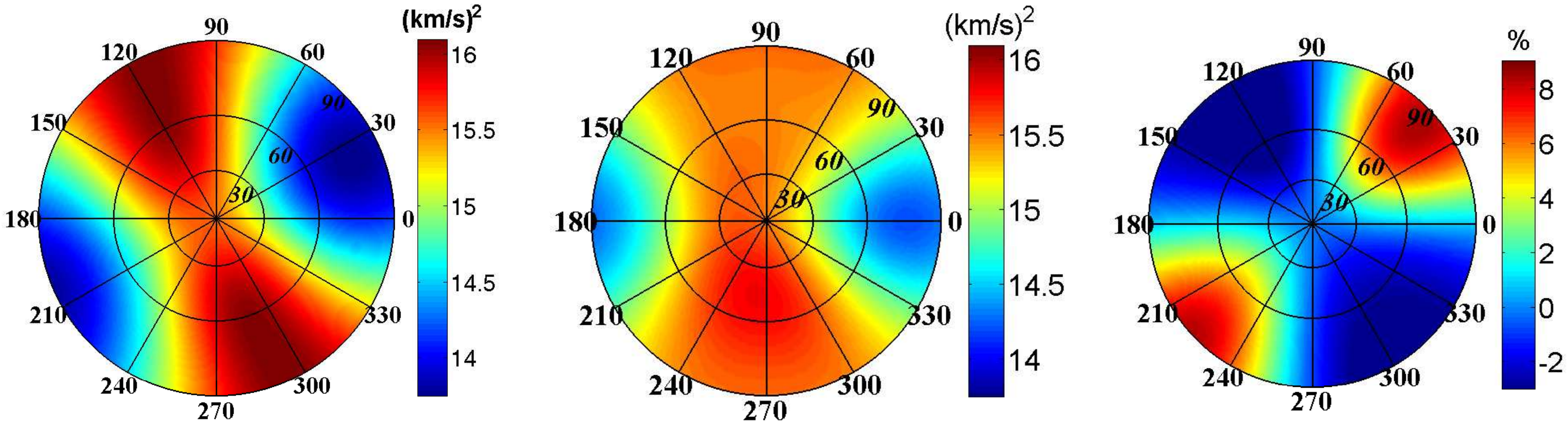
Results of numerical experiments

Resolution matrix for 3 profiles $0^0, 60^0, 120^0$



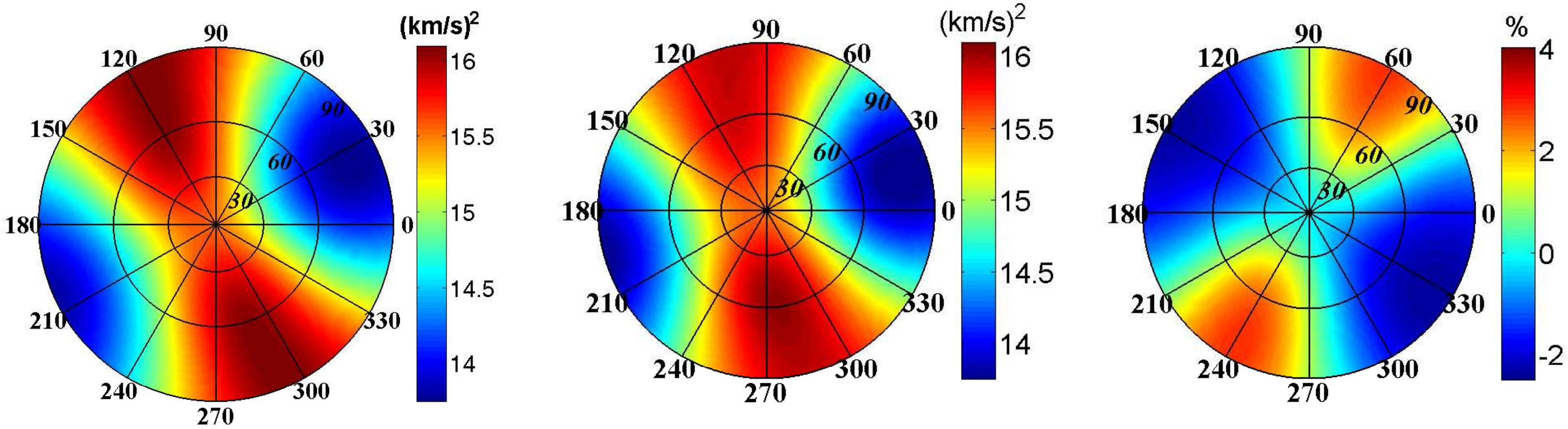
Results of numerical experiments

Squares of phase velocity with exact and inverted (left and middle) WA parameters; relative difference (right); rec. 0.1 km; two profiles: 0^0, 90^0



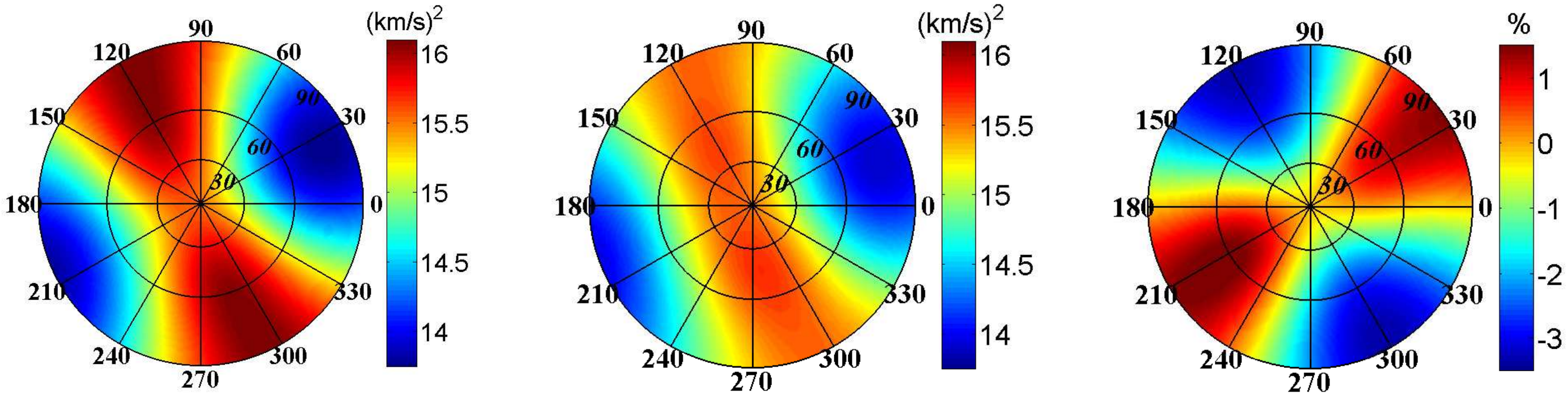
Results of numerical experiments

Squares of phase velocity with exact and inverted (left and middle) WA parameters; relative difference (right); rec. 0.1km; four profiles: 0^0, 45^0, 90^0, 135^0



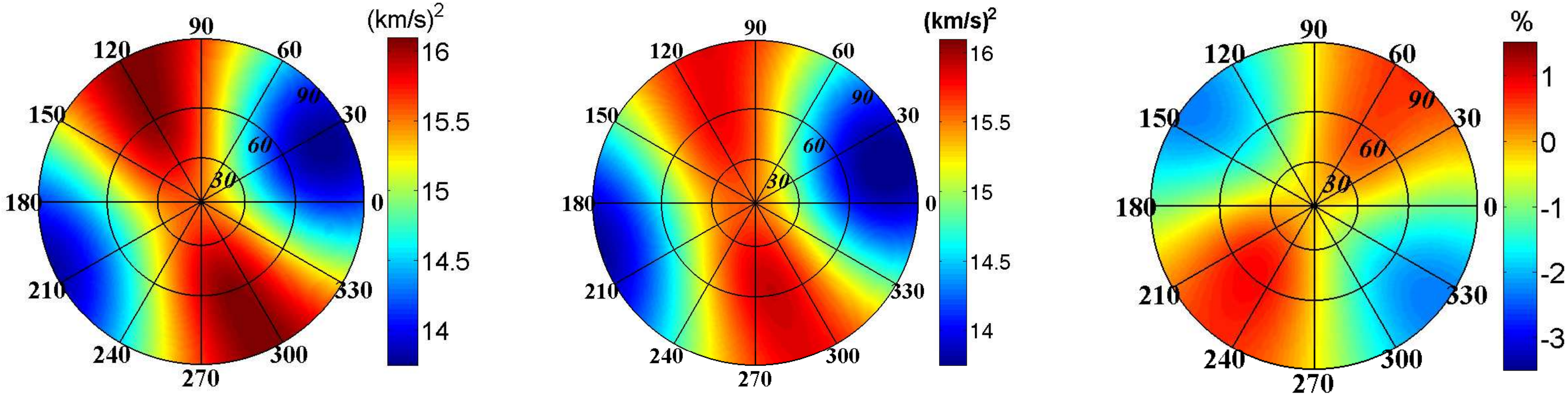
Results of numerical experiments

Squares of phase velocity with exact and inverted (left and middle) WA parameters; relative difference (right); rec. 0.1 km; five profiles: 0^0, 30^0, 60^0, 120^0, 150^0



Results of numerical experiments

Squares of phase velocity with exact and inverted (left and middle) WA parameters; relative difference (right); rec. 0.1 km; five profiles: 0^0, 72^0, 144^0, 216^0, 288^0



Results of numerical experiments

Effects of noise (downgoing wave)

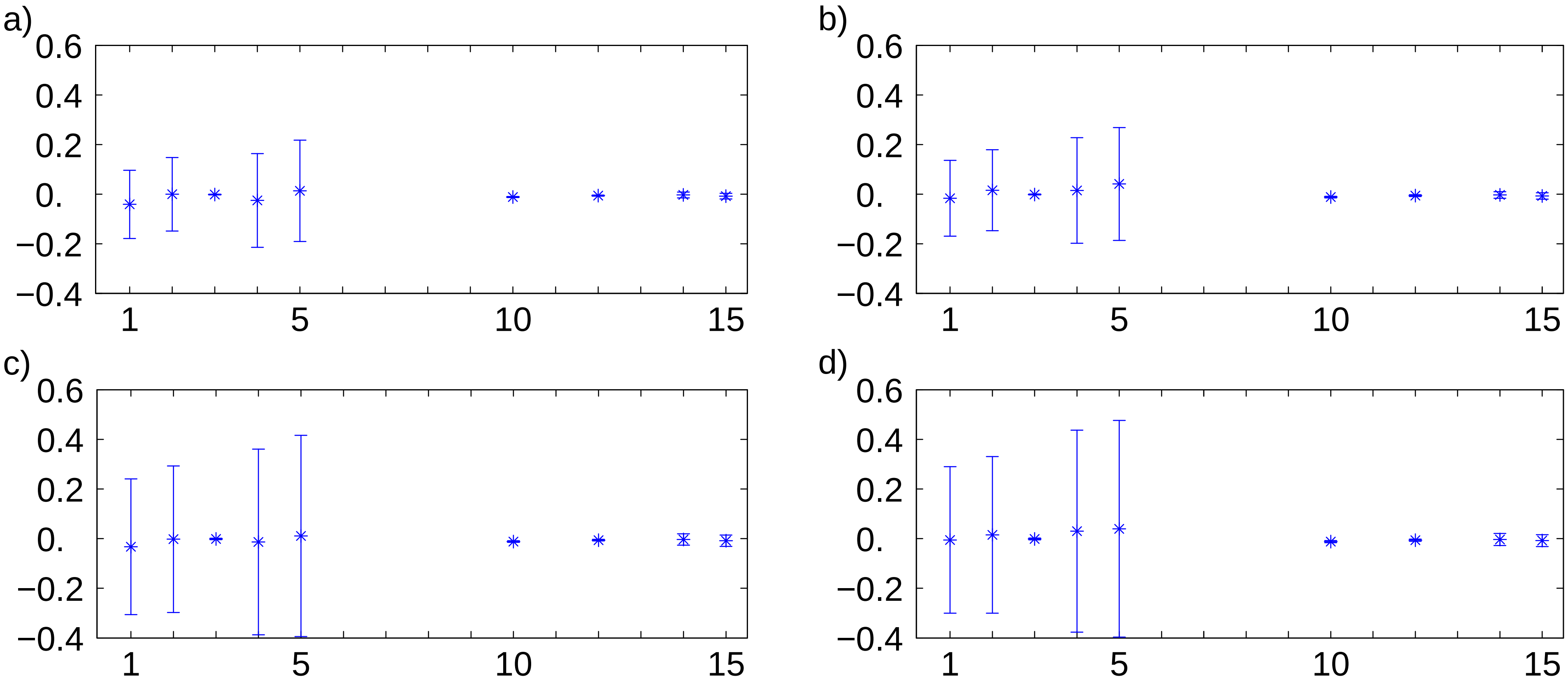
Noise	p_z	polarization angle
a	5%	1^0
b	5%	2^0
c	10%	1^0
d	10%	2^0

Noise of upgoing waves doubled

Results of numerical experiments

Estimates and variations of WA parameters

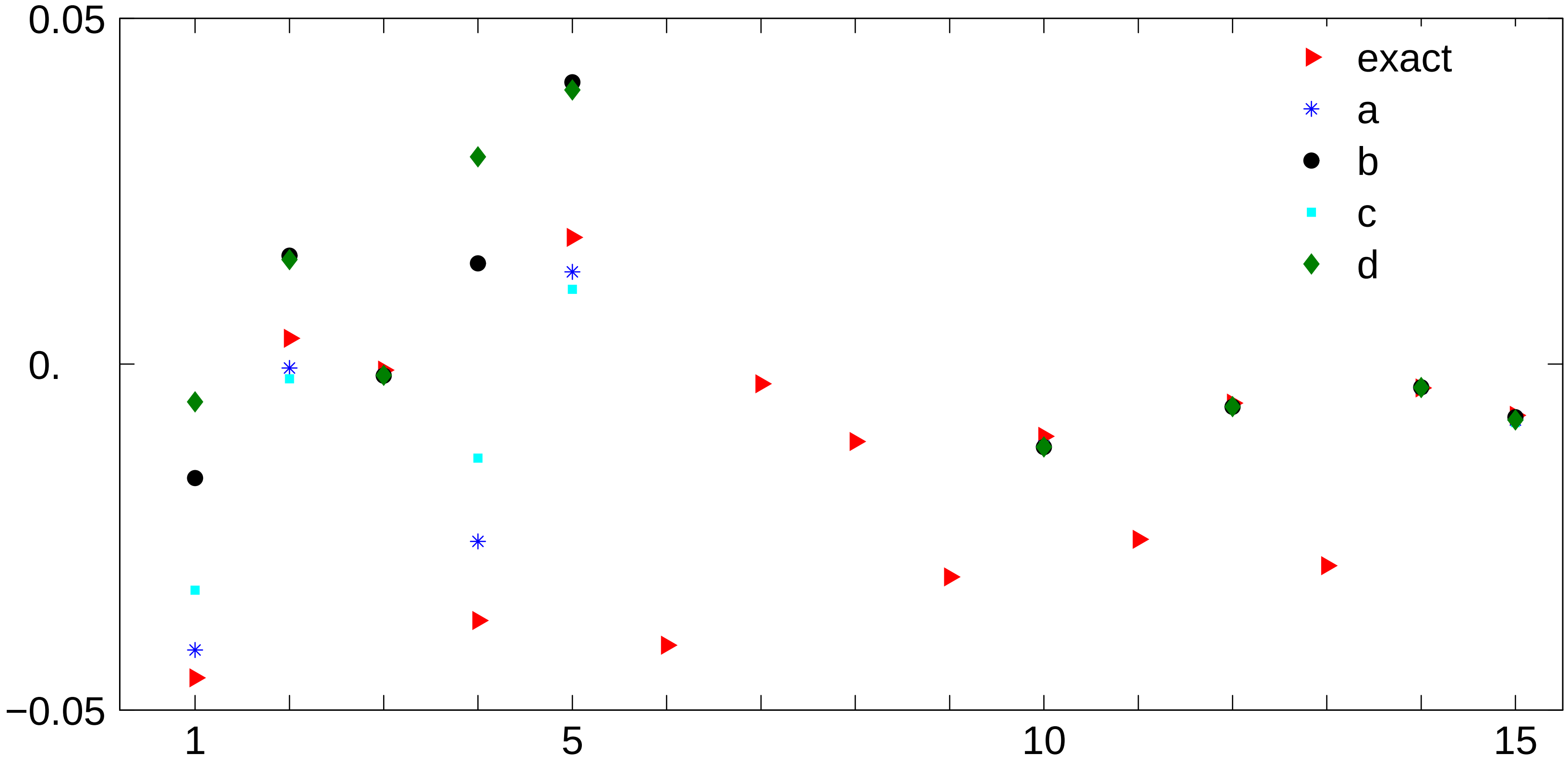
rec. 0.1 km; two profiles: 0^0, 90^0



Results of numerical experiments

Comparison of estimates of WA parameters

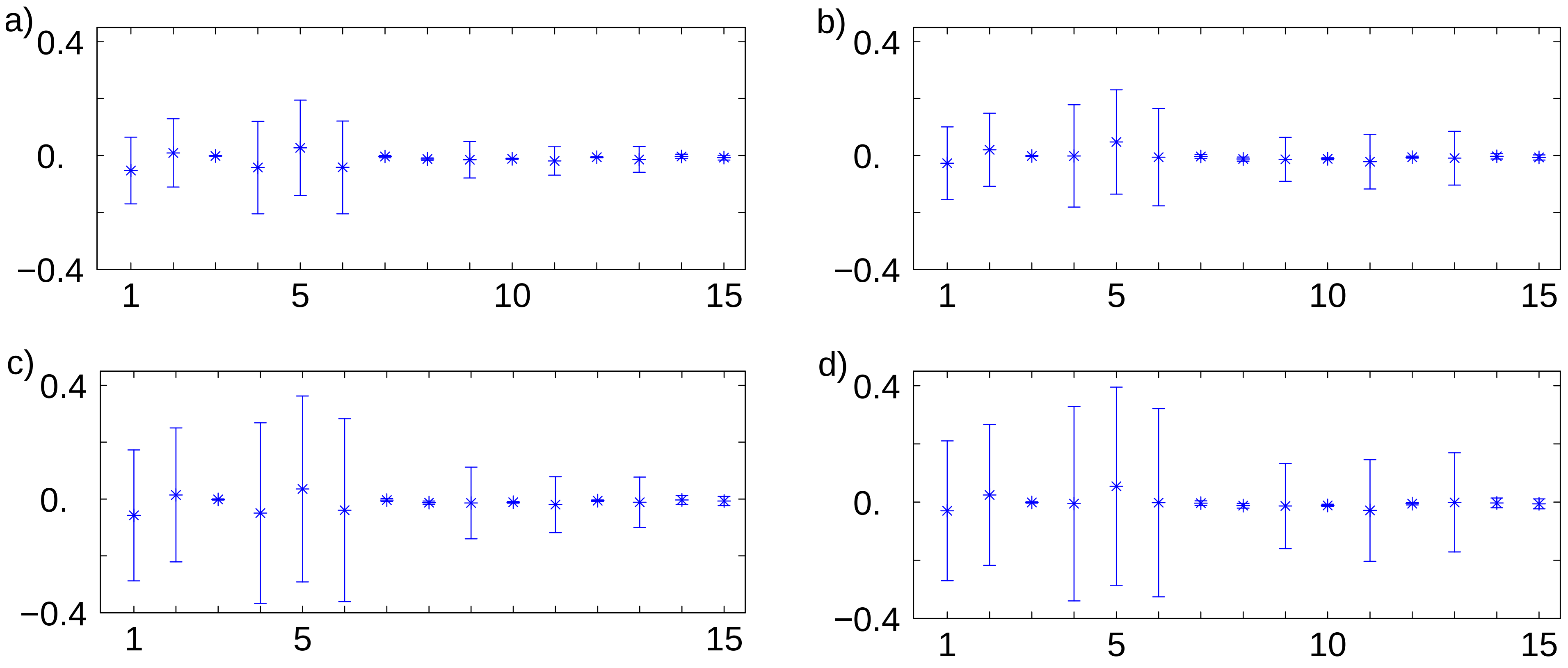
rec. 0.1 km; two profiles: 0^0, 90^0



Results of numerical experiments

Estimates and variations of WA parameters

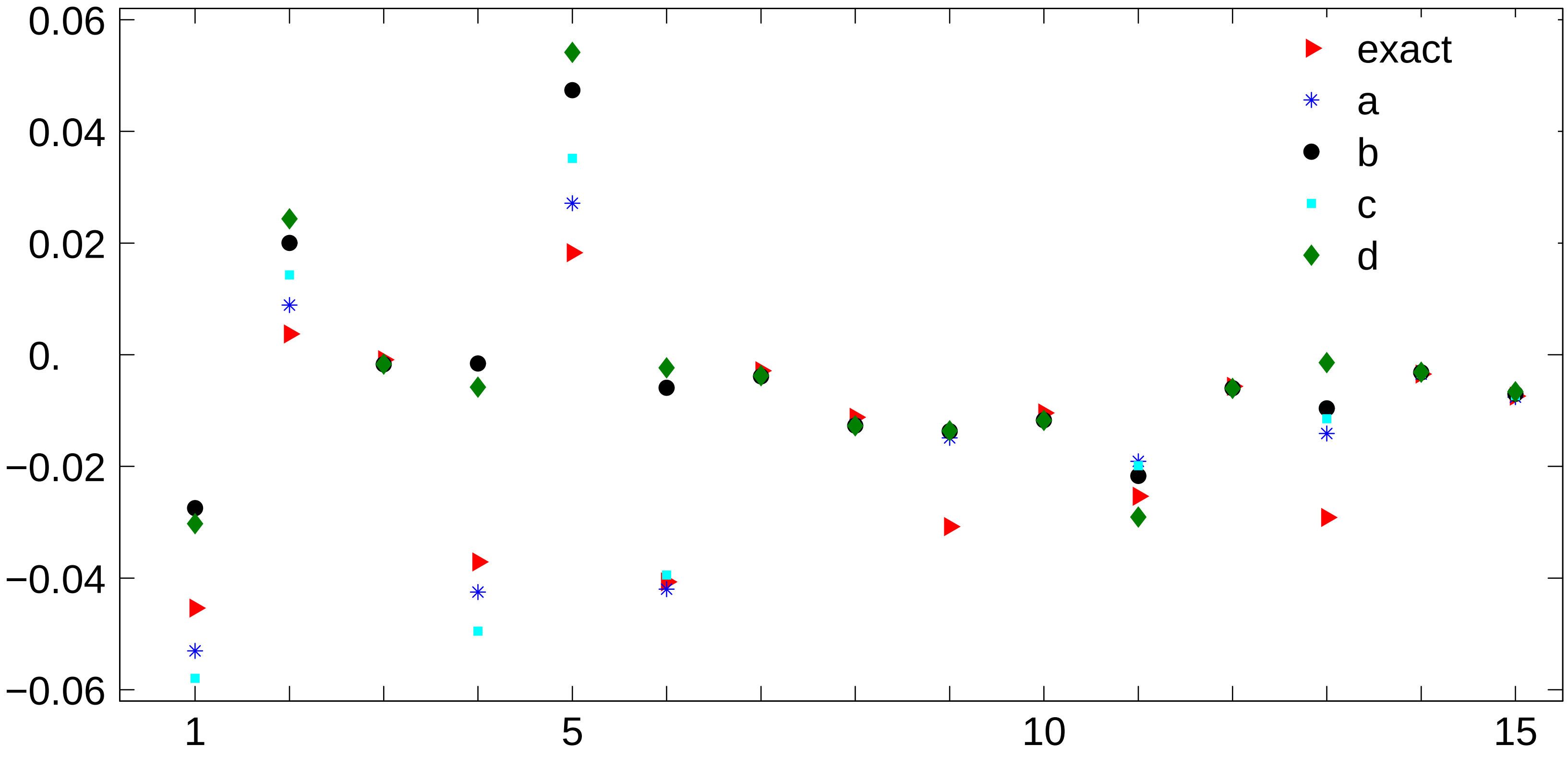
rec. 0.1 km; four profiles: 0^0, 45^0, 90^0, 135^0



Results of numerical experiments

Comparison of estimates of WA parameters

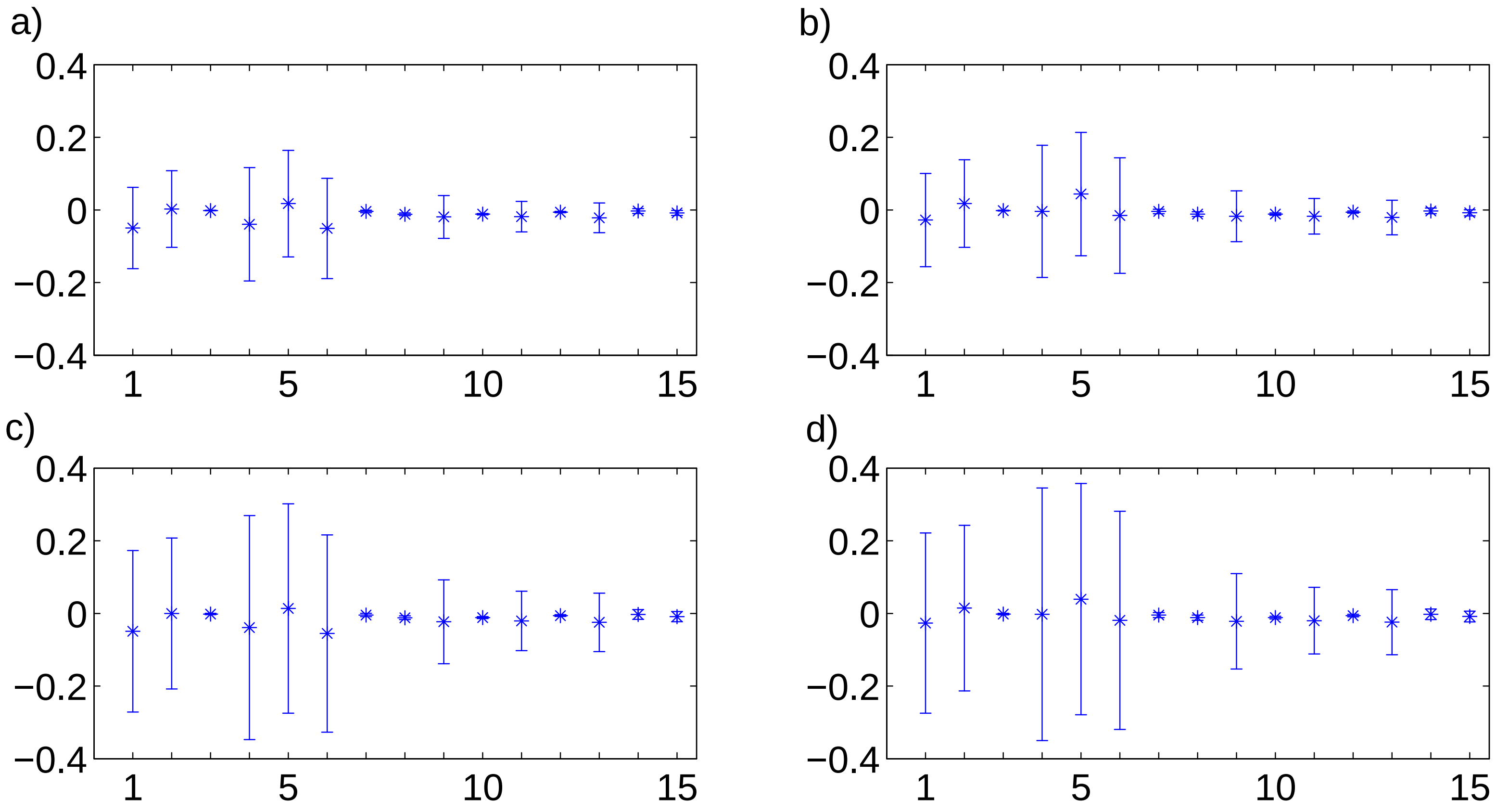
rec. 0.1 km; four profiles: 0^0, 45^0, 90^0, 135^0



Results of numerical experiments

Estimates and variations of WA parameters

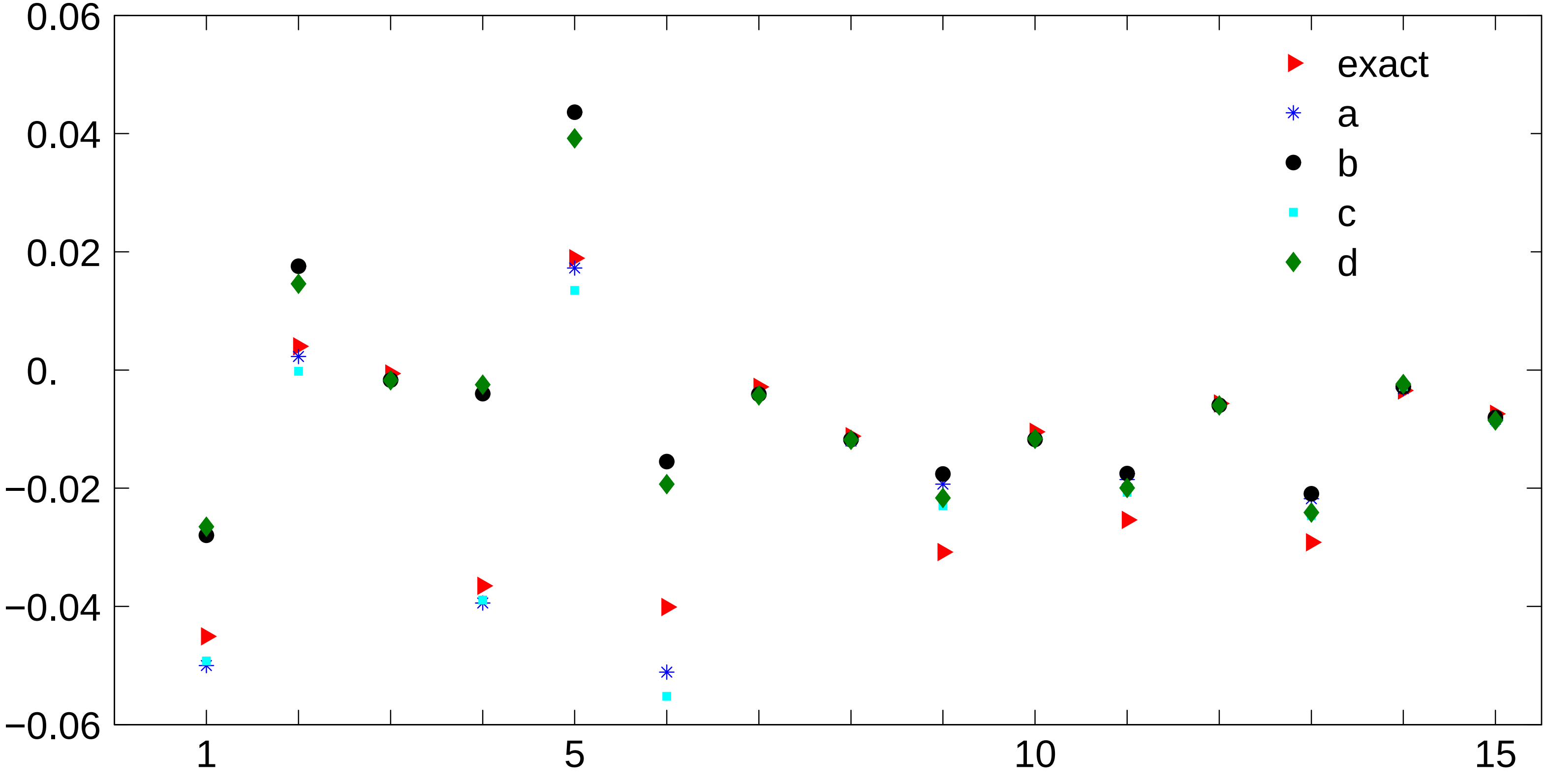
rec. 0.1 km; five profiles: 0^0, 72^0, 144^0, 216^0, 288^0



Results of numerical experiments

Comparison of estimates of WA parameters

rec. 0.1 km; five profiles: 0^0, 72^0, 144^0, 216^0, 288^0

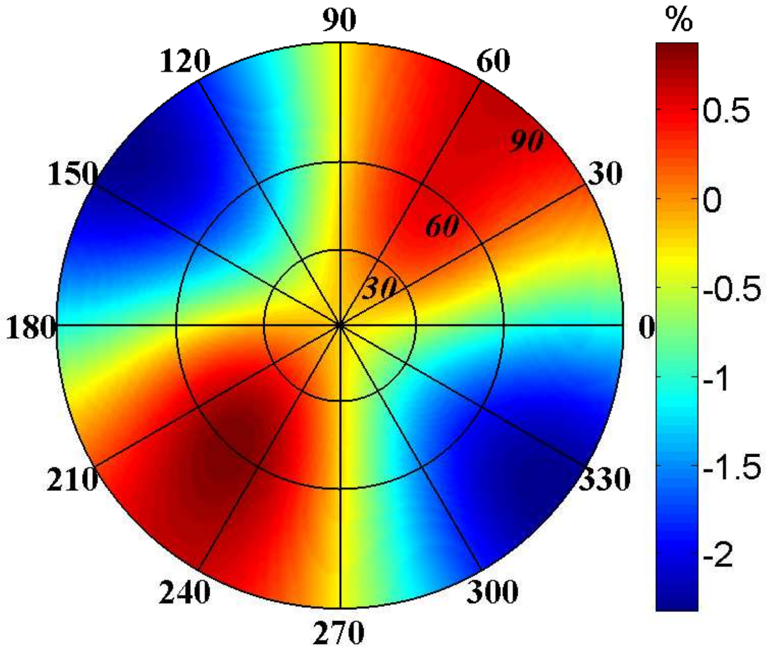


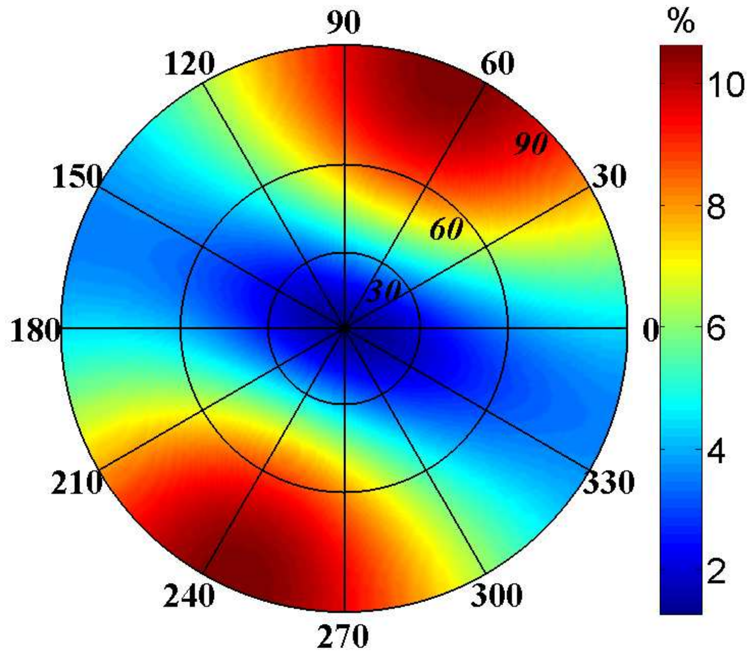
Results of numerical experiments

Effect of number of waves (relative differences)

rec. 0.1 km; five profiles; noise a

down- and upgoing wave (left); downgoing wave (right)

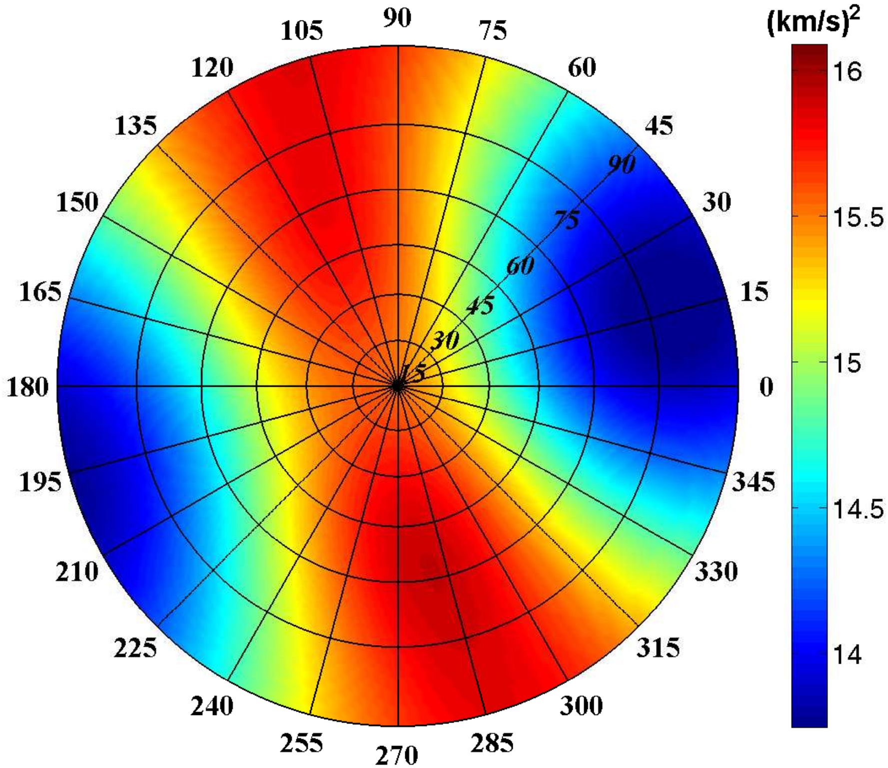




Results of numerical experiments

Orientation of axis of symmetry (inverted WA parameters)

rec. 0.1 km; five profiles; no noise; azimuth 25^0, inclination 80^0



Plans

- use of synthetic seismograms as input data
- use of S waves using
  the common S-wave ray concept
- tests in media with complex overburden

Conclusions

- 5 profiles optimum
- regular step in the orientation of profiles
- consideration of down- and upgoing P waves
- greater sensitivity to errors of the slowness vector
- no weighting of data (condition number $\sim$ 100)
- no dependence on the near-surface structure