Inverting finite-frequency traveltimes containing errors to reveal 2D velocity structures

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Outline

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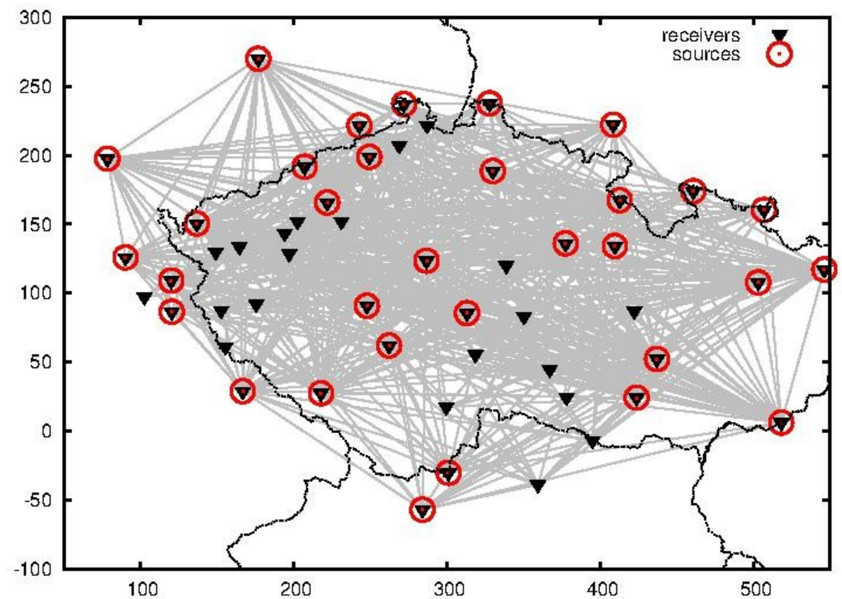
- Method
- Synthetic example – checkerboard test
- First results for real data
- Analysis of inversion with erroneous data:

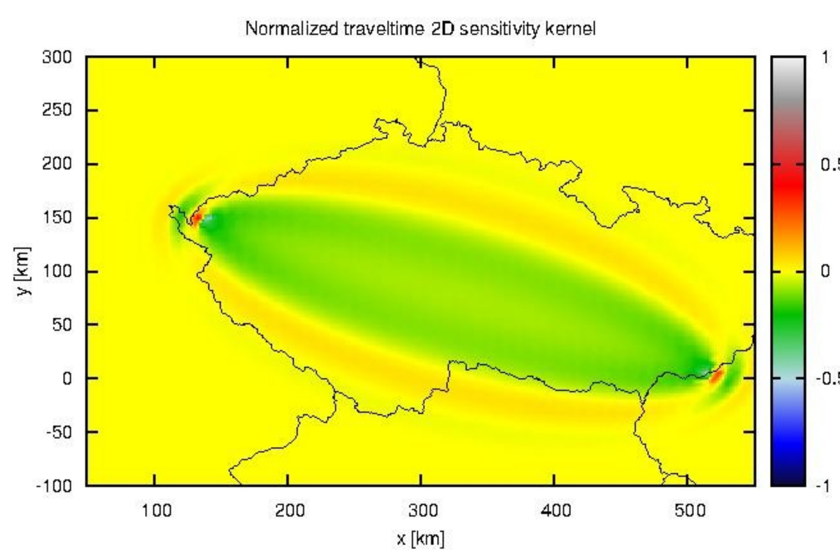
  - oversmoothing

  - data weighing
- Summary

Motivation

- Goal: group velocity maps of surface waves in the Czech Republic
- Data: surface wave group traveltimes between stations obtained from ambient noise crosscorrealation filtered for different periods (20s … 2s)
- Using finite-frequency inversion method is essential





Method

- Inversion using conjugate gradients
- Gradient calculated using adjoint method
- Love wave propagation approximated by membrane waves → 2D forward calculation

$$\rho \frac{\partial^2 u(\mathbf{x},t)}{\partial t^2} - \nabla.(\mu \nabla u(\mathbf{x},t)) = f(\mathbf{x},t)$$

- 2D kernel for parameter *μ* which is actually 2D kernel for group velocity

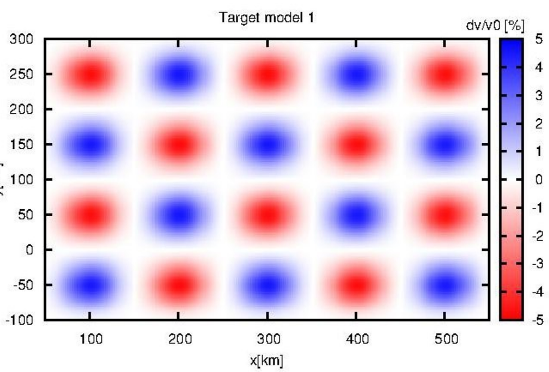
$$K_\mu = \int (\nabla u).(\nabla u^\dagger)\, dt$$

- Misfit: L2 norm of crosscorrelation traveltimes
- Adjoint source located in receiver: $f^\dagger = -\Delta T \frac{\dot{u}(t)}{\int \dot{u}^2(t)\, dt}$
- All calculations performed using adjoint 2D version of SeisSol (ADER-DG method)

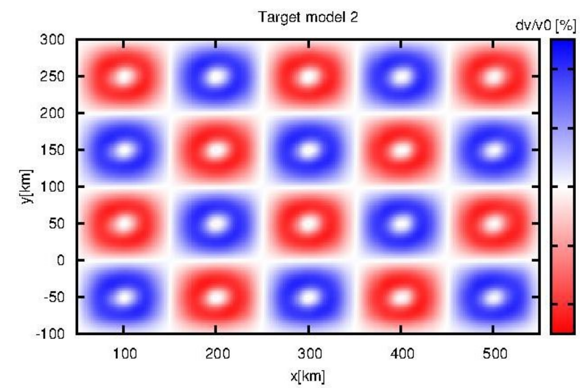
Synthetic inversion for 20s data

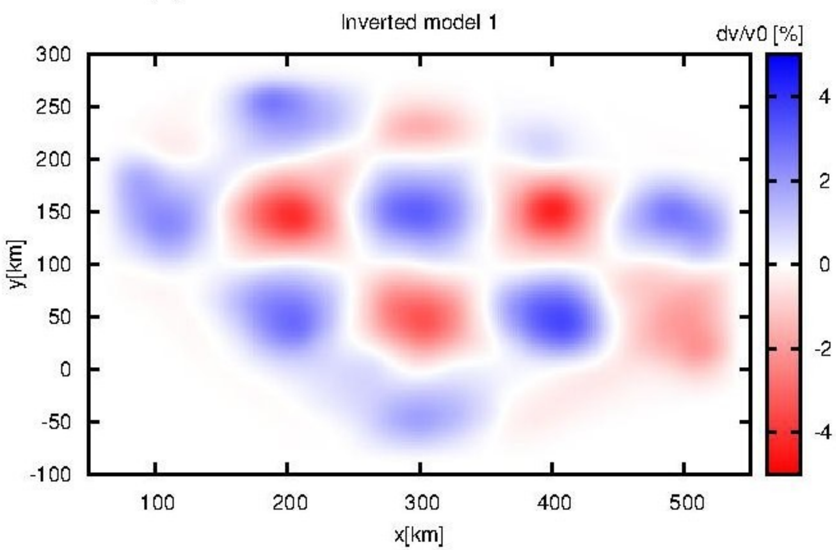
- Checkerboard test using real sources-stations configuration for 20s traveltimes
- Noise-free synthetic data

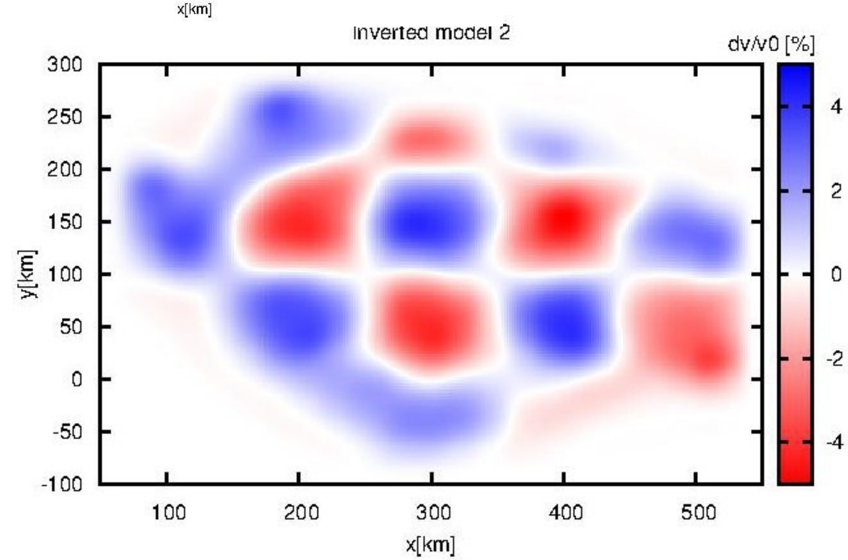
- Information about resolution



- Resolution of small scale heterogeneities

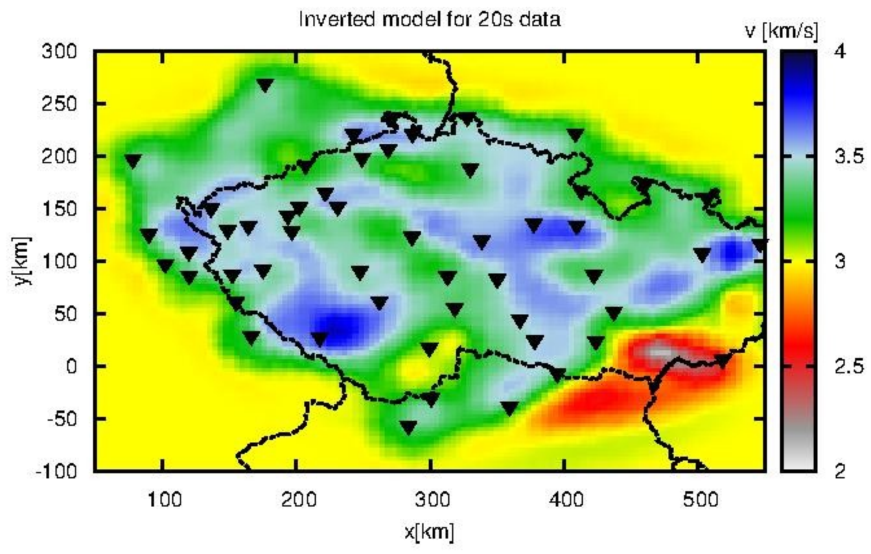


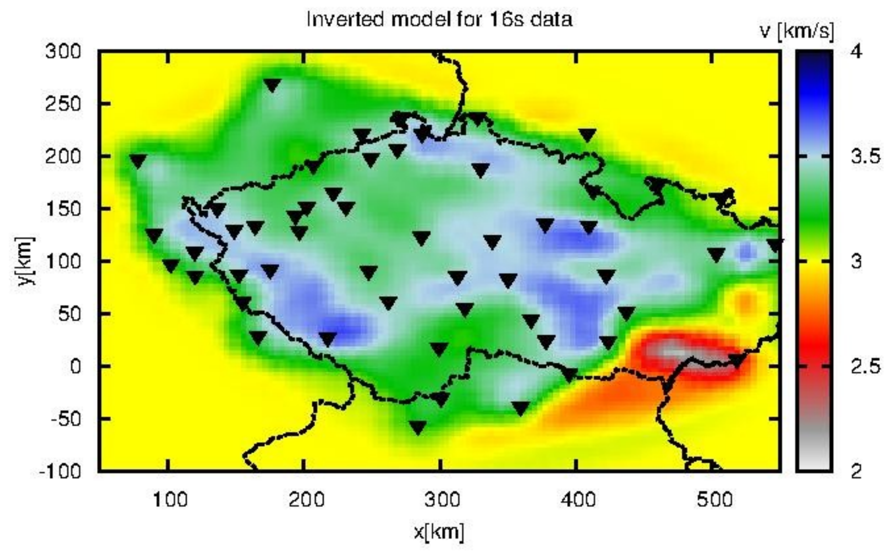




Comparing results for 20s and 16s real Love traveltimes

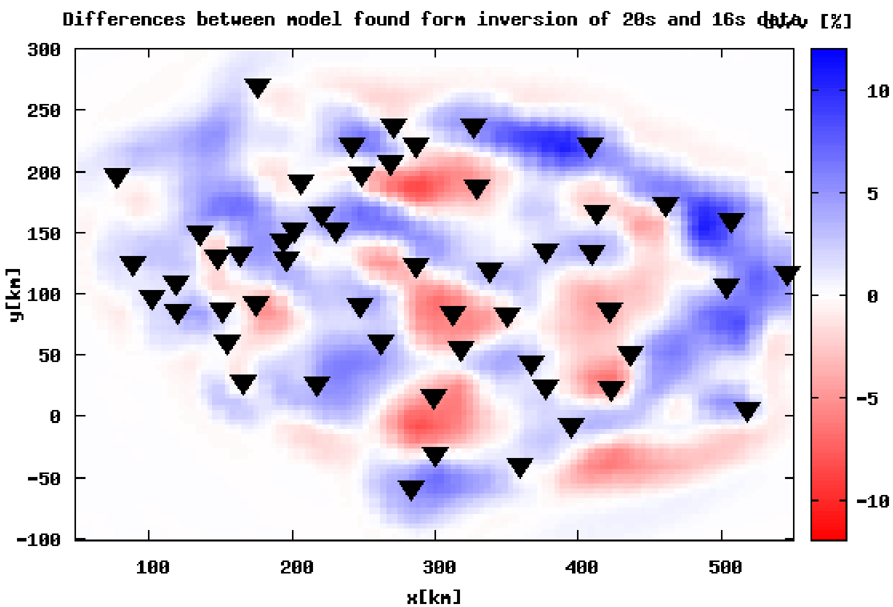
- Traveltimes come from ambient noise measurements
- Inversion starting from homogenous model
- Event kernels smoothed using convolution with Gaussian function (size close to the wavelength of waves used)

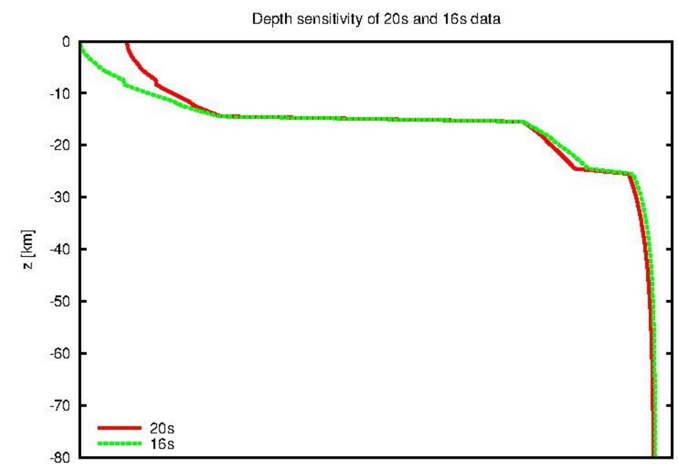


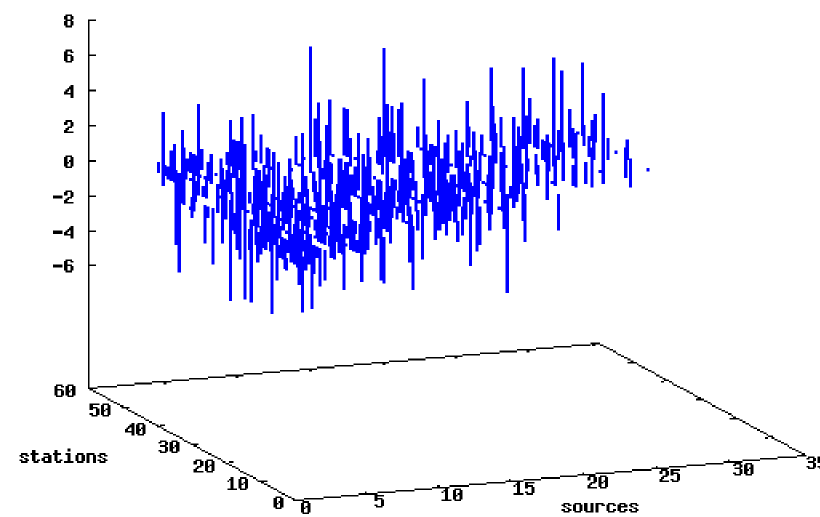


Comprehending the differences between 20s and 16s models

- Differences between final models ca 10%



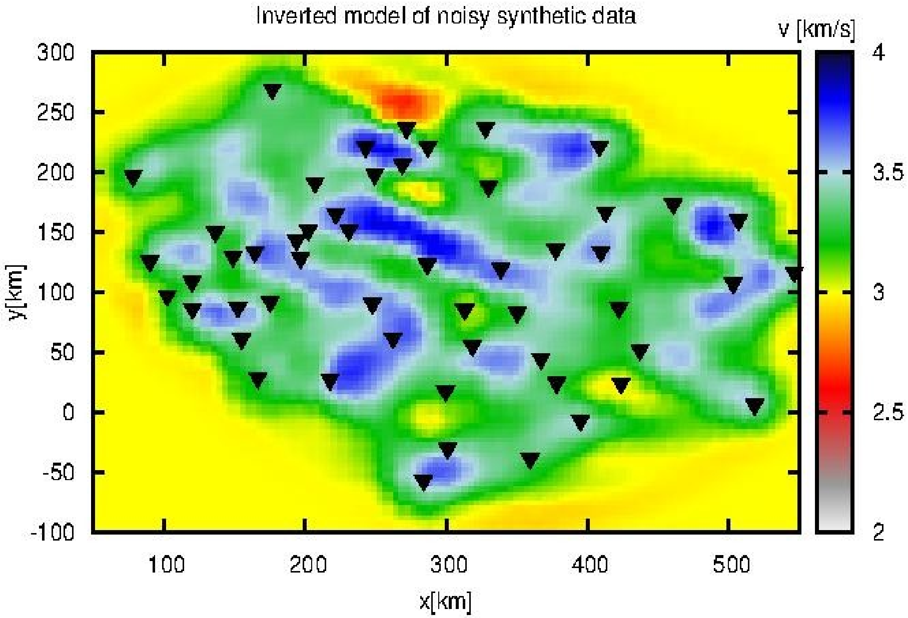


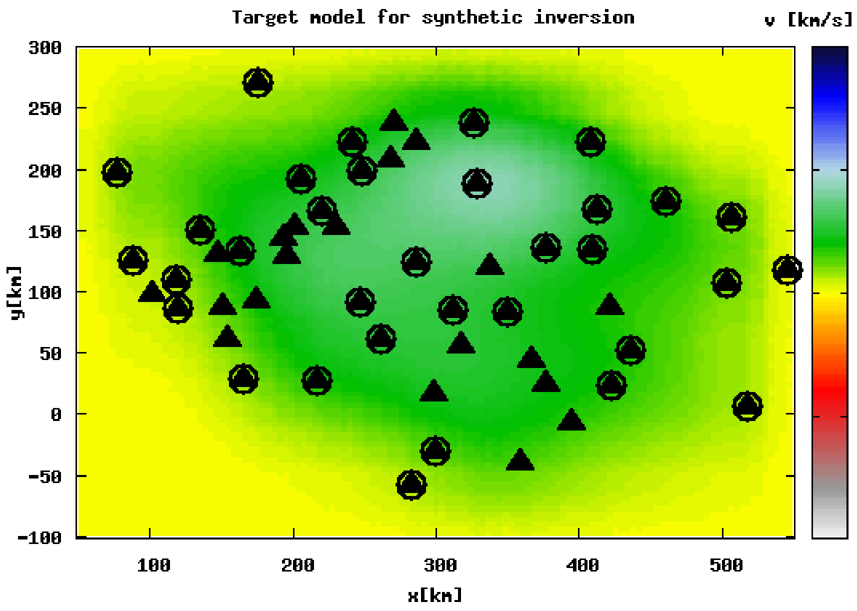


- Traveltime kernel of 20s and 16s showing similar depth sensitivities
- Differences in data → caused by errors in data
- RMS of differences ~ 2.3s

Synthetic inversions using noisy data

- Using simple smooth heterogenous model to create synthetic data
- Added noise to synthetic data, using differences between 20s and 16s real data as noise

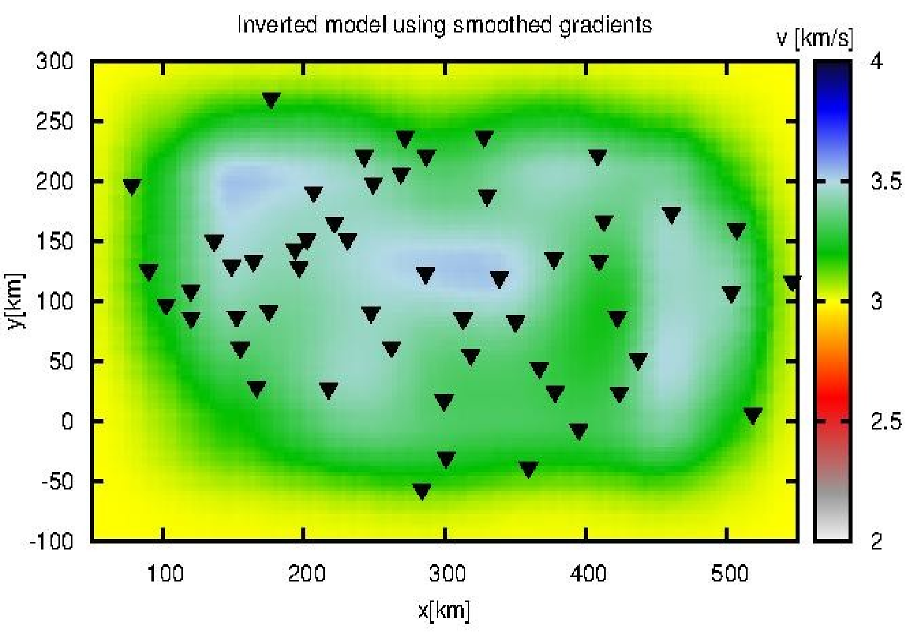




- In case the differences between 16s and 20s data represent errors in data, the complicated structures revealed by inversion are probably caused by errors not by the real model

Oversmoothing gradient kernels

- Gradient kernels are smoothed using convolution with Gaussian
- Large characteristic length of Gaussian leads to smooth gradients (using 150km-100km)
- Preference of smooth models



- Obtained heterogeneities are weaker than without oversmoothing, but they still represent the effect of data errors

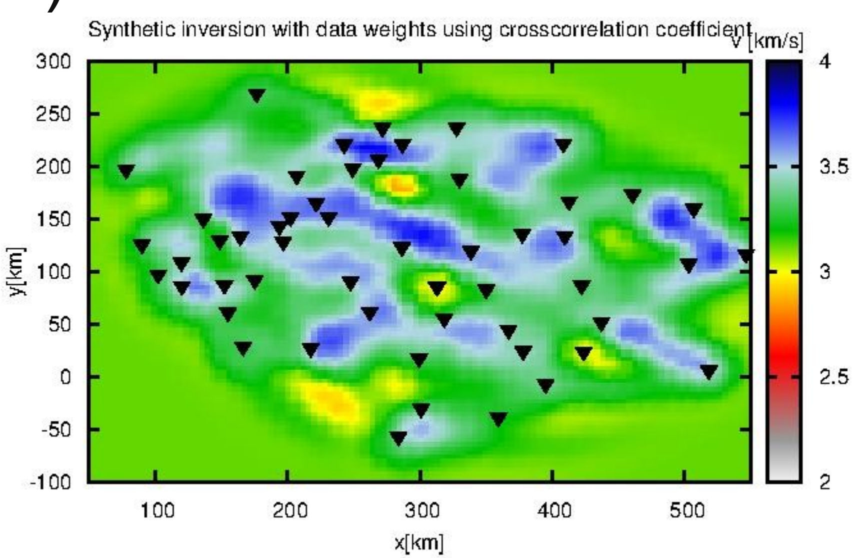
Weighing of data

- Dataweights should help the inversion prefer data containing smaller errors
- We have 2 possibilities of dataweights from real dataset at disposal

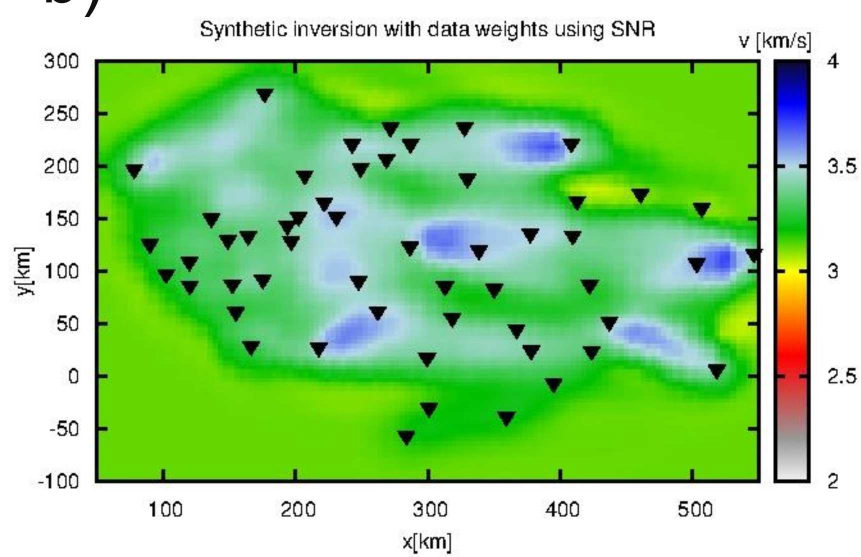
  a) crosscorrelation coefficient

  b) signal-to-noise ratio

a)



b)

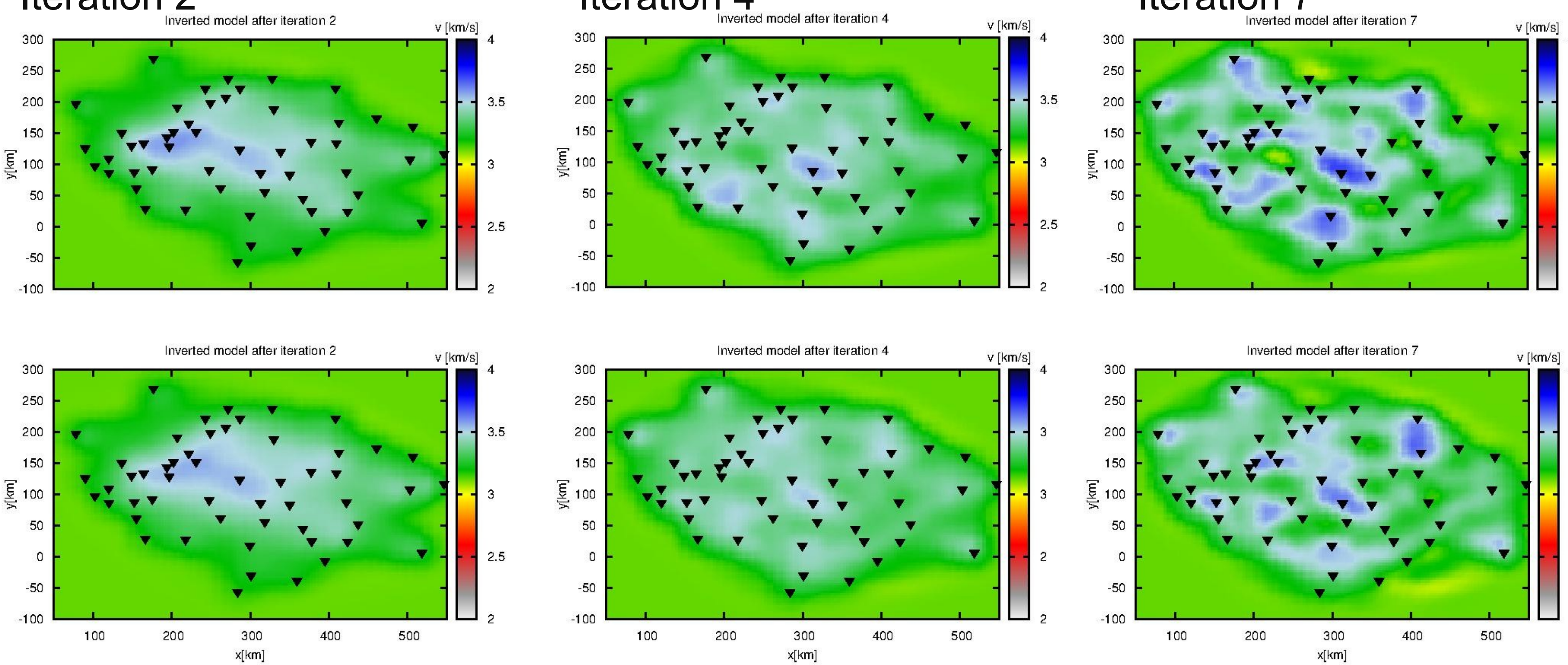


Changing the amount of data

- Overall >500 traveltimes at disposal
- We take only 50% and 90% of data available
- First iterations are unchanged, small scale structures may vary depending on the data used
- Iteration 2 Iteration 4 Iteration 7

50%

90%

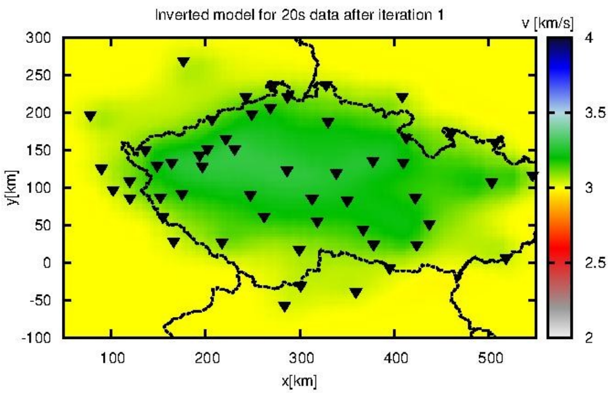


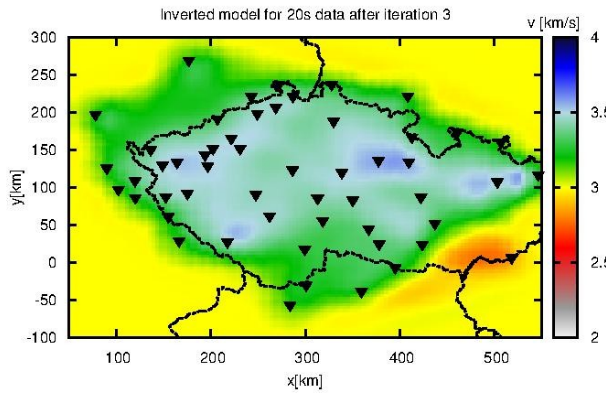
Summary

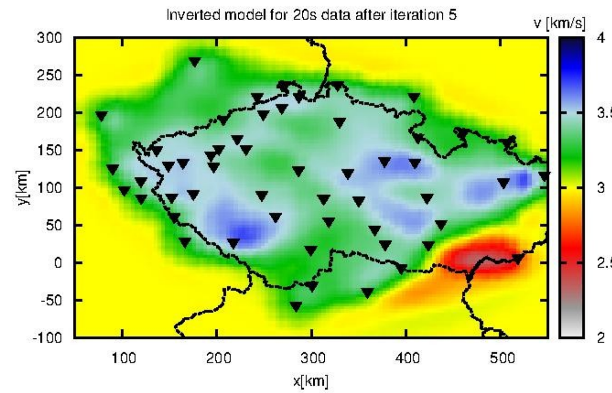
- Although synthetic inversion with exact data gives ideal results, when it comes to inversion of data corrupted by errors, the situation is much more complicated
- We tried several different methods to remove or reveal the effect of errors in our dataset (oversmoothing kernels, data weights) and analysed their effect on the inversion
- Important practical outcome for our problem: the best moment to stop iterations is when the inverted model starts to exhibit structures of wavelengths used in inversion

Iterations: 1, 3 and 5

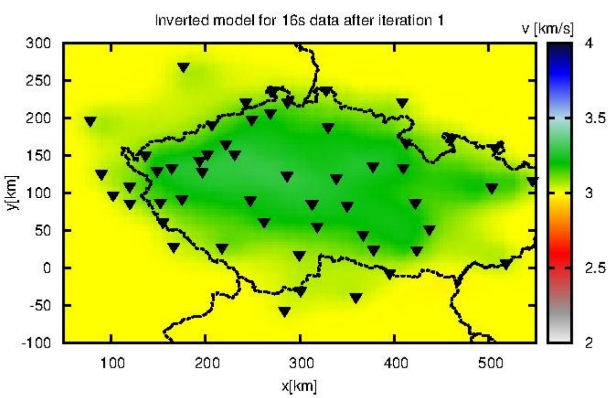
- T20:

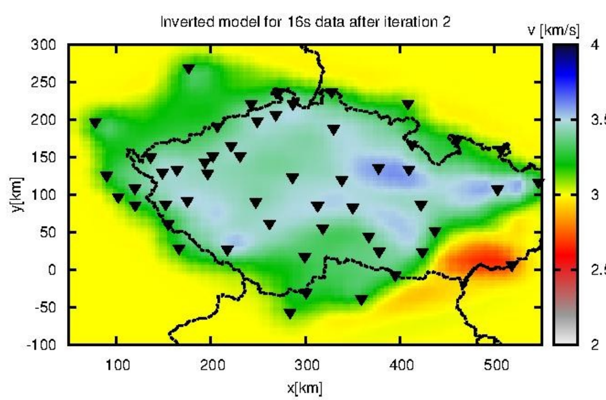


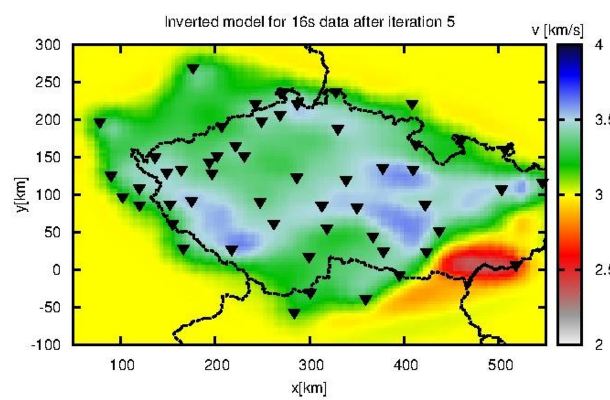




- T16:

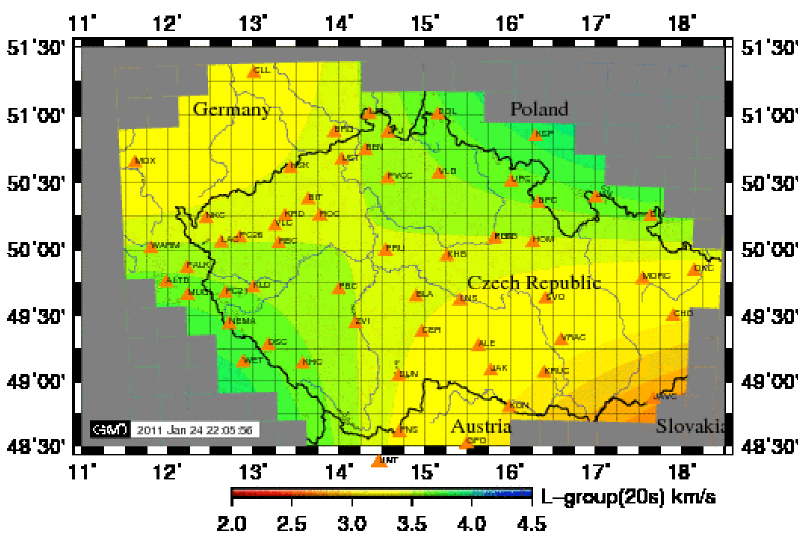


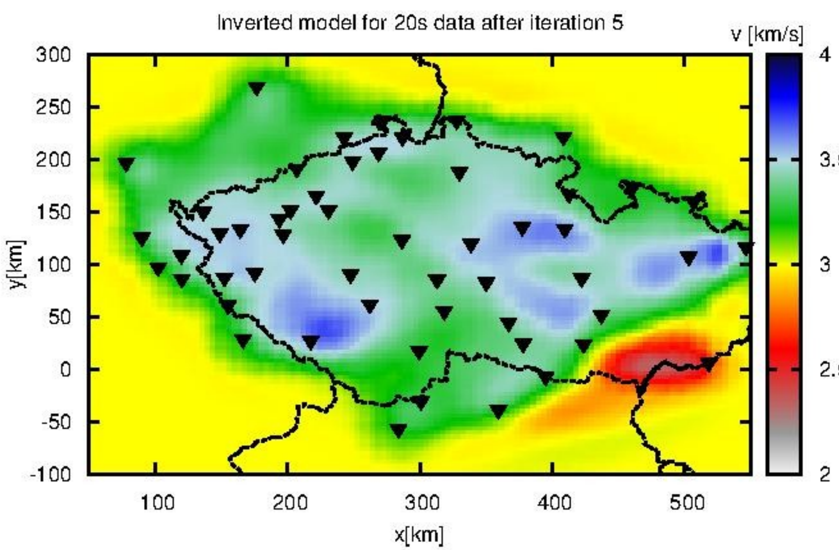




Conclusion

- Model obtained by classical ray tomography may exhibit loss information due to regularization of the problem in comparison with model obtained using finite-frequency kernels
- Which of the found structures are real and which are only artifacts of inversion?





Ruzek et al, Joint inversion of teleseismic P waveforms and surface-wave group velocities from ambient seismic noise in the Bohemian Massif, Studia Geophysica et Geodaetica, 2012.

Thank you.