# TOWARDS A COMPREHENSIVE SEISMIC MODEL (OF EUROPE)

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in close collaboration with

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# Development of Full Seismic Waveform Inversion

Data

broaden period range

dense arrays

jointly invert regional and teleseismic data

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multi-scale inversion

resolution analysis

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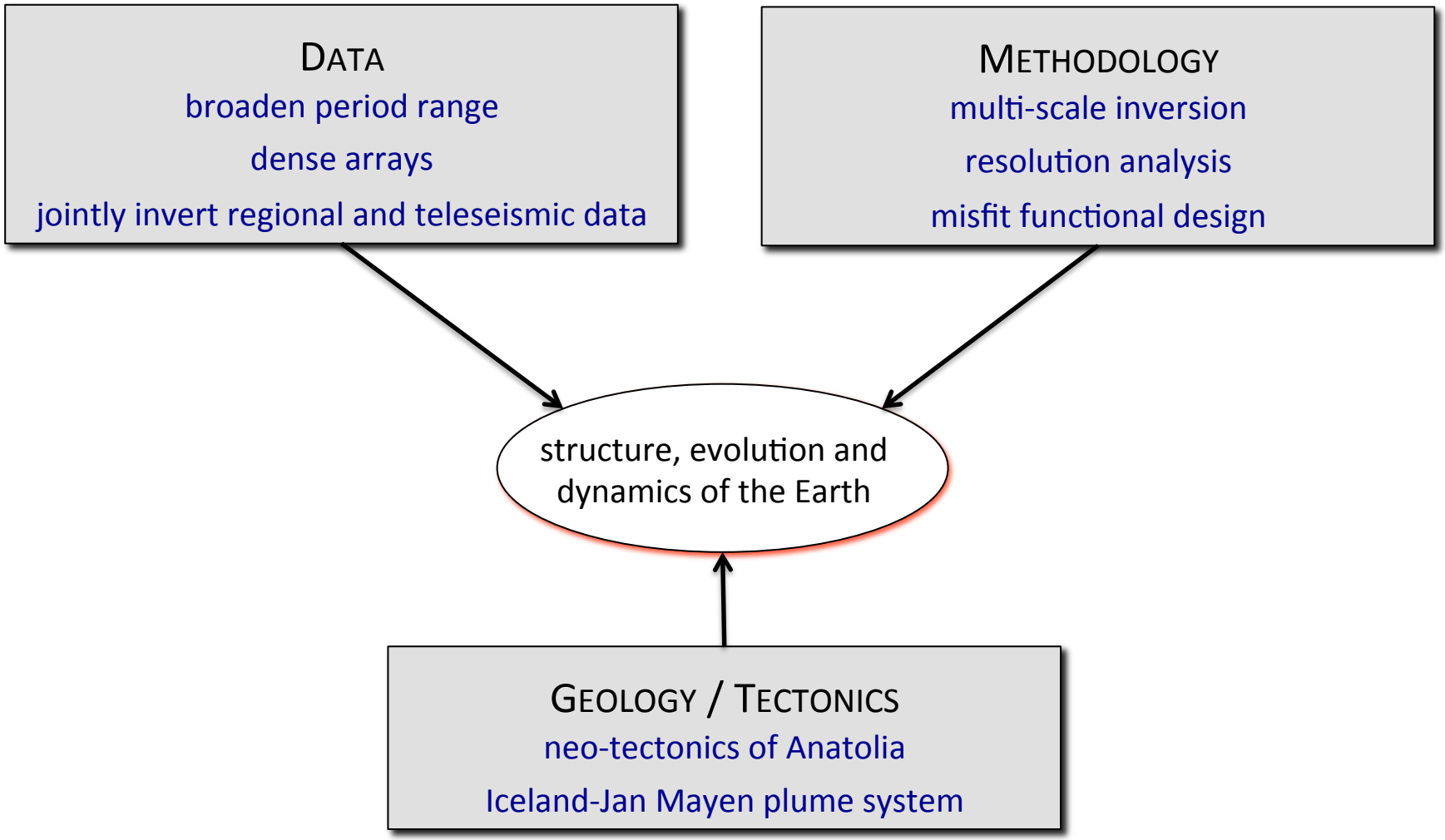
## Geology / Tectonics

neo-tectonics of Anatolia

Iceland-Jan Mayen plume system

# Development of Full Seismic Waveform Inversion



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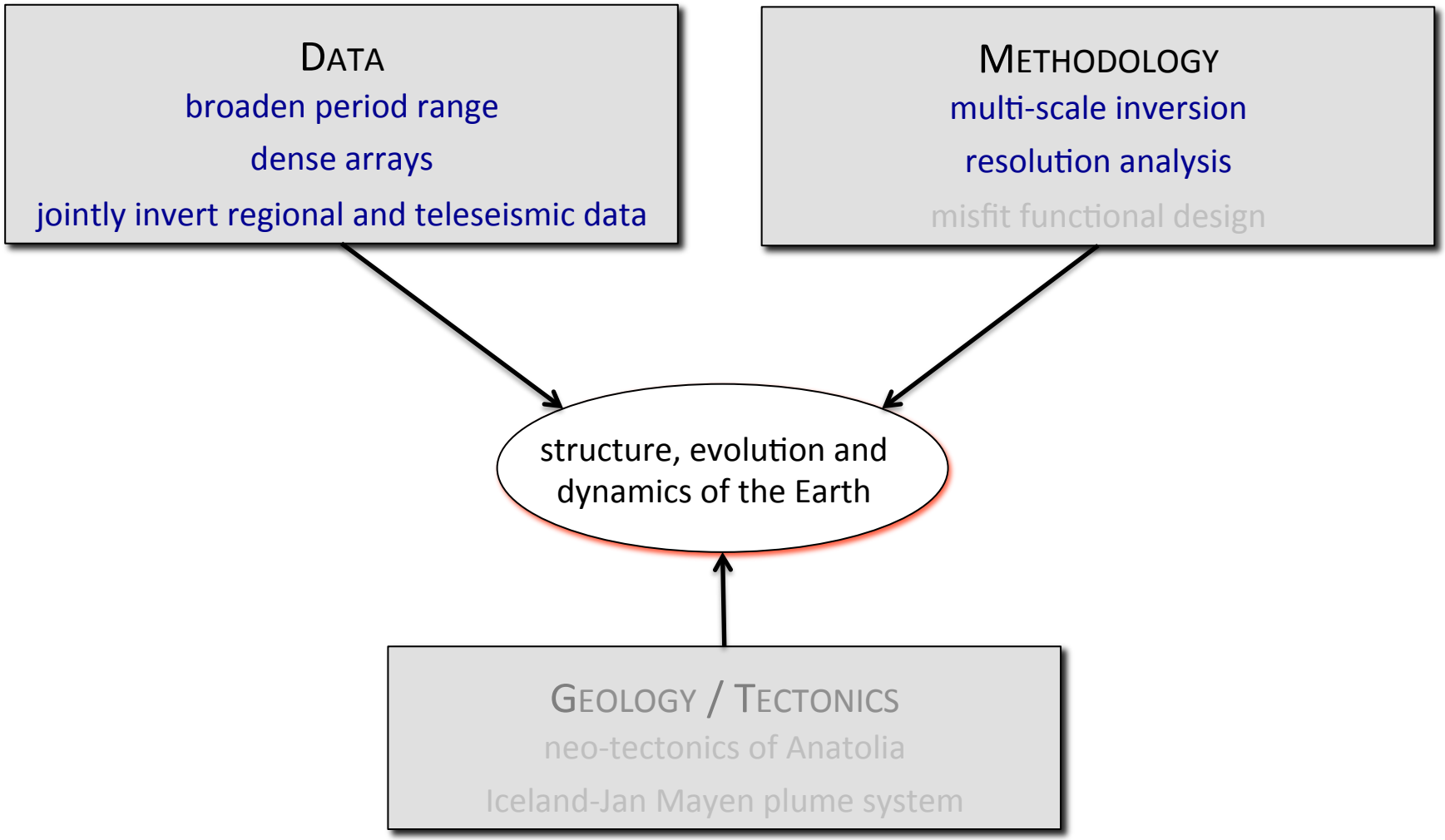

# **MOTIVATION**: THE SCALE-DEPENDENCE OF SEISMIC TOMOGRAPHY

Unresolvable small-scale structure may lead to incorrect images of large-scale structure.

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→ discrepant inferences on strength, depth-extent and sign of anisotropy

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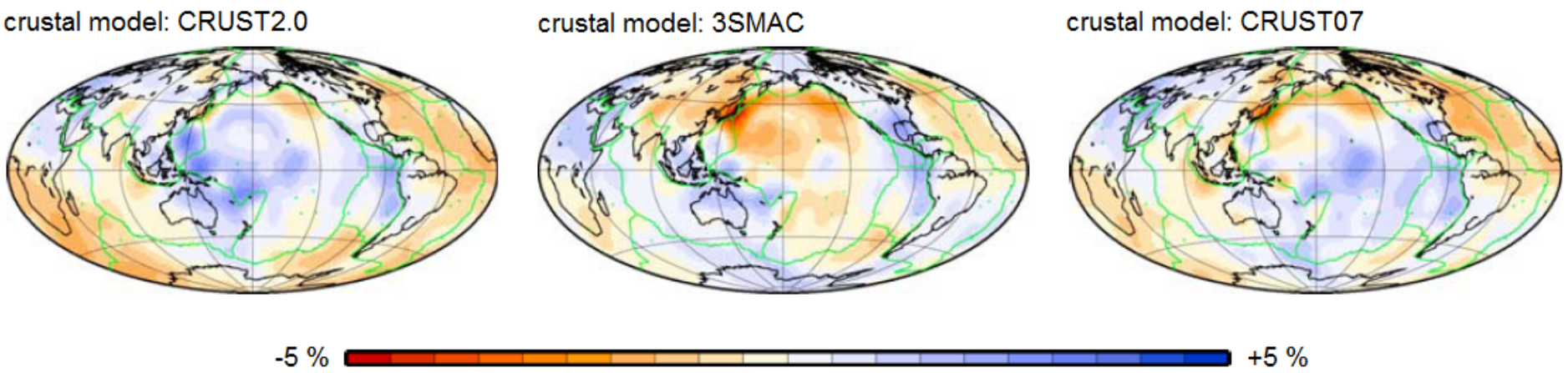
Global tomography with fixed crustal structure

**radial anisotropy @ 100 km depth, $(v_{sh}-v_{sv})/v_s$**




modified from Ferreira et al. (2010)

# **MOTIVATION**: THE SCALE-DEPENDENCE OF SEISMIC TOMOGRAPHY

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- **small-scale isotropic crustal structure** trades off with **large-scale anisotropy**

  → discrepant inferences on strength, depth-extent and sign of anisotropy

- **small-scale** (near-receiver) **velocity structure** trades off with **large-scale Q structure**

  → low correlation between various 3D attenuation models

# MOTIVATION: THE SCALE-DEPENDENCE OF SEISMIC TOMOGRAPHY

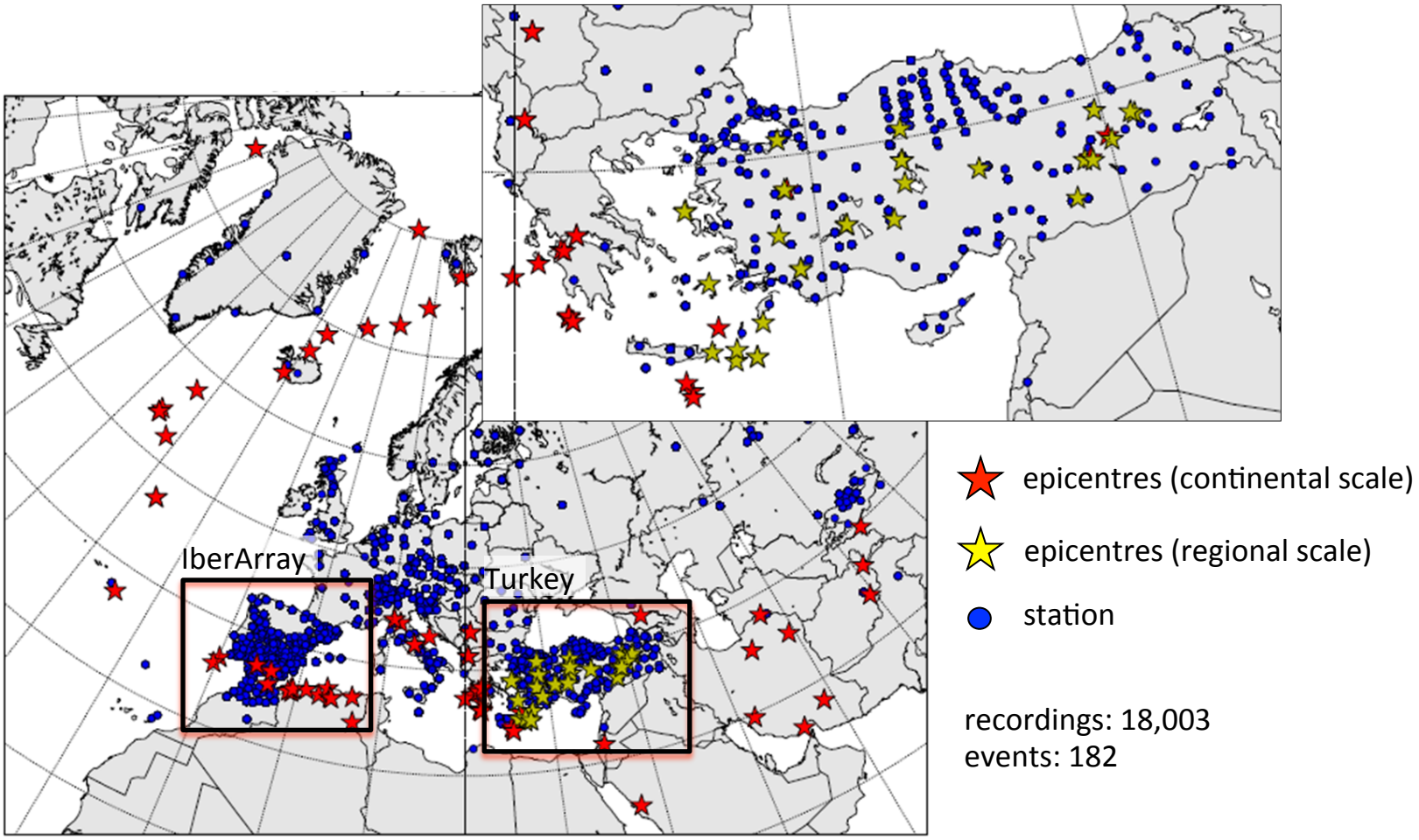
Unresolvable small-scale structure may lead to incorrect images of large-scale structure.

## Necessary improvements

- **Accurate seismic modelling and inversion in complex 3D media**
  - avoid crustal corrections
  - exploit as much waveform information as possible

- **Simultaneous inversion for crustal and mantle structure**
  - constrain small-scale heterogeneity as much as possible
  - reduce small-to-large-scale trade-offs (improve resolution)

# Multi-Scale Inversion



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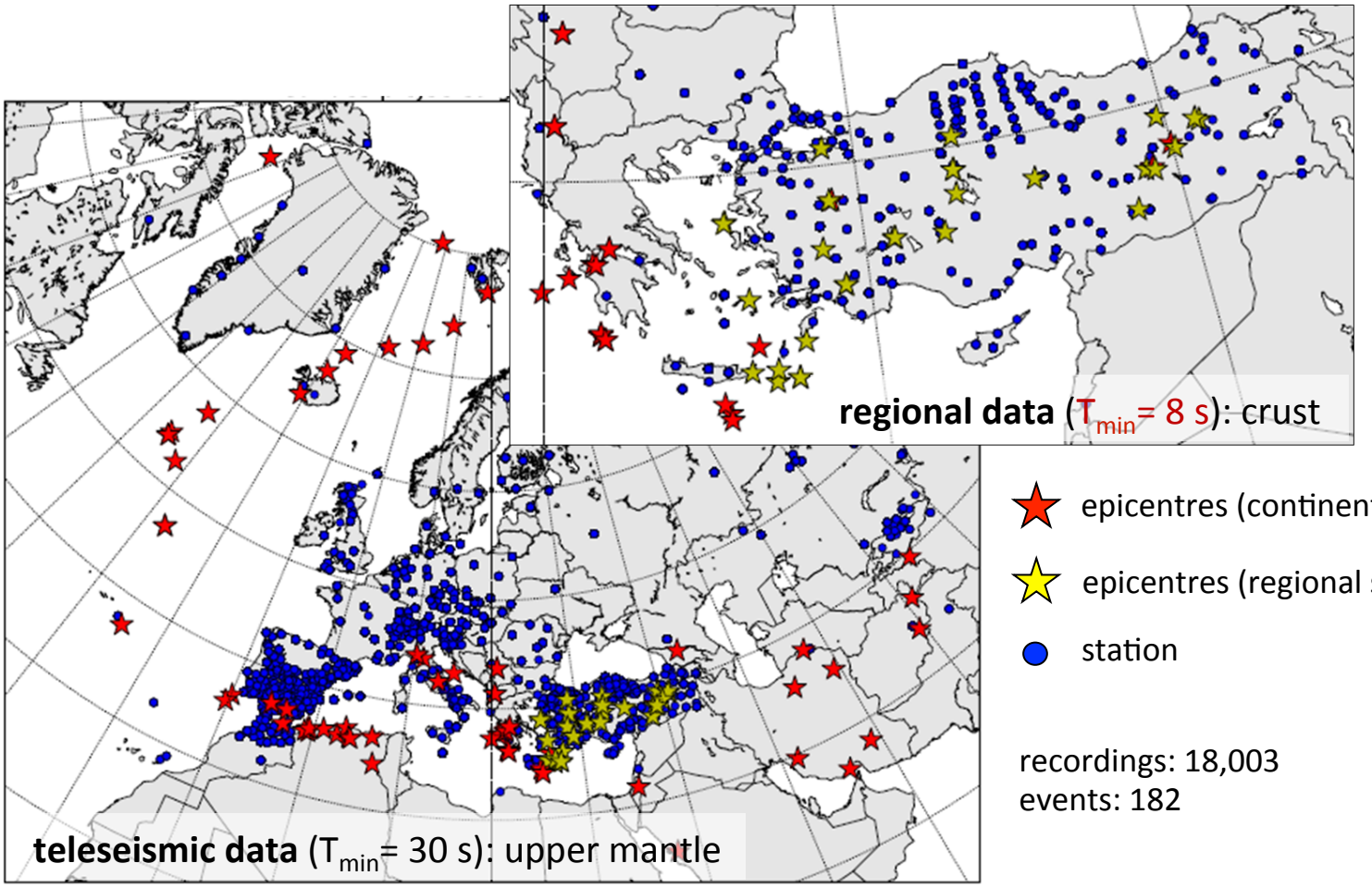



epicentres (continental scale)

epicentres (regional scale)

station

recordings: 18,003
events: 182

**Simultaneous** inversion of:

- longer-period waves on the continental scale (upper mantle)
- shorter-period waves on smaller scales (crust)
- Involves non-periodic homogenisation for upscaling small-scale structure.

# Multi-Scale Inversion

## Forward problem

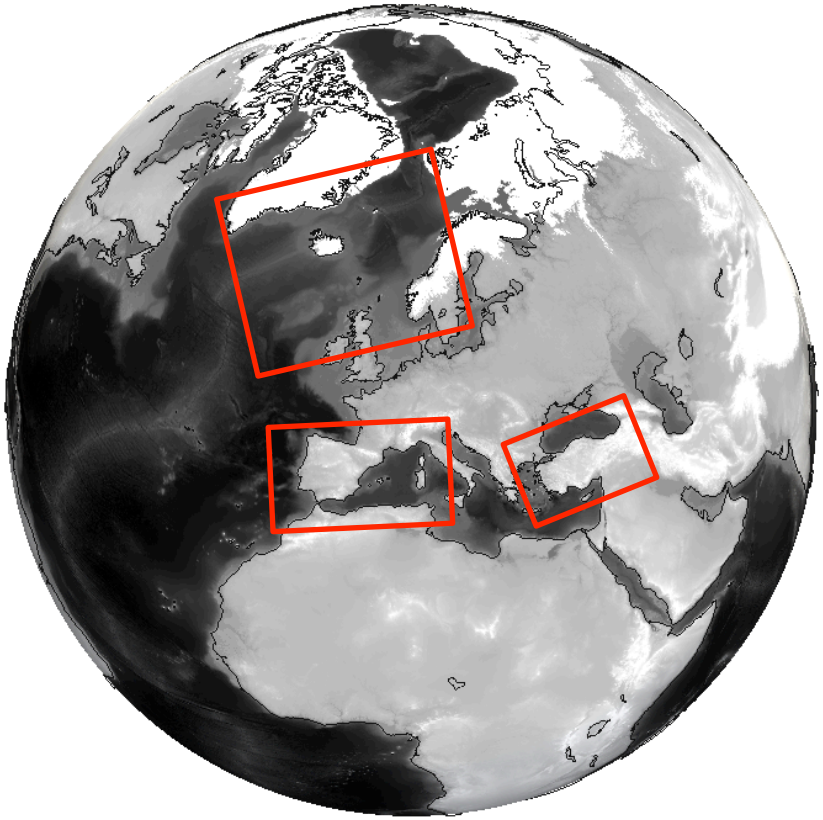
- Spectral elements (SES3D)

## Inversion

- Fréchet kernels via adjoint technqiues
- Conjugate gradient optimisation
- 53 iterations

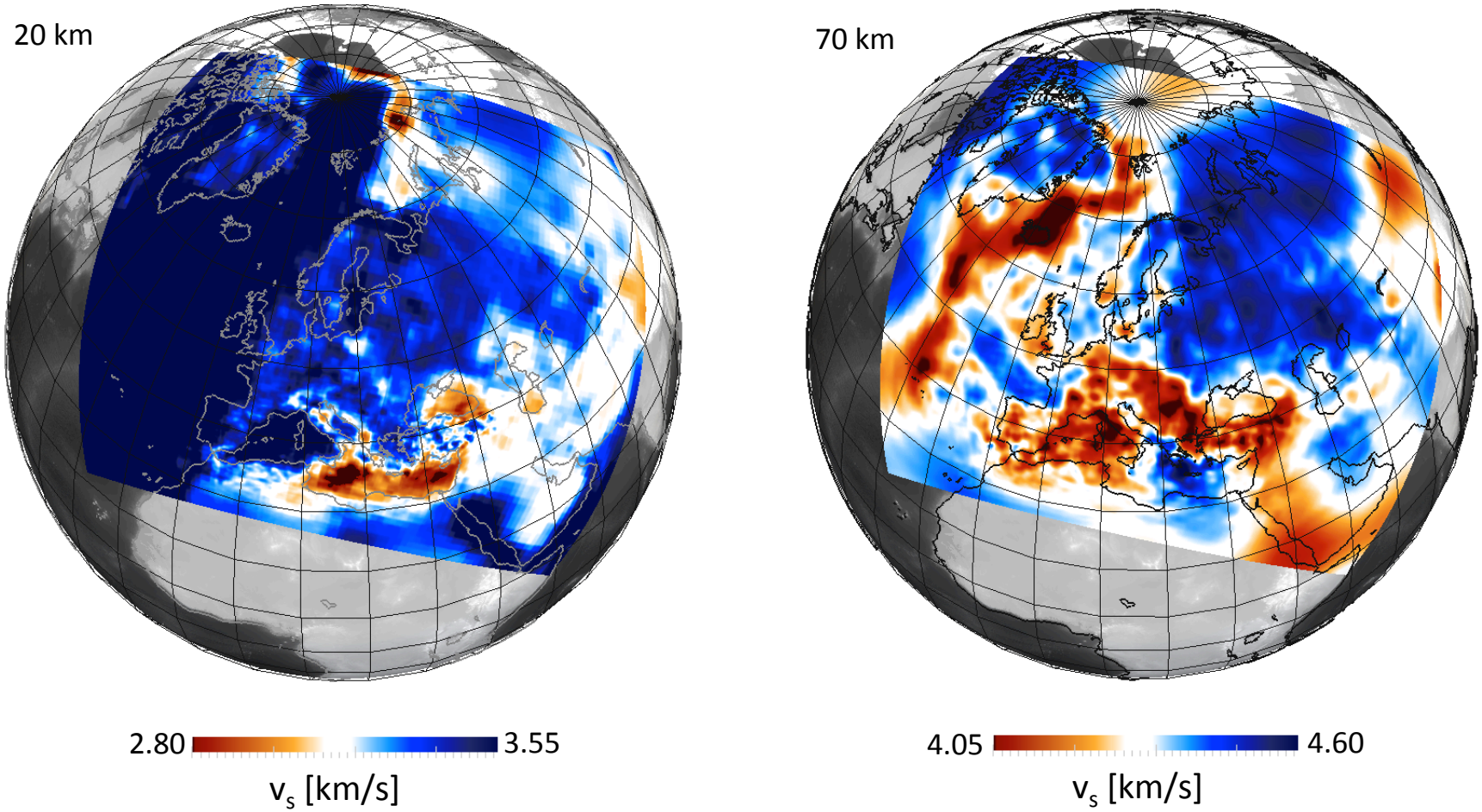
## Embedded sub-regions (higher frequencies)

- Anatolia
- North Atlantic
- Western Mediterranean



Sub-regions for higher-frequency modelling and inversion

# Multi-Scale Inversion



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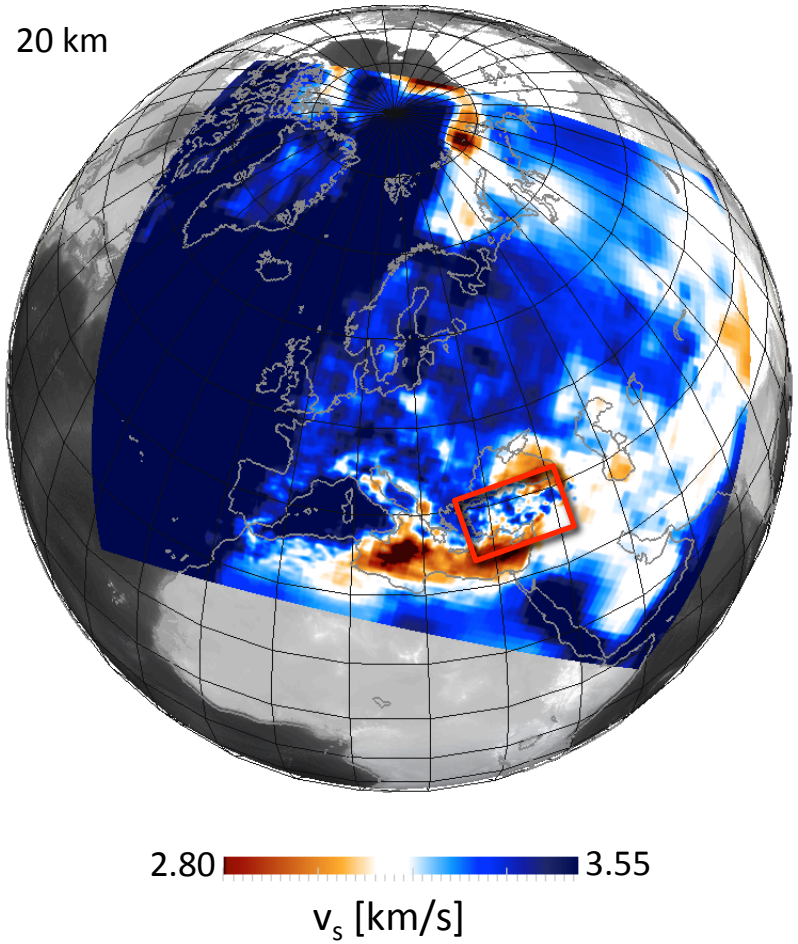


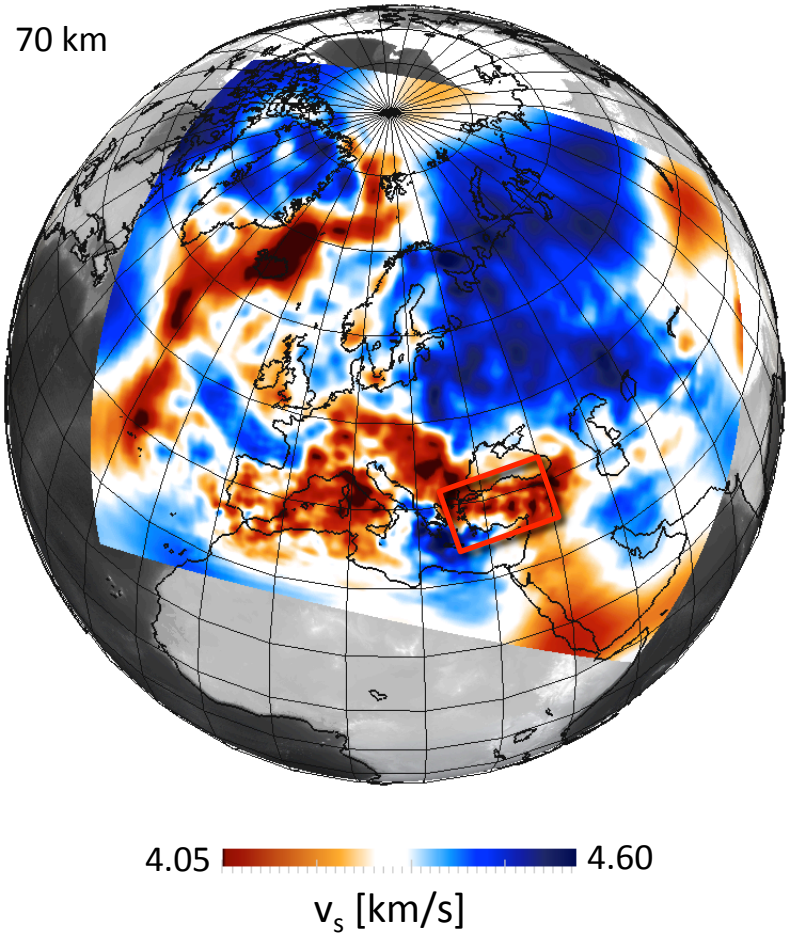

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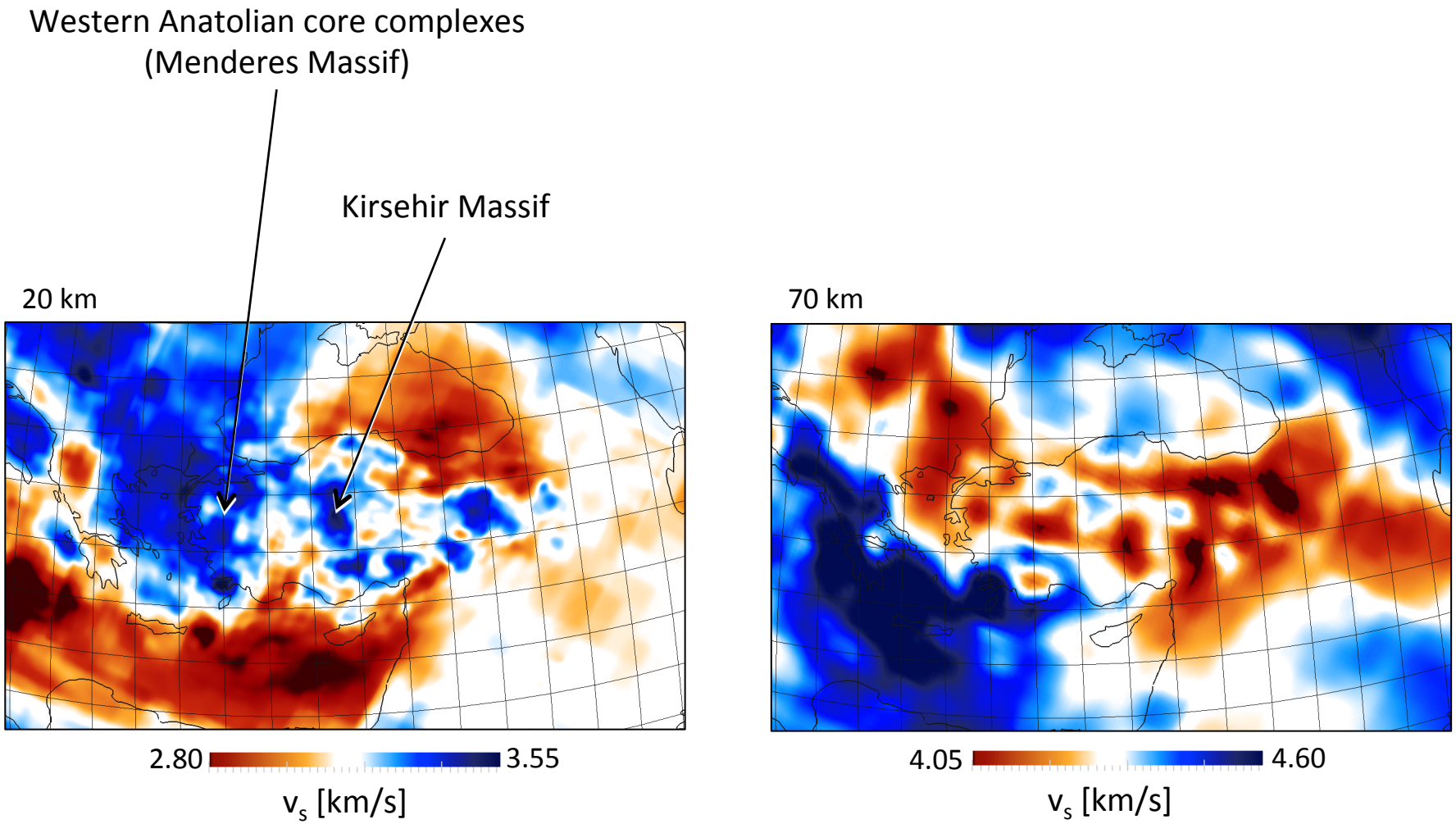

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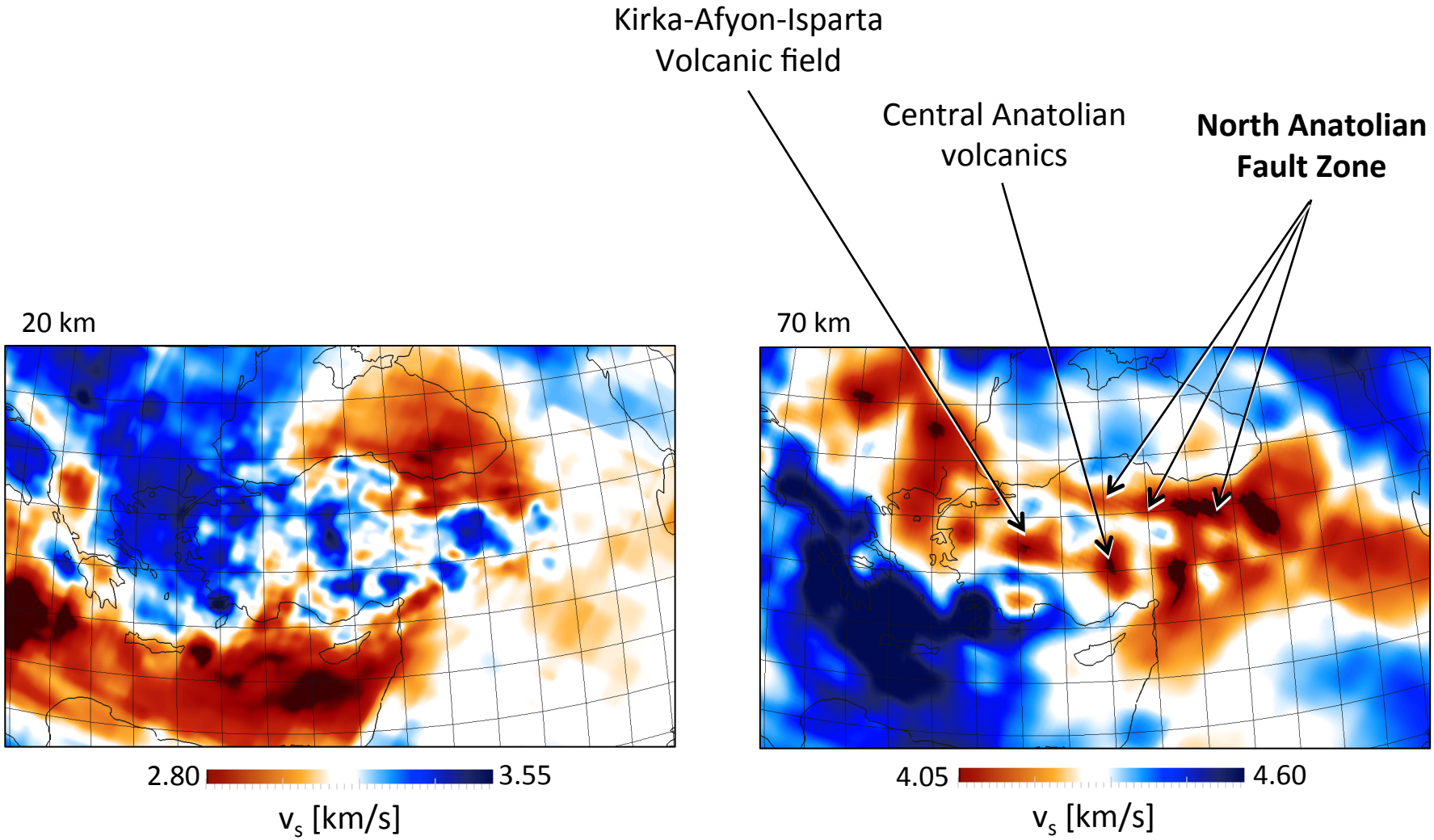

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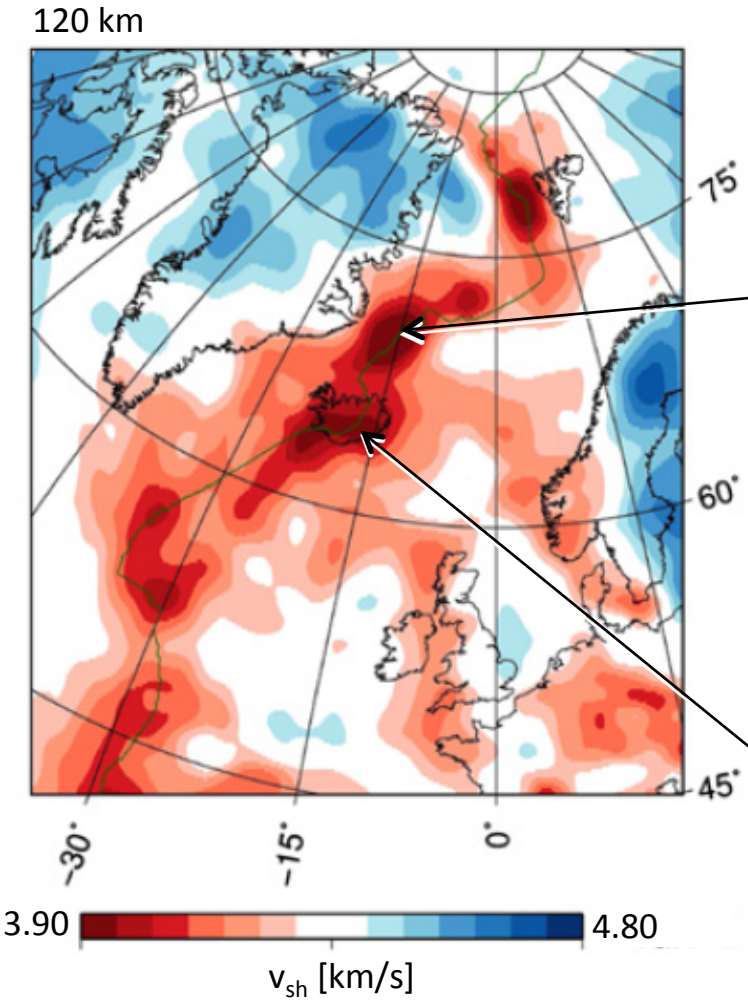
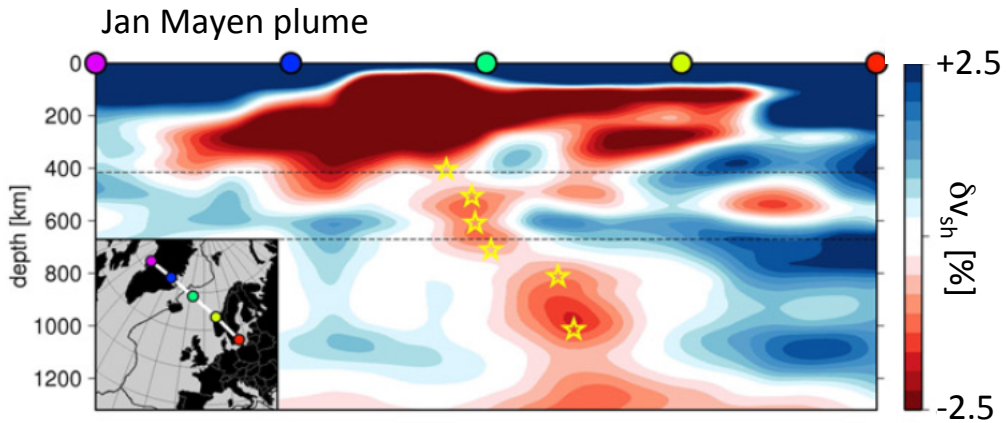
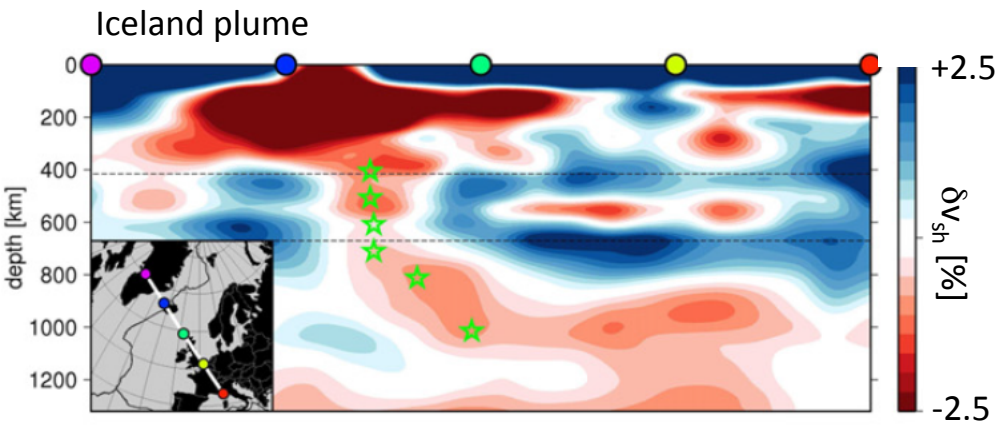


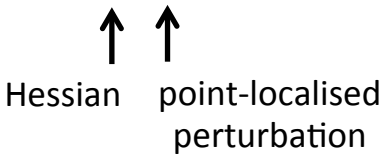




see the next talk by **Florian Rickers**!

# Resolution Analysis

Second-order adjoints to compute point-spread functions: $H \cdot \delta m$



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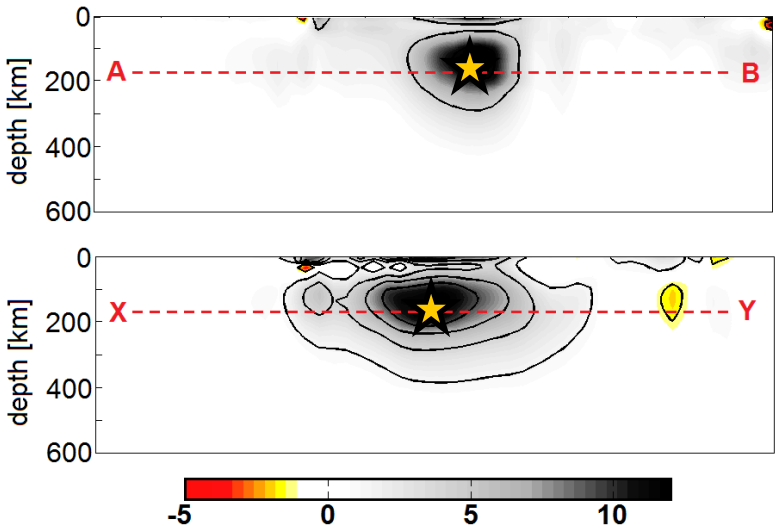
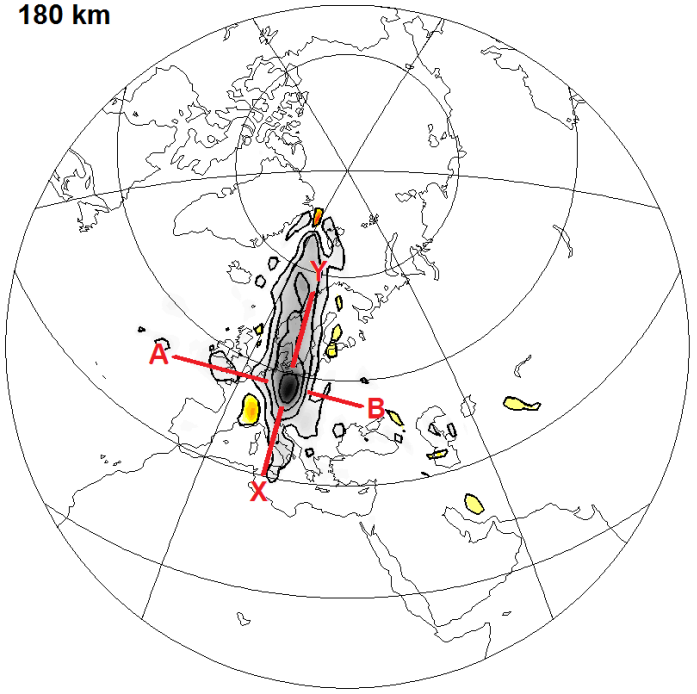
**Example:**

$\delta m$ = point-localised S velocity perturbation at ★



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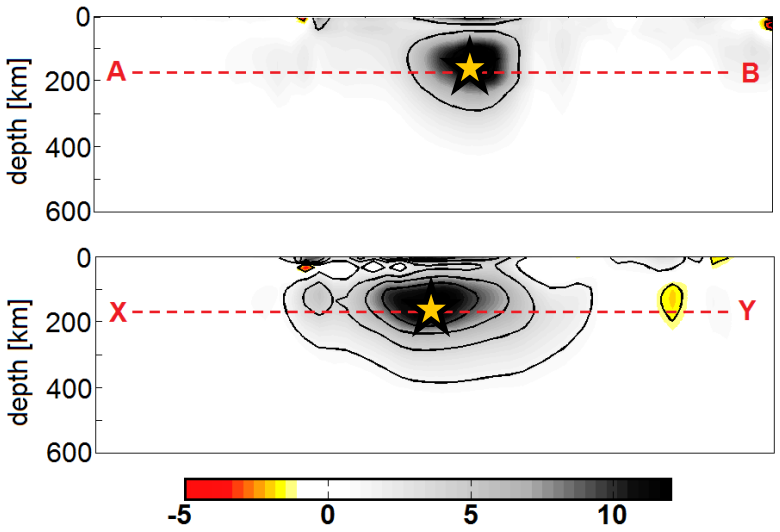
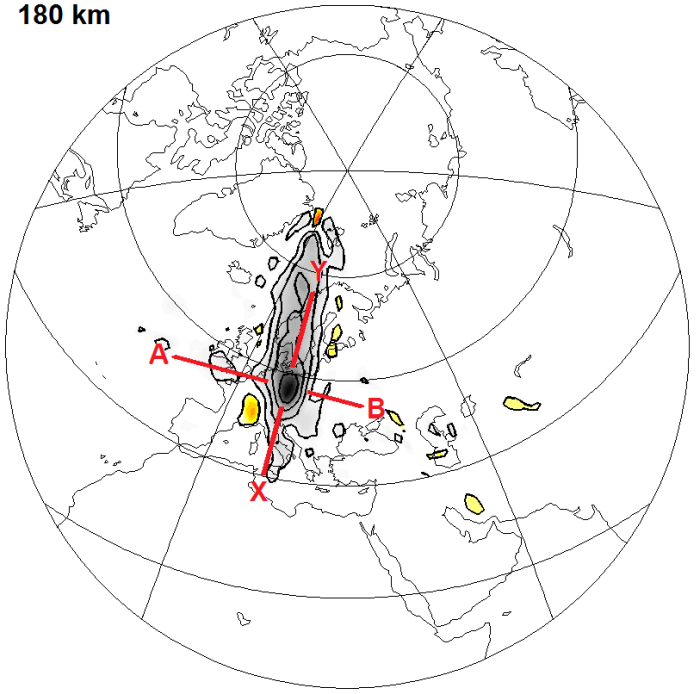


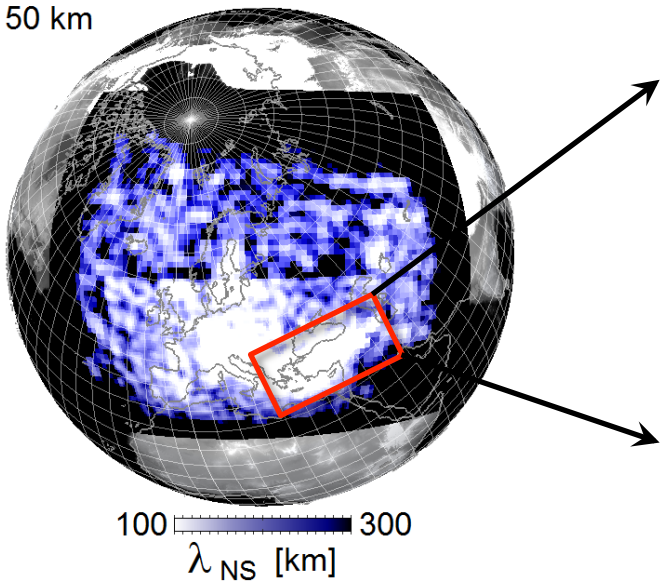

- continuous version of 1 column of the Hessian
- not symmetric
- direction-dependent width defines resolution lengths

# Resolution Analysis

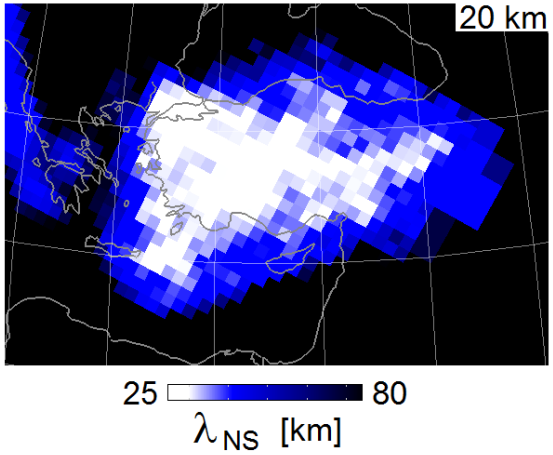
Direction- and position-dependent resolution length (Fichtner and Trampert, 2011a,b)

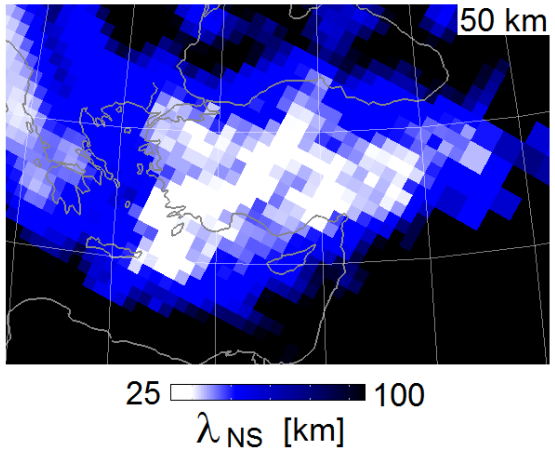
- computed via second-order adjoints

continental-scale resolution




regional-scale resolution (colour scale adapted)



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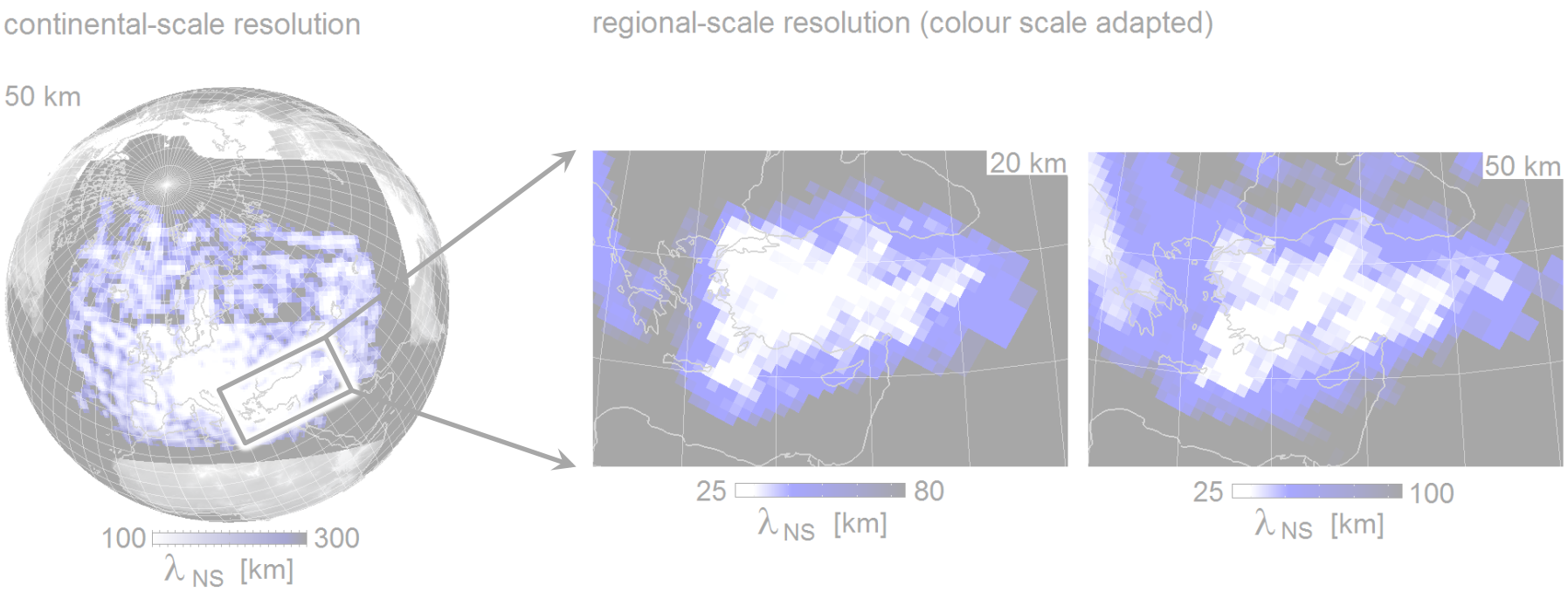
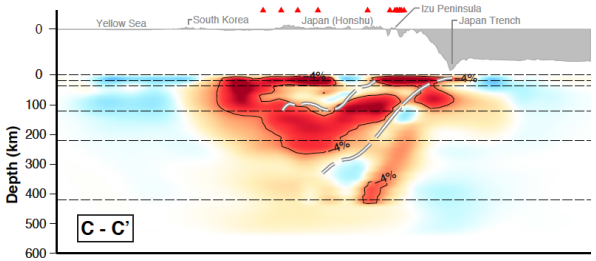


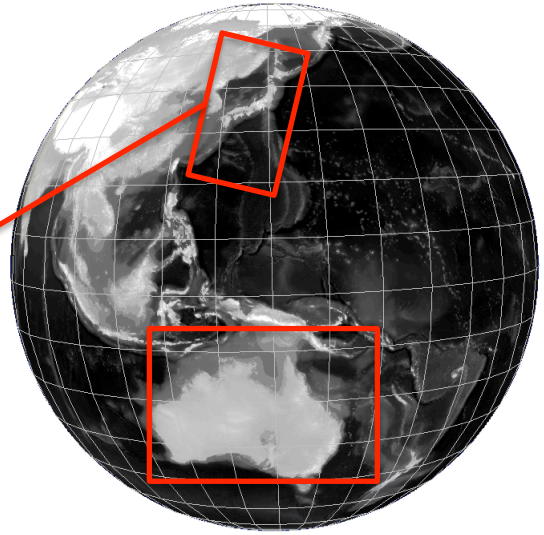

Crustal depth matches receiver function results (Vanacore et al., GJI 2013)

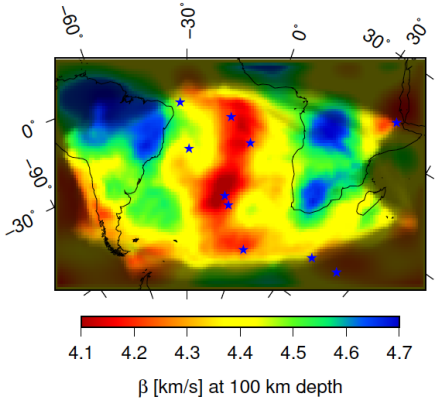
Inter-station Greens functions match noise correlations (not used to construct the model!)

# BEYOND EUROPE

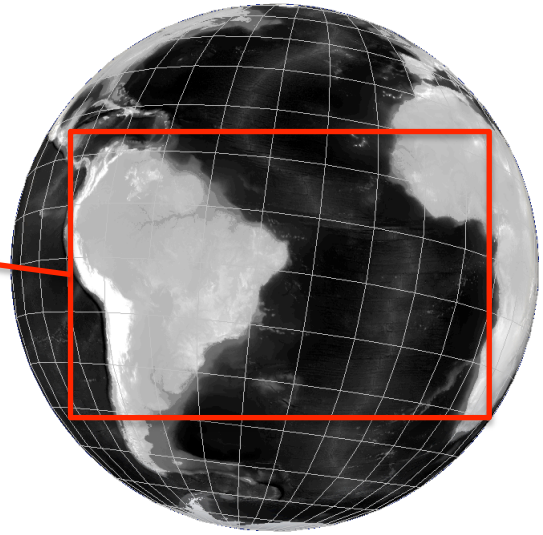


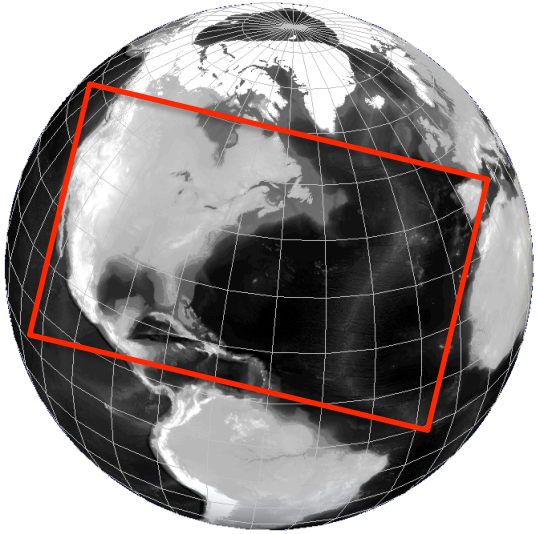

Steptoe et al. (in prep.)






joint with LMU
Colli et al. (in press.)

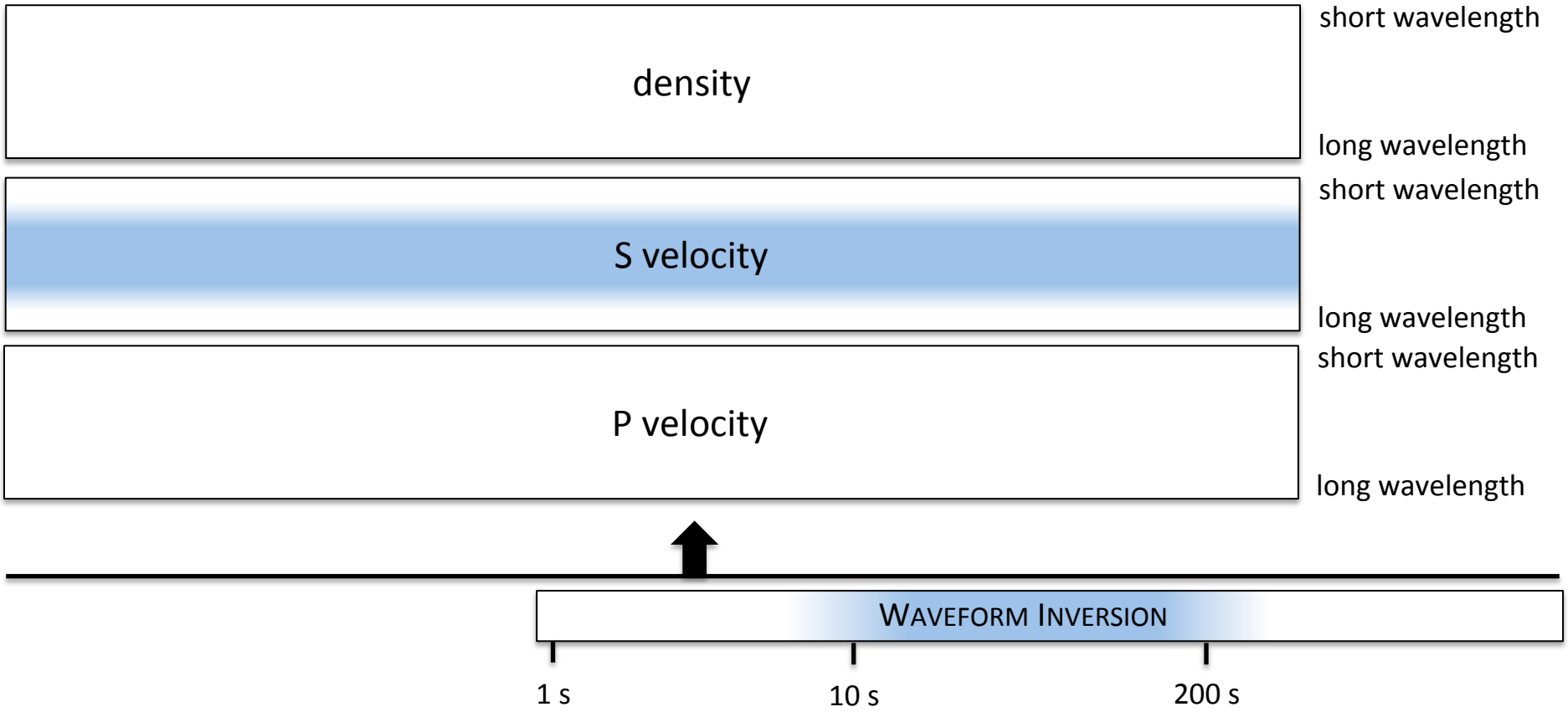


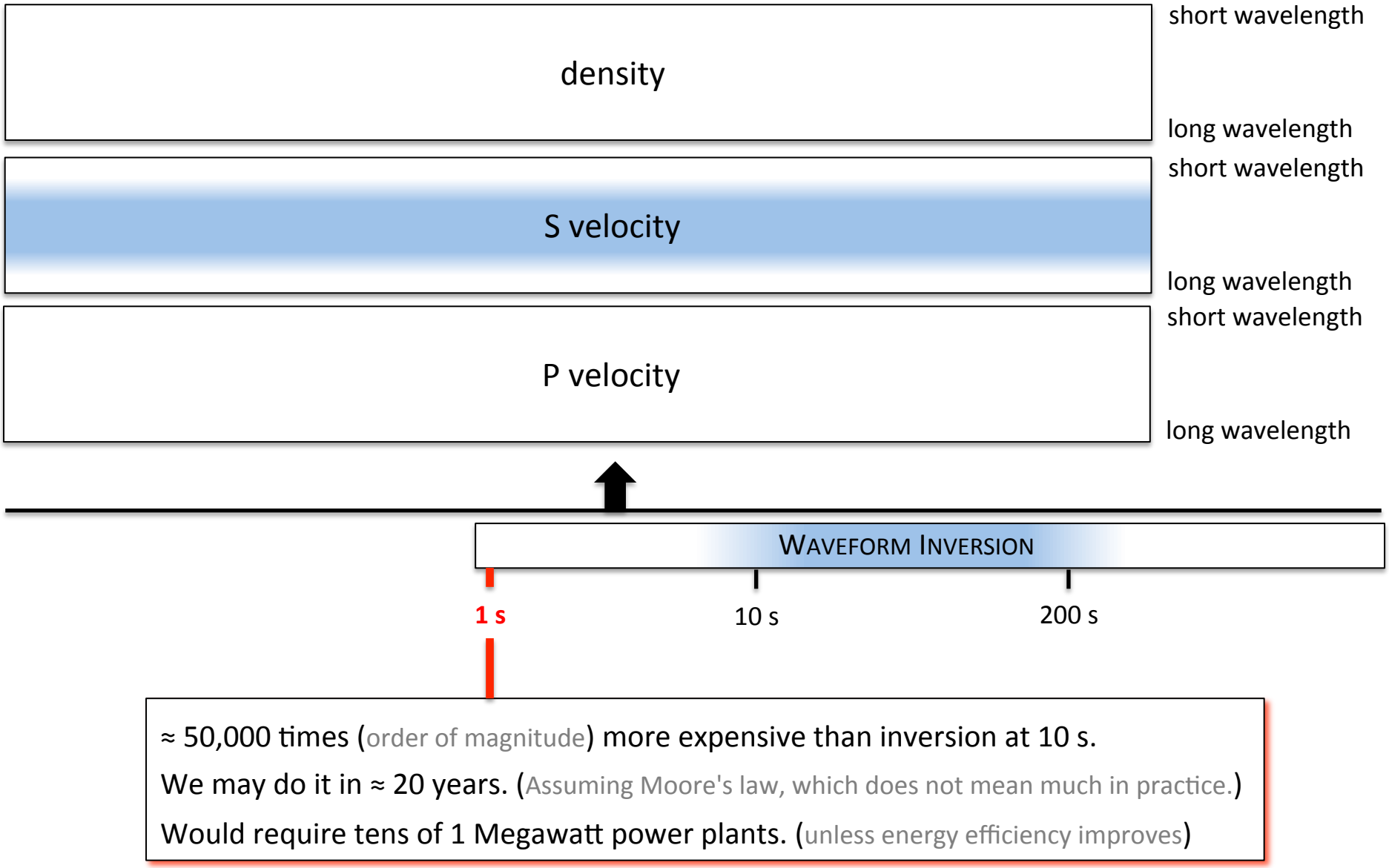


joint with LMU & U. Michigan
Krischer et al. (initial phase)

PhD project of Michael Afanasiev

# Future Plans

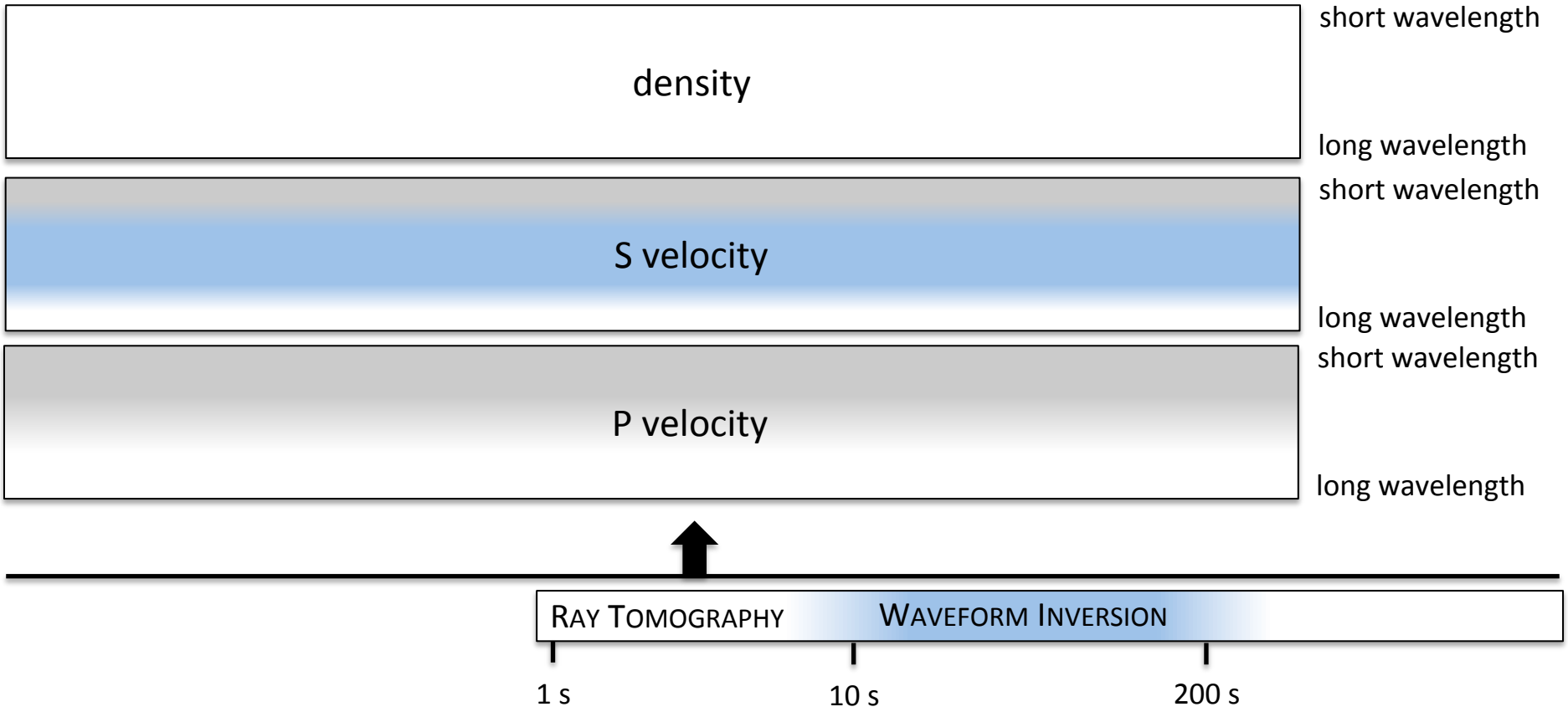

density
short wavelength
long wavelength
S velocity
short wavelength
long wavelength
P velocity
short wavelength
long wavelength
WAVEFORM INVERSION
1 s
10 s
200 s

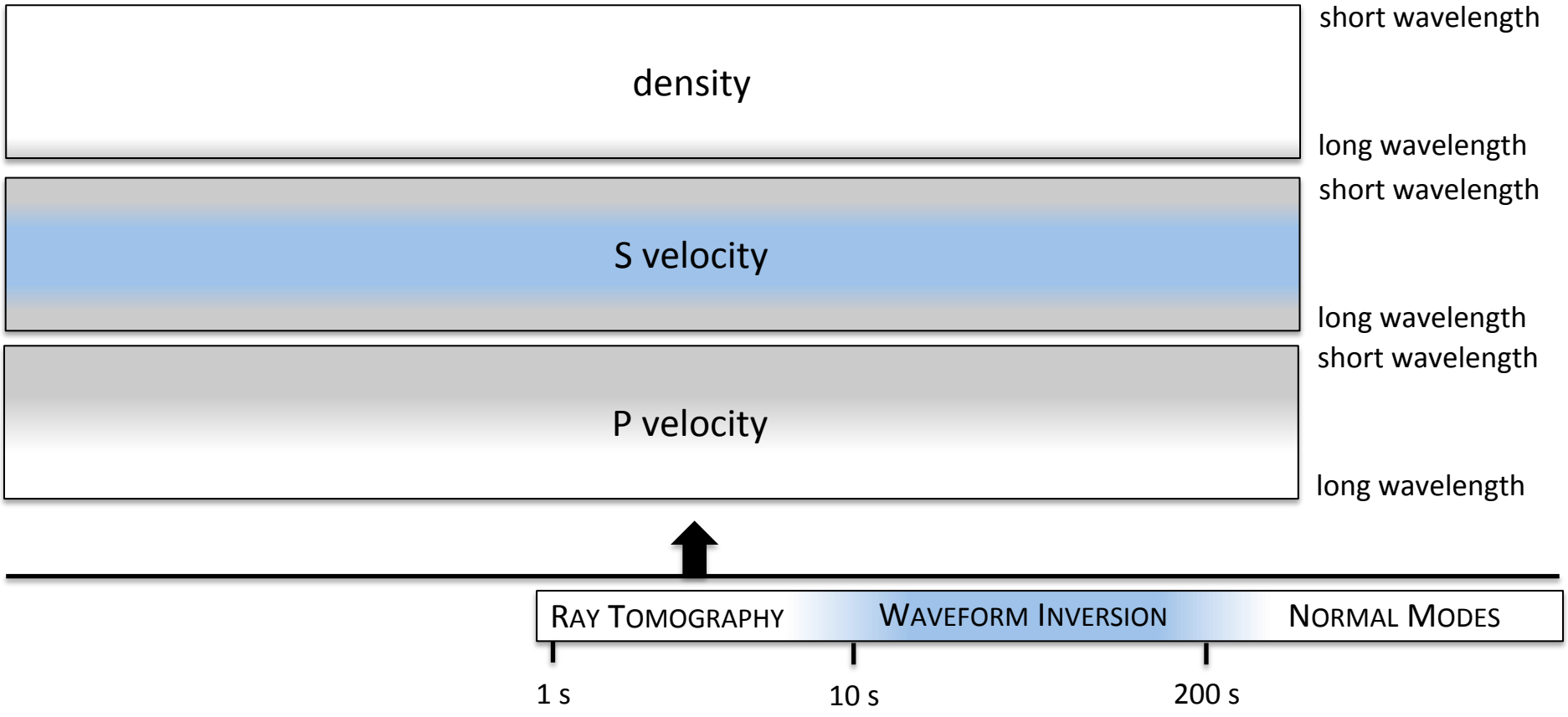


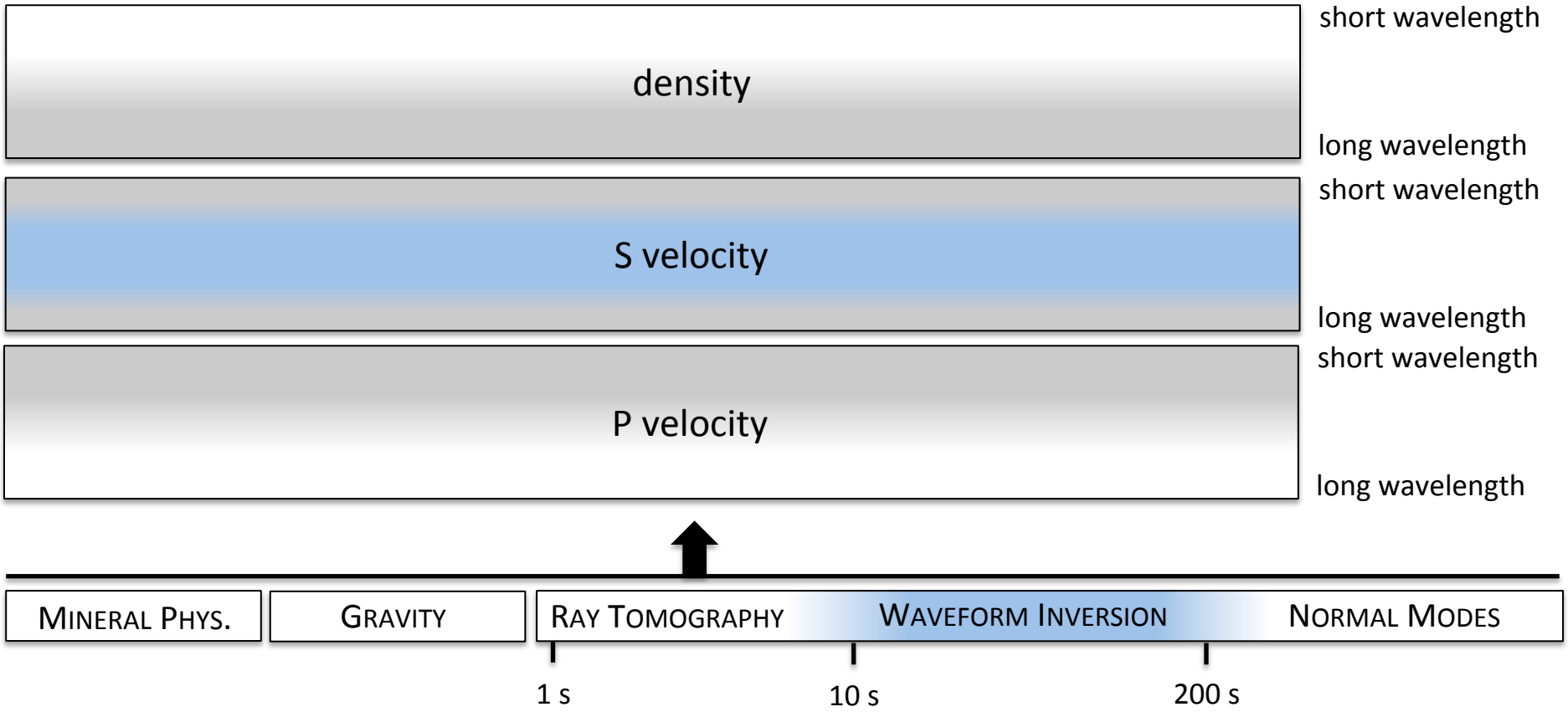

≈ 50,000 times (order of magnitude) more expensive than inversion at 10 s.

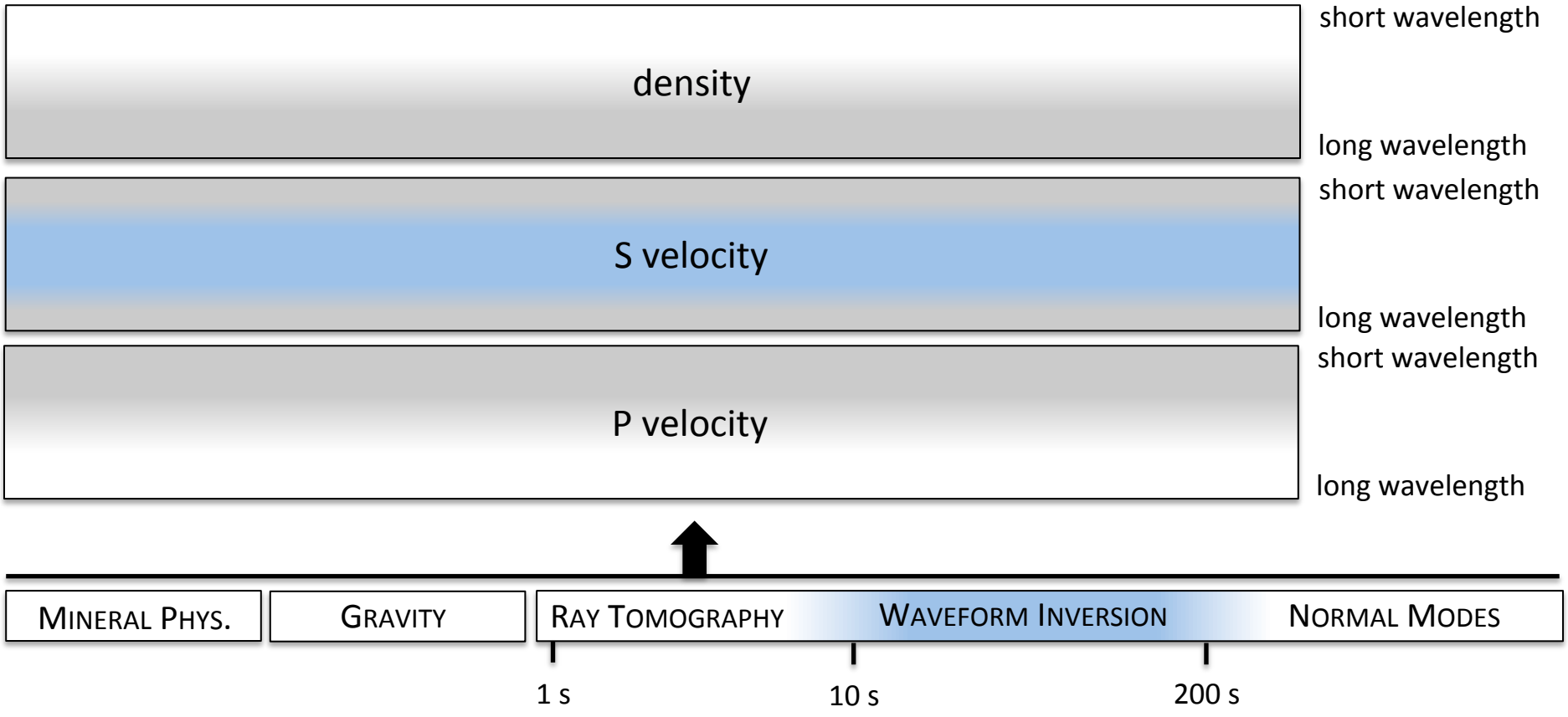
We may do it in ≈ 20 years. (Assuming Moore's law, which does not mean much in practice.)

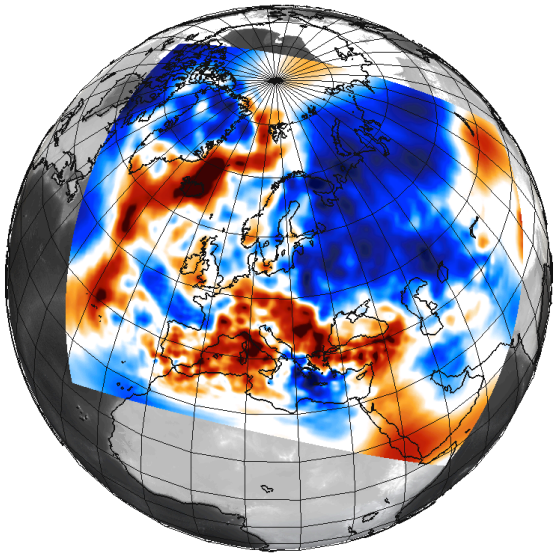
Would require tens of 1 Megawatt power plants. (unless energy efficiency improves)


density
short wavelength
long wavelength
S velocity
short wavelength
long wavelength
P velocity
short wavelength
long wavelength
RAY TOMOGRAPHY
WAVEFORM INVERSION
1 s
10 s
200 s


density
short wavelength
long wavelength
S velocity
short wavelength
long wavelength
P velocity
short wavelength
long wavelength
RAY TOMOGRAPHY
WAVEFORM INVERSION
NORMAL MODES
1 s
10 s
200 s


density
short wavelength
long wavelength
S velocity
short wavelength
long wavelength
P velocity
short wavelength
long wavelength
MINERAL PHYS.
GRAVITY
RAY TOMOGRAPHY
WAVEFORM INVERSION
NORMAL MODES
1 s
10 s
200 s




Towards a comprehensive Earth model ...

Thanks for your attention!