Joint inversion of gravity data together with Pg traveltimes

from shots and Pg/Sg onsets from earthquakes in the Western Bohemia/Vogtland swarm region

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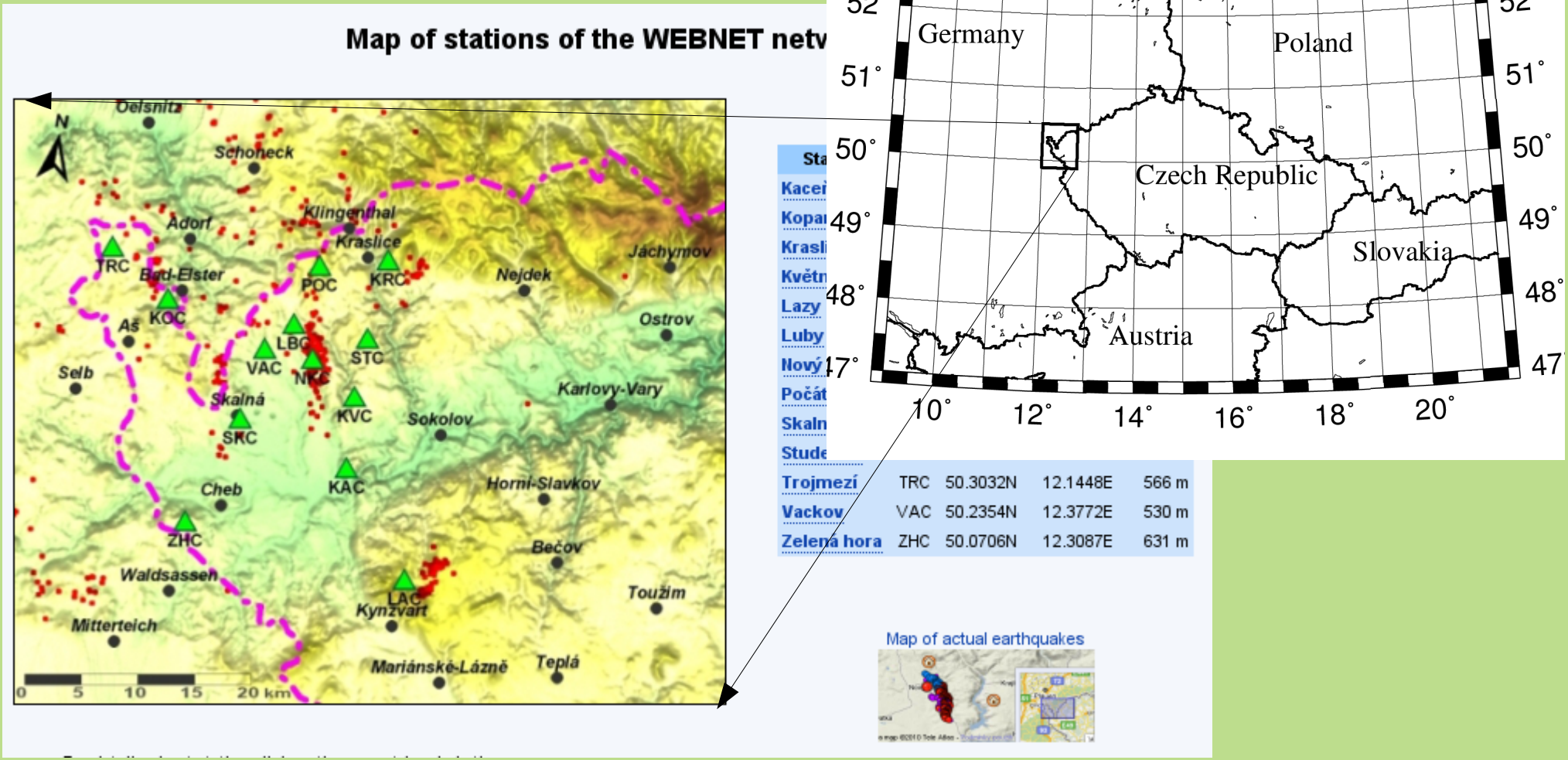
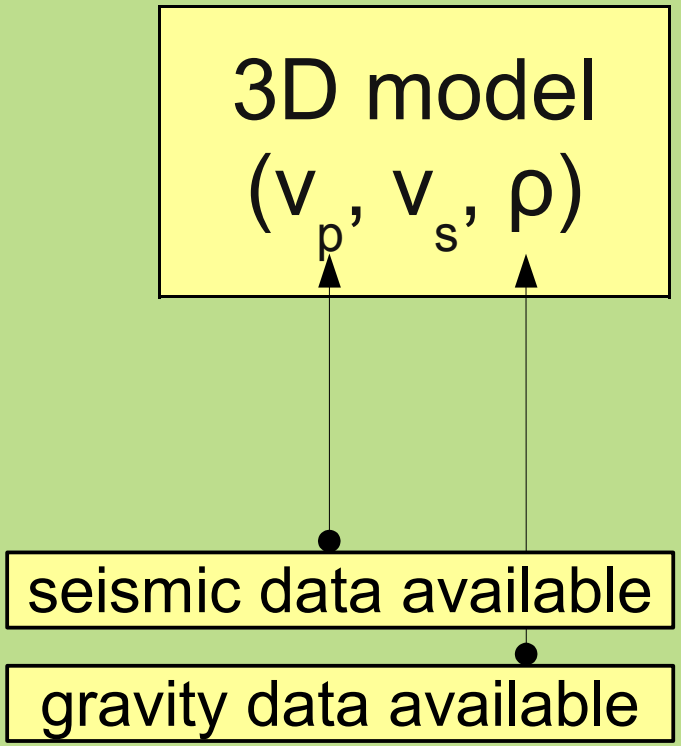
Western Bohemia/Vogtland region is known for the occurrence of seismic swarms,



but till now no commonly accepted 3D model is available ...



→ Geological building

→ Foci localization

→ Foci mechanisms

→ Understanding seismograms

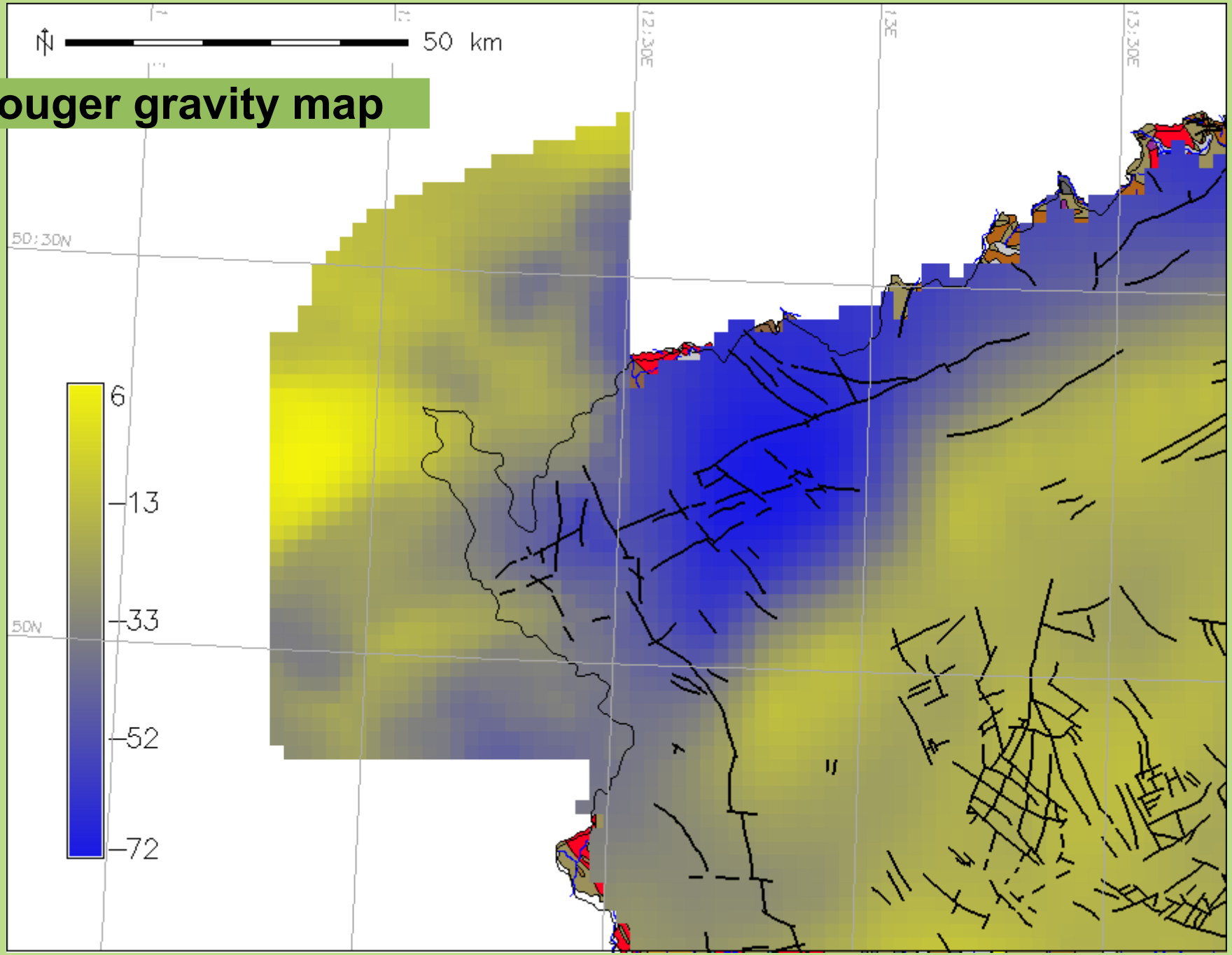
→ Methodology

→ ???

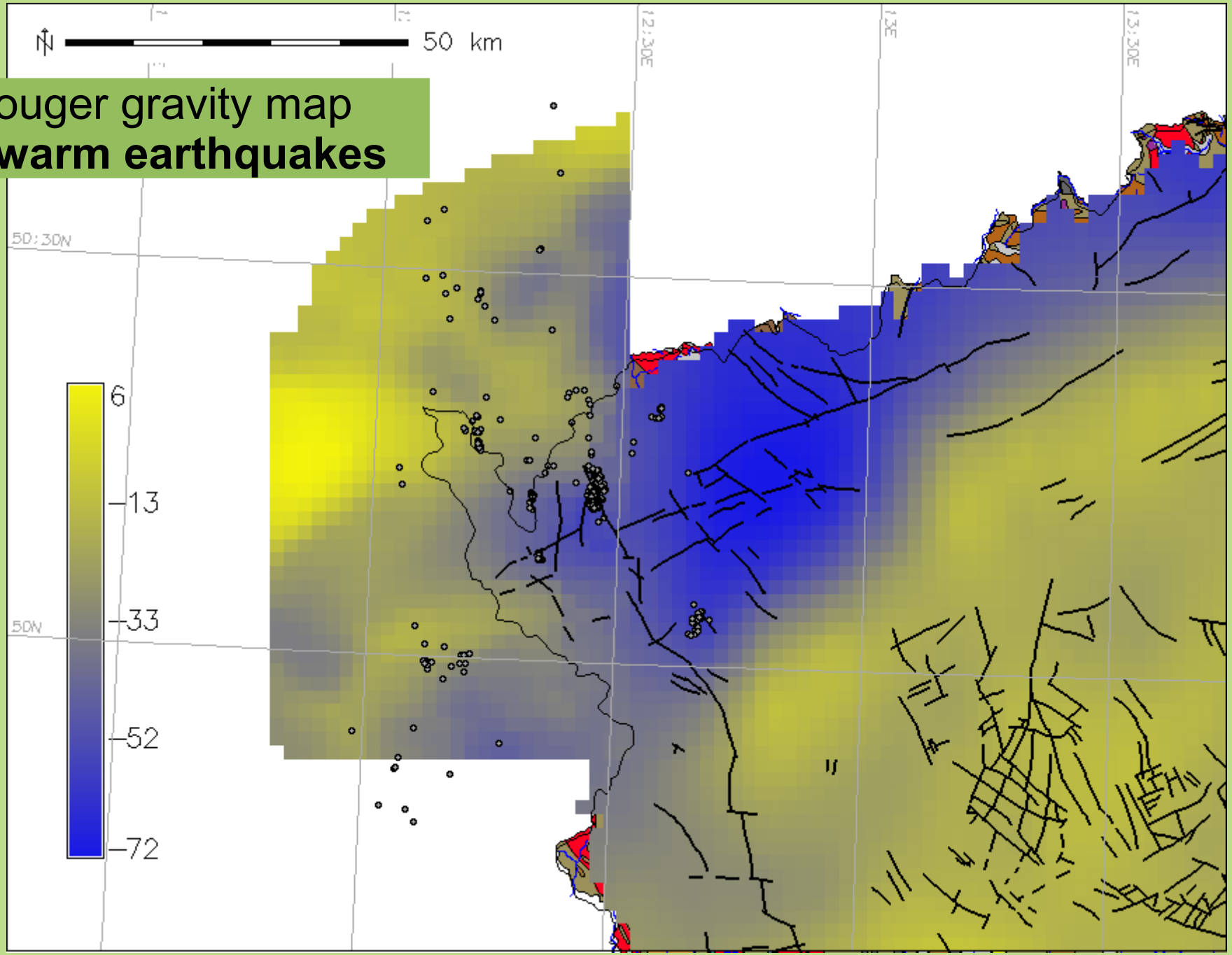
Contents

- Data sets available
- Methodology
- Test
- Indicative result

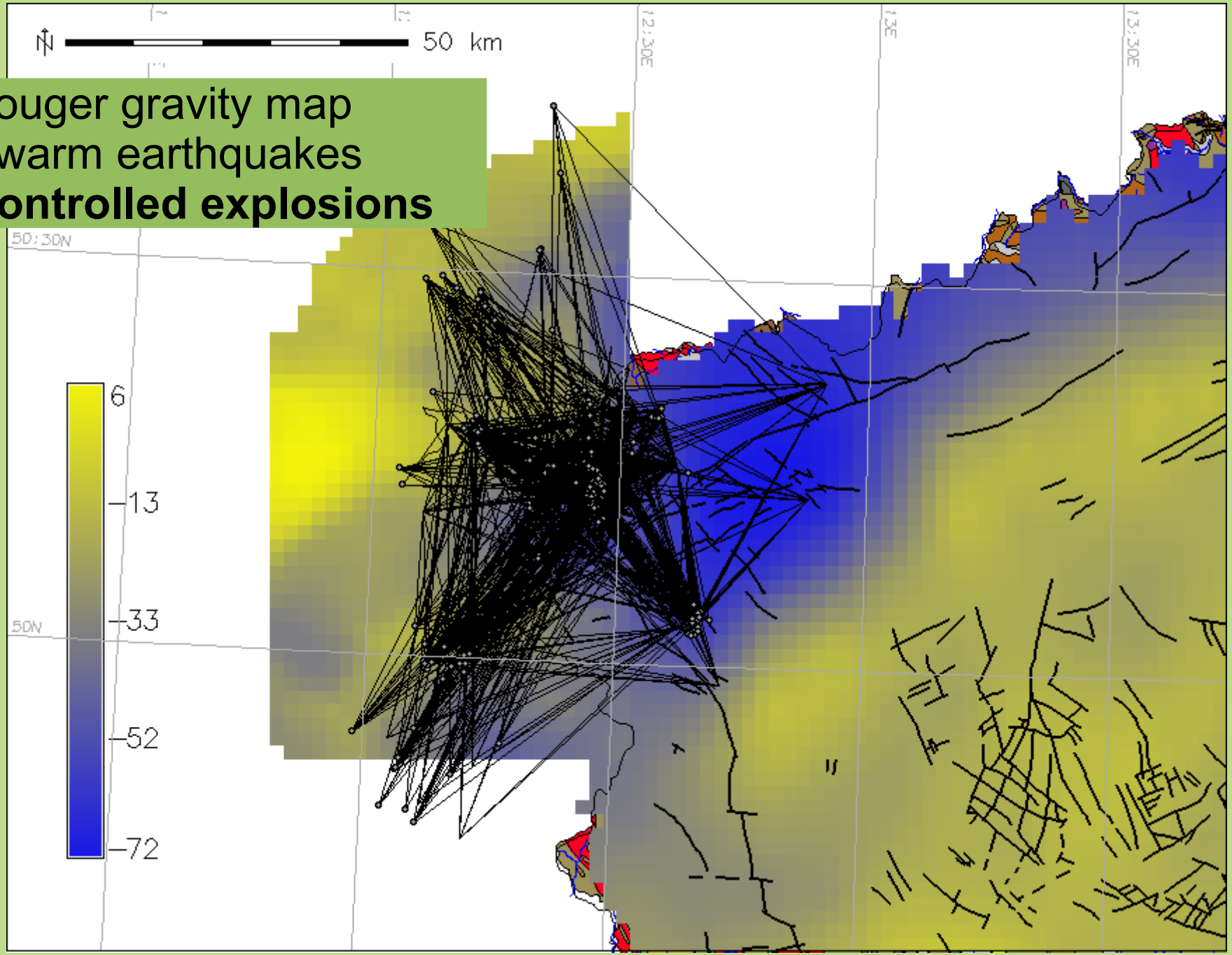
- **Bouger gravity map**



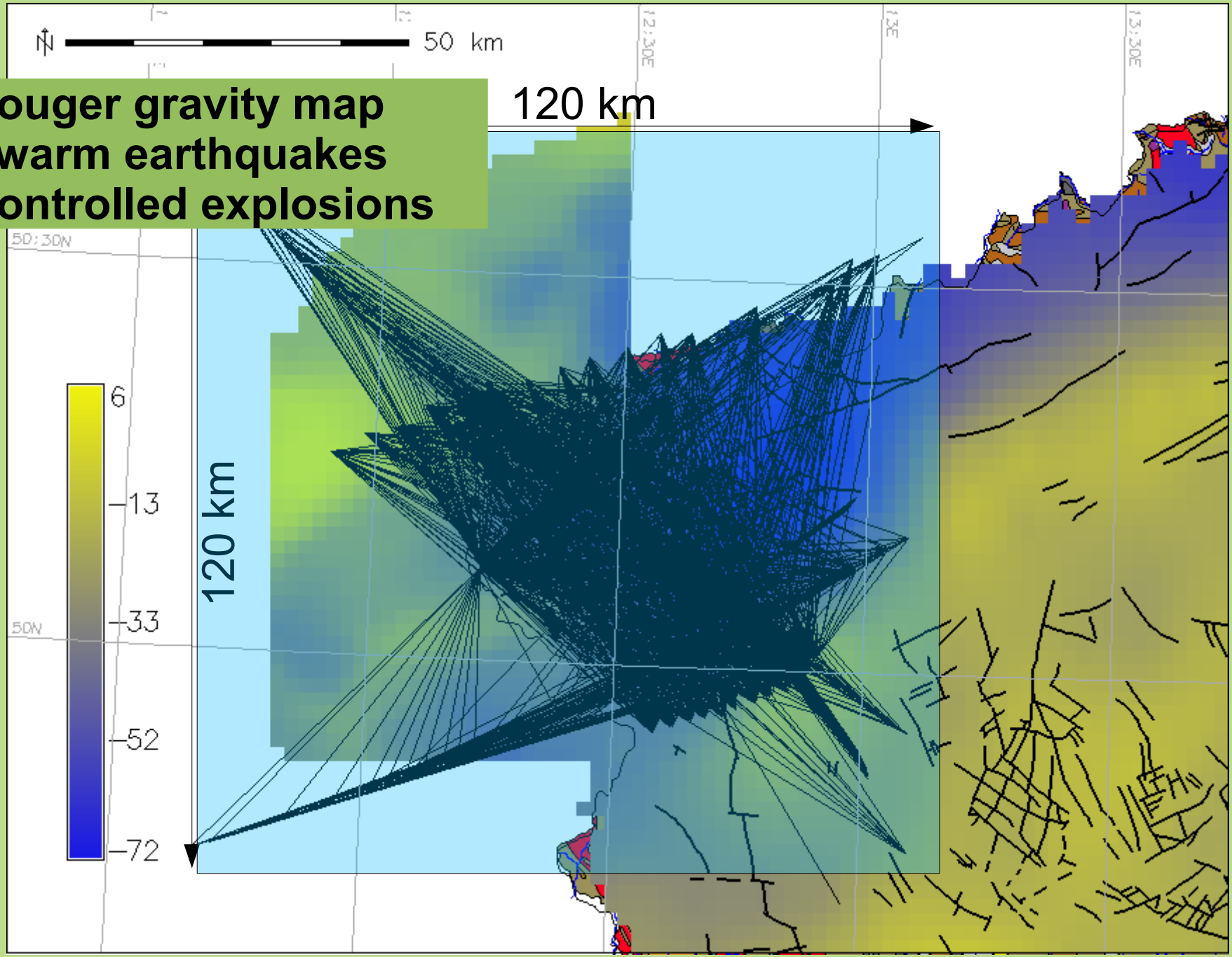
- Bouger gravity map
- **Swarm earthquakes**



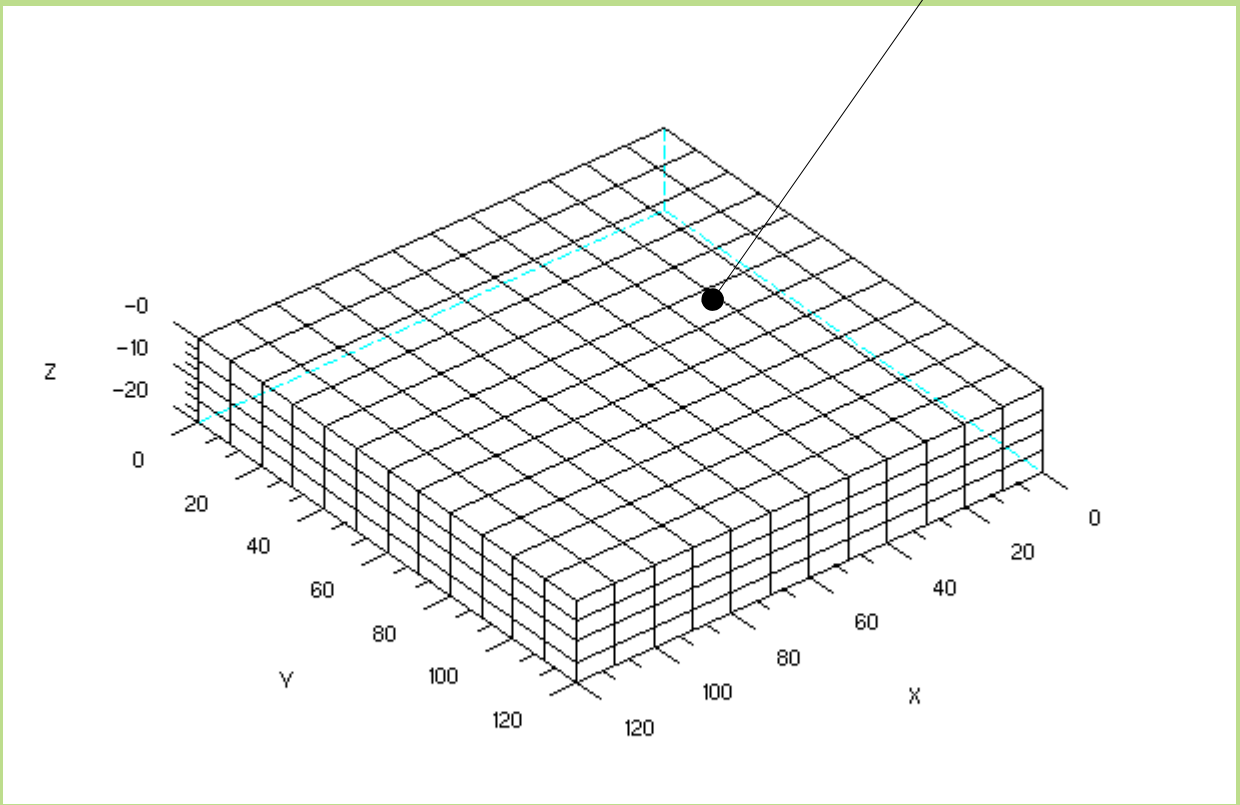
- Bouger gravity map
- Swarm earthquakes
- **Controlled explosions**



- **Bouger gravity map**
- **Swarm earthquakes**
- **Controlled explosions**



Globe ↔ rectangle
Lambert projection



dx = dy = dz = 2 km
nx = 48
ny = 54
nz = 17
44064 cells

Data space

2821 rays from explosions (P)

6405 rays from earthquakes (P)

6716 rays from earthquakes (S)

1371 gravity measurements

n = 17323

Model space

732 earthquake localizations (x,y,z,T)

44064 x (v_p,v_s,ρ)

m = 732*4 + 54000*3 = 135120

m ≤≤ 135120

Single inversion

$$g(m)=d$$
$$d^{obs}$$
$$m^{sol}: g(m)\rightarrow d^{obs}$$

Joint inversion of 1st kind

$$g_1(m)=d_1$$
$$g_2(m)=d_2$$

$$\begin{bmatrix} g_1(m) \\ g_2(m) \end{bmatrix}=\begin{bmatrix} d_1 \\ d_2 \end{bmatrix}$$

$$m^{sol}:\begin{bmatrix} g_1(m) \\ g_2(m) \end{bmatrix}\rightarrow\begin{bmatrix} d_1^{obs} \\ d_2^{obs} \end{bmatrix}$$

Joint inversion of 2nd kind

$$g_1(m_1)=d_1$$
$$g_2(m_2)=d_2$$

$$\begin{bmatrix} g_1(m_1) \\ g_2(m_2) \\ g_r(m_1,m_2) \end{bmatrix}=\begin{bmatrix} d_1 \\ d_2 \\ 0 \end{bmatrix}$$

$$g_r(m_1,m_2): \rho=k_1 * v_p+k_2 \, etc.$$

“Cross-gradient method”

$$\boldsymbol{m}_1 \rightarrow \rho(x, y, z)$$
$$\boldsymbol{m}_2 \rightarrow v_p(x, y, z)$$

$$\nabla(\rho) * \nabla(v_p) = \mathbf{0}$$

- ρ = const
- v_p = const
- grad(ρ) || grad(v_p)

Decoupled inversion

Collocated structures

Gallardo, L. A., and M. A. Meju, 2004. Joint two-dimensional DC resistivity and seismic travel time inversion with cross-gradients constraints: *Journal of Geophysical Research*, **109**, B03311, doi: 10.1029/2003JB002716.

Tryggvason, A., and N. Linde, 2006. Local earthquake (LE) tomography with joint inversion for P- and S-wave velocities using structural con-straints: *Geophysical Research Letters*, **33**, L07303, doi: 10.1029/2005GL025485.

Fregoso E. and Gallardo L.A., 2009. Cross-gradients joint 3D inversion with applications to gravity and magnetic data. *Geophysics* **74**, No. 4, P. L31–L42, 10.1190/1.3119263.

Synthetic example

10 x 10 = 100 cells

90 P-measurements

90 S-measurements

No constraints

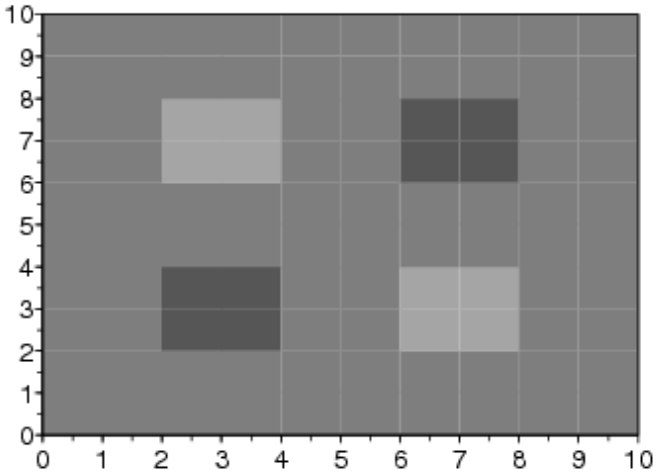
Regularization via SVD

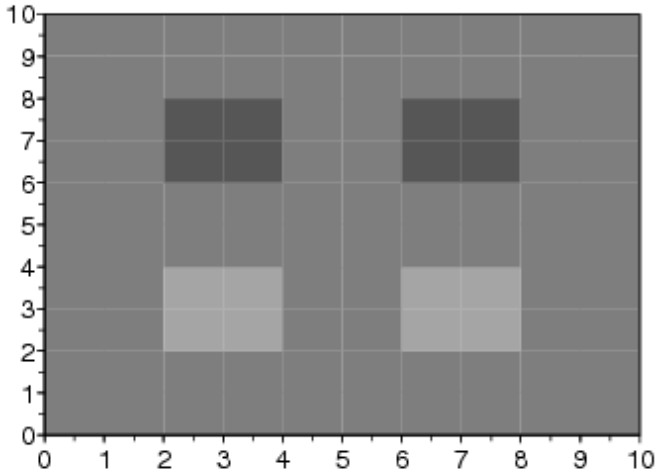
P-slowness

S-slowness

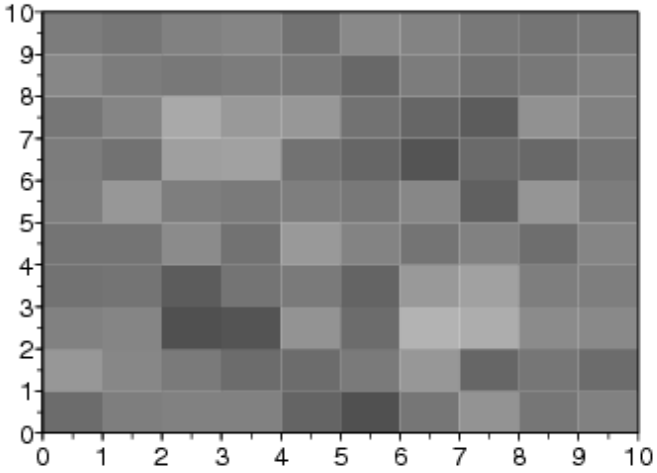
± 10 % anomalies

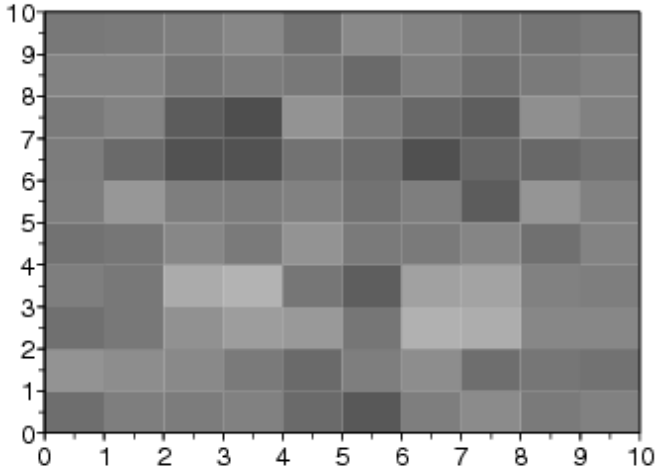
Input patterns





Reconstruction





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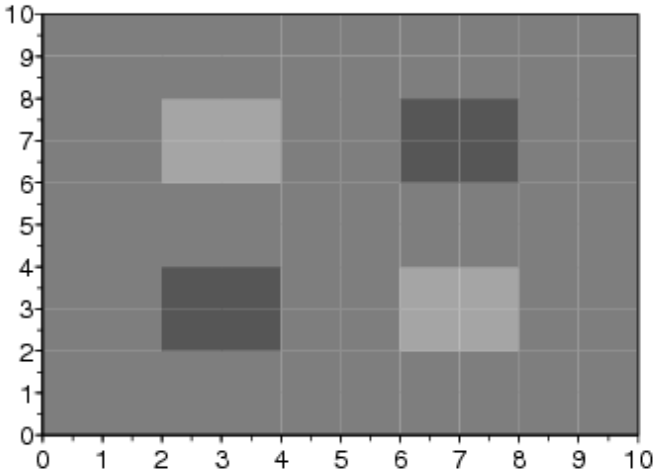

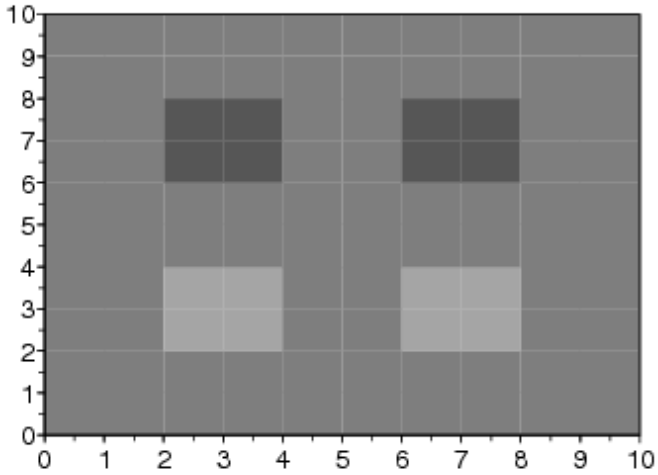

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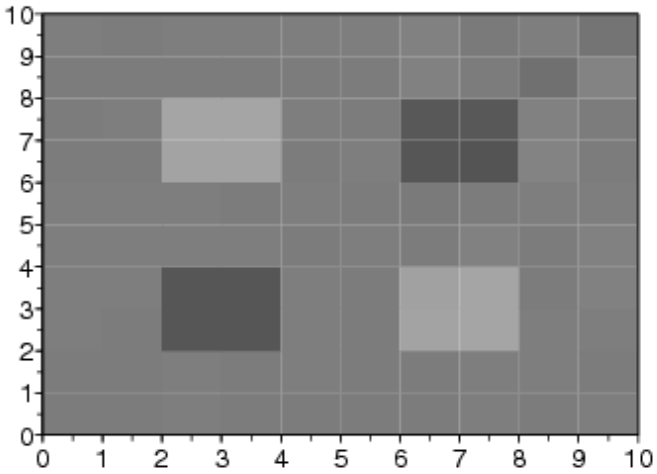

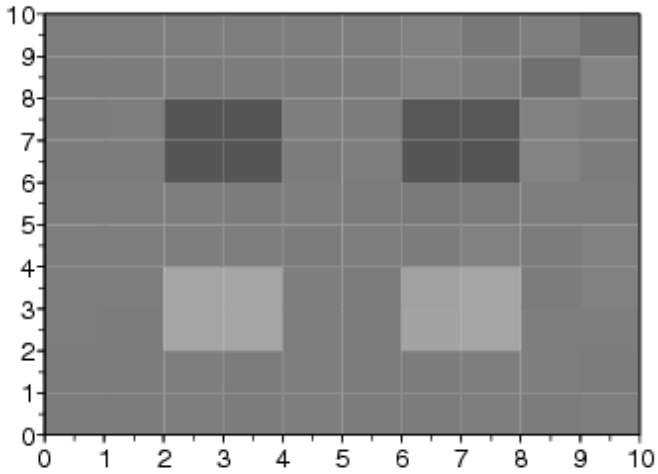

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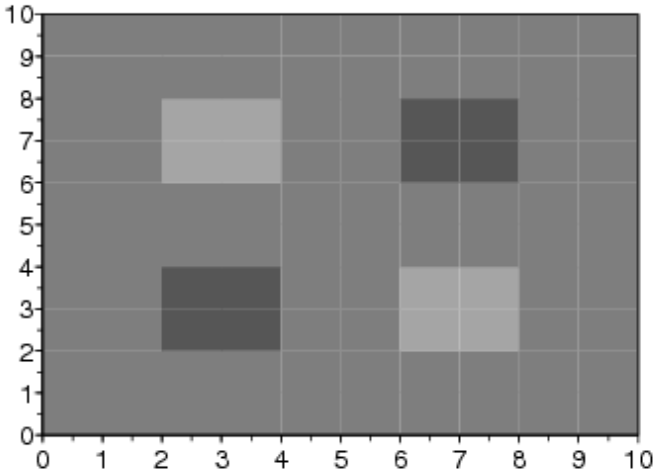

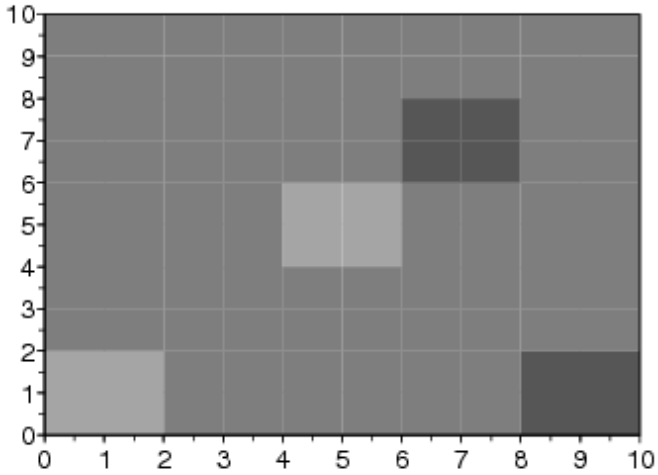

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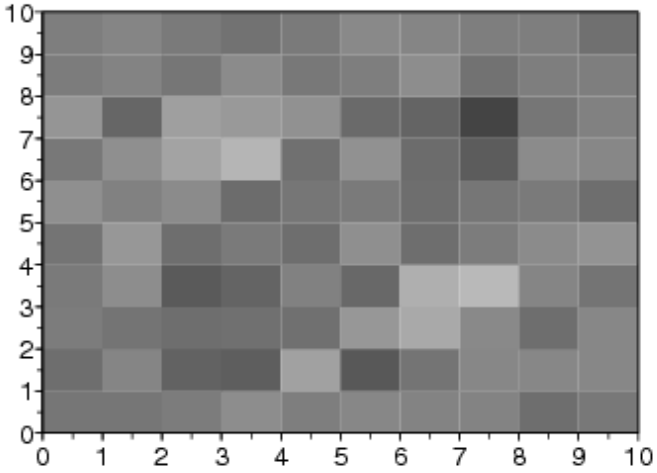
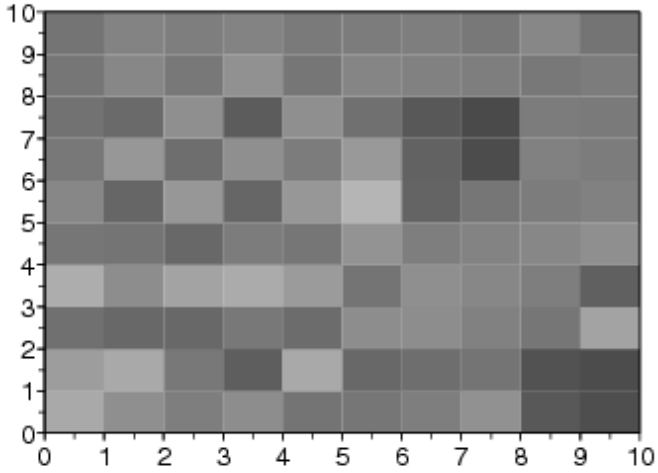
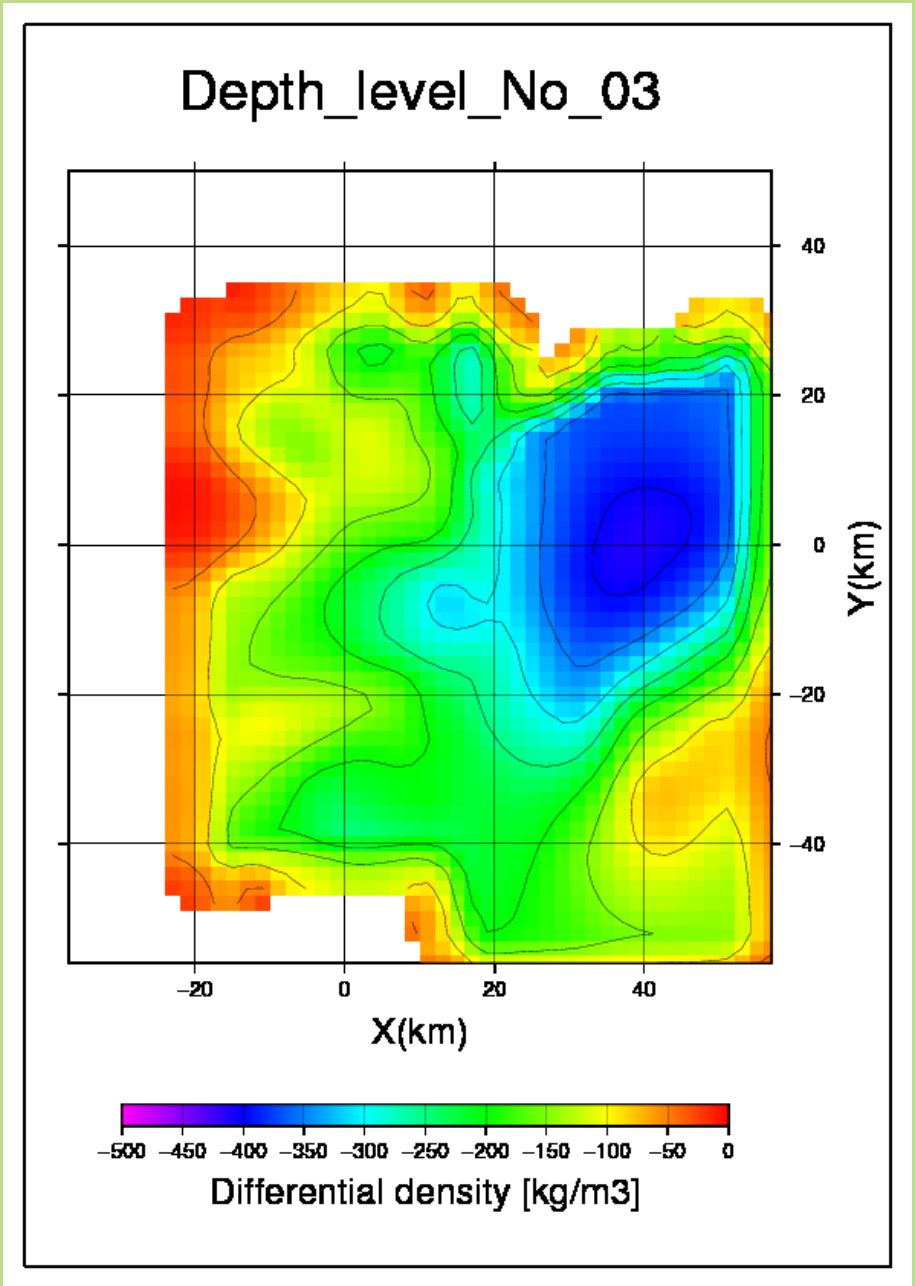
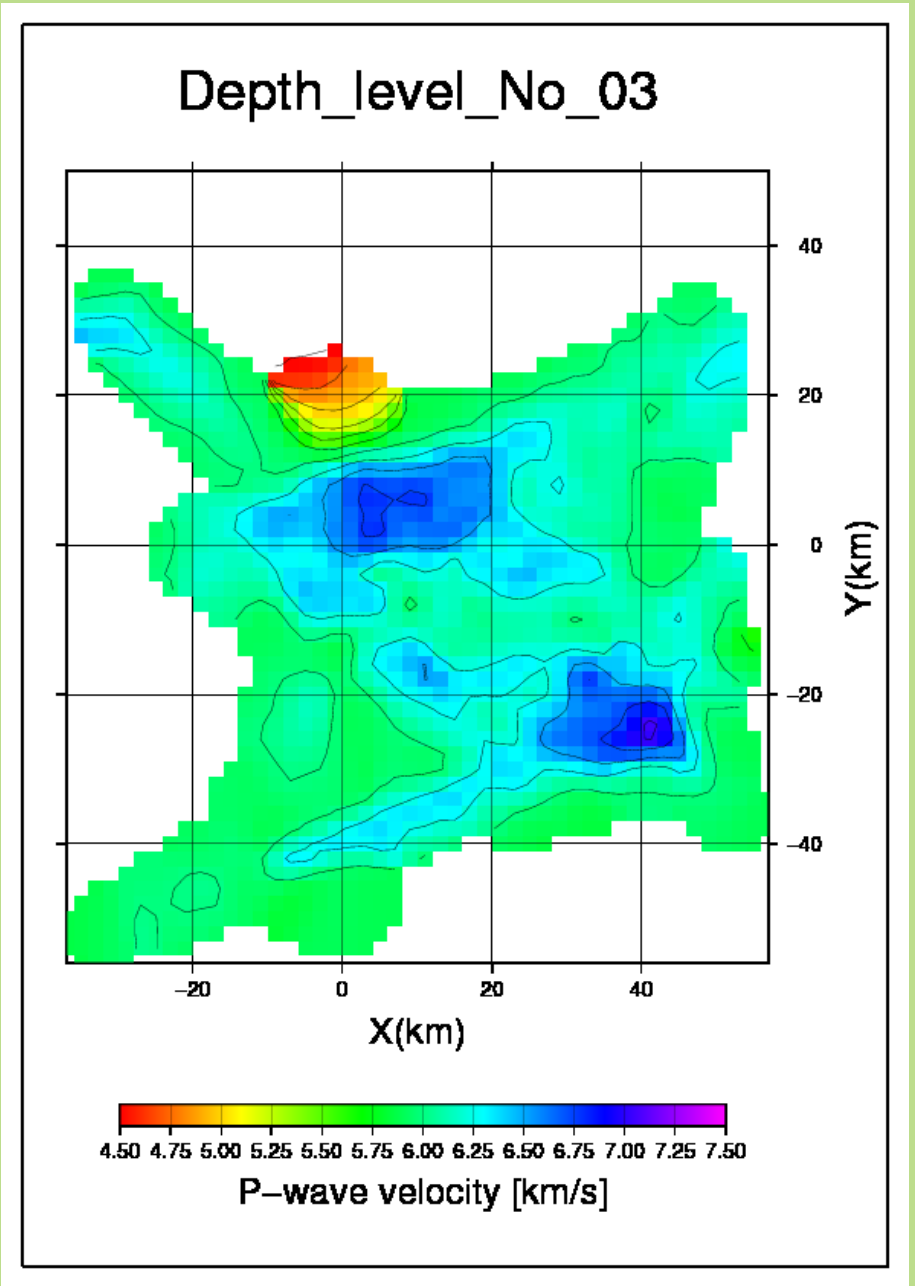




Including cross-gradient constraint helps to discover structurally similar objects

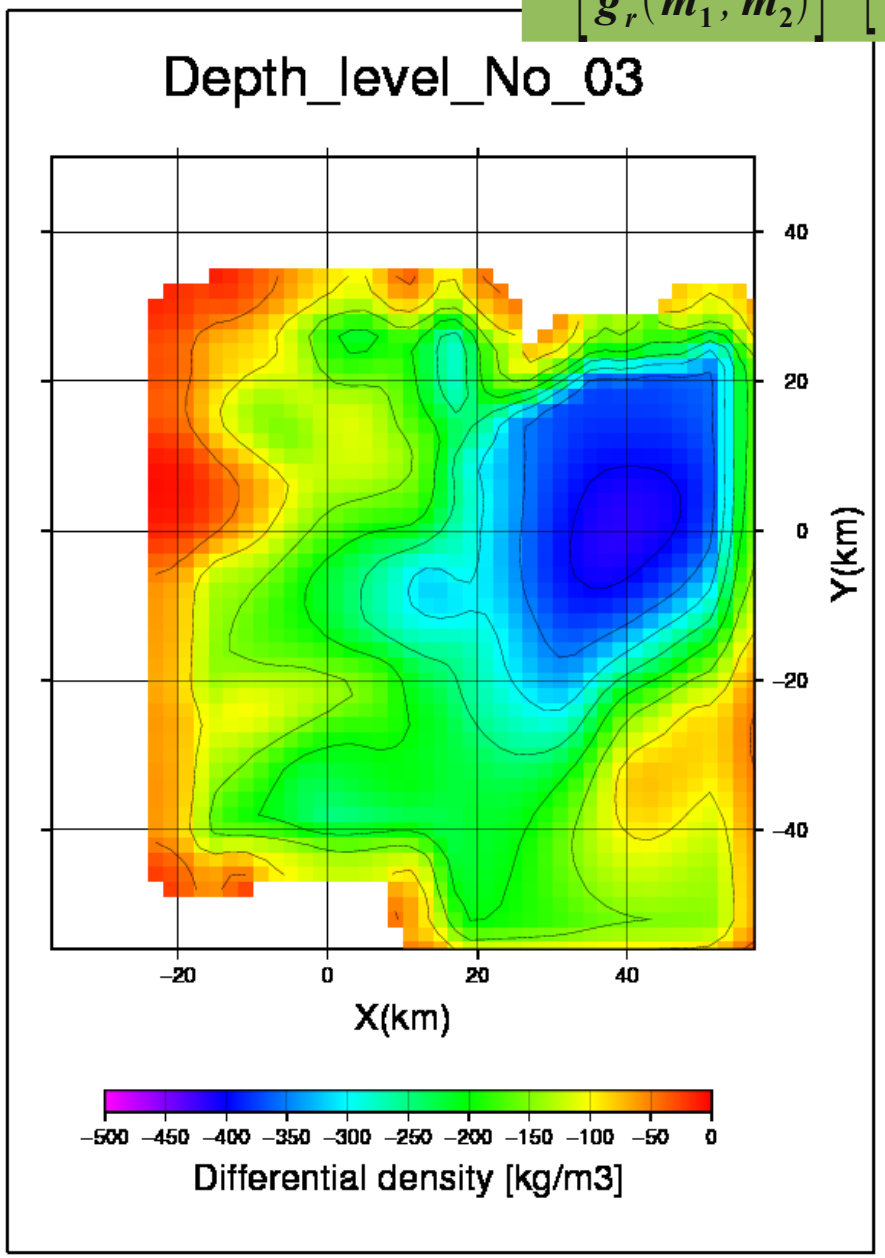
Horizontal cross-sections in a depth of 4 km

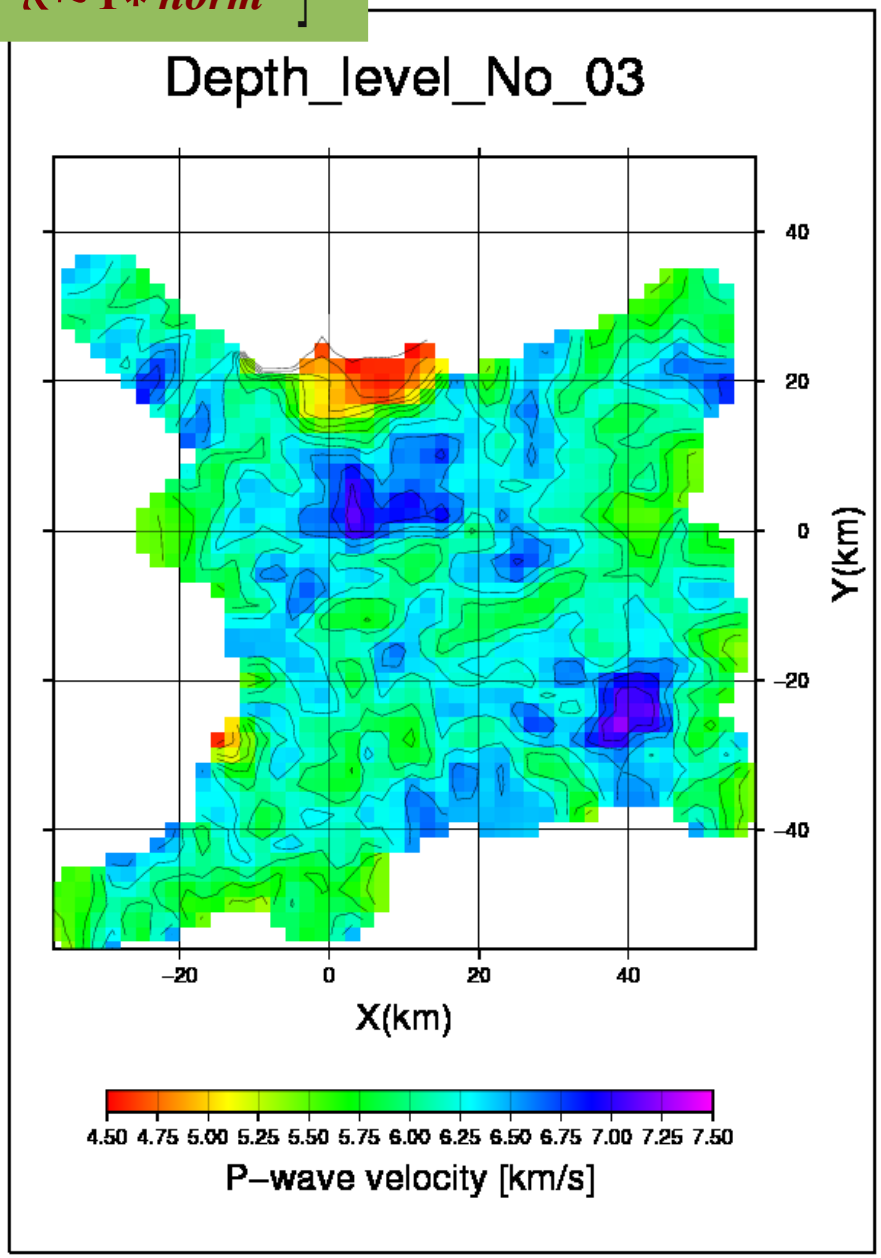




Horizontal cross-sections in a depth of 4 km

$$\begin{bmatrix} g_1(m_1) \\ g_2(m_2) \\ g_r(m_1, m_2) \end{bmatrix} = \begin{bmatrix} d_1 \\ d_2 \\ 0 \end{bmatrix} \leftarrow \begin{bmatrix} \Delta t \approx 0.1\,s \\ \Delta g \approx 0.4\,mGal \\ \lambda \approx 1 * norm \end{bmatrix}$$





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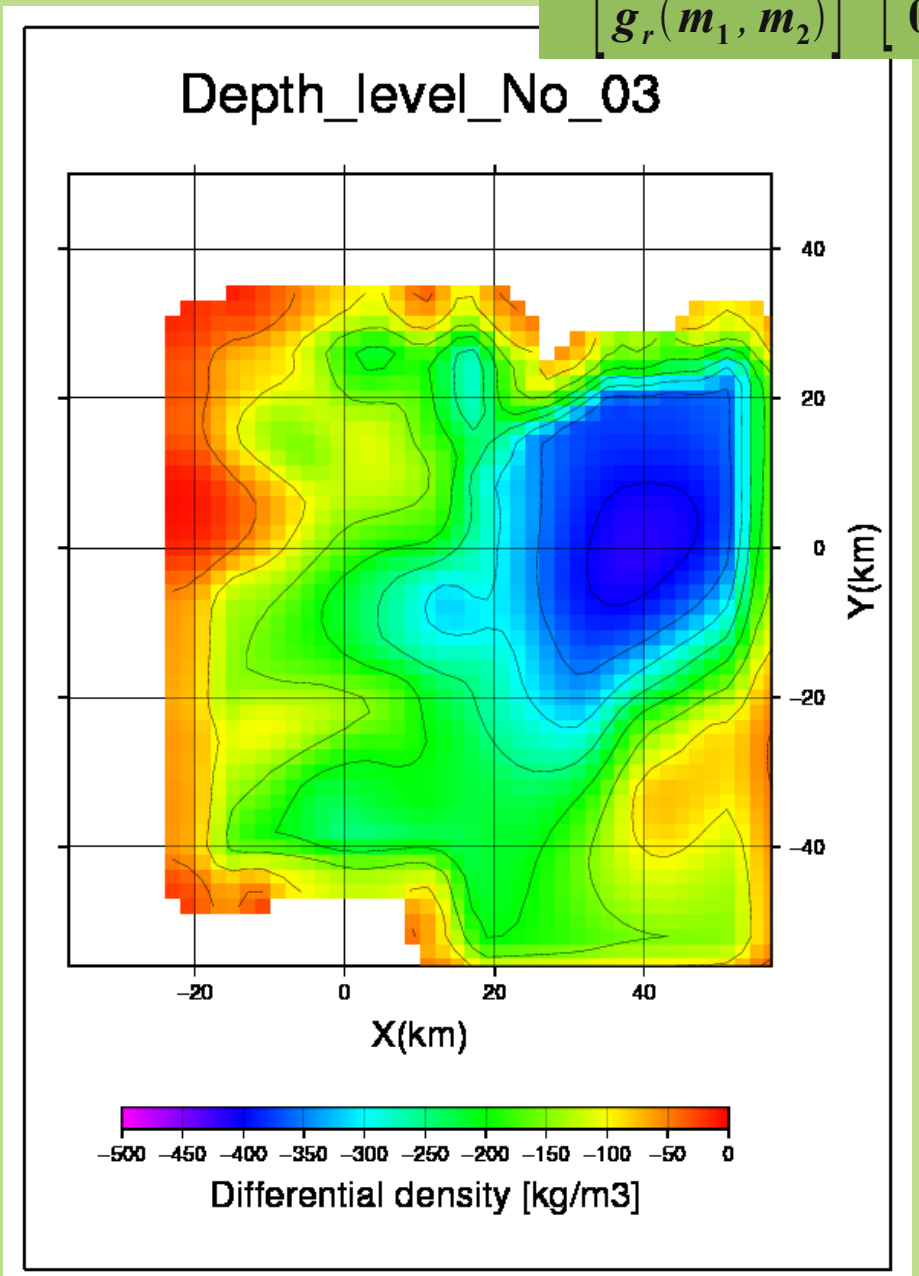

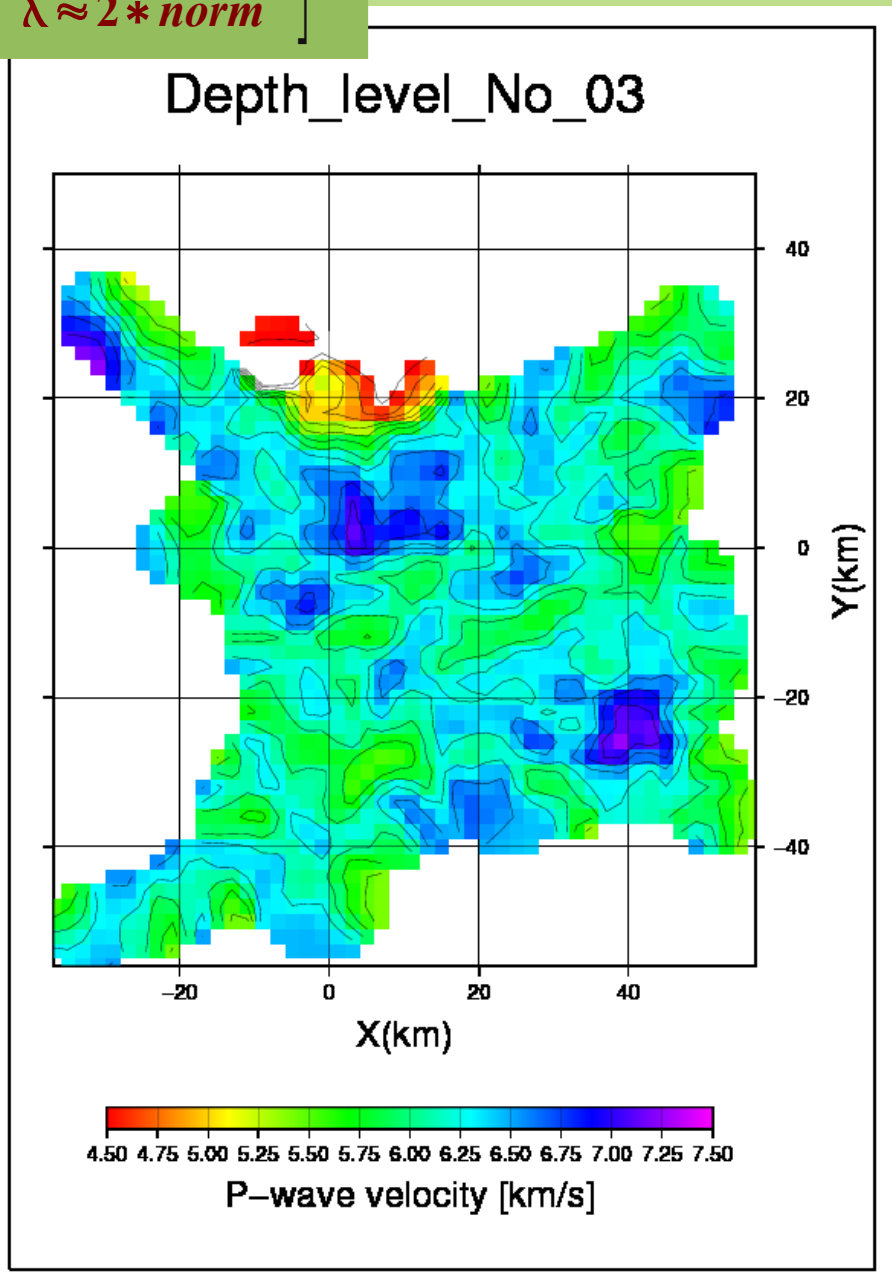

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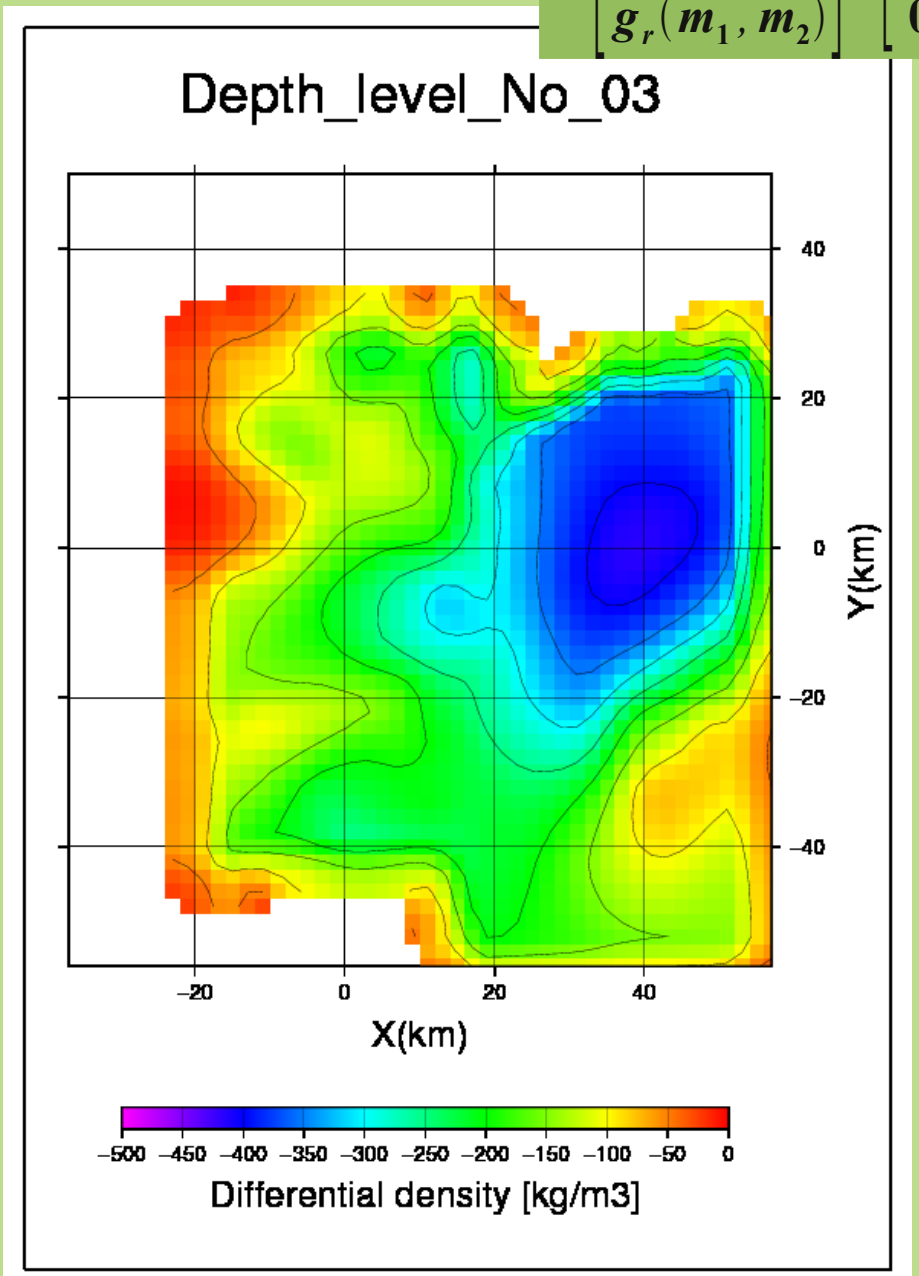

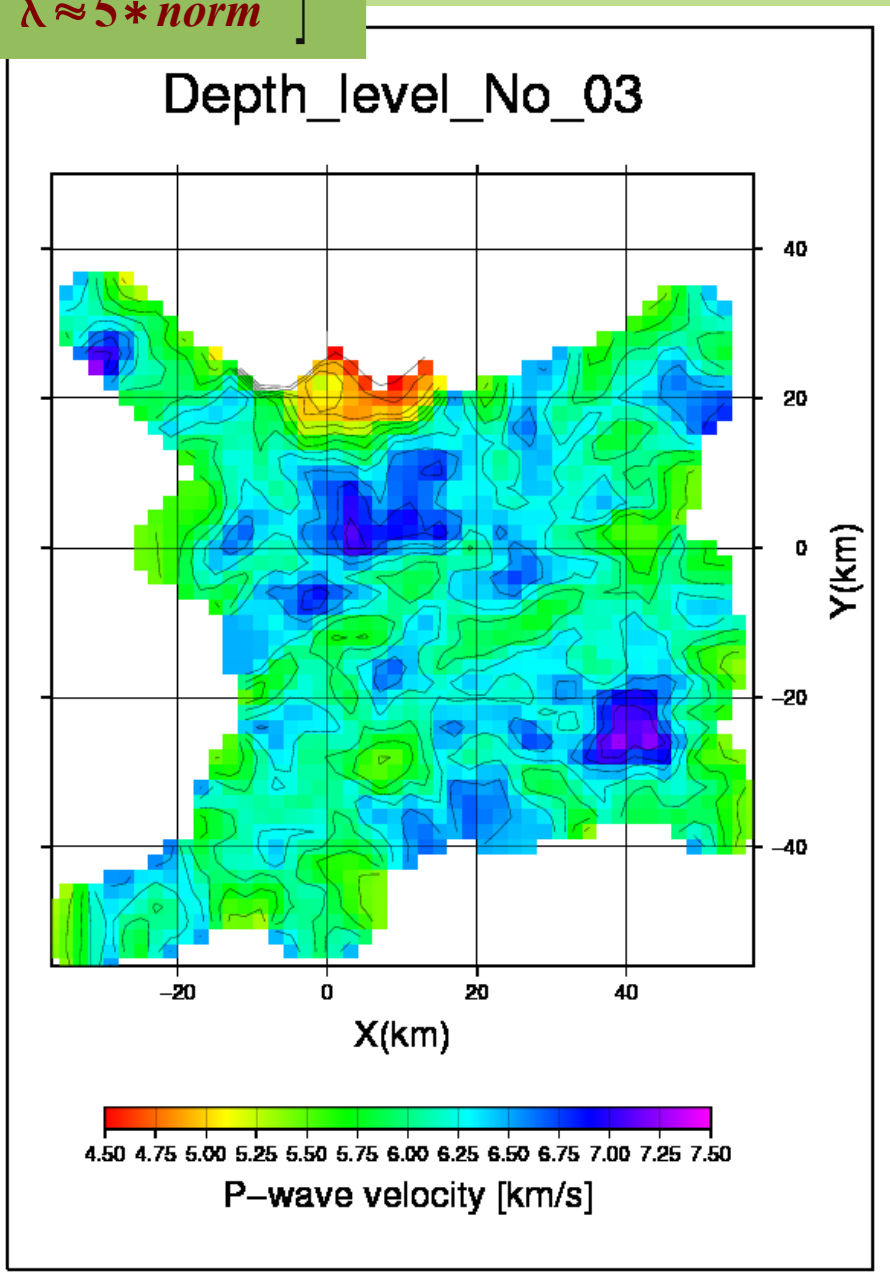

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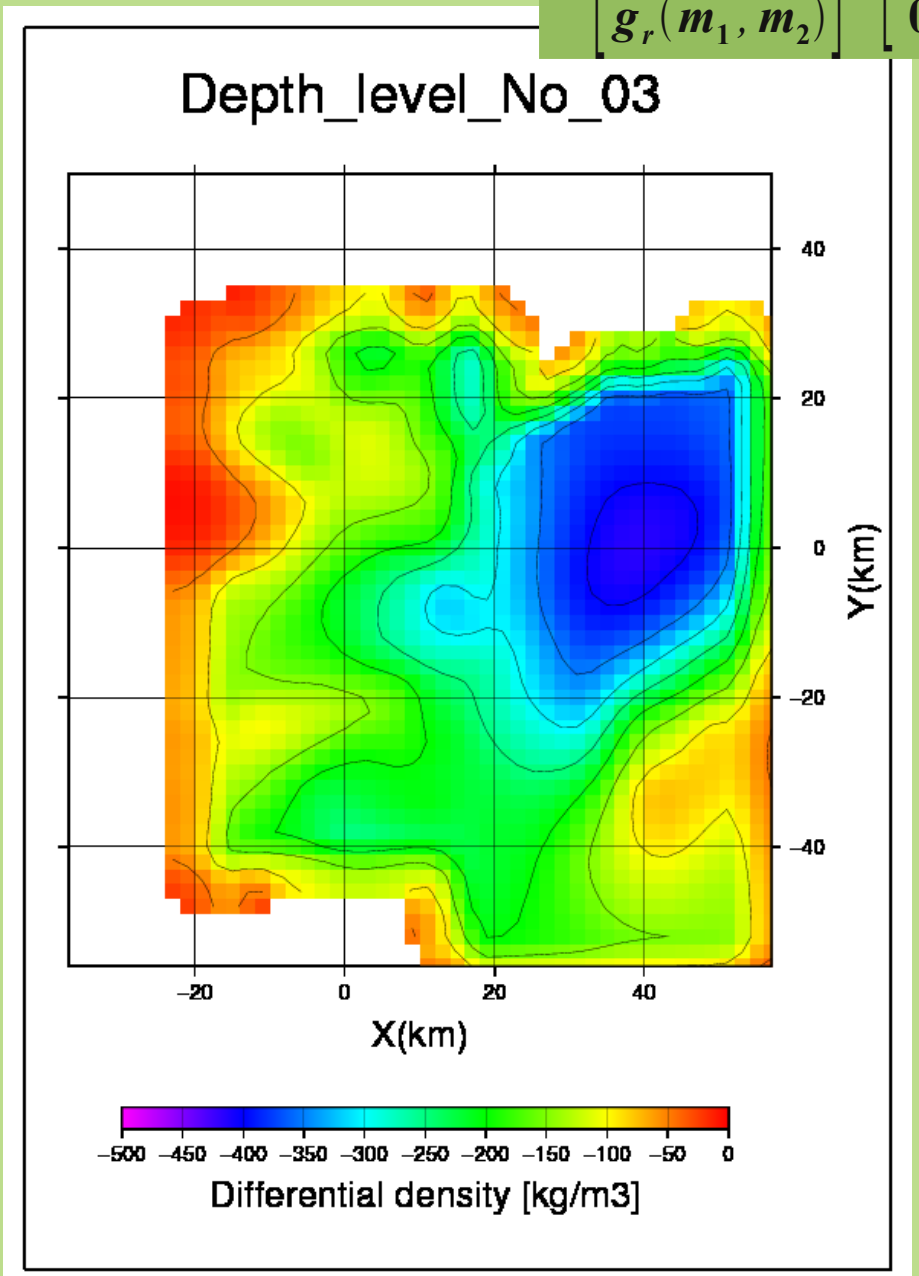

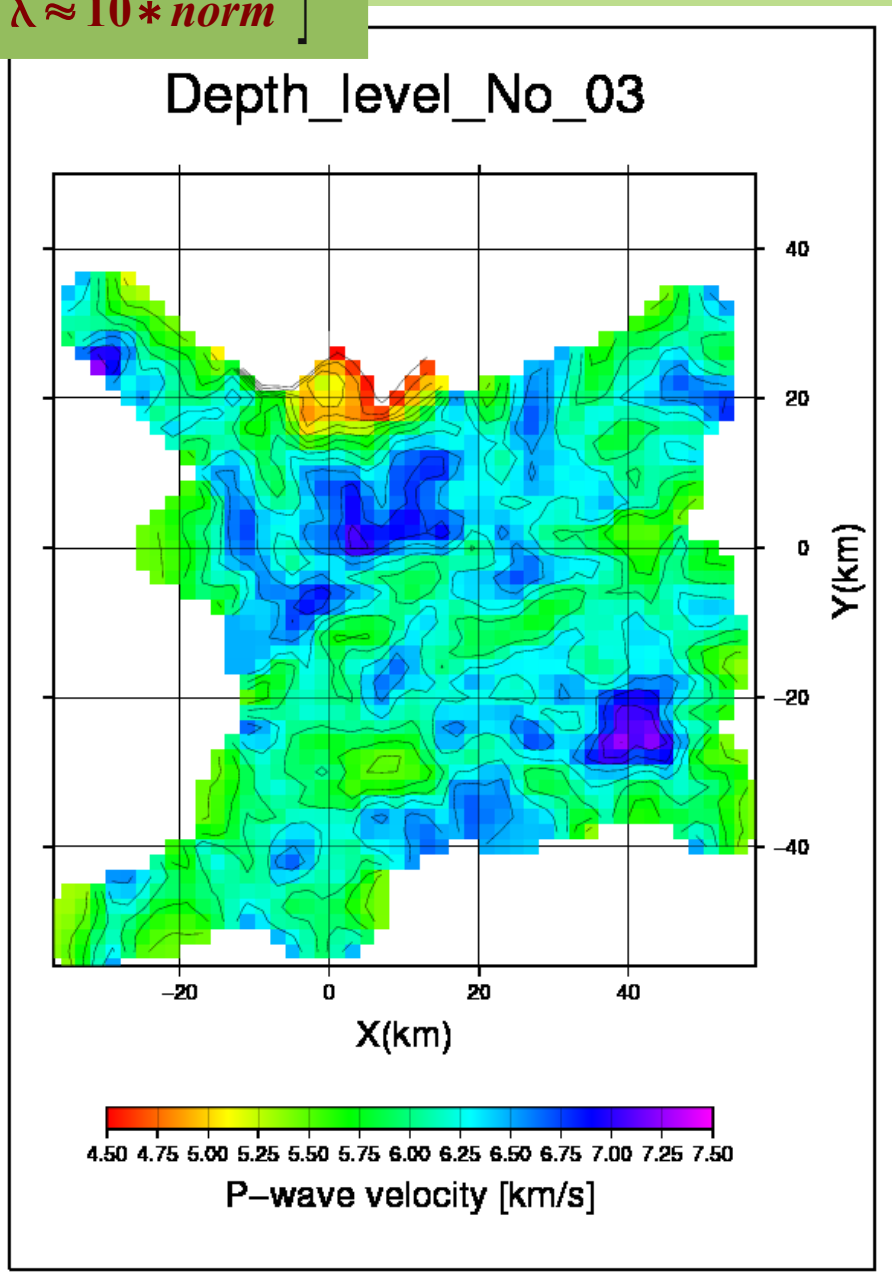

Joint inversion combining gravity and seismic measurements

- can be linked by cross-gradient constraint, then
- no a-priori relation between model subspaces is required;
- stable solutions to both methods are produced;
- results seem to be reasonable and
- resulting models will be offered for free testing via web.

Thanks !