

Robust 3D gravity gradient inversion by planting anomalous densities

Leonardo Uieda

Valéria C. F. Barbosa



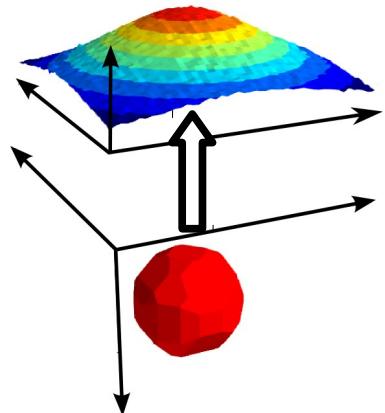
Observatório Nacional

2011

Outline

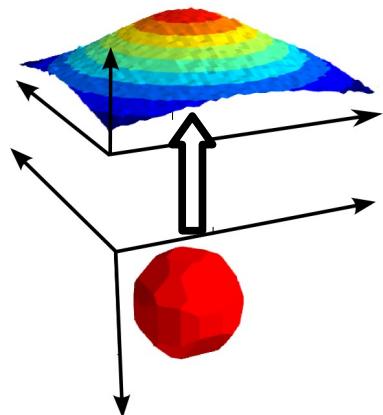
Outline

Forward Problem

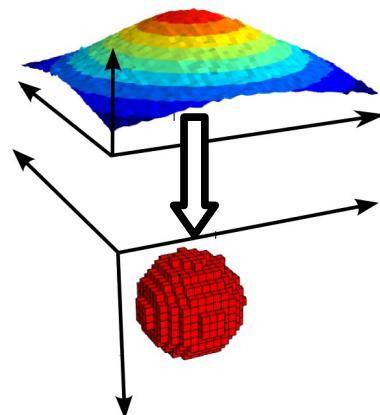


Outline

Forward Problem

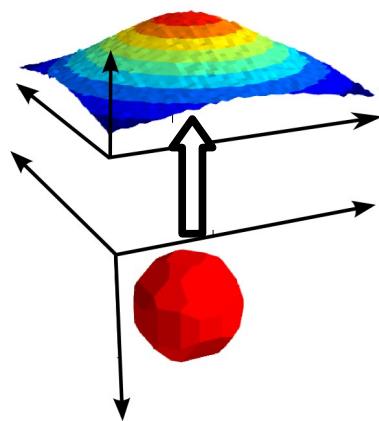


Inverse Problem

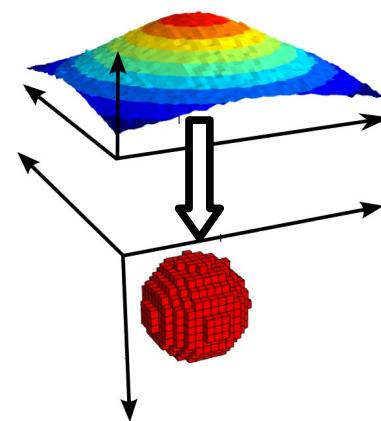


Outline

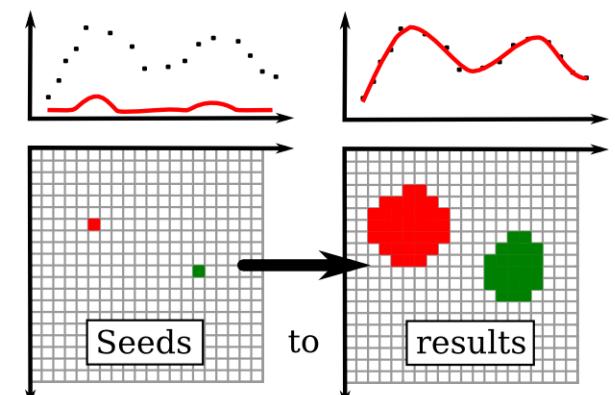
Forward Problem



Inverse Problem



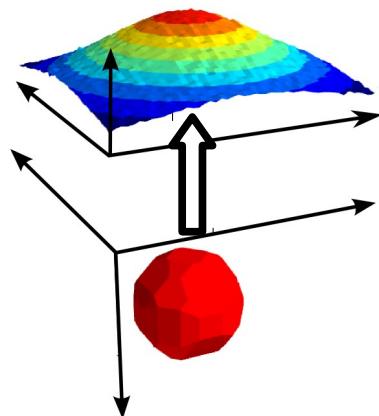
Planting Algorithm



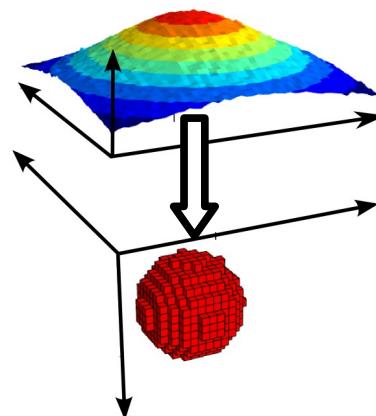
Inspired by René (1986)

Outline

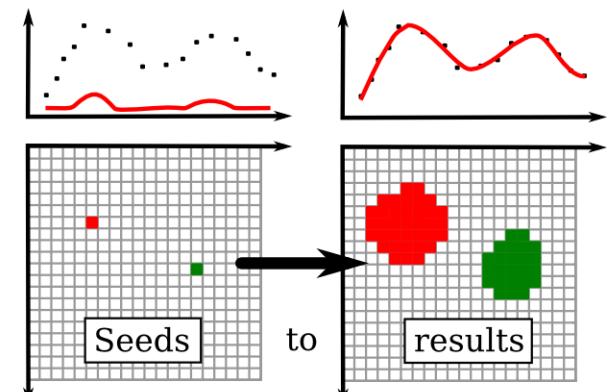
Forward Problem



Inverse Problem

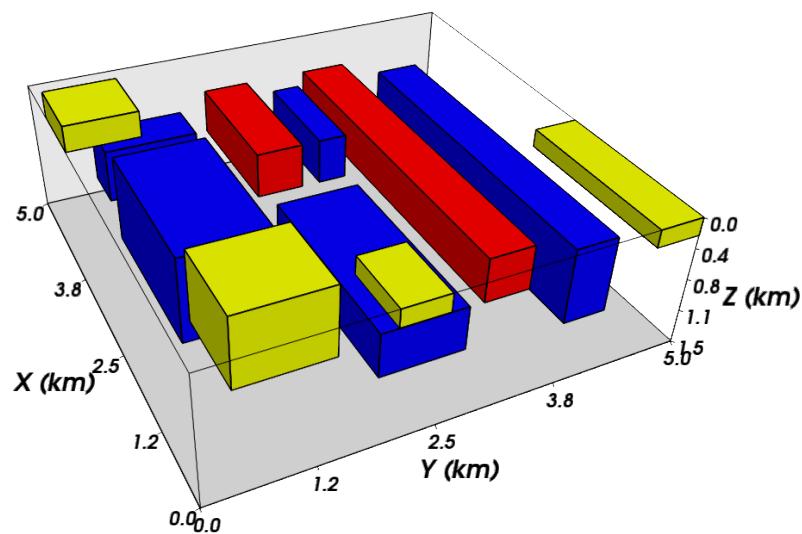


Planting Algorithm



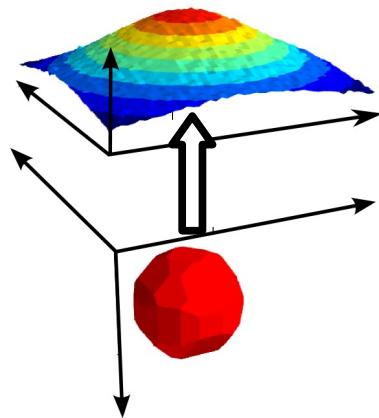
Inspired by René (1986)

Synthetic Data

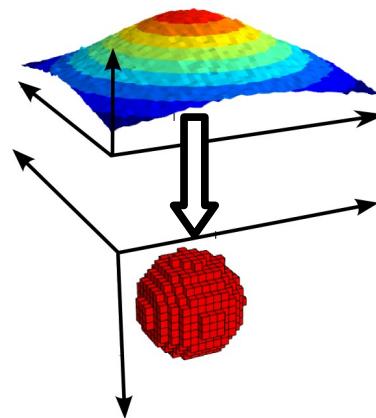


Outline

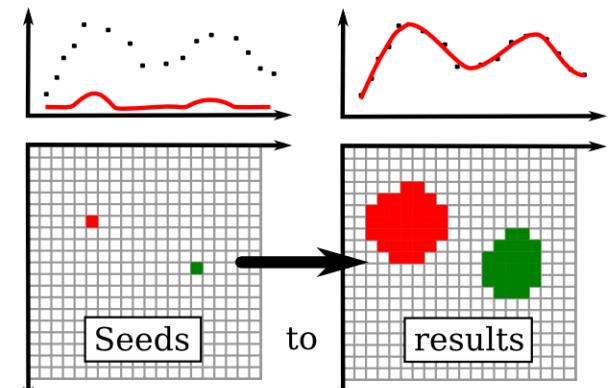
Forward Problem



Inverse Problem

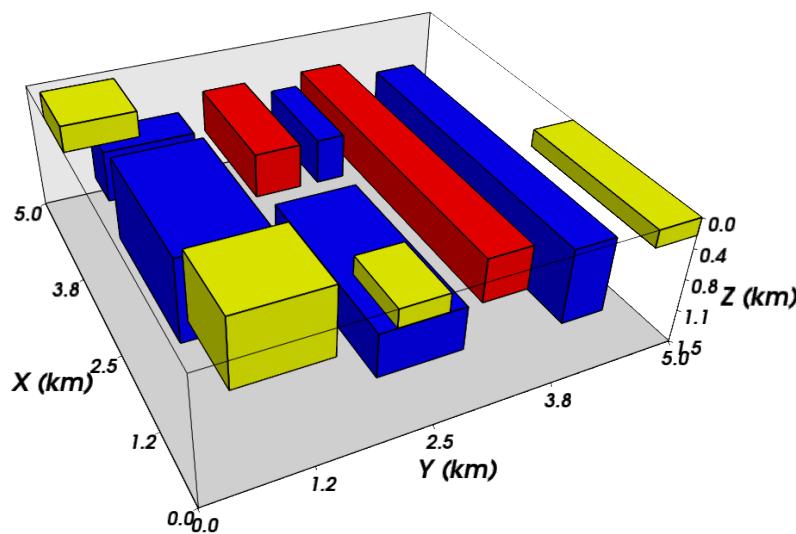


Planting Algorithm

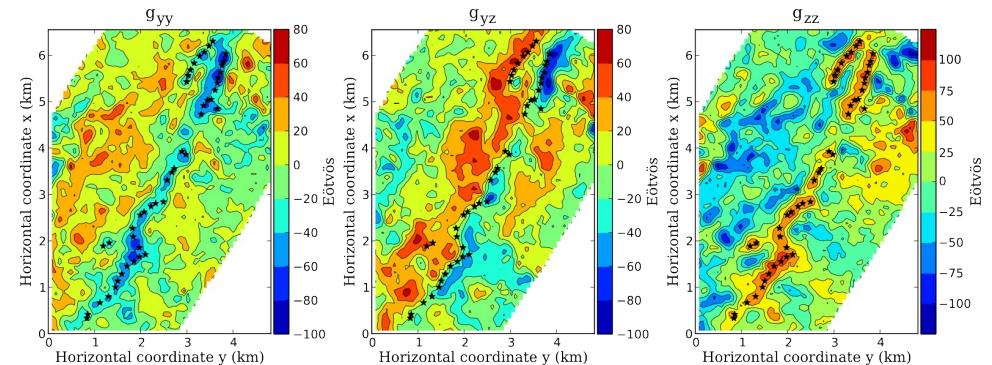


Inspired by René (1986)

Synthetic Data

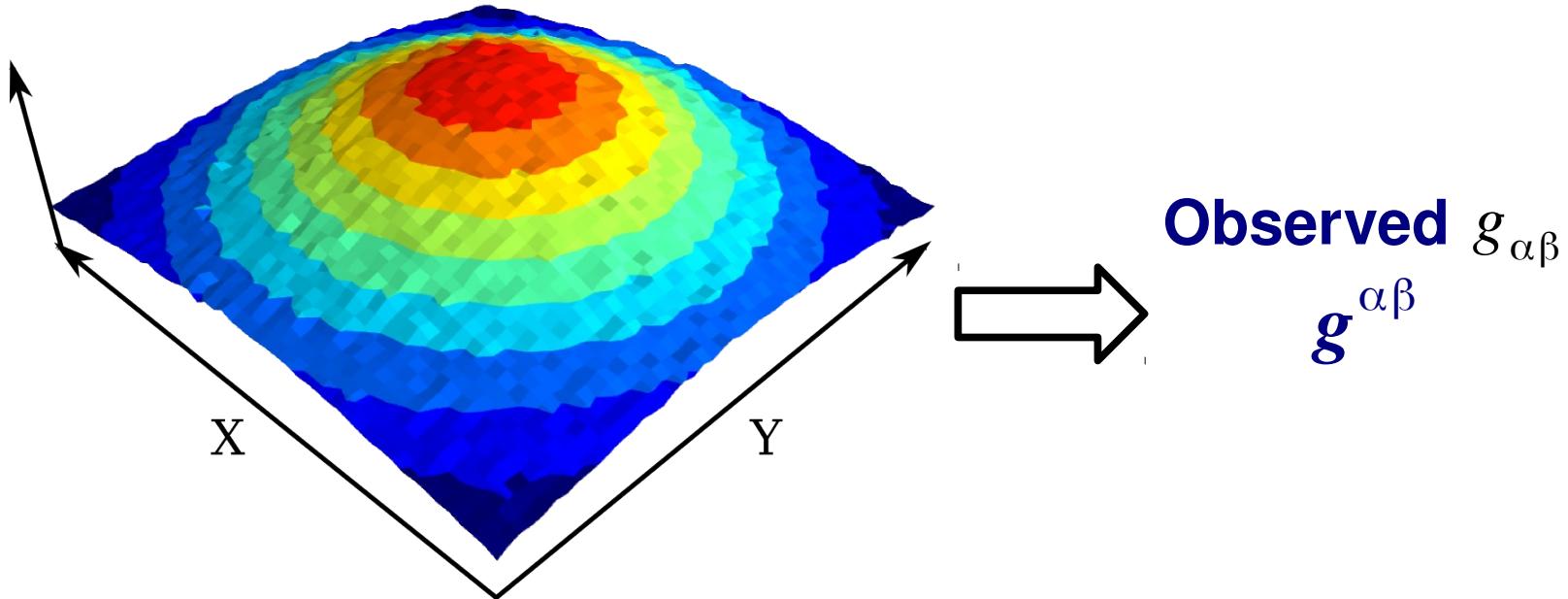


Real Data



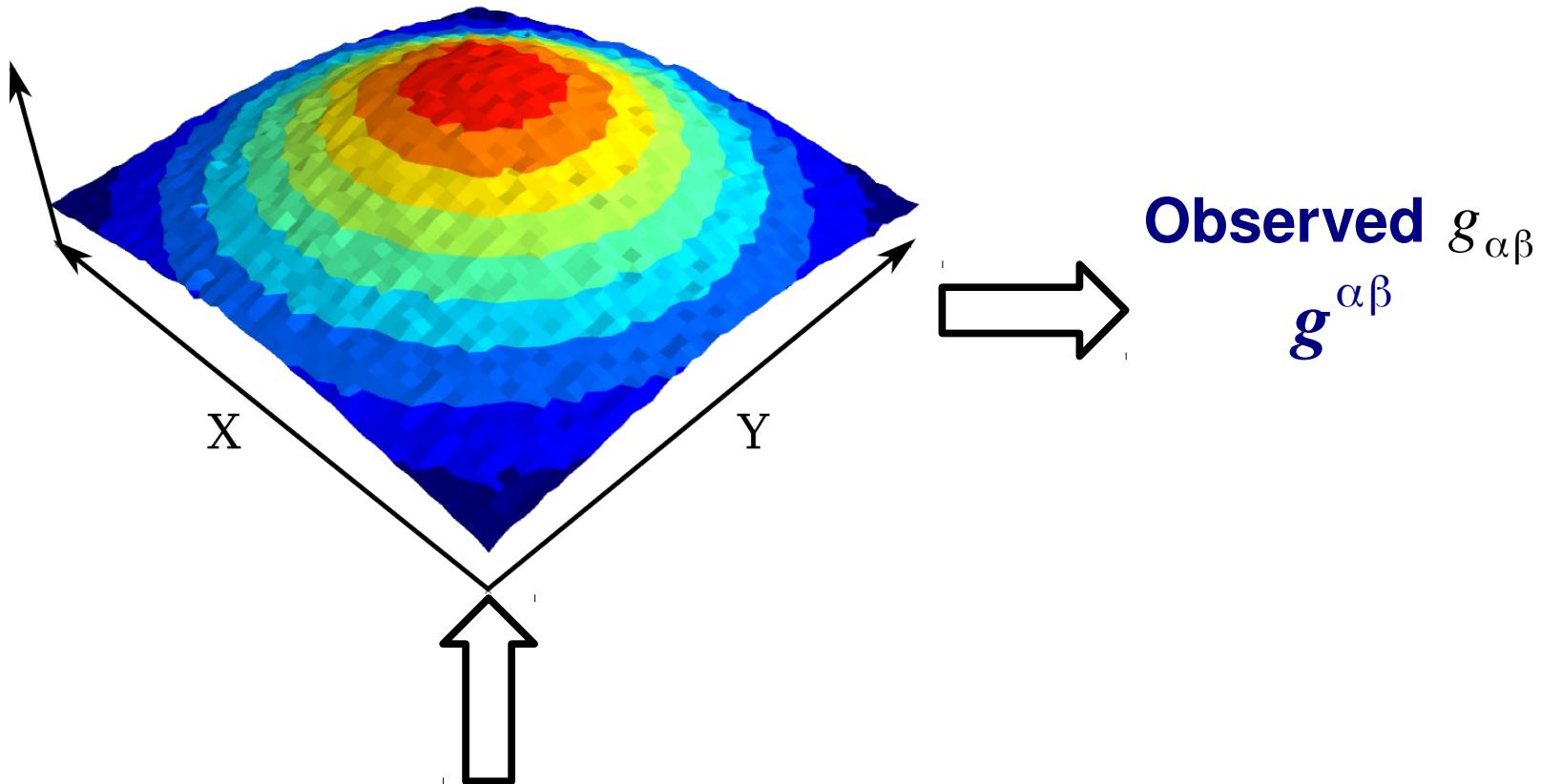
Quadrilátero Ferrífero

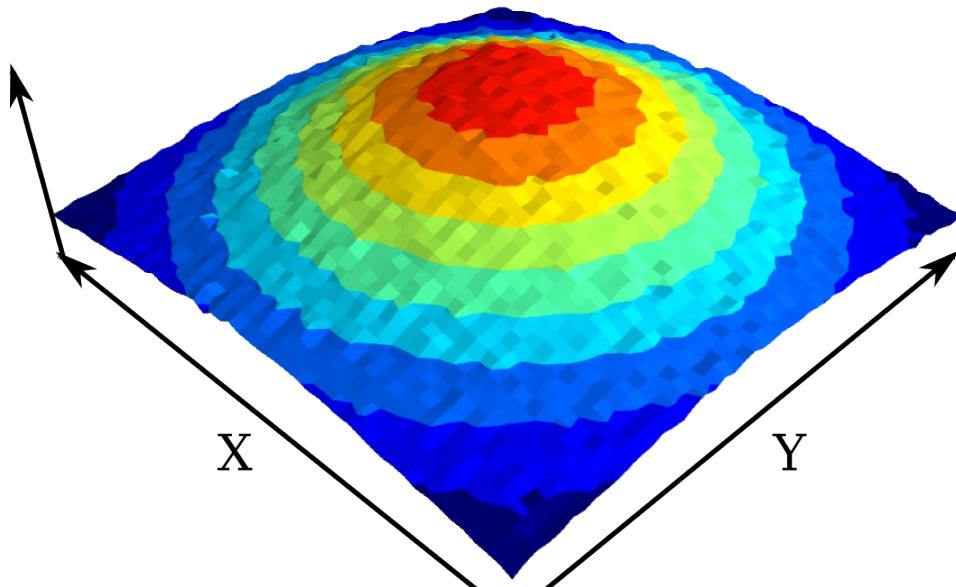
Forward problem



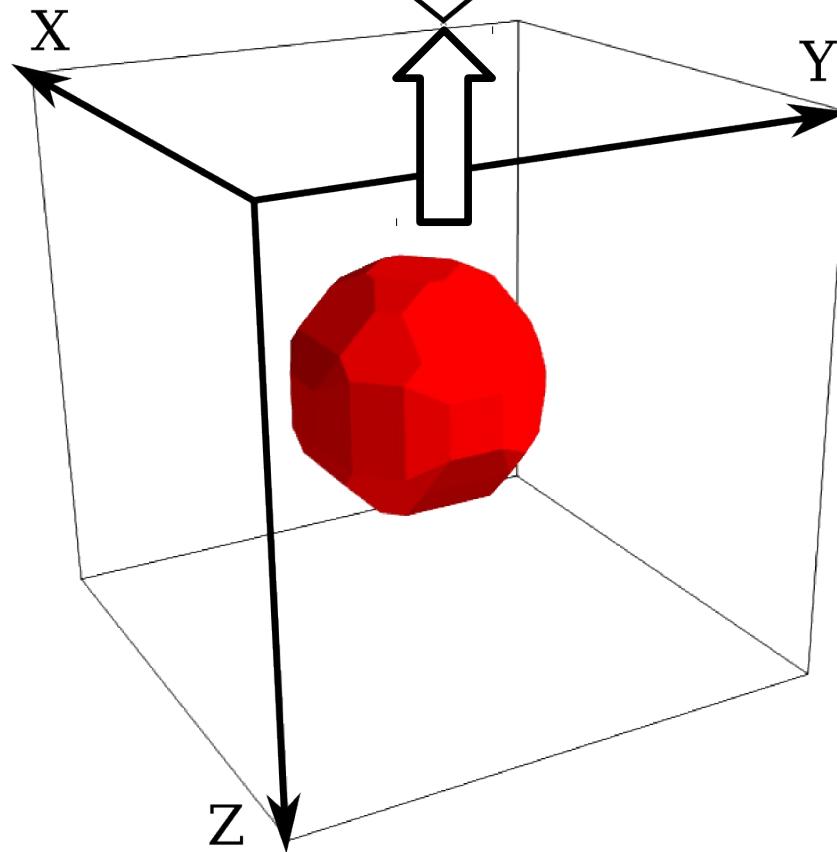
Observed $g_{\alpha\beta}$

$$g^{\alpha\beta}$$

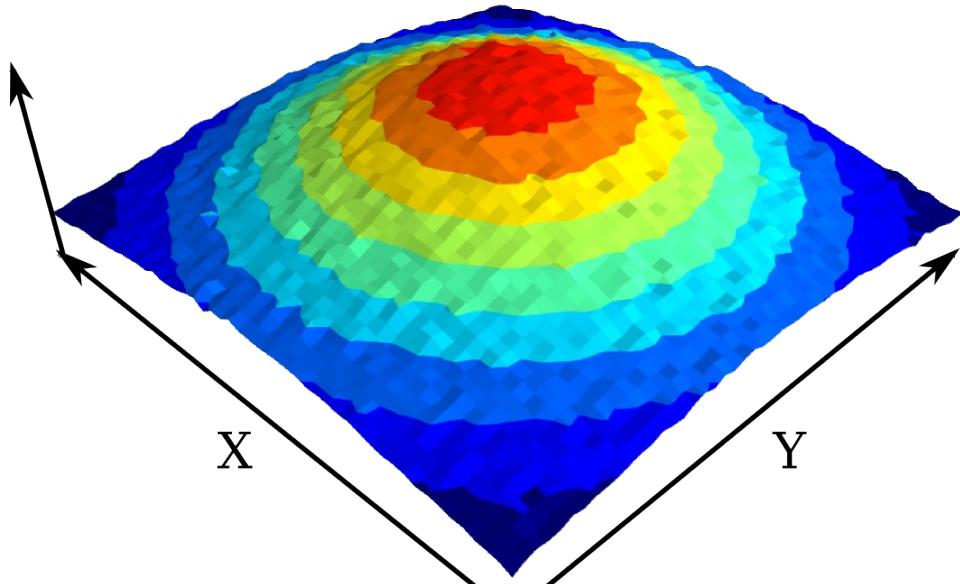




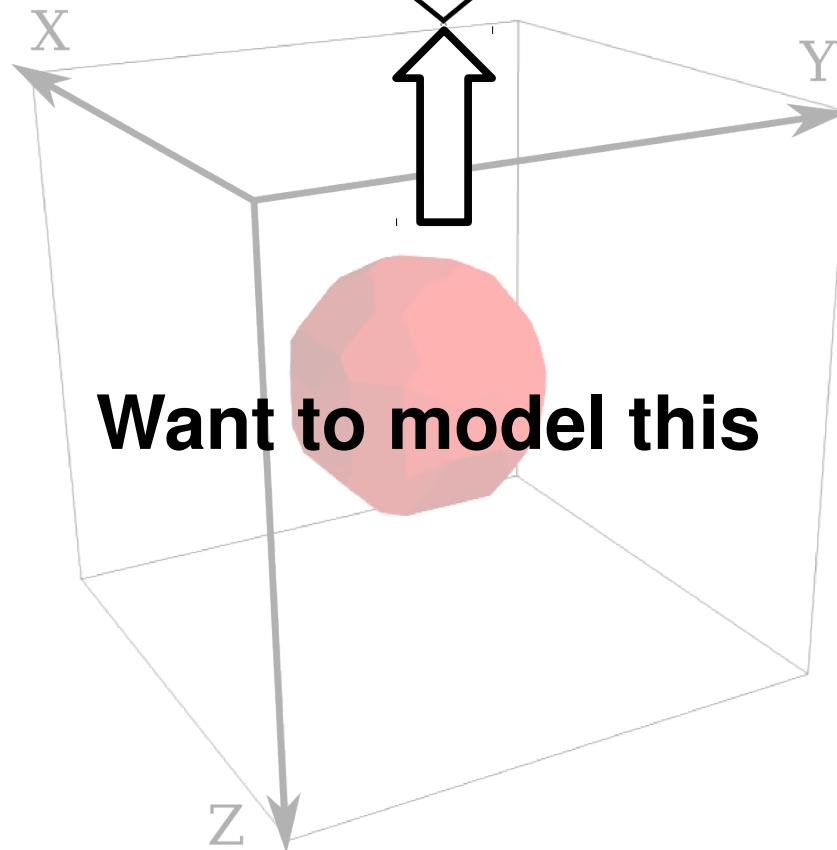
Observed $g_{\alpha\beta}$
 $g^{\alpha\beta}$



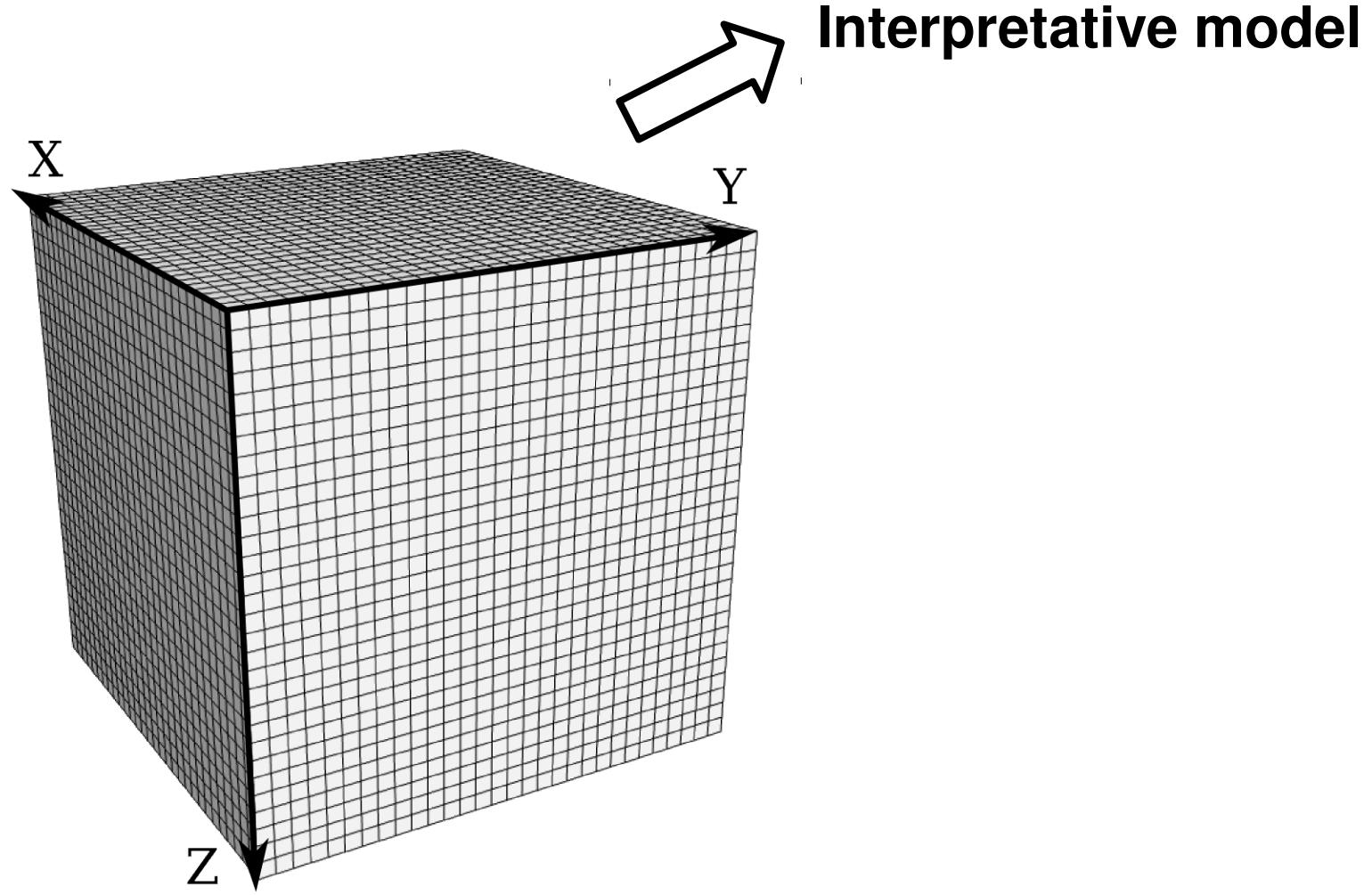
Anomalous density

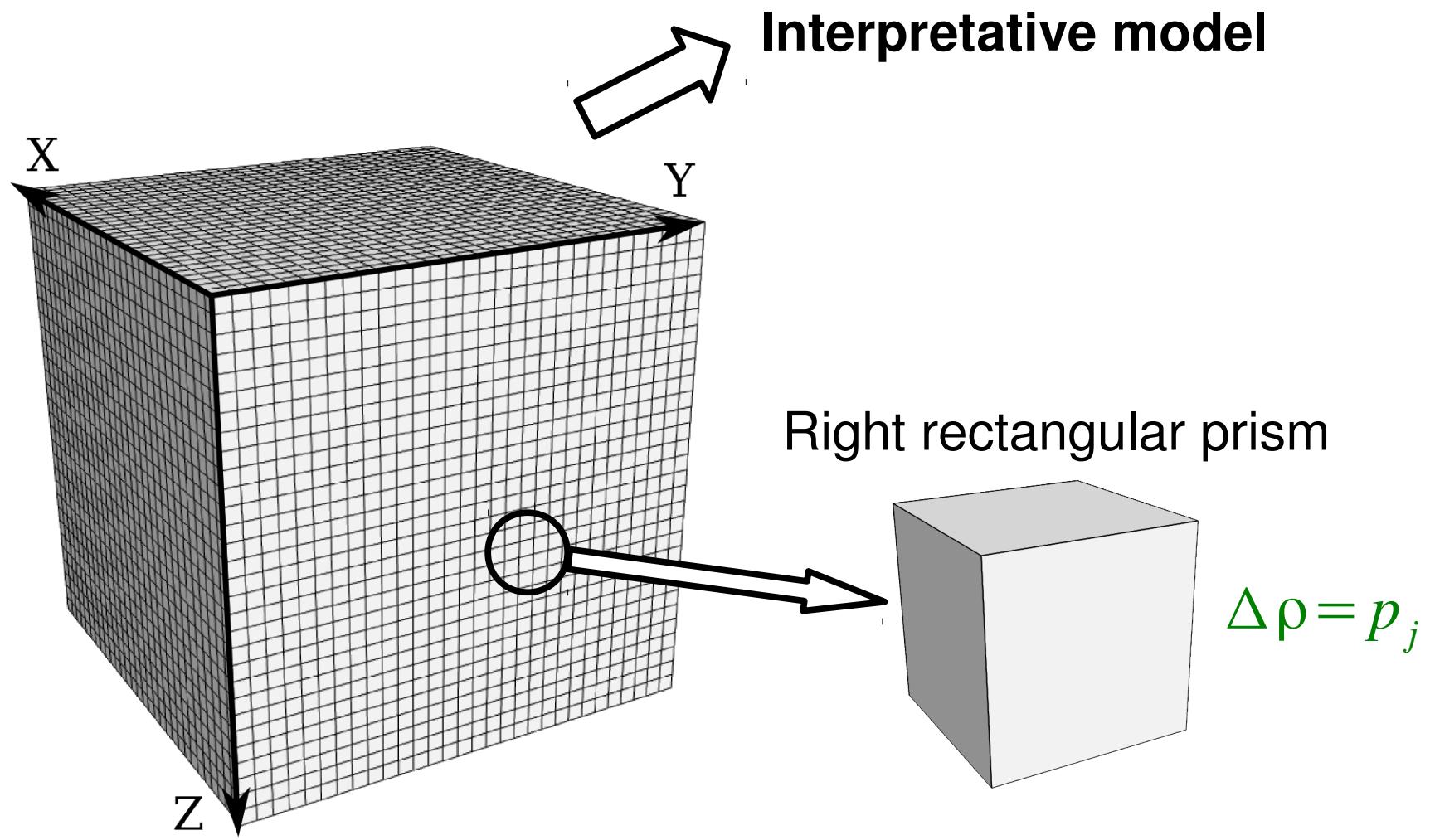


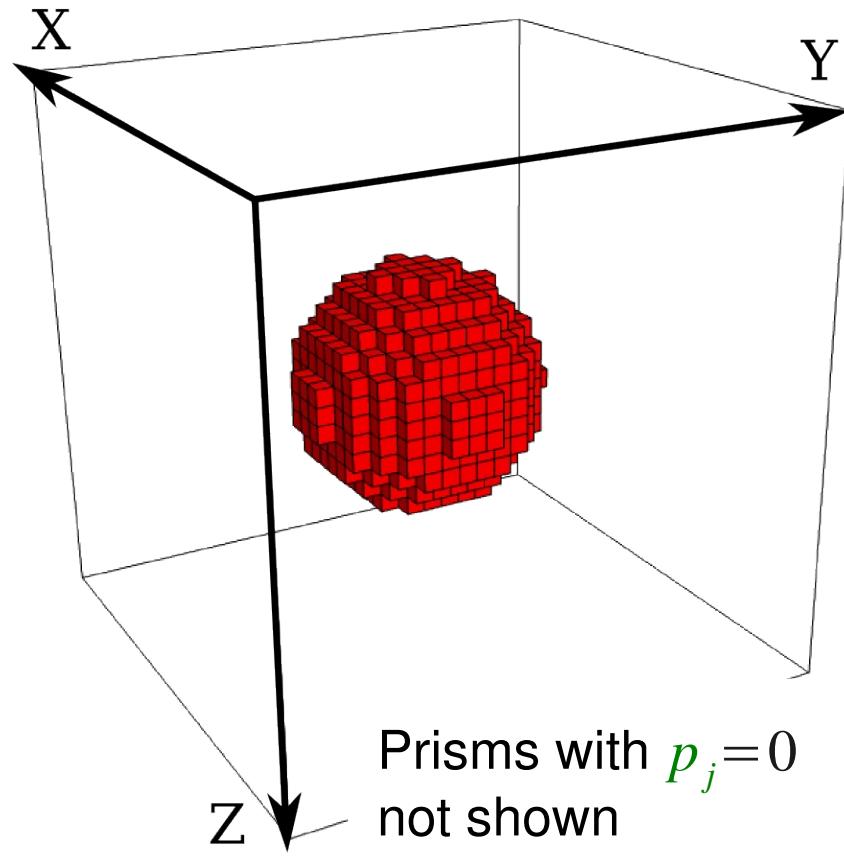
Observed $g_{\alpha\beta}$
 $g^{\alpha\beta}$

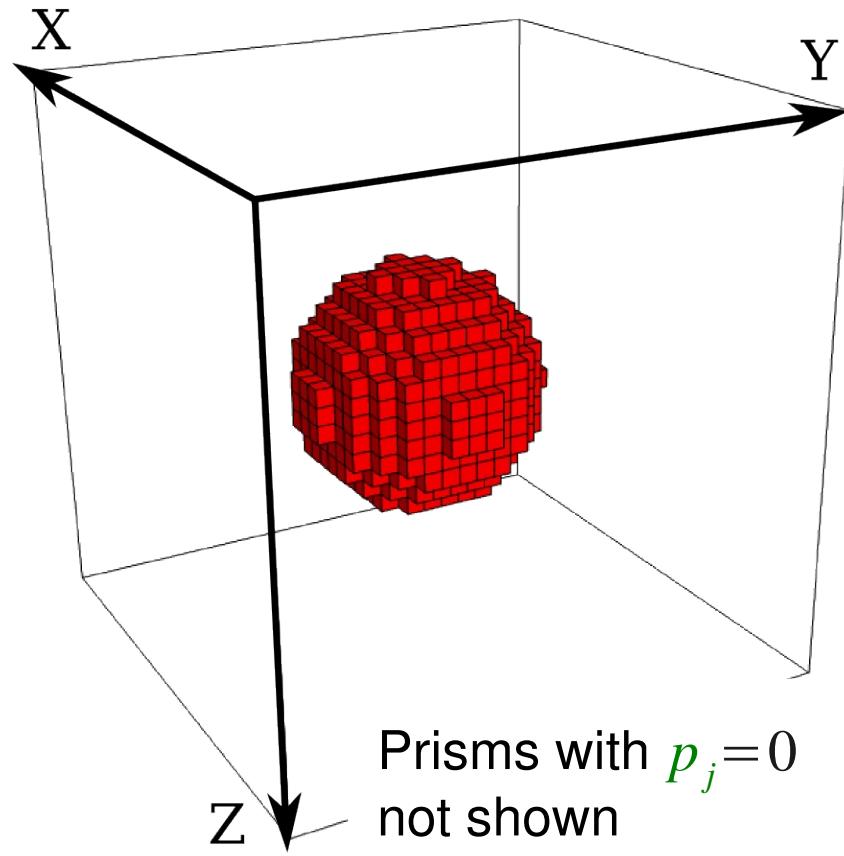


Anomalous density

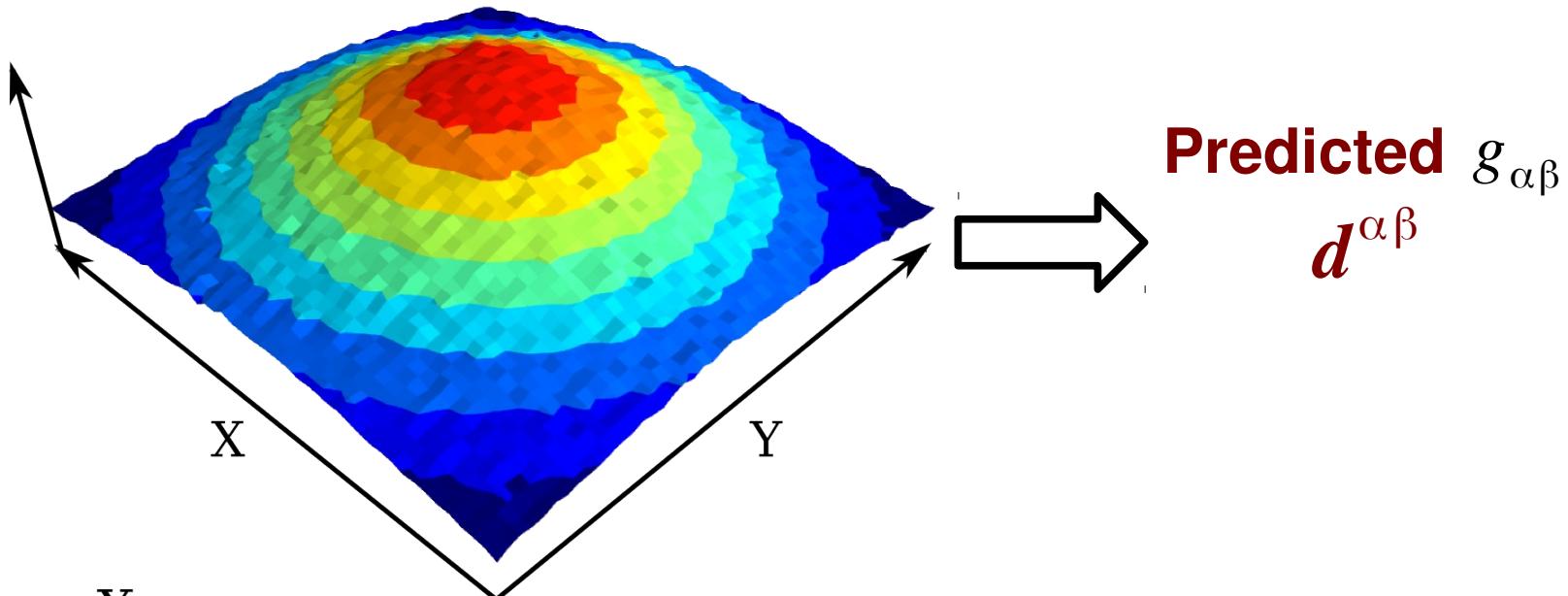




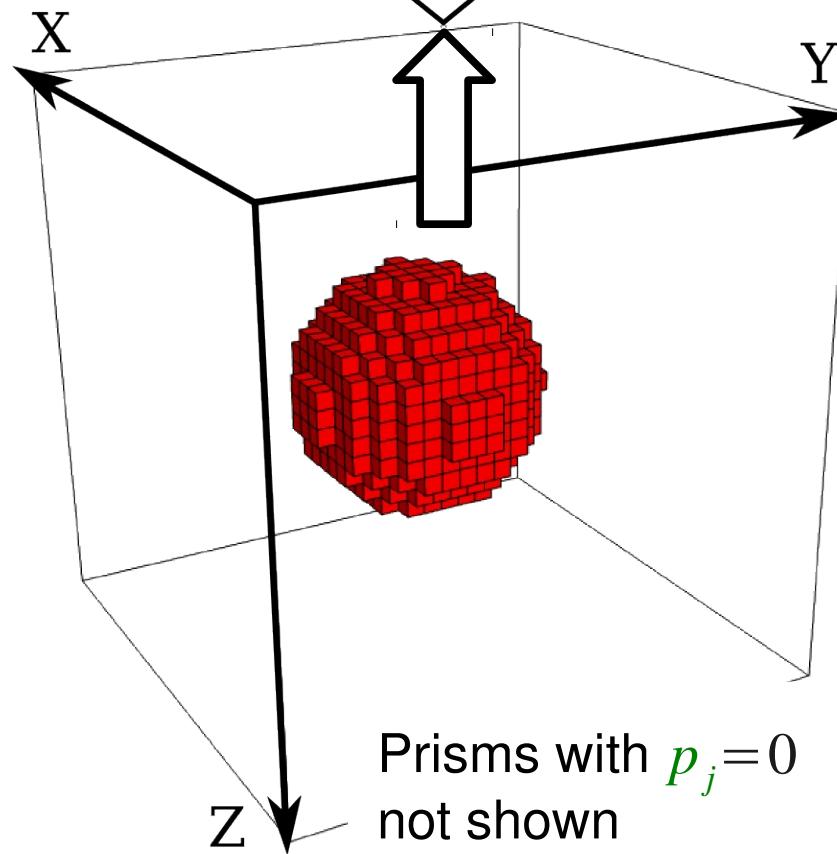




$$\mathbf{p} = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_M \end{bmatrix}$$

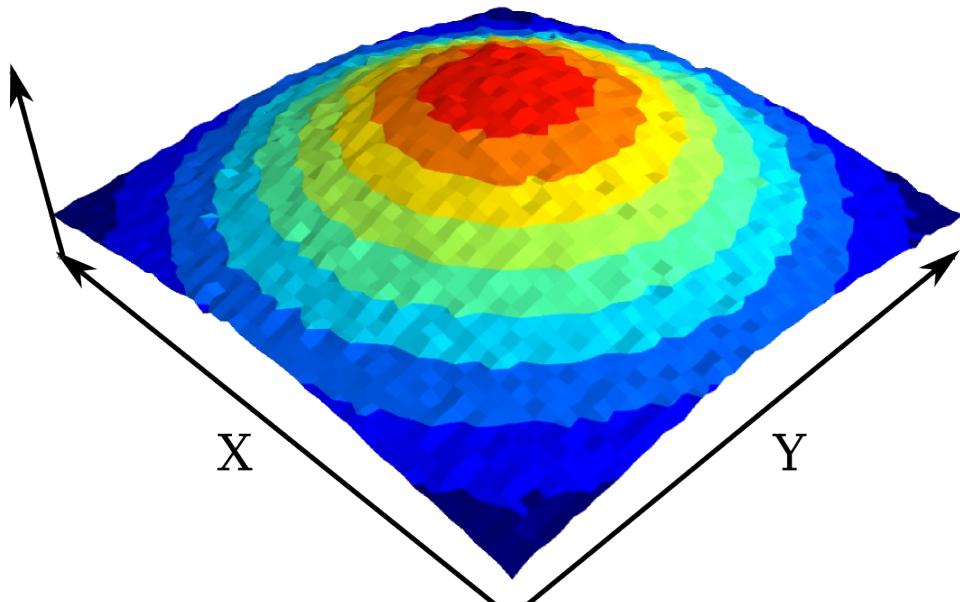


Predicted $g_{\alpha\beta}$
 $d^{\alpha\beta}$

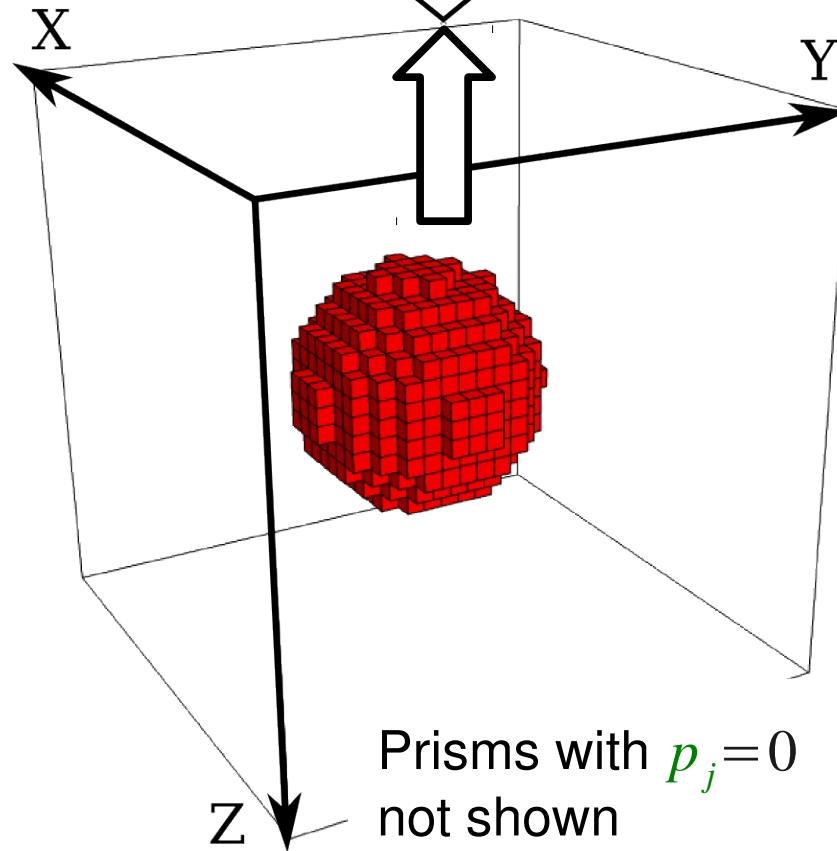


Prisms with $p_j = 0$
not shown

$$\mathbf{p} = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_M \end{bmatrix}$$

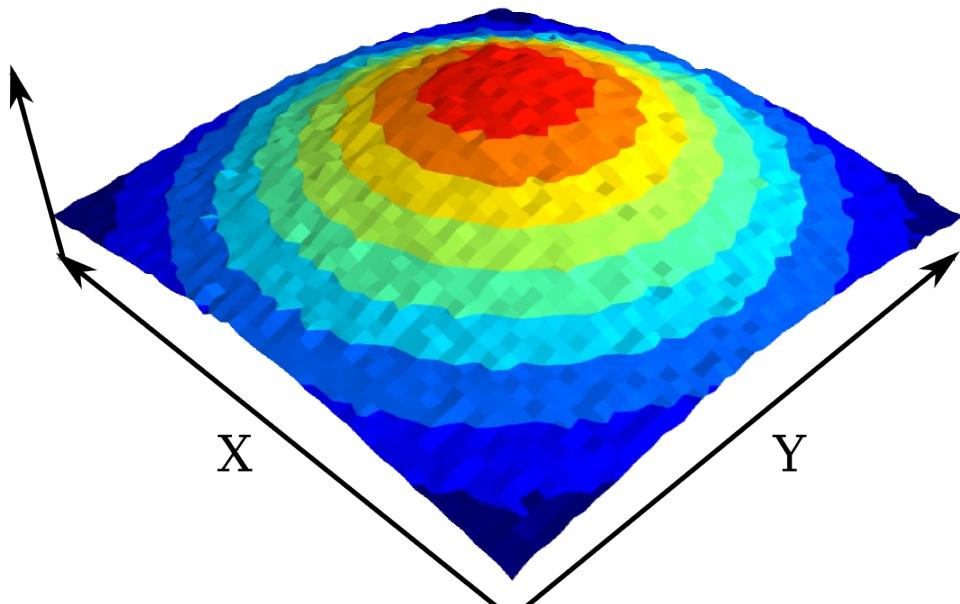


Predicted $g_{\alpha\beta}$
 $d^{\alpha\beta}$

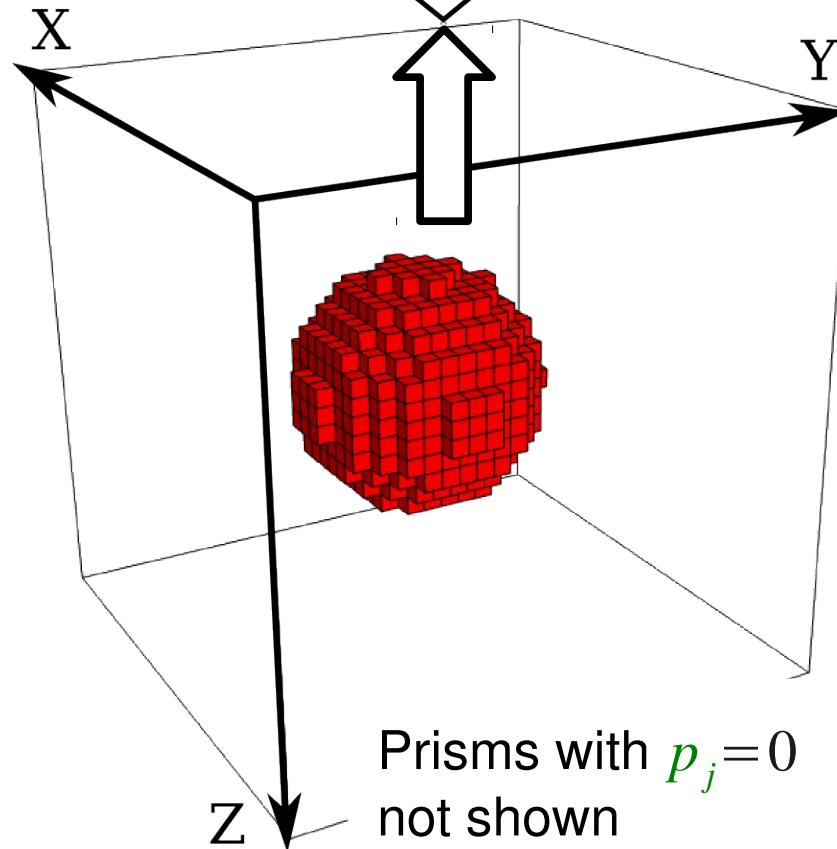


$$d^{\alpha\beta} = \sum_{j=1}^M p_j a_j^{\alpha\beta}$$

$$\mathbf{p} = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_M \end{bmatrix}$$



Predicted $g_{\alpha\beta}$
 $d^{\alpha\beta}$



$$d^{\alpha\beta} = \sum_{j=1}^M p_j a_j^{\alpha\beta}$$

Contribution of jth prism

$$\mathbf{p} = \begin{bmatrix} p_1 \\ p_2 \\ \vdots \\ p_M \end{bmatrix}$$

More components:

d^{xx}

d^{xy}

d^{xz}

d^{yy}

d^{yz}

d^{zz}

More components:

d^{xx}

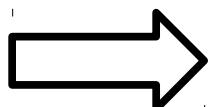
d^{xy}

d^{xz}

d^{yy}

d^{yz}

d^{zz}



d

More components:

$$d^{xx}$$

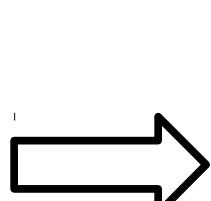
$$d^{xy}$$

$$d^{xz}$$

$$d^{yy}$$

$$d^{yz}$$

$$d^{zz}$$



$$d = \sum_{j=1}^M p_j a_j$$

More components:

$$\mathbf{d}^{xx}$$

$$\mathbf{d}^{xy}$$

$$\mathbf{d}^{xz}$$

$$\mathbf{d}^{yy}$$

$$\mathbf{d}^{yz}$$

$$\mathbf{d}^{zz}$$

$$\longrightarrow \mathbf{d} = \sum_{j=1}^M p_j \mathbf{a}_j = A \mathbf{p}$$

More components:

$$d^{xx}$$

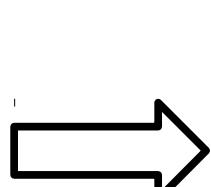
$$d^{xy}$$

$$d^{xz}$$

$$d^{yy}$$

$$d^{yz}$$

$$d^{zz}$$



$$d = \sum_{j=1}^M p_j a_j = A \ p$$



Jacobian (sensitivity) matrix

More components:

$$d^{xx}$$

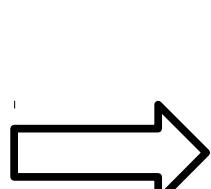
$$d^{xy}$$

$$d^{xz}$$

$$d^{yy}$$

$$d^{yz}$$

$$d^{zz}$$



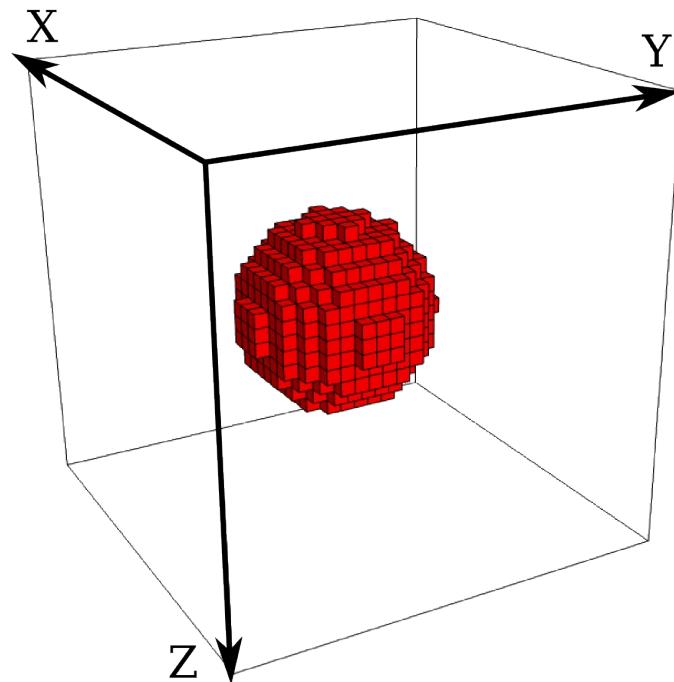
$$d = \sum_{j=1}^M p_j a_j = A p$$



Column vector of A

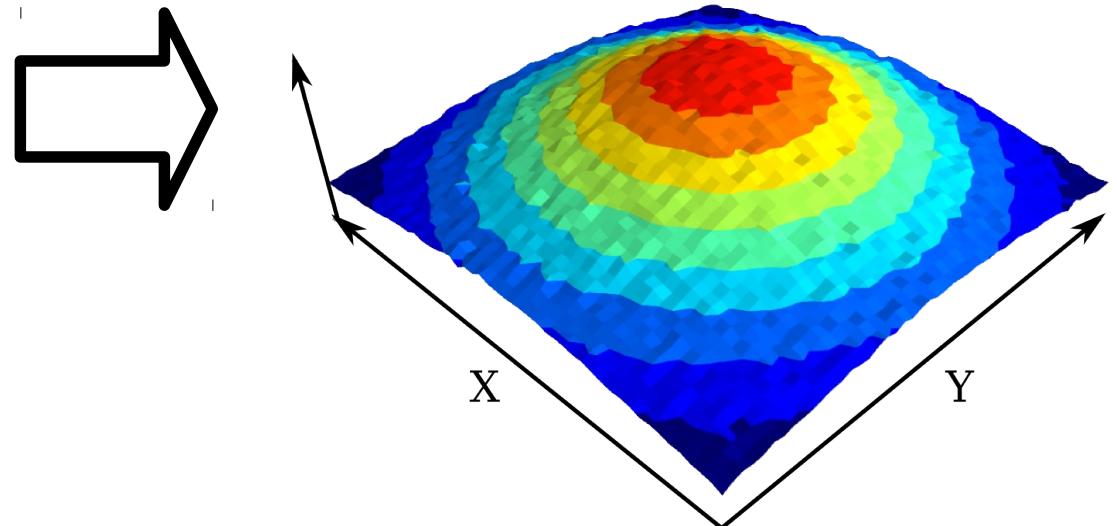
Forward problem:

p

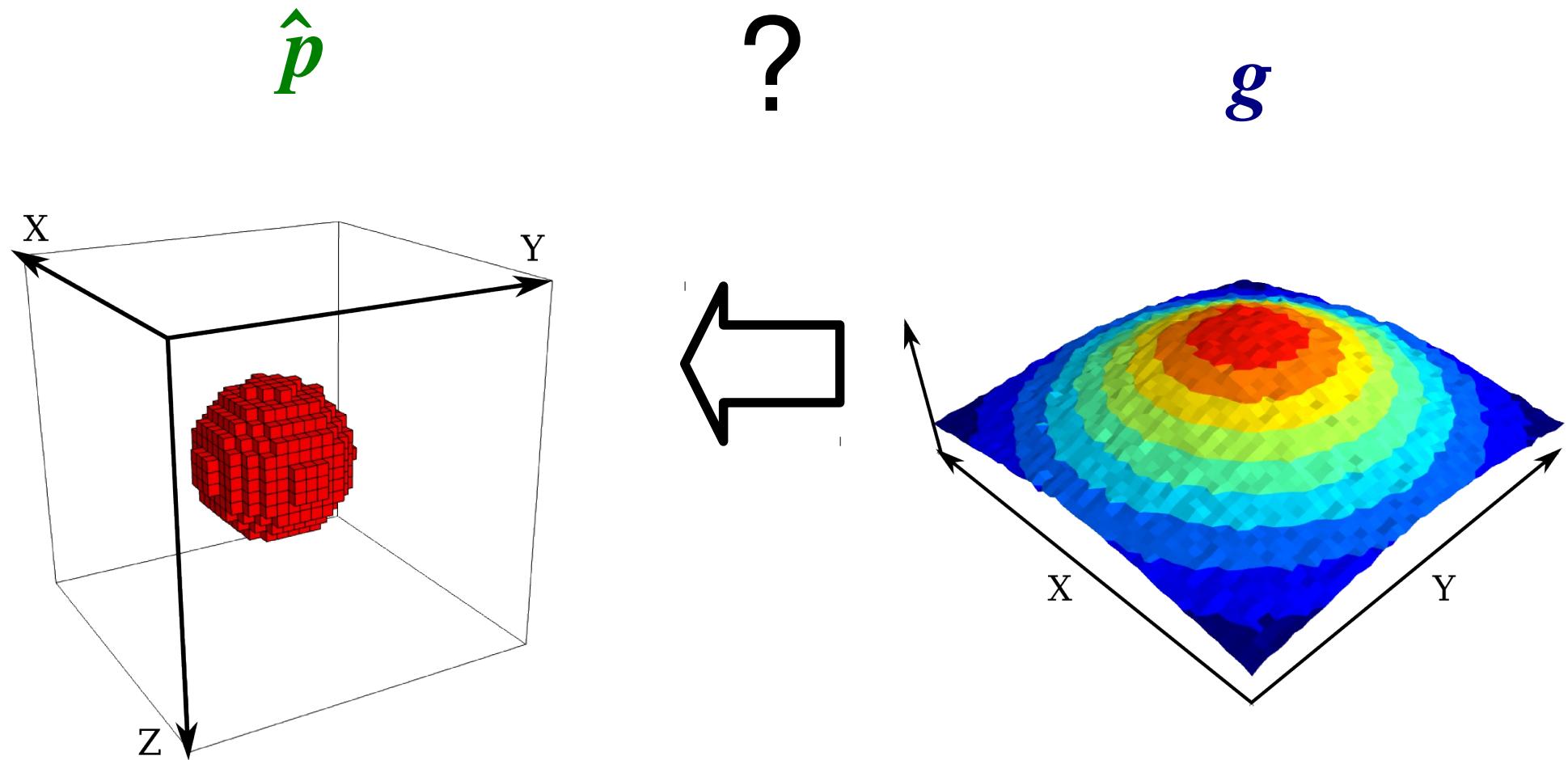


$$\mathbf{d} = \sum_{j=1}^M p_j \mathbf{a}_j$$

d



Inverse problem:



Inverse problem

Minimize difference between \mathbf{g} and \mathbf{d}

Residual vector $\Rightarrow \mathbf{r} = \mathbf{g} - \mathbf{d}$

Minimize difference between \mathbf{g} and \mathbf{d}

Residual vector $\Rightarrow \mathbf{r} = \mathbf{g} - \mathbf{d}$

Data-misfit function:

$$\phi(\mathbf{p}) = \|\mathbf{r}\|_2 = \left(\sum_{i=1}^N (\mathbf{g}_i - \mathbf{d}_i)^2 \right)^{\frac{1}{2}}$$

Minimize difference between \mathbf{g} and \mathbf{d}

Residual vector $\Rightarrow \mathbf{r} = \mathbf{g} - \mathbf{d}$

Data-misfit function:

$$\phi(\mathbf{p}) = \|\mathbf{r}\|_2 = \left(\sum_{i=1}^N (\mathbf{g}_i - \mathbf{d}_i)^2 \right)^{\frac{1}{2}}$$

ℓ_2 -norm of \mathbf{r}

Minimize difference between \mathbf{g} and \mathbf{d}

Residual vector $\Rightarrow \mathbf{r} = \mathbf{g} - \mathbf{d}$

Data-misfit function:

$$\phi(\mathbf{p}) = \|\mathbf{r}\|_2 = \left(\sum_{i=1}^N (\mathbf{g}_i - \mathbf{d}_i)^2 \right)^{\frac{1}{2}}$$



ℓ_2 -norm of \mathbf{r}

Least-squares fit

Minimize difference between \mathbf{g} and \mathbf{d}

Residual vector $\Rightarrow \mathbf{r} = \mathbf{g} - \mathbf{d}$

Data-misfit function:

$$\phi(\mathbf{p}) = \|\mathbf{r}\|_2 = \left(\sum_{i=1}^N (g_i - d_i)^2 \right)^{\frac{1}{2}}$$

\uparrow
 ℓ_2 -norm of \mathbf{r}

Least-squares fit

$$\phi(\mathbf{p}) = \|\mathbf{r}\|_1 = \sum_{i=1}^N |g_i - d_i|$$

\uparrow

ℓ_1 -norm of \mathbf{r}

Minimize difference between \mathbf{g} and \mathbf{d}

Residual vector $\Rightarrow \mathbf{r} = \mathbf{g} - \mathbf{d}$

Data-misfit function:

$$\phi(\mathbf{p}) = \|\mathbf{r}\|_2 = \left(\sum_{i=1}^N (g_i - d_i)^2 \right)^{\frac{1}{2}}$$

\uparrow
 ℓ_2 -norm of \mathbf{r}

Least-squares fit

$$\phi(\mathbf{p}) = \|\mathbf{r}\|_1 = \sum_{i=1}^N |g_i - d_i|$$

\uparrow

ℓ_1 -norm of \mathbf{r}

Robust fit

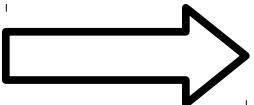
ill-posed problem

non-existent

non-unique

non-stable

constraints

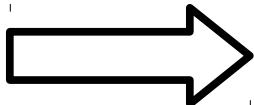
ill-posed problem 

non-existent

non-unique

non-stable

constraints

ill-posed problem  **well-posed problem**

non-existent

exist

non-unique

unique

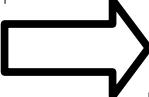
non-stable

stable

Constraints:

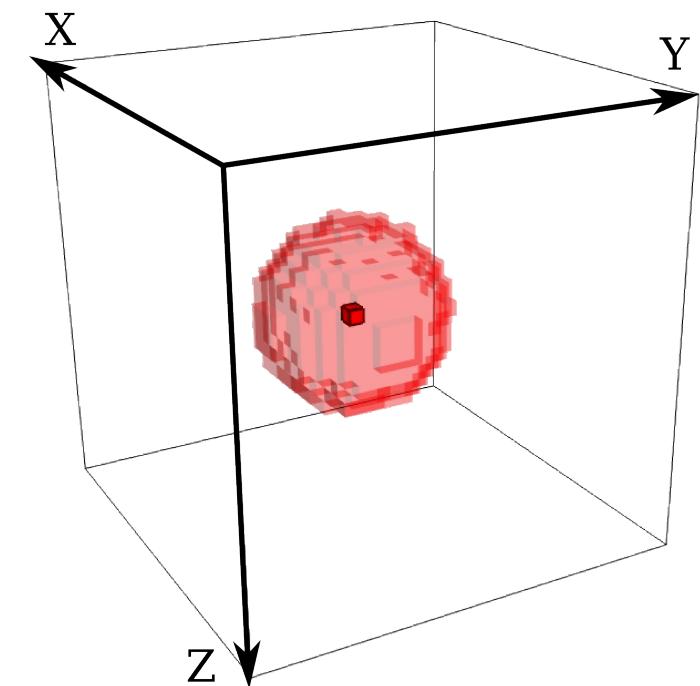
1. Compact

Constraints:

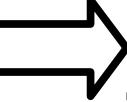
1. Compact  no holes inside

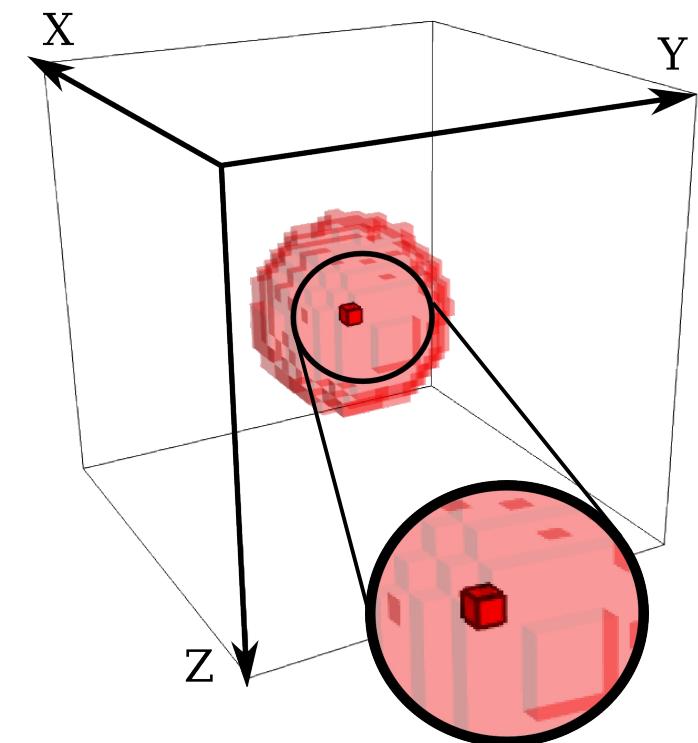
Constraints:

1. Compact  no holes inside
2. Concentrated around “seeds”



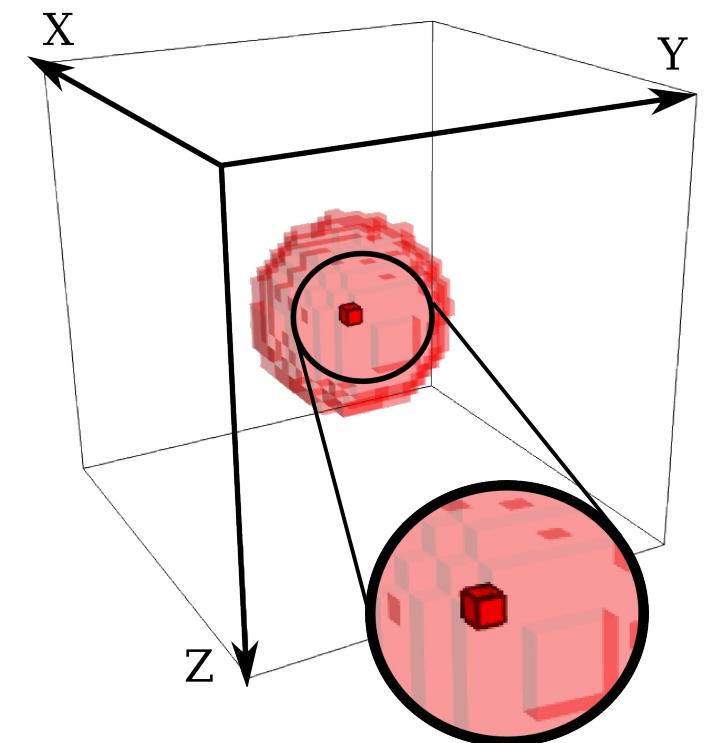
Constraints:

1. Compact  no holes inside
2. Concentrated around “seeds”
 - **User-specified** prisms
 - **Given** density contrasts ρ_s
 - Any # of \neq density contrasts

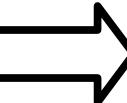


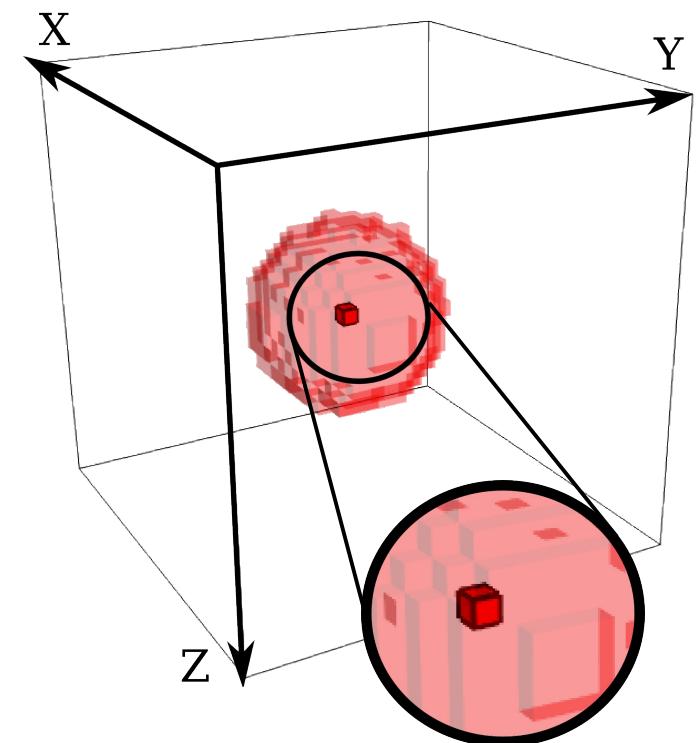
Constraints:

1. Compact  no holes inside
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 - **User-specified** prisms
 - **Given** density contrasts ρ_s
 - Any # of \neq density contrasts
3. Only $p_j=0$ or $p_j=\rho_s$



Constraints:

1. Compact  no holes inside
2. Concentrated around “seeds”
 - **User-specified** prisms
 - **Given** density contrasts ρ_s
 - Any # of \neq density contrasts
3. Only $p_j=0$ or $p_j=\rho_s$
4. $p_j=\rho_s$ of closest seed



Well-posed problem: Minimize goal function

$$\Gamma(\mathbf{p}) = \phi(\mathbf{p}) + \mu \theta(\mathbf{p})$$

Well-posed problem: Minimize goal function

$$\Gamma(\mathbf{p}) = \phi(\mathbf{p}) + \mu \theta(\mathbf{p})$$



Data-misfit function

Well-posed problem: Minimize goal function

$$\Gamma(\mathbf{p}) = \phi(\mathbf{p}) + \mu \theta(\mathbf{p})$$



Regularizing parameter
(Tradeoff between fit and regularization)

Well-posed problem: Minimize goal function

$$\Gamma(\mathbf{p}) = \phi(\mathbf{p}) + \mu \theta(\mathbf{p})$$



Regularizing function

$$\theta(\mathbf{p}) = \sum_{j=1}^M \frac{p_j}{p_j + \epsilon} l_j^\beta$$

Well-posed problem: Minimize goal function

$$\Gamma(\mathbf{p}) = \phi(\mathbf{p}) + \mu \theta(\mathbf{p})$$



Regularizing function

Similar to
Silva Dias et al. (2009)

$$\theta(\mathbf{p}) = \sum_{j=1}^M \frac{p_j}{p_j + \epsilon} l_j^\beta$$

Well-posed problem: Minimize goal function

$$\Gamma(\mathbf{p}) = \phi(\mathbf{p}) + \mu \theta(\mathbf{p})$$



Regularizing function

Similar to
Silva Dias et al. (2009)

$$\theta(\mathbf{p}) = \sum_{j=1}^M \frac{p_j}{p_j + \epsilon} l_j^\beta$$

Distance between
jth prism and seed

Well-posed problem: Minimize goal function

$$\Gamma(\mathbf{p}) = \phi(\mathbf{p}) + \mu \theta(\mathbf{p})$$



Regularizing function

Similar to
Silva Dias et al. (2009)

$$\theta(\mathbf{p}) = \sum_{j=1}^M \frac{p_j}{p_j + \epsilon} l_j^\beta$$

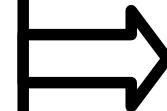
Distance between
jth prism and seed

Imposes:

- Compactness
- Concentration around seeds

Constraints:

- 1. Compact
- 2. Concentrated around “seeds”



Regularization

- 3. Only $p_j = 0$ or $p_j = \rho_s$
- 4. $p_j = \rho_s$ of closest seed

Constraints:

- 1. Compact
- 2. Concentrated around “seeds”



Regularization

- 3. Only $p_j = 0$ or $p_j = \rho_s$
- 4. $p_j = \rho_s$ of closest seed



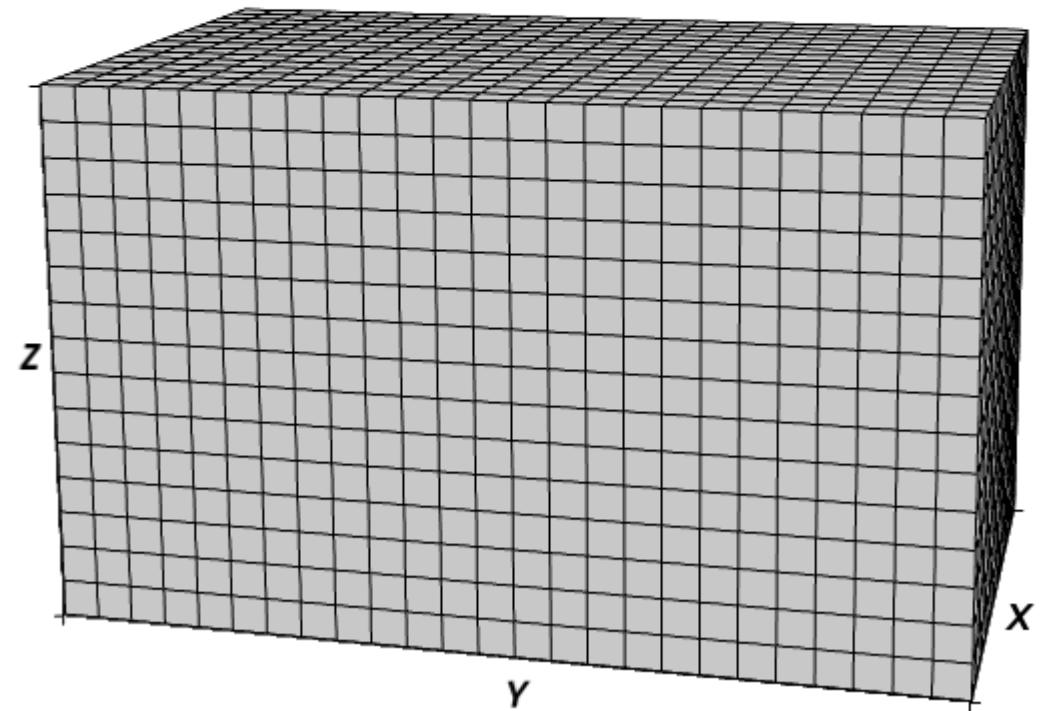
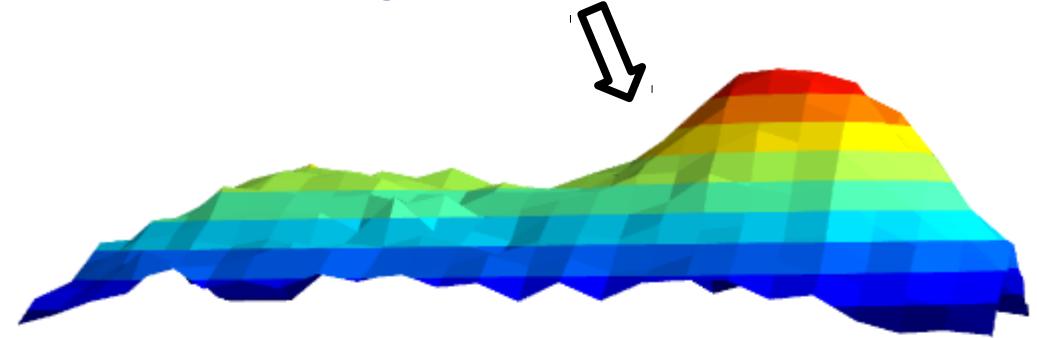
Algorithm

Based on René (1986)

Planting Algorithm

Setup:

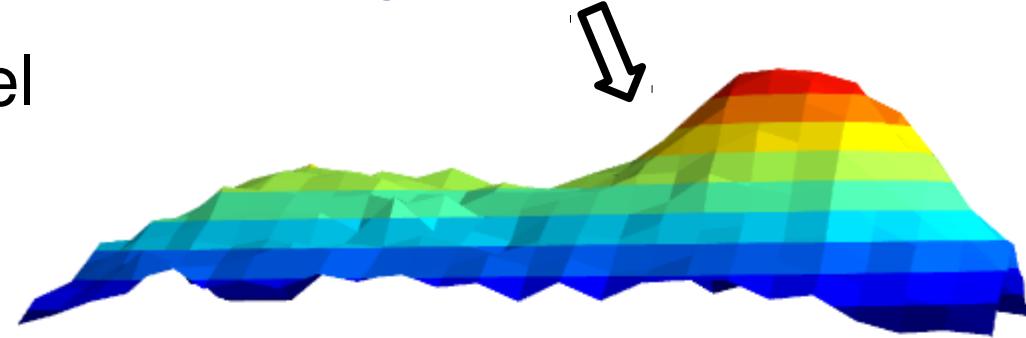
g = observed data



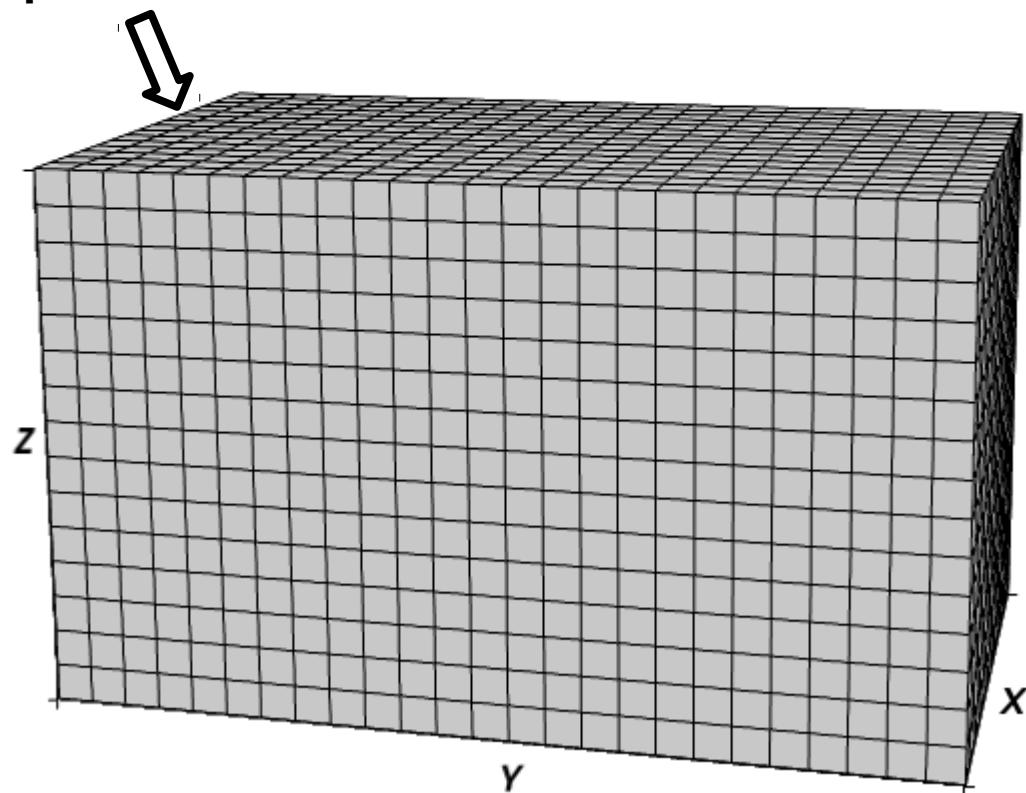
Setup:

Define interpretative model

$g = \text{observed data}$



Interpretative model

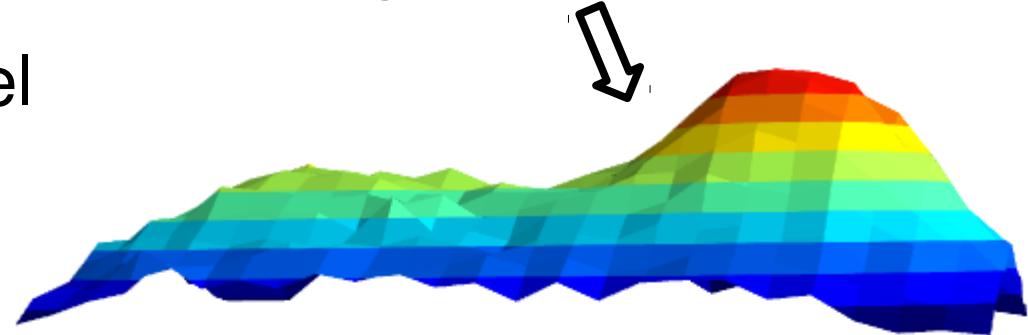


Setup:

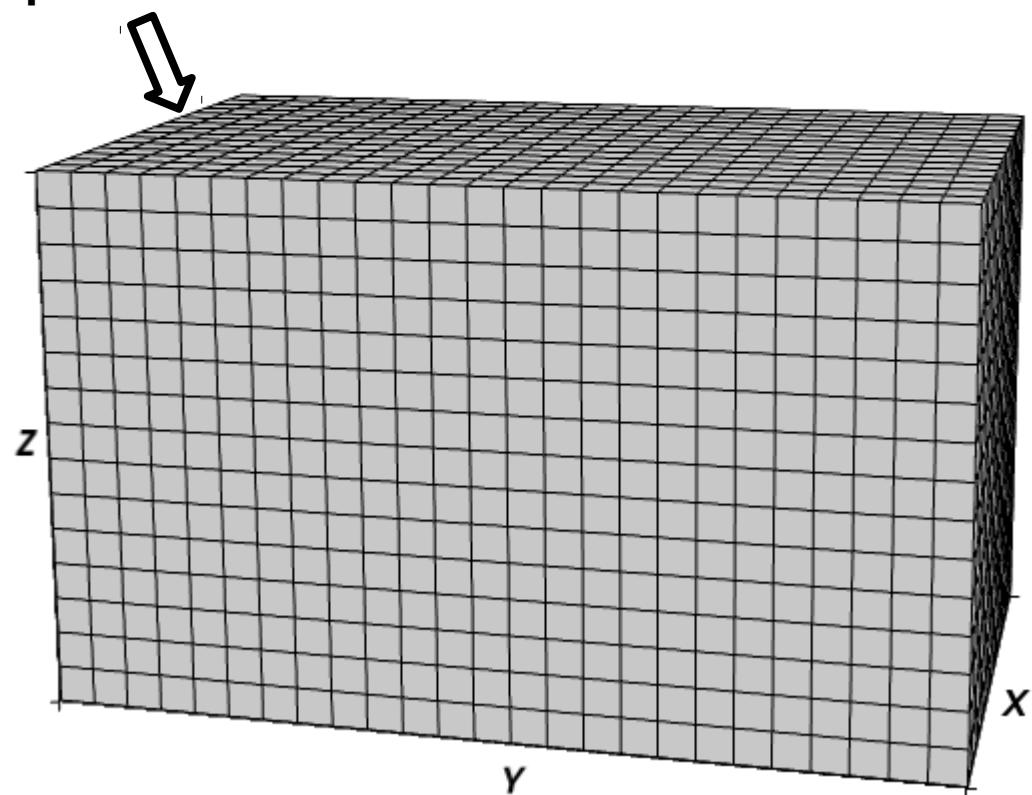
Define interpretative model

All parameters zero

$g = \text{observed data}$



Interpretative model



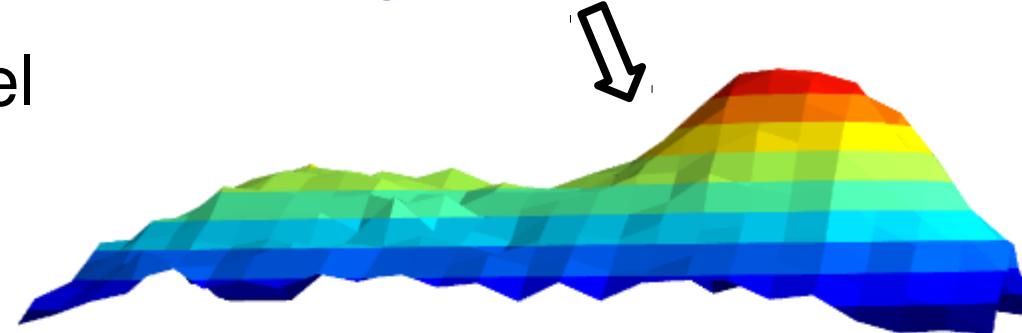
Setup:

Define interpretative model

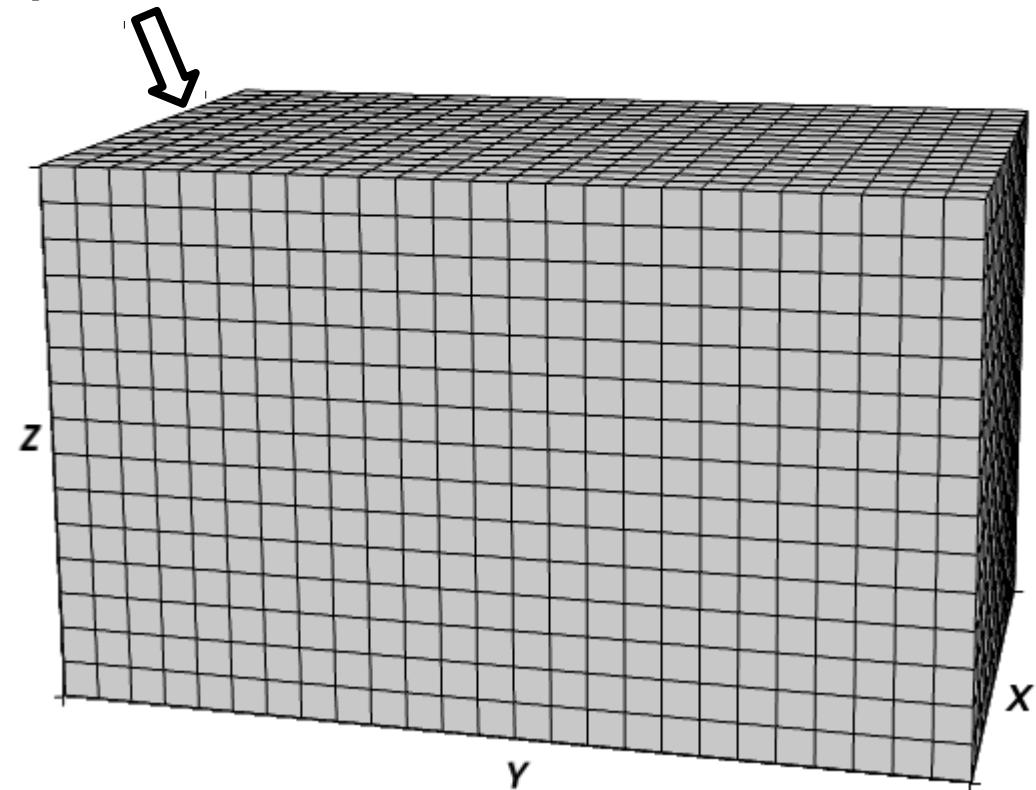
All parameters zero

N_s seeds

$g = \text{observed data}$



Interpretative model



Setup:

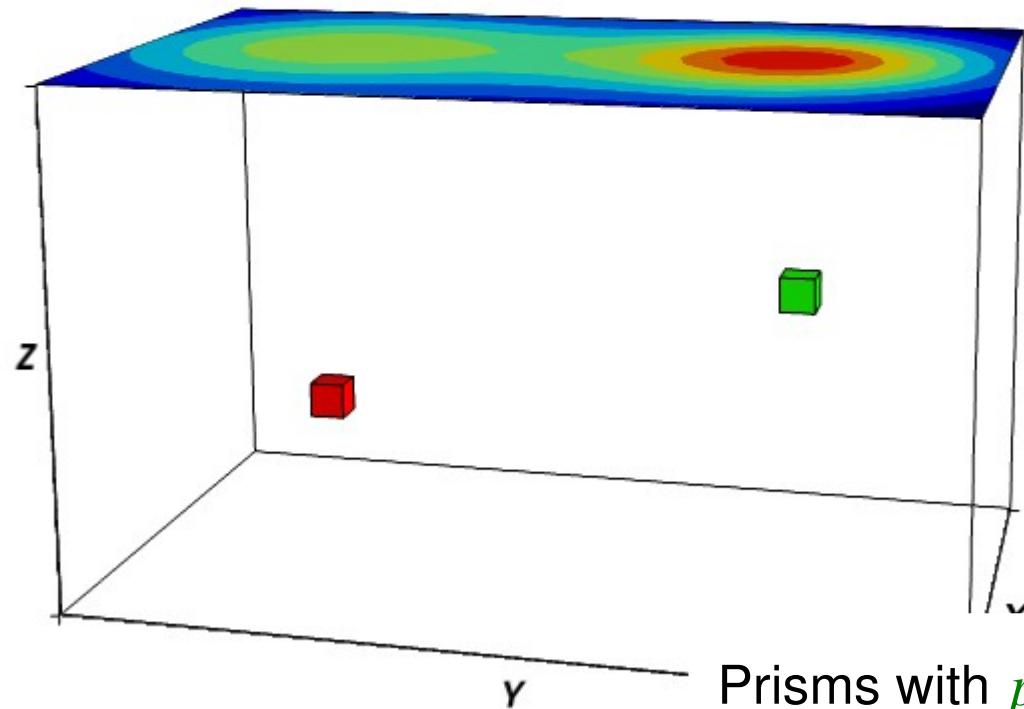
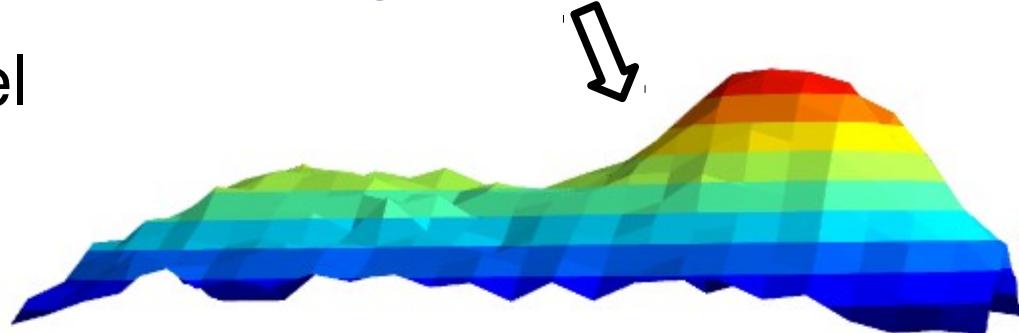
Define interpretative model

All parameters zero

N_s seeds

Include seeds

$g = \text{observed data}$



Setup:

Define interpretative model

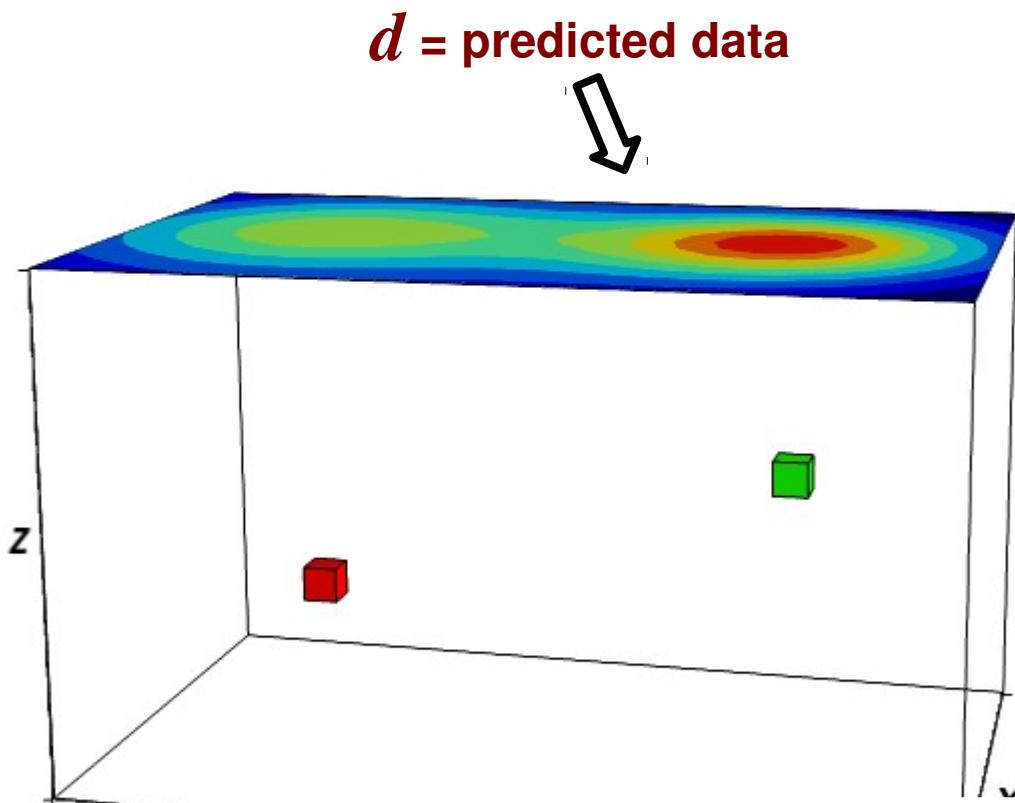
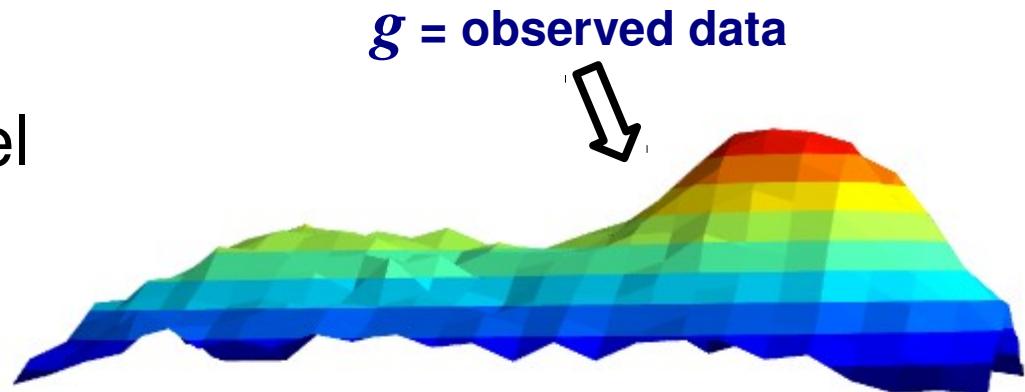
All parameters zero

N_s seeds

Include seeds

Compute initial residuals

$$r^{(0)} = g - d^{(0)}$$



Prisms with $p_j = 0$
not shown

Setup:

Define interpretative model

All parameters zero

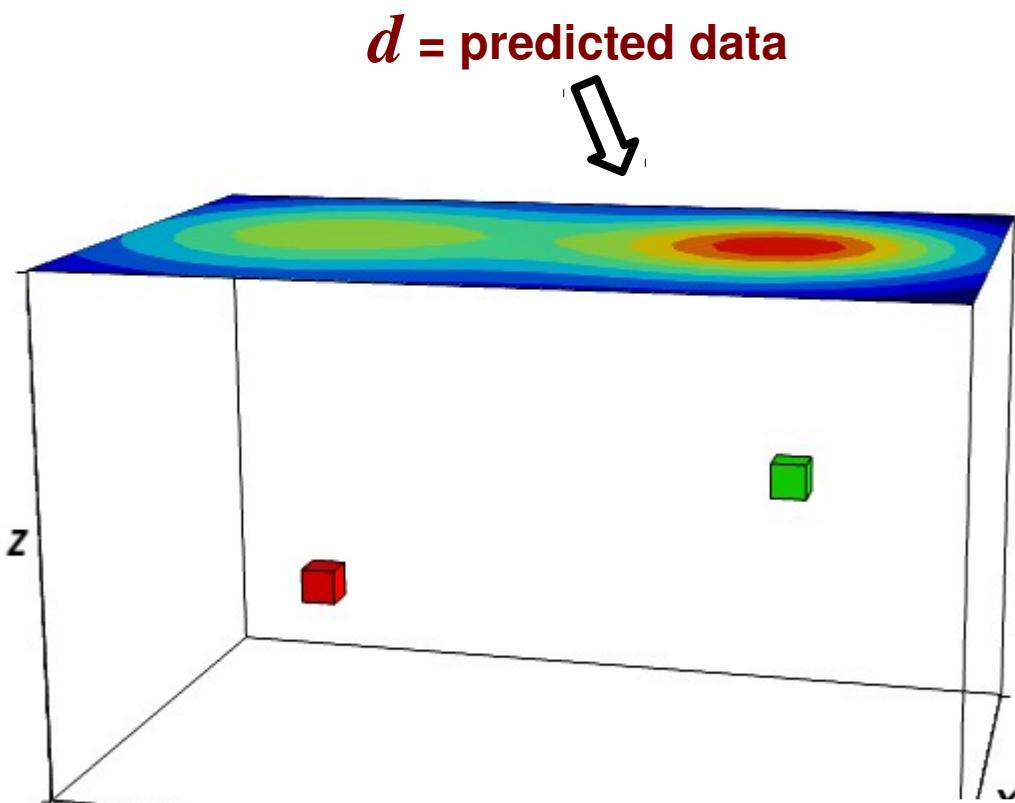
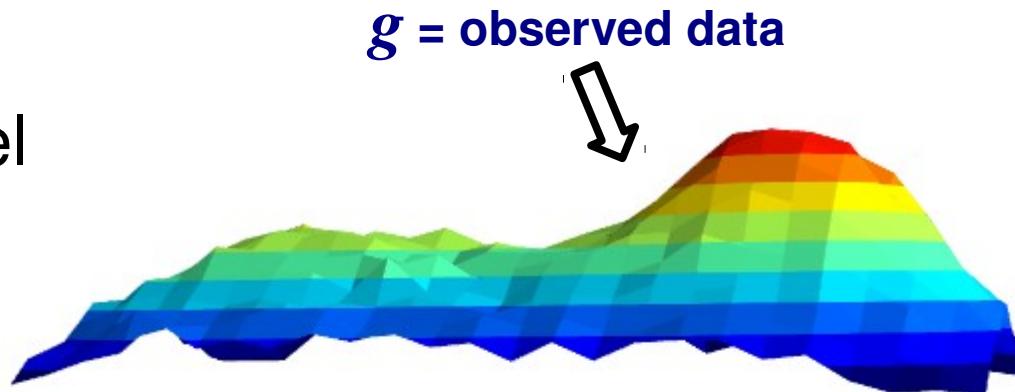
N_s seeds

Include seeds

Compute initial residuals

$$r^{(0)} = g - d^{(0)}$$

Predicted by seeds



Prisms with $p_j = 0$
not shown

Setup:

Define interpretative model

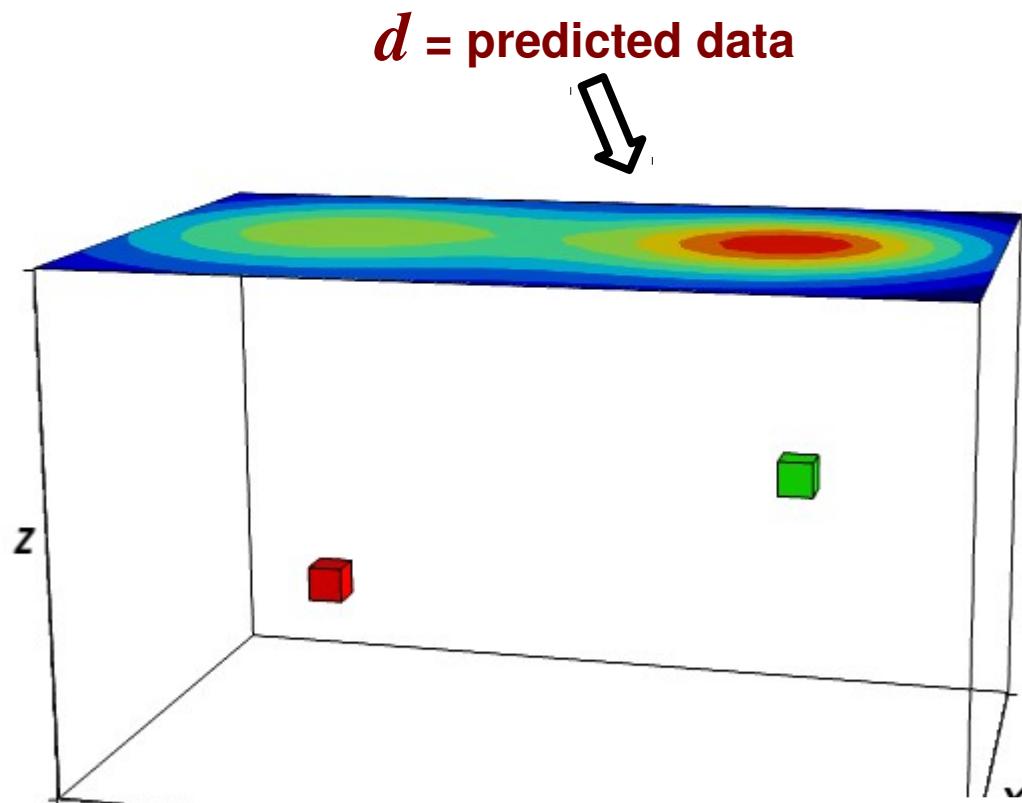
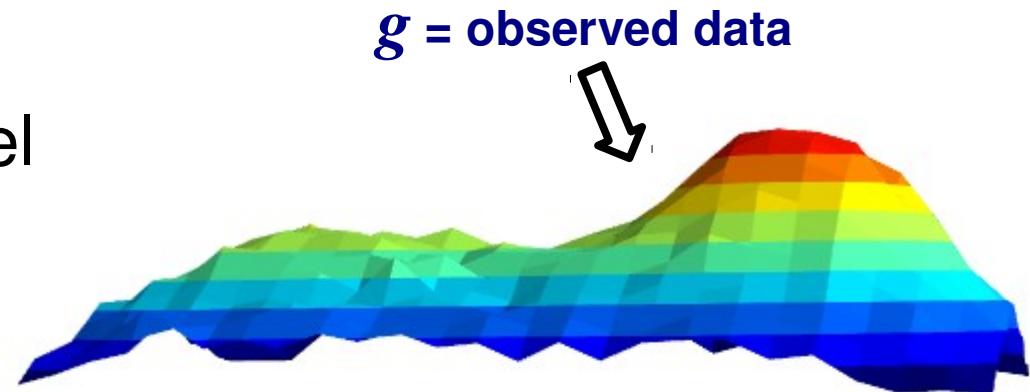
All parameters zero

N_s seeds

Include seeds

Compute initial residuals

$$\mathbf{r}^{(0)} = \mathbf{g} - \left(\sum_{s=1}^{N_s} \rho_s \mathbf{a}_{j_s} \right)$$



Prisms with $p_j = 0$
not shown

Setup:

Define interpretative model

All parameters zero

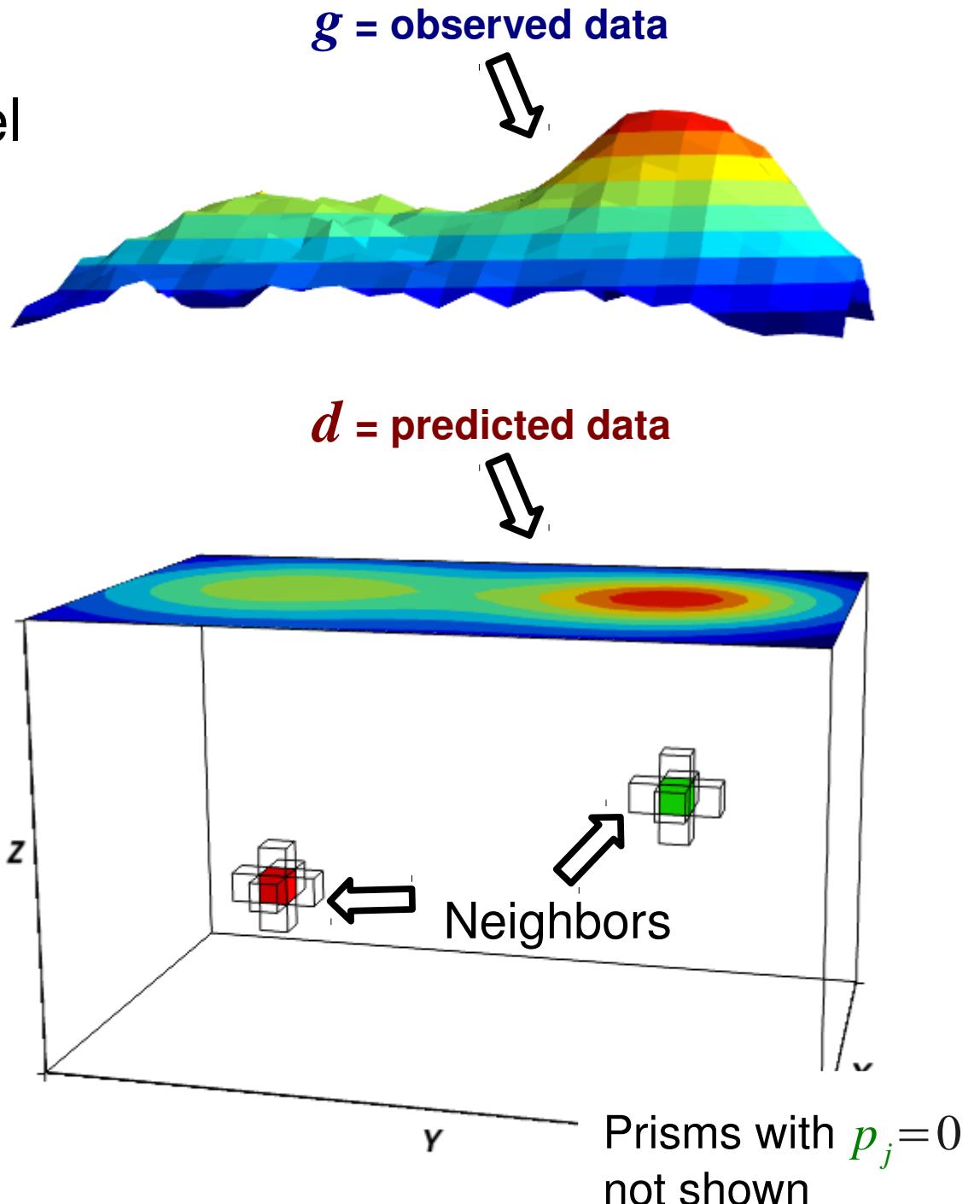
N_s seeds

Include seeds

Compute initial residuals

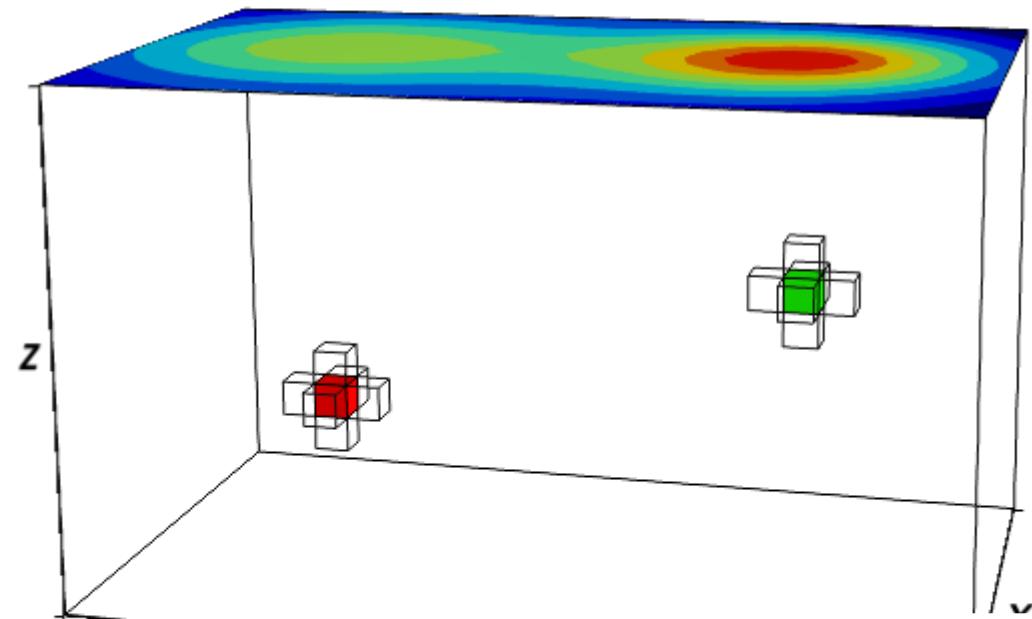
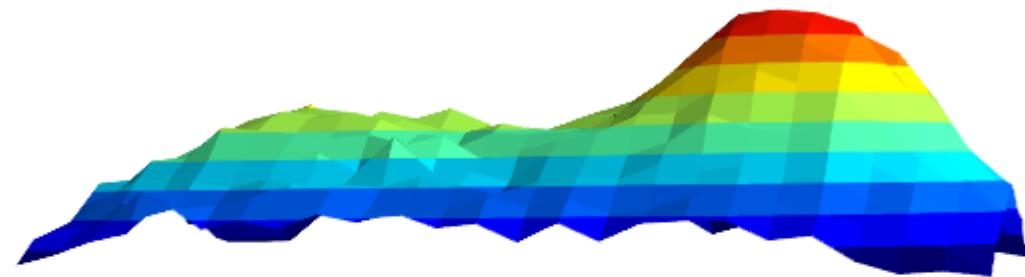
$$\mathbf{r}^{(0)} = \mathbf{g} - \left(\sum_{s=1}^{N_s} \rho_s \mathbf{a}_{j_s} \right)$$

Find neighbors of seeds



Growth:

Try accretion to sth seed:



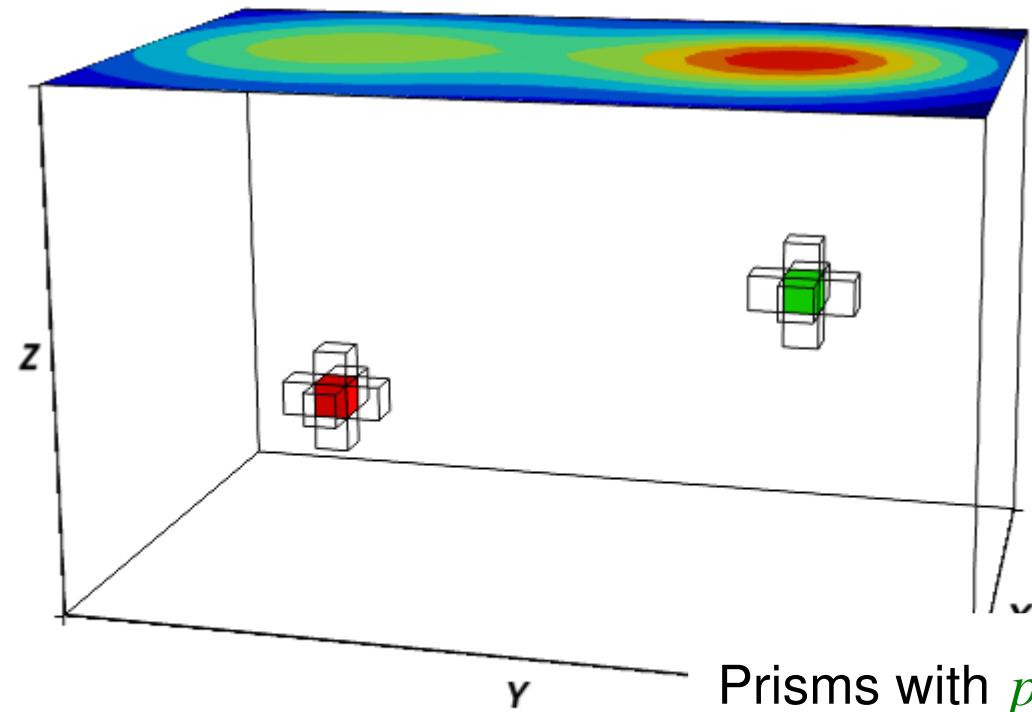
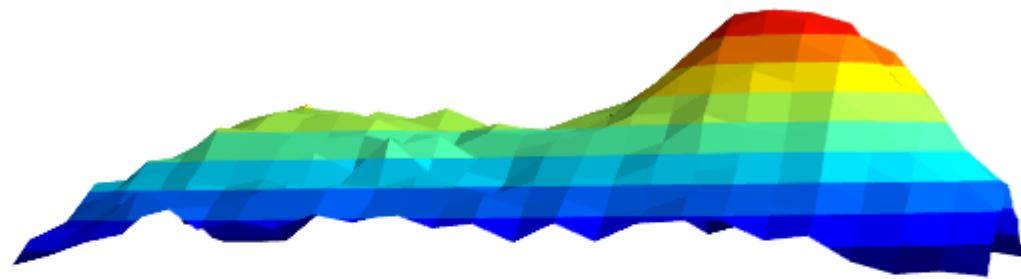
Prisms with $p_j=0$
not shown

Growth:

Try accretion to sth seed:

Choose neighbor:

1. **Reduce** data misfit
2. **Smallest** goal function



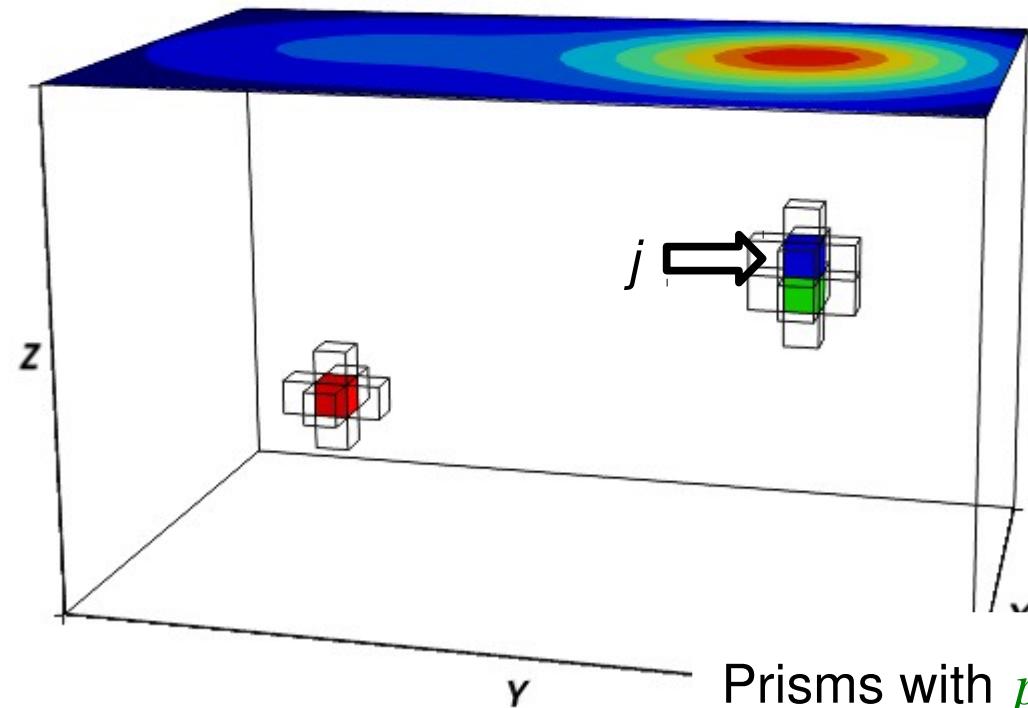
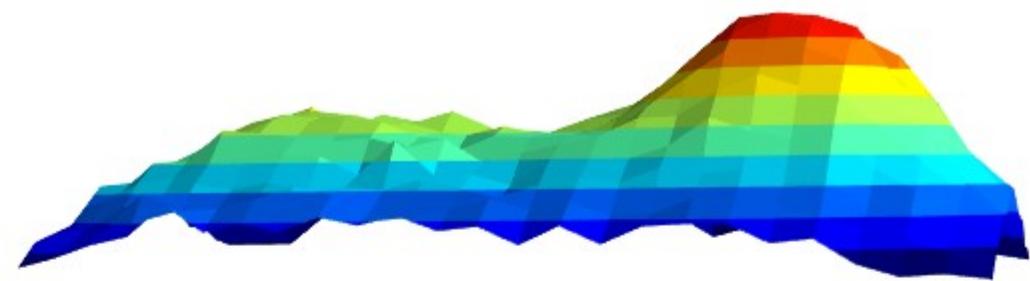
Growth:

Try accretion to sth seed:

Choose neighbor:

1. **Reduce** data misfit
2. **Smallest** goal function

$j = \text{chosen} \rightarrow p_j = \rho_s$ (**New elements**)



Growth:

Try accretion to sth seed:

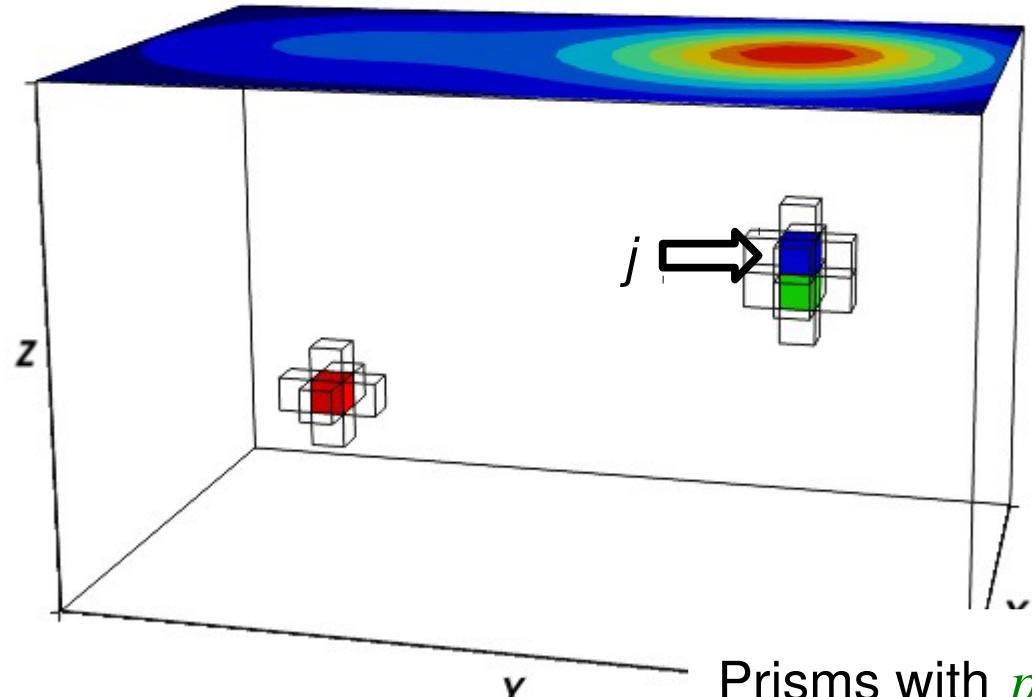
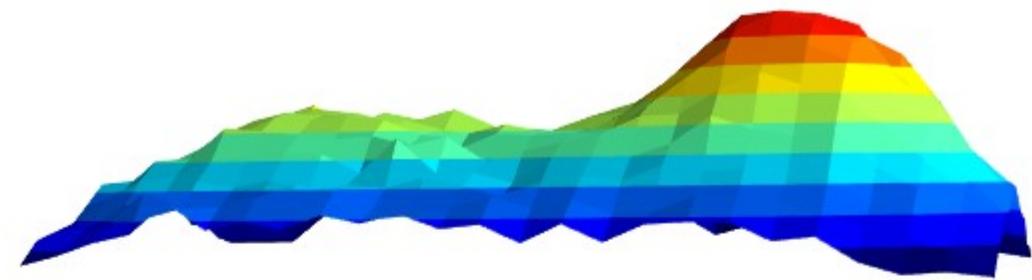
Choose neighbor:

1. **Reduce** data misfit
2. **Smallest** goal function

$$j = \text{chosen} \rightarrow p_j = \rho_s \quad (\text{New elements})$$

Update residuals

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$



Growth:

Try accretion to sth seed:

Choose neighbor:

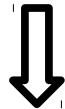
1. **Reduce** data misfit
2. **Smallest** goal function



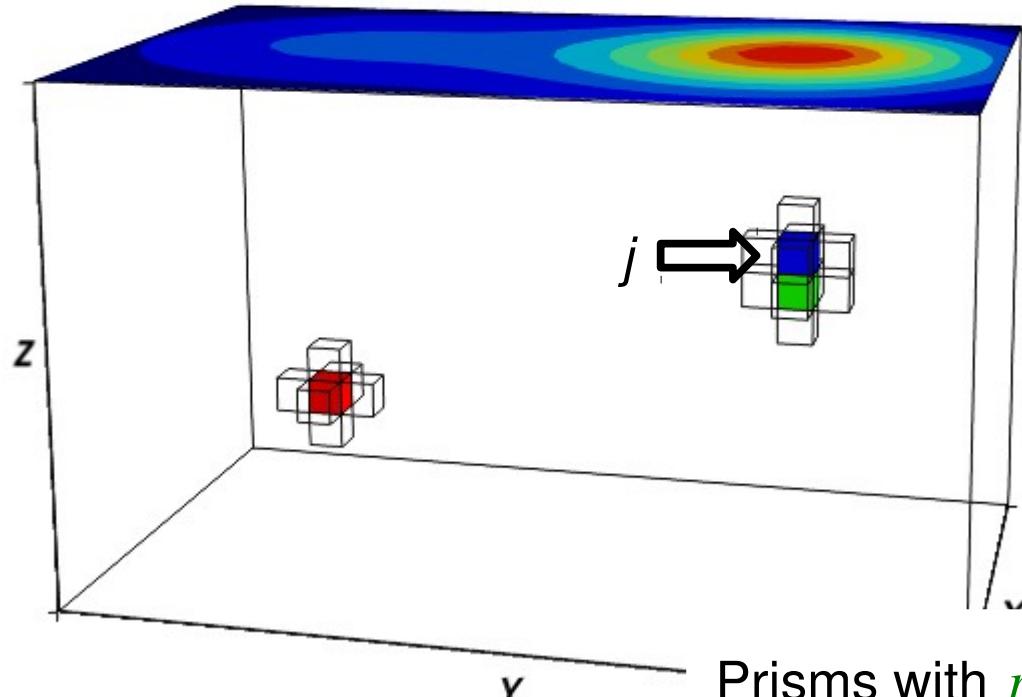
$j = \text{chosen} \rightarrow p_j = \rho_s$ (**New elements**)

Update residuals

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$



Contribution of j



Prisms with $p_j = 0$
not shown

Growth:

Try accretion to sth seed:

Choose neighbor:

1. **Reduce** data misfit
2. **Smallest** goal function

$$j = \text{chosen} \rightarrow p_j = \rho_s \quad (\text{New elements})$$

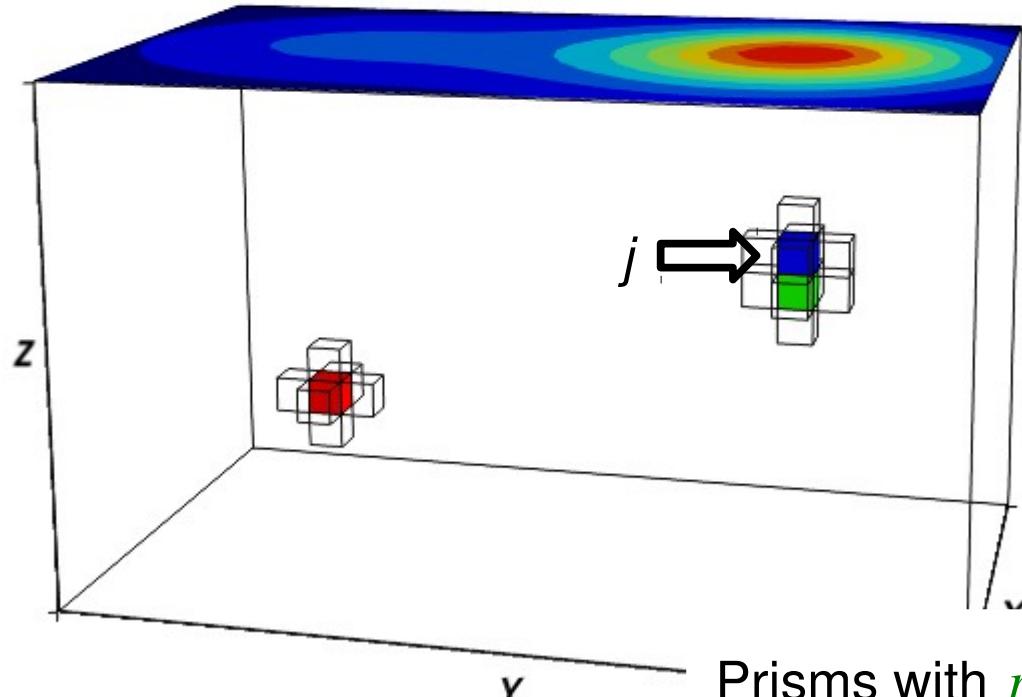
Update residuals

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

None found = no accretion



Variable sizes



Prisms with $p_j=0$ not shown

Growth:

Try accretion to sth seed:



Choose neighbor:

1. **Reduce** data misfit



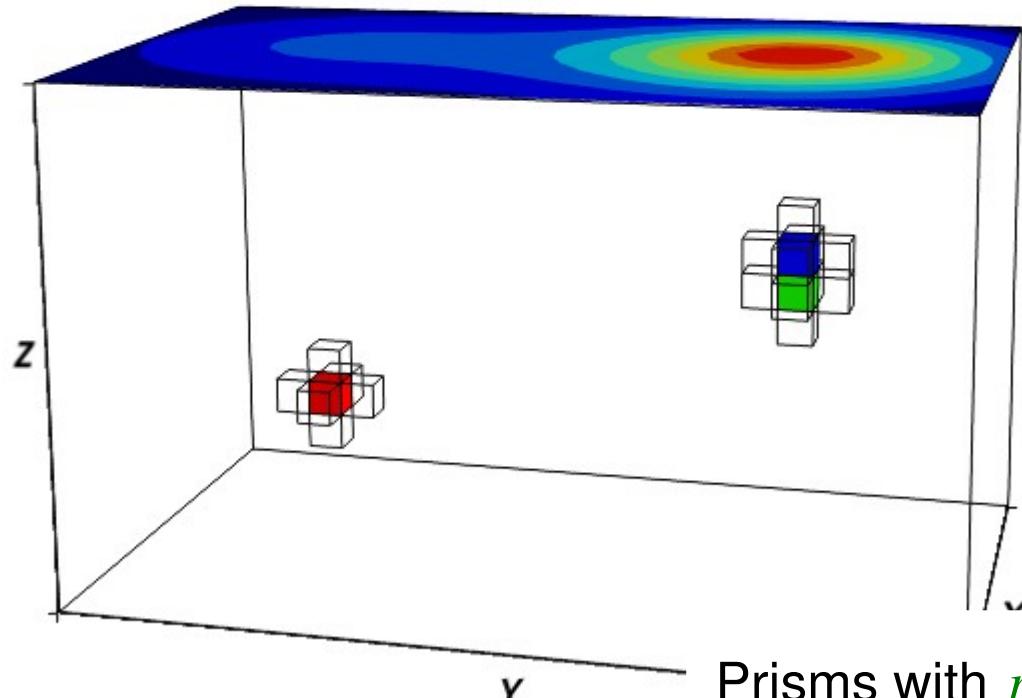
N_s 2. **Smallest** goal function

$j = \text{chosen} \rightarrow p_j = \rho_s$ (**New elements**)

Update residuals

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

None found = no accretion

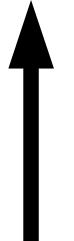


y

Prisms with $p_j = 0$
not shown

Growth:

Try accretion to sth seed:



Choose neighbor:

1. **Reduce** data misfit



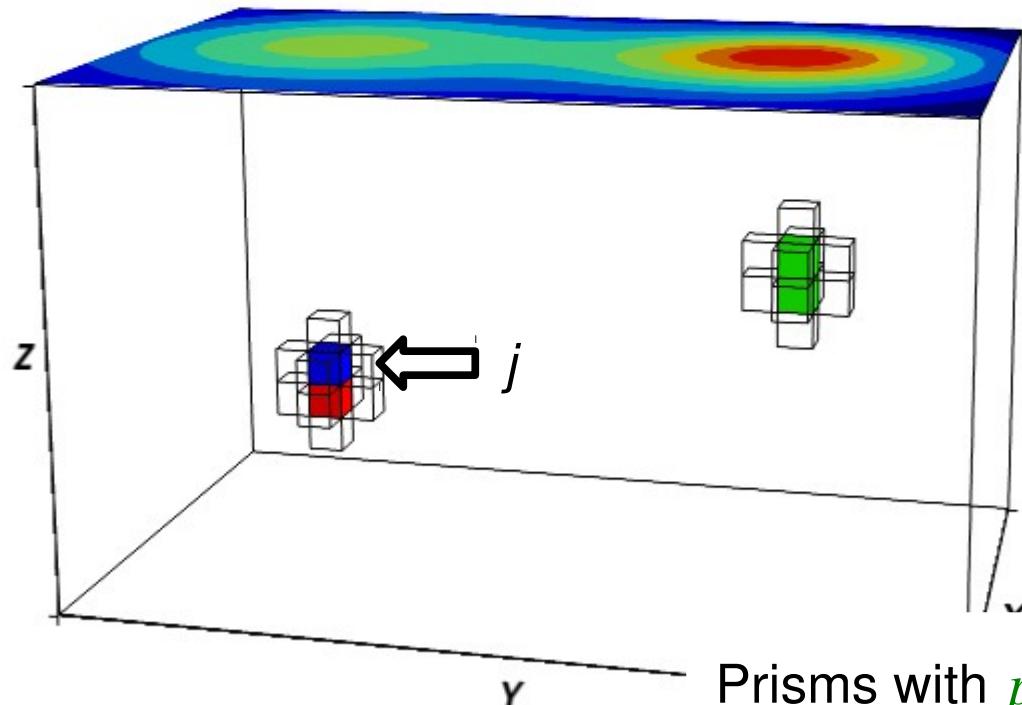
N_s 2. **Smallest** goal function

$j = \text{chosen} \rightarrow p_j = \rho_s$ (**New elements**)

Update residuals

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

None found = no accretion



Prisms with $p_j = 0$
not shown

Growth:

Try accretion to sth seed:



Choose neighbor:

1. **Reduce** data misfit



N_s 2. **Smallest** goal function

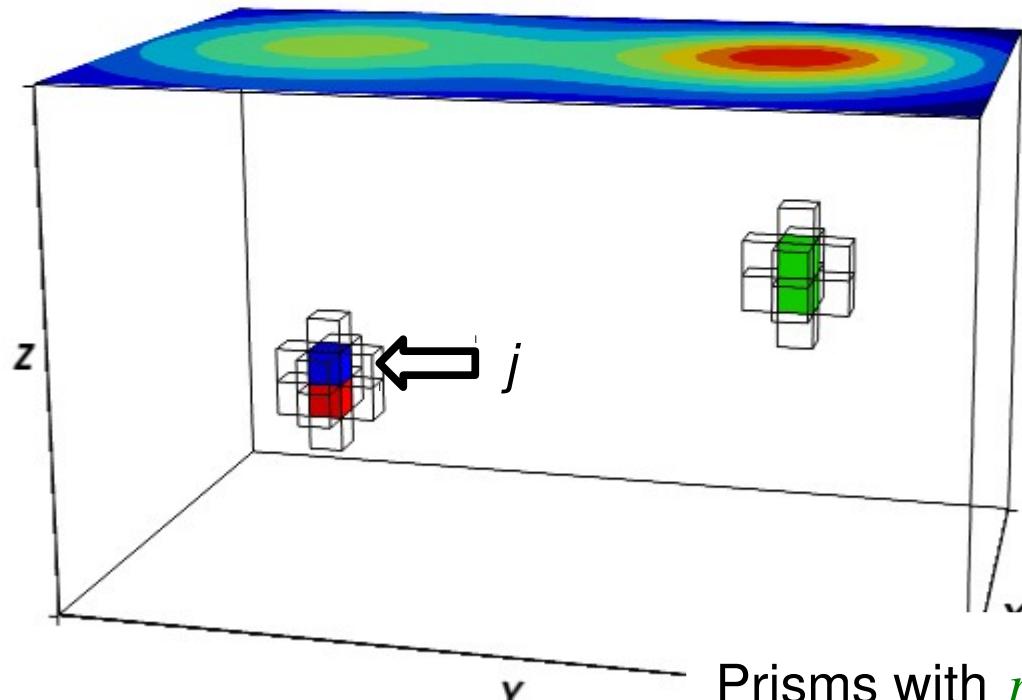
$j = \text{chosen} \rightarrow p_j = \rho_s$ (**New elements**)

Update residuals

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

None found = no accretion

At least **one** seed grow?



Prisms with $p_j = 0$
not shown

Growth:

Try accretion to sth seed:

Choose neighbor:

1. **Reduce** data misfit

N_s 2. **Smallest** goal function

$j = \text{chosen} \rightarrow p_j = \rho_s$ (**New elements**)

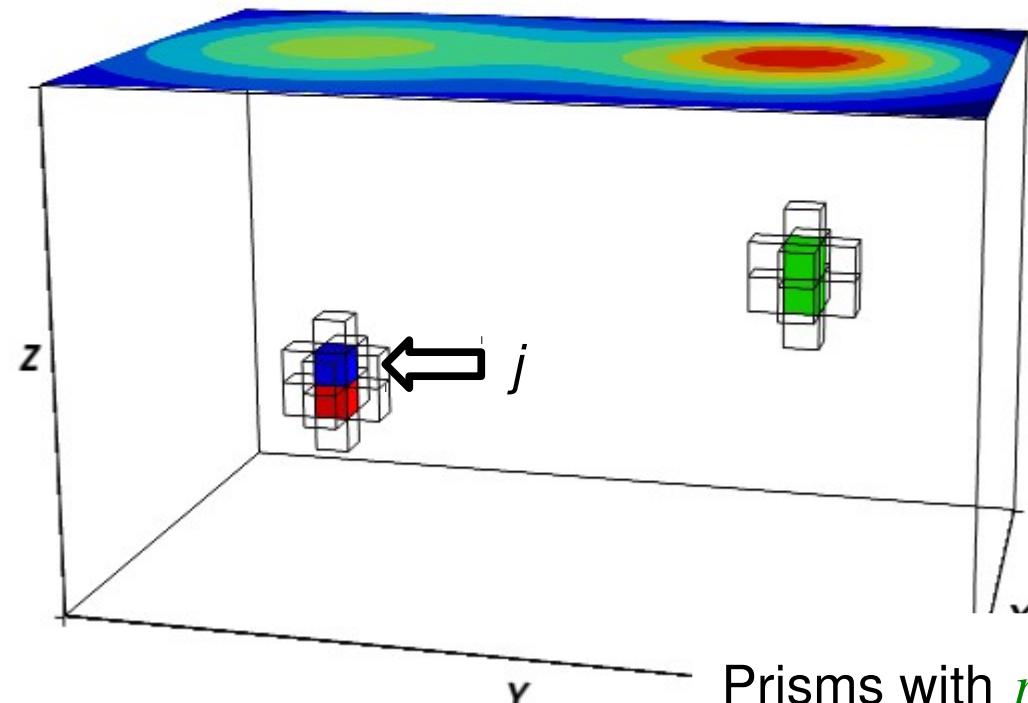
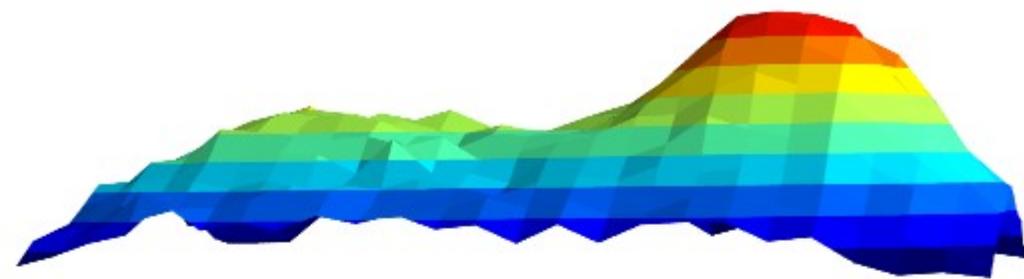
Update residuals

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

None found = no accretion

At least **one** seed grow?

Yes



Growth:

Try accretion to sth seed:

Choose neighbor:

1. **Reduce** data misfit

N_s 2. **Smallest** goal function

$j = \text{chosen} \rightarrow p_j = \rho_s$ (**New elements**)

Update residuals

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

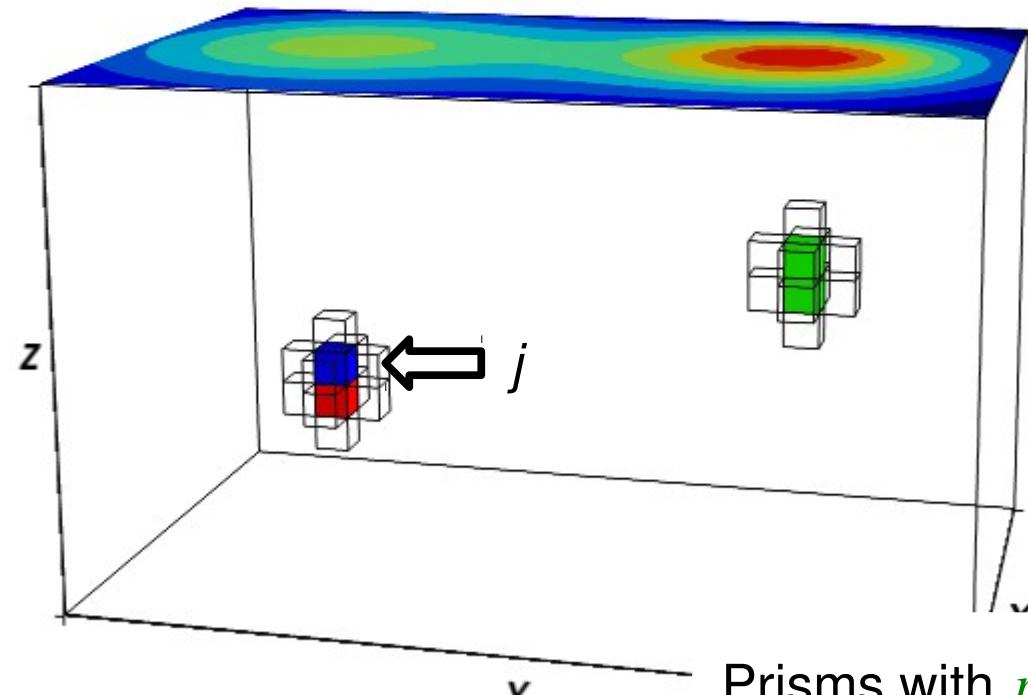
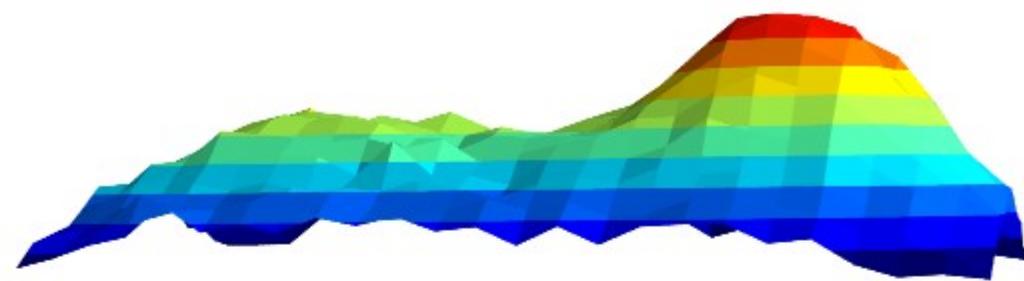
None found = no accretion

At least **one** seed grow?

Yes

No

Done!



Prisms with $p_j = 0$
not shown

Advantages:

Compact & non-smooth

Any number of sources

Any number of different density contrasts

No large equation system

Search limited to neighbors

Remember equations:

Initial residual

$$\mathbf{r}^{(0)} = \mathbf{g} - \left(\sum_{s=1}^{N_s} \rho_s \mathbf{a}_{j_s} \right)$$

Update residual vector

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

Remember equations:

Initial residual

$$\mathbf{r}^{(0)} = \mathbf{g} - \left(\sum_{s=1}^{N_s} \rho_s \mathbf{a}_{j_s} \right)$$

Update residual vector

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

No matrix multiplication (only vector +)

Remember equations:

Initial residual

$$\mathbf{r}^{(0)} = \mathbf{g} - \left(\sum_{s=1}^{N_s} \rho_s \mathbf{a}_{j_s} \right)$$

Update residual vector

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

No matrix multiplication (only vector +)

Only need some **columns** of **A**

Remember equations:

Initial residual

$$\mathbf{r}^{(0)} = \mathbf{g} - \left(\sum_{s=1}^{N_s} \rho_s \mathbf{a}_{j_s} \right)$$

Update residual vector

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

No matrix multiplication (only vector +)

Only need some **columns** of **A**

Calculate only when needed

Remember equations:

Initial residual

$$\mathbf{r}^{(0)} = \mathbf{g} - \left(\sum_{s=1}^{N_s} \rho_s \mathbf{a}_{j_s} \right)$$

Update residual vector

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

No matrix multiplication (only vector +)

Only need some **columns** of **A**

Calculate only when needed & delete after update

Remember equations:

Initial residual

$$\mathbf{r}^{(0)} = \mathbf{g} - \left(\sum_{s=1}^{N_s} \rho_s \mathbf{a}_{j_s} \right)$$

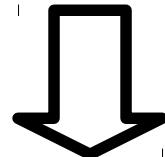
Update residual vector

$$\mathbf{r}^{(new)} = \mathbf{r}^{(old)} - p_j \mathbf{a}_j$$

No matrix multiplication (only vector +)

Only need some **columns** of **A**

Calculate only when needed & delete after update



Lazy evaluation

Advantages:

Compact & non-smooth

Any number of sources

Any number of different density contrasts

No large equation system

Search limited to neighbors

Advantages:

Compact & non-smooth

Any number of sources

Any number of different density contrasts

No large equation system

Search limited to neighbors

No matrix multiplication (only vector +)

Lazy evaluation of Jacobian

Advantages:

Compact & non-smooth

Any number of sources

Any number of different density contrasts

No large equation system

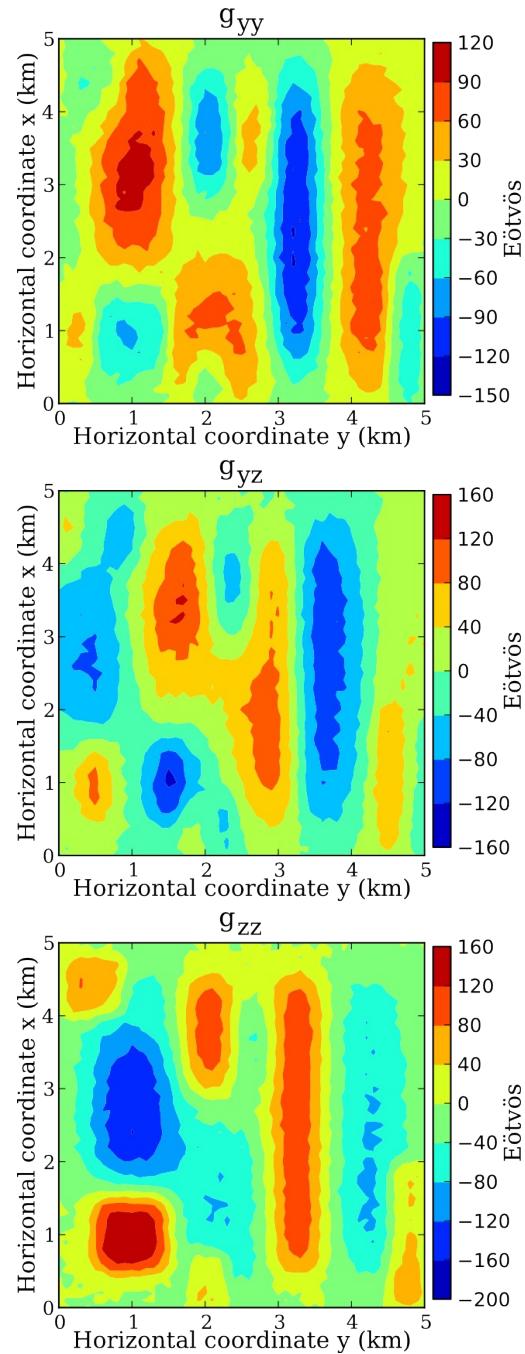
Search limited to neighbors

No matrix multiplication (only vector +)

Lazy evaluation of Jacobian

Fast inversion + low memory usage

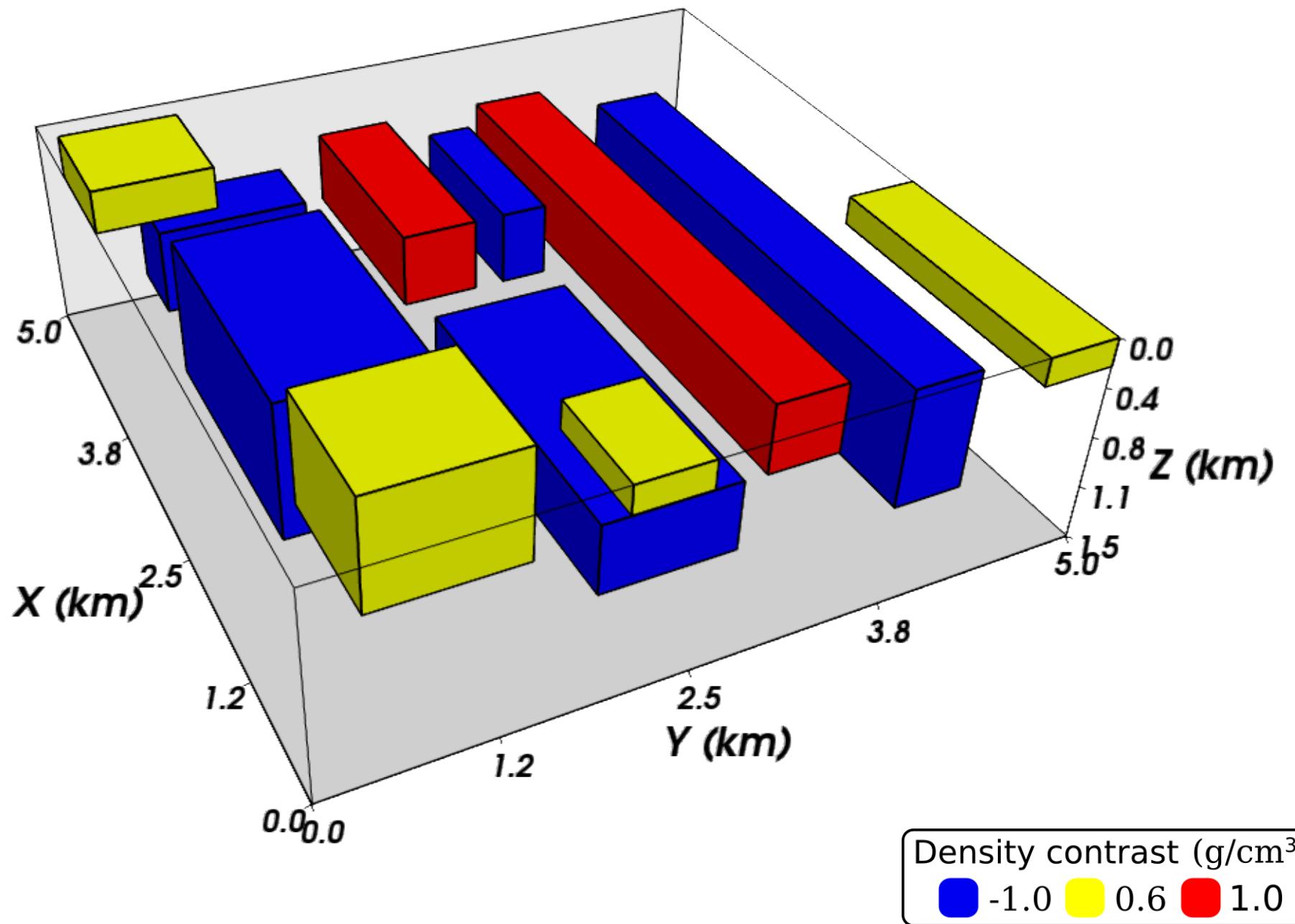
Synthetic Data



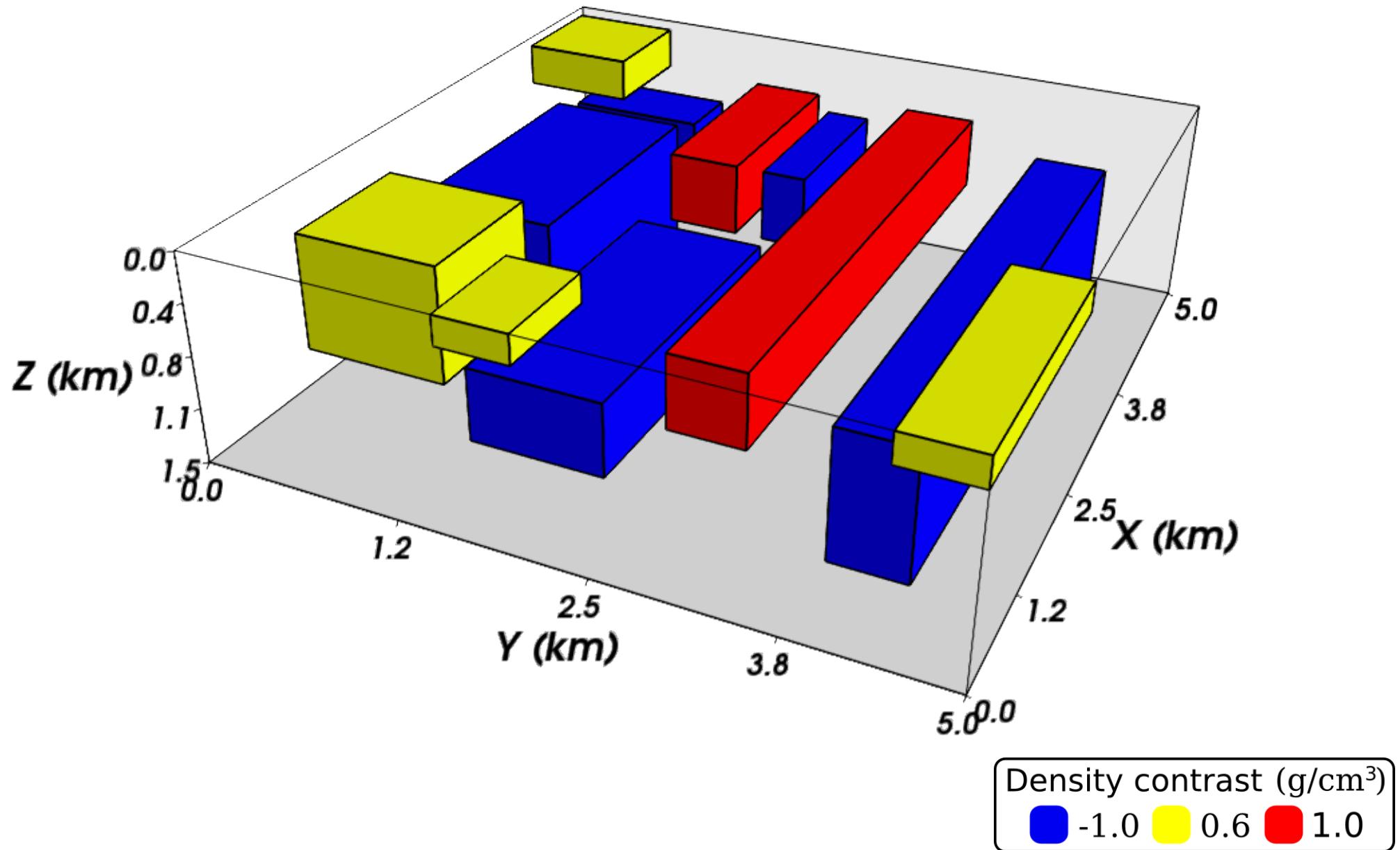
Data set:

- 3 components
- 51×51 points
- 2601 points/component
- 7803 measurements
- 5 Eötvös noise

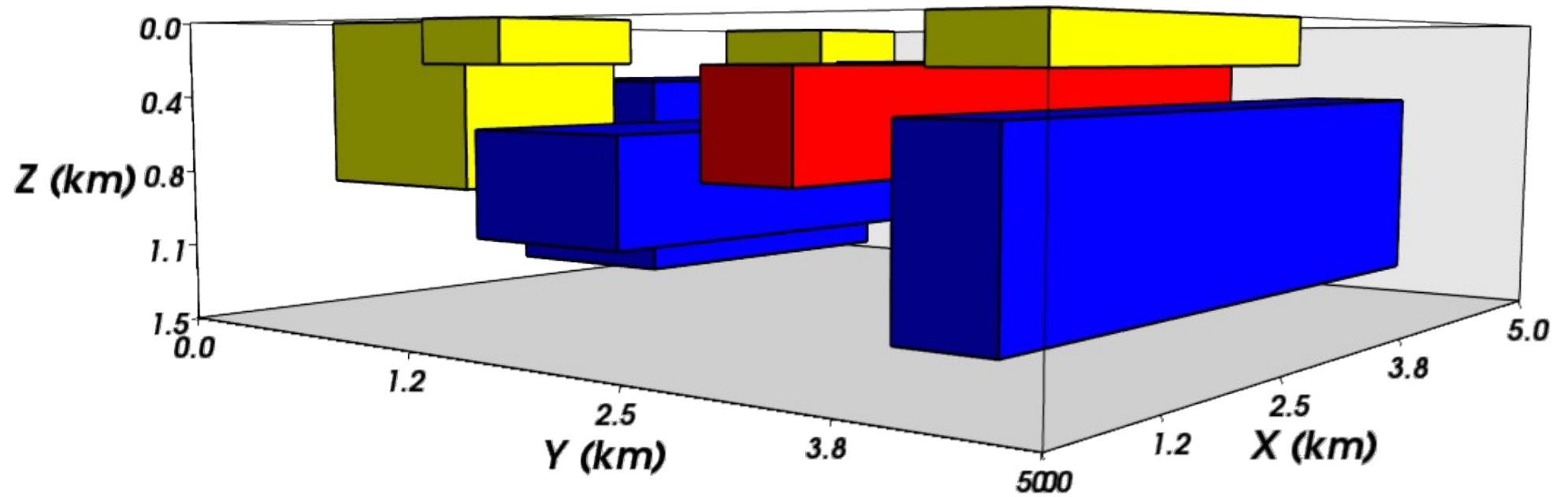
Model:



Model: • 11 prisms



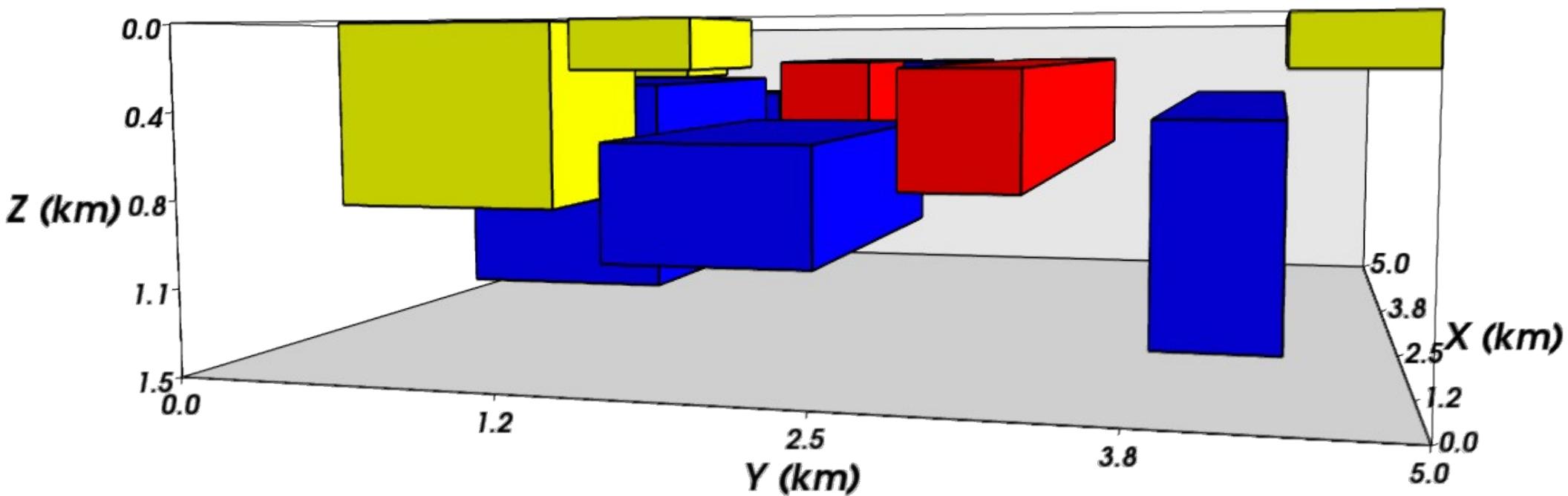
Model: • 11 prisms • 4 outcropping



Density contrast (g/cm^3)

■	-1.0	■	0.6	■	1.0
---	------	---	-----	---	-----

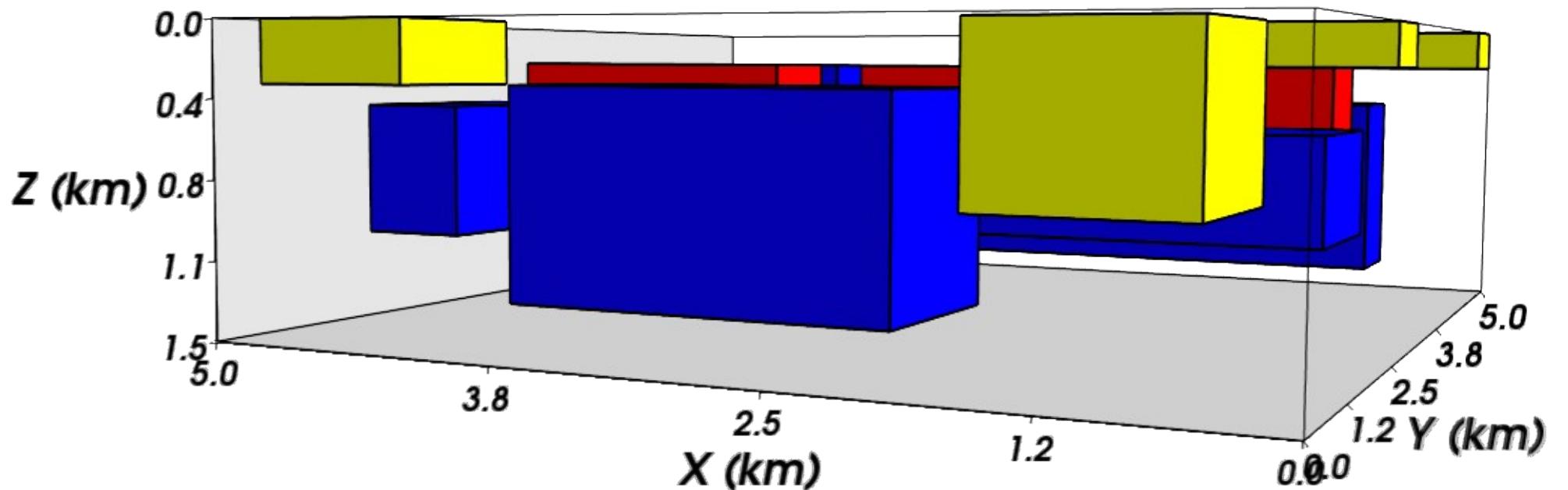
Model: • 11 prisms • 4 outcropping

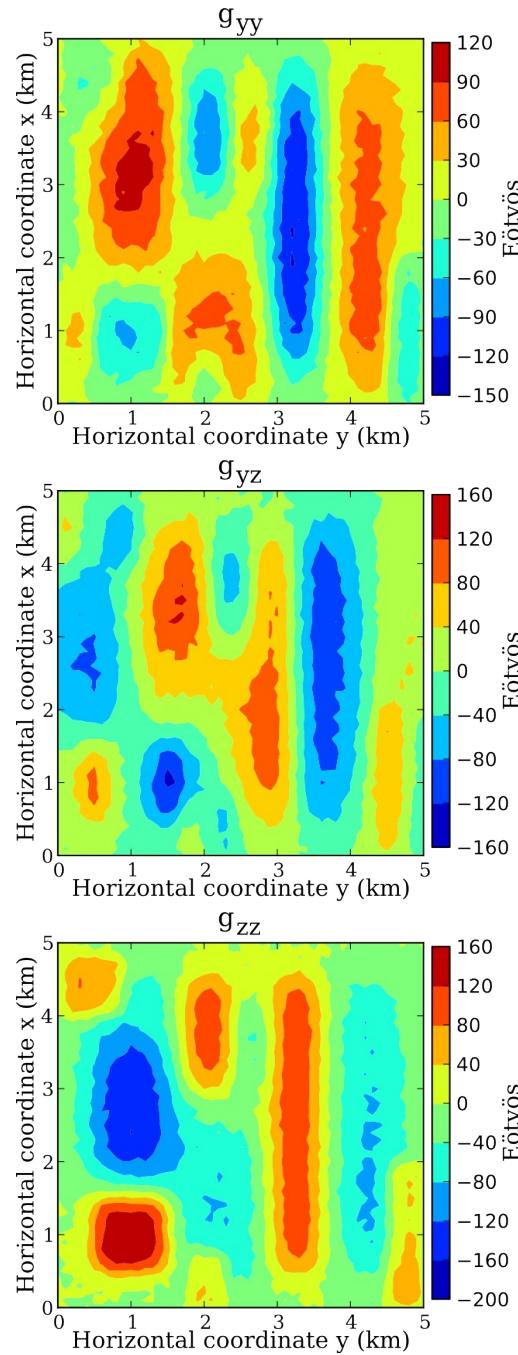


Density contrast (g/cm³)

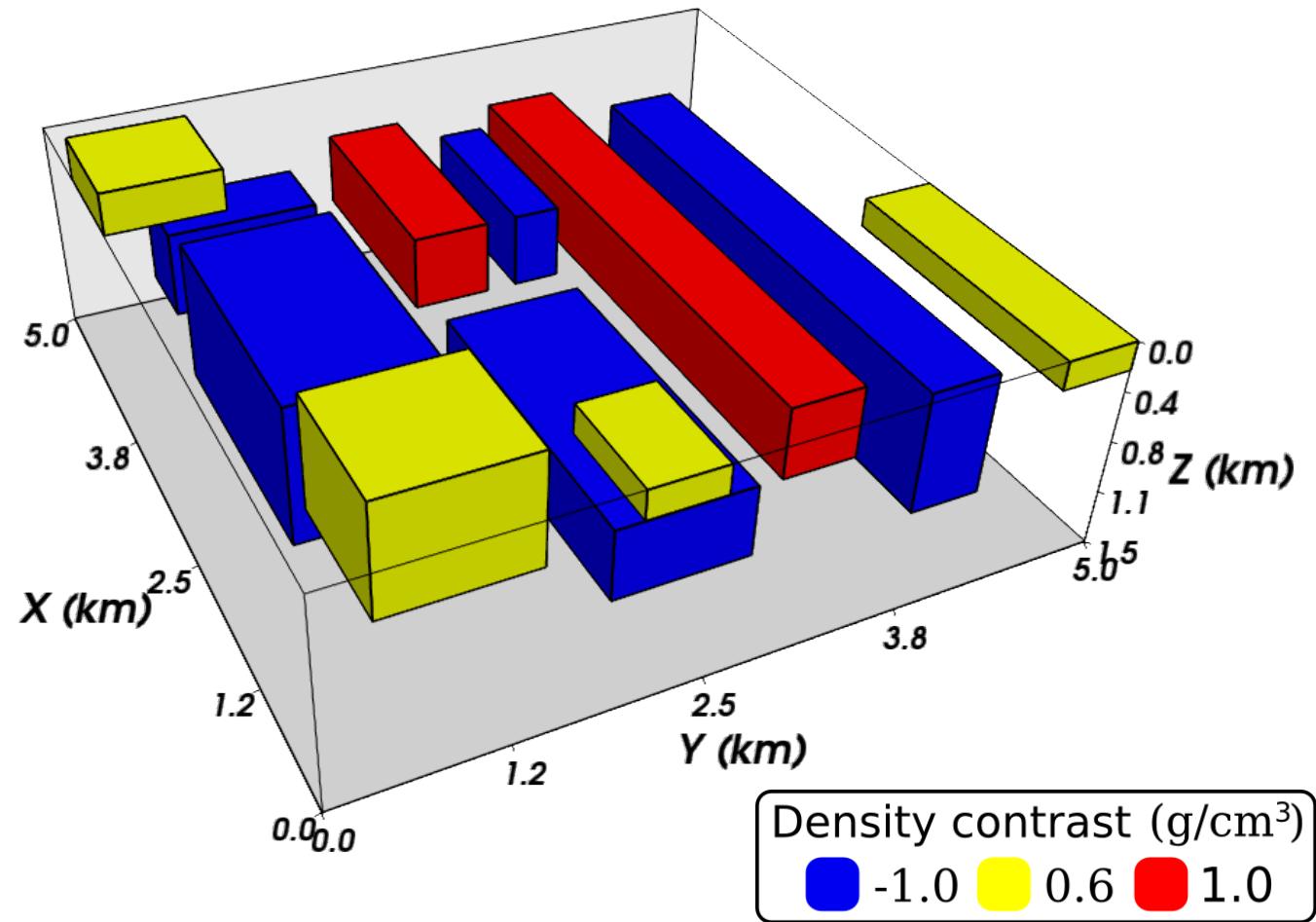
■	-1.0	■	0.6	■	1.0
---	------	---	-----	---	-----

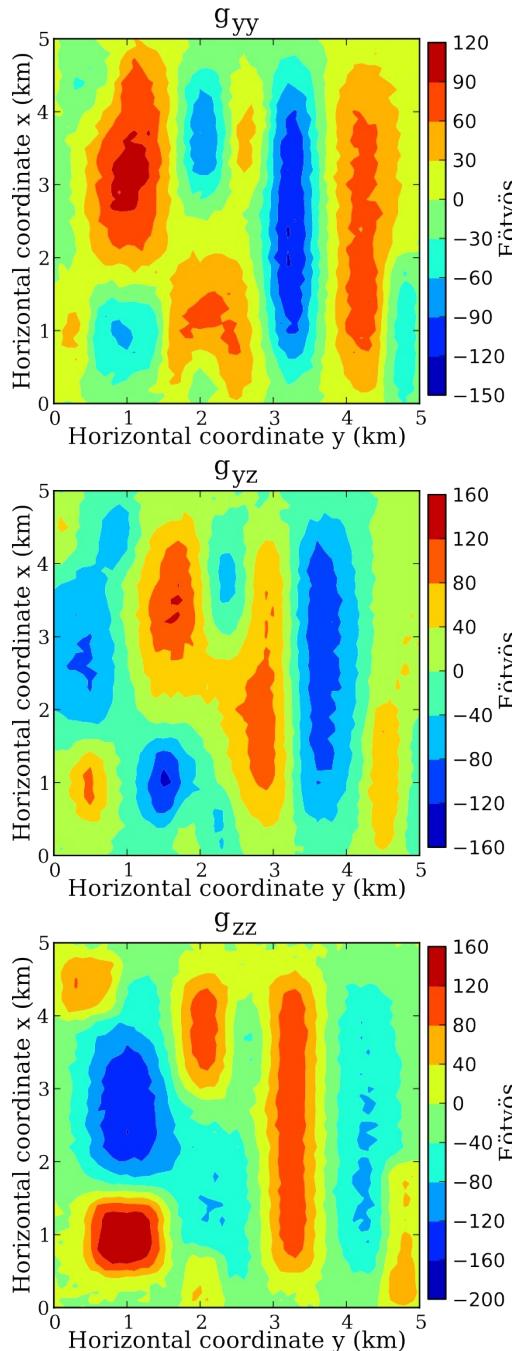
Model: • 11 prisms • 4 outcropping



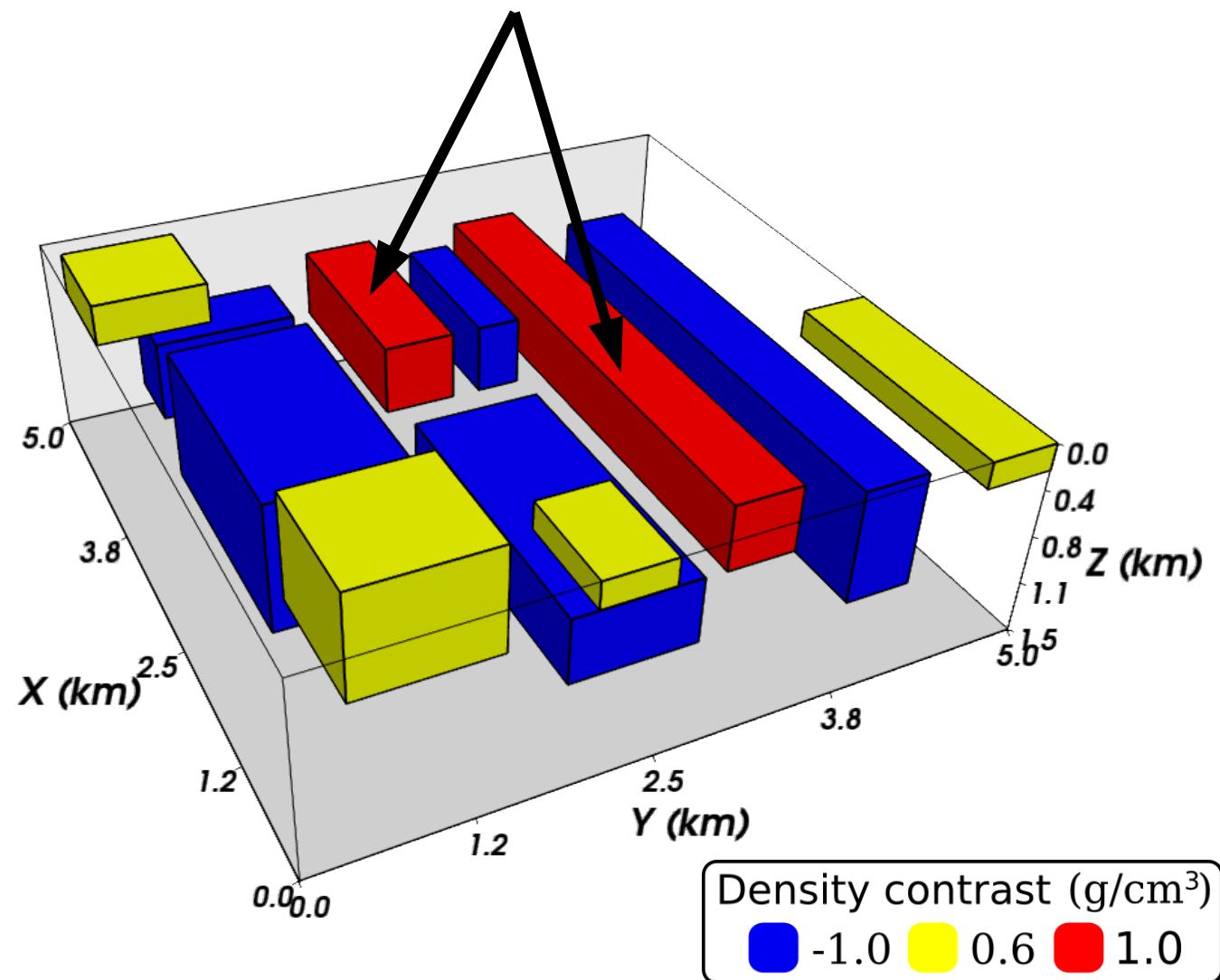


- Strongly interfering effects

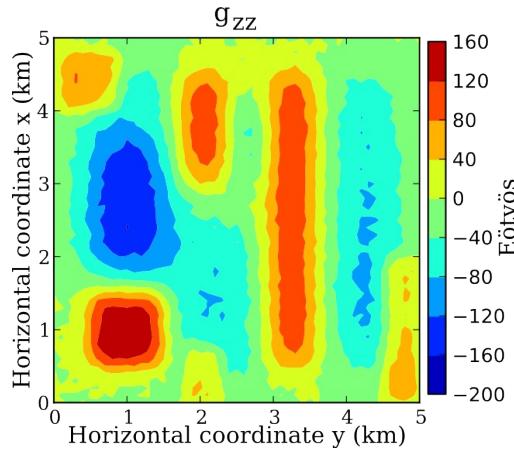
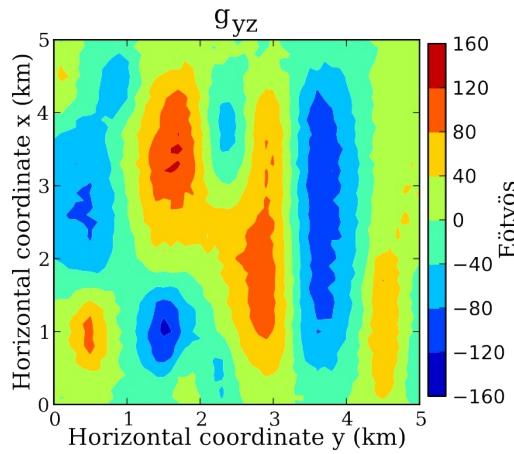
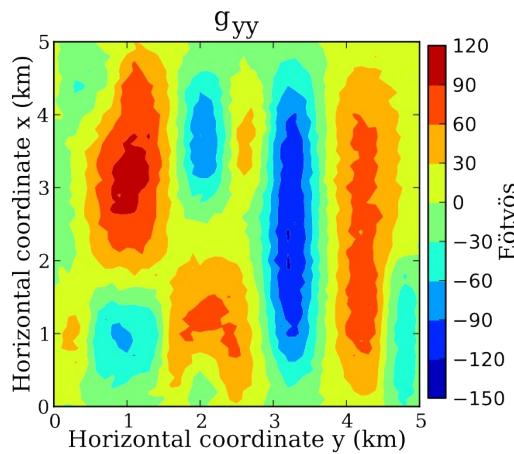


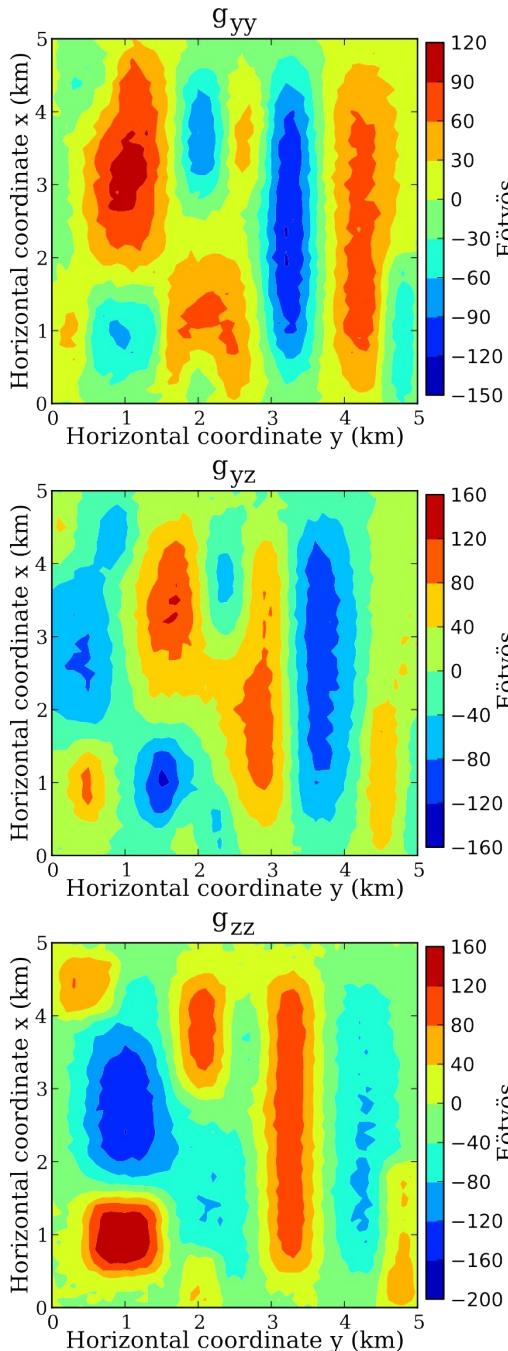


- Strongly interfering effects
- What if only interested in these?

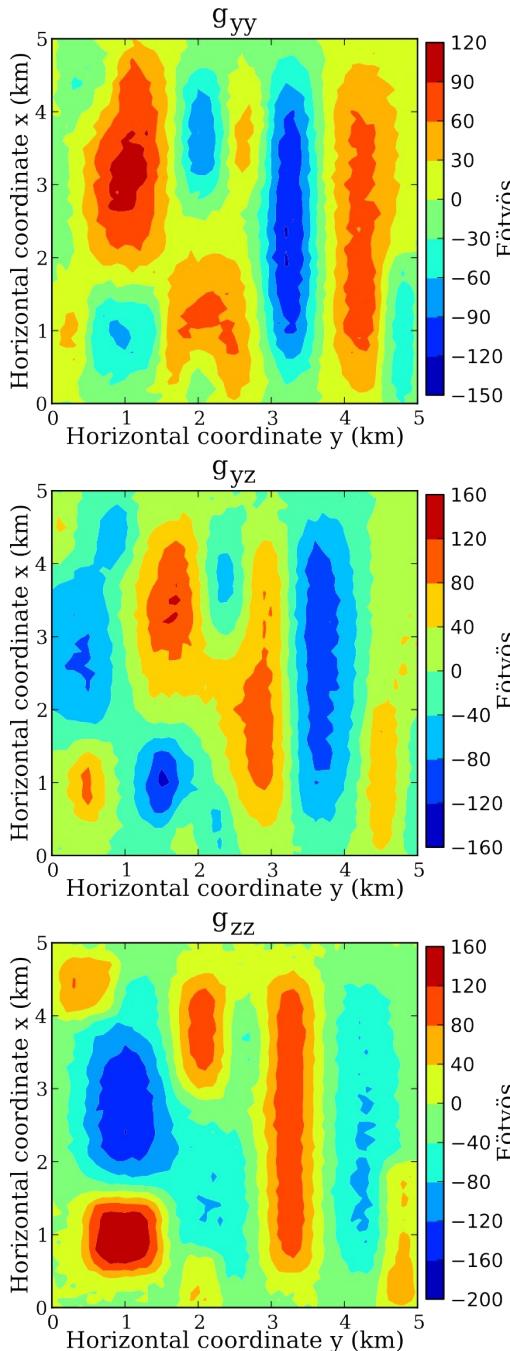


- Common scenario

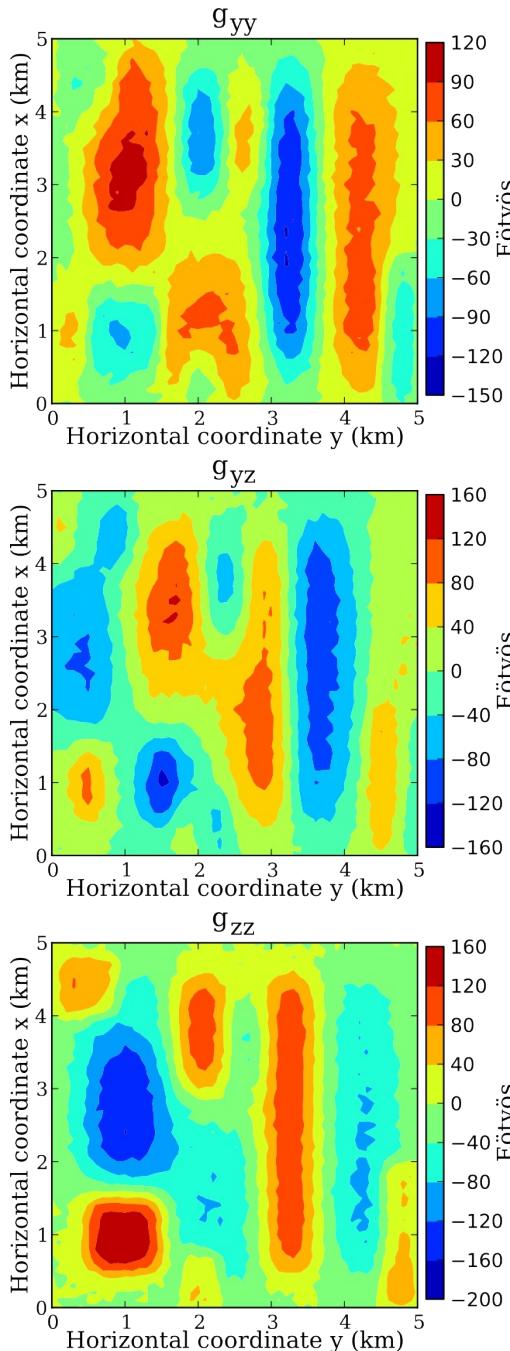




- Common scenario
- May not have prior information
 - Density contrast
 - Approximate depth

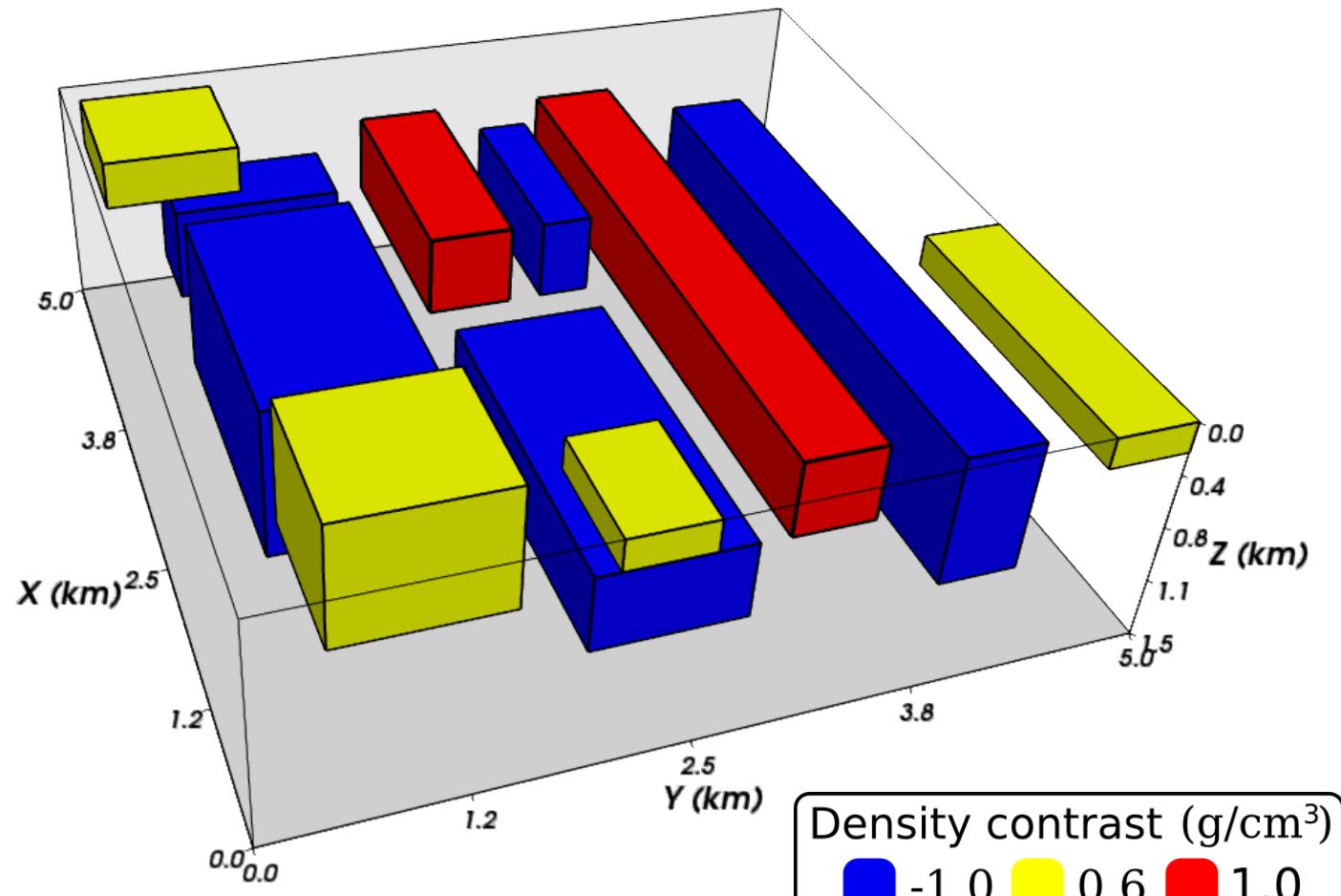
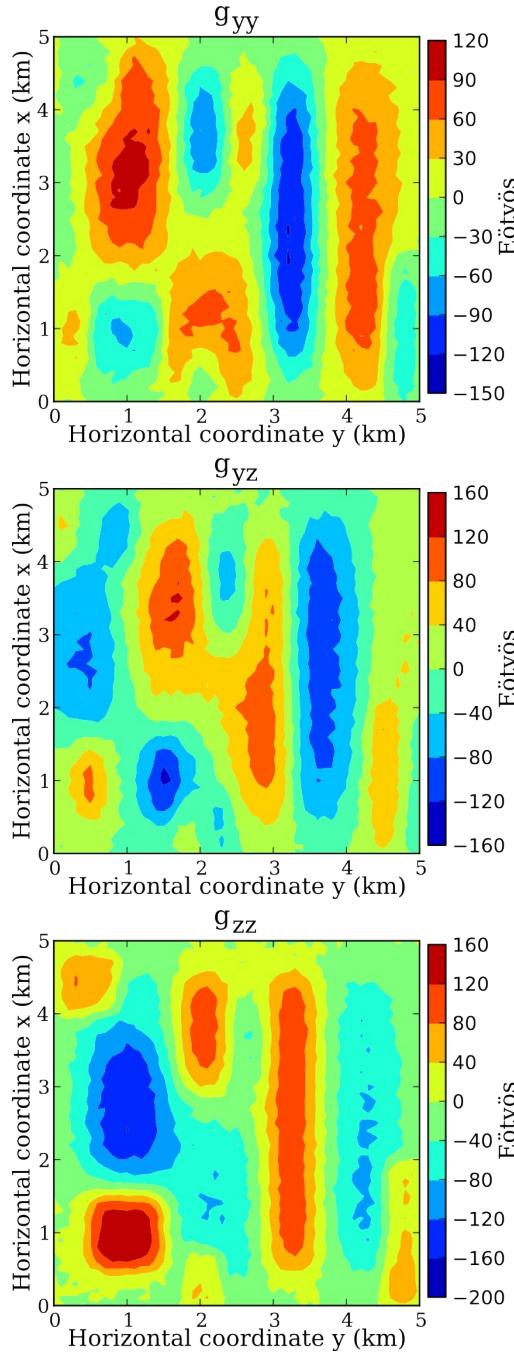


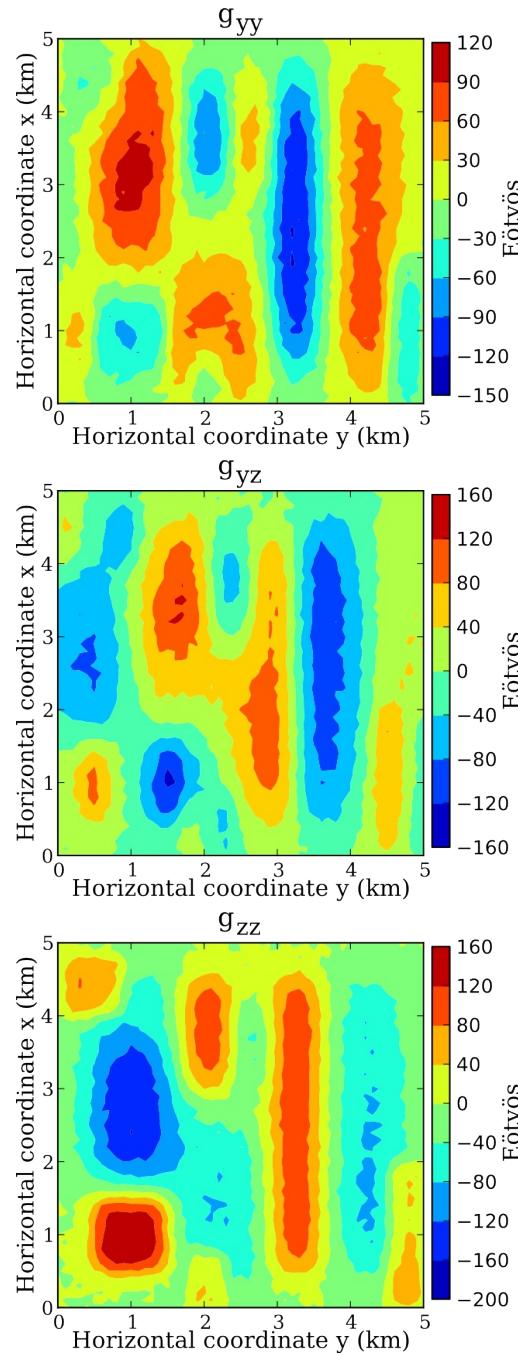
- Common scenario
- May not have prior information
 - Density contrast
 - Approximate depth
- No way to provide seeds



- Common scenario
- May not have prior information
 - Density contrast
 - Approximate depth
- No way to provide seeds
- Difficult to isolate effect of targets

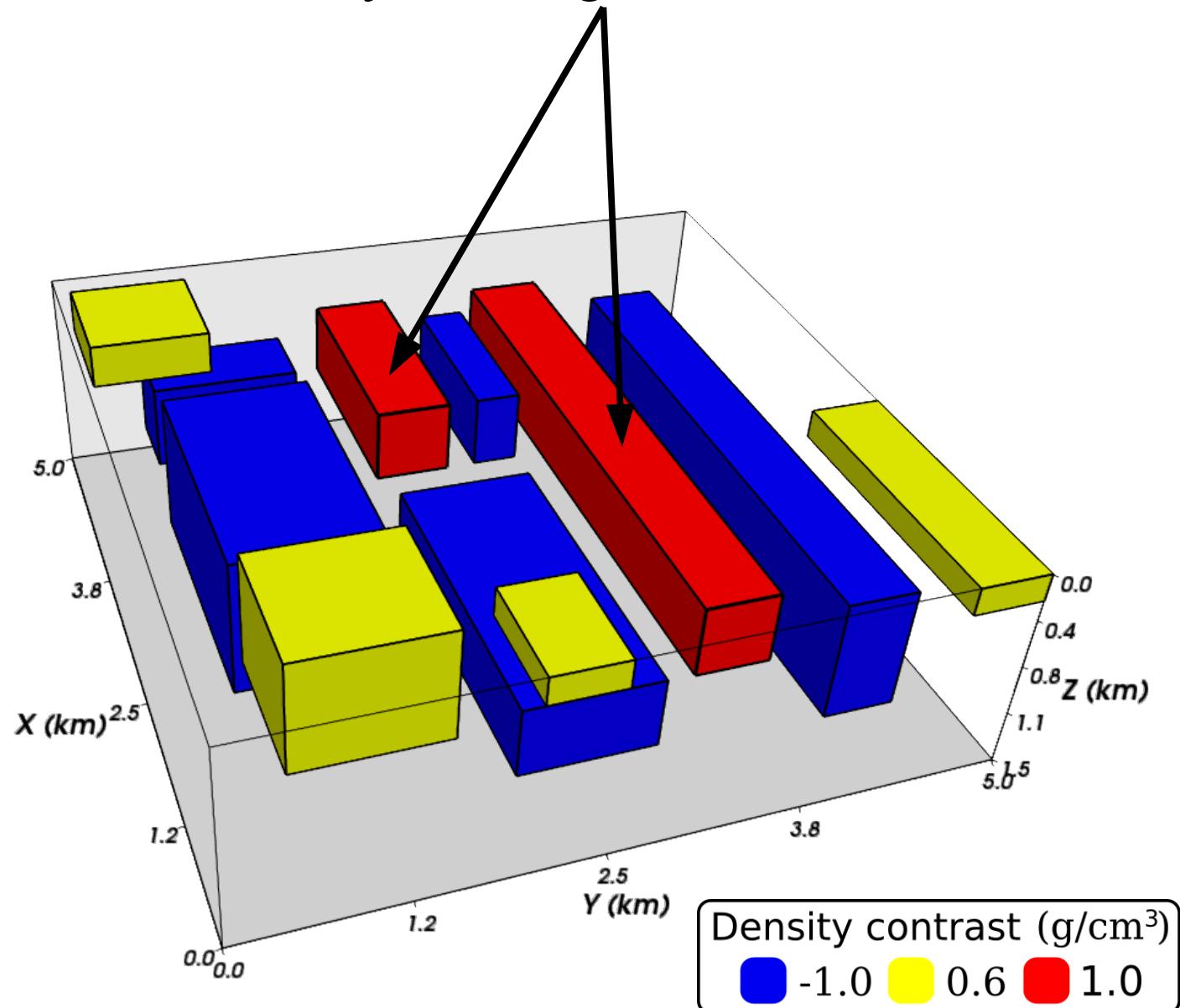
Robust procedure:

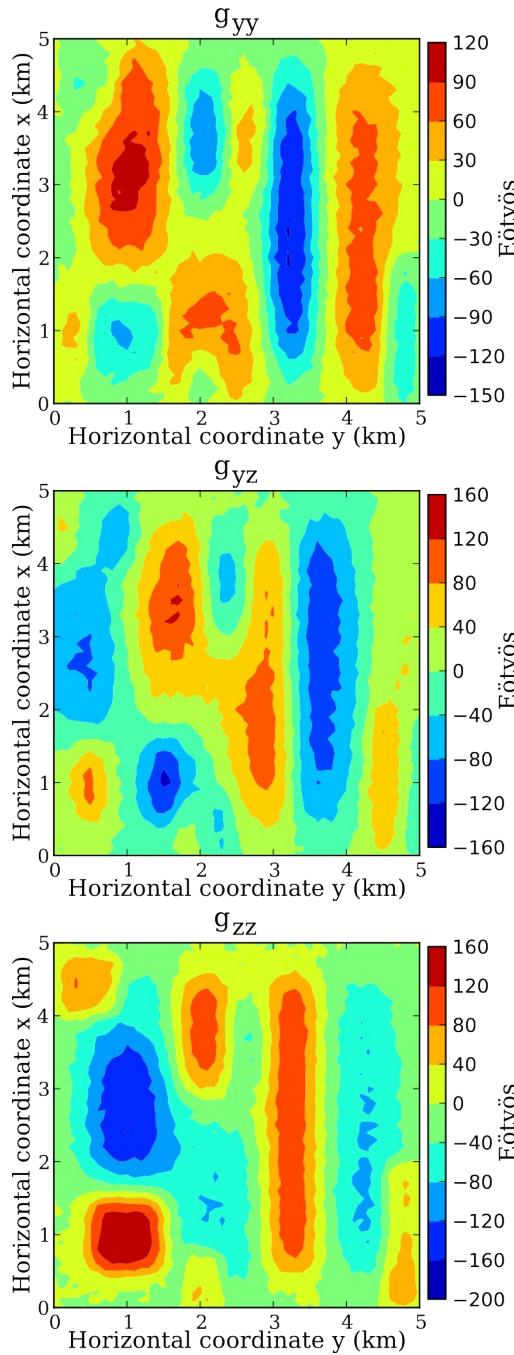




Robust procedure:

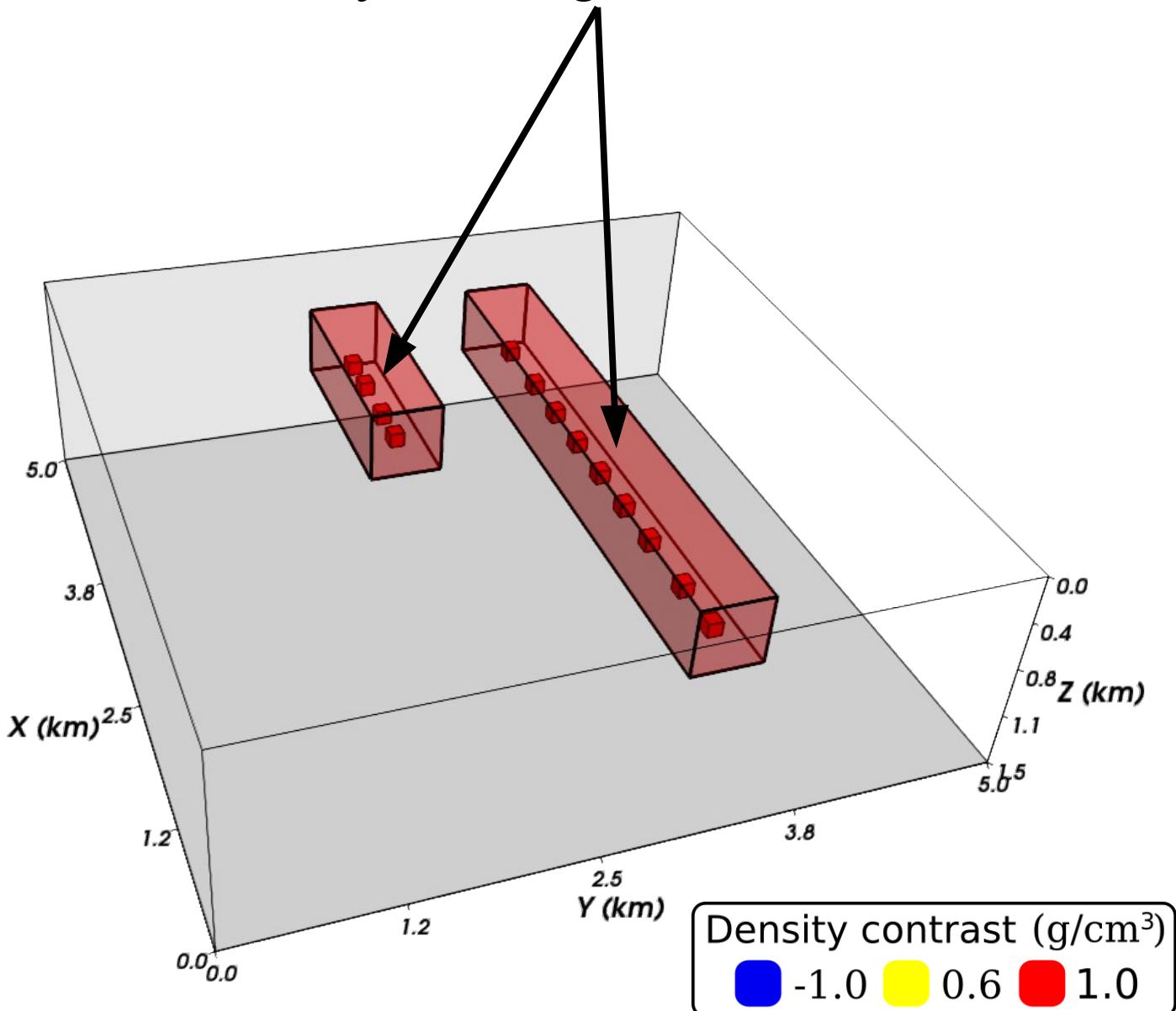
- Seeds only for targets



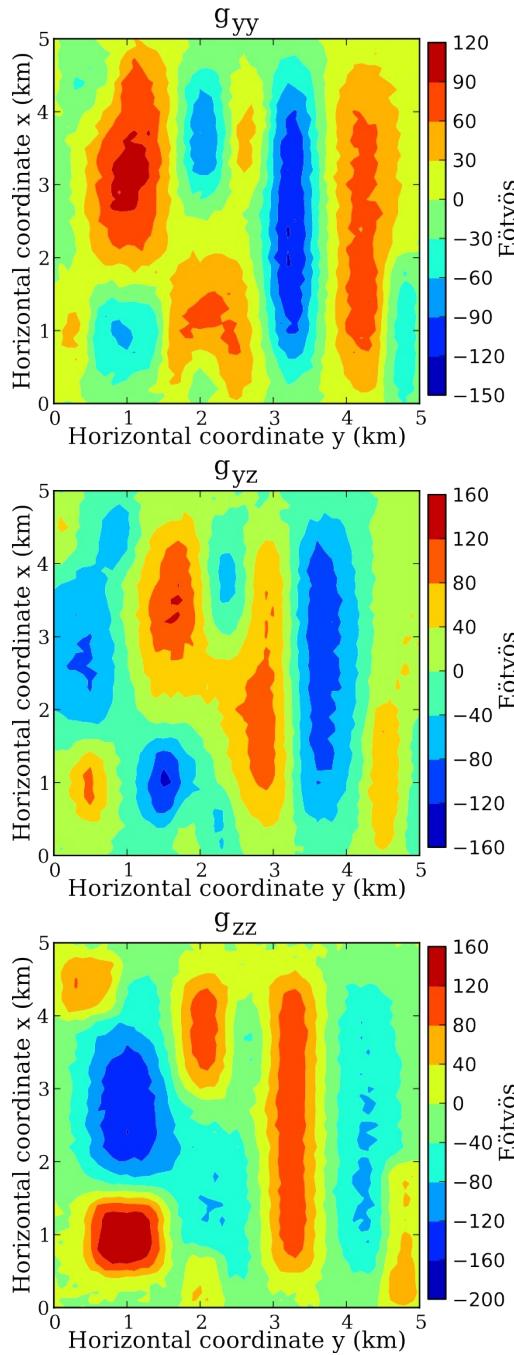


Robust procedure:

- Seeds only for targets

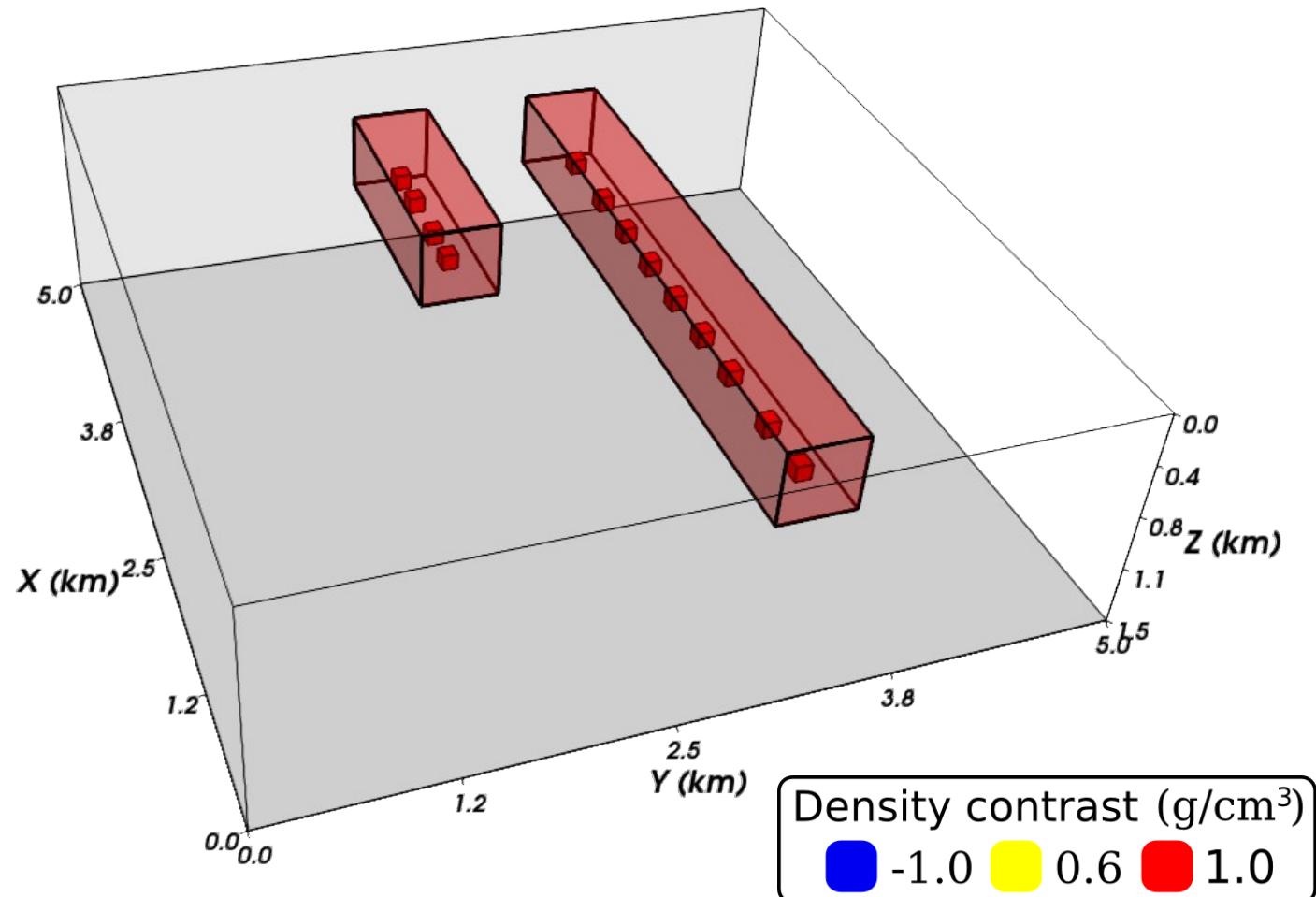


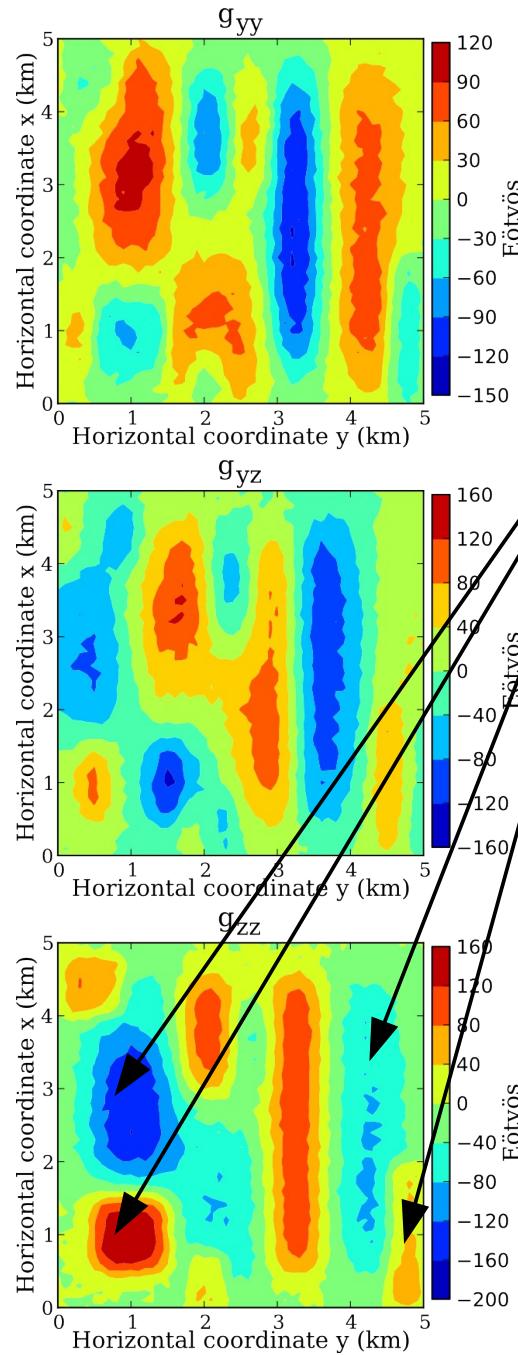
Density contrast (g/cm^3)					
	-1.0		0.6		1.0



Robust procedure:

- Seeds only for targets
- ℓ_1 -norm to “ignore” non-targeted

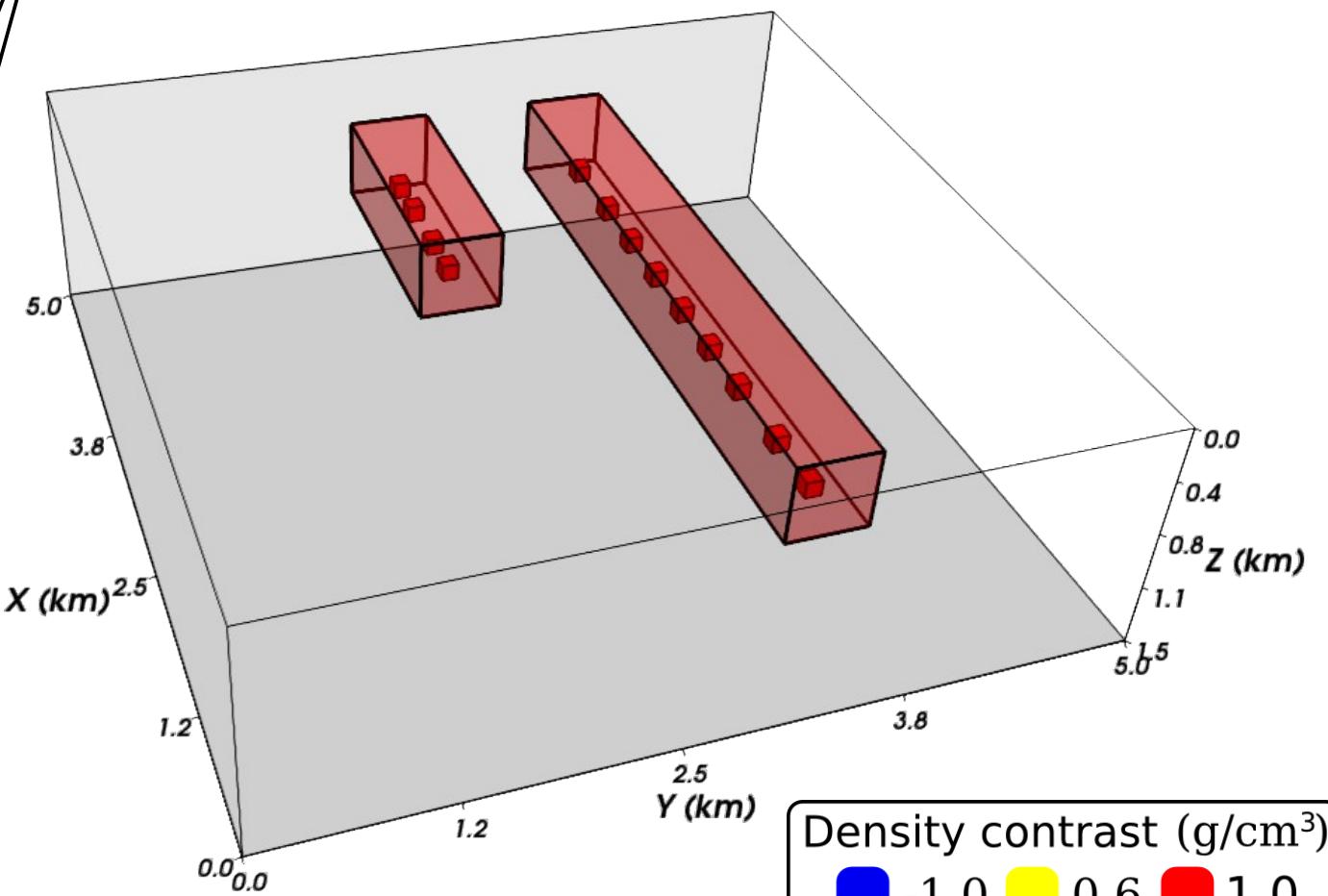




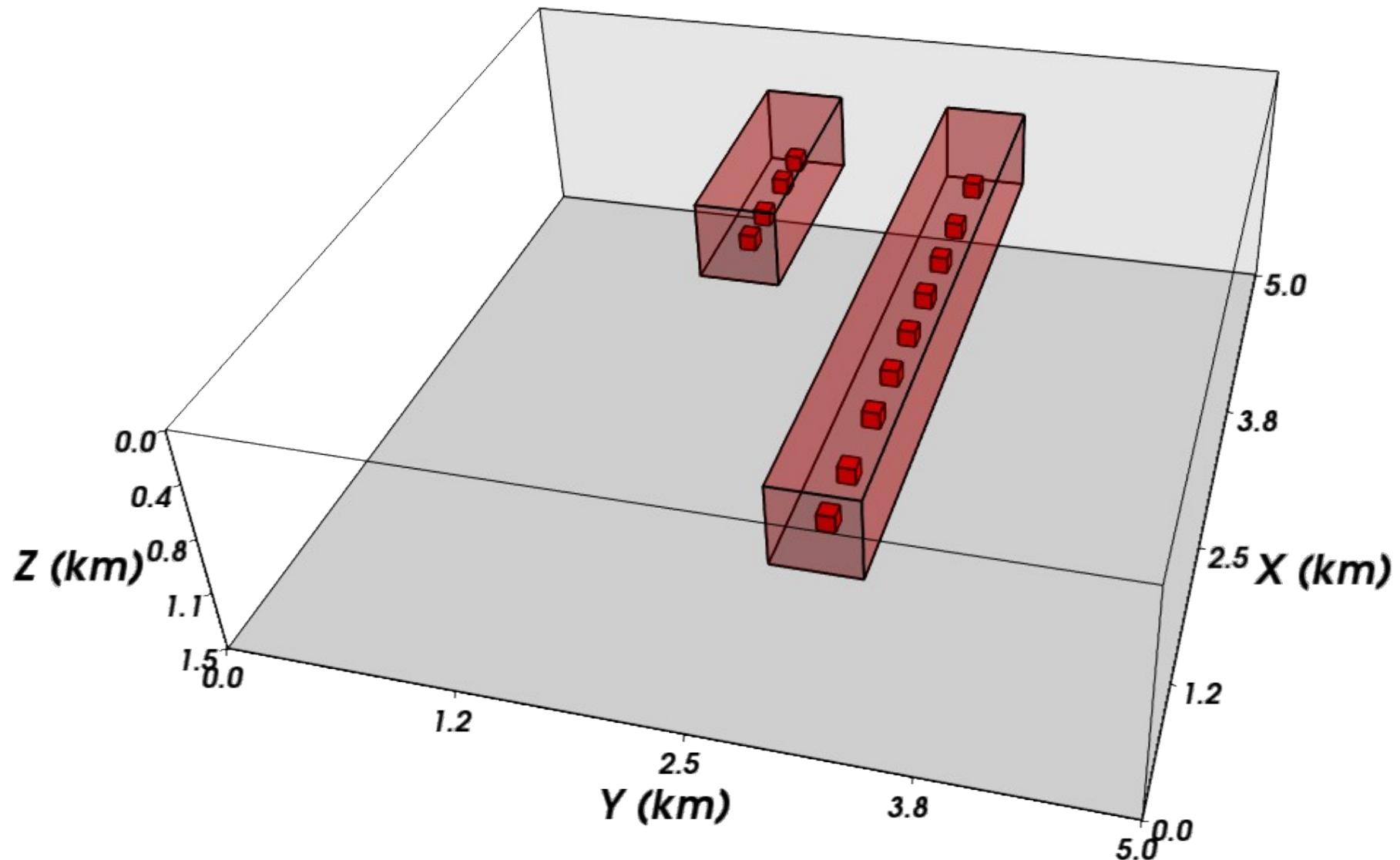
Robust procedure:

- Seeds only for targets

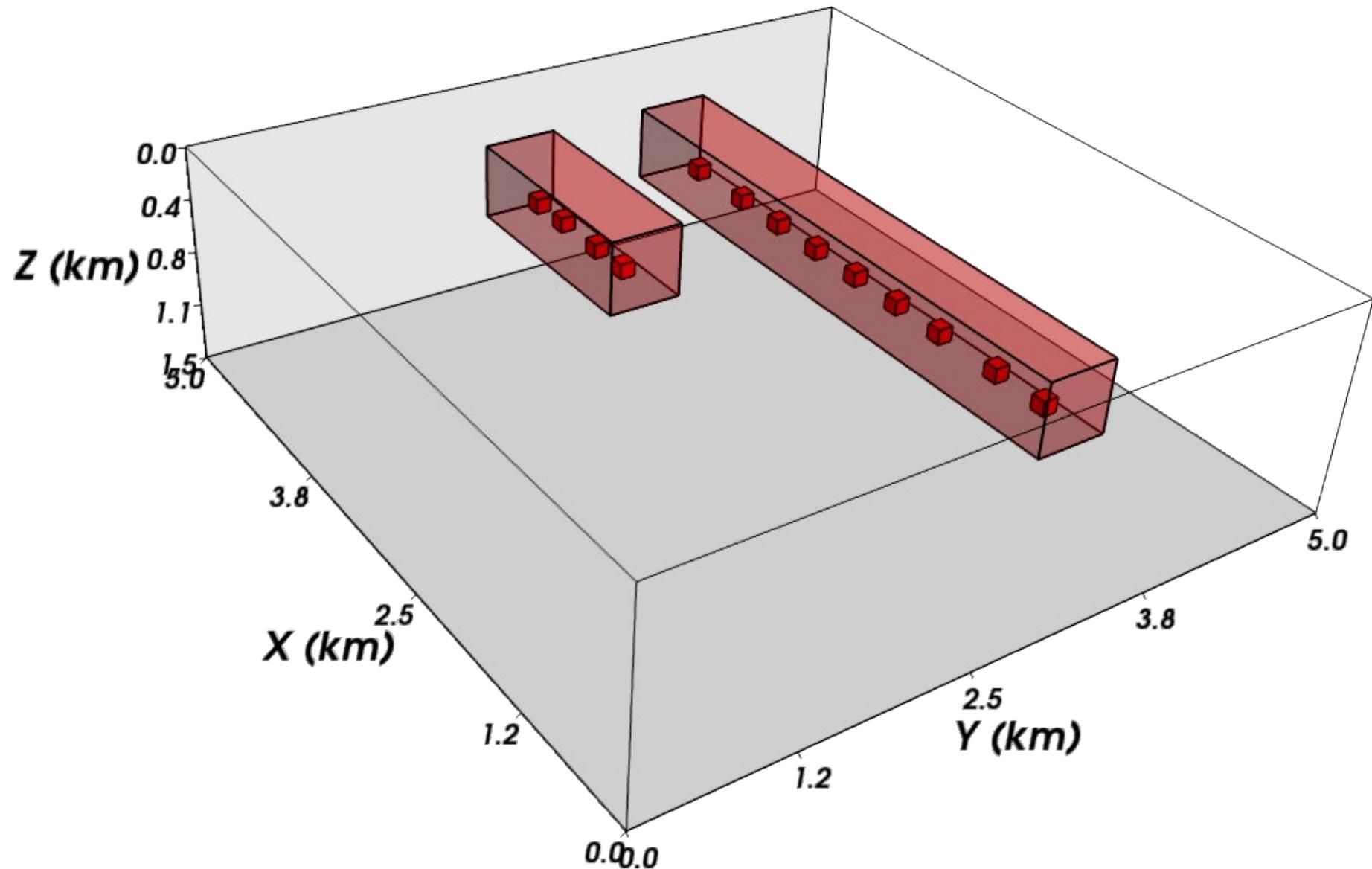
- ℓ_1 -norm to “ignore” non-targeted



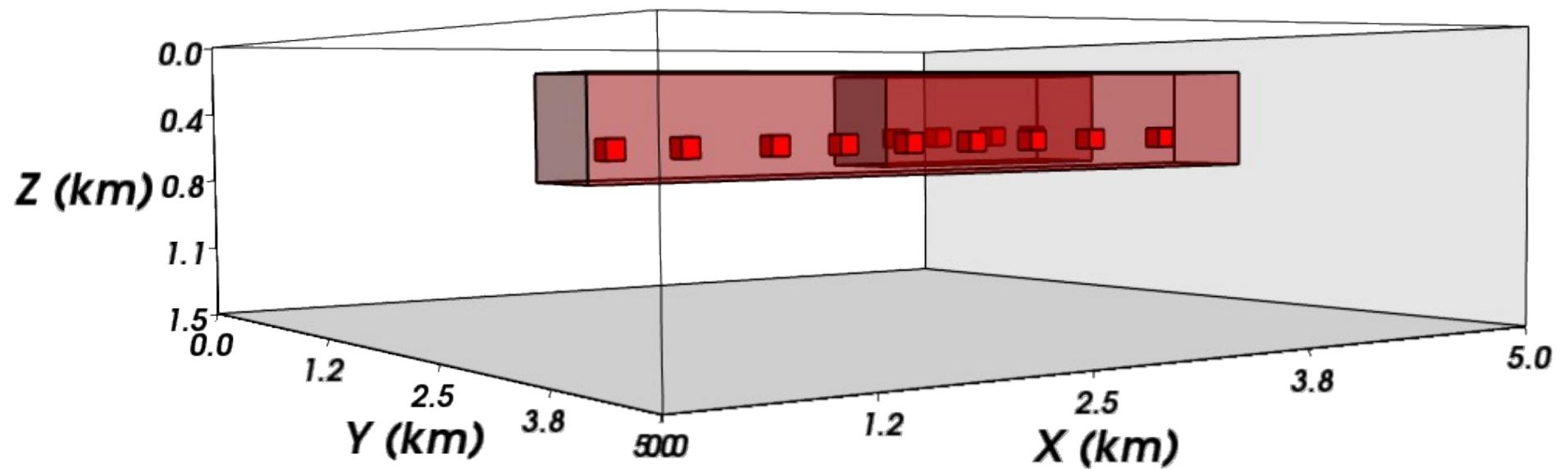
Inversion: • 13 seeds • 7,803 data



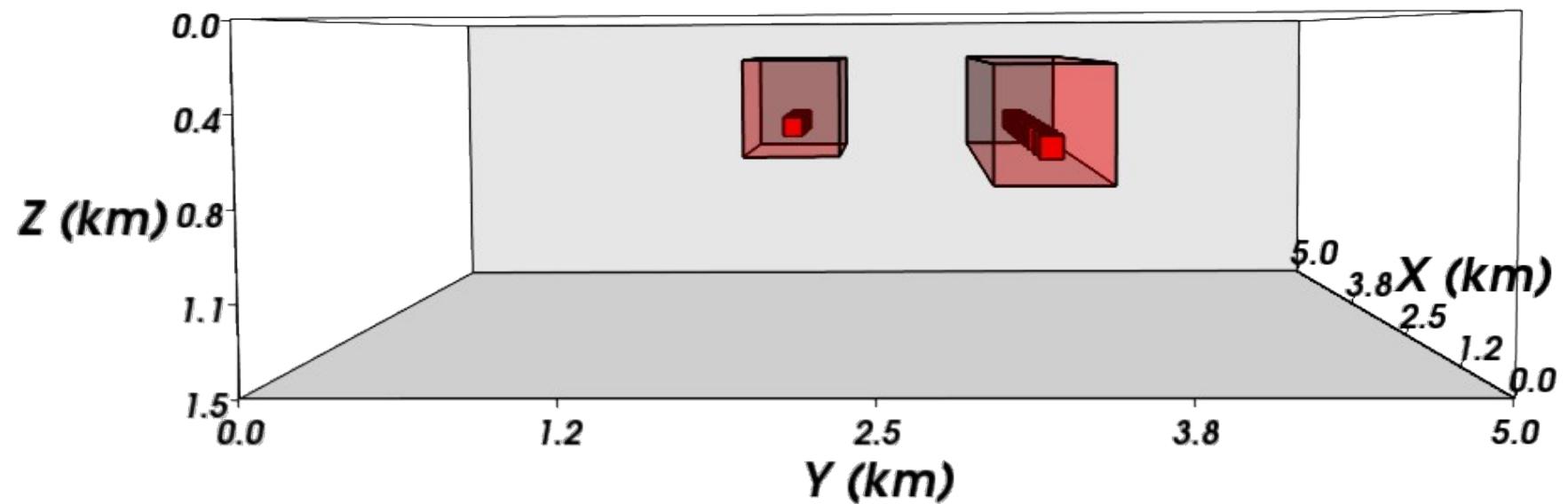
Inversion: • 13 seeds • 7,803 data



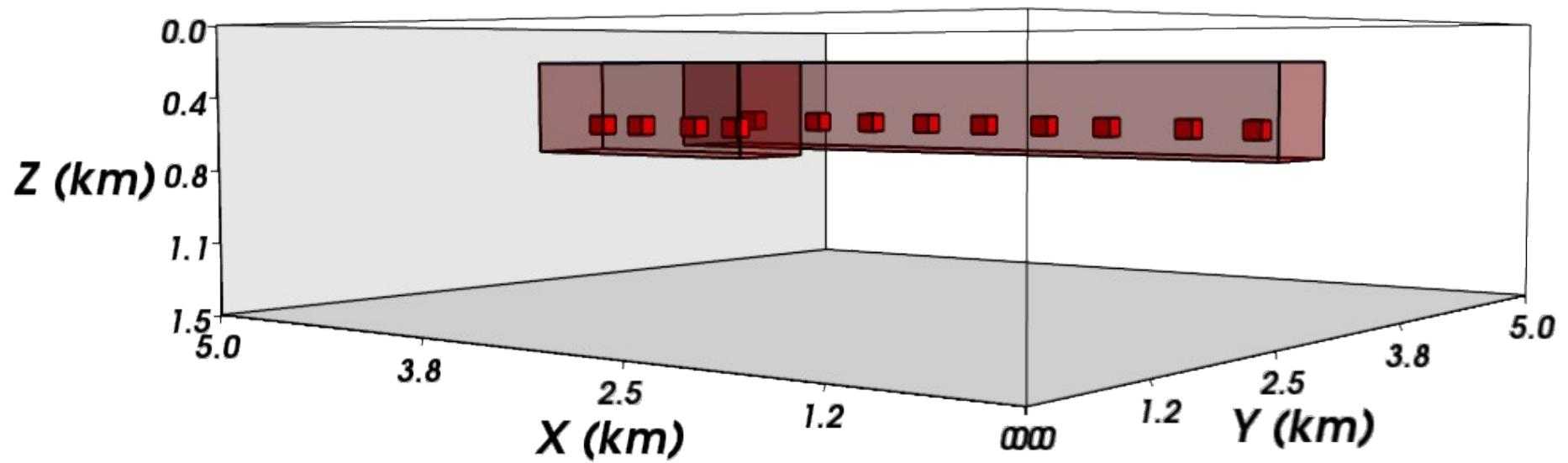
Inversion: • 13 seeds • 7,803 data



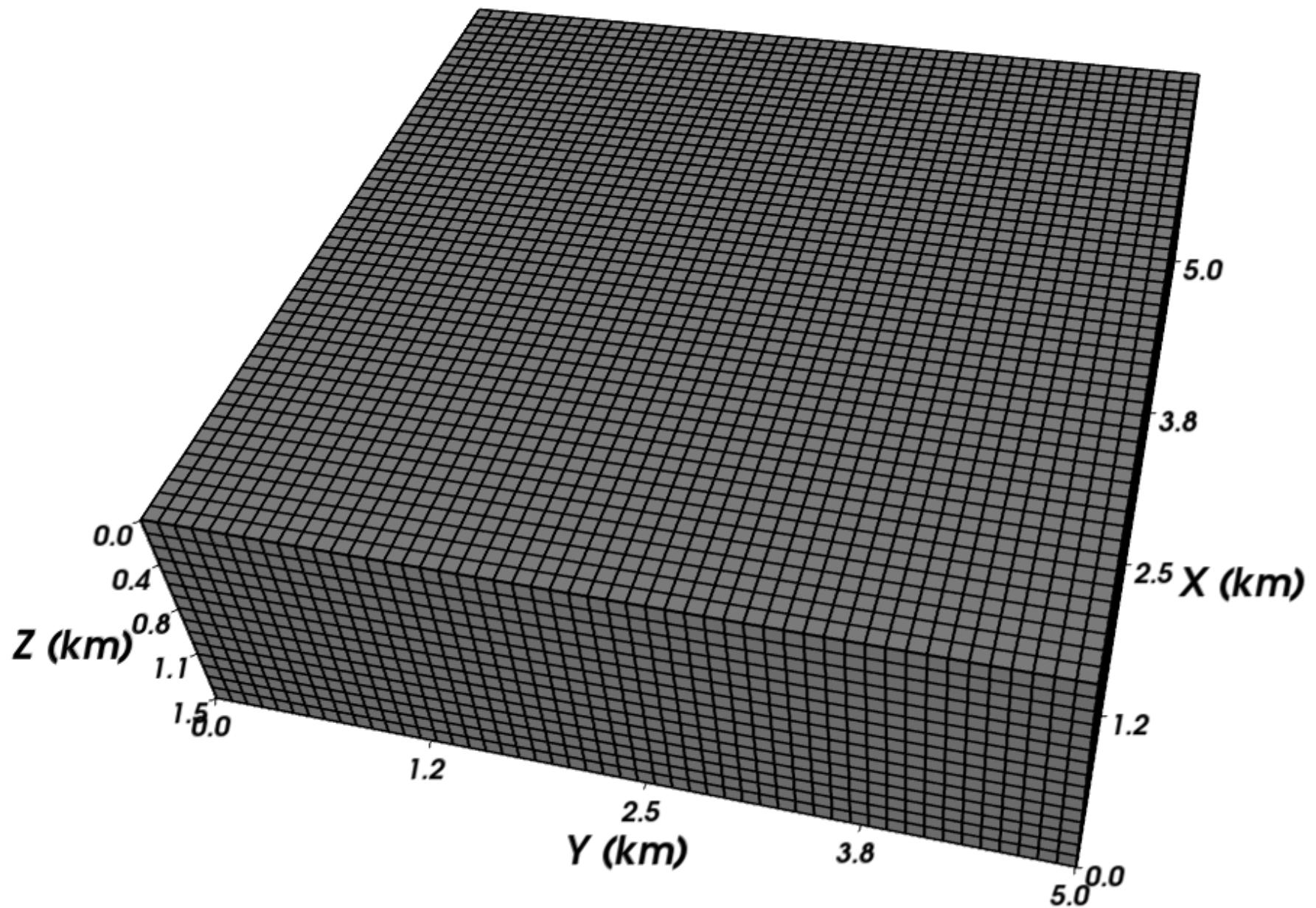
Inversion: • 13 seeds • 7,803 data



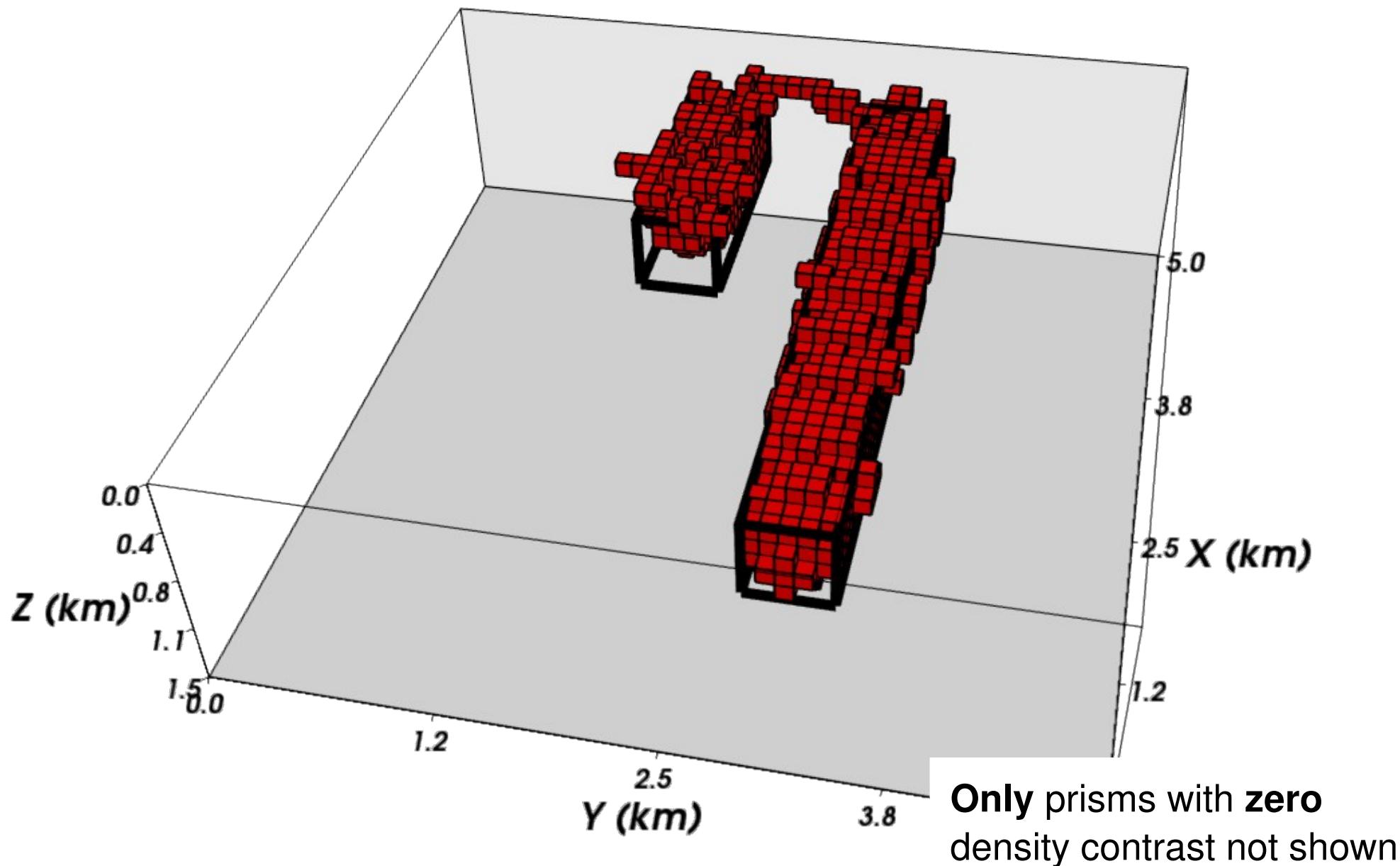
Inversion: • 13 seeds • 7,803 data



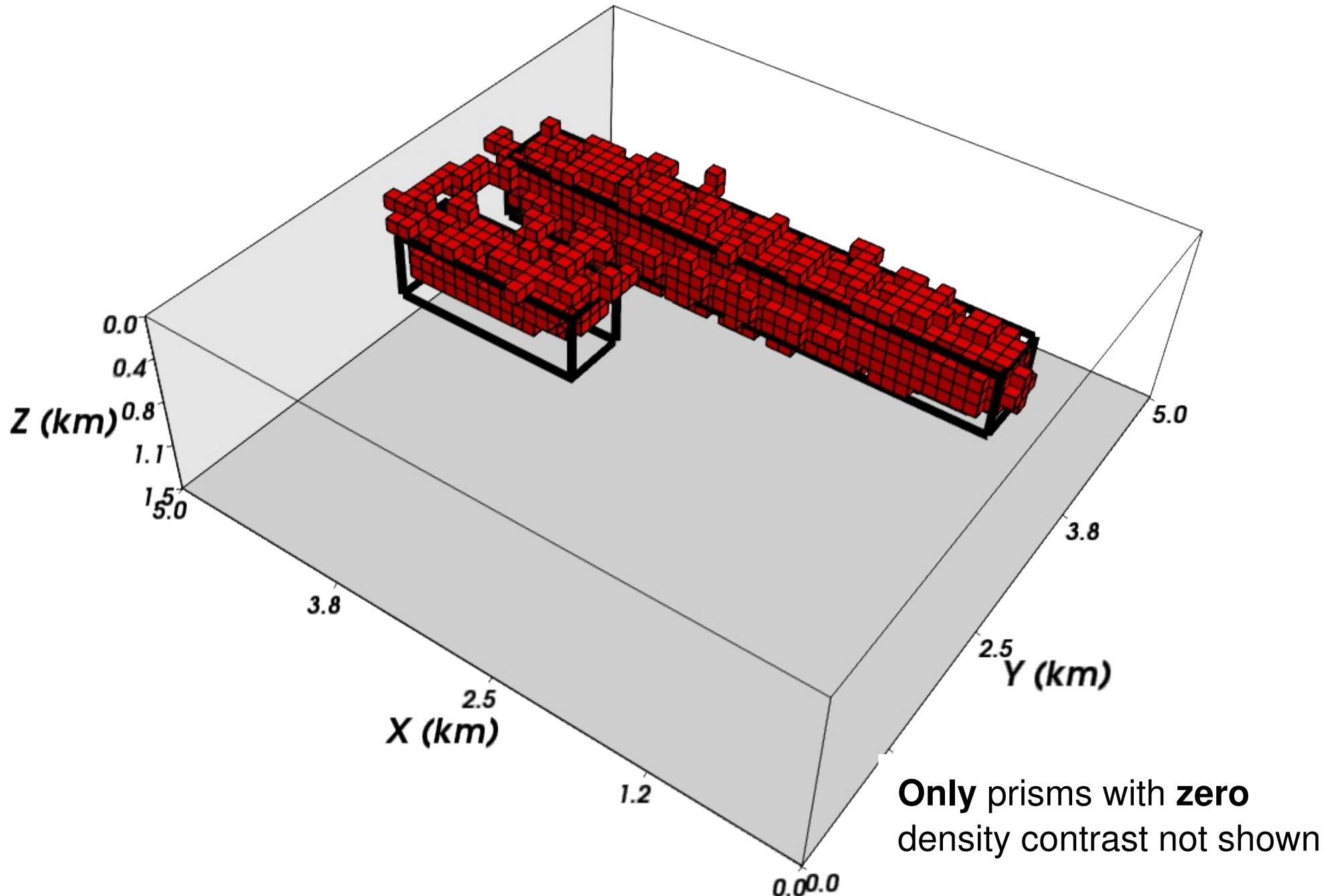
Inversion: • 13 seeds • 7,803 data • 37,500 prisms



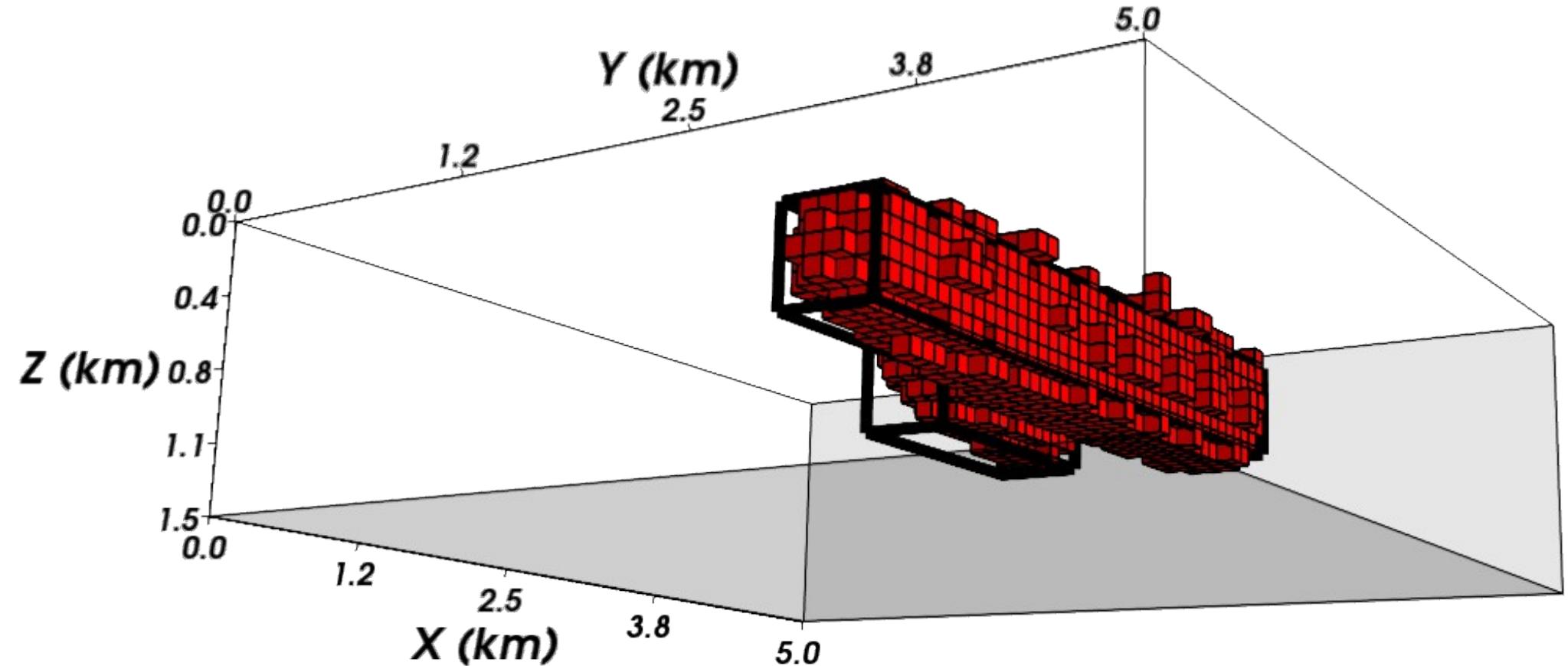
Inversion: • 13 seeds • 7,803 data • 37,500 prisms



Inversion: • 13 seeds • 7,803 data • 37,500 prisms

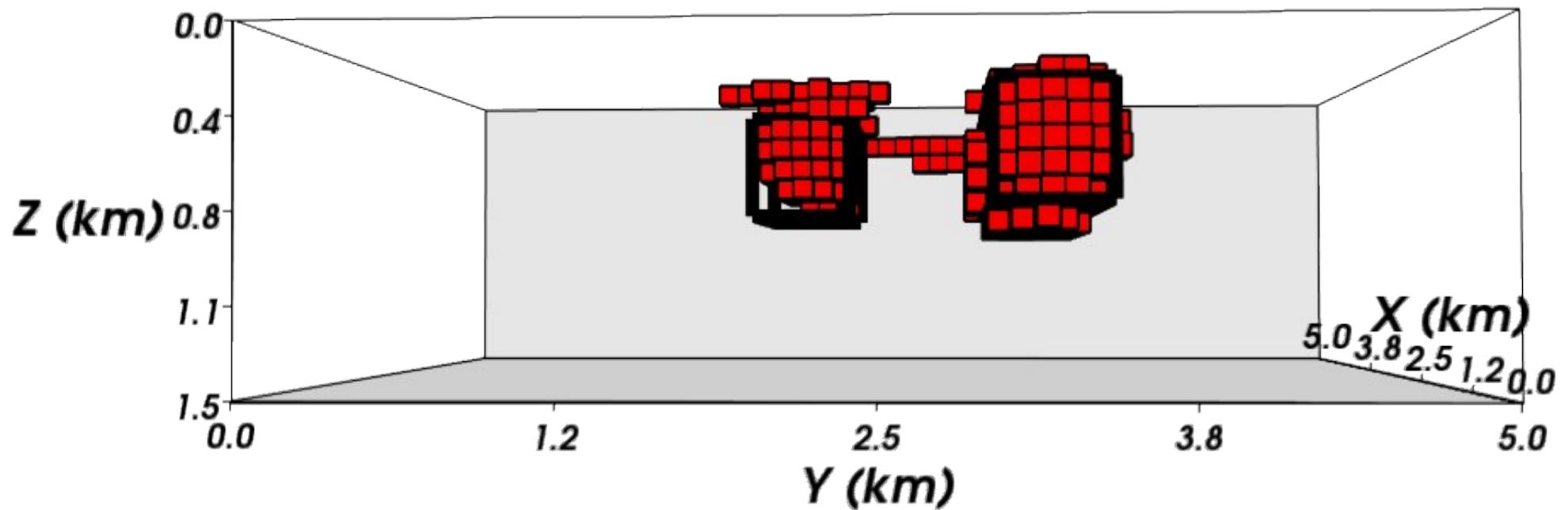


Inversion: • 13 seeds • 7,803 data • 37,500 prisms



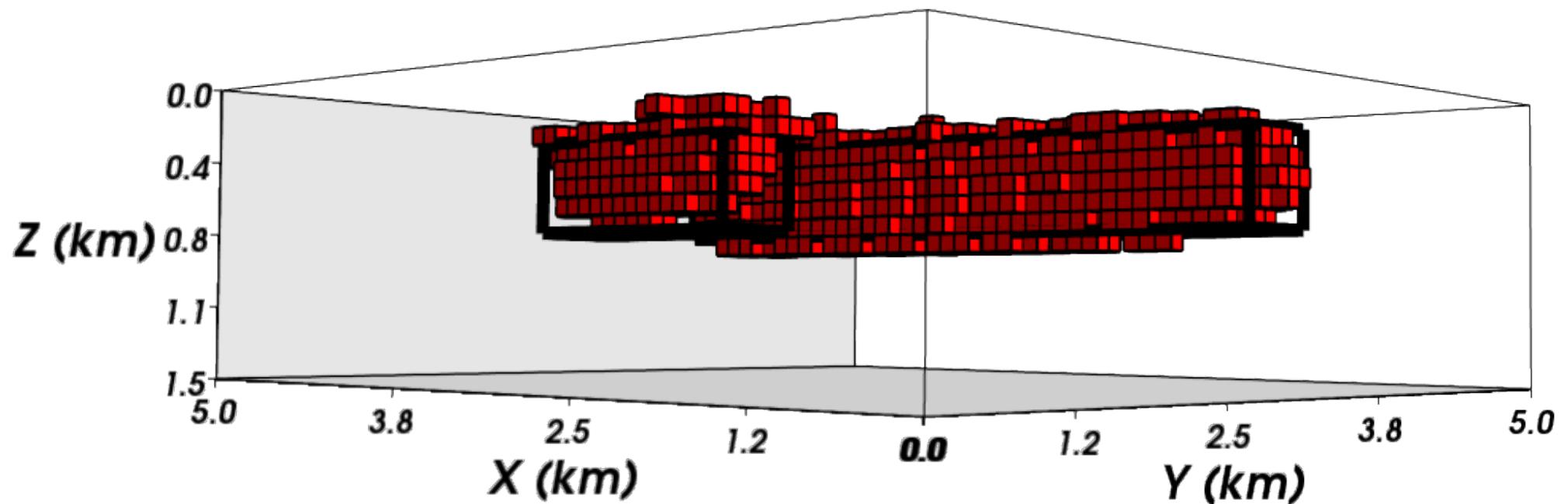
Only prisms with **zero** density contrast not shown

Inversion: • 13 seeds • 7,803 data • 37,500 prisms



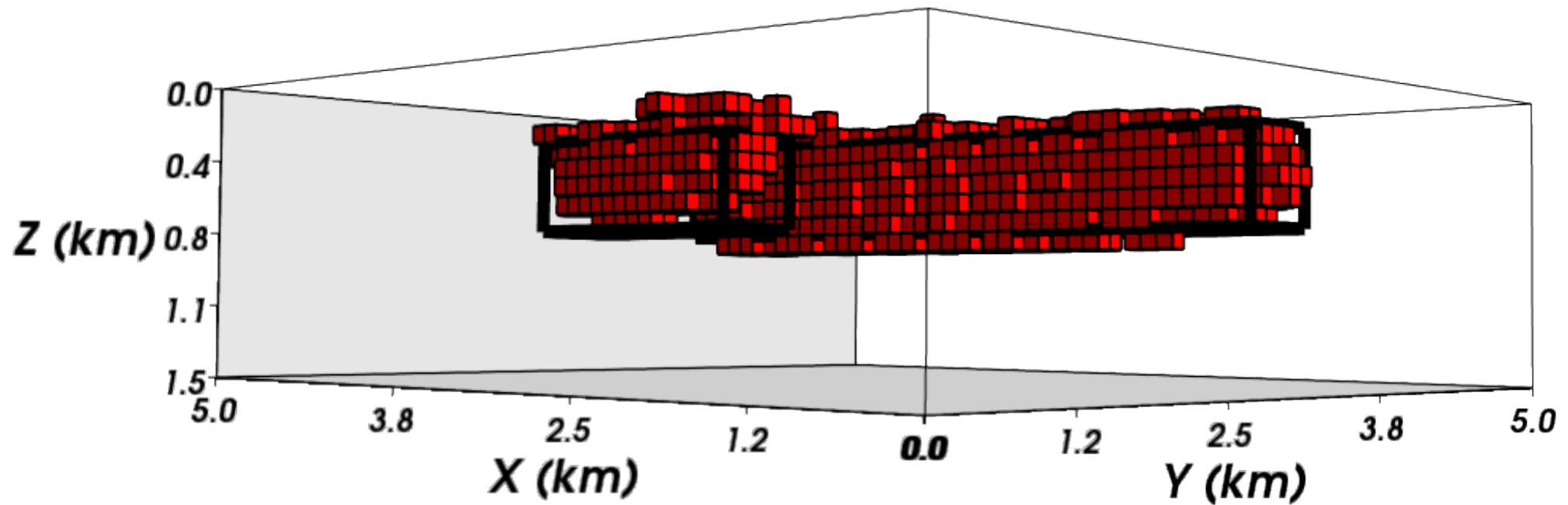
Only prisms with **zero**
density contrast not shown

Inversion: • 13 seeds • 7,803 data • 37,500 prisms



Only prisms with **zero** density contrast not shown

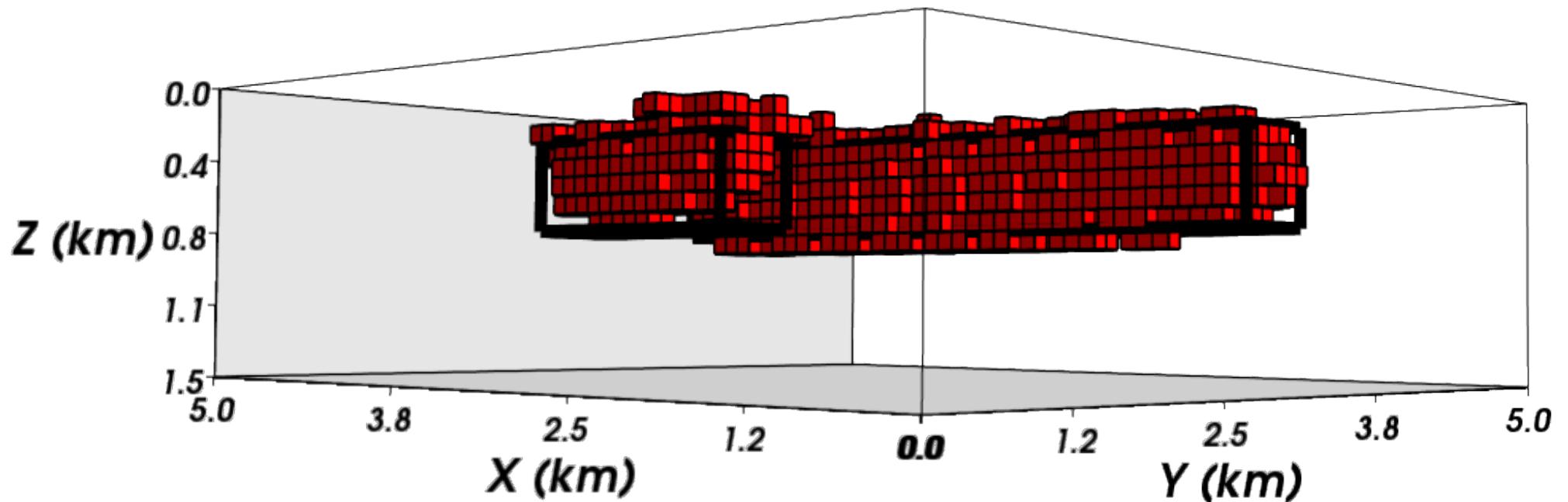
Inversion: • 13 seeds • 7,803 data • 37,500 prisms



- Recover shape of targets

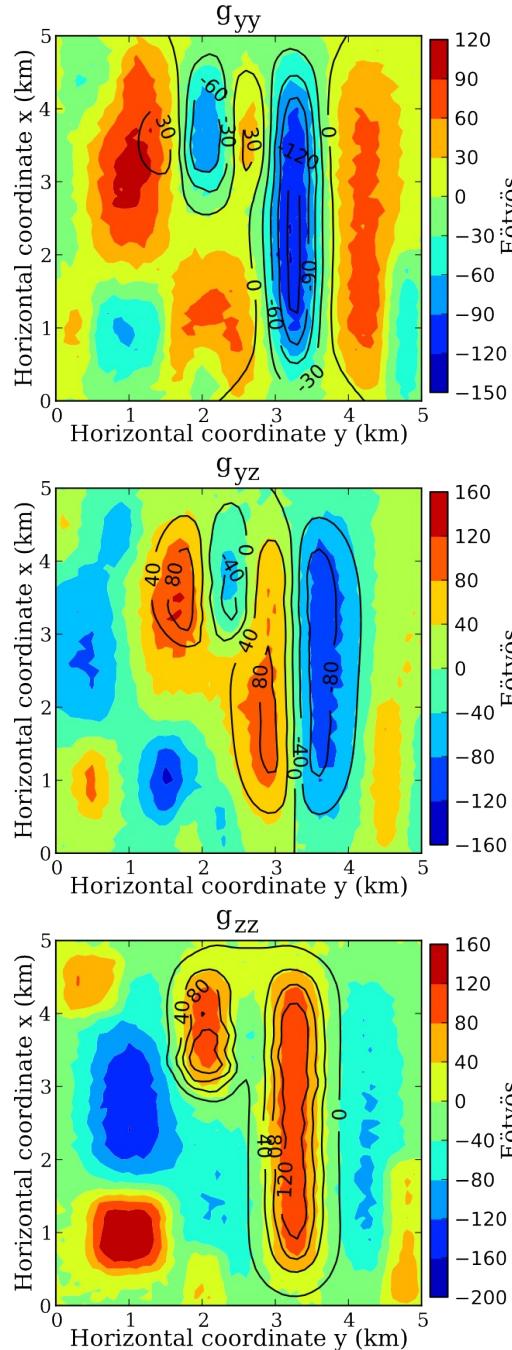
Only prisms with **zero** density contrast not shown

Inversion: • 13 seeds • 7,803 data • 37,500 prisms

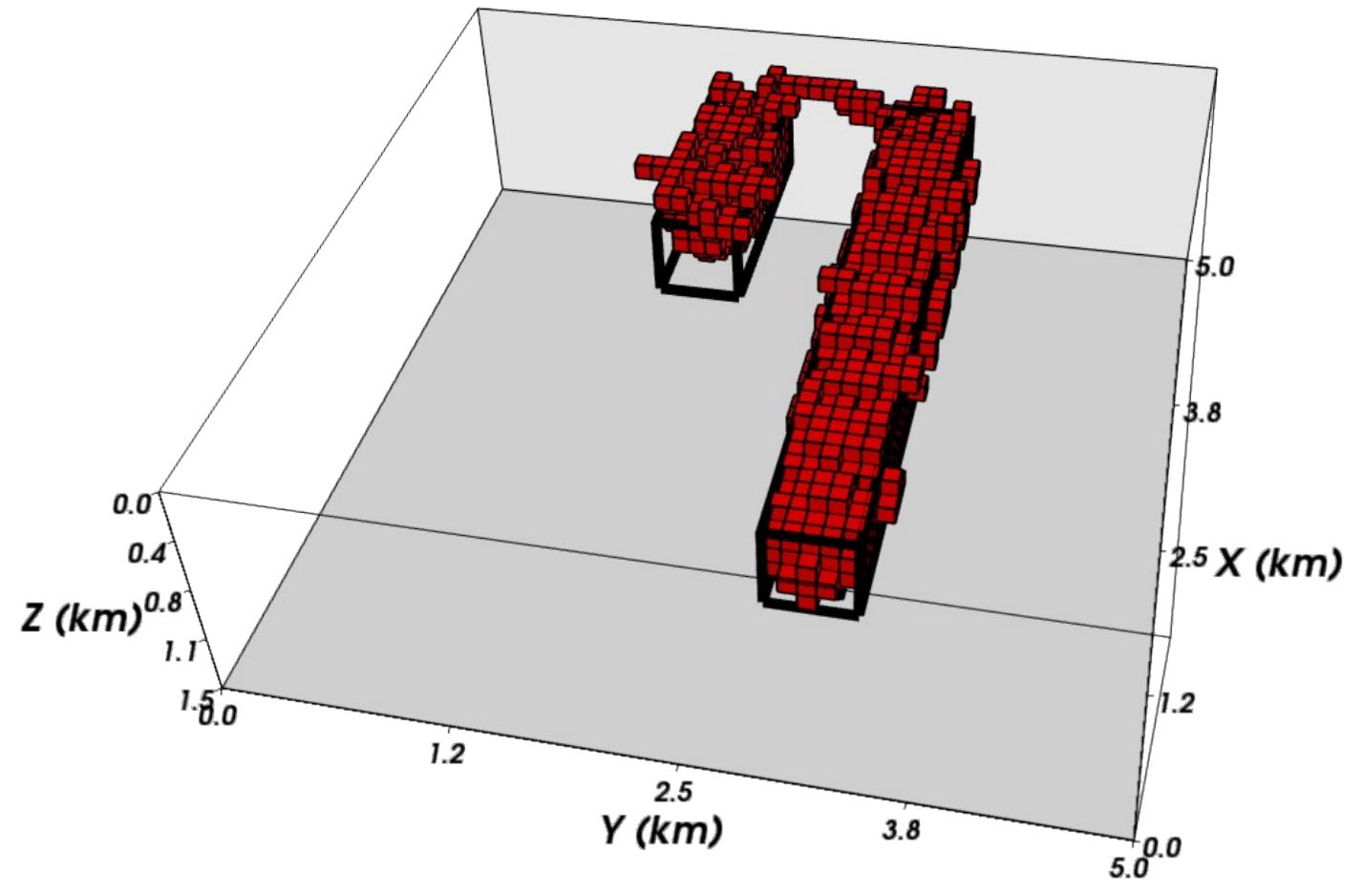


- Recover shape of targets
- Total time = 2.2 minutes (on laptop) Only prisms with **zero** density contrast not shown

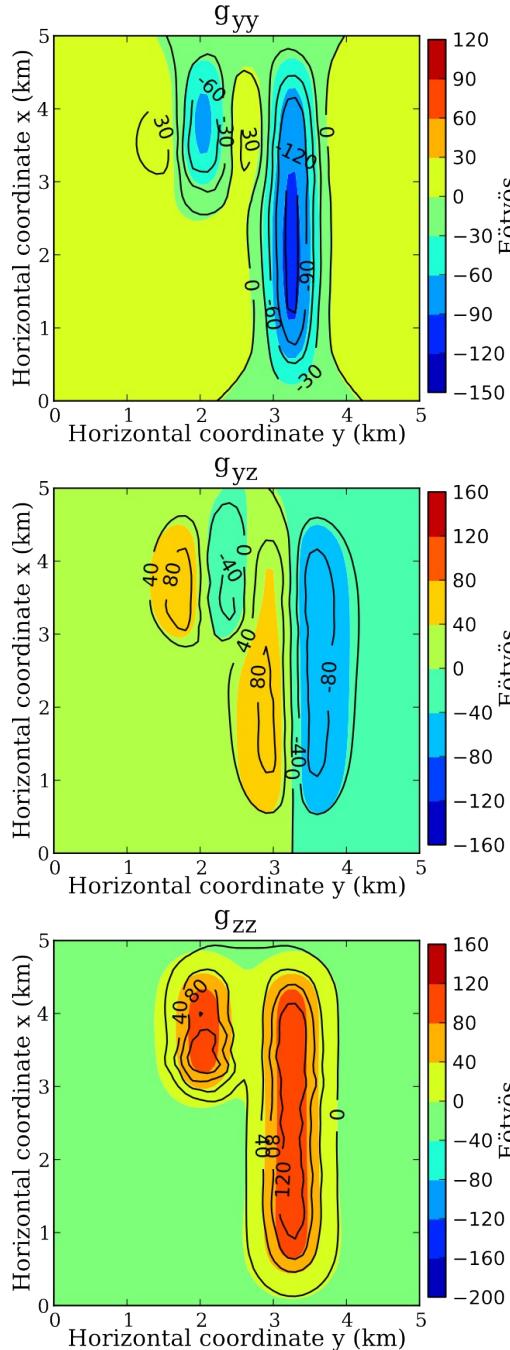
Inversion: • 13 seeds • 7,803 data • 37,500 prisms



Predicted data in contours

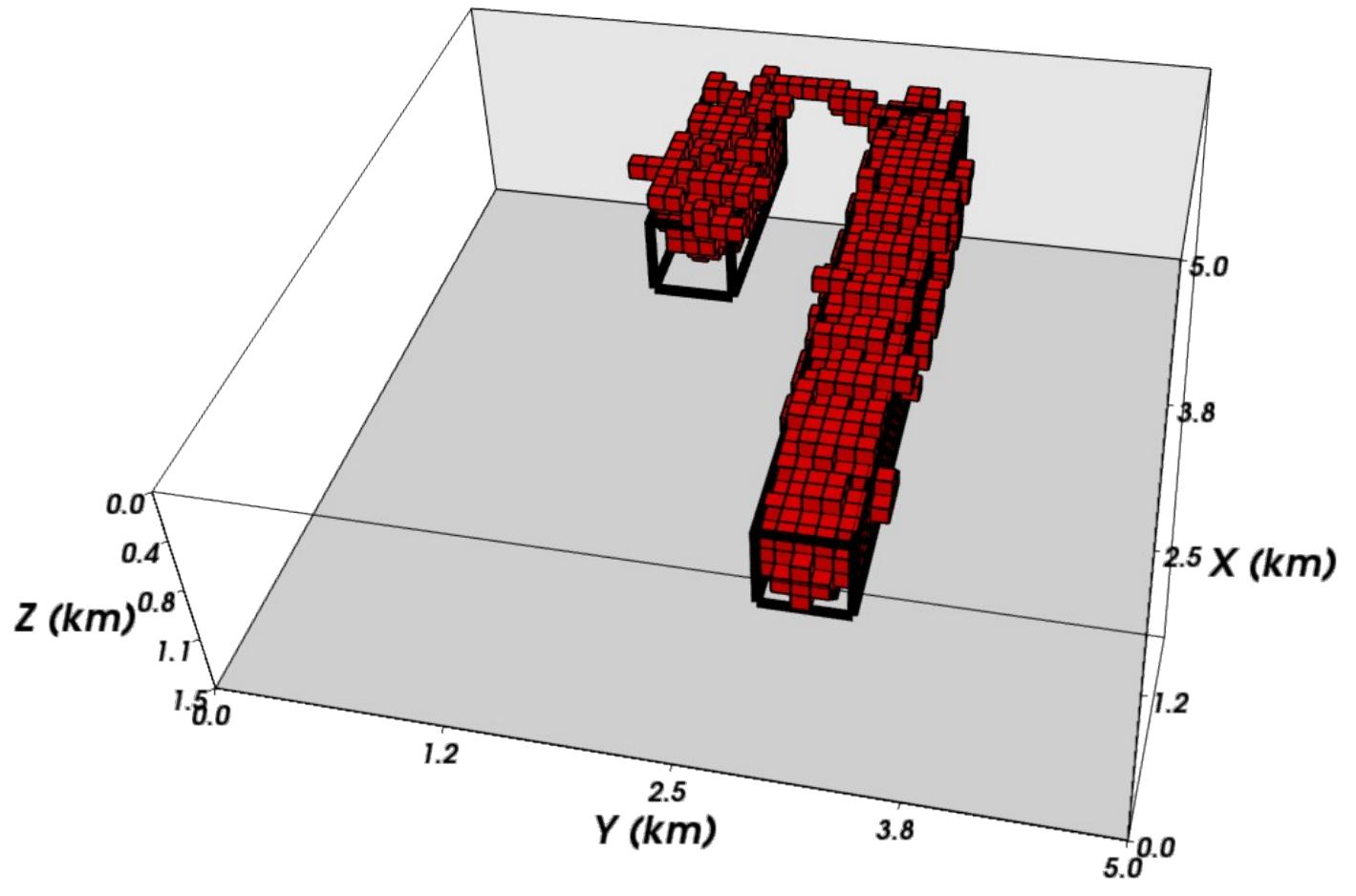


Inversion: • 13 seeds • 7,803 data • 37,500 prisms



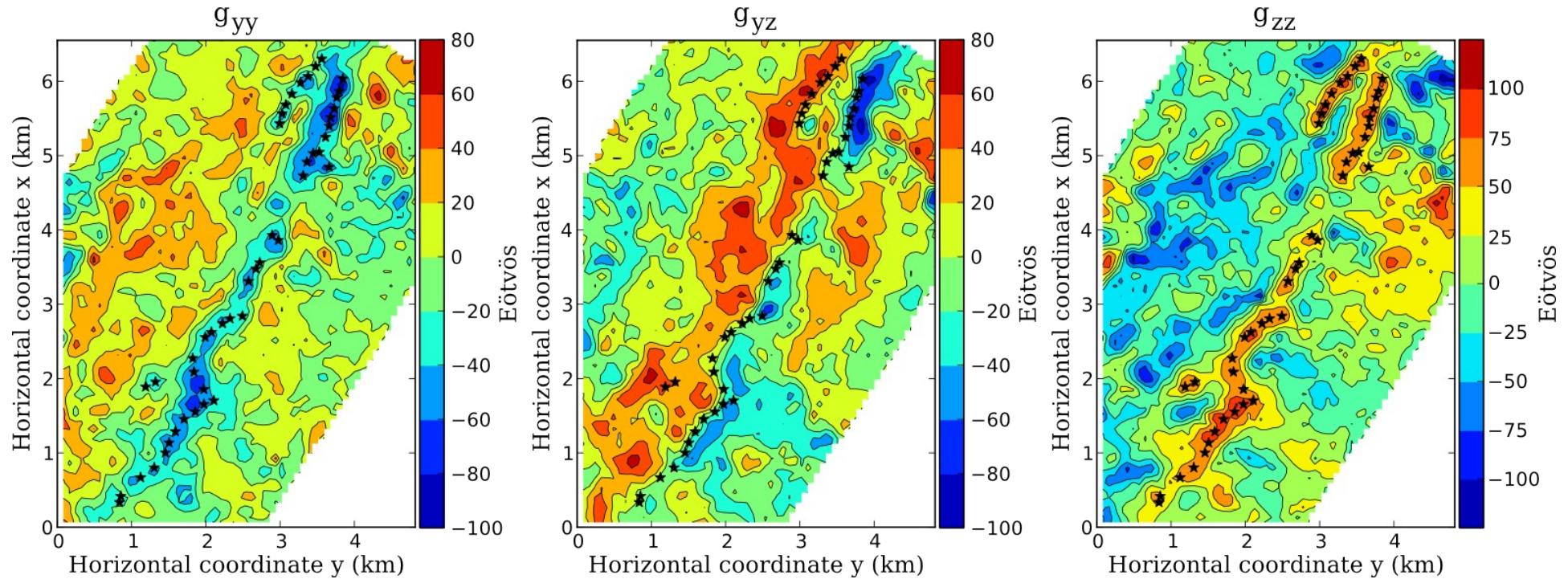
Predicted data in contours

Effect of **true** targeted sources



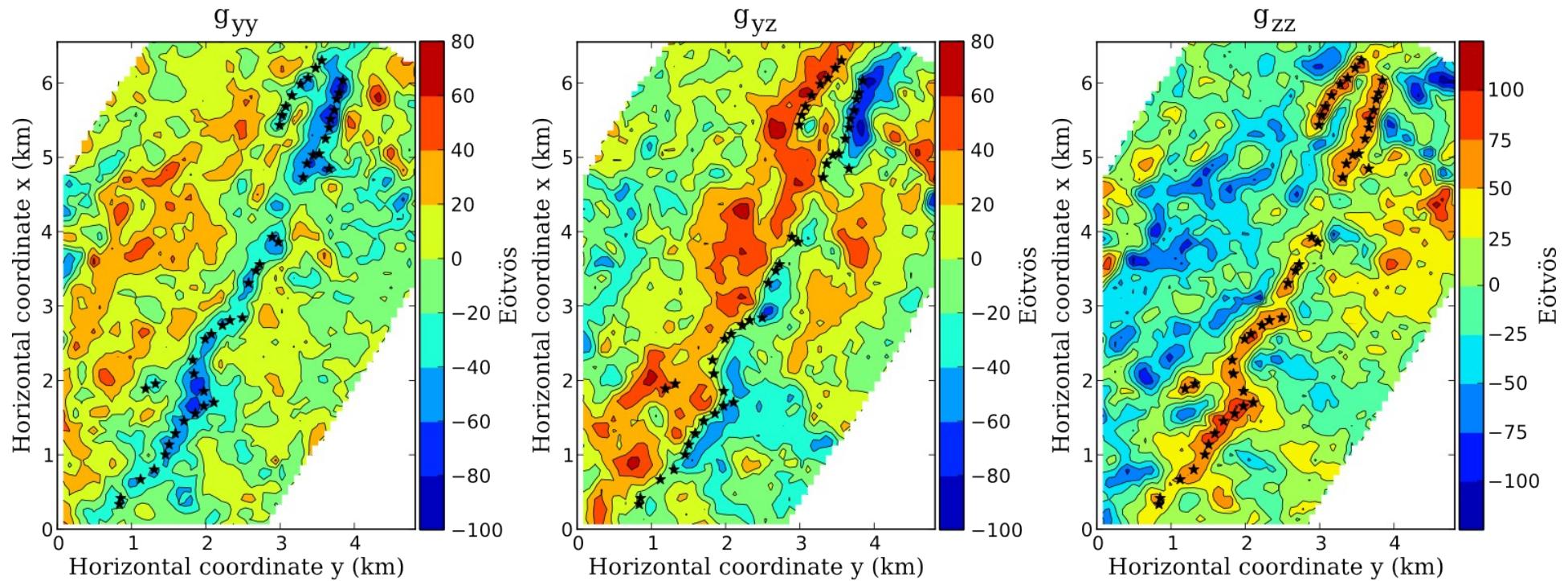
Real Data

Data:



- 3 components
- FTG survey
- Quadrilátero Ferrífero, Brazil

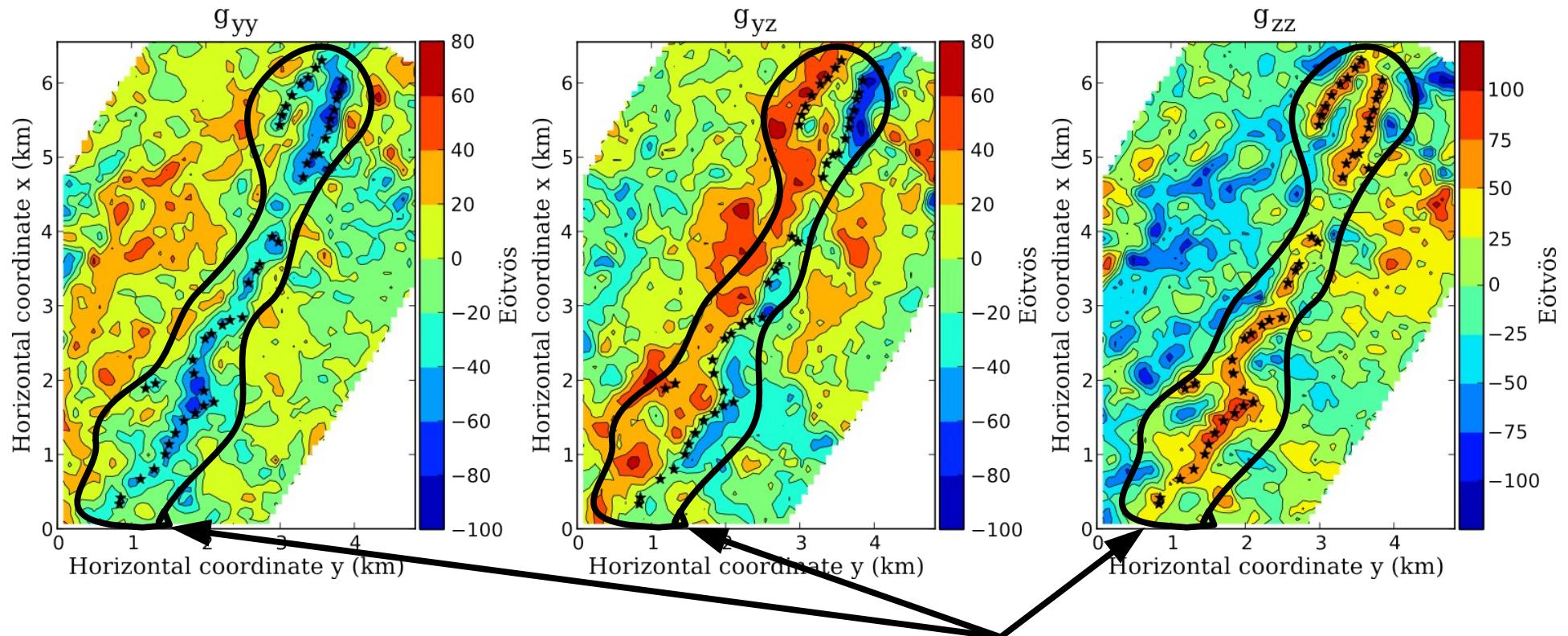
Data:



- 3 components
- FTG survey
- Quadrilátero Ferrífero, Brazil

- Targets:
- Iron ore bodies
 - BIFs of Cauê Formation

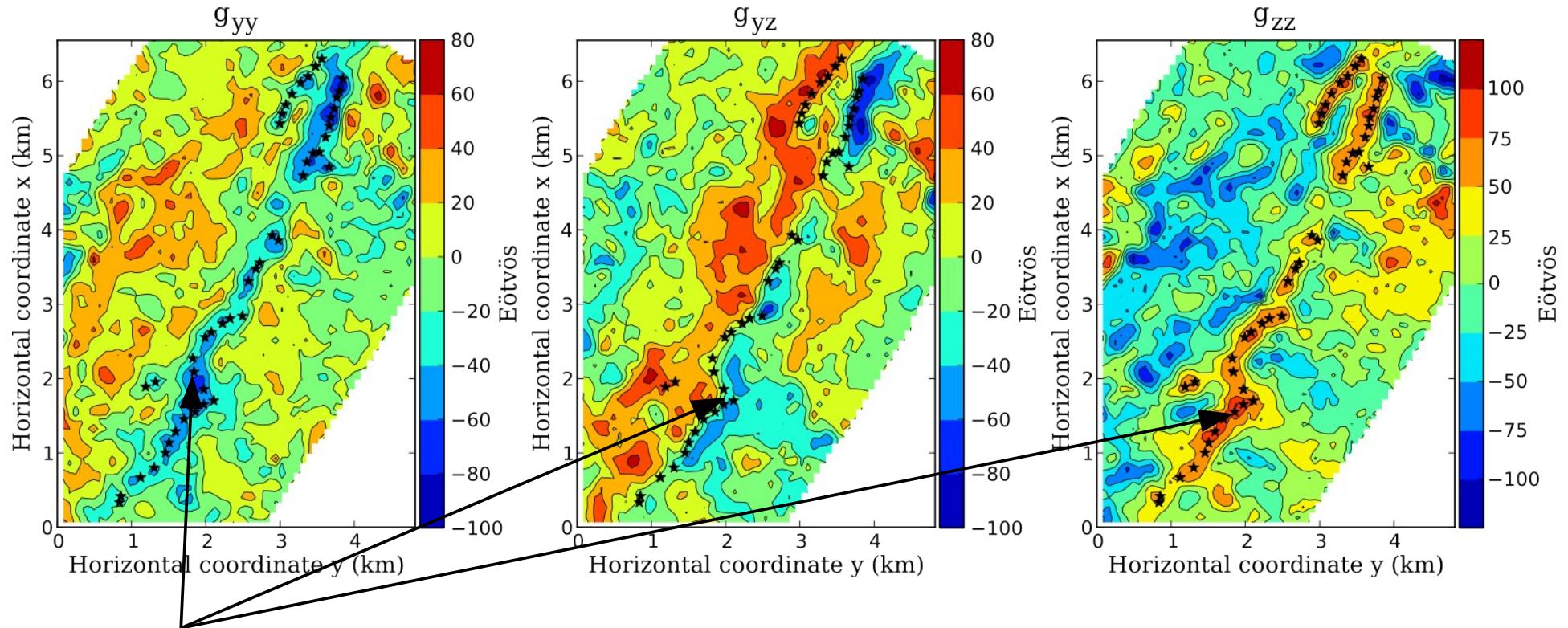
Data:



- 3 components
- FTG survey
- Quadrilátero Ferrífero, Brazil

- Targets:
- Iron ore bodies
 - BIFs of Cauê Formation

Data:

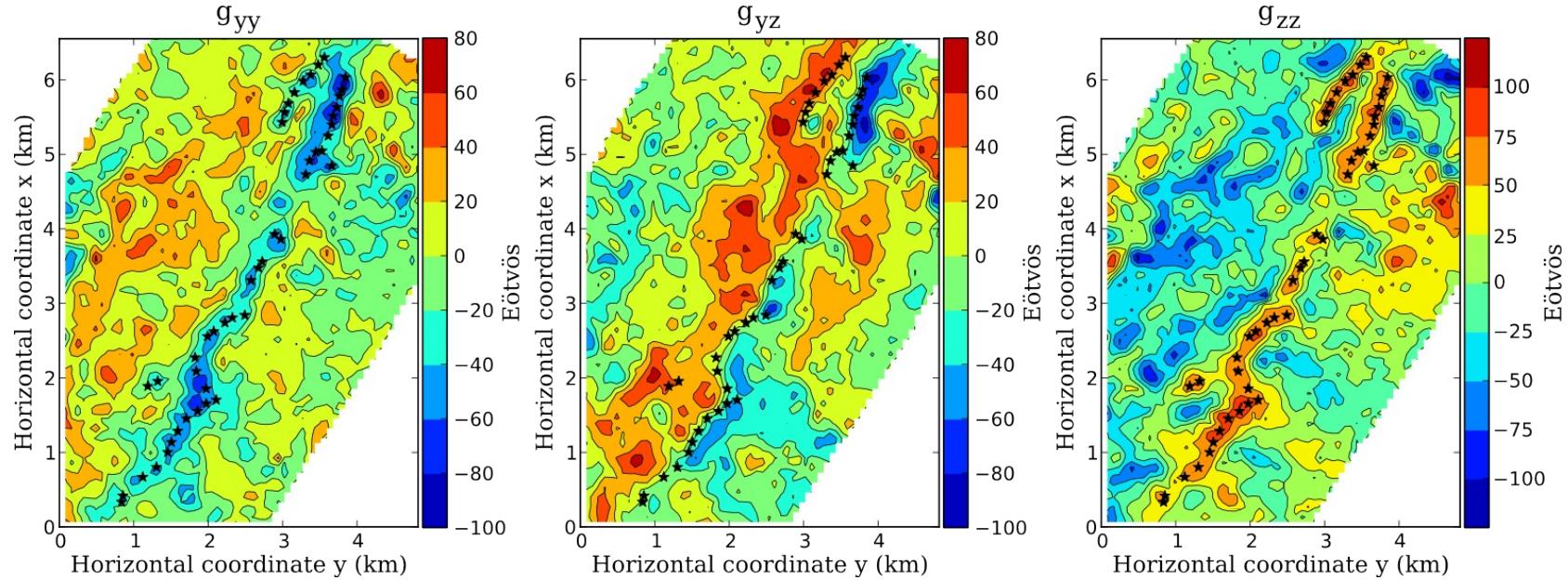


Seeds for iron ore:

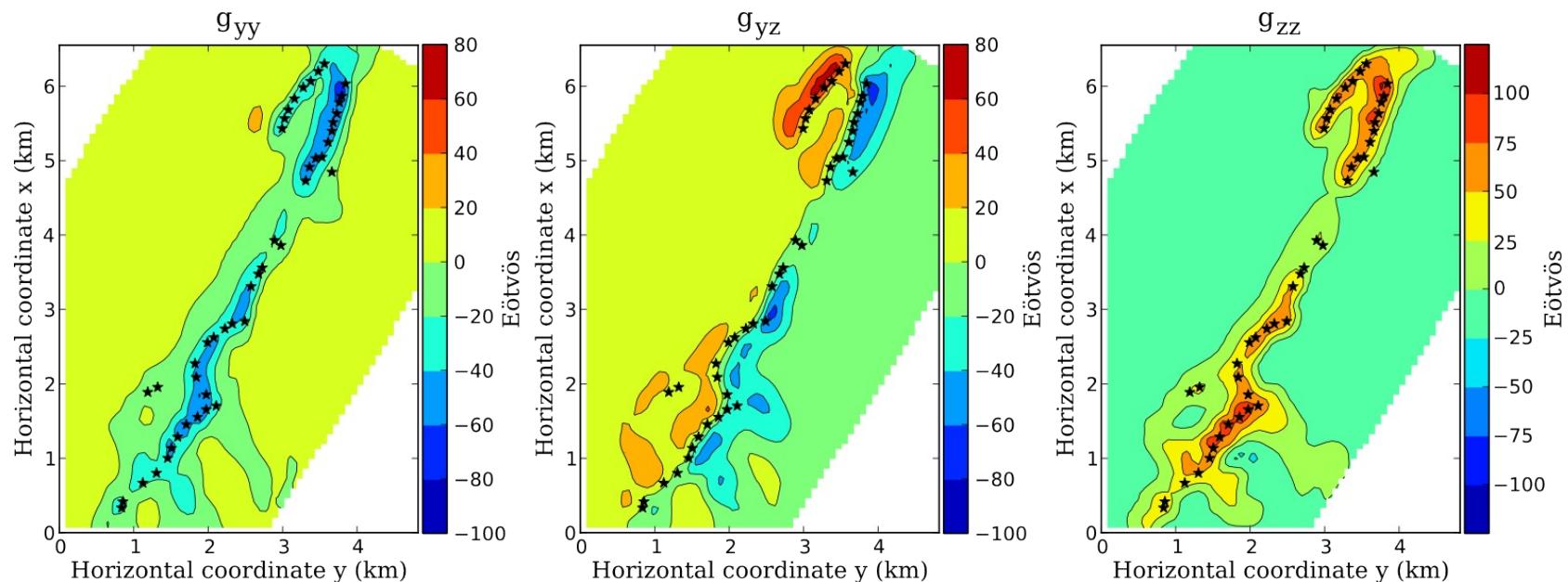
- Density contrast 1.0 g/cm^3
- Depth 200 m

Inversion: • 46 seeds • 13,746 data

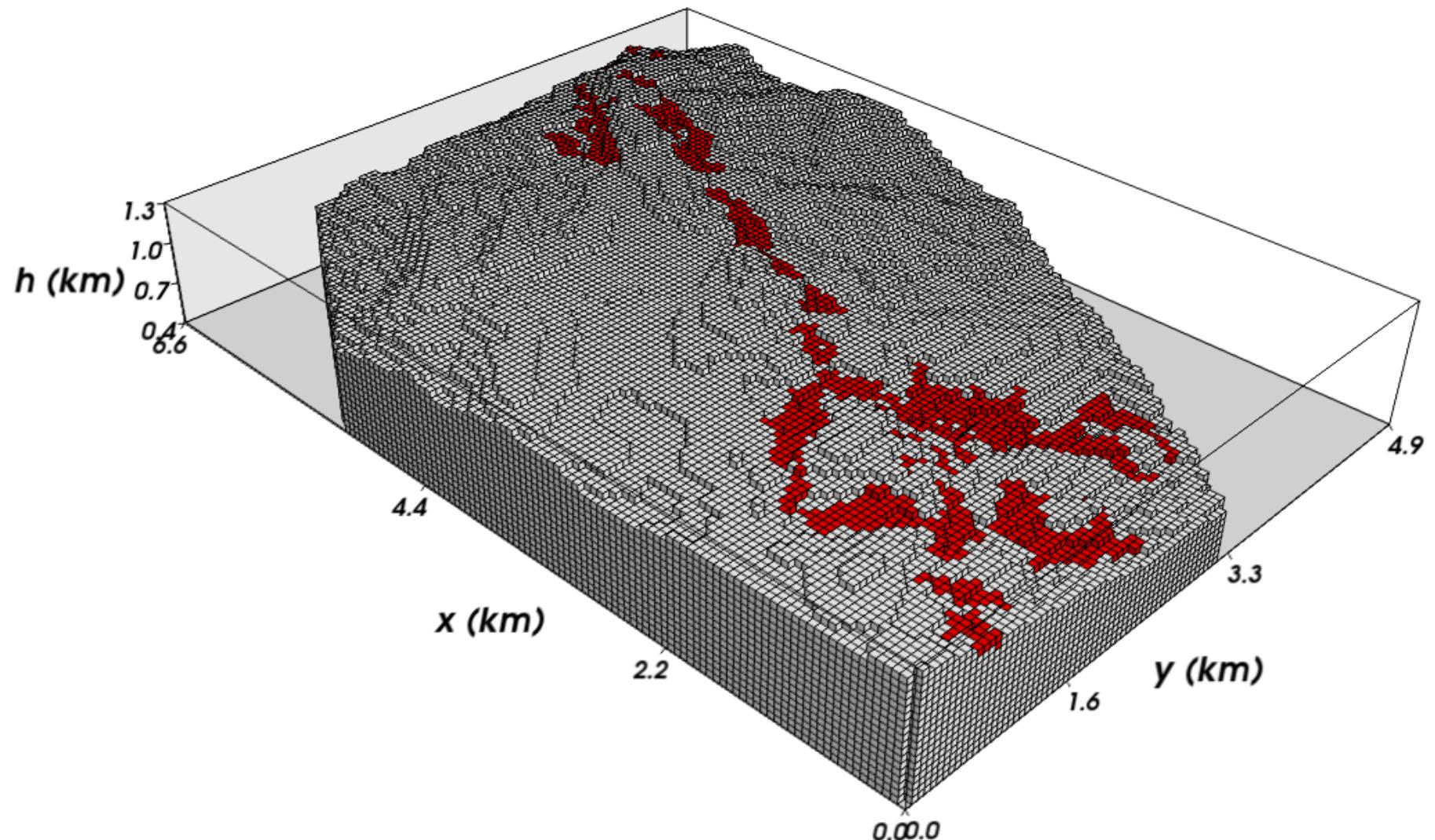
Observed



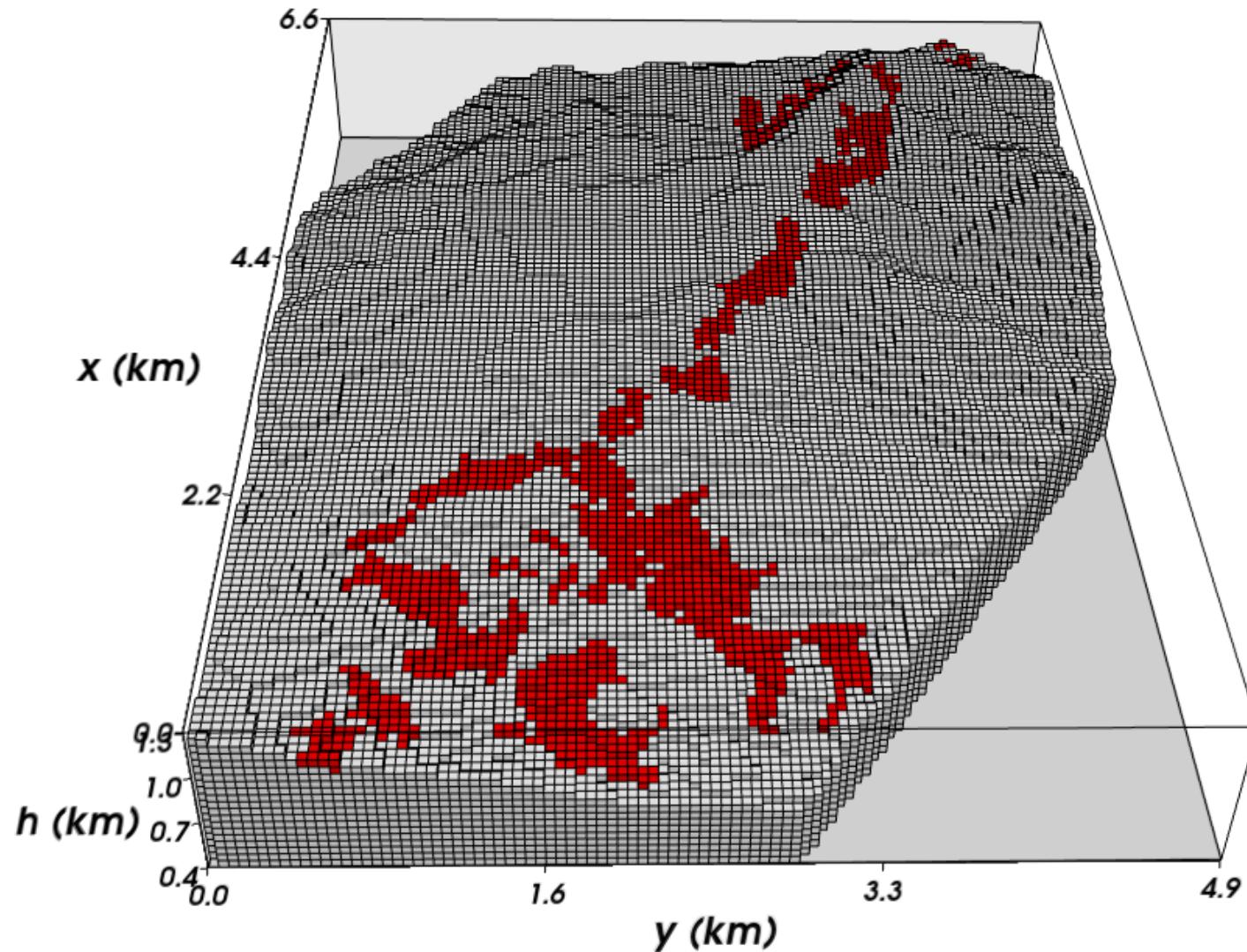
Predicted



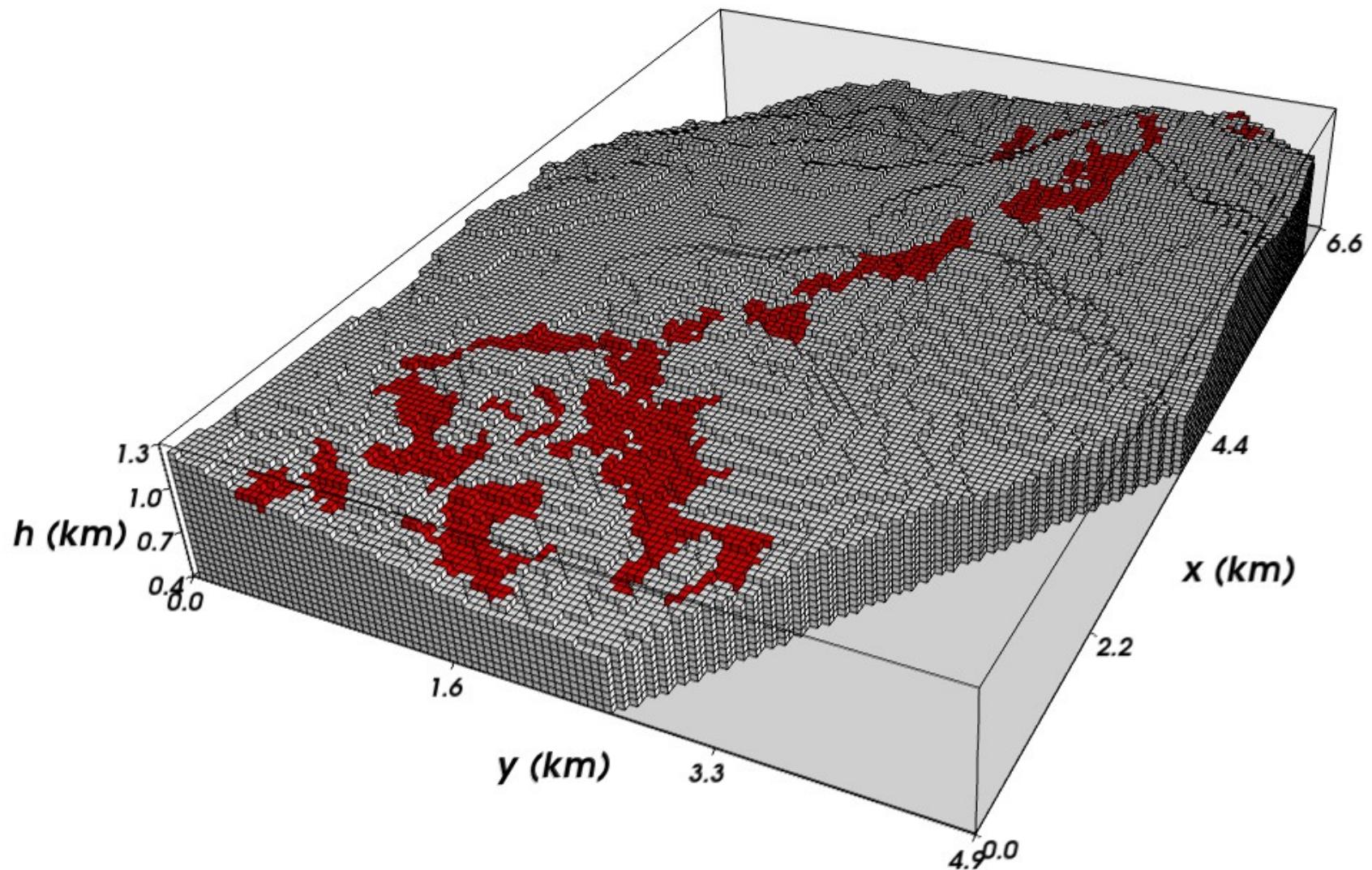
Inversion: • 46 seeds • 13,746 data • 164,892 prisms



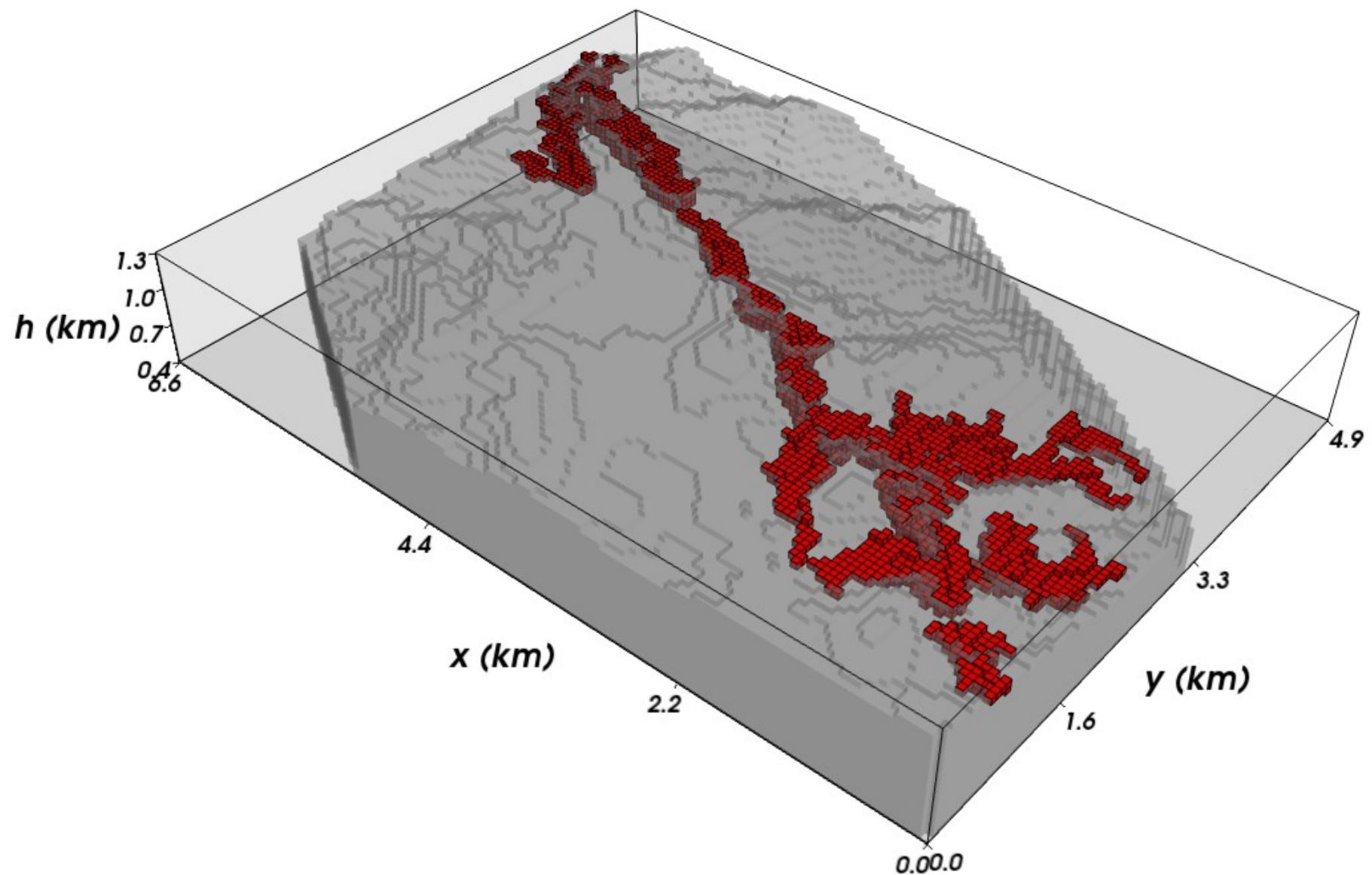
Inversion: • 46 seeds • 13,746 data • 164,892 prisms



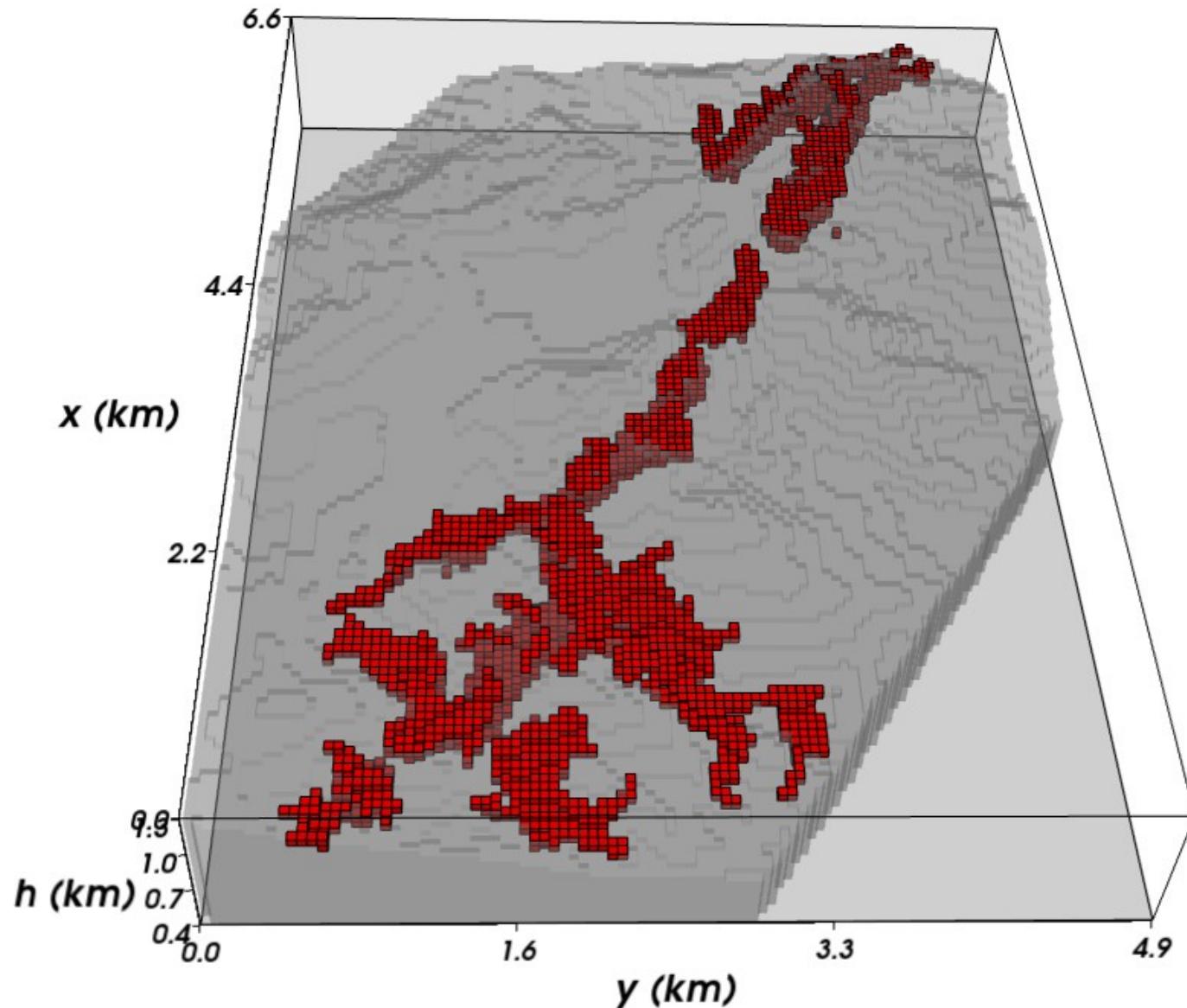
Inversion: • 46 seeds • 13,746 data • 164,892 prisms



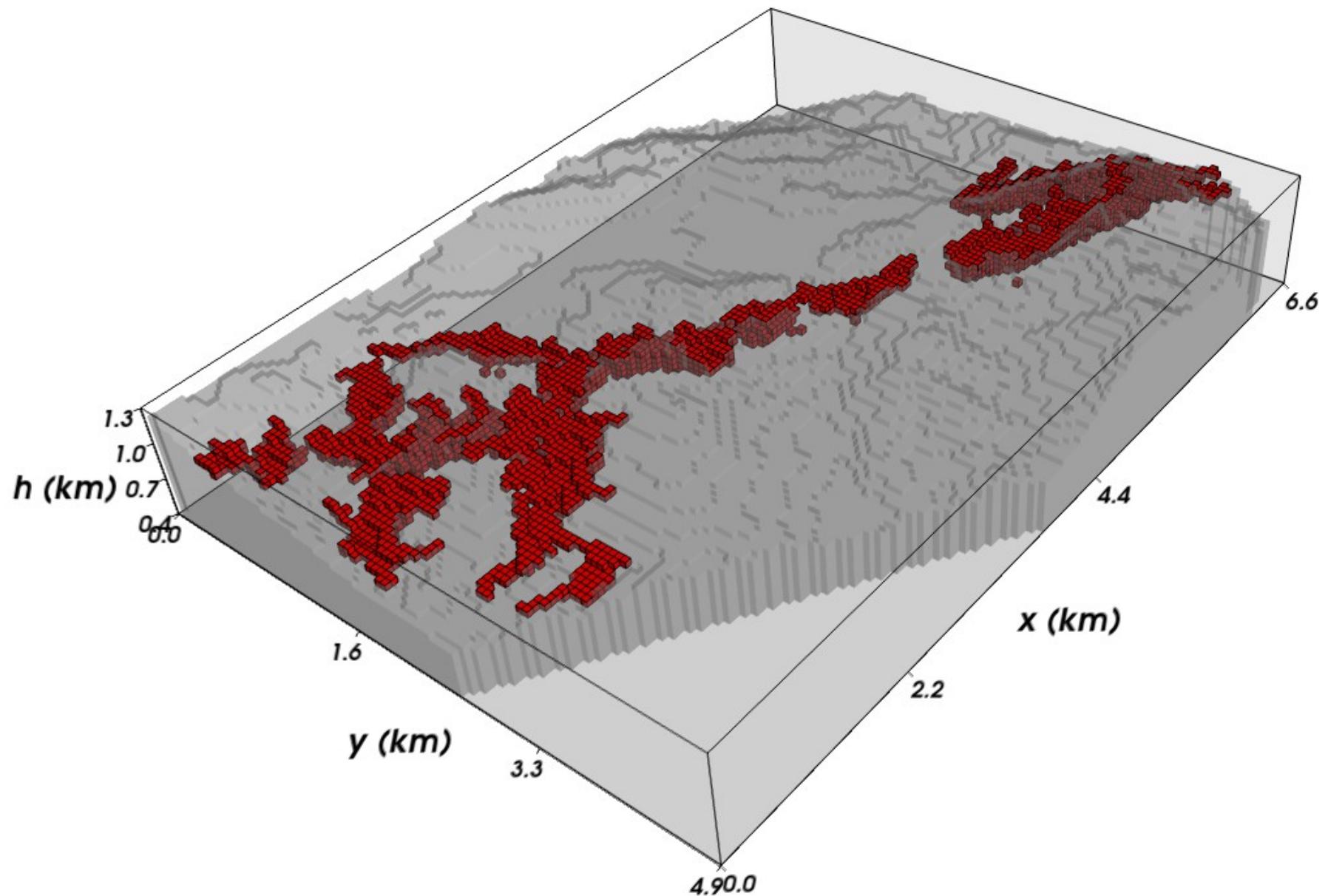
Inversion: • 46 seeds • 13,746 data • 164,892 prisms



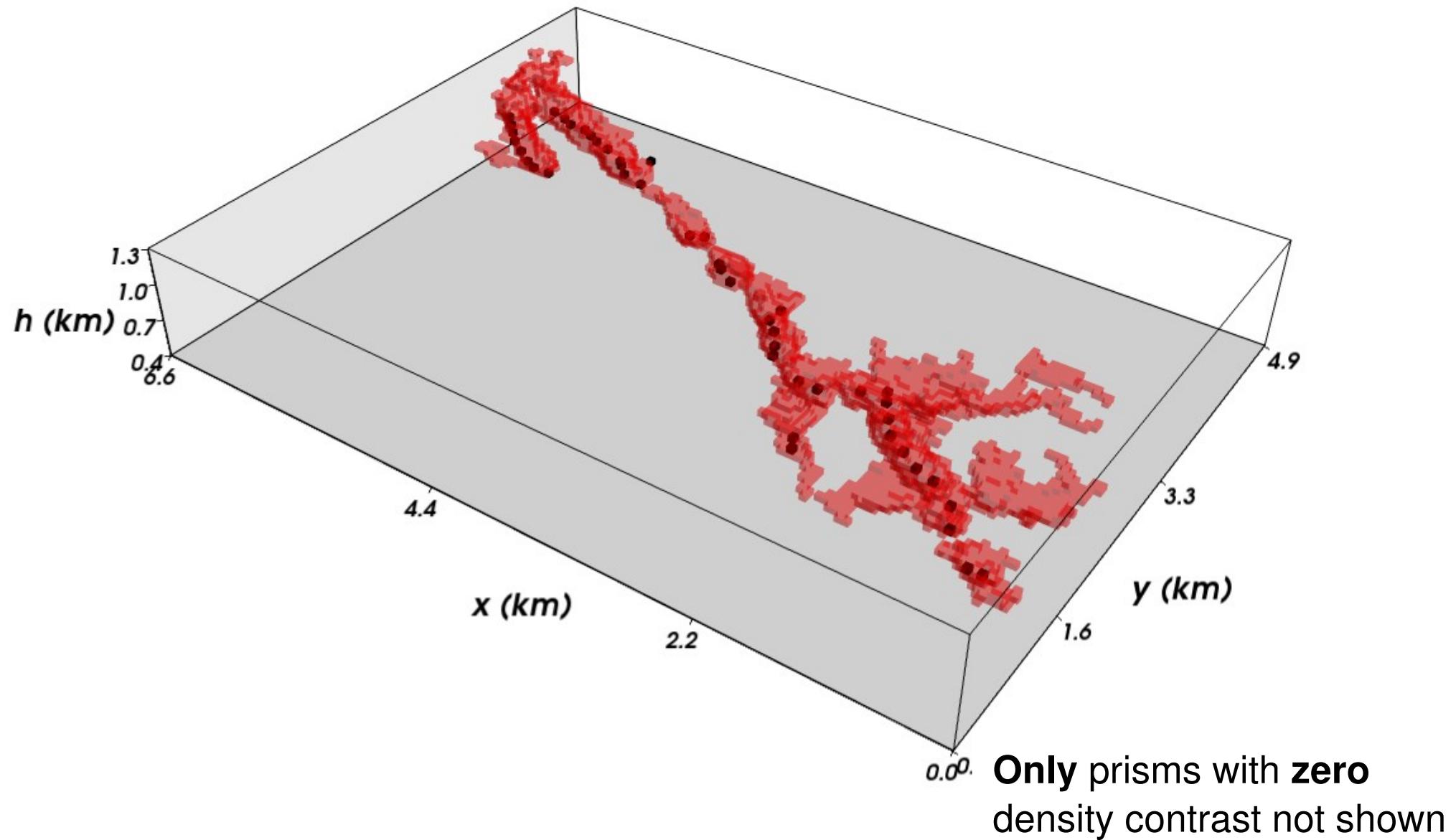
Inversion: • 46 seeds • 13,746 data • 164,892 prisms



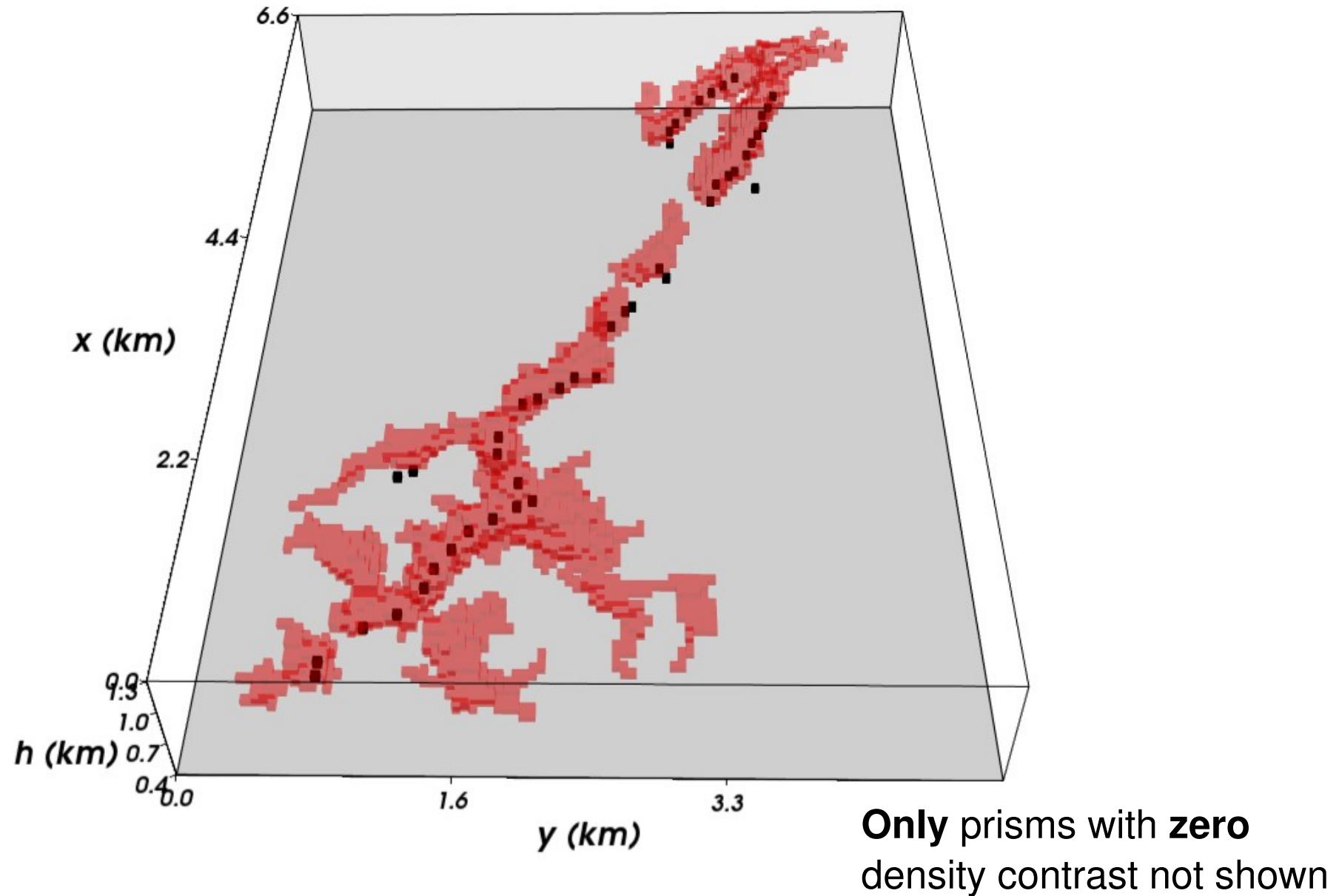
Inversion: • 46 seeds • 13,746 data • 164,892 prisms



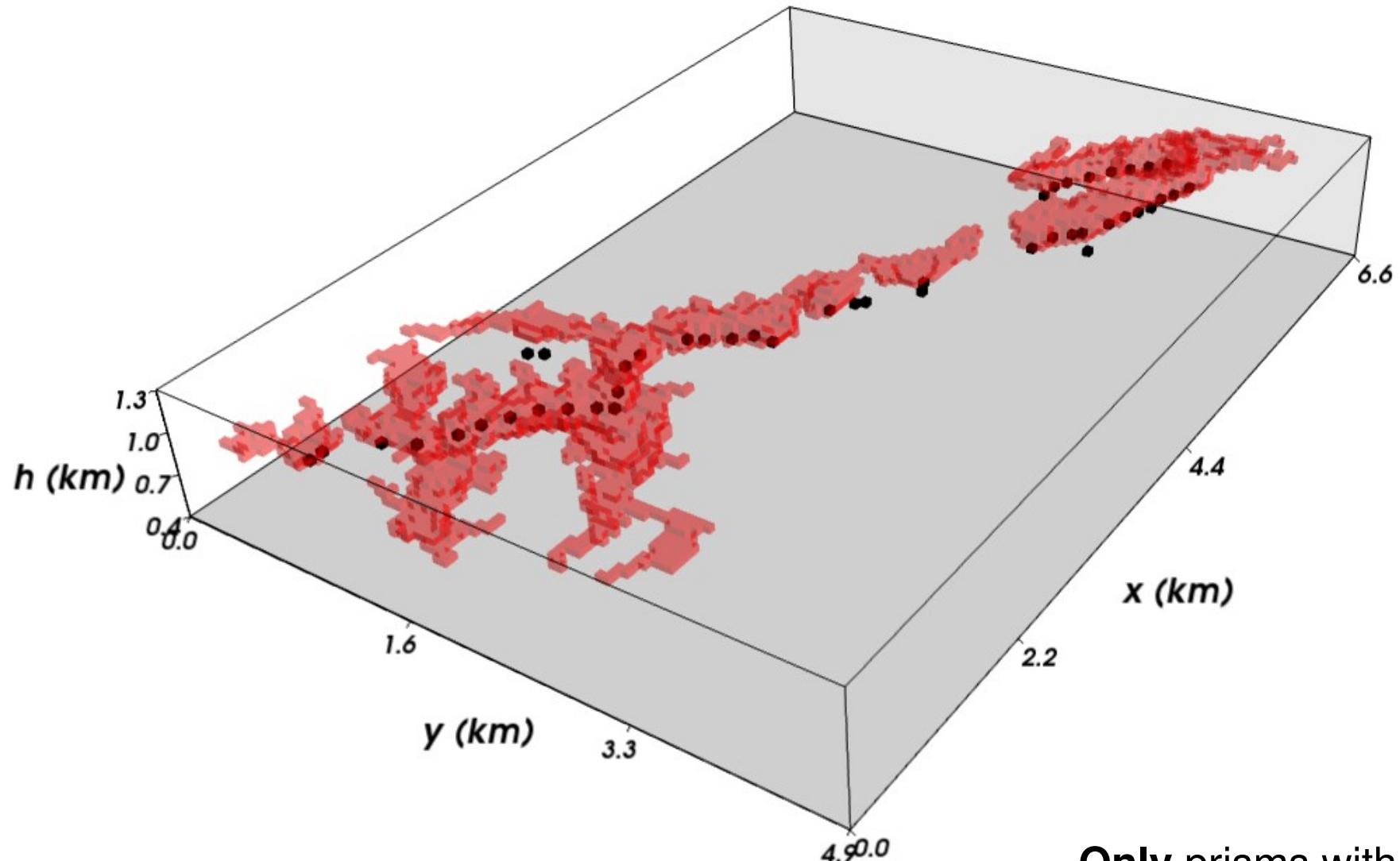
Inversion: • 46 seeds • 13,746 data • 164,892 prisms



Inversion: • 46 seeds • 13,746 data • 164,892 prisms

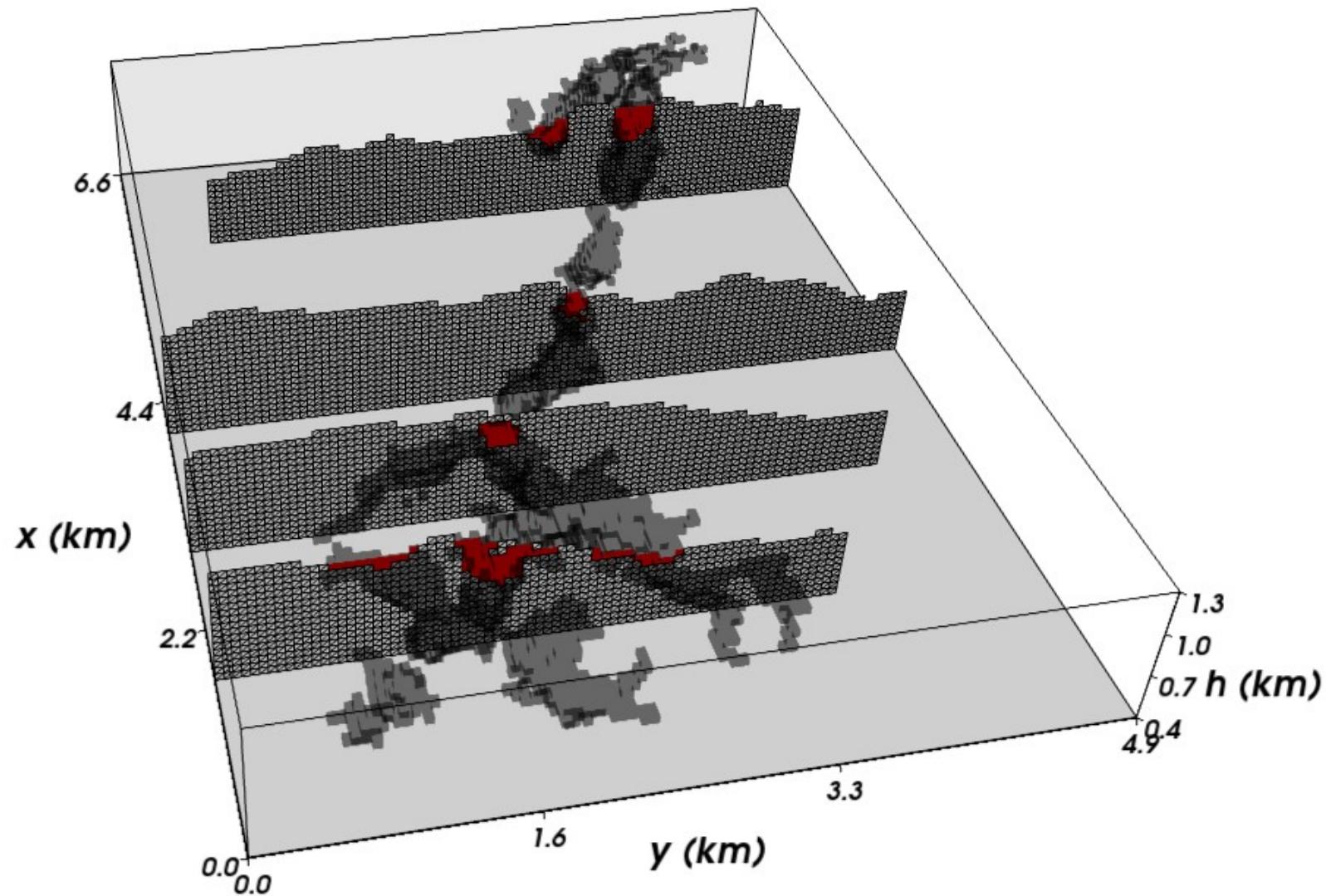


Inversion: • 46 seeds • 13,746 data • 164,892 prisms

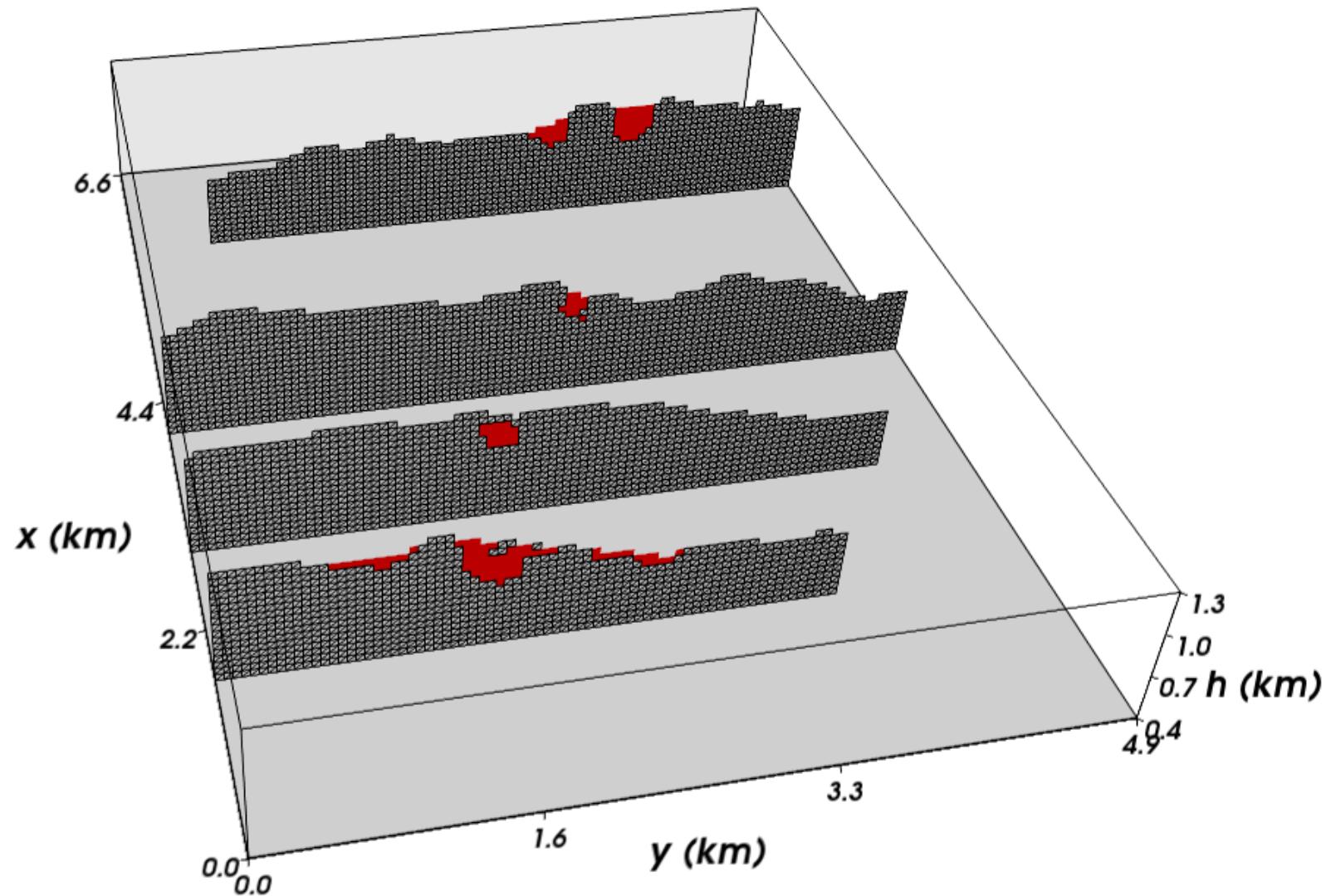


Only prisms with **zero**
density contrast not shown

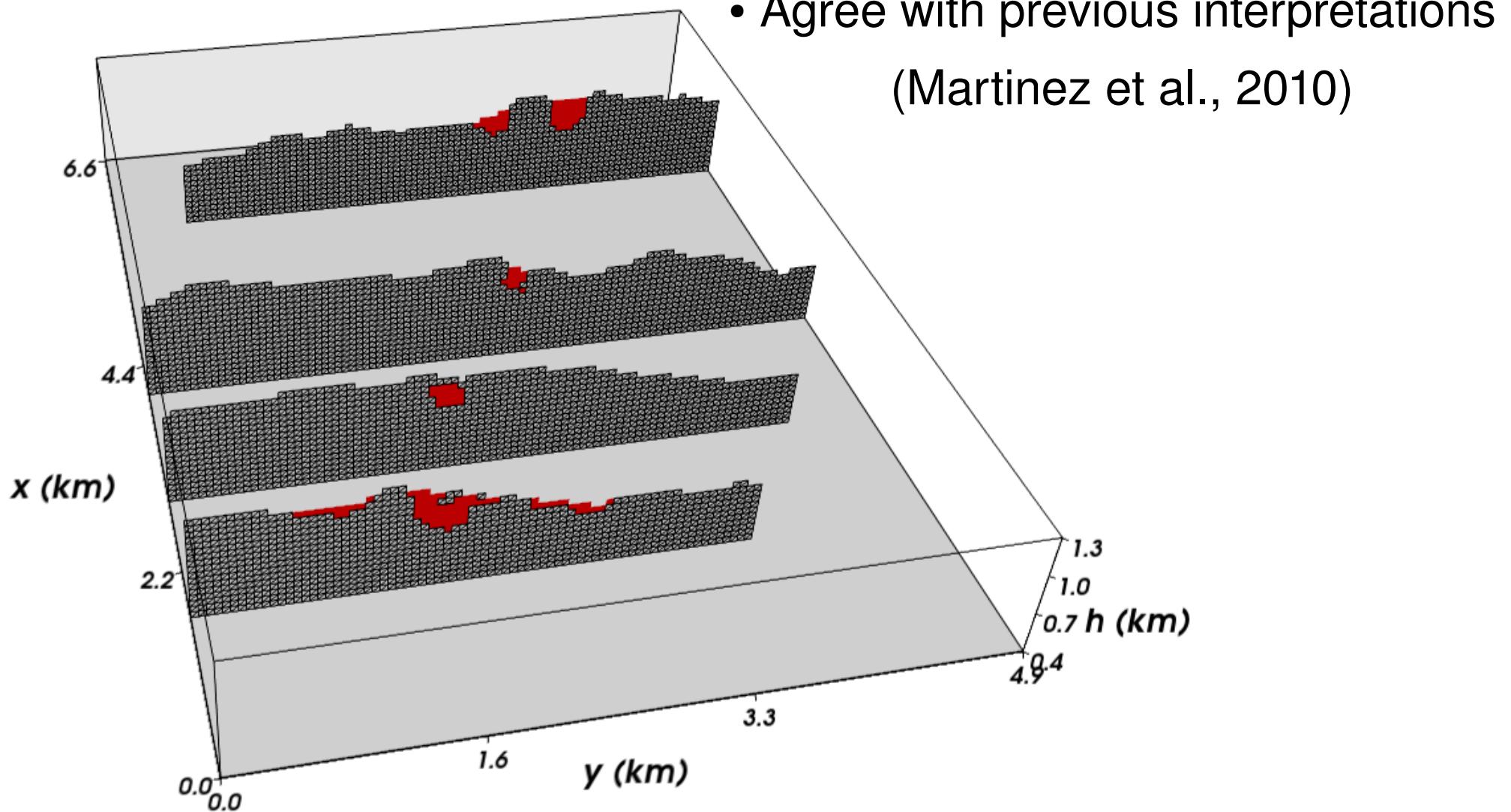
Inversion: • 46 seeds • 13,746 data • 164,892 prisms



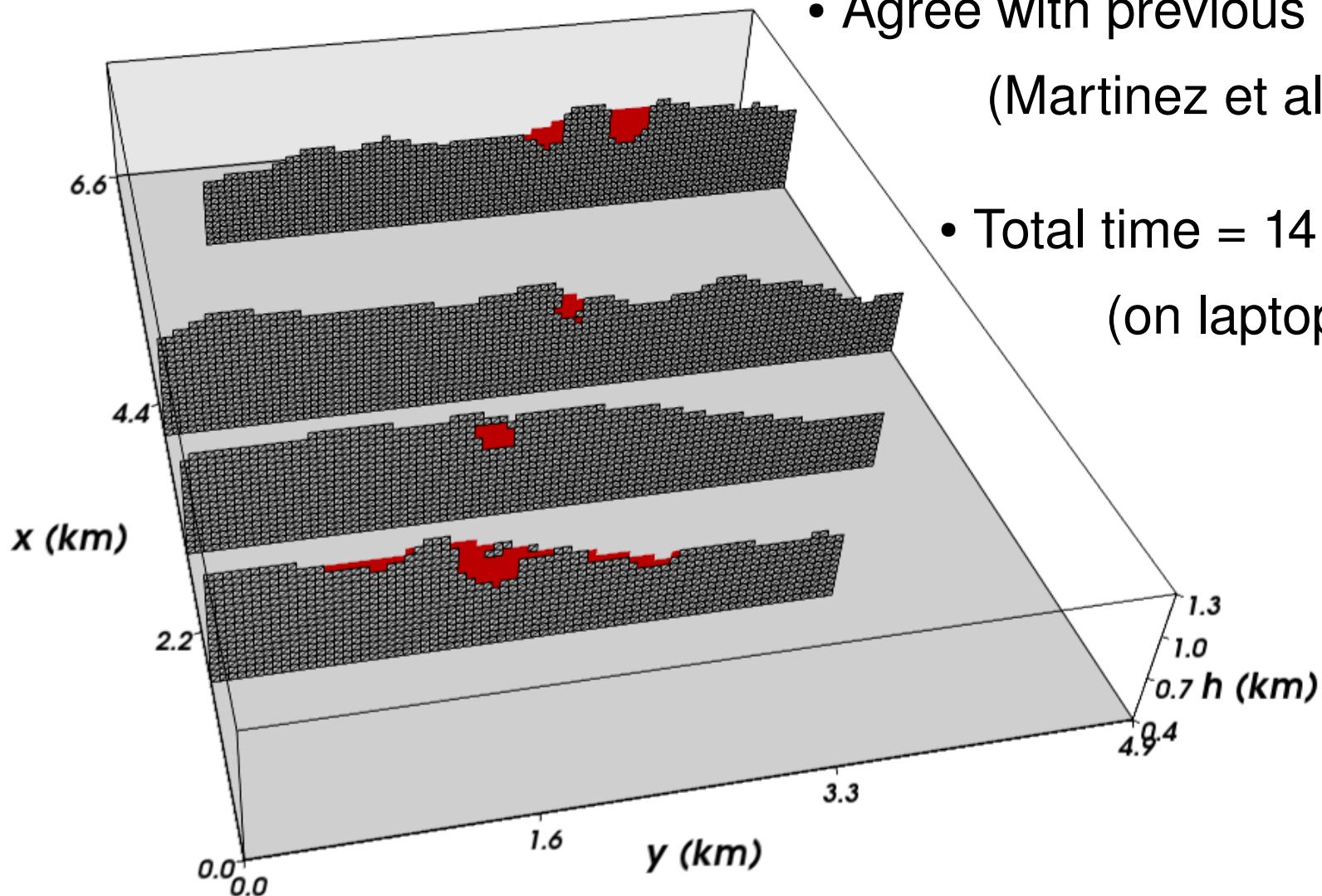
Inversion: • 46 seeds • 13,746 data • 164,892 prisms



Inversion: • 46 seeds • 13,746 data • 164,892 prisms



Inversion: • 46 seeds • 13,746 data • 164,892 prisms



- Agree with previous interpretations
(Martinez et al., 2010)
- Total time = 14 minutes
(on laptop)

Conclusions

Conclusions

- New 3D gravity gradient inversion
- Multiple sources
- Interfering gravitational effects
- Non-targeted sources
- No matrix multiplications
- No linear systems
- Lazy evaluation of Jacobian matrix

Conclusions

- Estimates geometry
- Given density contrasts
- Ideal for:
 - Sharp contacts
 - Well-constrained physical properties
 - Ore bodies
 - Intrusive rocks
 - Salt domes

Cronograma

Mestrado

- 2010: Cumprir disciplinas
- 2010-2011: 7 trabalhos em congresso (5 primeiro autor)
- 10/2011: Submeter artigo para *Geophysics*
- 11/2011: Defesa da dissertação de mestrado

Continuação

- Adaptar para gravimetria e magnetometria
- Disponibilizar software Open Source