POSTER: P284

3D gravity gradient inversion by planting density anomalies

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INTRODUCTION

Large effort directed to 3D gravity inversion.

Traditional methods produce blurred images, e.g., Li and Oldenburg (1998).

Portniaguine and Zhdanov (2002) and Silva Dias et al. (2009) produce sharp images.

Computational bottlenecks:

- Calculating the Jacobian (sensitivity) matrix;
- Solution of large equation system;

Trying to solve bottlenecks, René (1986) grows the solution around "seeds" (but it is 2D).

Camacho et al. (2000) use a systematic search algorithm (doesn't guarantee compactness).

We present a new 3D inversion that uses "seeds", like René (1986), and imposes compactness like Silva Dias et al. (2009).

Doesn't require solving a large equation system.

Only calculates parts of the Jacobian matrix (lazy evaluation).

INVERSE PROBLEM

N observations of GGT components.

Interpretative model:

- M juxtaposed prisms;

Appoximate anomalous density by summed effect of prisms:

$$\mathbf{d} = \mathbf{G}\mathbf{p}$$

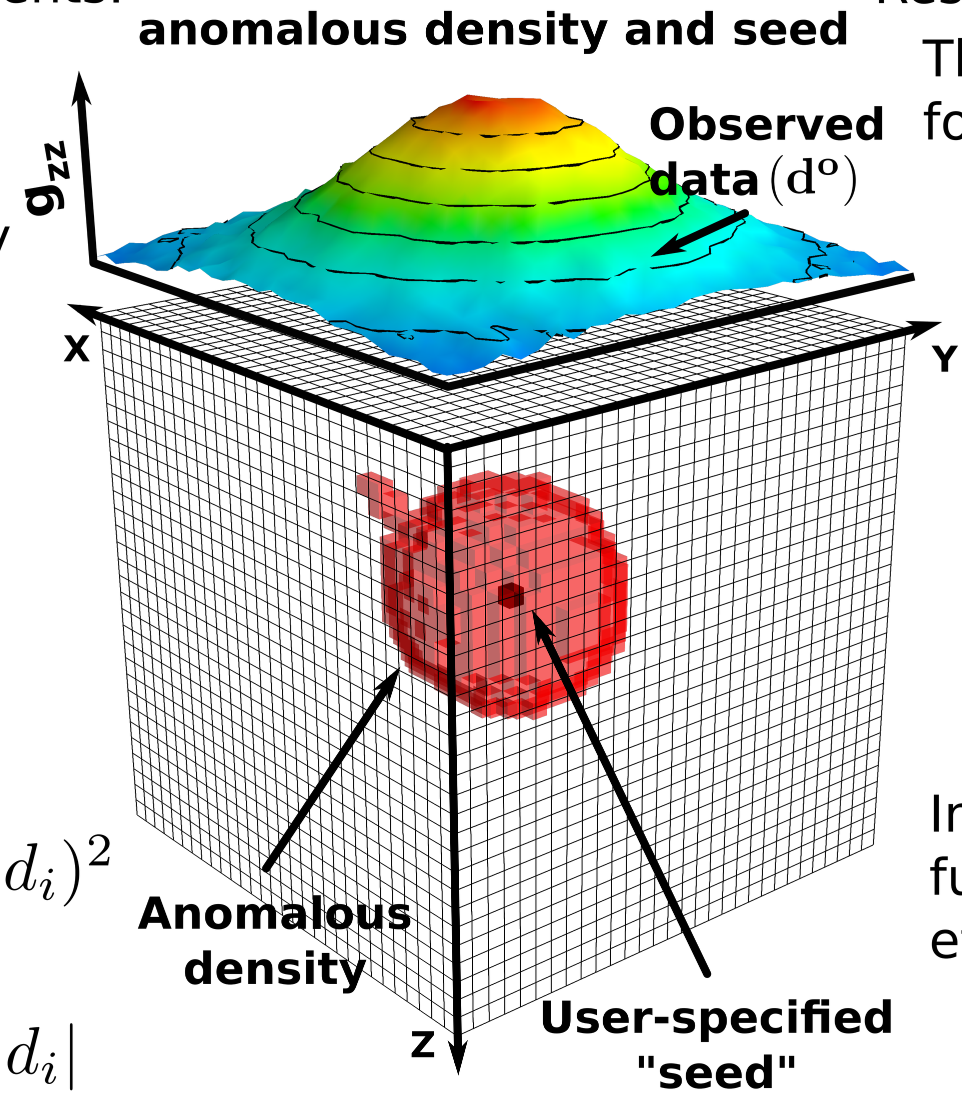
Formulate the goal function as:

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

Function $\phi(\mathbf{p})$ is a measure of the data misfit and can be:

- ℓ_2-norm: $\phi(\mathbf{p}) = \sum_{i=1}^{N} (d_i^o - d_i)^2$
- ℓ_1-norm: $\phi(\mathbf{p}) = \sum_{i=1}^{N} |d_i^o - d_i|$

Interpretative model, anomalous density and seed



Residuals vectors: $\mathbf{r} = \mathbf{d^o} - \mathbf{d}$

The ℓ_1-norm can be used for robust inversion.

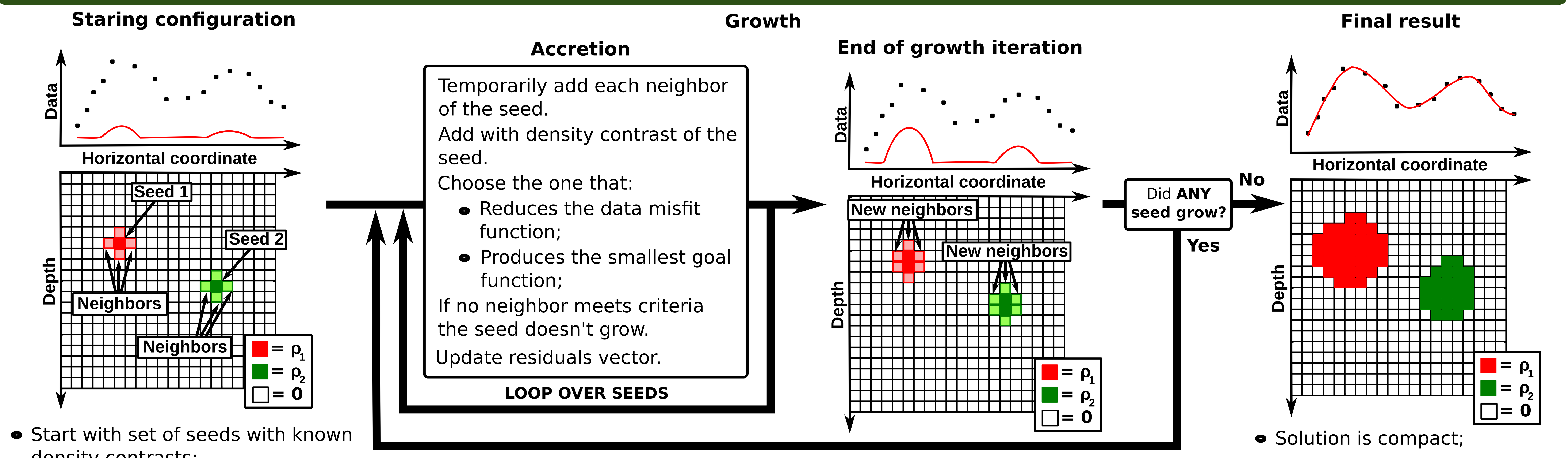
Estimating **p** from **d** is ill-posed and requires **constraints**:

- Mass is concentrated around user-specified prisms (called "seeds");
- Solution is compact;
- Known density contrasts;

Imposed using regularizing function similar to Silva Dias et al. (2009):

$$\theta(\mathbf{p}) = \sum_{i=1}^{M} \frac{p_i}{p_i + \epsilon} l_i^{\beta}$$

PLANTING ALGORITHM



- Start with set of seeds with known density contrasts;
- Find the neighbors of each seed;
- Initialize **p** with the density of the seeds;
- All other parameters start with zero;

- Attempt to grow each seed;
- In each iteration grow one seed at a time;
- Find new neightbors of solution at the end of each iteration;
- Not all seeds grow each iteration = bodies with different sizes;
- Grow while at least one seed grows;

- Solution is compact;
- Seeds produce bodies of different sizes;
- Estimate fits observed data (according to ℓ_1- or ℓ_2-norms);
- No equation system to solve;

LAZY EVALUATION

The search is limited to neighboring prisms of the current solution.

Each column of **G** refers to one parameter (prism in the interpretative model).

So don't need to know all columns of **G**.

Only calculate the ones corresponding to neighboring prisms.

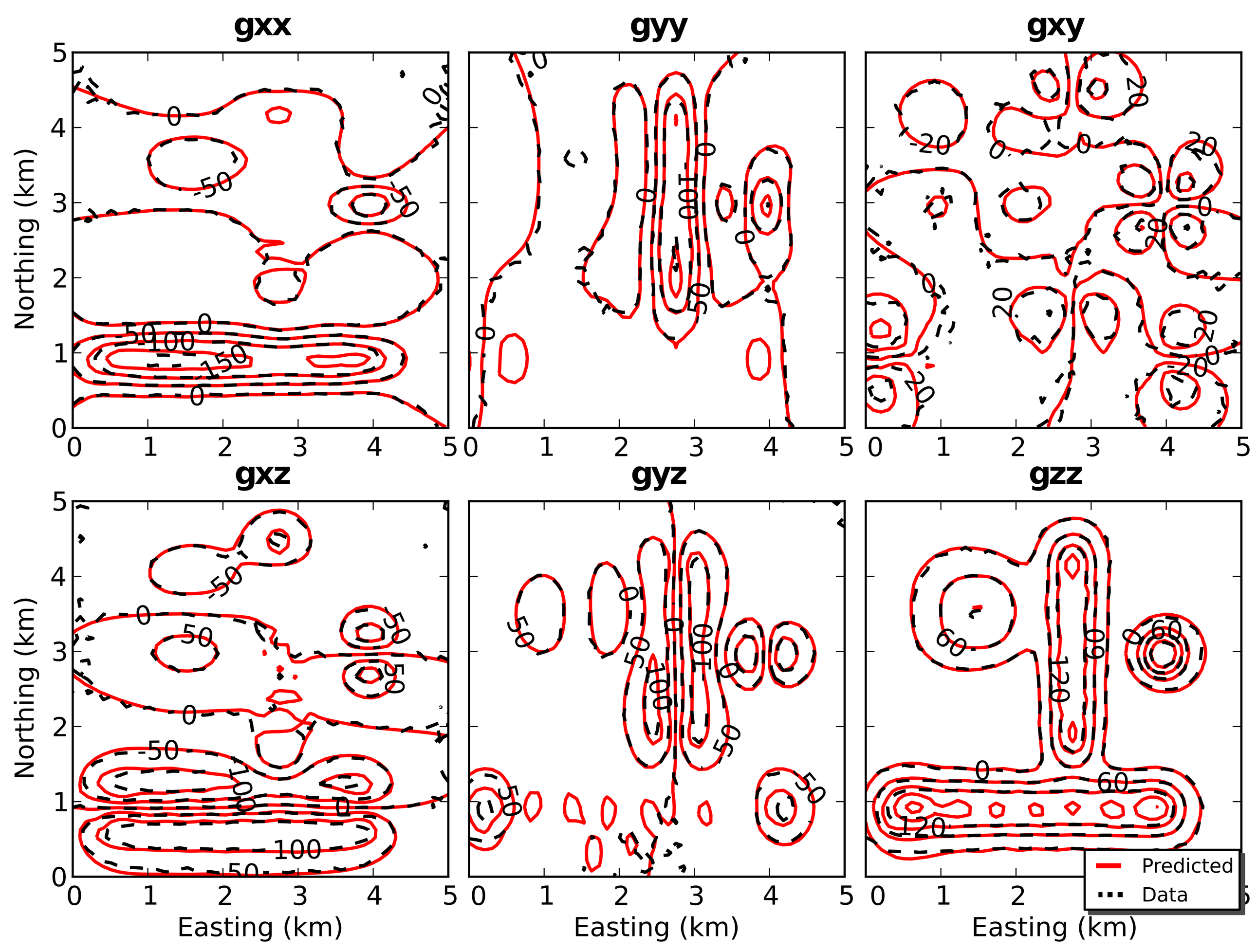
Can delete the column once a prism is added to the estimate.

Called *lazy evaluation* in computer science.

Reduce computation time and memory usage.

No need for data compression algorithms, e.g., Portniaguine and Zhdanov (2002).

SYNTHETIC EXAMPLE USING THE L2-NORM



Dashed **black** contours = **synthetic** gradiometry data produced by (a).

Calculated at 150 m height.

Added 2 Eötvös pseudorandom Gaussian noise.

Used set of 18 seeds shown in (b).

Data set = 15,000 measurements.

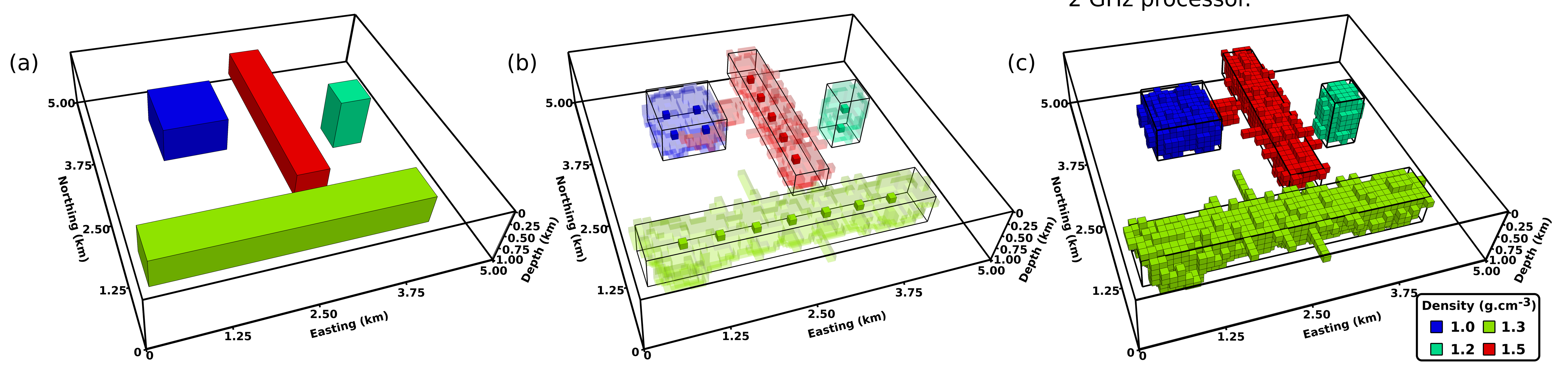
Interpretative model = 25,000 prisms.

Estimate in (c) is close to the model in (a).

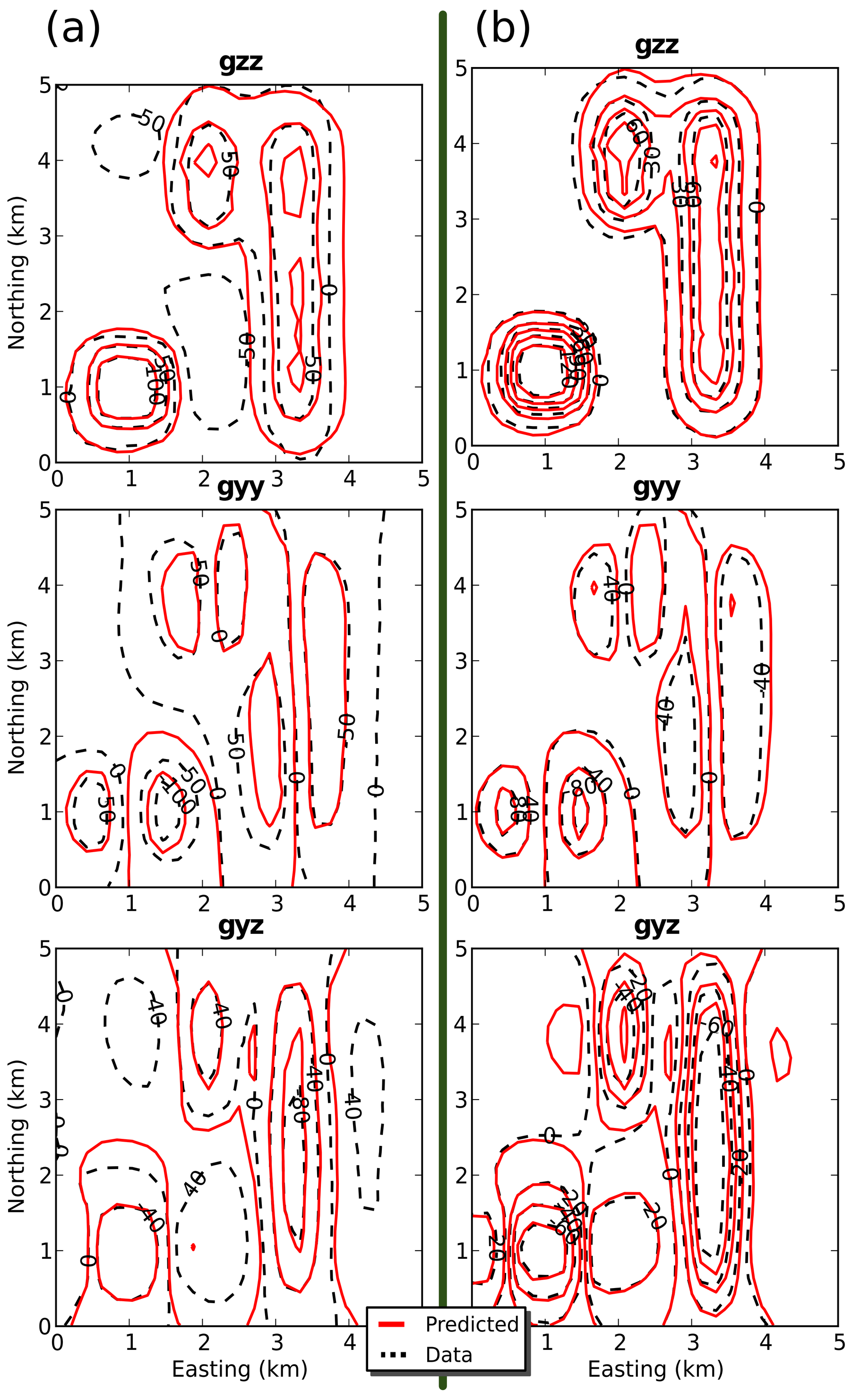
Red contours = data **predicted** by (c).

Very close fit to synthetic data with noise.

Inversion time ~ 7 min. on Intel Core 2 Duo 2 GHz processor.



SYNTHETIC EXAMPLE USING THE L1-NORM



Simulate real world scenario:

- Multiple sources;
- Interfering gravitational effects;
- Only interested in positive density constrasts;

Use ℓ_1-norm to consider the effect of negative density constrasts as *outliers*.

(a): Dashed **black** contours = **synthetic** gradiometry data produced by (c) (Data set **used in the inversion**).

(b): Dashed **black** contours = **synthetic** gradiometry data produced by blocks with **positive** density contrasts in (c).

Calculated at 150 m height.

Added 0.5 Eötvös pseudorandom Gaussian noise.

Used set of 14 seeds shown in (d).

Data set = 1,875 measurements.

Interpretative model = 37,500 prisms.

Estimate produced by the inversion shown in (e).

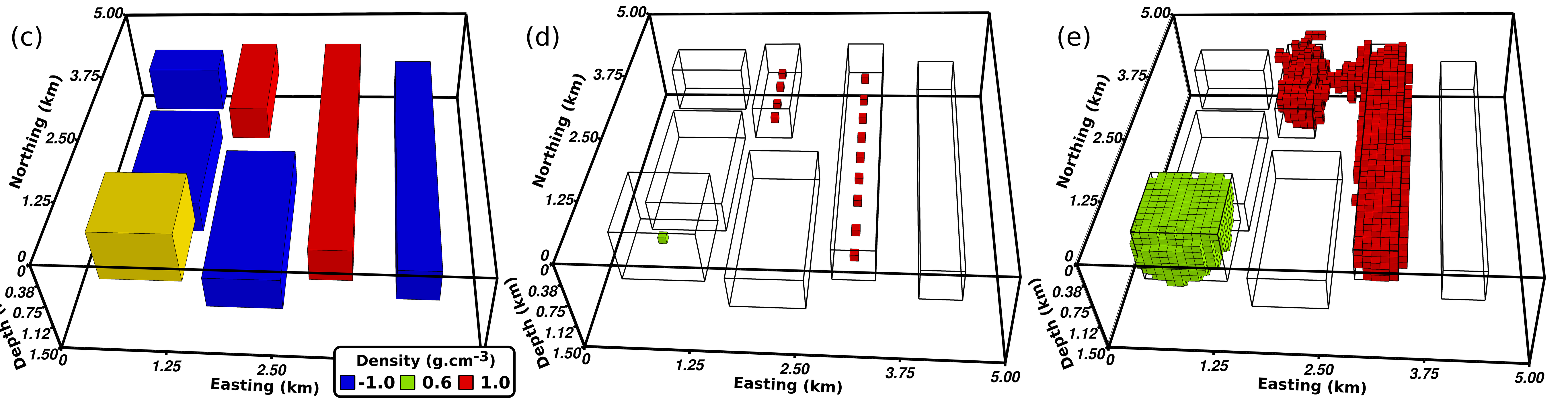
Able to recover blocks with positive density contrasts despite interfering gravitational effects.

Red contours = data **predicted** by (e).

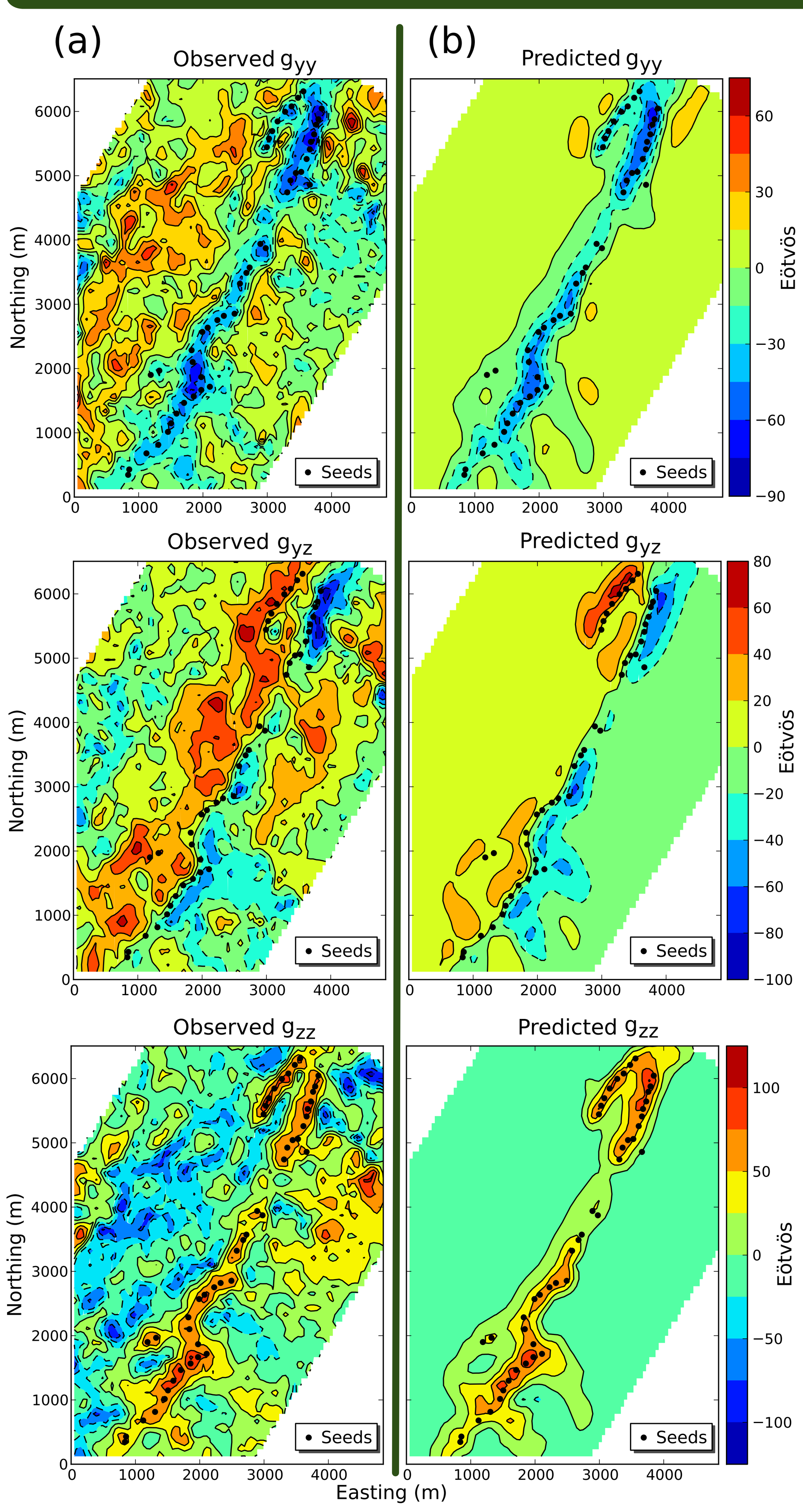
Inversion performed on **FULL DATA SET** (a) is able to fit the effect of only positive density constrasts (b) despite the presence of interfering gravitational effects.

ℓ_1-norm allows large residuals where effect of negative density contrasts is dominant.

Inversion time ~ 1.7 min. on Intel Core 2 Duo 2 GHz processor.



APPLICATION TO REAL DATA



Airborne survey over iron ore deposits of the Cauê Itabirite.

Located in the Quadrilátero Ferrífero, southeastern Brazil.

Banded Iron Formations (BIFs).

(a): Measured tensor components.

Data set = 13,746 measurements.

Target of the interpretation = elongated SW-NE feature.

Assumed density contrast for Cauê Itabirite = 1.0 g.cm^{-3}.

Data was terrain corrected with density 2.67 g.cm^{-3}.

Negative values of g_{zz} component.

Can't be caused by Cauê Itabirite which has positive density contrast.

Indicates presence of non-targeted sources with interfering gravitational effects.

Use ℓ_1-norm in the inversion to "ignore" these undesired effects.

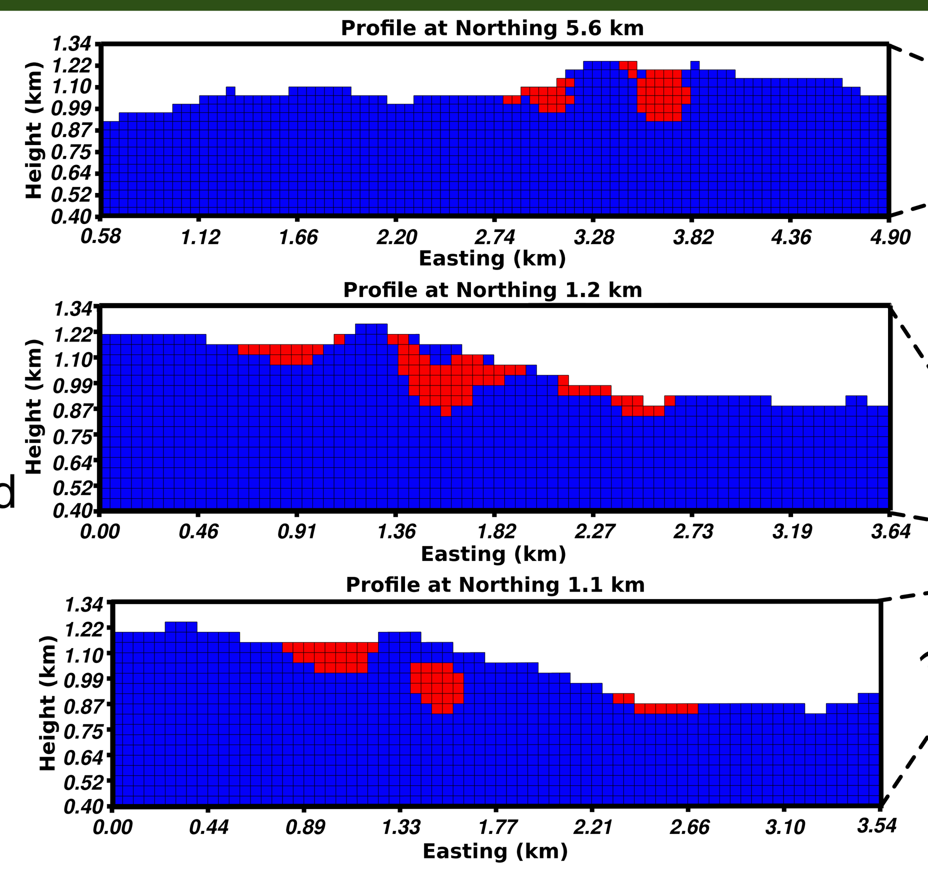
Interpretative model = 164,892 prisms.

Used 46 **seeds** (**black dots**).

Seeds chosen using g_{zz} component.

(b): Data **predicted** by inversion result (c-g).

Able to fit desired features of the data while ignoring effects of non-targeted sources.



Blue prisms = **0.0** g.cm^{-3}.

Red prisms = **1.0** g.cm^{-3}.

Profiles show that the result is compact and has non-outcropping parts.

(c): interpretative model and outcropping portion of the result.

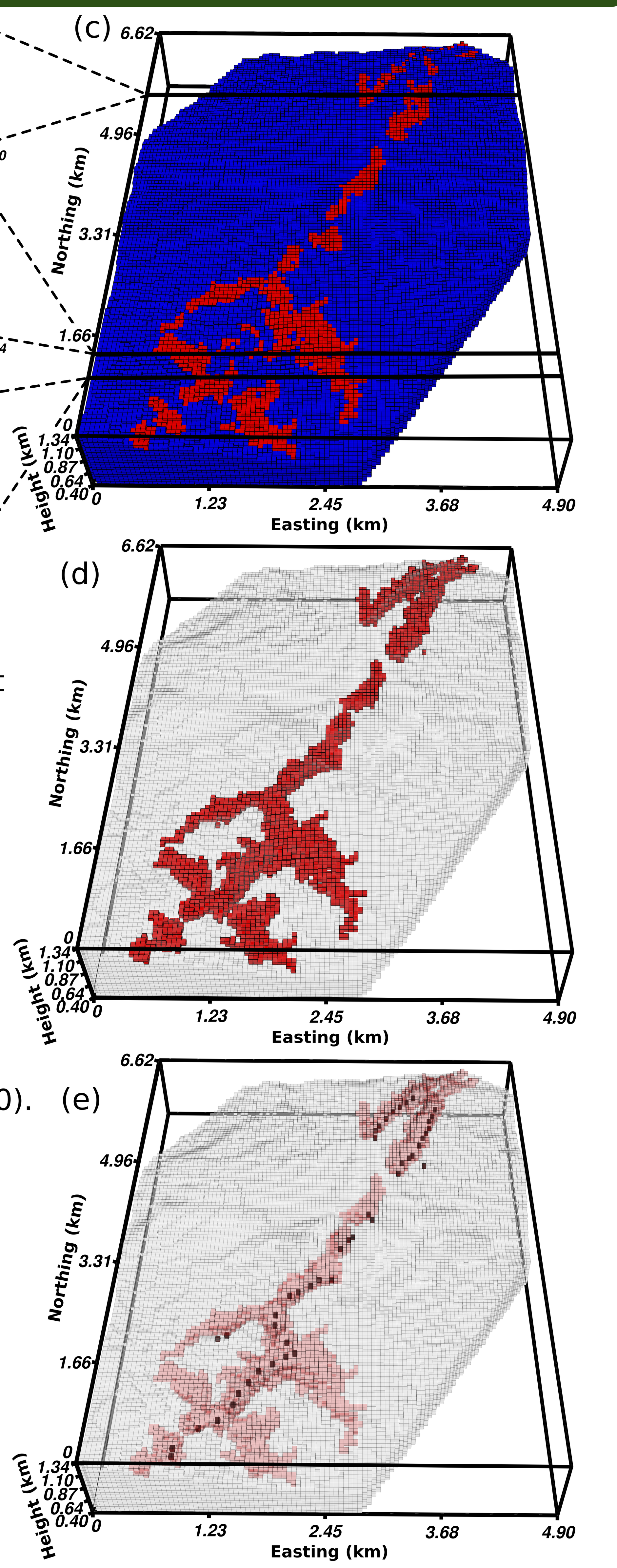
(d): inversion result. Prisms with zero density contrast in transparent grey.

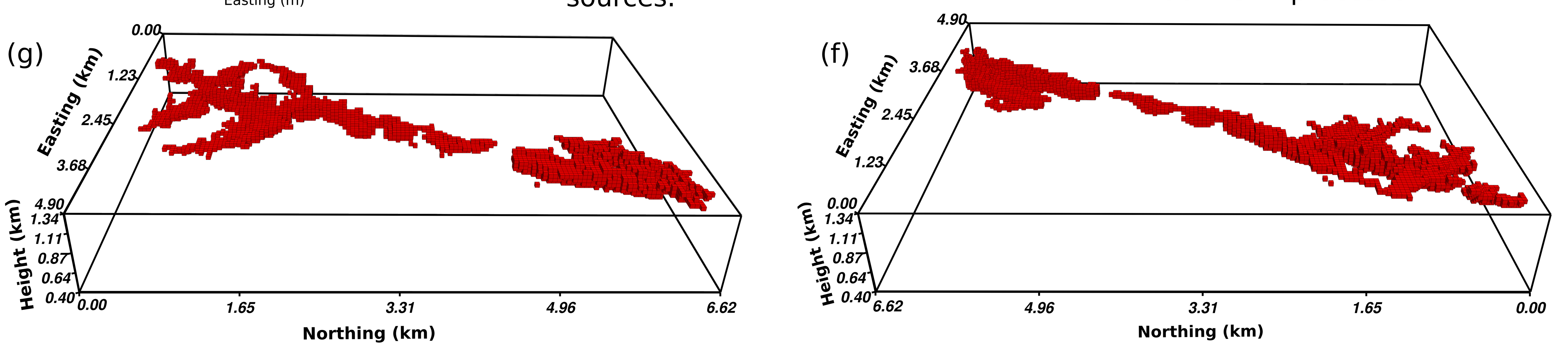
(e): **black** prisms represent the seeds used in the inversion.

(f) west and **(g)** east side views of the inversion result. Prisms with zero density contrast not shown.

Results agree with Martinez et al. (2010).

Inversion time ~ 15 min. on Intel Core 2 Duo 2 GHz processor.





CONCLUSIONS

Presented a new method for 3D inversion of gravity gradient data based on a systematic search algorithm.

Prior information is incorporated by means of user-specified "seeds".

Enforces compactness of the solution using a regularizing function.

Can perform a robust inversion through ℓ_1-norm of the residulas.

Fast inversion and able to handle large data sets and fine interpretative models:

- Search is limited to neighboring prisms of the current solution;
- Implementation of *lazy evalutation* of the Jacobian matrix **G**;

Synthetic tests show that:

- Can recover multiple sources with different density contrasts;
- Is able to handle the presence of non-targeted sources with interfering gravitational effects, a common case in real world scenarios;

Results of application to real data from the Quadrilátero Ferrífero agree with previous interpretations.

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