# Gravity kernel method for implicit geological modeling

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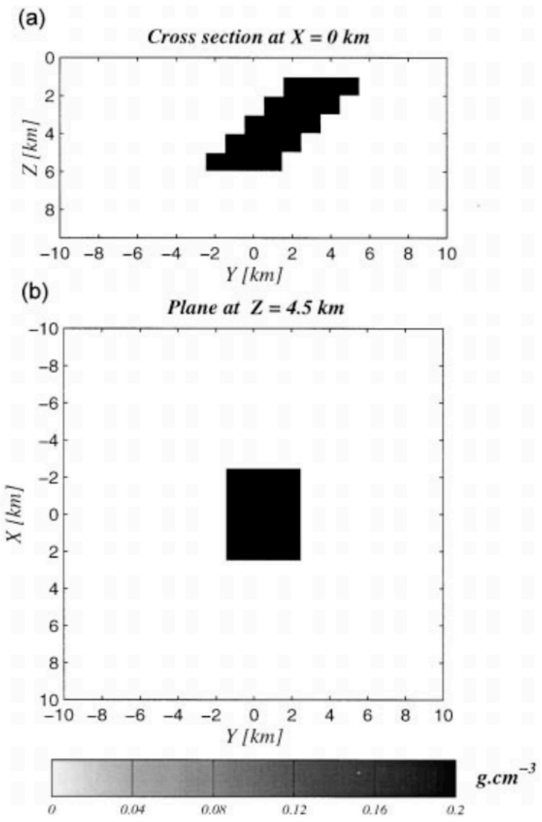
# Introduction

## Conventional gravity method (Voxel-based)

True Model




(Boulanger, O., & Chouteau, M. ,2001)

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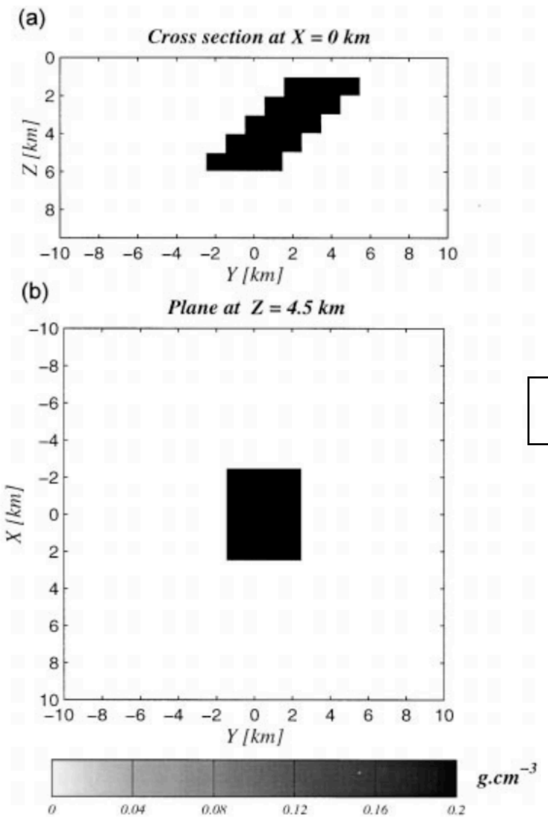
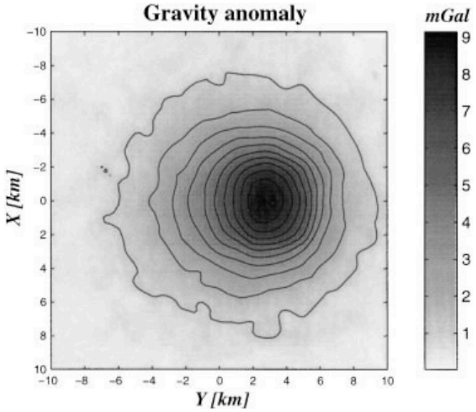



Forward

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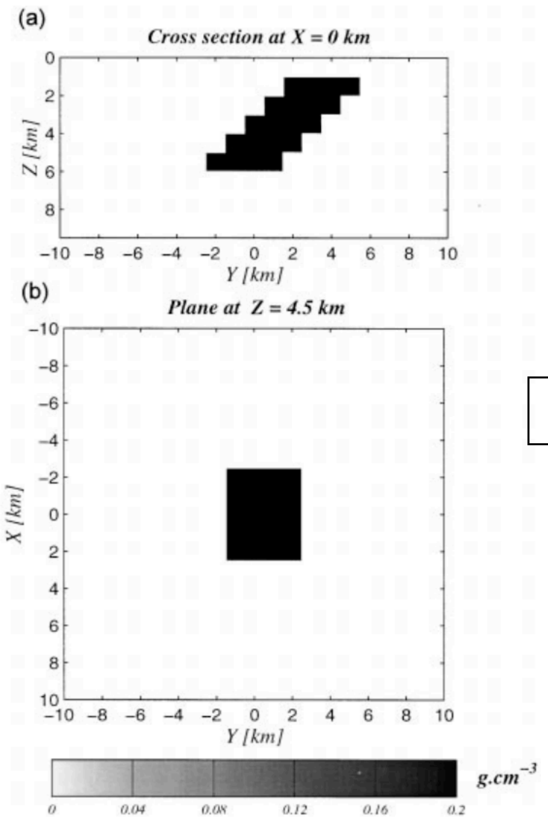
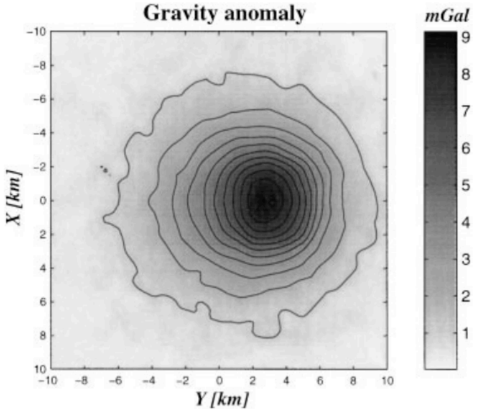
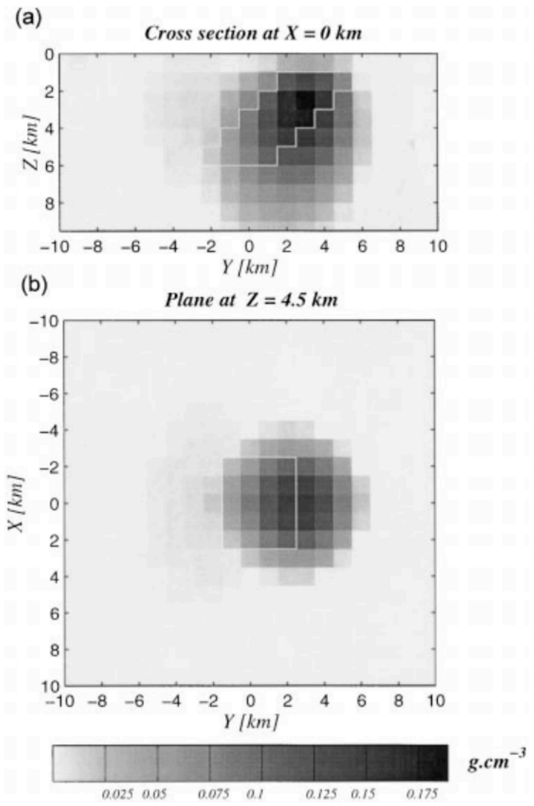



Forward




Inverse

Inverse Model




(Boulanger, O., & Chouteau, M. ,2001)

## Methods

### Model-based inversion

- Implicit geomodeling method (GemPy)
- Interpolate a scalar field based on the interface data (surface/orientation/fault points)
- Lower dimensional parametric representation
- Query lithology at any location
- Suitable for structural geological modeling

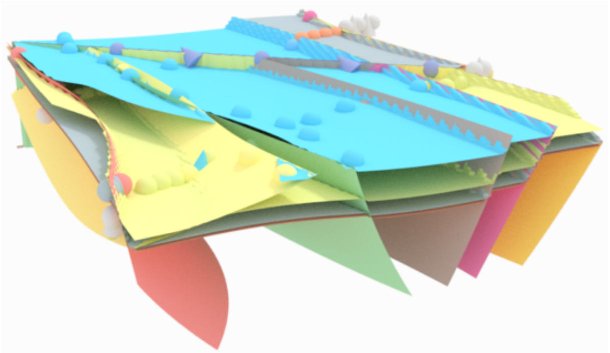


Fig. 1: Example of a 3D geological model in GemPy (de la Varga et. al., 2019)

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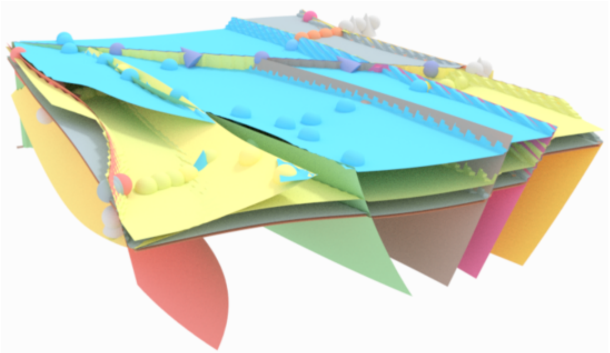


Fig. 1: Example of a 3D geological model in GemPy (de la Varga et. al., 2019)

## Kernel method - Gravity simulation

- Receiver - based
- Stochastic modeling
- Implicit methods
- Sparse data / Highly correlated data
- Large scale model
- Tensor grid - analytical solution of gravity
- Pre-compute $T_z$, integration with differentiable modeling framework [1]

- Gravity $g_z = T_z \rho$
- Sensitivity matrix

$$T_z = -\left|\left|\left| x \ln(y+r) + y \ln(x+r) - z \arctan\left(\frac{xy}{zr}\right) \right|_{x_1}^{x_2}\right|_{y_1}^{y_2}\right|_{z_1}^{z_2}$$



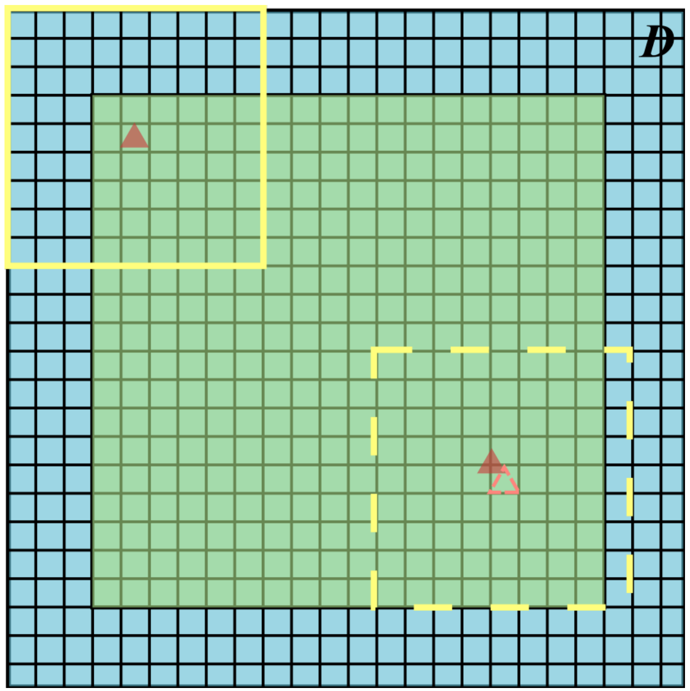


[1] M, de la Varga, et al. "GemPy 1.0: open-source stochastic geological modeling and inversion."

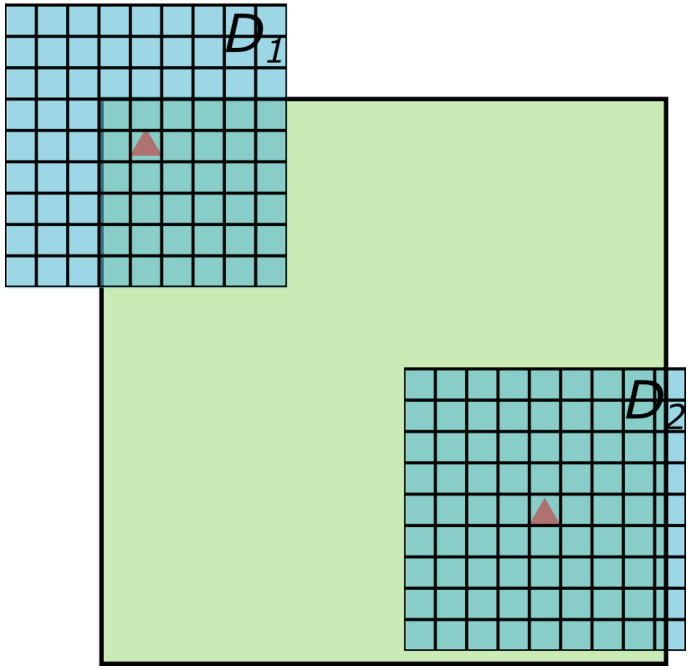
# Methods

## Forward gravity

Spatial convolution scheme

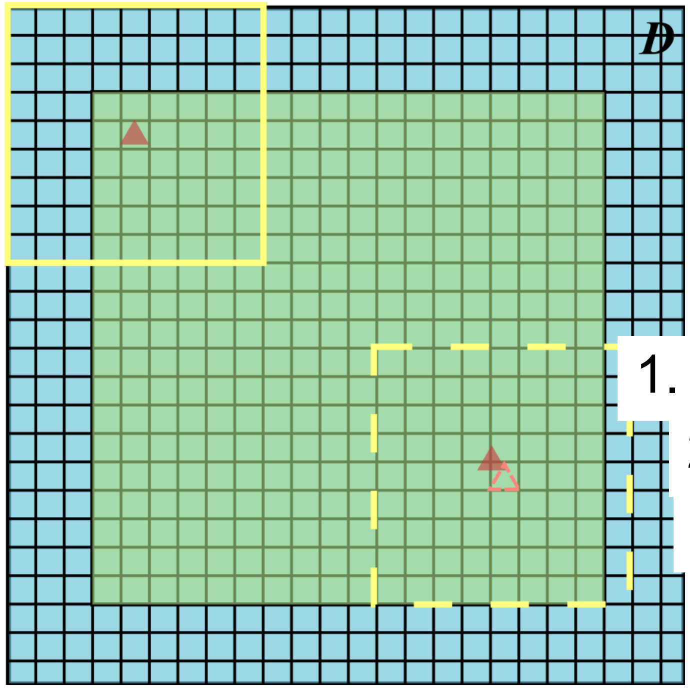



Kernel method

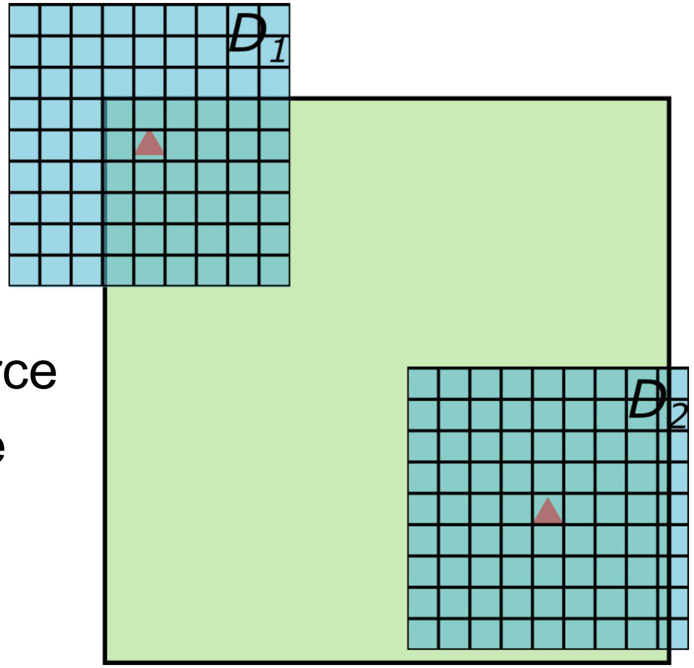


## Forward gravity

Spatial convolution scheme




Kernel method




1. Save computation resource
2. Integrate padding zone
3. Eliminate slicing errors

# Methods

## Kernel method - refinement strategy

*Optimal grid design without knowing the underlying geometry is not straightforward before evaluating the model.*

- Tensor grid allows a parametric representation
- Refine based on the sensitivity $T_z$ of the cell to the corresponding receiver
- Average the risk of aliasing
- Use AD to minimize $std(T_z)$

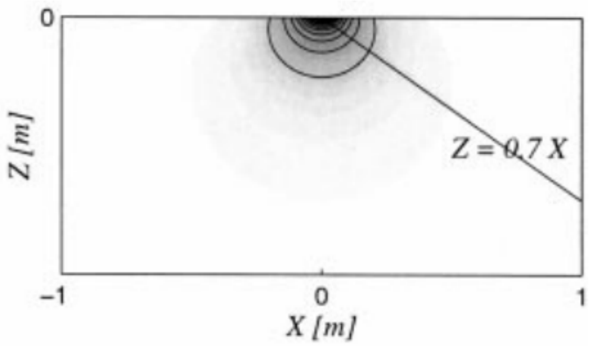
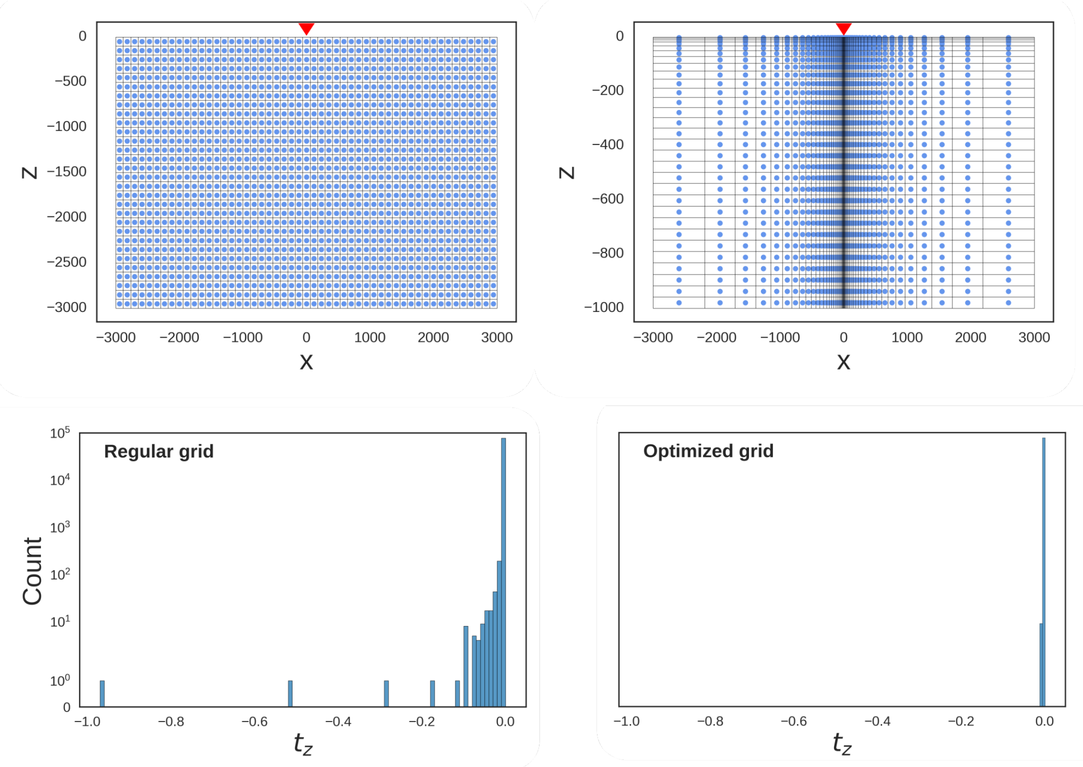



Fig. 2: Normalized sensitivity coefficients (Boulanger, O., & Chouteau, M. ,2001)



# Examples

## Greenstone belt, Western Australia

- Archaean greenstone belt in the Youanmi Terrane of the Yilgarn Craton in Western Australia
- Interest for mineral exploration
- 69 surfaces points and 40 orientation points

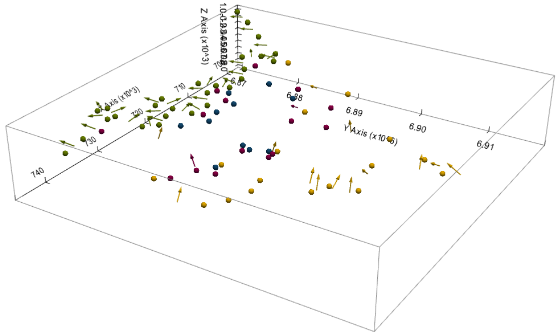


Fig. 3: Input data

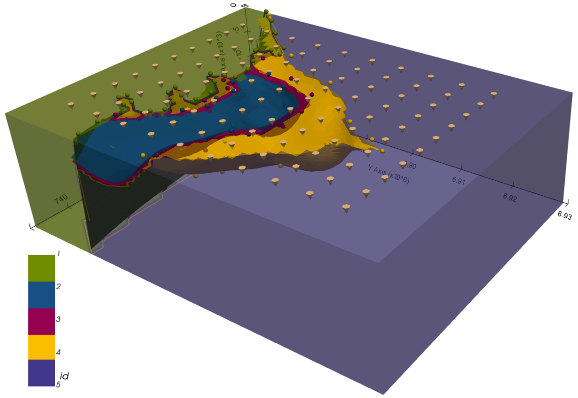



Fig. 4: 3D GemPy Greenstone model

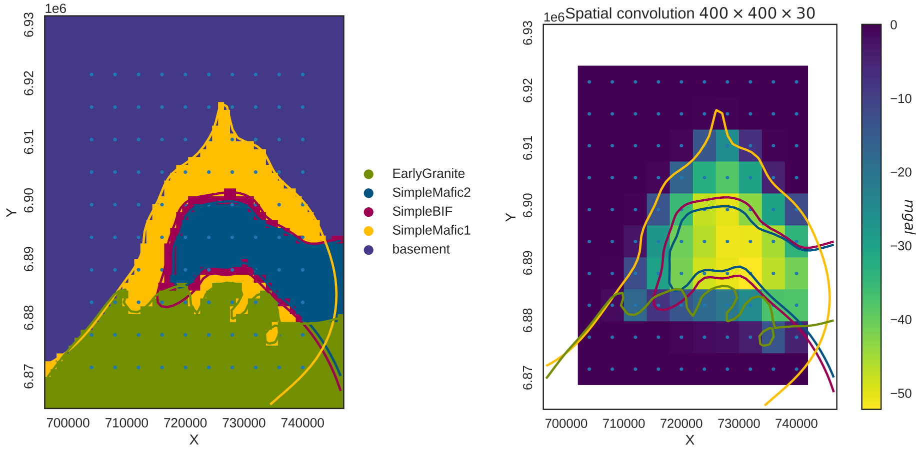



Fig. 5: Lithologies at the surface and gravity forward simulation

# Examples

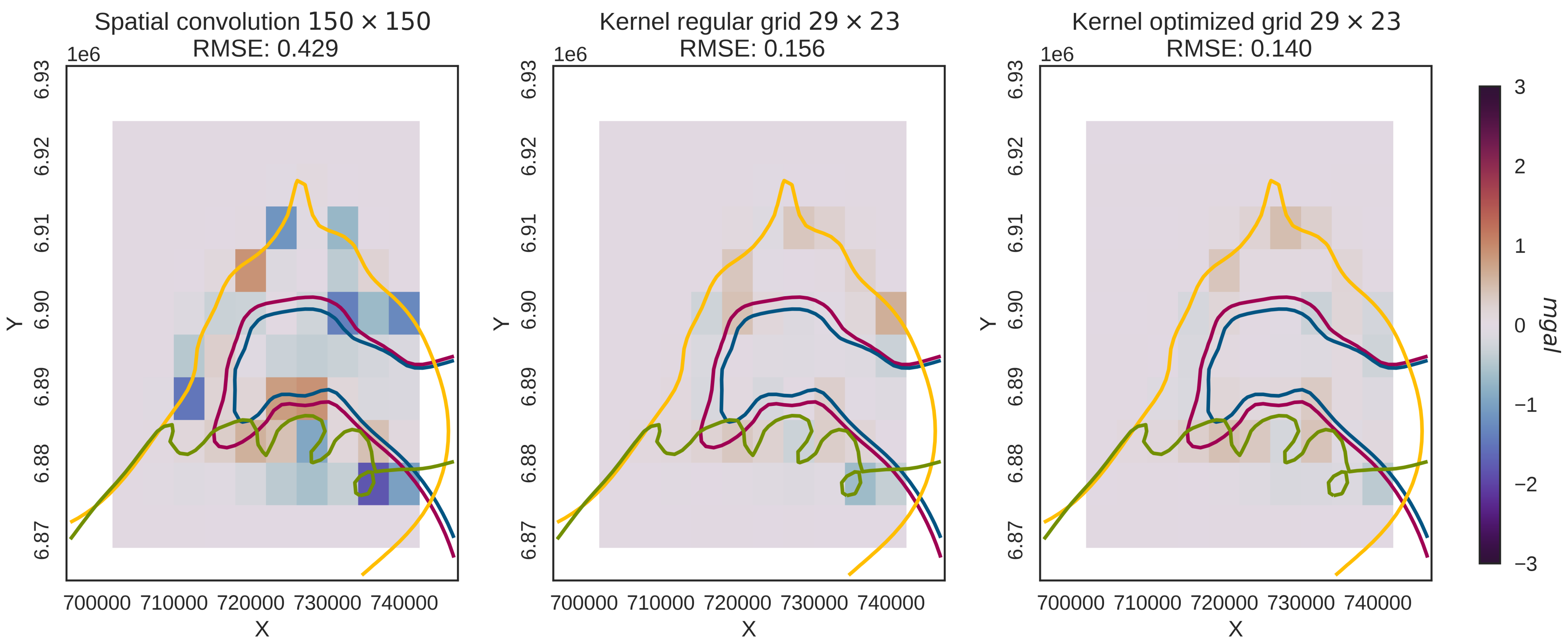


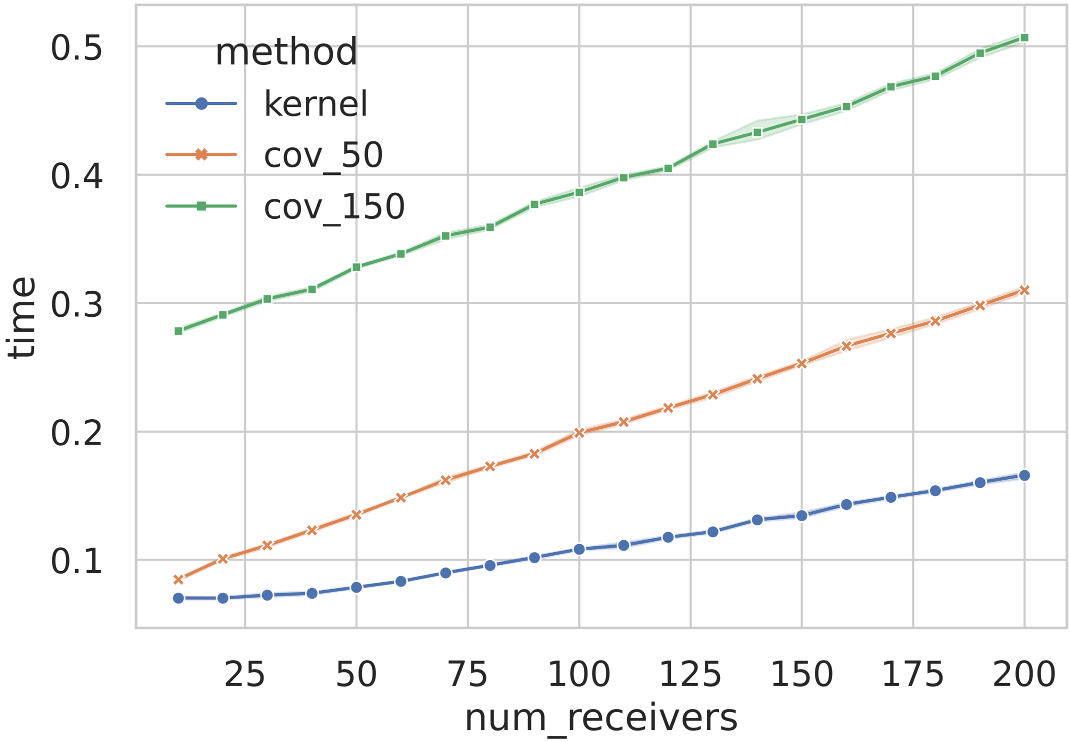

Fig. 6: Gravity forward simulation using spatial convolution scheme and kernel method on centered regular grid and optimized grid

# Conclusion

- Kernel method
  - Individual grid for receivers
  - Less error than the spatial convolution scheme
  - Time complexity of $\mathcal{O}(1)$ compared to spatial convolution scheme $\mathcal{O}(n)$ (although memory overhead still exists)
- Optimized grid
  - Average risk of aliasing due to low resolution
  - Optimization only need to be run once for a given grid setup

Future work

- Memory scalability with the number of data
- Inversion



# Acknowledgment

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**Deutsche Forschungsgemeinschaft (DFG)**
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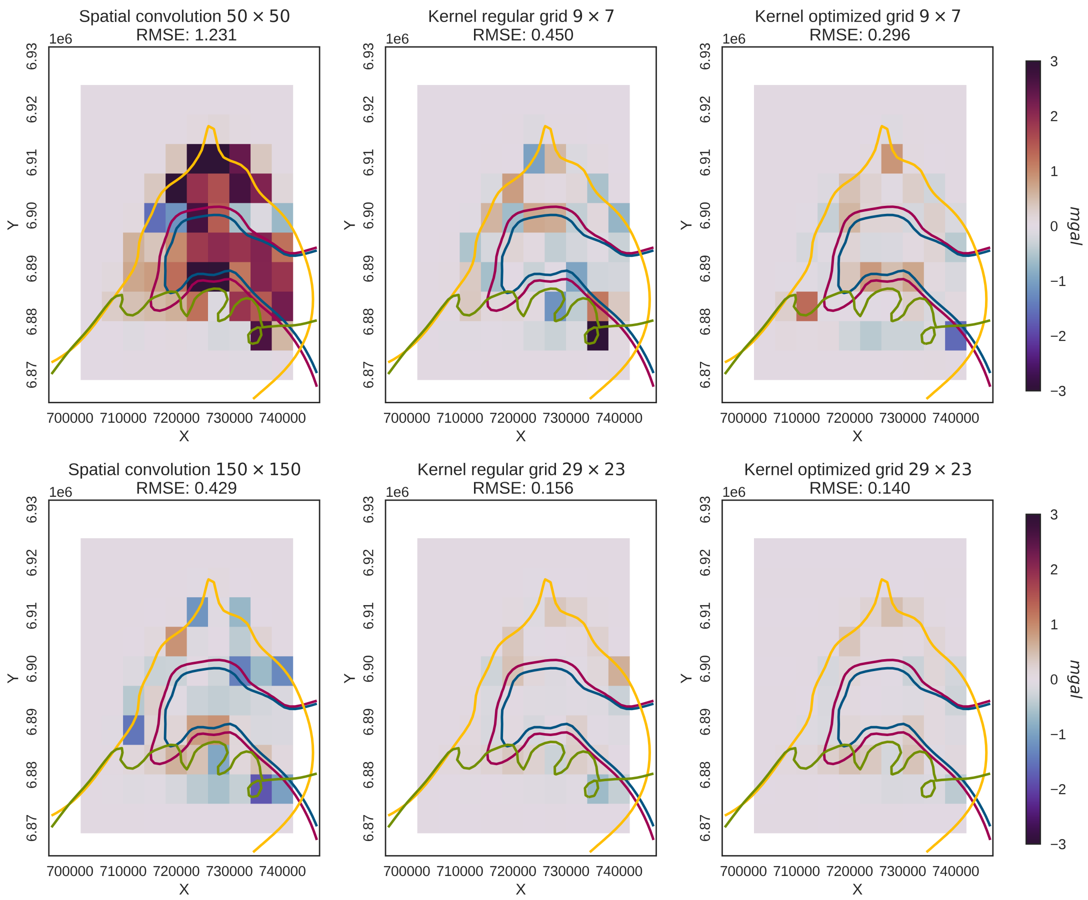
gratefully acknowledged

# Thank you for your attention

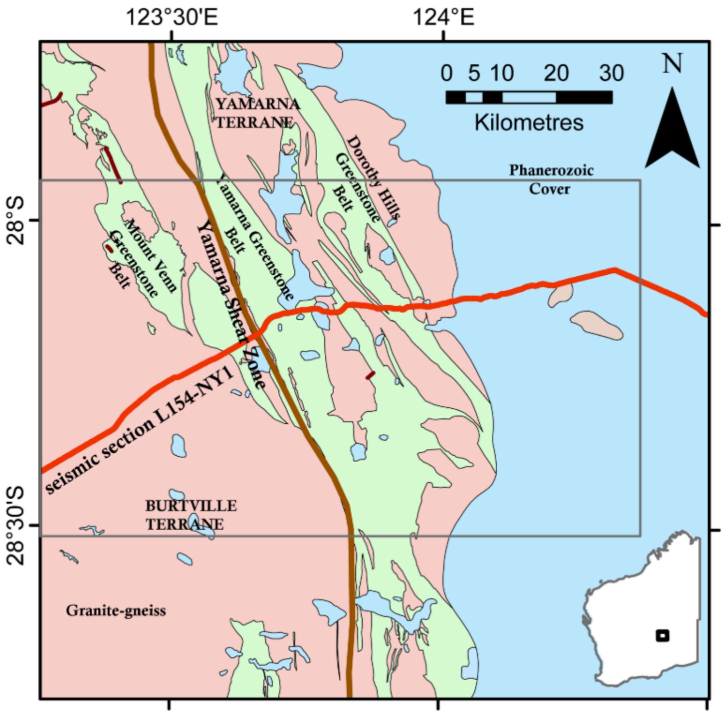



## Any questions?

# Additional Material

## Yamarna Terrane, Western Australia

Geographical Map




Gravity anomaly

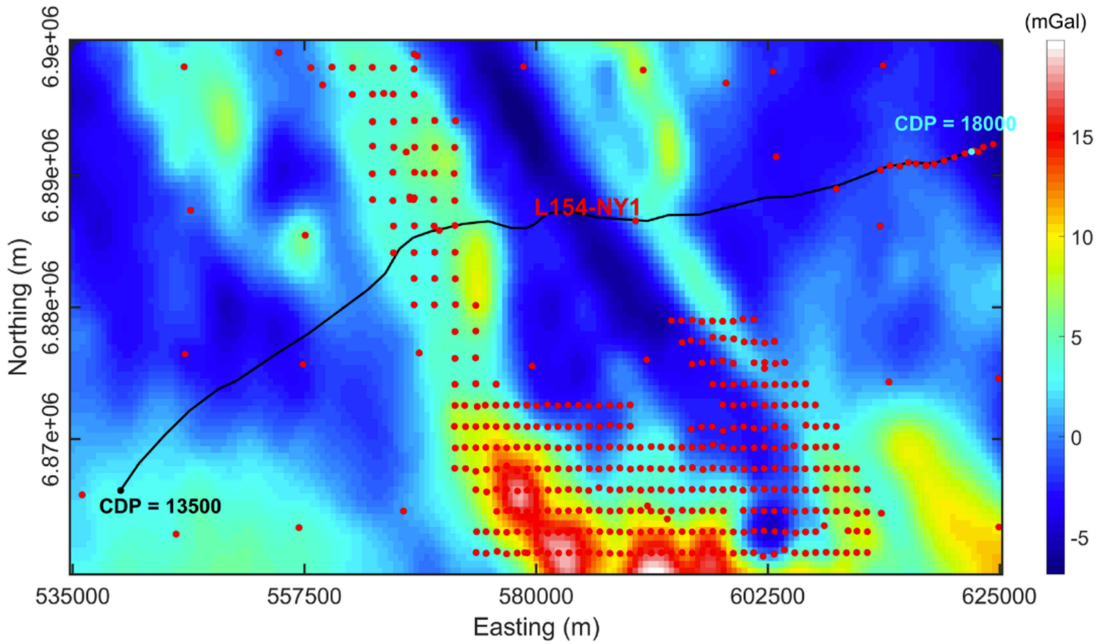



Fig. 8: Rashidifard et. al. (2021)

## Synthetic spherical geobody

$$Z = \left(x^2 + y^2 + z^2\right), \rho(Z) = \begin{cases} \rho_1, & Z < Z_0 \\ \rho_2, & Z > Z_0 \end{cases}$$

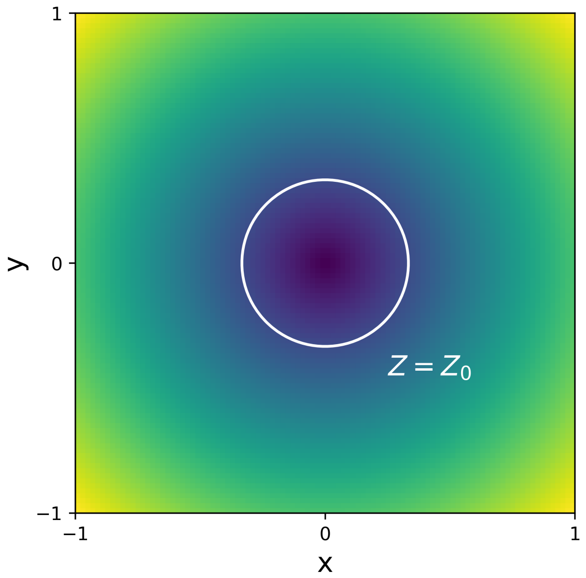



Fig. 9: 2D scalar field of a spherical geobody

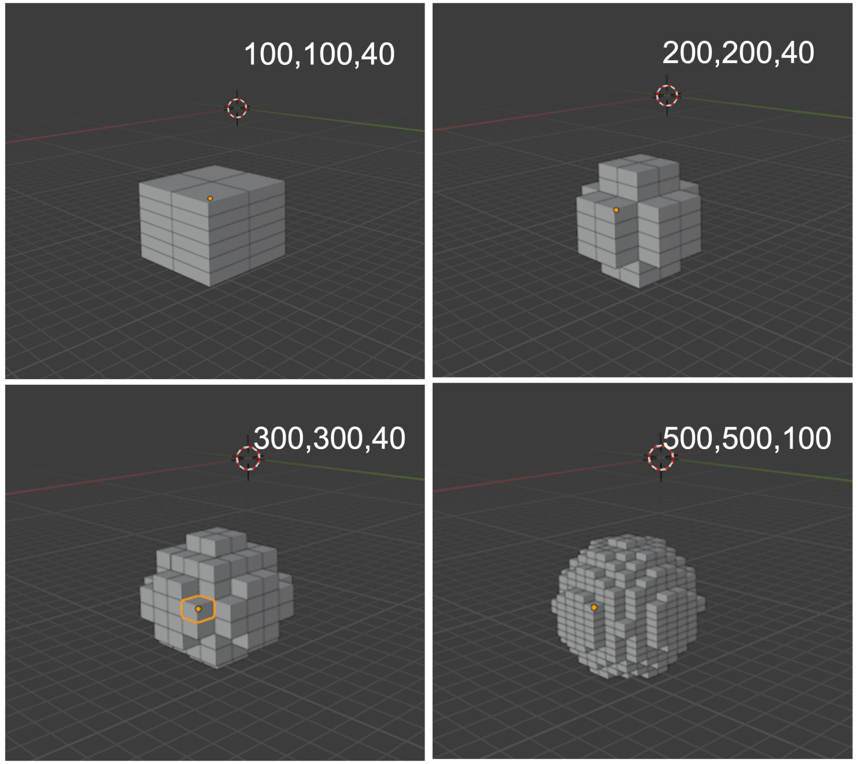



Fig. 10: 3D grid representation of sphere

## Synthetic spherical geobody

sphere position: x = 5000, z = 870; radius = 100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# Additional Material

## Synthetic spherical geobody

sphere position: x = 4100, z = 110; radius = 100