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The role of a laterally varying density contrast for gravity inversion of the Moho depth

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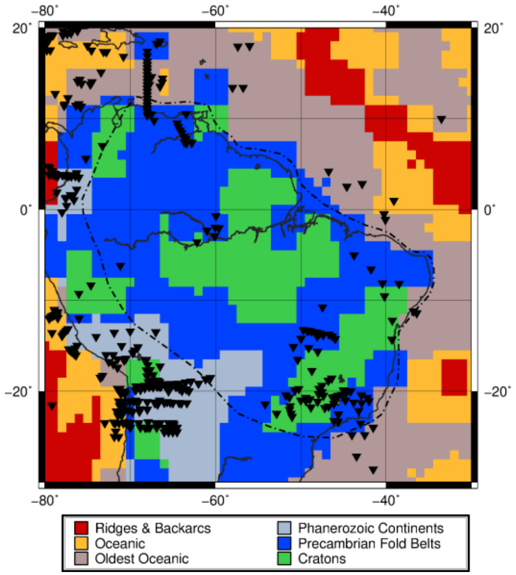
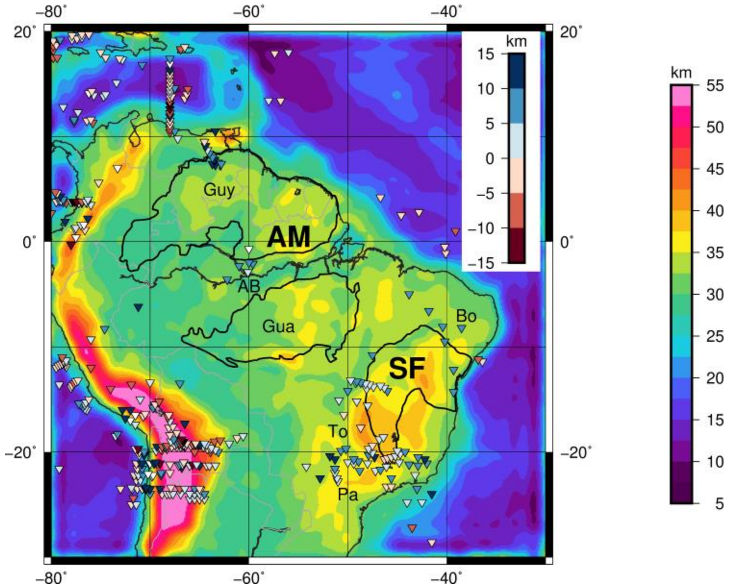
SM7.1 – Advances in Modelling,
Inversion and Interpretation of Geophysical Data





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Inversion Setup

$$\Delta g = A \Delta z$$

$$\Delta z = \left[A^T A\right]^{-1} A^T \Delta g$$

Inverse problem is solved with Gauss-Newton algorithm

Technical Advancement

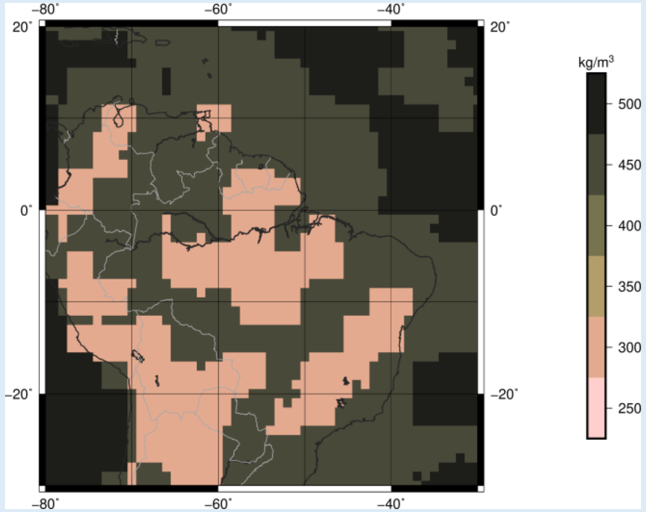
$$A_n = A_{n-1} \frac{\Delta\rho_n}{\Delta\rho_{n-1}}$$

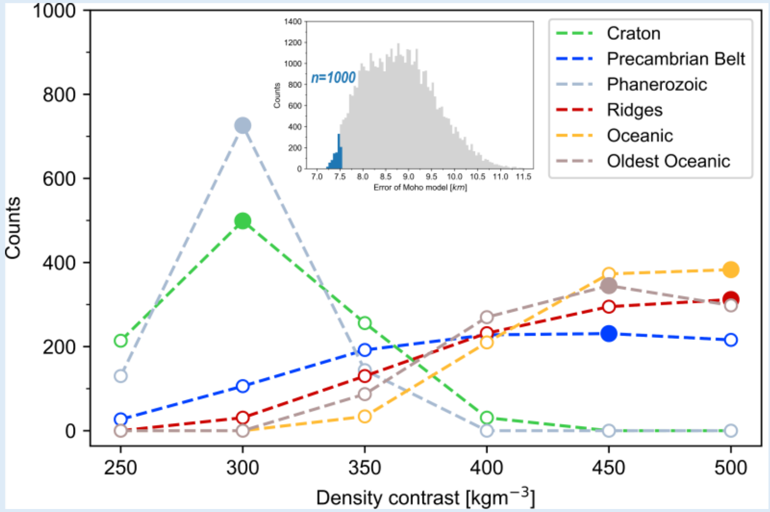
1. Calculate Jacobian Matrix only ONCE
2. Re-weight matrix with laterally variable density contrasts *Δρ*

→ Saves a lot of computational time

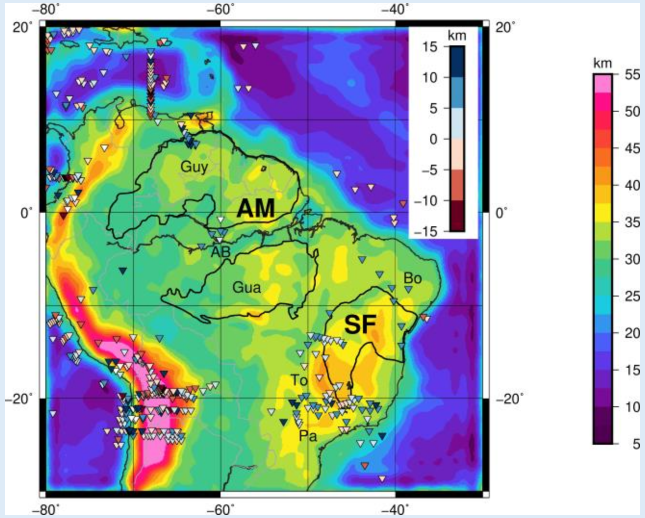
Results

Inverted density contrasts





Inverted Moho depth



Density contrasts and Moho depth show different lithospheric architecture

Getting interested?

Check out our publication in GJI:
https://doi.org/10.1093/gji/ggaa122

Calculate Moho depth for your study area!
https://github.com/peterH105/Gradient_Inversion

Haas et al. – The role of laterally varying density contrast for gravity inversion

2min pitch

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Introduction

- We developed a new inverse scheme to invert for the Moho depth that works with any gravitational component
- We use two independent datasets of active seismics and seismic tomography to constrain the inversion
- This allows to simultaneously invert for a laterally variable density contrast at the Moho depth
- The Amazonian Craton and its surroundings is a well-suited study area to test the inversion, as it is poorly covered by seismic measurements

Inverse theory (a few equations are necessary)

In the following inverse formulation, Δg is the difference between observed and predicted gravity gradient data:

$$\Delta g = g - F(z_0) \quad (1)$$

Then the inverse problem can be defined as:

$$\Delta g = A \Delta z \quad (2)$$

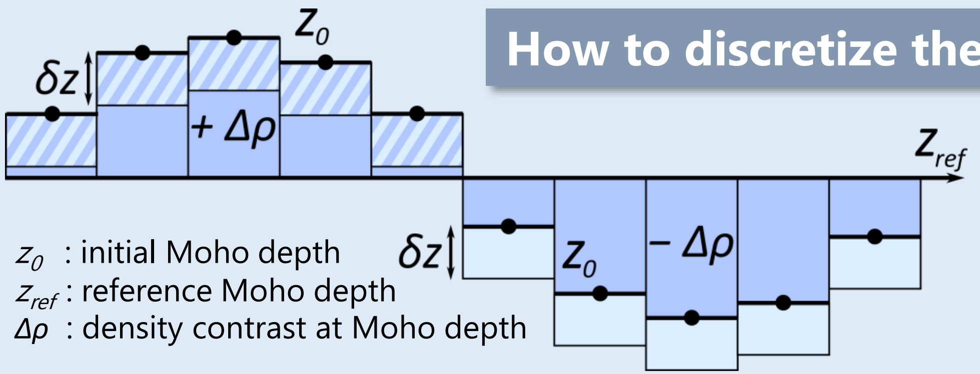
The inverse problem is solved with the Gauss-Newton algorithm accounting for 2nd order Tikhonov regularization:

$$\Delta z = \left[A^T A + \beta D^T D\right]^{-1} A^T \Delta g - \beta D^T D z_i \quad (3)$$

The undulation of the Moho depth Δz is added to an initial Moho depth z_0:

$$z_1 = z_0 + \Delta z \quad (4)$$

How to discretize the model



Now the gravitational effect *F(z₀)* of the initial Moho model can be calculated!

The Jacobian is designed as gravitational effect of each station (row) for each mass element (column) in the study area:

$$A = \begin{bmatrix} \Delta\mathcal{F}^{(1,1,1)} & \dots & \Delta\mathcal{F}^{(1,1,K)} \\ \vdots & \ddots & \vdots \\ \Delta\mathcal{F}^{(I,J,1)} & \dots & \Delta\mathcal{F}^{(I,J,K)} \end{bmatrix} \quad (5)$$

We calculate the Jacobian only once. Afterwards the matrix is re-weighted using a laterally variable density contrast Δρ:

$$A_n = A_{n-1} \frac{\Delta\rho_n}{\Delta\rho_{n-1}} \quad (6)$$

Now the computational cost is not the multiple calculation of the Jacobian, but solving the equation system in Eq. 3!

Preparing the inversion

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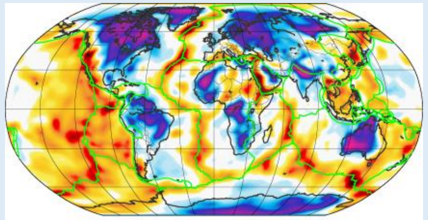
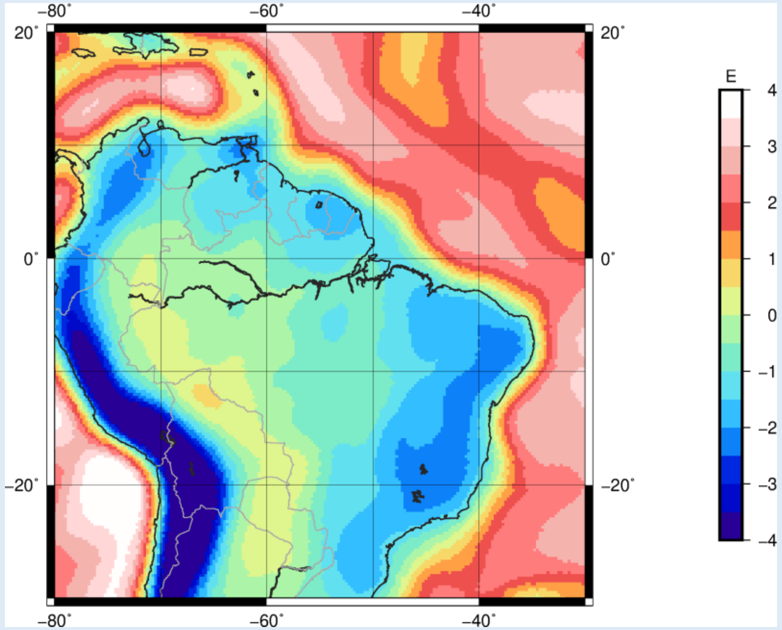
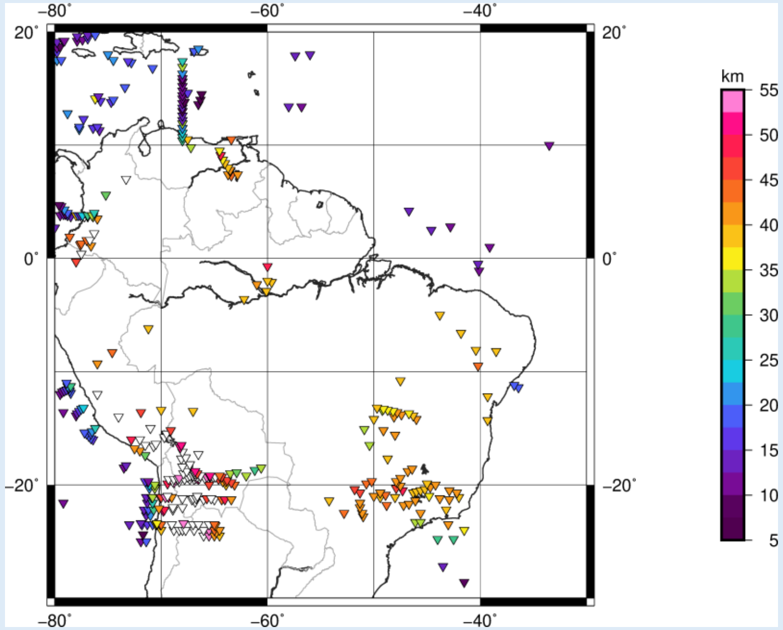


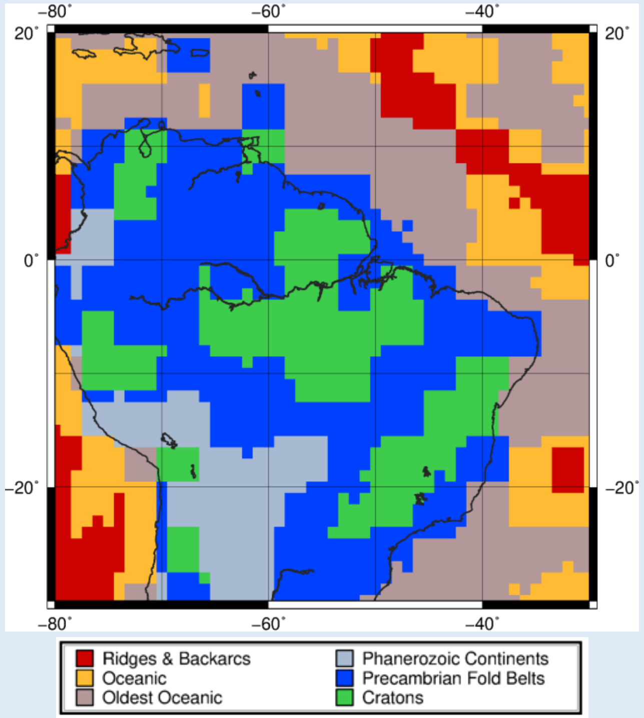
Seismological regionalization of SL2013sv (Schaeffer & Lebedev, 2016), doi:10.1007/978-3-319-15627-9_1



Vertical gravity gradient of GOCE (Bouman et al. 2016)

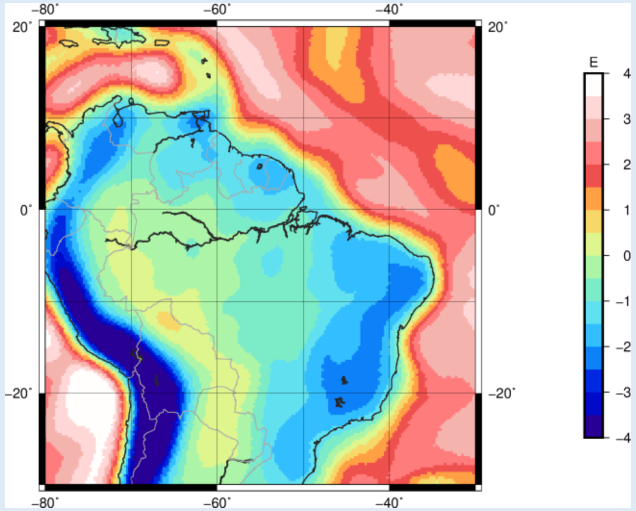


Seismic Moho depth of USGS seismic catalogue (Chulick et al. 2013)

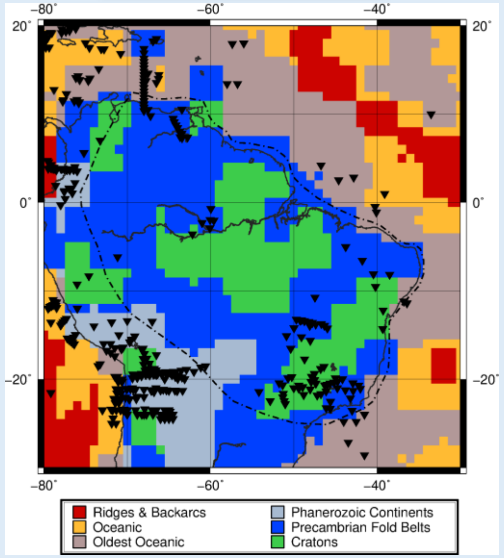


Data

Constraints



Initial Data



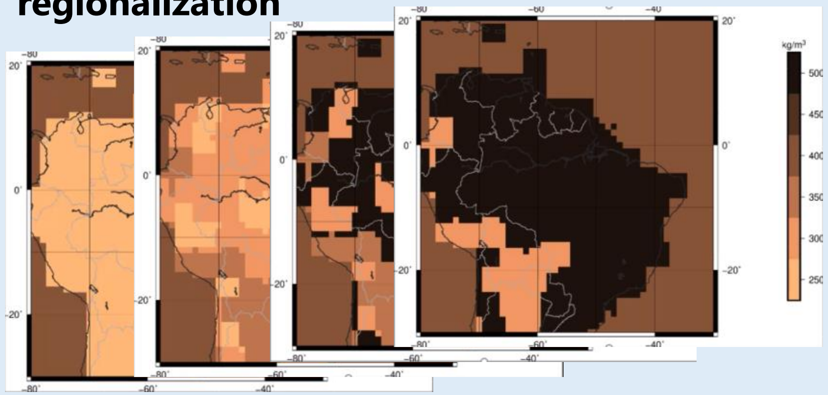
Inversion procedure

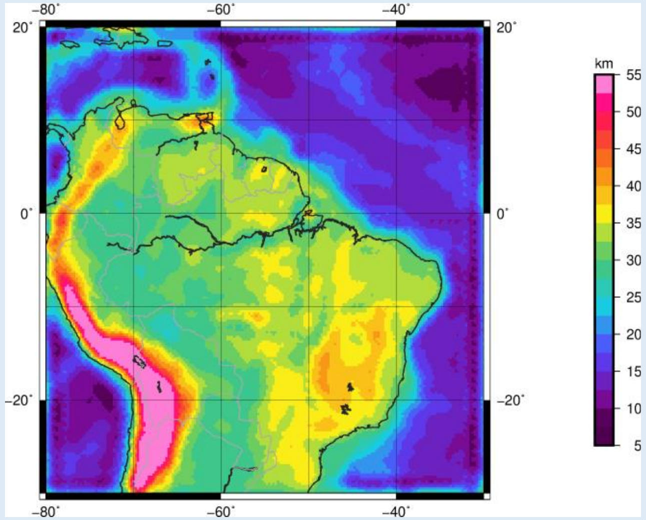
Two important technical remarks:

1. Sensitivity tests have shown that g_{zz} is most suitable for inversion of satellite gravity data (see paper of Haas et al. 2020)
2. We chose z_{ref}=30 km based on global average value of extended crust (Christensen and Mooney 1995)

Inversion

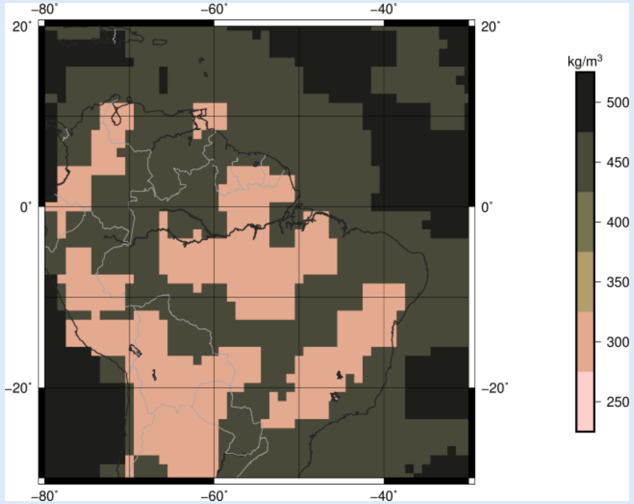
Loop over all possible combinations of density contrasts, geometry comes from regionalization





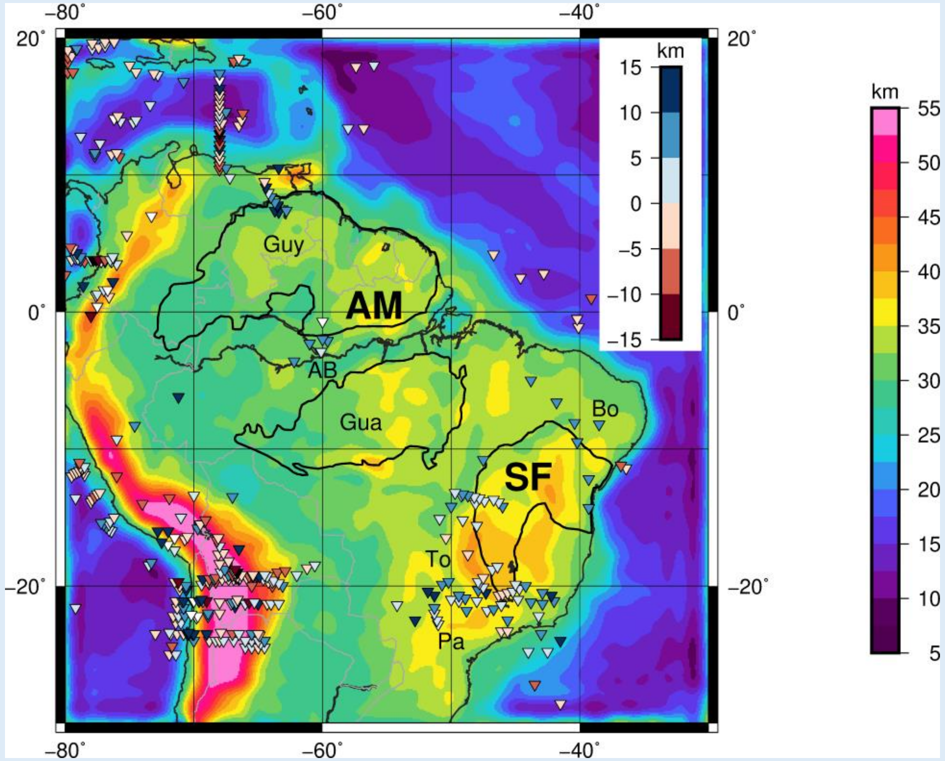
Best fitting Moho depth

Results



Best fitting density contrast

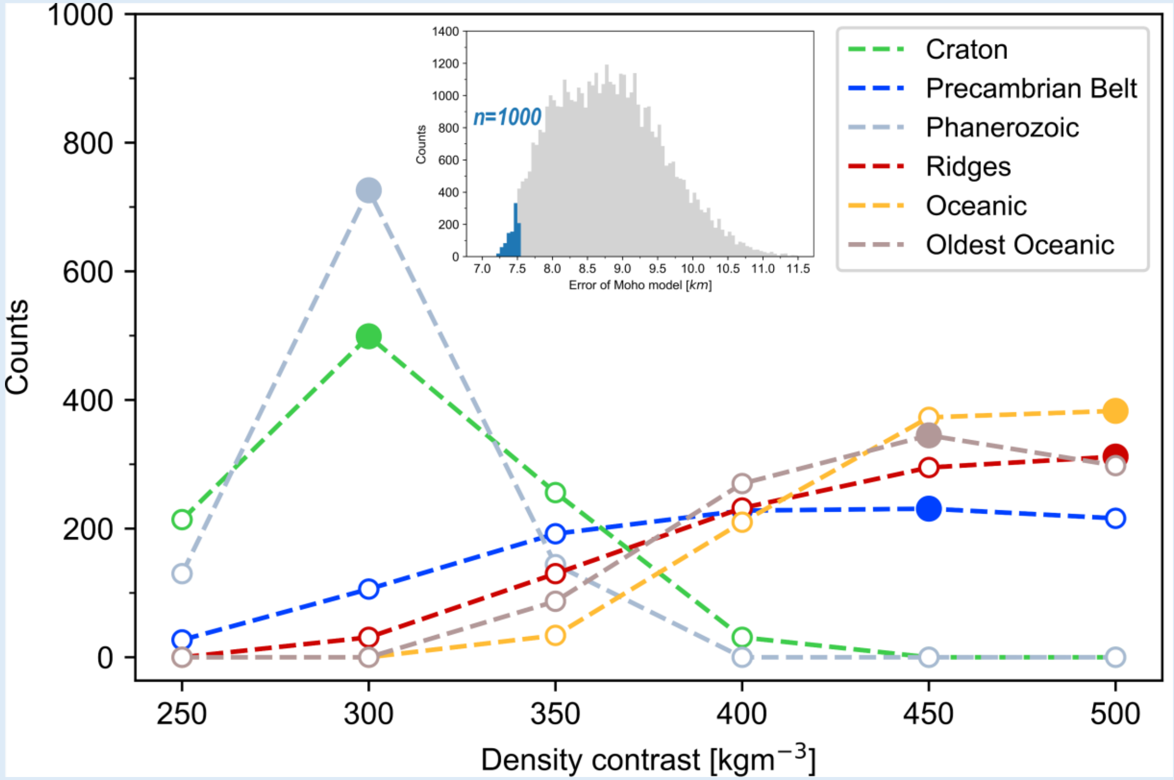
Inverted Moho depth



AM=Amazonia, SF=Sao Francisco, Guy=Guyana Shield, Gua=Guapore Shield, AB=Amazonian Basin, Bo=Borborema Province, To=Tocantins Province, Pa=Parnaiba Basin

- Moho model that fits best the seismic constraints (RMS=7.2 km)
- Amazonian Craton has shallower Moho depth than Sao Francisco Craton

Inverted density contrasts



Distribution of the 1000 best-fitting density models

- Cratons and Phanerozoic Continents with highest sensitvity
- Continental domains prefer lower density contrast than oceanic domains

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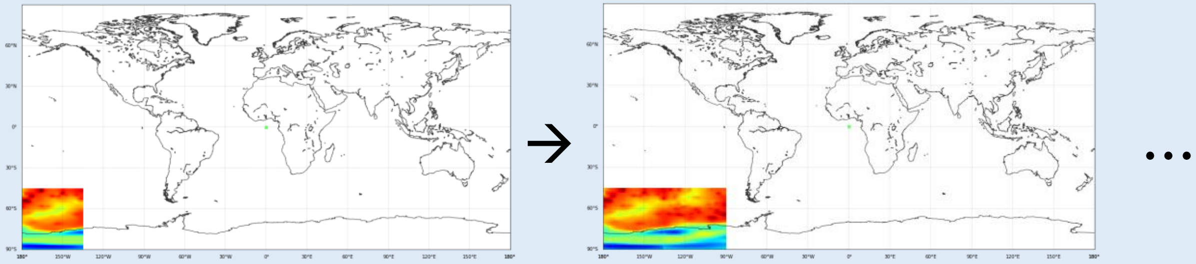
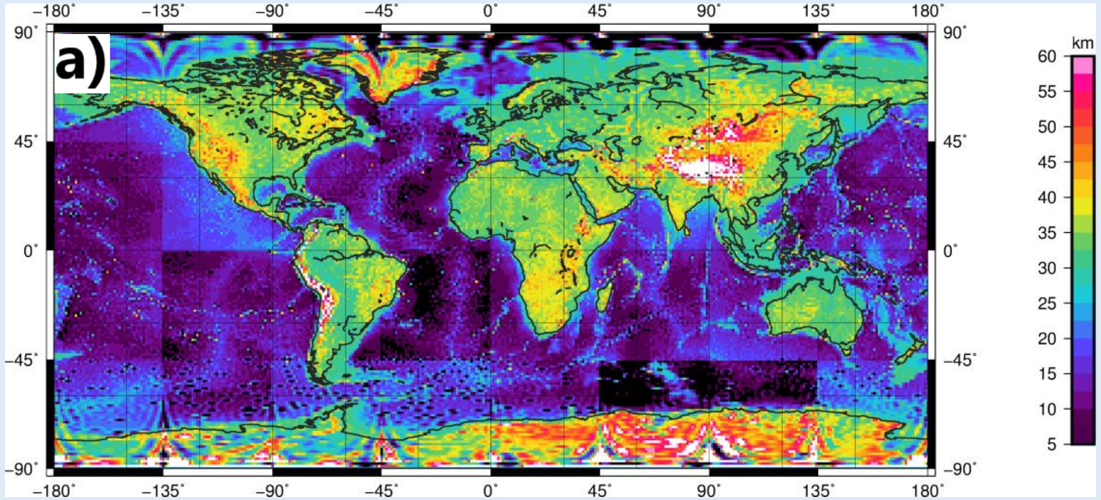
Outlook: Inversion on a global scale

- Using a moving window approach to invert gravity data around the globe
- First calculate Bouguer anomaly, afterwards invert for Moho depth for each window

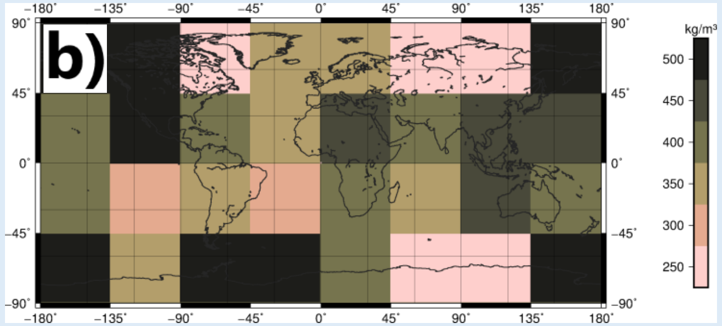


Bouguer anomaly for each window

- Saves a lot of computational time, as size of Jacobian is limited to window size
- Inverted density contrast is kept laterally constant and shows various fit (see figure on the right side)
- Next steps:
  - Expand with laterally variable density contrast
  - Identify regional trends of different tectonic domains
  - Estimate an updated value for reference Moho depth



Window size: 45°, Bouguer anomaly is calculated with 5° overlap for each window to avoid edge effects. However, the equiangular grid leads to edge effects at the polar regions.



a) **Inverted Moho depth** shows expected features, steep gradients occur at boundaries of density contrast

b) **Inverted density contrasts** show a variablity of different values, huge differences at the poles

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Summary

- Gravity inversion is linked with constraints of active source seismics and seismic tomography
- New inversion technique allows laterally variable density contrast by calculating the Jacobian matrix only once
- Inversion applied to South American Cratons show lower density contrasts for cratonic lithosphere
- Inversion can be applied in user-defined study area or even on global scale

Check out our recent publication in GJI:
https://doi.org/10.1093/gji/ggaa122

Geophysical Journal International

Geophys. J. Int. (2020) **221**, 1896–1912 doi: 10.1093/gji/ggaa122
Advance Access publication 2020 March 17
GJI Gravity, Geodesy and Tides

Sensitivity analysis of gravity gradient inversion of the Moho depth—a case example for the Amazonian Craton

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Contains also synthetic examples of important technical details of gravity inversion!

Calculate Moho depth for your own study area:
https://github.com/peterH105/Gradient_Inversion

Contains also a Binder-file to interactively run the inversion online!

Want to get in contact?

Write me an e-mail: peter.haas@ifg.uni-kiel.de

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