Depth sensitivity of satellite gravity gradients inferred from a density model of North America

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Introduction

Surface topography can be compensated isostatically (by the lithosphere) or by dynamic topography (viscous flow below the lithosphere). In both cases compensation is ultimately caused by density anomalies. Thus, information about the deep density structure of the earth is crucial.

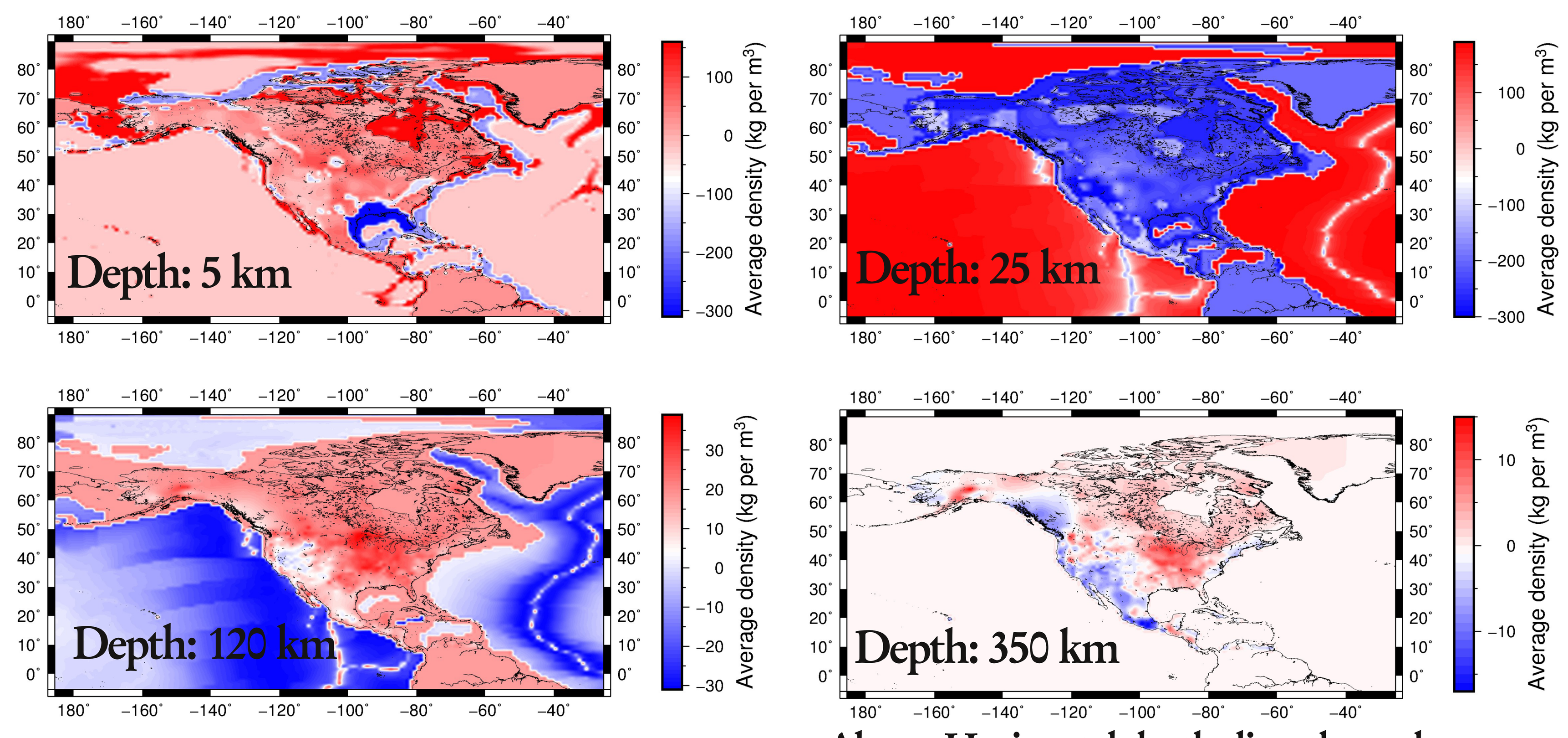
Using a model of lithospheric density, observed gravity can be stripped of the lithospheric contribution. However, the residual gravity field after stripping reflects not only sub-lithospheric sources, but also any errors in the model. Since both errors and sub-lithospheric sources can have long wavelengths, they can not be separated by filtering.

We investigate if the components of satellite gravity gradients differ with respect to their depth sensitivity. This would open up a new way of separating sources from different depths.

Density model

We constructed a density model of the North American continent and surrounding oceans (see tables)

Model property	Value
Horizontal resolution	1 ° (about 110 km)
Vertical resolution	5 km
Max depth	600 km



Above: Horizontal depth slices through the density model at four different depths

Below: Table of data used to construct the density model

Data	Source	Conversion to density
Crustal model NACr14	Tesauro et al. 2014	$\rho = a(z)\, v_p(z) + b(z)$ (Zoback and Mooney 2003)
Sediments	Kaban (pers. comm.)	$\rho(z)$ from in-situ measurements
Ocean floor age	Müller et al. 2008	$\rho(z) = (1 - \alpha\, T(z))\rho_0$. T from plate-cooling model
P-wave tomography	Burdick et al. 2014	$\delta\rho_{rel} = 0.4\, \delta v_{rel}$. Use reference model ak135 (Kennett et al. 1995): $\rho = (1+\delta\rho_{rel})\, \rho_{ak135}(z)$

Forward calculation

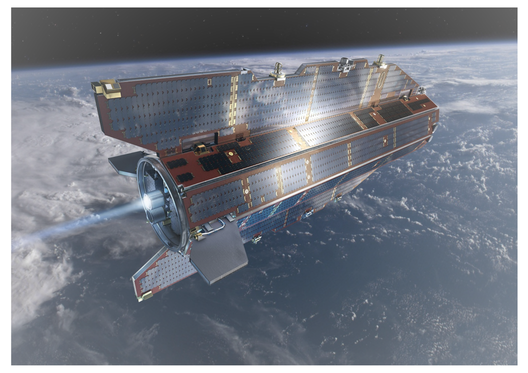
We calculated the gravity response of the density model

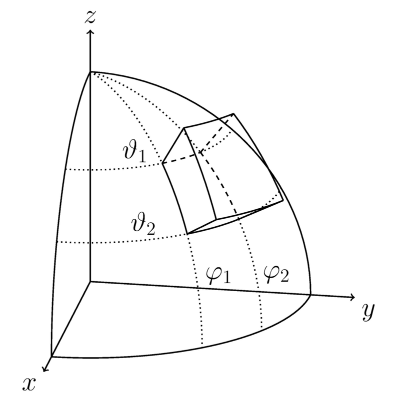
- on a 1°x1° degree grid
- at a height of 225 km (GOCE satellite).

The model geometry is represented using **tesseroids.**

Gravity effect of each tesseroid is calculated using adaptive numerical integration.

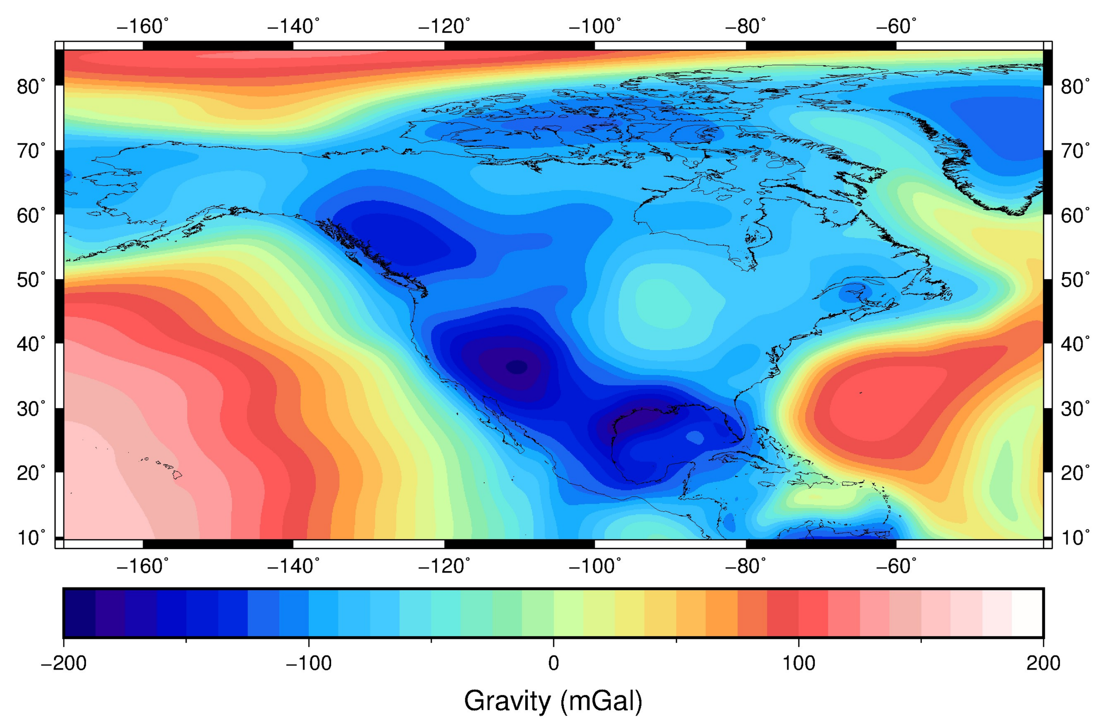
Below: The Goce Satellite (ESA)





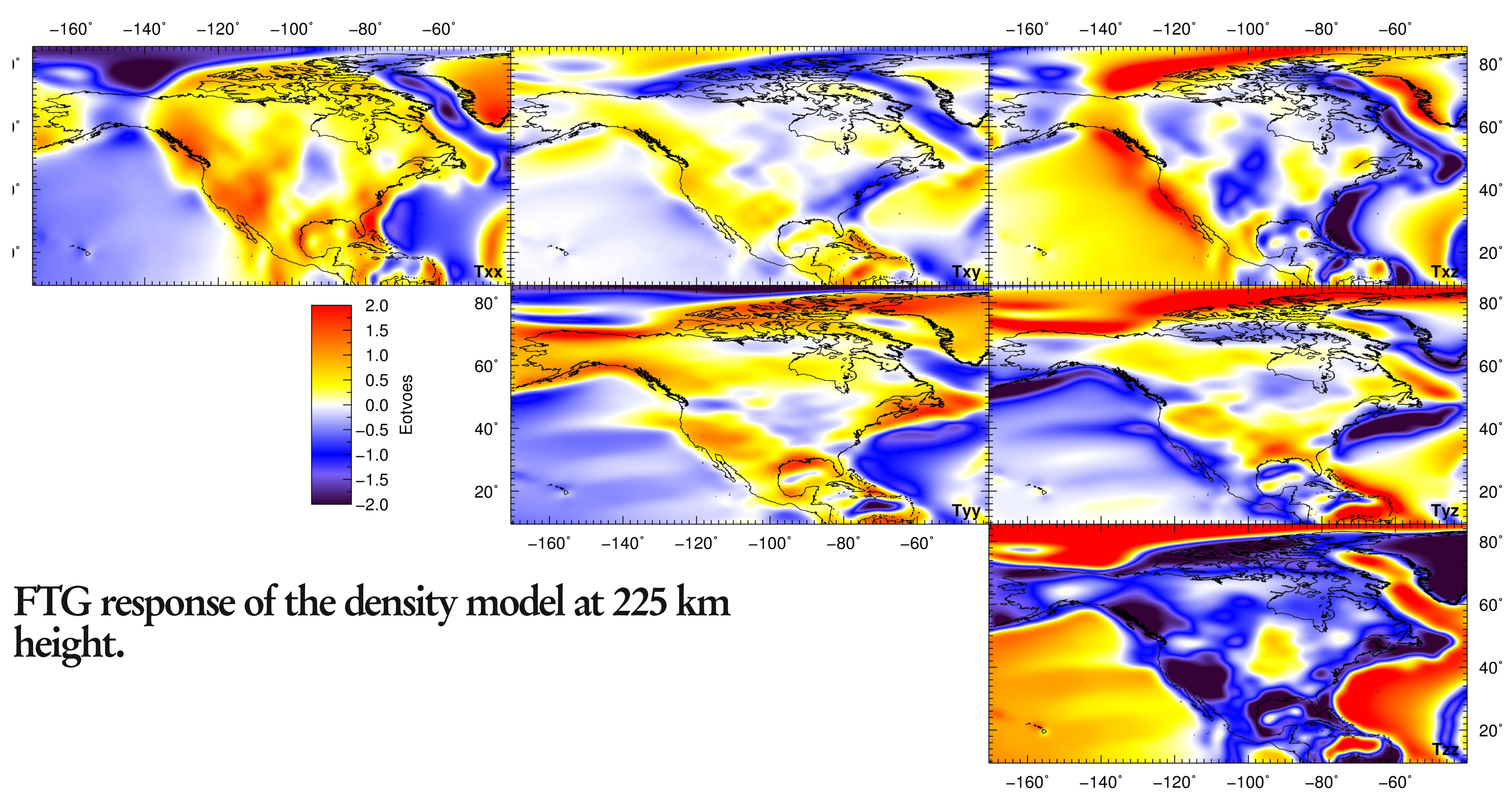
Above: Tesseroids arise naturally, when a model is given as a regular grid in geographic coordinates.

Right: Gravity response of the density model at 225 km height.



FTG calculation

The full gravity gradient tensor was calculated. We use an East-North-Up (ENU) coordinate system.



FTG response of the density model at 225 km height.

References

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S. Burdick, R. D. van der Hilst, F. L. Vernon, V. Martynov, T. Cox, J. Eakins, G. H. Karasu, J. Tylell, L. Astiz, G. L. Pavlis (2014) Model Update January 2013: Upper Mantle Heterogeneity beneath North America from Travel-Time Tomography with Global and USArray Transportable Array Data, Seismological Research Letters, January/February 2014,
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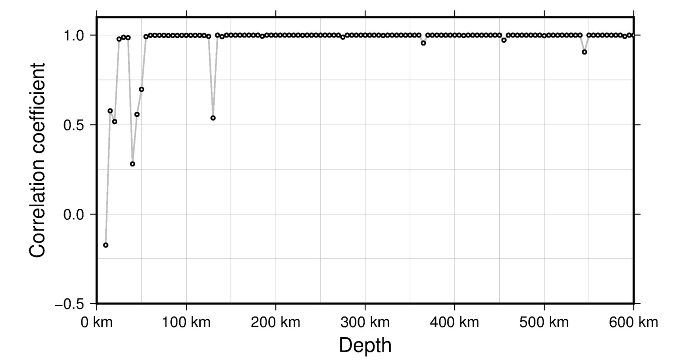
Sensitivity estimation

Idea

- Use density model to determine how much signal comes from each depth
- Compare the different amounts of signal for the different gravity (gradient) components

Merging

- Successive depth layers with similar gravity effect should be merged into one for sensitivity estimation.
- The correlation coefficient can be used to assess the coherency of successive layers.
- Layers with correlation > 0.99 will be merged into one layer



Above: Correlation coefficient of vertical gravity effect of successive layers

Sensitivity calculation

For each gravity (gradient) component

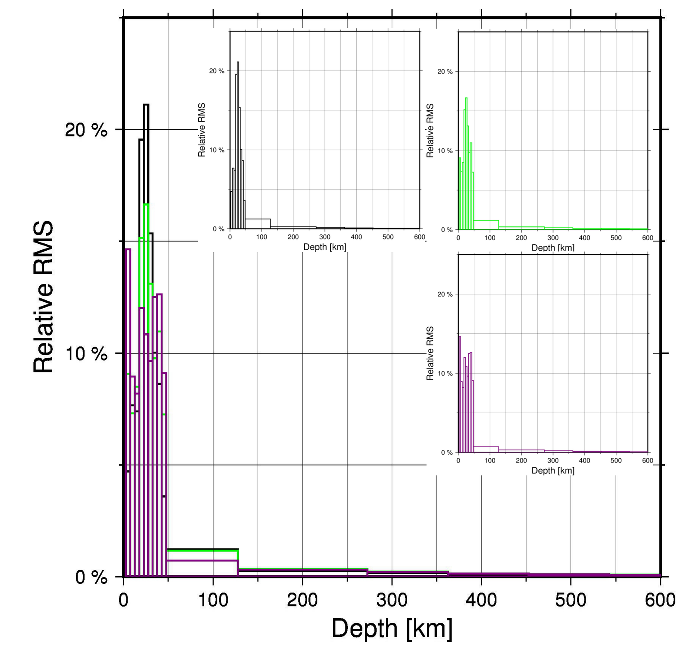
1.) calculate RMS of gravity from each depth layer k, P_k

2.) calculate total RMS **P**

3.) divide P_k by **P**, to get ***relative RMS amplitude***

Results for selected components

- > 95 % of the signal comes from depths of less than 50 km
- Vertical gravity (black) and vertical gravity gradient (green) are very sensitive to crust-mantle boundary
- xy-gradient (pink) has increased sensitivity to structures within the crust



Above: Depth sensitivity of vertical gravity (black), vertical gravity gradient g_{zz} (green) and xy-gradient (pink)

Conclusions

Do satellite gravity gradients components differ with respect to their depth sensitivity?

» Yes: The purely horizontal gradient components are most sensitive to shallow structures. The vertical gravity gradient (gzz) behaves more like vertical gravity. Remaining gradient components fall somewhere between these end-members.

How strong is the gravity field predicted by mantle tomography?

» About 1% of total signal response comes from mantle density anomalies.

Next steps?

» Optimize density model with respect to gravity gradients
» Include petrology of upper mantle for velocity to density conversion