On the accuracy of gravity fields obtained with Newton integrals on a hollow sphere

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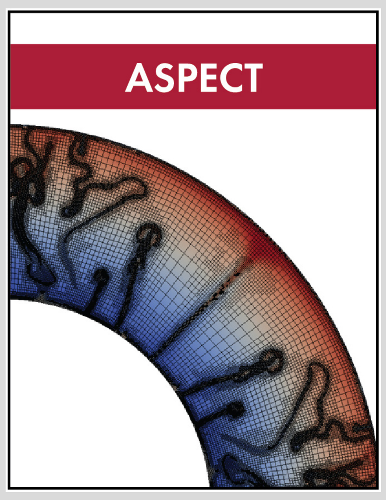
1 INTRODUCTION:

We aim to predict gravity fields as a constraint for geodynamical modelling. This requires using density models for the whole crust and mantle. Gravity is calculated using a direct integration method in the state-of-the-art finite element code ASPECT.

What this poster shows:

2. How we calculate gravity in ASPECT
3. Radial and Moho benchmarks to show that the gravity plugin works - ASPECT vs spherical harmonics
4. Gravity fields from CRUST1.0 and tomographic models (S40RTS, SL3013, LLNL_G3D_JPS) – test scaling factors
5. Perspectives – work in progress



https://aspect.geodynamics.org

2 GRAVITY FORMULATION:

We use Newton integrals to calculate gravitational acceleration (g_m). The post-processor receives as argument the coordinates x, y, z of a point and returns the gravity vector components g_x, g_y, g_z at this location by means of

$$g_m = \frac{GM}{r^2} \qquad g_m(r) = G \iiint_V \frac{\delta\rho(r')}{|r-r'|^3}(r-r')dr'$$

ASPECT is a FEM code, and volume integration is at the core of the FEM through Gauss Legendre Quadrature (GLQ):

$$g_m = G\sum_{e=1}^{N_{elements}}\sum_{i=1}^{N_{GLQ}}\sum_{j=1}^{N_{GLQ}}\sum_{k=1}^{N_{GLQ}}\frac{\rho(r_{ijk})}{|r-r_{ijk}|^3}(r-r_{ijk})|J_e|\omega_i\omega_j\omega_k$$

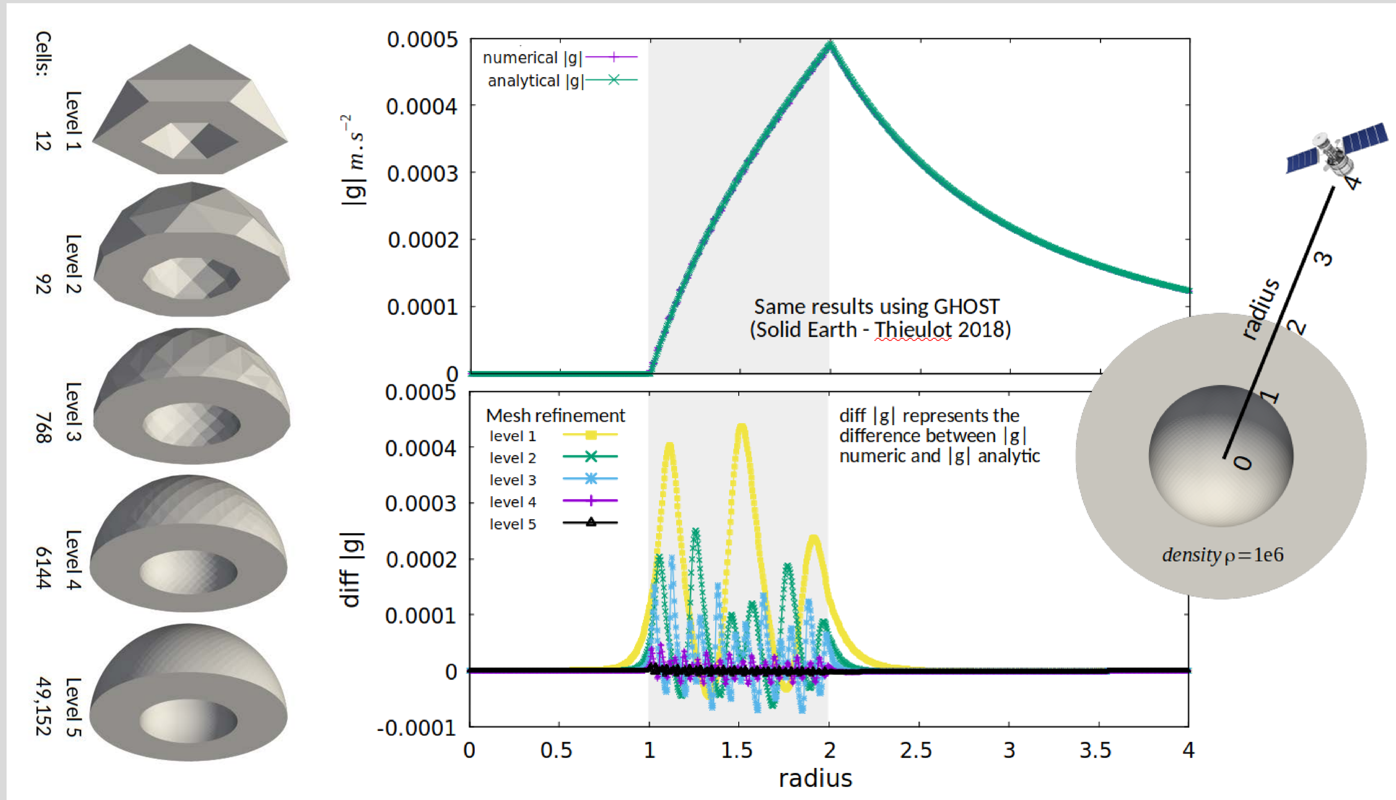
Gravity anomalies are obtained by subtracting the average of Earth's gravity to the gravity at the point.

3 BENCHMARKS:

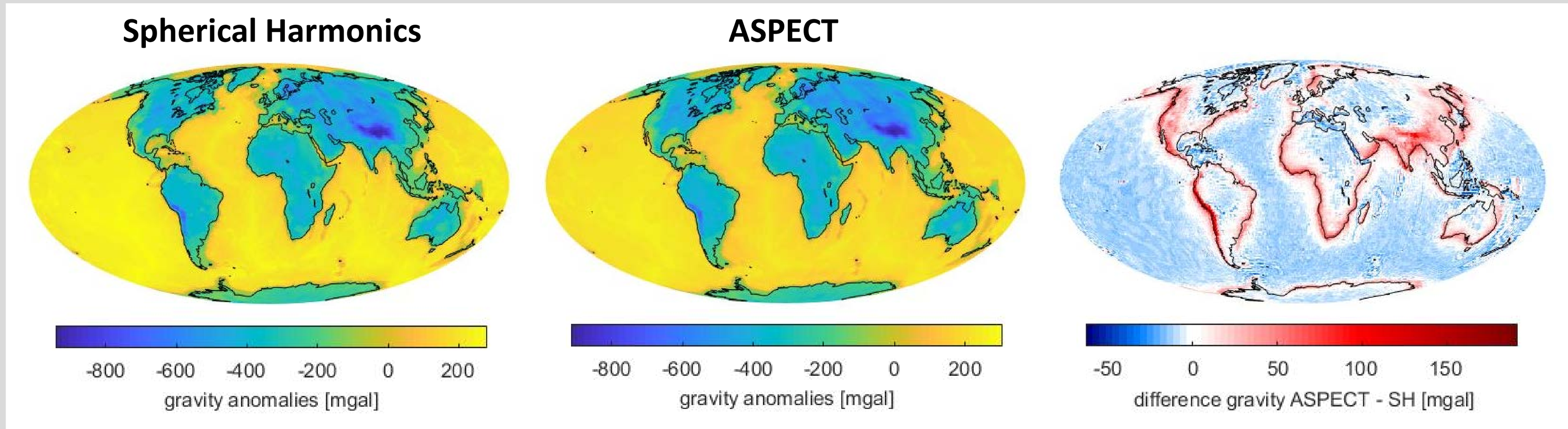
Radial gravity:

- Analytical solution exists for $\rho = \rho_0$ in a hollow sphere:
- Dimensionless hollow sphere $(1 < R < 2)$
- Radial gravity solution $|g|$
- Test different mesh resolution

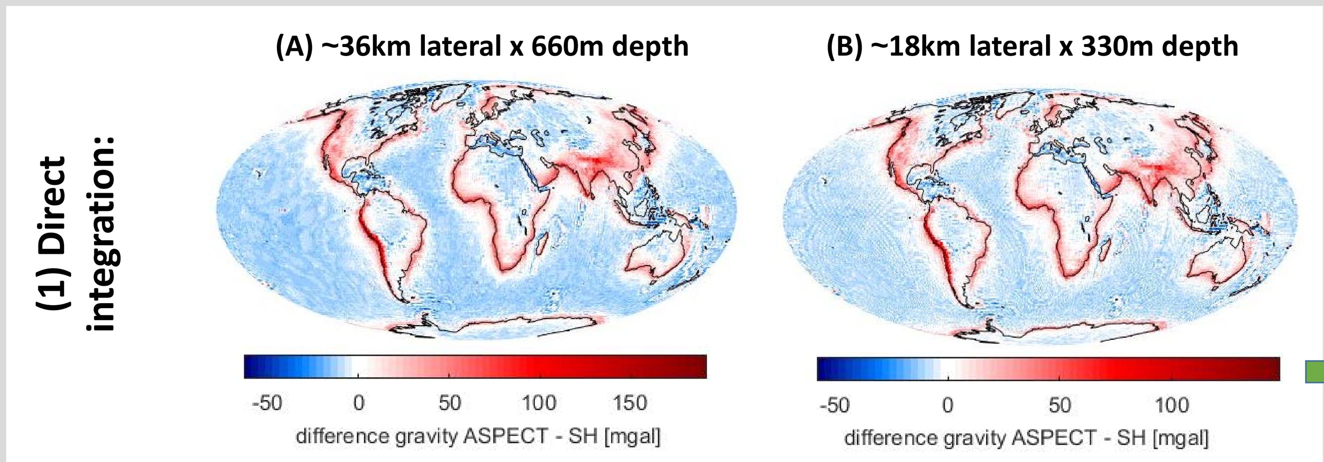
#1 Good fit between analytical and numerical solution.
#2 An increase of mesh resolution decreases numerical error.



MOHO benchmark (*Root et al., 2016*): Using the CRUST1.0 dataset (*Laske et al., 2013*), a density of 0 is set for the continental and oceanic crust, above a mantle of density 450 kg/m³.
We compare gravity prediction from the direct integration method in ASPECT with a spherical harmonic code.

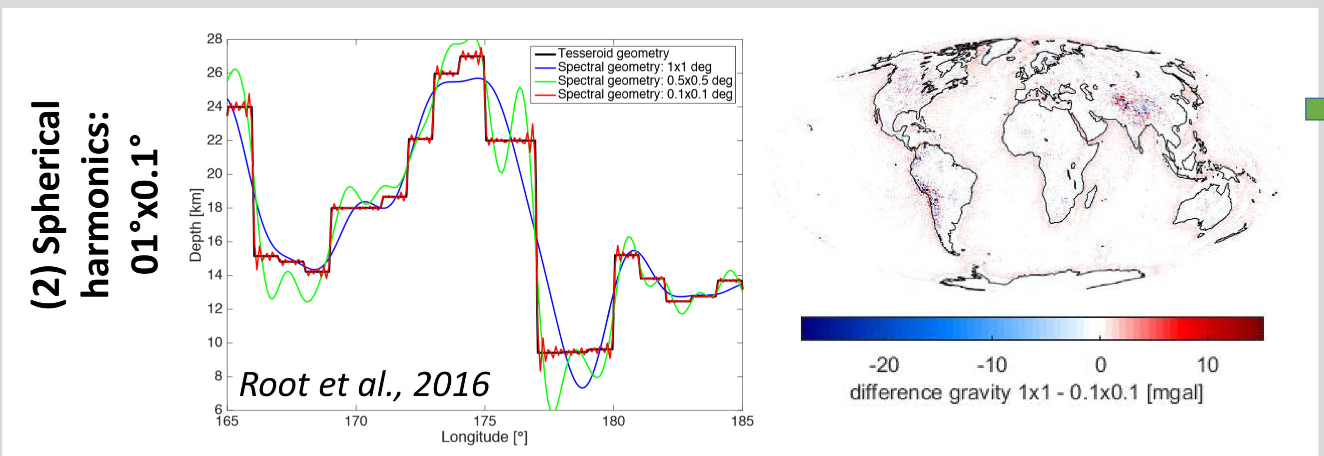


Both codes give similar results but gravity anomalies diverge at the ocean-continent transition (-60 to 160 mgal !)



Why gravity diverges?
→ Interpolation of the data into the mesh grid geometry for the direct integration **(1)** or the spherical harmonics **(2)**?

A higher ASPECT resolution slightly decreases the divergence, but still does not explain the high difference!



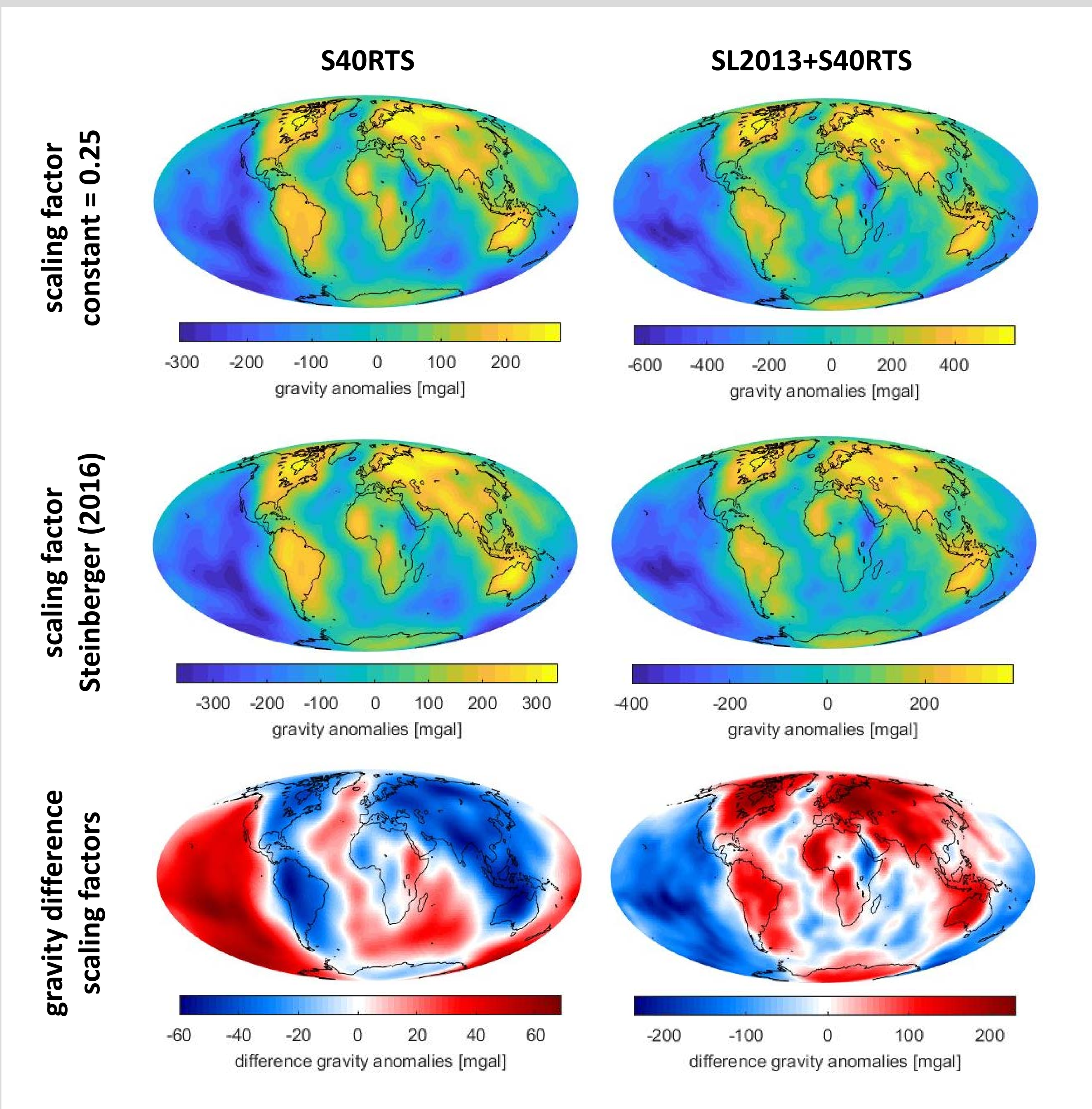
A higher spectral geometry for the SH slightly decreases the divergence, but still does not explain the high difference

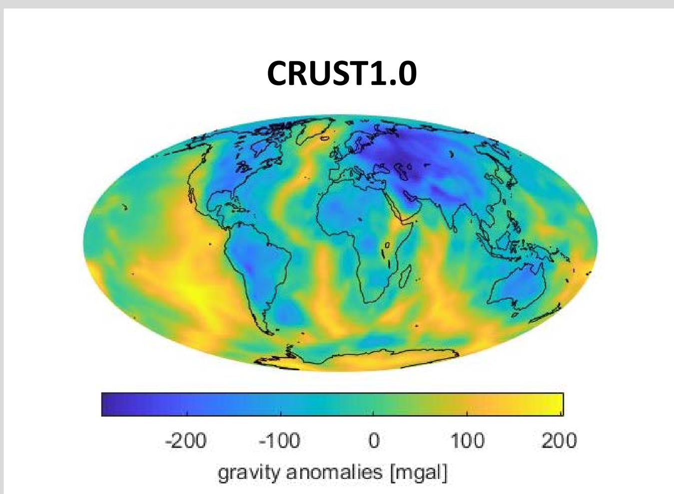
The problem resides in how ASPECT interpolates the data in the geometry – so that the densities are actually different between the two methods.

4 TOMOGRAPHIC MODELS:

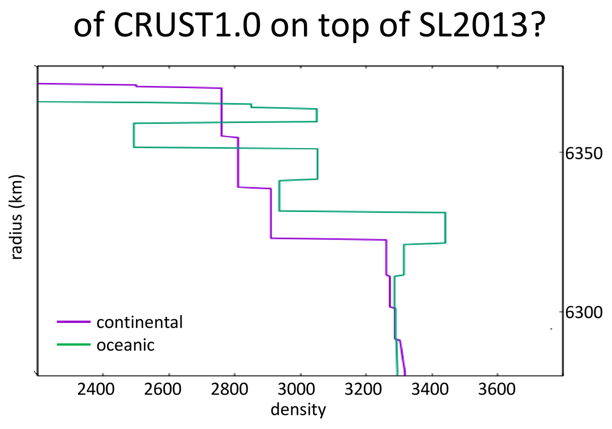
We use tomographic models to convert wave velocities to density for the whole mantle down to the CMB. Converting speed waves to density requires the use of a scaling factor so that: $(\delta ln V_p) \rightarrow \delta ln V_s \rightarrow \delta ln\rho$

- We test a constant scaling factor and a scaling profile from Steinberger et al. (2016) applied to the reference density profile ak135 (Amaru, 2007).
- It also exists several tomographic models. Here we test S40RTS (Ritsema et al., 2011), SL2013 (Schaeffer & Lebedev, 2013) on top of S40RTS
- We add CRUST1.0 on top of SL2013+S40RTS and test the sensitivity on gravity of the merging method between those two dataset.

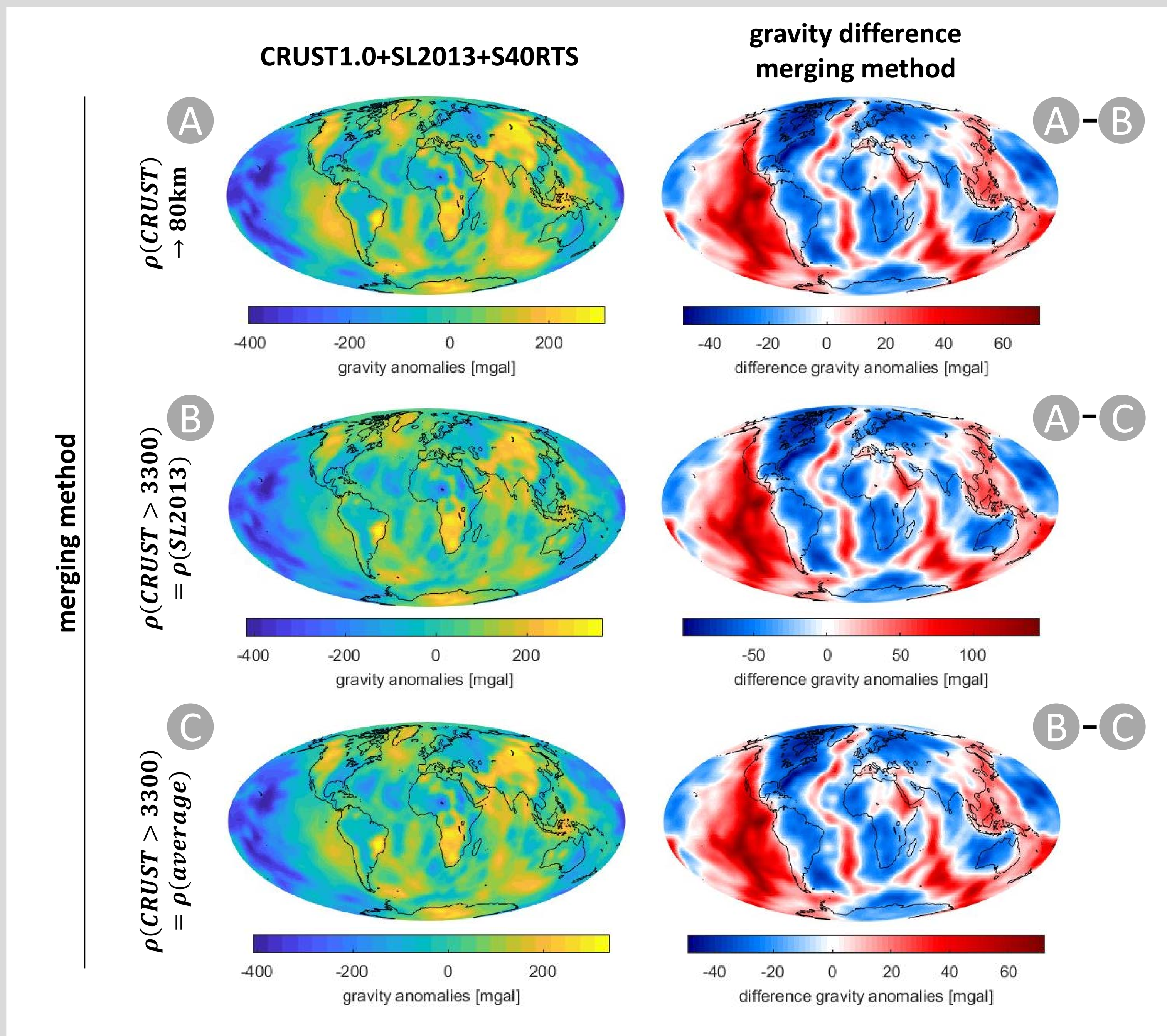




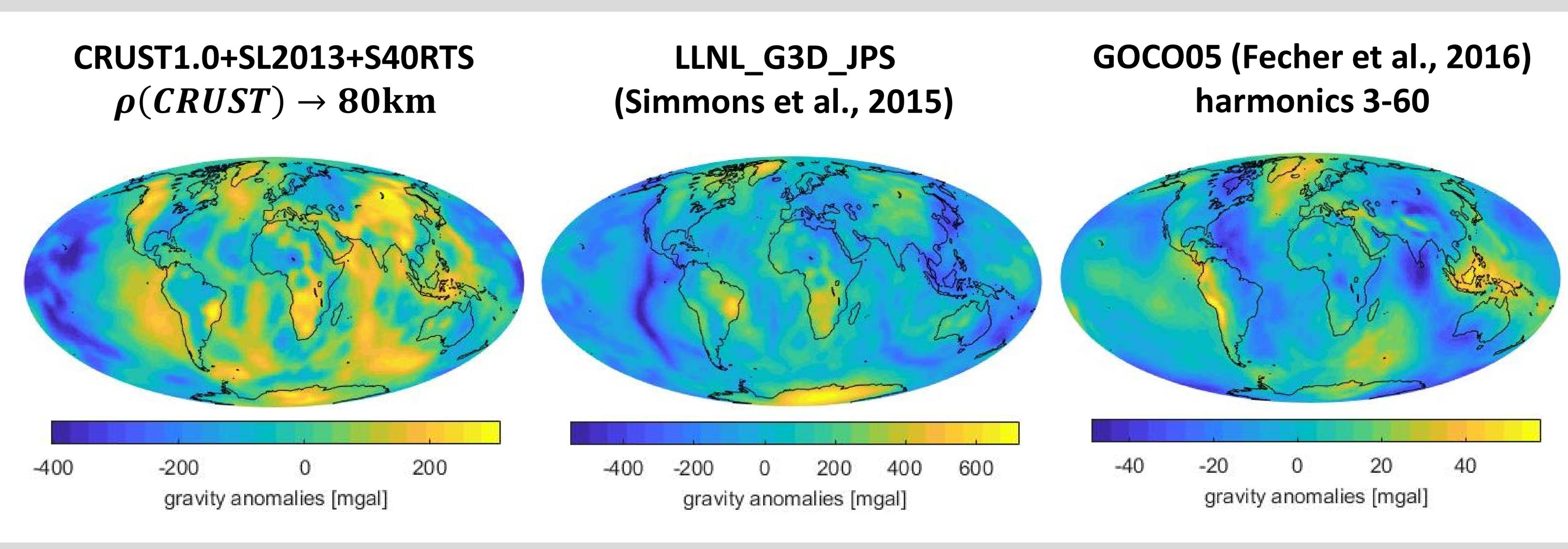
How to merge the uniform mantle density of CRUST1.0 on top of SL2013?



#1 how tomographic models are scaled impact on the gravity solution.
#2 gravity for this crust + mantle composite model varies according how dataset are merged (-60 to 140 mgal).



So far, can we match synthetic gravity g_m with the observed g_s?



The pattern between synthetic and satellite gravity differs: why?
- tomographic models?
- scaling factor?
- dataset merging?
- ...
- dynamic topography?

5 CONCLUSION:

- The direct integration is an accurate numerical method to calculate gravity fields, with a numerical error of less than 1 mgal achievable at low resolution.
- High resolution density models (e.g. CRUST1.0) require a higher discretized hollow sphere for the gravity solution to converge.
- How the tomographic models are scaled to density highly affect gravity predictions.
- A lithospheric density model is required to better calibrate global density fields.
- There is a long way before we can compare and constrain predicted gravity from density models to satellite data.