Towards a 3D model of the Sumatra slab using combined gravity and gravity gradients constraints with seismic tomography

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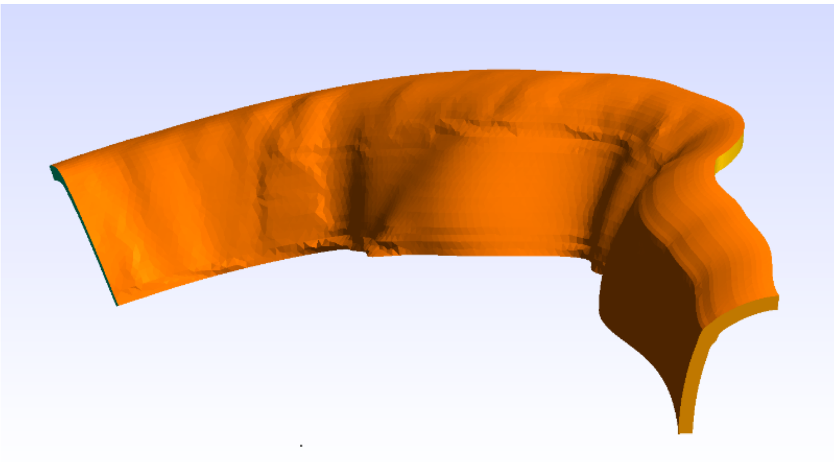
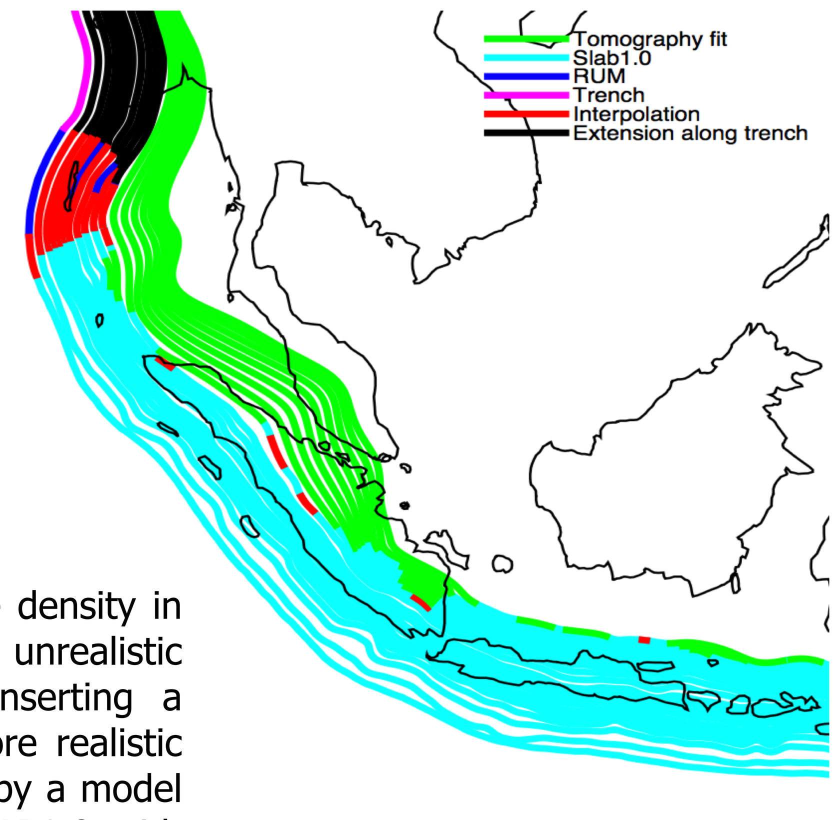
Satellite-derived gravity and gravity gradient models can provide new insights in addition to seismic and tomographic models, with regard to geometry and density distributions of subducting plates. These satellite-derived gravity gradient models have been used in modelling of several different subduction zones, but not yet for the Sumatra subduction zone. There, the gravity models can shed light on the shape of the plate, and whether a slab tear is present or not under northern Sumatra. Gravity gradient tensor invariants contain information from all gravity gradient components, but are non-directional, which makes them useful for modelling curved subduction zones.

We use combined terrestrial-satellite-derived gravity and gravity gradients (XGM2016) to model the density and thickness of the Sumatra slab in 3D. A spectral forward modelling method is used to identify signals related to the slab. Spectral analysis will determine the optimal spherical harmonic bandwidth that contains most of the slab signal. The synthetic slab is created using a top-slab surface model combining information from seismic information and tomography models. The slab is modelled as a slab with along-dip and along-strike varying thickness and density. Furthermore, we include a slab conduction model to determine the 3D density structure of the slab and an isostatic compensation model for the density in the mantle. Different external models are incorporated: high-resolution topography, high-resolution sediment models, a crustal model, top-slab surface geometry, and oceanic lithosphere age for first-order slab thickness estimates. An iterative algorithm is used to find the slab geometry and density distribution that fits the observations. A sensitivity analysis is performed to quantify the error in the used models (e.g. Moho depths) and their implications on the final slab model. After an extended Bouguer correction, we observe a different signal for the second tensor invariants in northern Sumatra.

1. Introduction

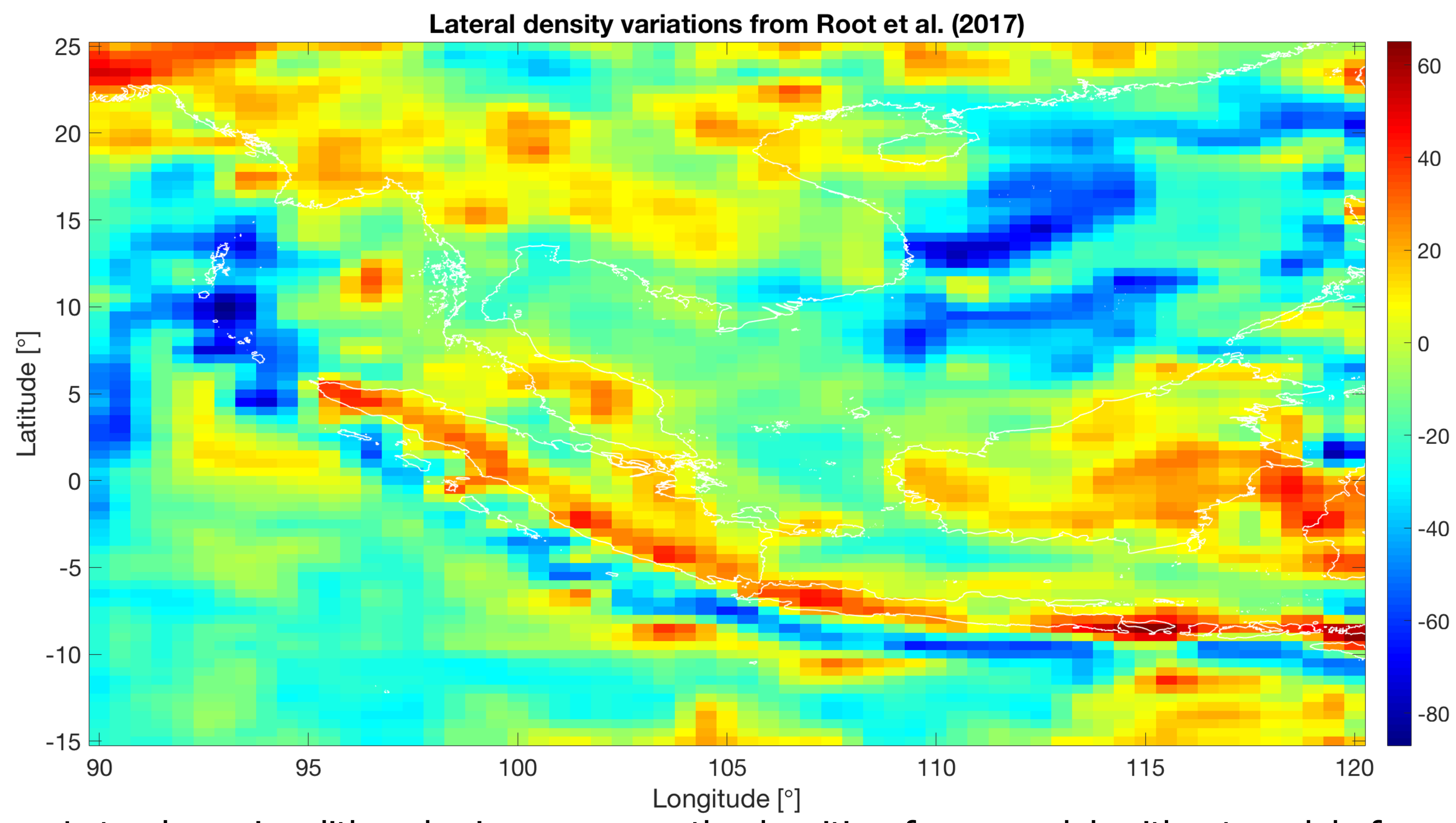
The Sumatra subduction zone is well-known for its mega-earthquake in 2004. To better study the behaviour of the slab, we use satellite gravity and gravity gradients data to improve the density and geometrical structure of the slab.





The approach in Root et al. (2017) to invert the density in the lithosphere from gravity data, results in unrealistic density structures close to the trench. So, inserting a **geometrical slab** can help in estimating a more realistic density structure. The **top** of the **slab** is obtain by a model from Broerse (pers. comm.), who combined SLAB1.0 with tomographic observations to determine the geometry.

Broerse (2016, pers. comm.)

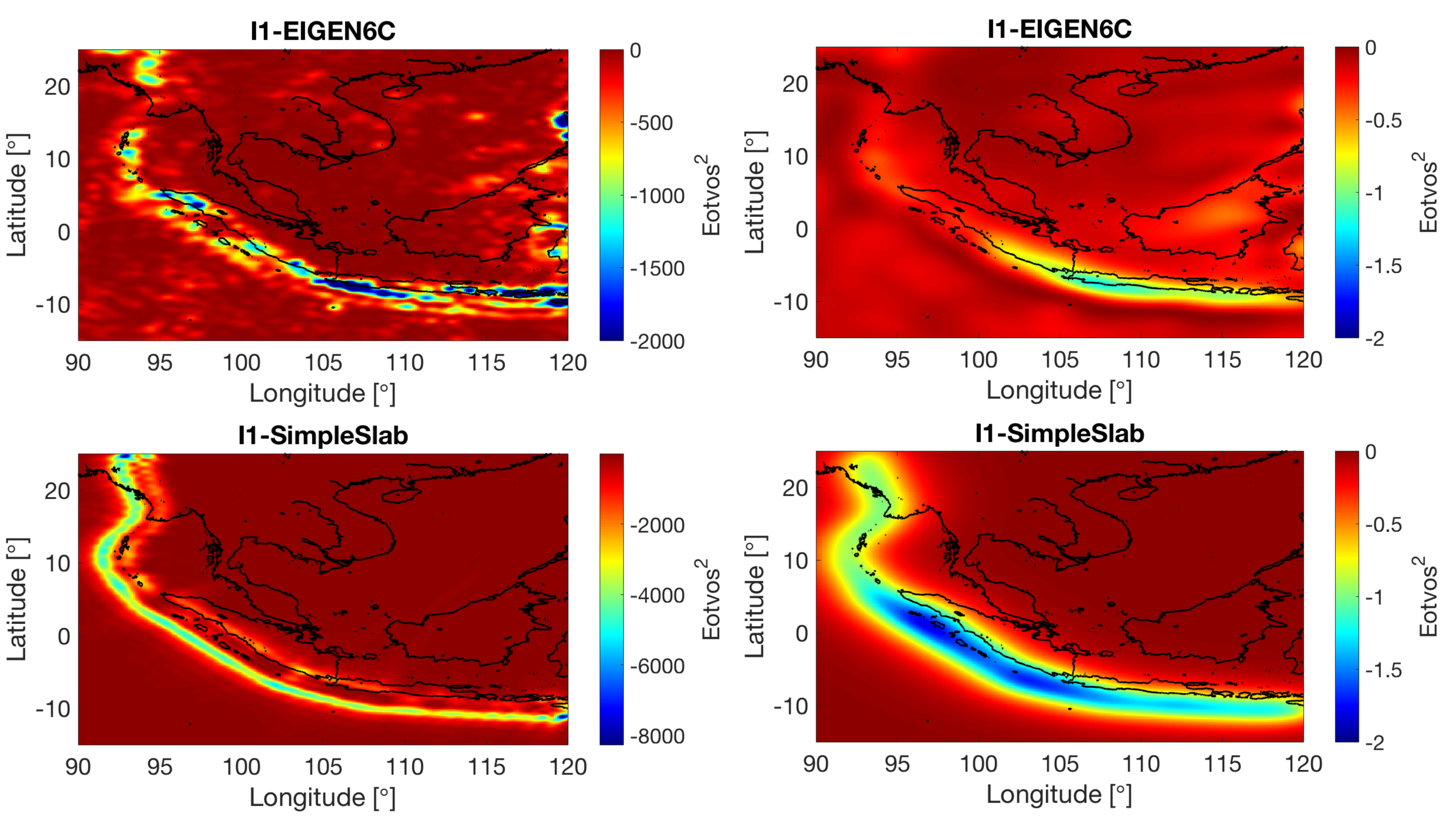


Lateral varying lithospheric upper-mantle densities for a model without a slab from Root et al. (2017) approach, which is better suited for passive continental areas.

2. Gravity data

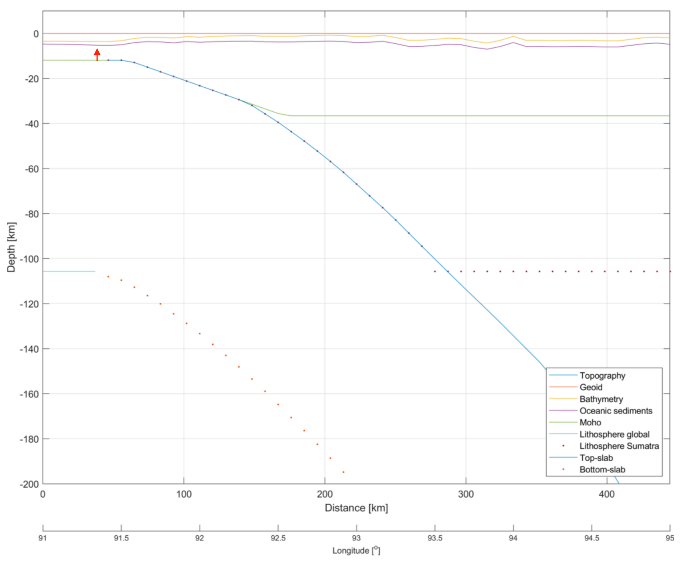
The **second invariant** of the gravity gradients can be used for subduction zones that do not have a clear north-south or east-west direction. In this case, all the information of the gravity gradient tensor is used. Here, we present the **observed** (EIGEN-6C) second invariant and the **forward modelled** from a simple slab with constant density and thickness. The gravity signal shows that the model produces a large signal south of Sumatra, which is not present in the observed field.

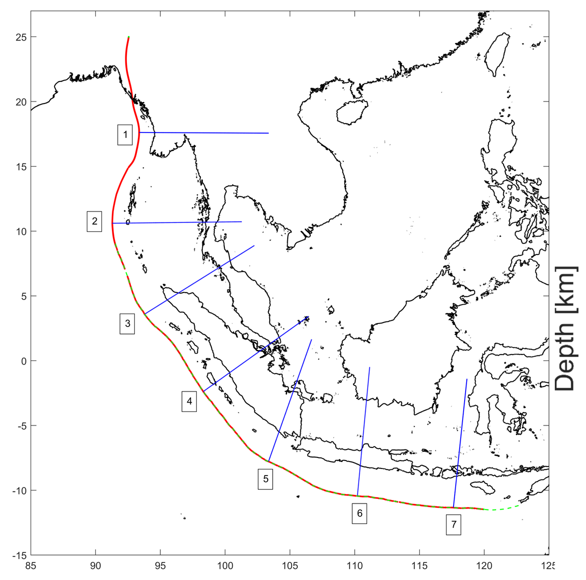
At sea-level | **At 225 km height**

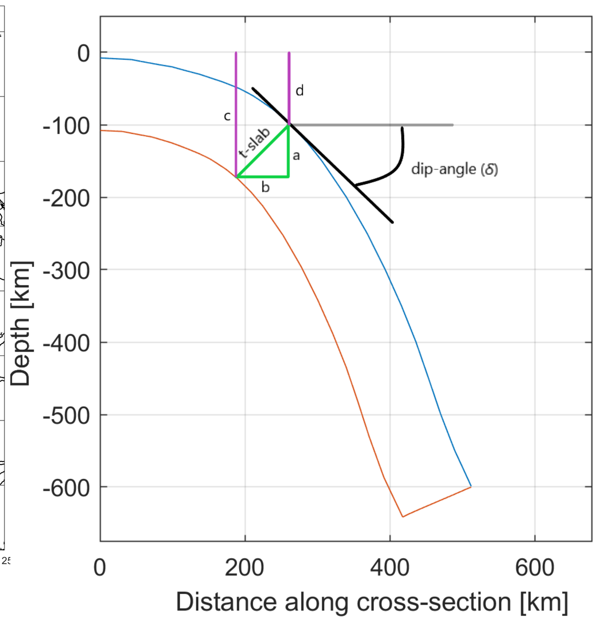


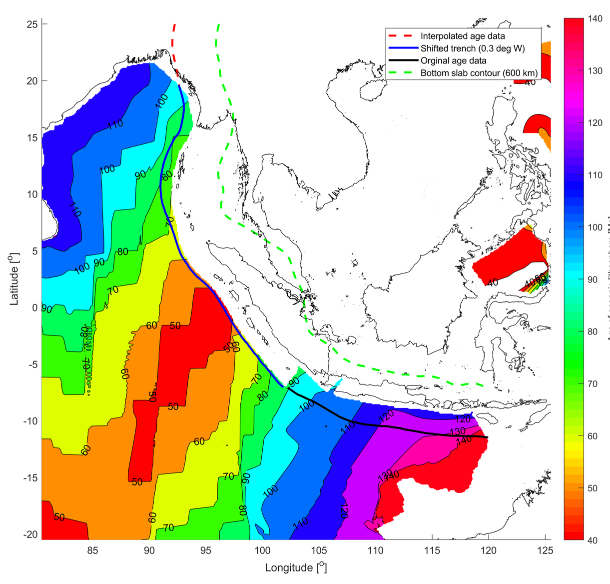
3. Approach

To realistically model the gravity signal, sedimentary, crustal, and isostatic lithosphere masses should be included in the model. The oceanic **sedimentary** rocks are obtained from Whittaker et al. (2013) and the **crustal** masses and remaining continental sedimentary rocks are obtained from CRUST1.0. Szwillus et al. (2018) shows that limited data is available in the Indonesian archipelago. However, large wavelength structures are assumed to represent a realistic model for the crust. The **top** of the slab will be fixed to the **basement**, neglecting any sediments on the slab.









The direction of thickness of the slab can be determined using the depth, dip angle and strike angle. The thickness is computed by the age of the oceanic plate and the theoretical model of Jacob et al. (2014).

$$a_i = t_{i,slab} \cdot \cos(\delta_i) \qquad b_i = t_{i,slab} \cdot \sin(\delta_i)$$

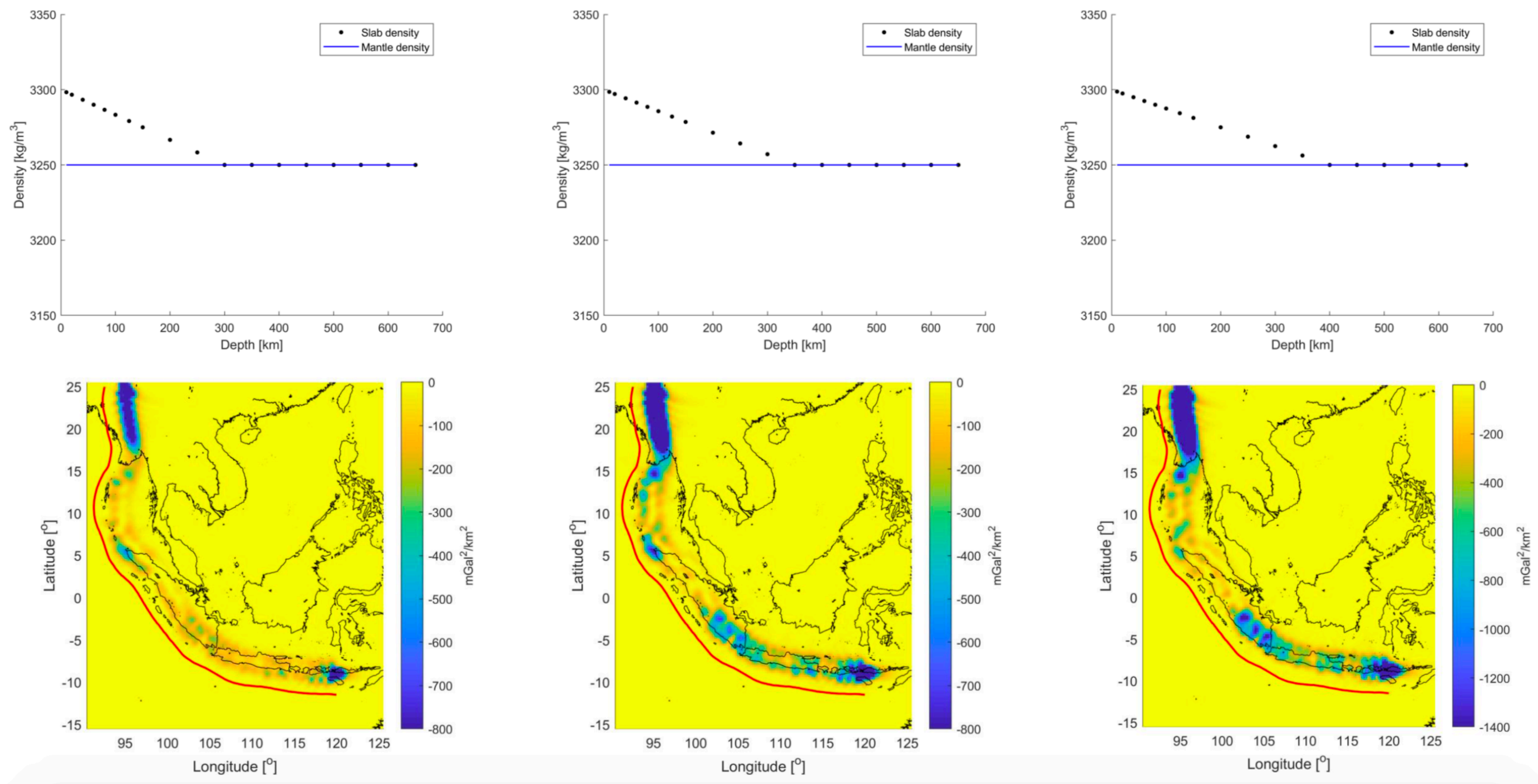
$$c_i = a_i + d_i$$

$$\Delta\phi_i = b_i \cdot \sin(\sigma_i) \qquad \Delta\lambda_i = b_i \cdot \cos(\sigma_i)$$

$$\phi_{i,b} = \lambda_i + \Delta\phi_i \qquad \lambda_{i,b} = \lambda_i + \Delta\lambda_i$$

4. Sensitivity results

Several sensitivity studies have been performed. The radial density distribution will approach the surrounding mantle density at a certain depth, removing the gravity signal from the deep slab. This affects mainly the gravity observed at the volcanic arc.



5. Future work

- We have constructed a forward model for the Sumatra subduction zone, combining model sand data: SLAB1.0, CRUST1.0, oceanic sediments, tomographic interpretation and satellite gravity gradients.
- The second invariant of the gravity gradient is a suitable representation of the satellite gravity gradients to use in the inversion of density structures of a subduction zone, because it does not depend on the geographic placement. Gravity gradients at satellite level still reveal signal related to the subduction zone.
- Both a variable along-dip and along-strike thickness of the slab will be implemented, related to the age of the oceanic slab. The density of the slab will be a function of the pressure and temperature in the slab.
- Lithospheric masses will be calculated in the accretion wedge and mantle wedge. These regions are needed to improve on the unrealistic densities in the upper mantle found in the Root et al. (2017) results.

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