Sensitivity of GOCE along the Andean subduction zone

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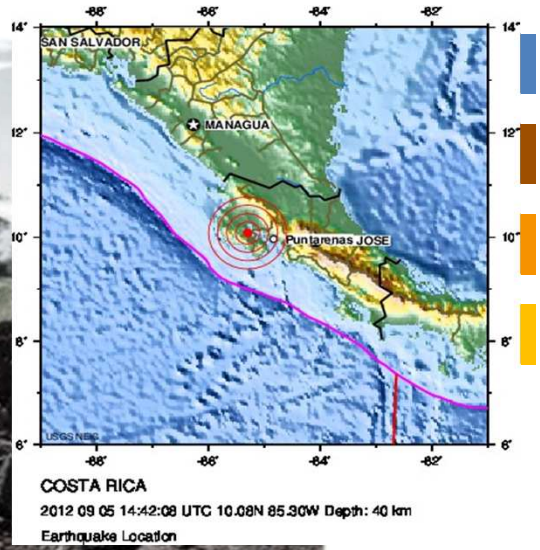
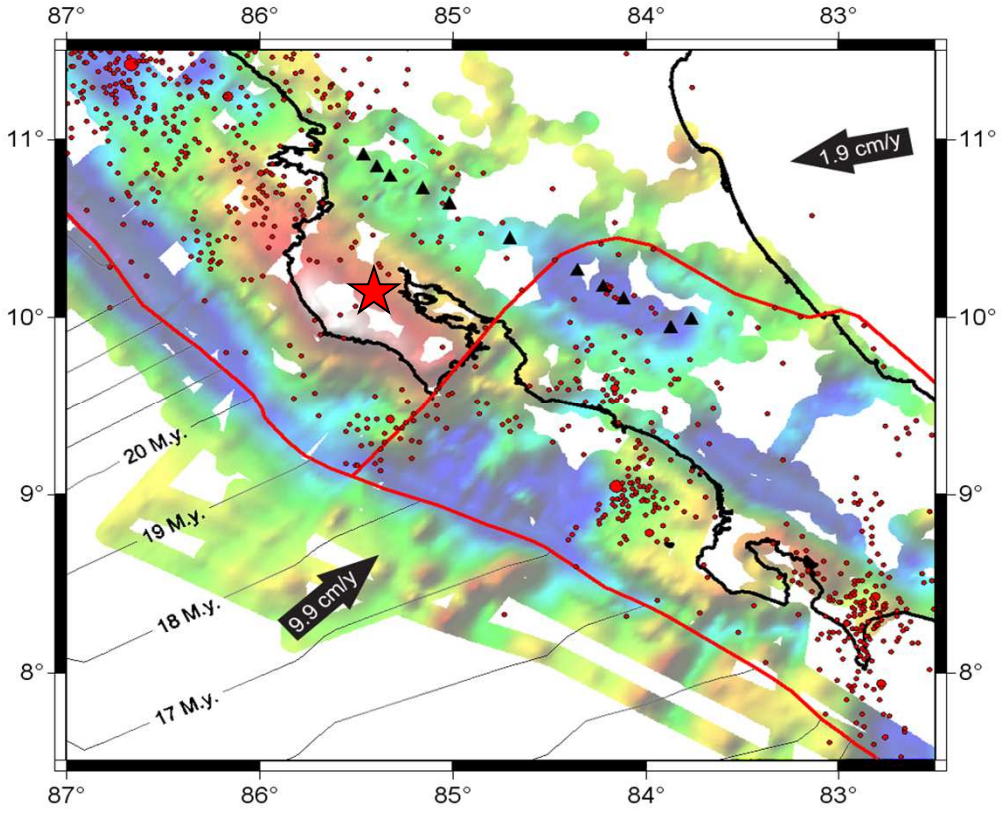
C|A|U
Christian-Albrechts-Universität zu Kiel

DFG SPP 1257

Mw7.6 Earthquake, Nicoya peninsula, Costa Rica, 2012-09-05

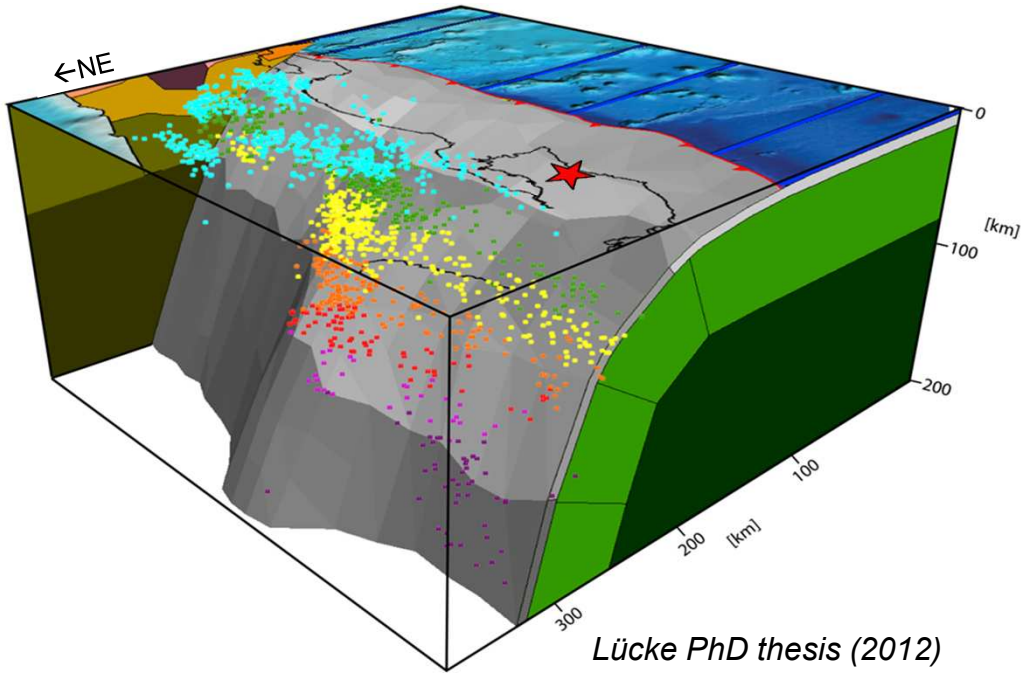


3D density model of Costa Rica / Central America



Satellite gravity provides information in inaccessible areas (geographically, politically, …)

➔ Fill data gaps



Lücke PhD thesis (2012)

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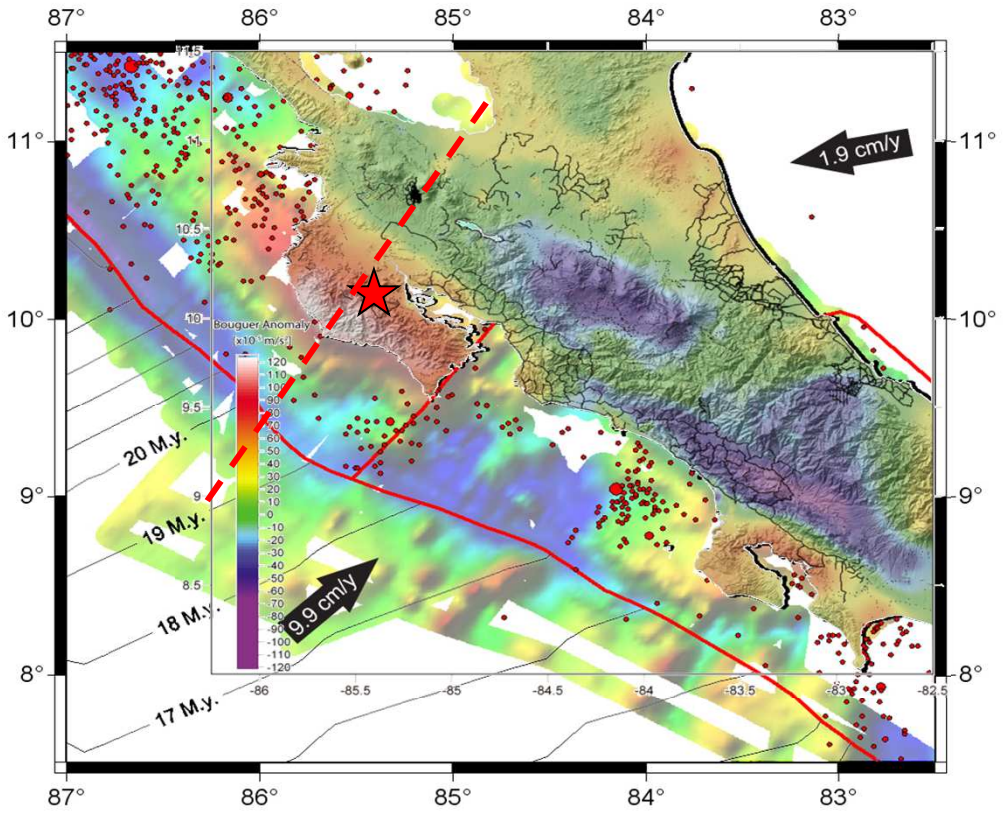

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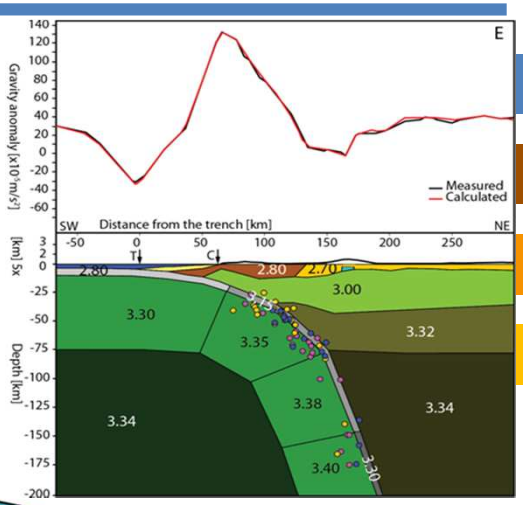
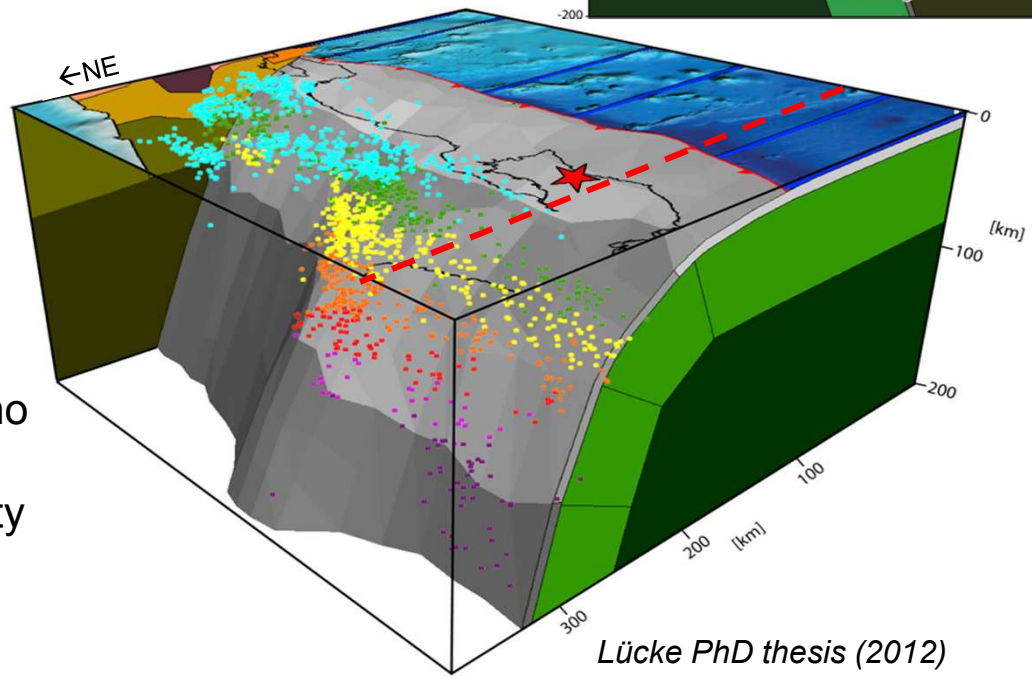
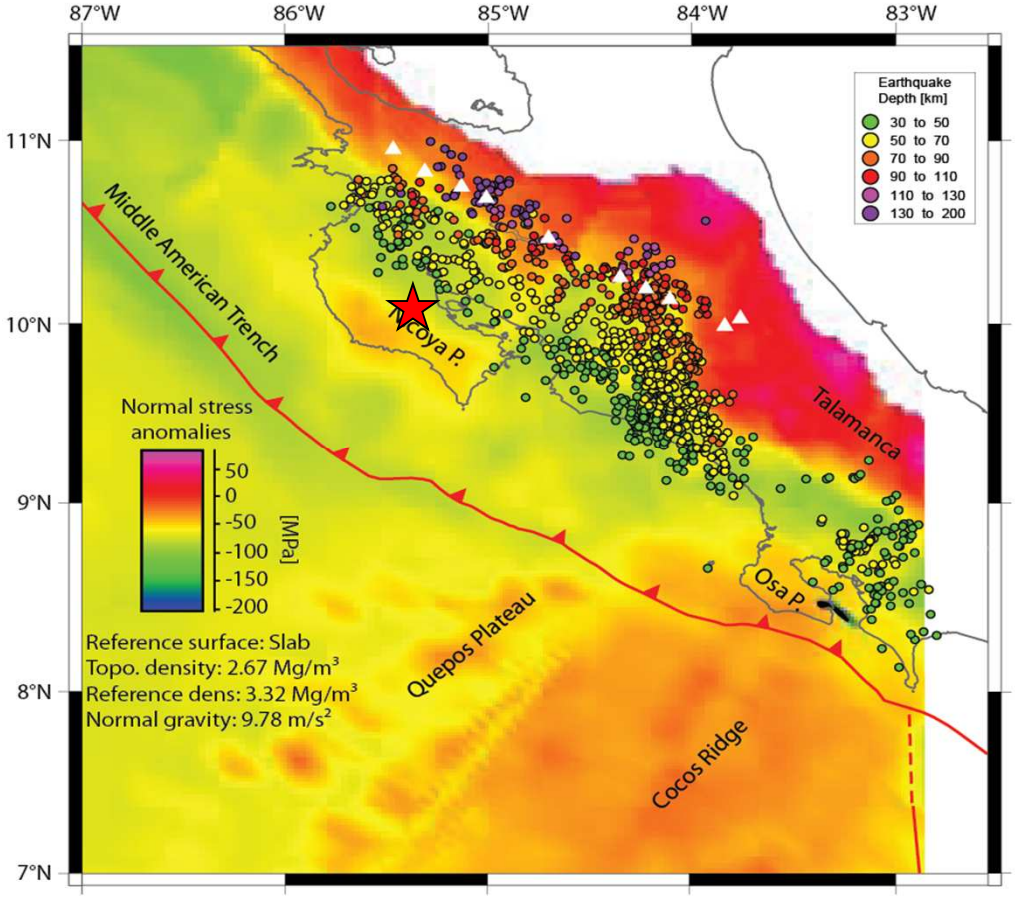


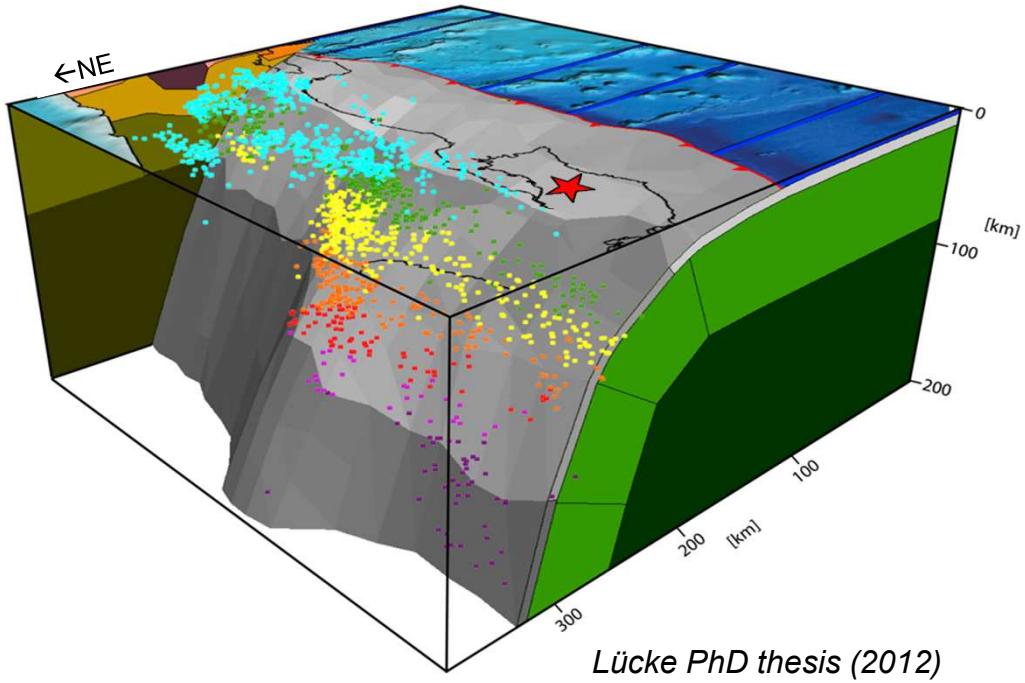


Major lithospheric structures such as the slab, Moho interface and lateral segmentation of the crustal basement could be resolved using combined gravity models

Lücke PhD thesis (2012)

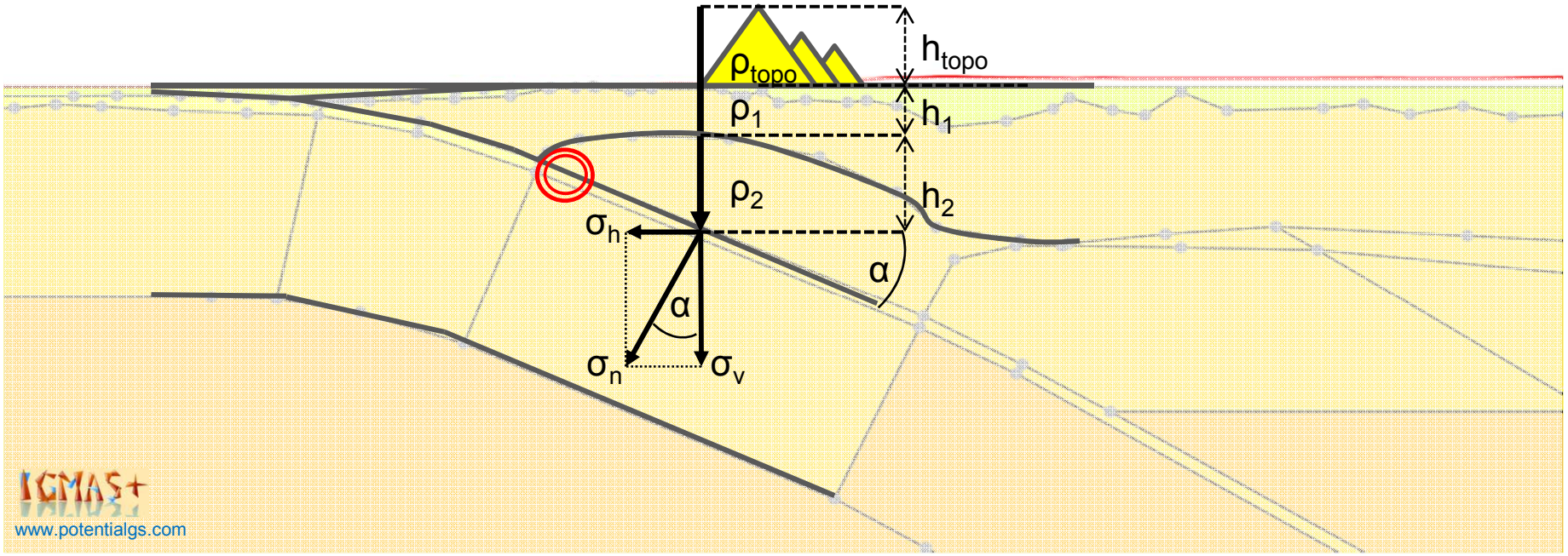
Static normal stress anomaly: 3D density model of Costa Rica





Lücke PhD thesis (2012)

Static stress and GPE derived from 3D density model



Tassara 2006, 2010

$$\sigma_v = \gamma \cdot \int_0^z \rho(z)\, dz$$

$$\sigma_v = \gamma \cdot \left(\rho_{topo} h_{topo} + \sum \rho_i h_i \right)$$

$$= \gamma \cdot \left(\rho_{topo} h_{topo} + \rho_1 h_1 + \rho_2 h_2 \right)$$

$$\sigma_n = \sigma_v \cos\alpha + \sigma_h \sin\alpha$$

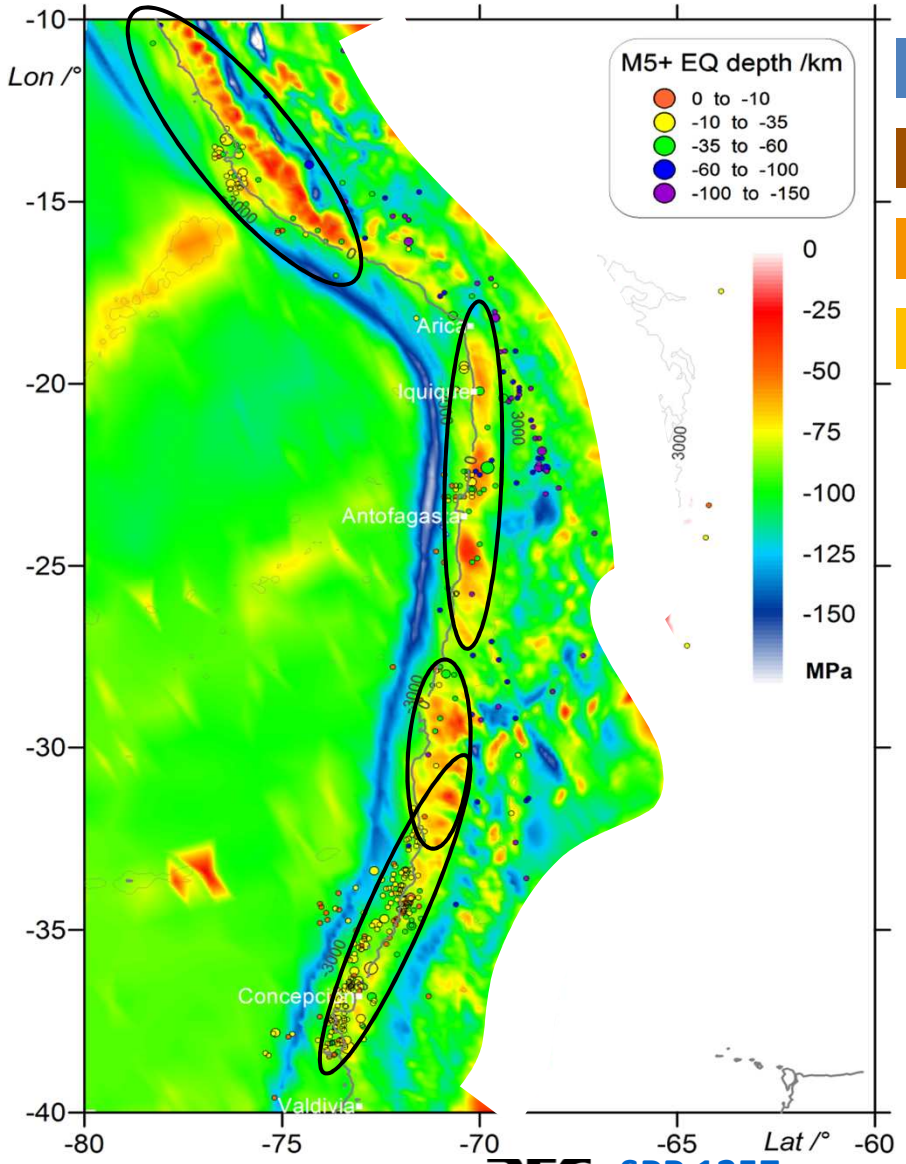
$$GPE = \int_{-h}^{L} \rho(z)\gamma L\, dz - \int_{-h}^{L} \rho(z)\gamma z\, dz$$

$$= -\int_{-h}^{L} \sigma_v(z)\, dz$$

Static stress anomalies & Gravitational Potential Energy

Normal stress anomaly on top of the oceanic Nazca plate and the subducted slab:

- Fore-arc region is characterized by trench parallel normal stress anomalies (up to 100 MPa higher than in the adjacent regions)
- Domains are attributed to high density structures above the plate interface and indicate regions of enhanced strain energy
- M_W>5 seismicity correlates well with peaks of the high stress anomaly



Static stress anomalies & Gravitational Potential Energy

Normal stress anomaly on top of the oceanic Nazca plate and the subduc

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  than in the adjace
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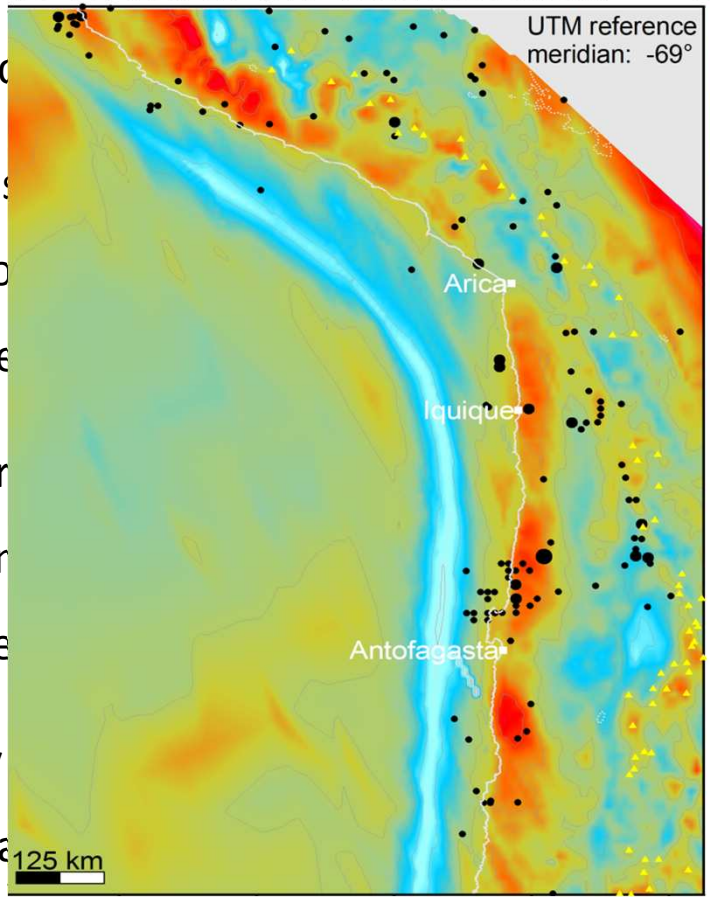
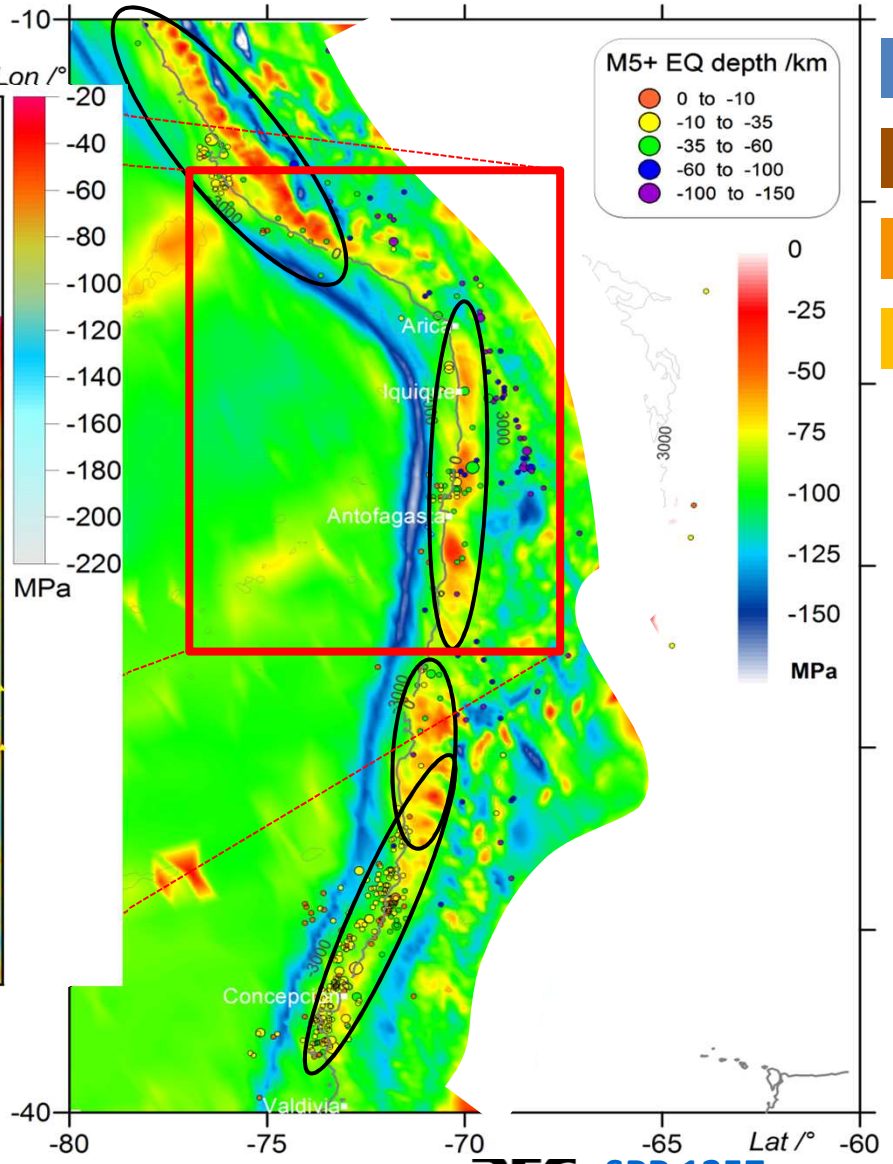
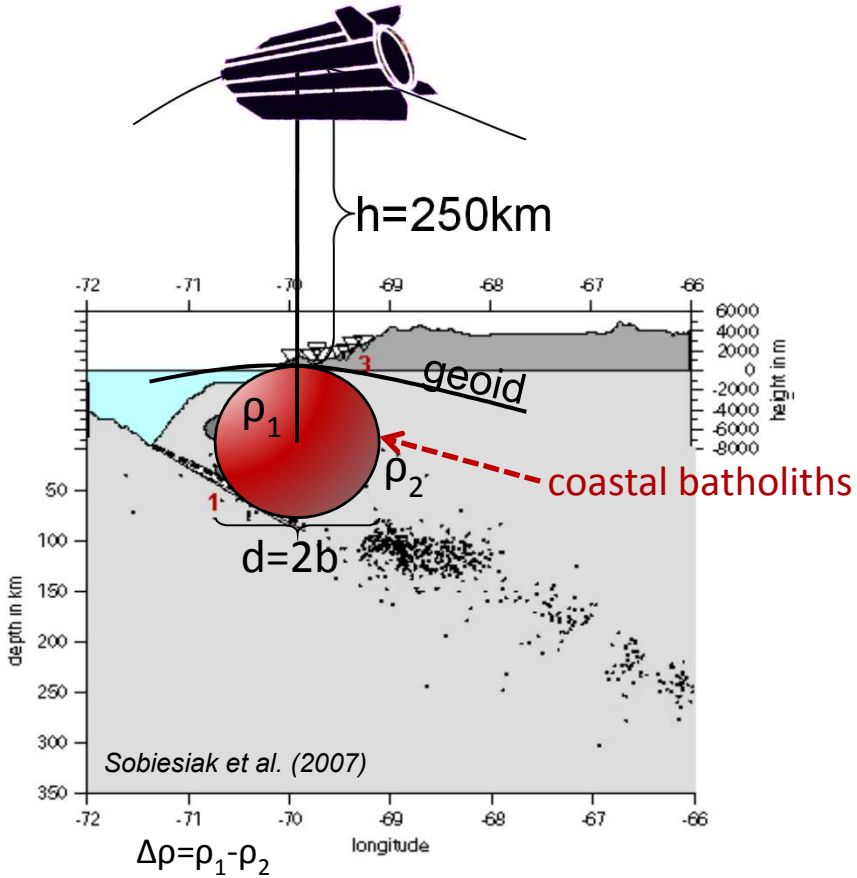




Gravity and gravity gradients – sensitivity analysis

OK - but can we benefit from GOCE gravity, or even the gradients ?

Gravity and gravity gradients – sensitivity analysis



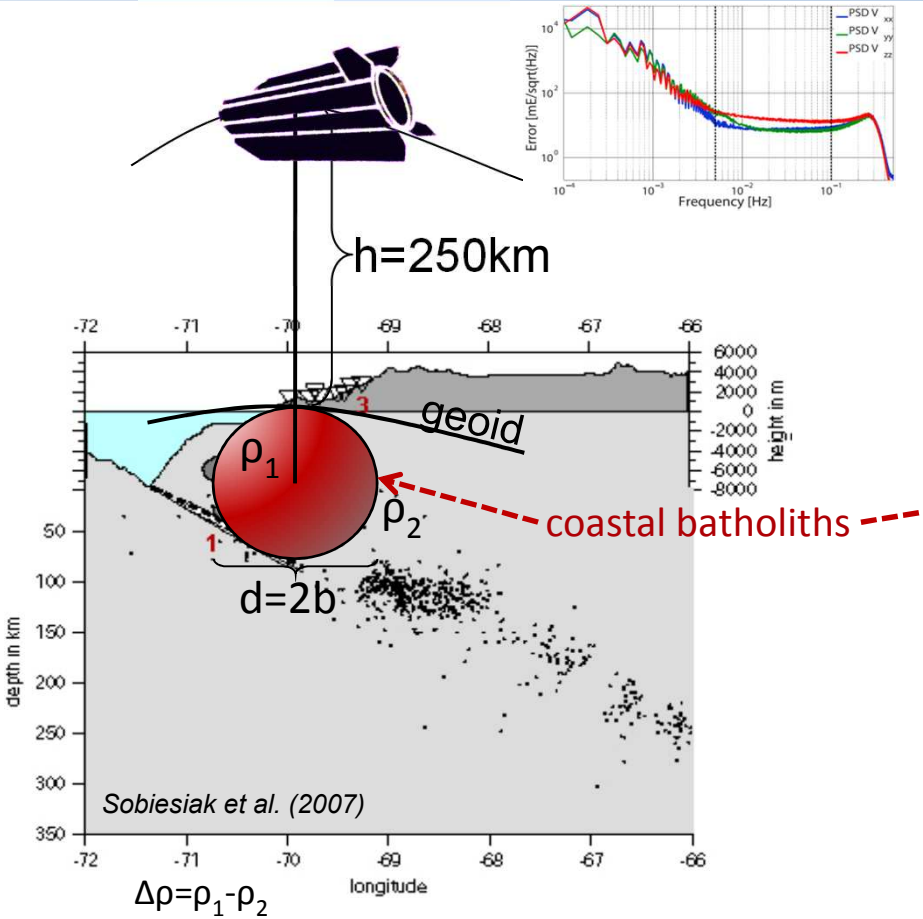
$\Delta\rho=\rho_1-\rho_2$

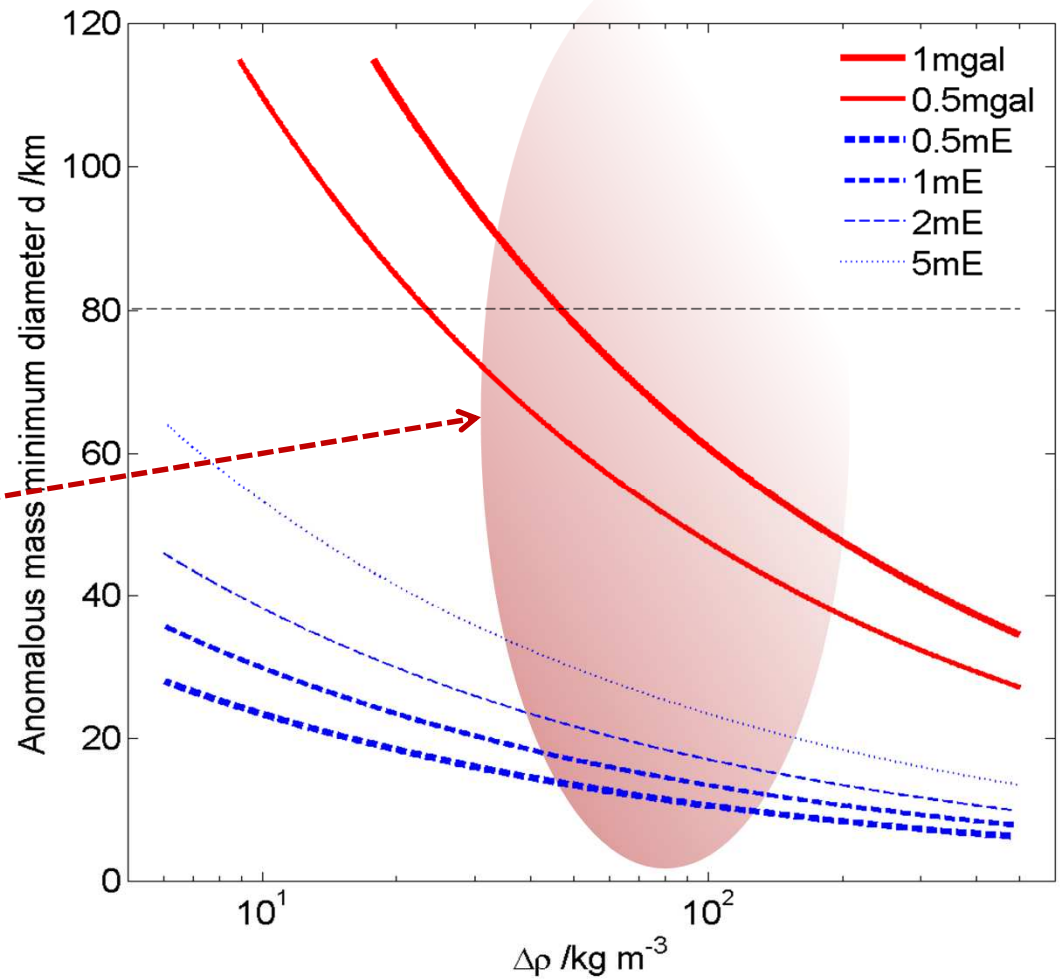
$z=h+b$

ρ: density

G: Gravity constant

Gravity and gravity gradients – sensitivity analysis





$\Delta\rho=\rho_1-\rho_2$
$z=h+b$
ρ: density
G: Gravity constant

$$\Delta\rho(b) = \frac{3}{4}\cdot\frac{\Delta V_z}{\pi G}\cdot\frac{(h+b)^2}{b^3}$$

$$|\Delta\rho(b)| = \frac{3}{8}\cdot\frac{\Delta V_{zz}}{\pi G}\cdot\frac{(h+b)^3}{b^3}$$

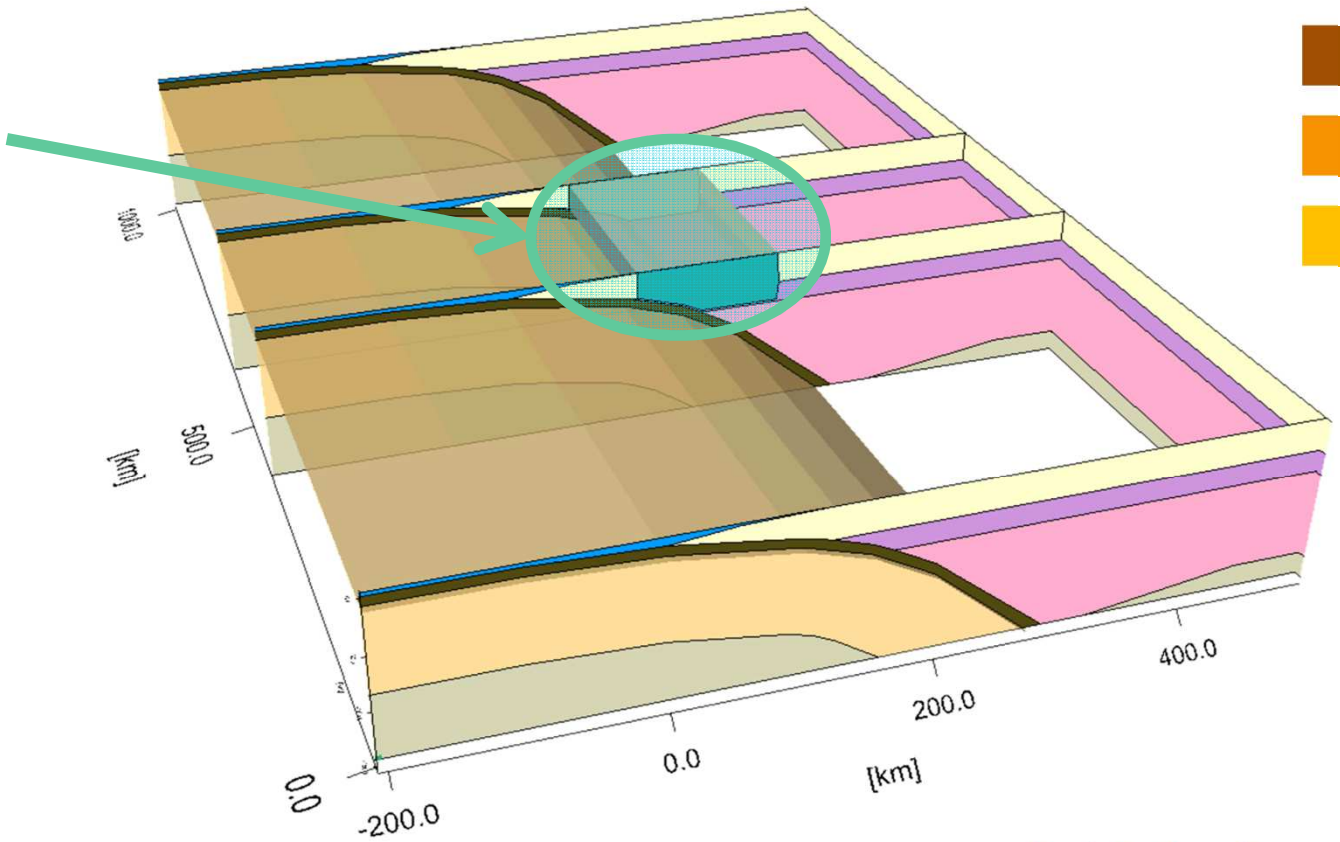
Gravity and gravity gradients – forward modeling of the ‘shoe-box’ model

Embedded crustal body with anomalous density

$\Delta\rho$ = 0 - 300 kg m³

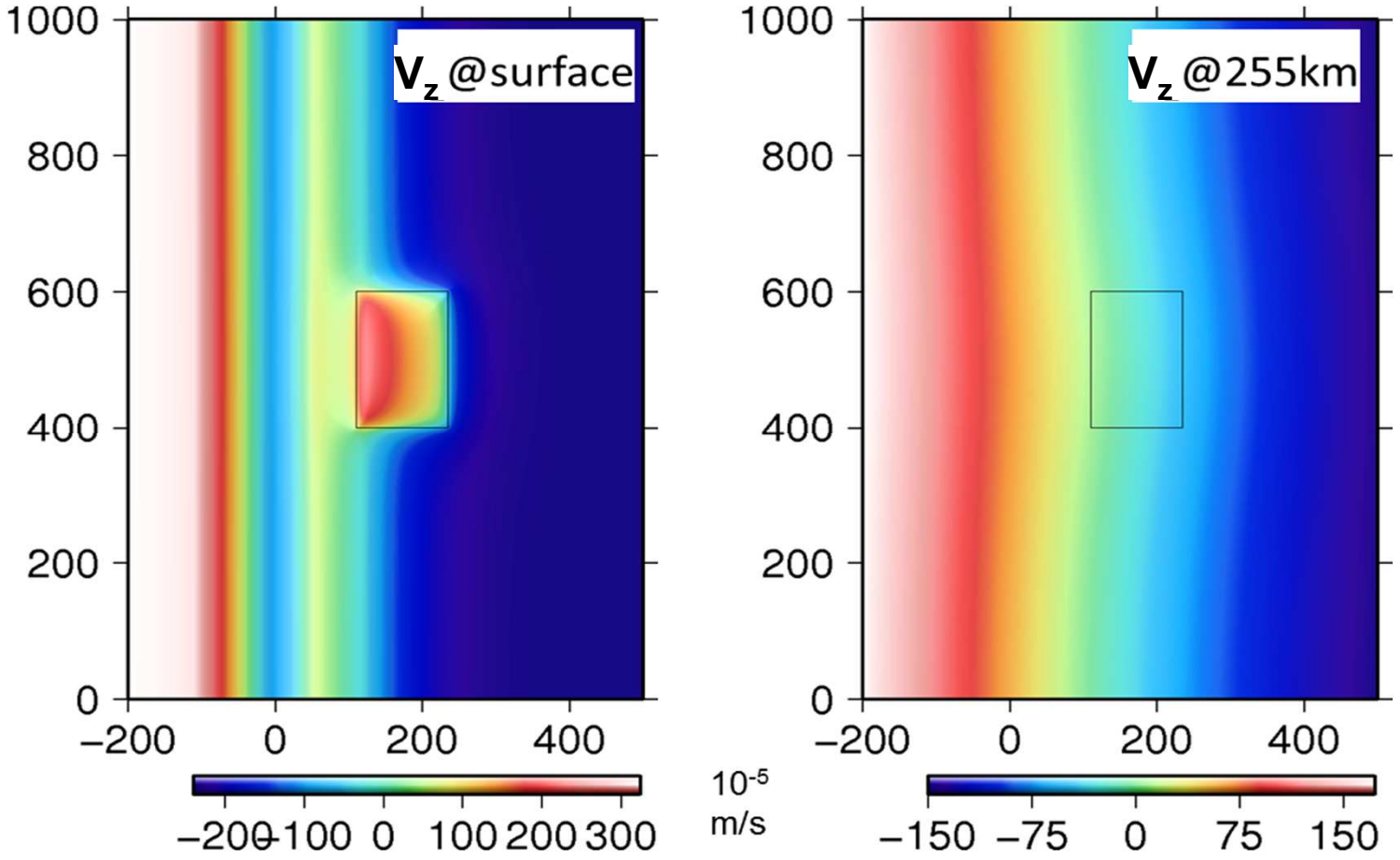
~ 115 x 200 x 40 km

2D geometry of the Chile trench (simplified, Δy=const.)

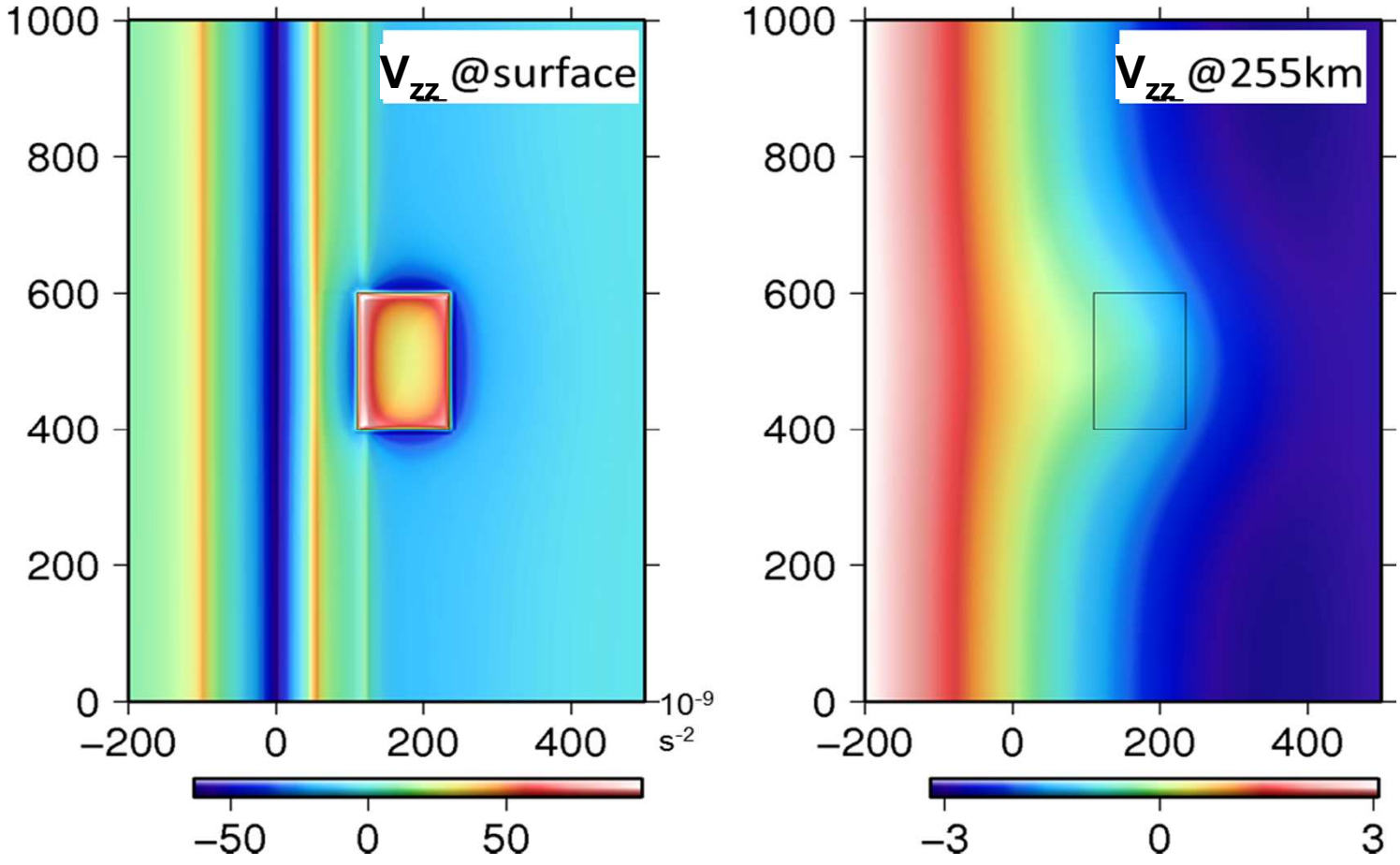


www.potentialgs.com

Gravity and gravity gradients – forward modeling of the ‘shoe-box’ model

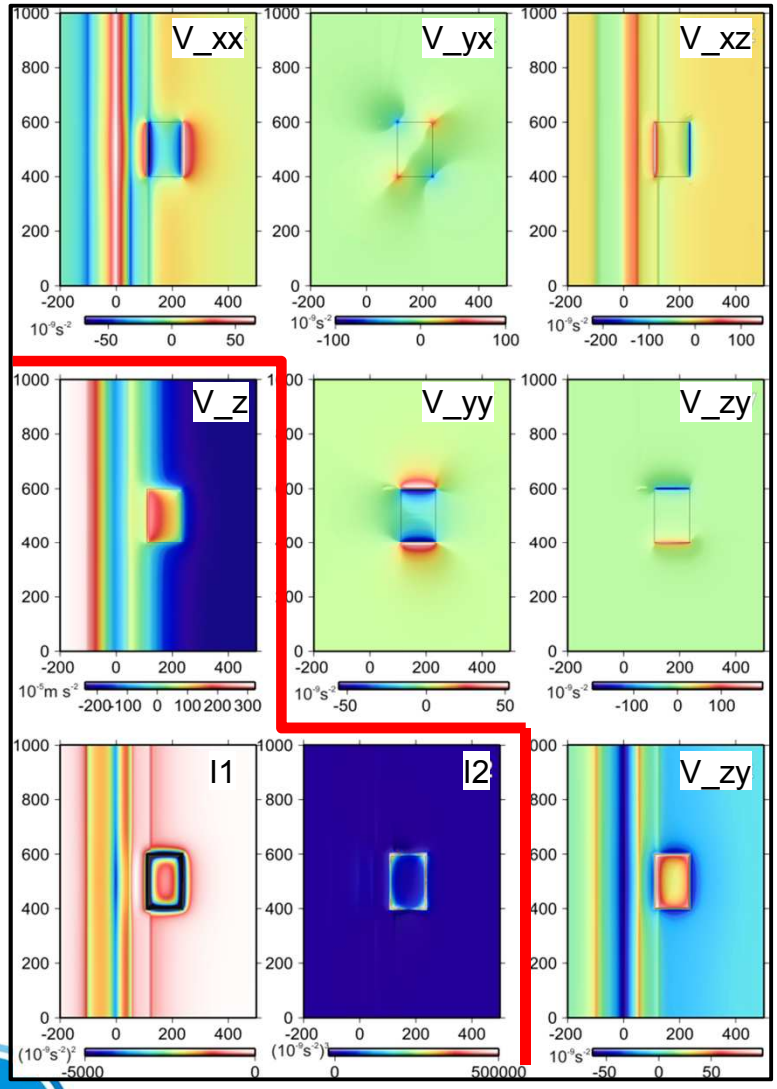


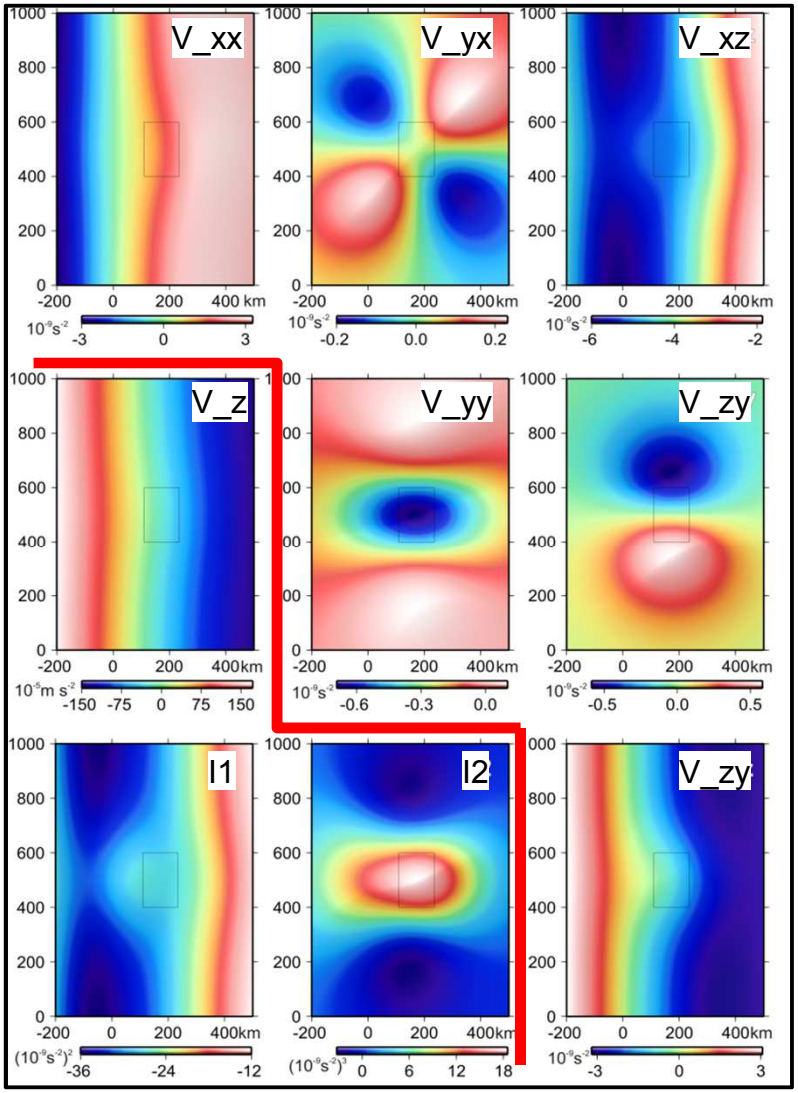
Gravity and gravity gradients – forward modeling of the ‘shoe-box’ model



Gravity, gravity gradient tensor and invariants

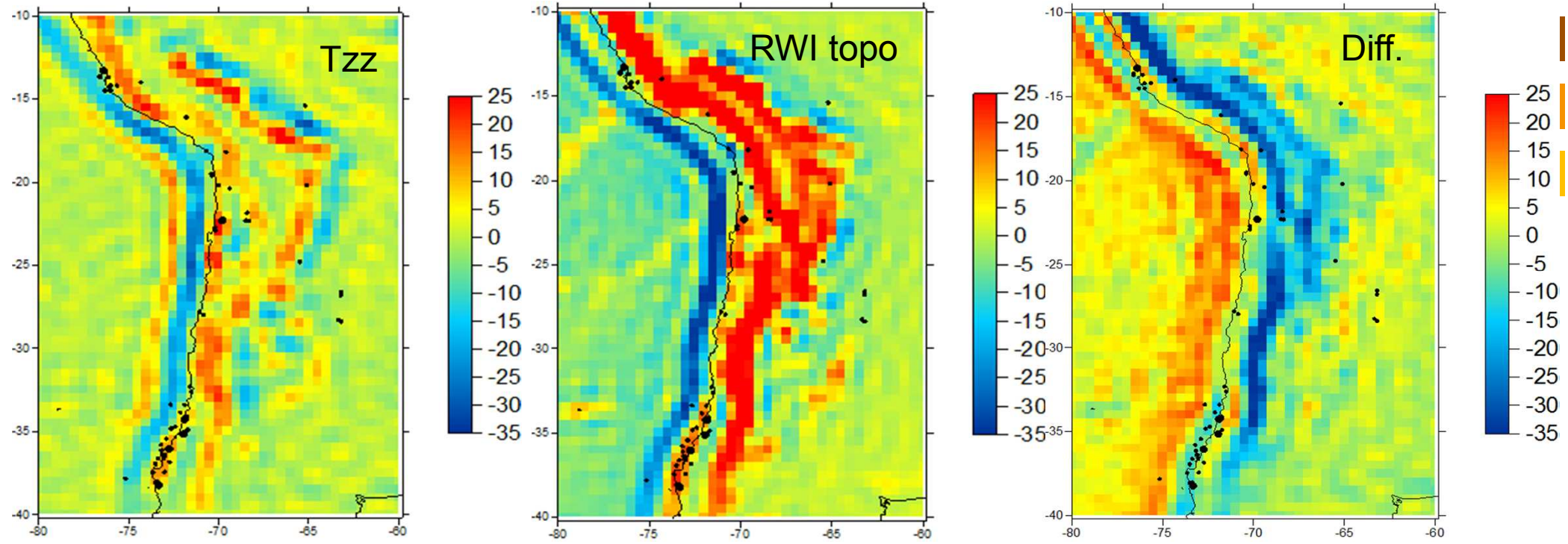
@surface





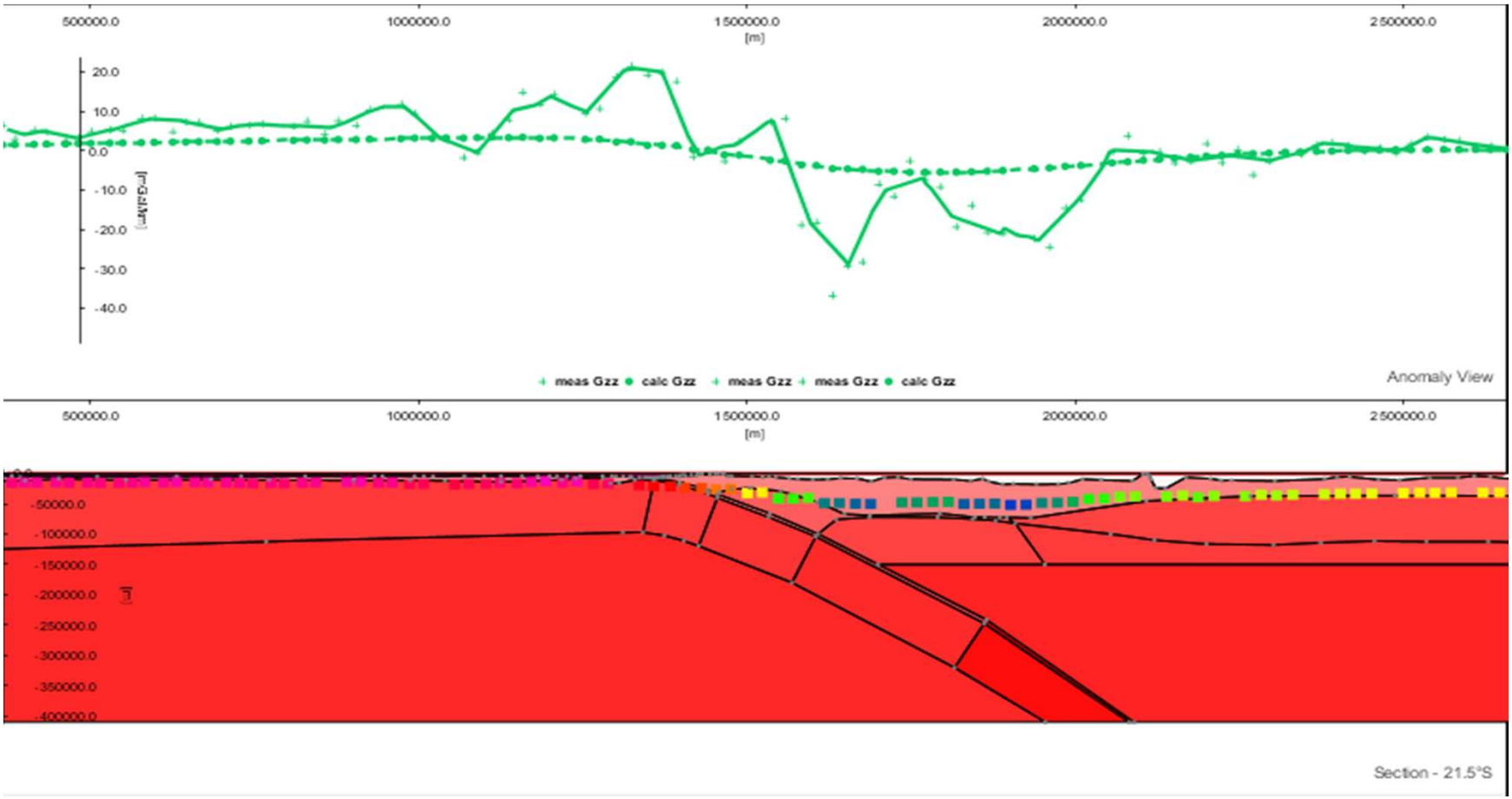
@255km

Goco02s Tzz – RWI topo @9km (/EU)

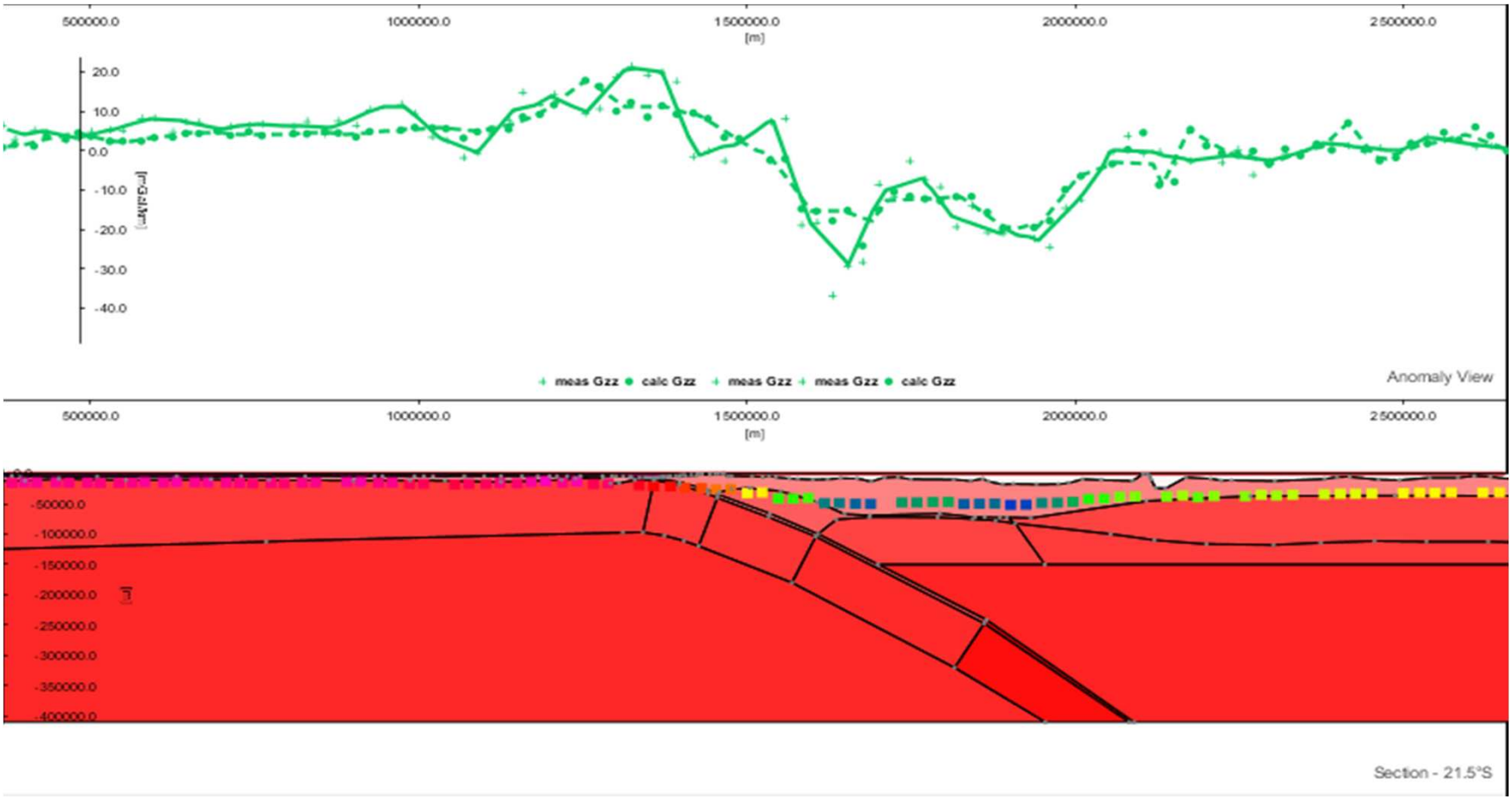


How ‚deep' can we go with a reduction of topographic masses of a certain d/o ?

Goco02s Tzz – RWI topo @250km (dotted)



Goco02s Tzz – RWI topo @9km (dotted)

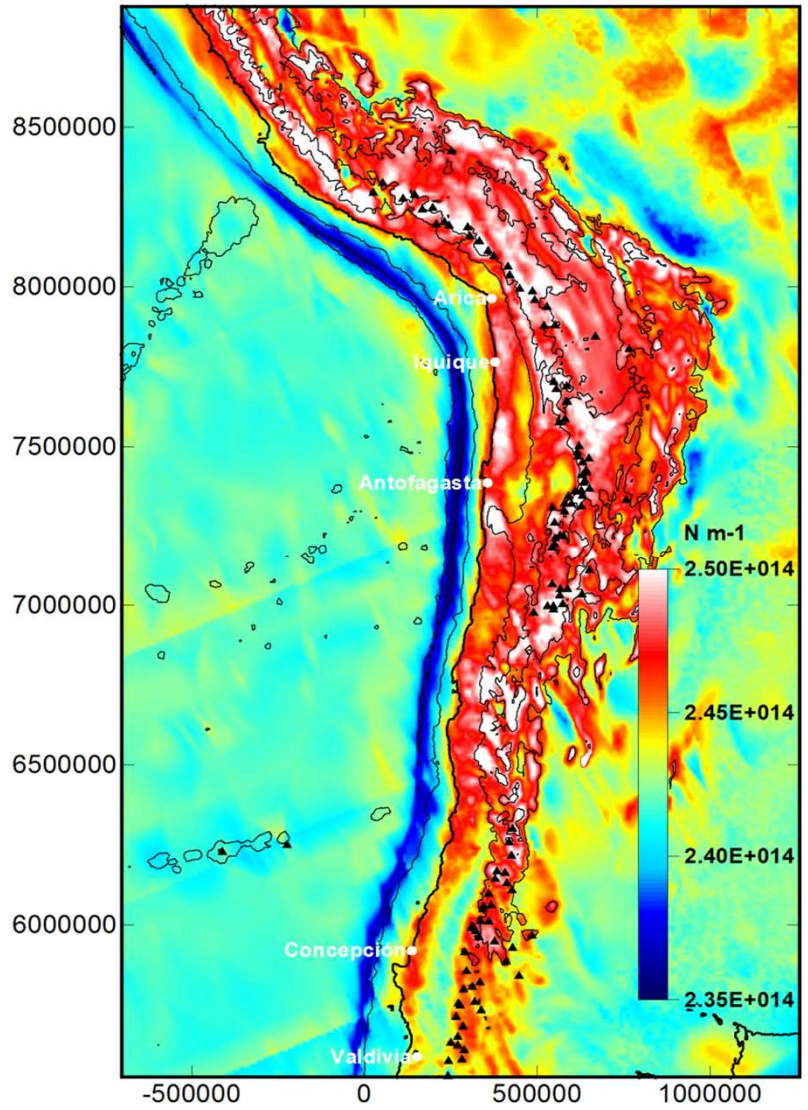


Gravitational Potential Energy

Gravitational Potential Energy (GPE):

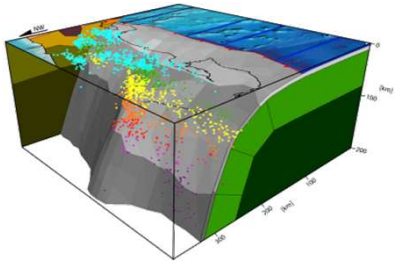
- High topography of the Andes and ridges in the Nazca plate exhibit high GPE values (+10^{14} N m^{-1}) relative to the global mean at the 125km depth level

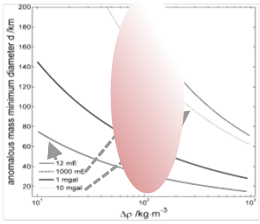
- The resulting stress from GPE could influence the state of stress in the Nazca plate and adjacent regions (ridge push ~ 10^{12} N m^{-1})

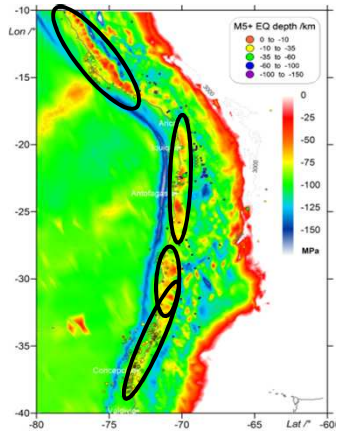


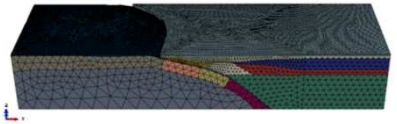
Summery / conclusion

- Density models can be used to derive the state of stress and Gravitational Potential Energy
- Stress anomalies on the subducted slab correlate well with the observed seismicity
- Satellite gravity and gravity gradient data could be used to map asperities along active continental margins to some extend; BUT: higher spatial resolution desired.
- GGs more promising to crustal/lithospheric studies than previously thought; BUT: topo-corr. To diskuss @ which altitude?
- Try global GPE w.r.t. GEMMA Moho
- Static density models handed over to FE dynamic modeling







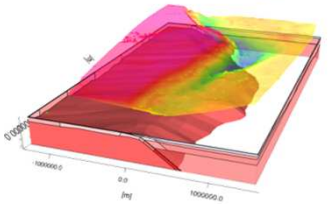


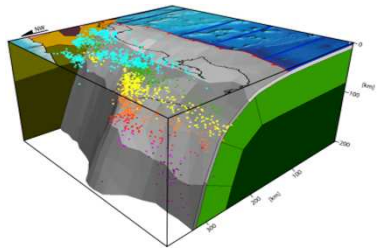
Qs&As

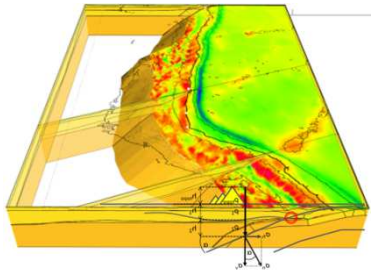
Backup slides

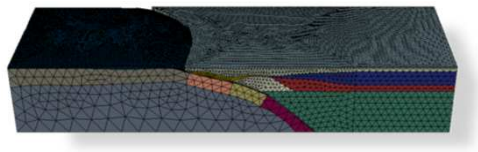
Sensitivity of GOCE along the Andean subduction zone

- Motivation
- Methods
  - Sensitivity analysis
    - Gravity and gravity gradients of a crustal density anomaly
    - Synthetic ‚shoe-box' gravity model
  - Stress- & GPE estimates from 3D density modeling
    - Static normal stress and GPE
- Qs&As









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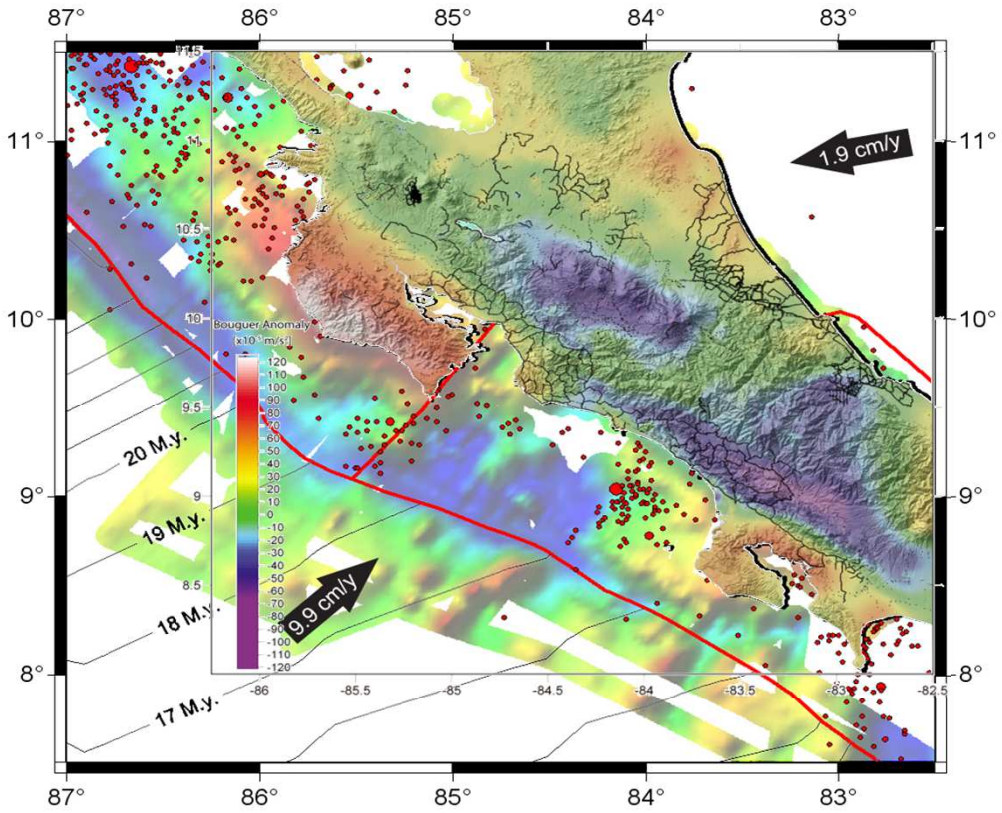

Satellite gravity provides information in inaccessible areas (geographically, politically, …)

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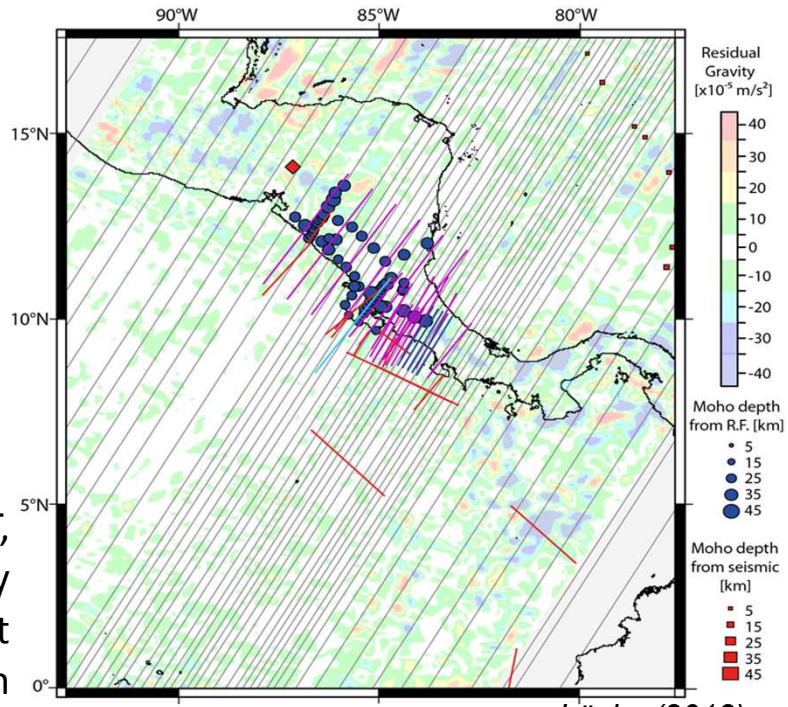


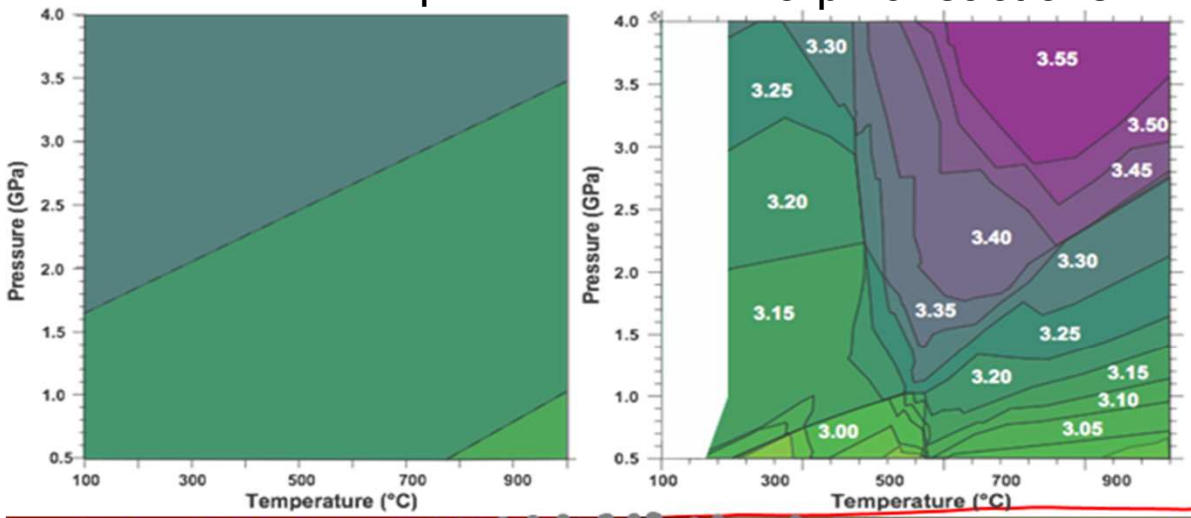
Other geo-information (e.g., seismology, MT, GPS, tectonics) provide constraints for density forward modeling → significant improvement of process interpretation

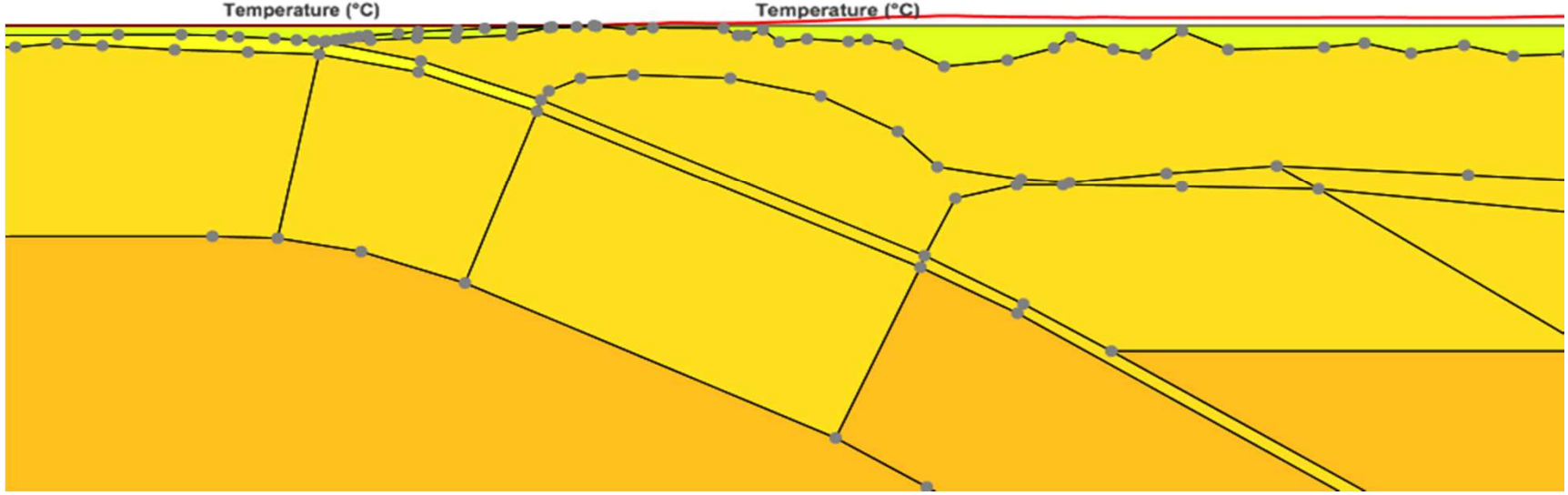
Lücke (2012)

Model constraints: rock density

Non-metamorphic

Considering meta-morphic reactions:





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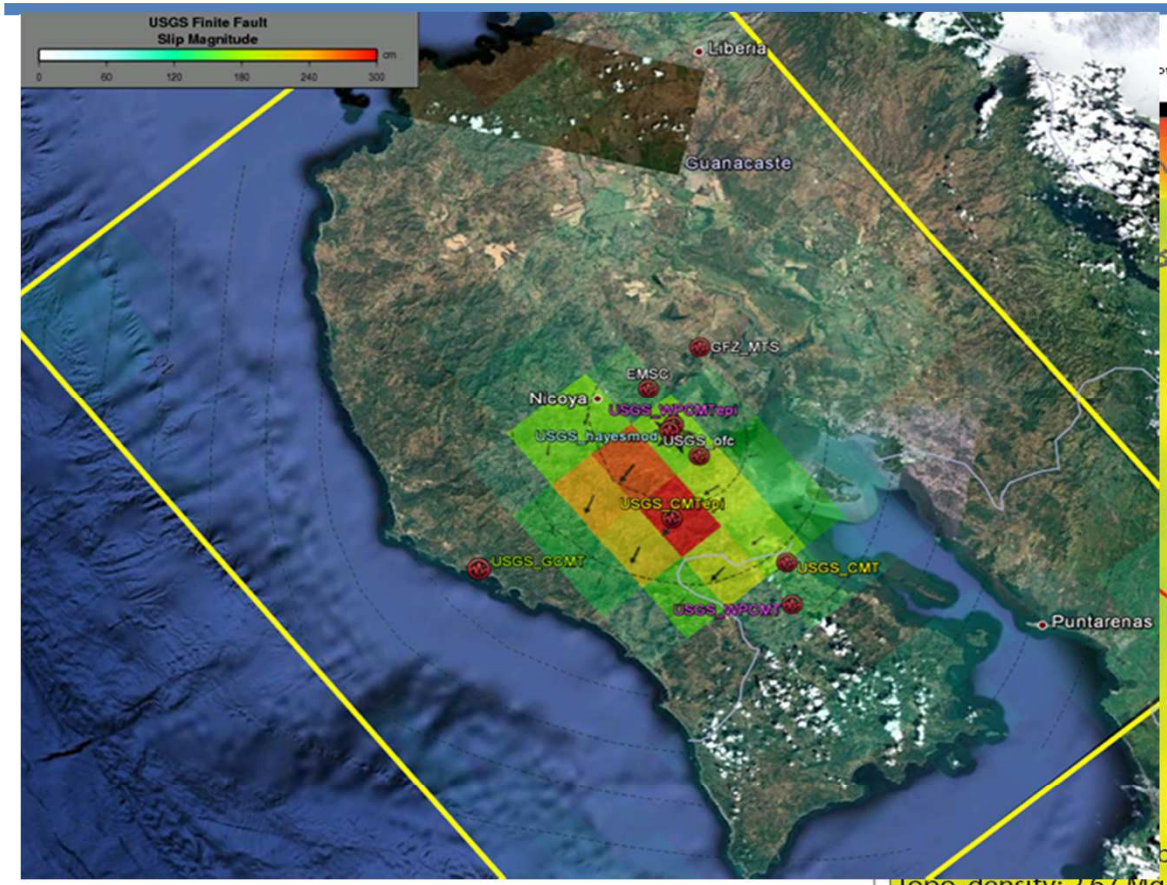
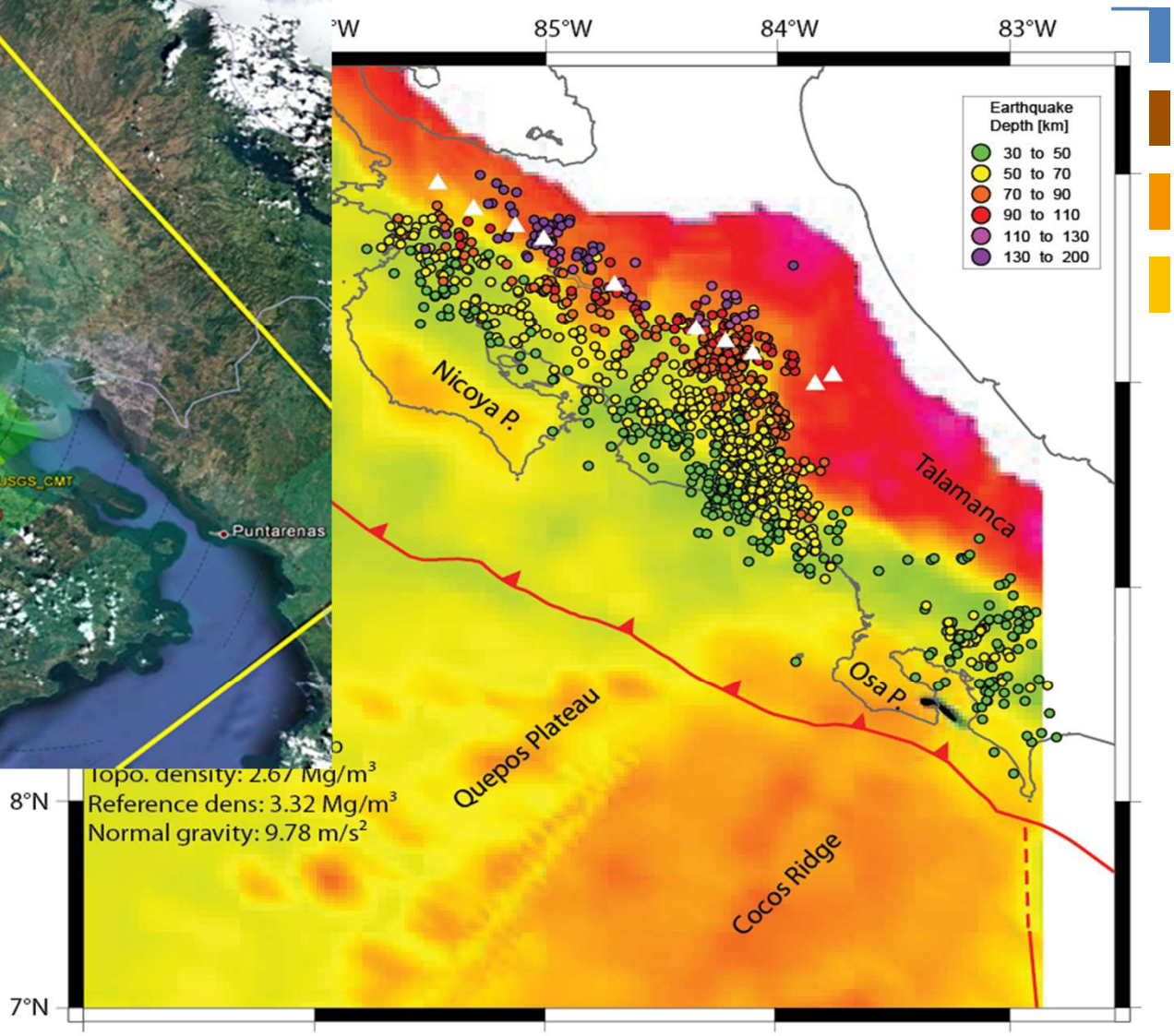
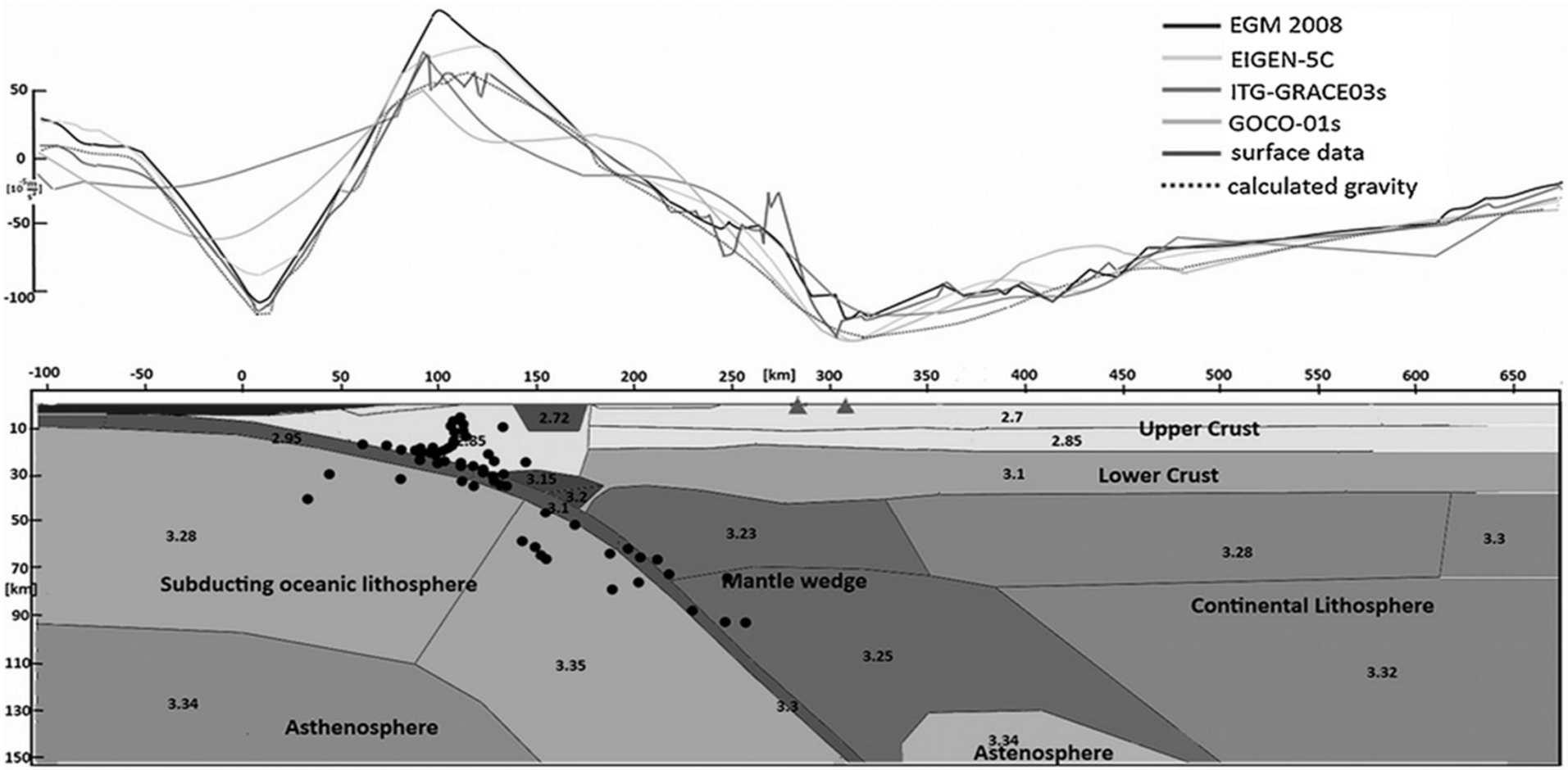


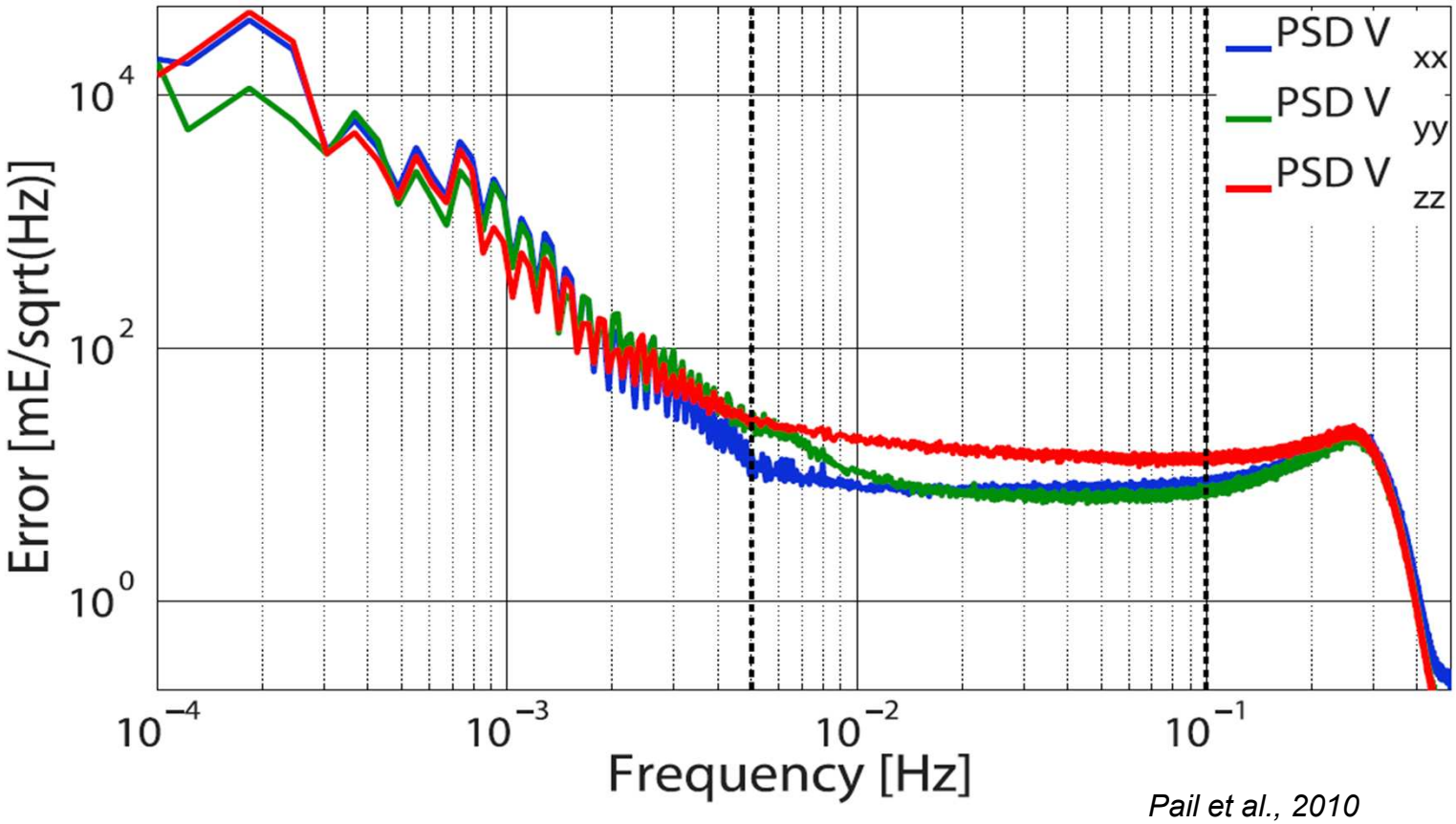


Gravity models



Gravity models

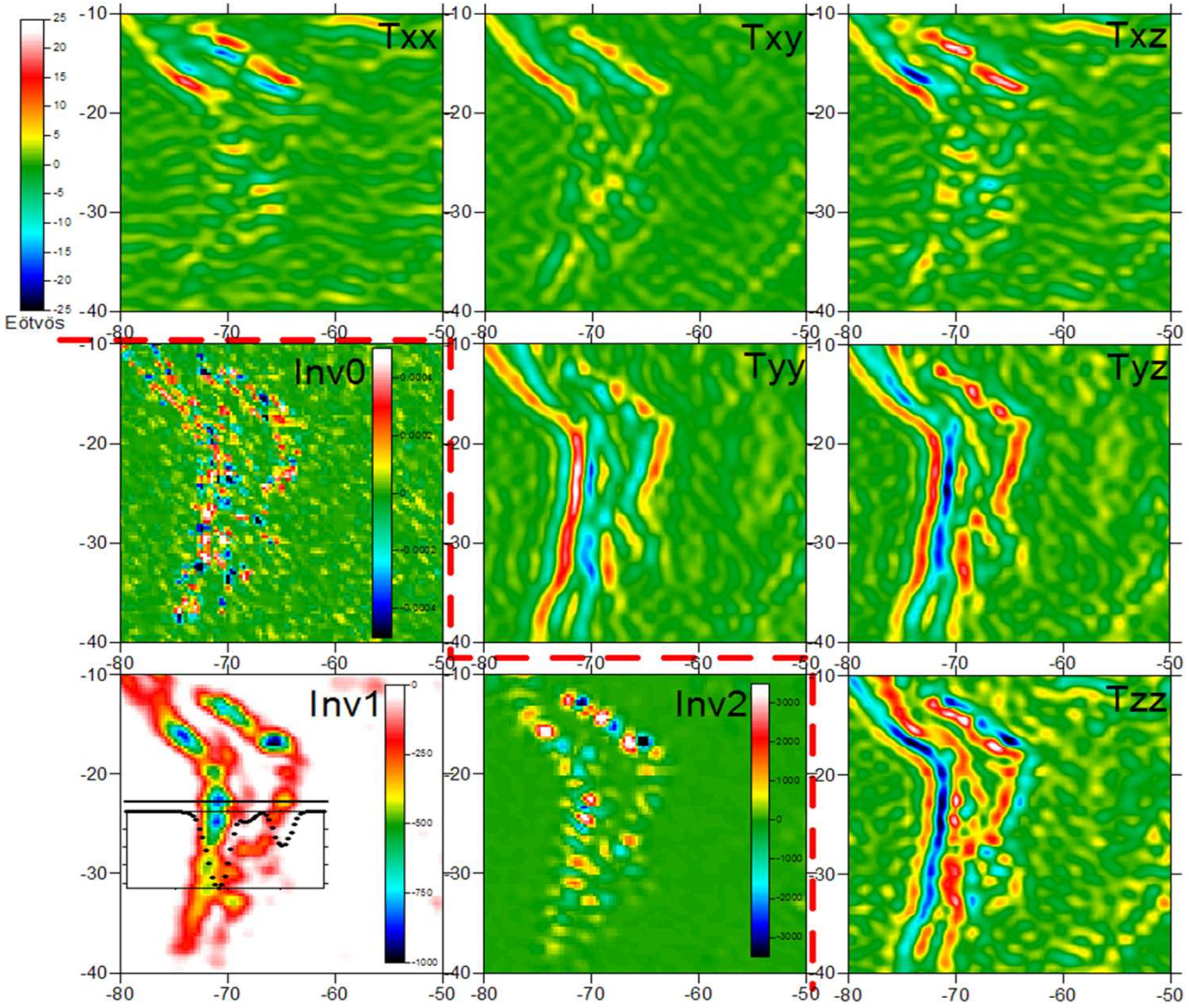
GOCE gradiometer error power spectral density (diagonal tensor components)



Pail et al., 2010

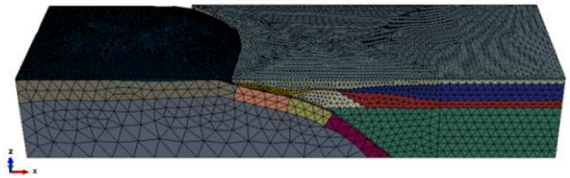
GOCE gravity gradient tensor and invariants

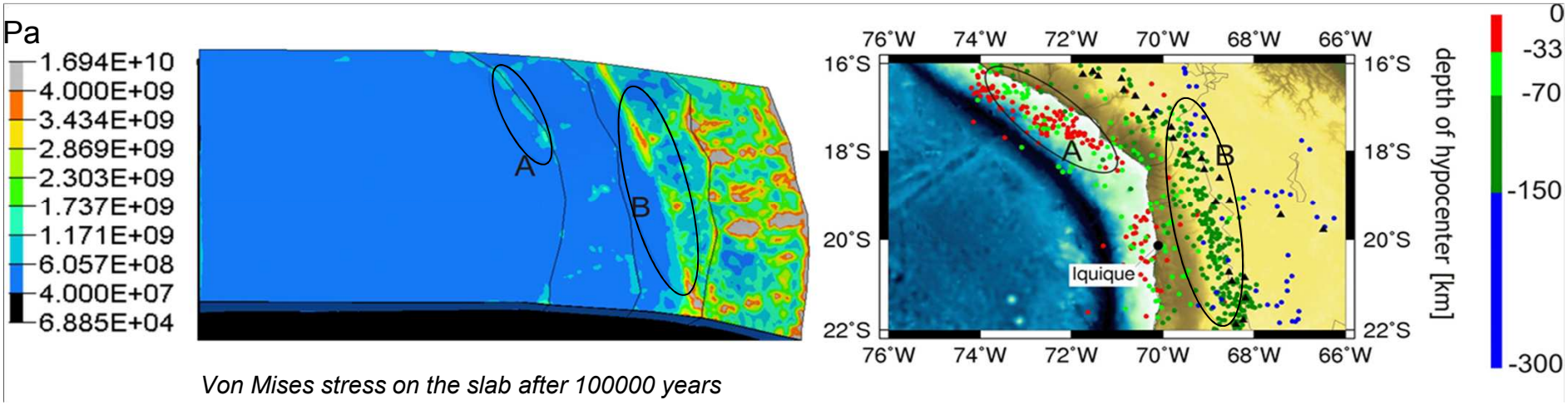
Goco02s gradients (‚free-air')



Stress estimates from dynamic modeling

- Regions with stress accumulation fit earthquake distribution
- Rheological parameters and friction coefficients influence the modeling results (stress and deformation field)
- Upper plate movement (South America) influences uplift



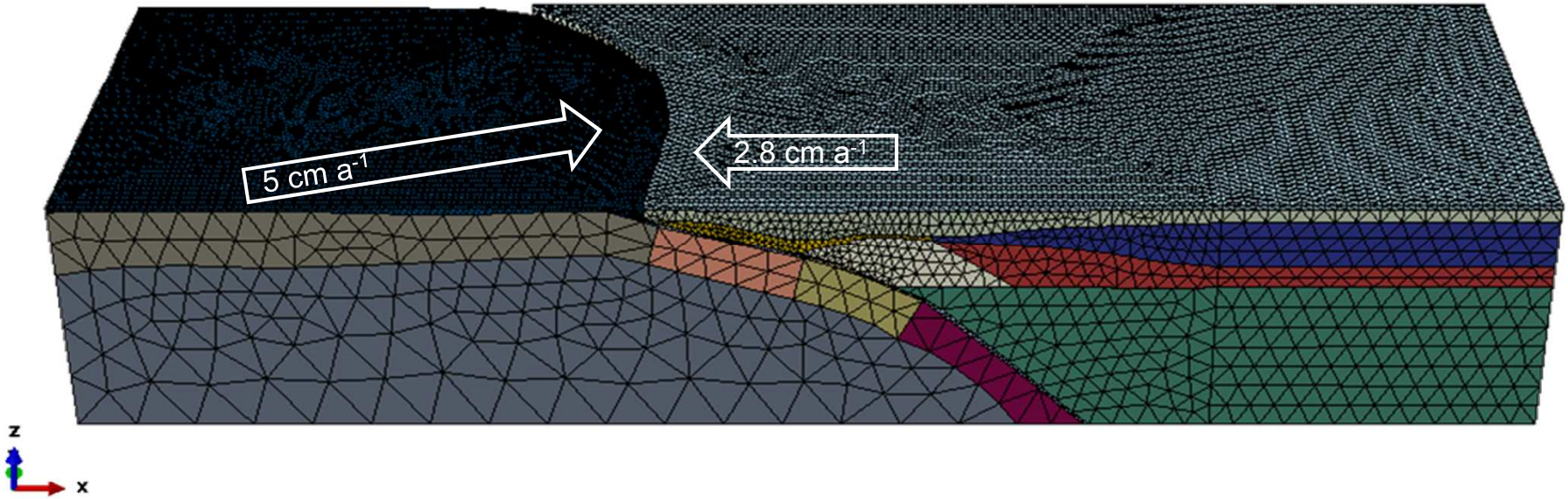


Von Mises stress on the slab after 100000 years

→ B1 poster: *St. Zeumann et al.*: Estimates of stress and deformation from static and dynamic modeling along the Andean convergent margin (IMOSAGA, SPP1257).

Stress estimates from dynamic modeling

- Gravity/density forward modeling is static but subduction is a geo*dynamic* process
- Developed a dynamic 3D model for the Iquique region (16°S-22°S) based on the Finite Element Method (FEM)



- Geometry of Tassara et al., 2006.
- Nazca plate oblique convergence: 5 cm a^{-1}, South America 2.8 cm a^{-1}
- Upper continental and oceanic crust is elastic, mantle and lithosphere viscoelastic