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Gravitational Seismology Project

NEW INSIGHTS ON THE DYNAMICS OF SUMATRA AND MARIANA COMPLEXES INFERRED FROM THE COMPARATIVE ANALYSIS OF GRAVITY DATA AND MODEL PREDICTIONS

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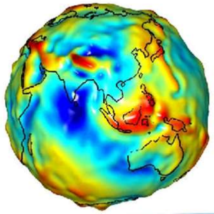
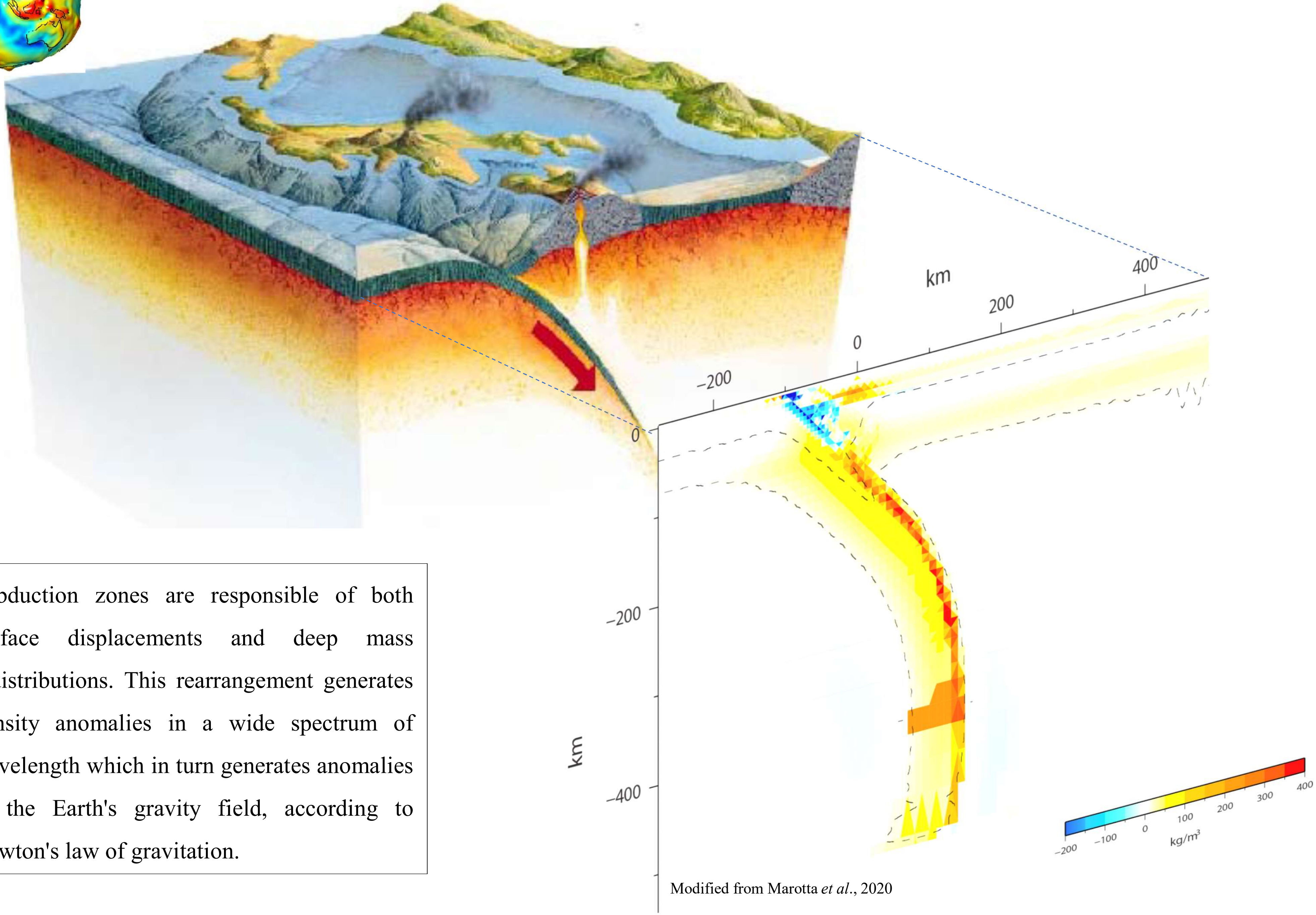
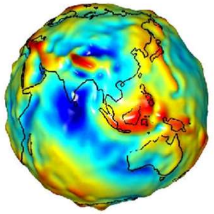


1. ORIGIN OF GRAVITY ANOMALIES



Subduction zones are responsible of both surface displacements and deep mass redistributions. This rearrangement generates density anomalies in a wide spectrum of wavelength which in turn generates anomalies in the Earth's gravity field, according to Newton's law of gravitation.

Modified from Marotta *et al.*, 2020



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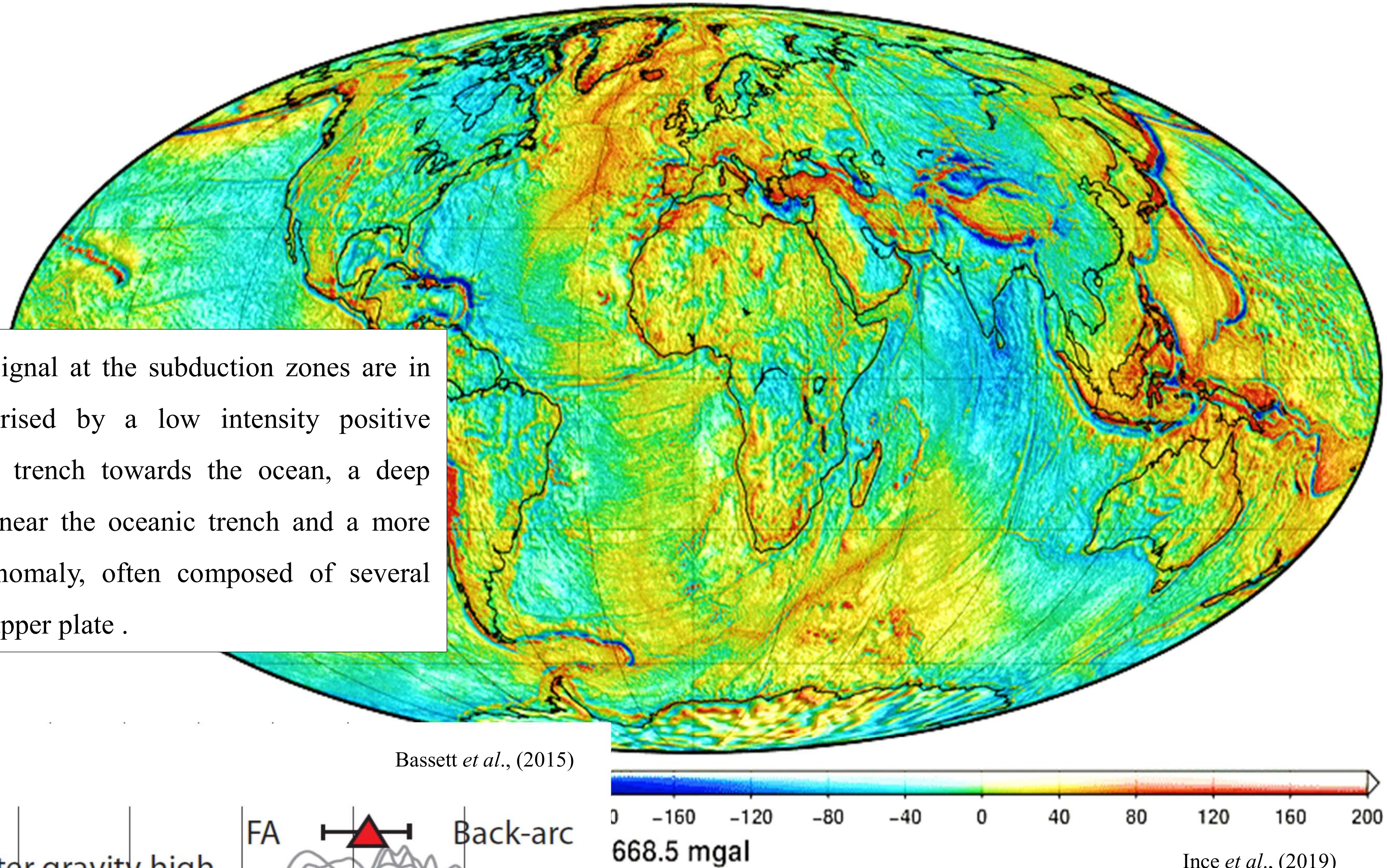
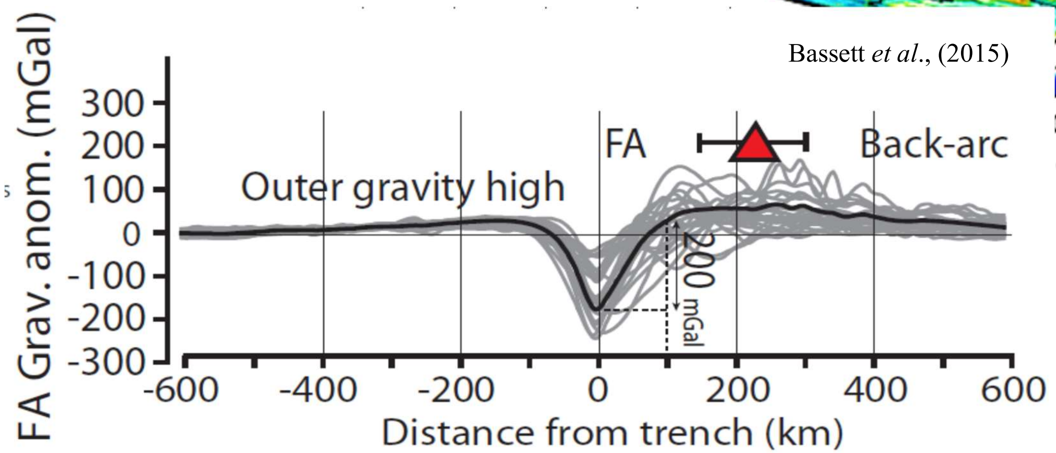


Ince *et al*., (2019)

The gravitational signal at the subduction zones are in generally characterised by a low intensity positive anomaly from the trench towards the ocean, a deep negative anomaly near the oceanic trench and a more intense positive anomaly, often composed of several peaks, toward the upper plate .



Bassett *et al*., (2015)

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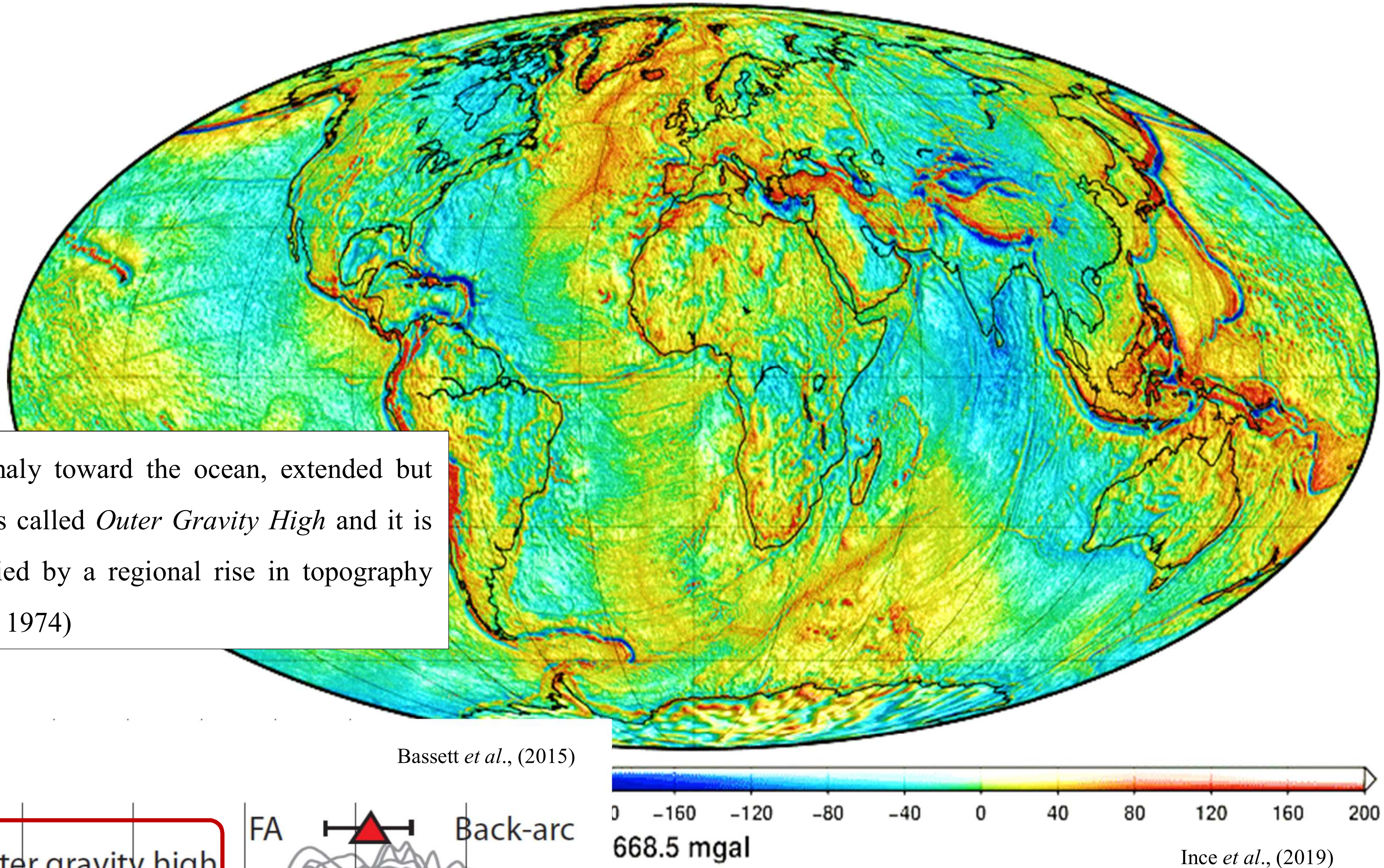
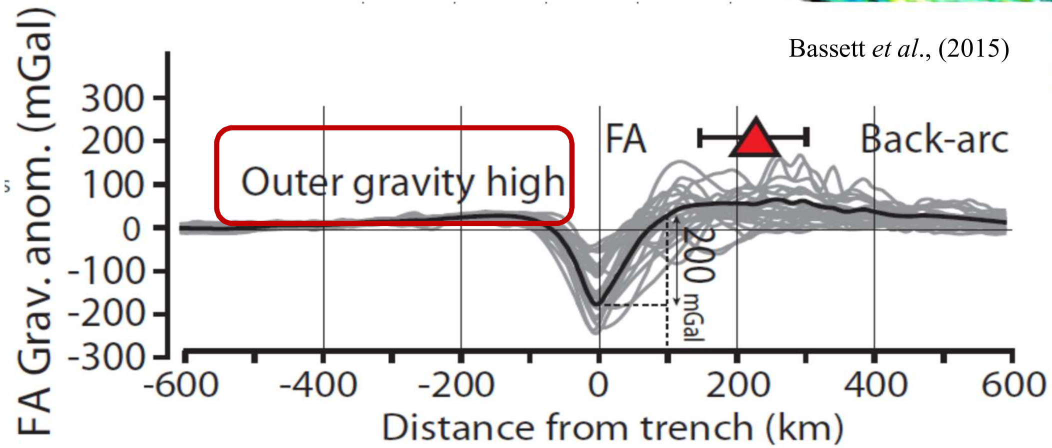
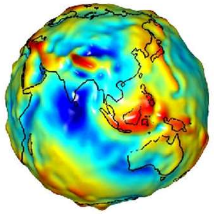


Ince *et al.*, (2019)

The positive anomaly toward the ocean, extended but not very intense, is called *Outer Gravity High* and it is general accompanied by a regional rise in topography (*Watt and Talwani*, 1974)



Bassett *et al.*, (2015)



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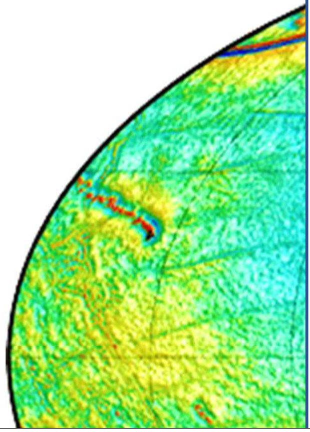
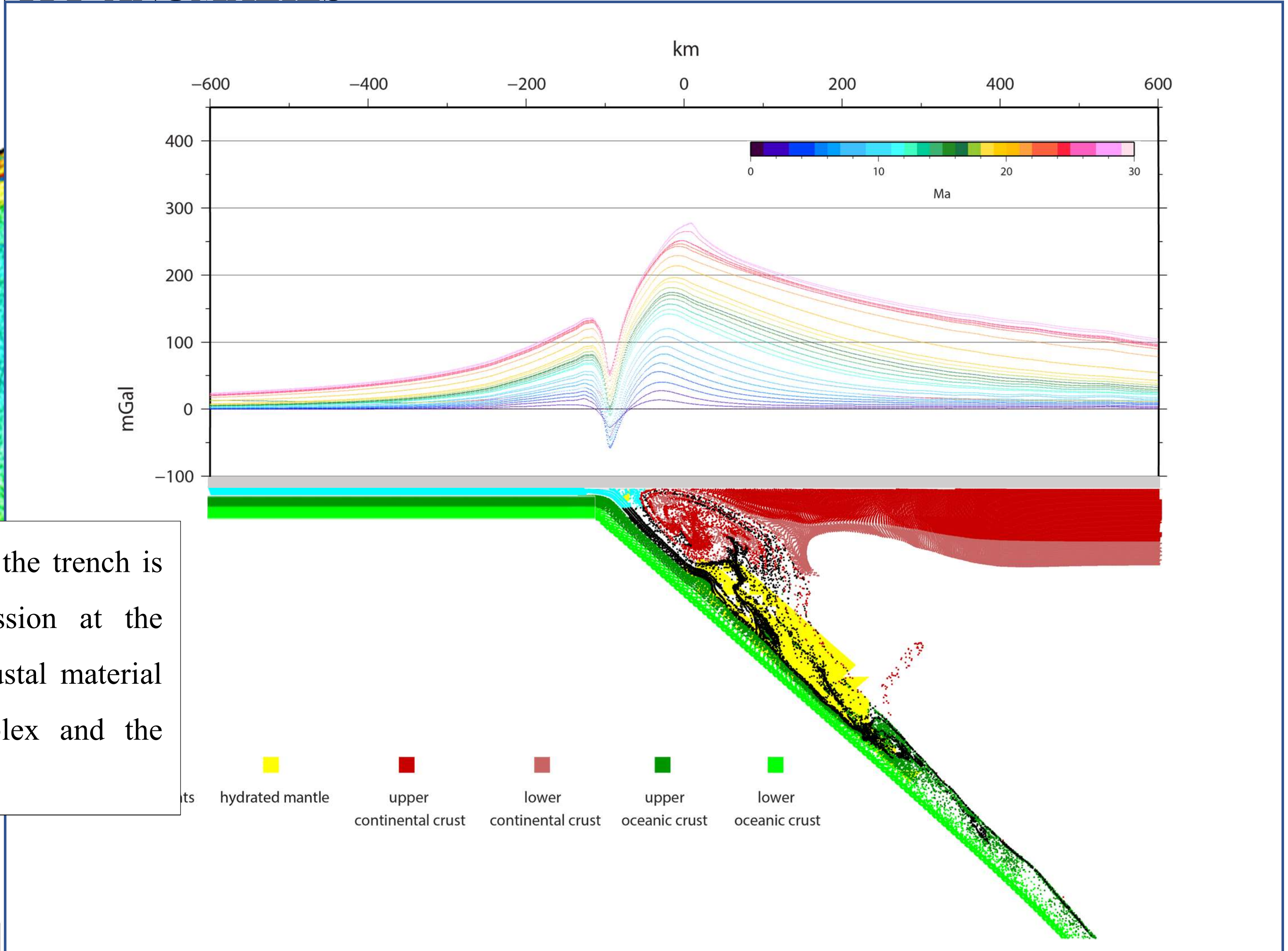
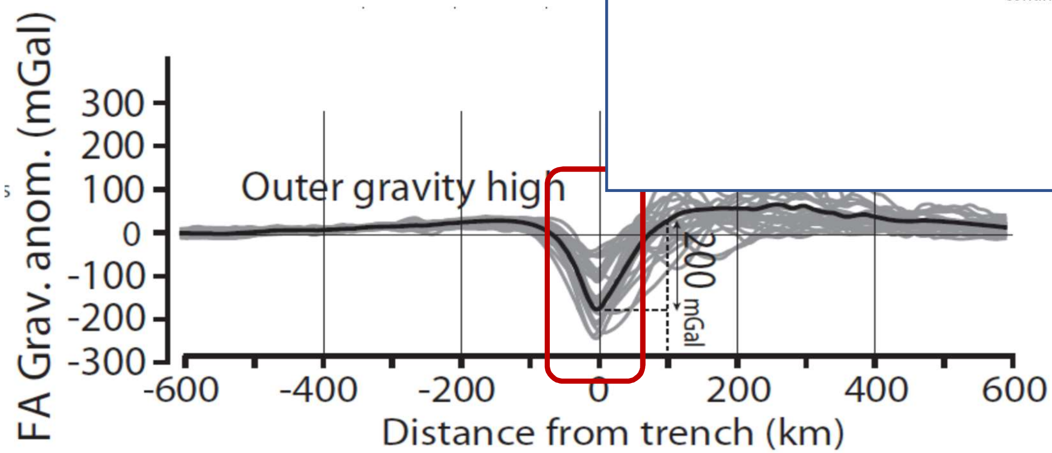
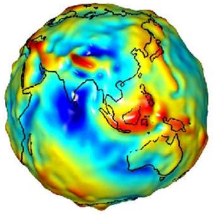




Modified from Marotta *et al.*, 2020

The negative anomaly in the vicinity of the trench is correlated to the topographical depression at the oceanic trench, the presence of light crustal material entrapped within the subduction complex and the hydration of the mantle wedge.





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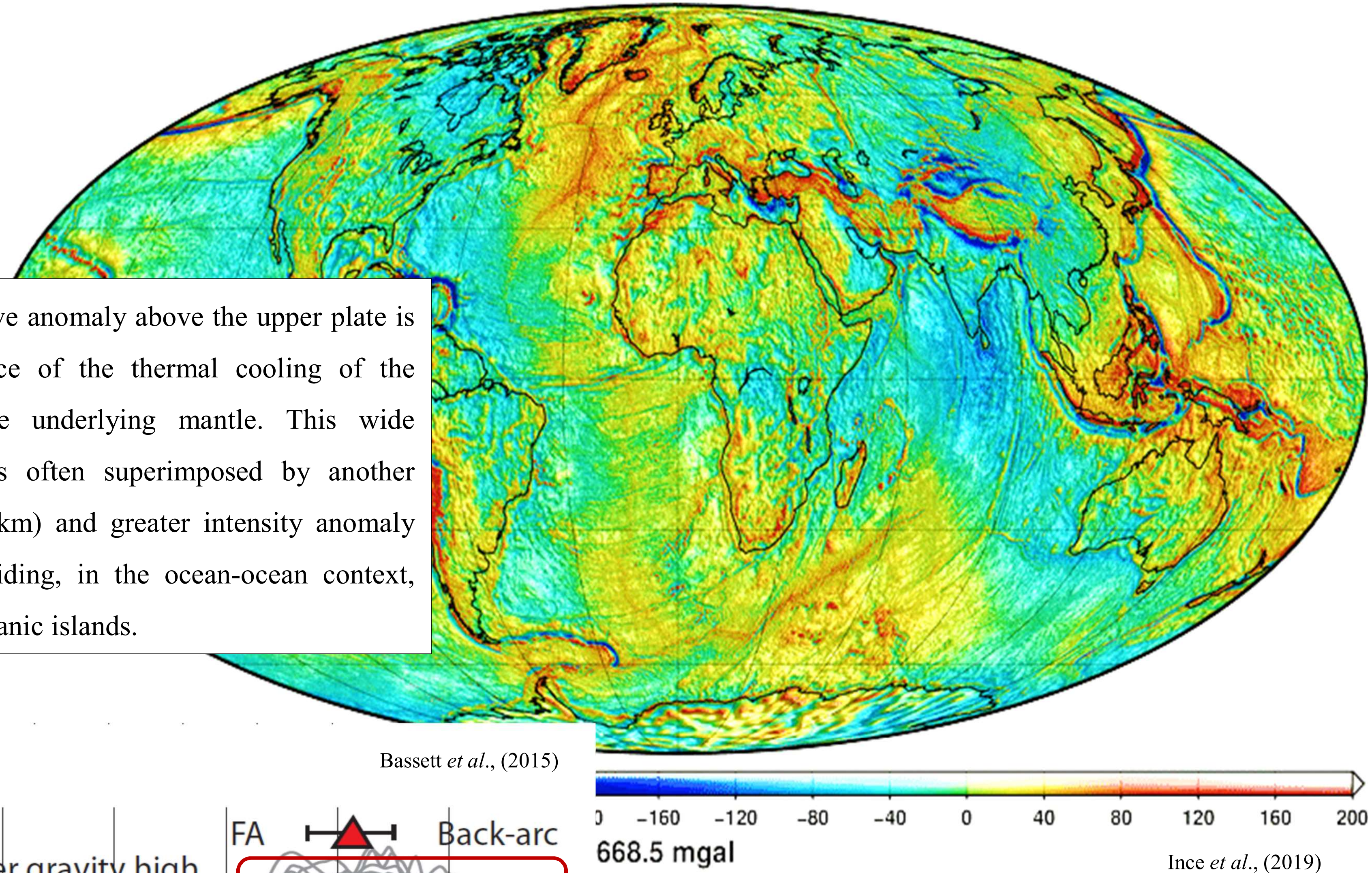
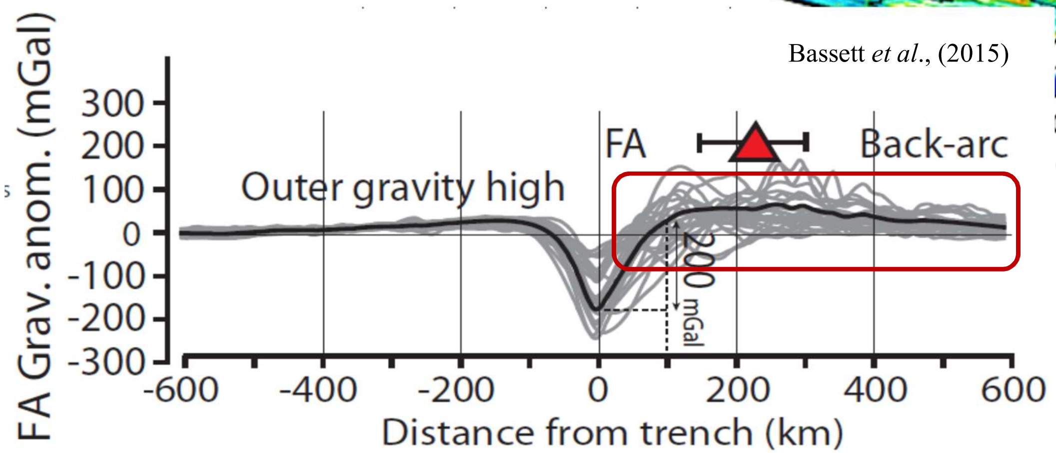


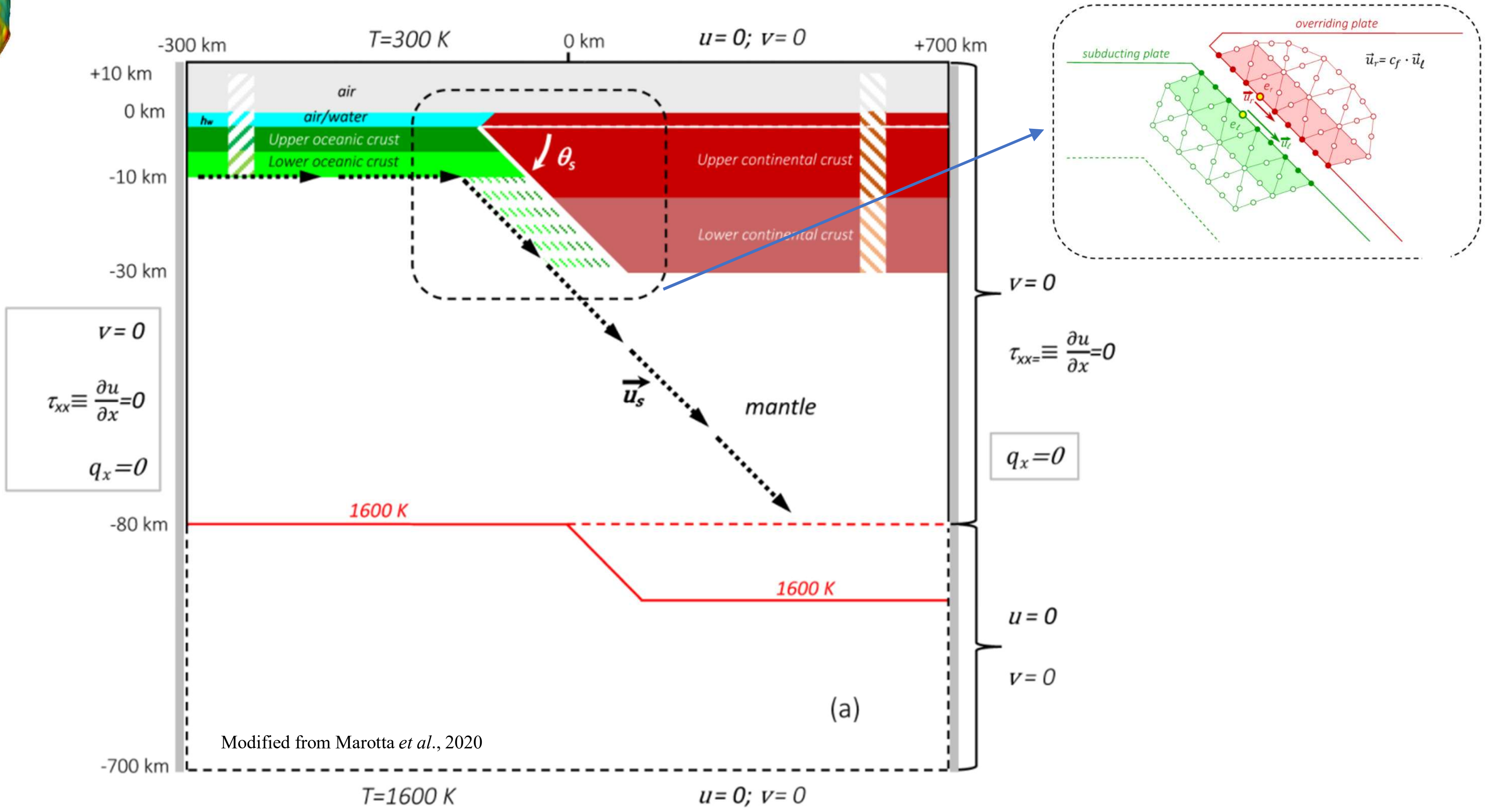
Ince *et al*., (2019)

The extended positive anomaly above the upper plate is a direct consequence of the thermal cooling of the lithosphere and the underlying mantle. This wide positive anomaly is often superimposed by another narrower (100-150 km) and greater intensity anomaly (>100 mGal) coinciding, in the ocean-ocean context, with the arcs of volcanic islands.



Bassett *et al*., (2015)

2. MODEL SETUP



MATHEMATICAL FORMULATION

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0$$

$$-\nabla p + \nabla \cdot \boldsymbol{\tau} + \rho \mathbf{g} = 0$$

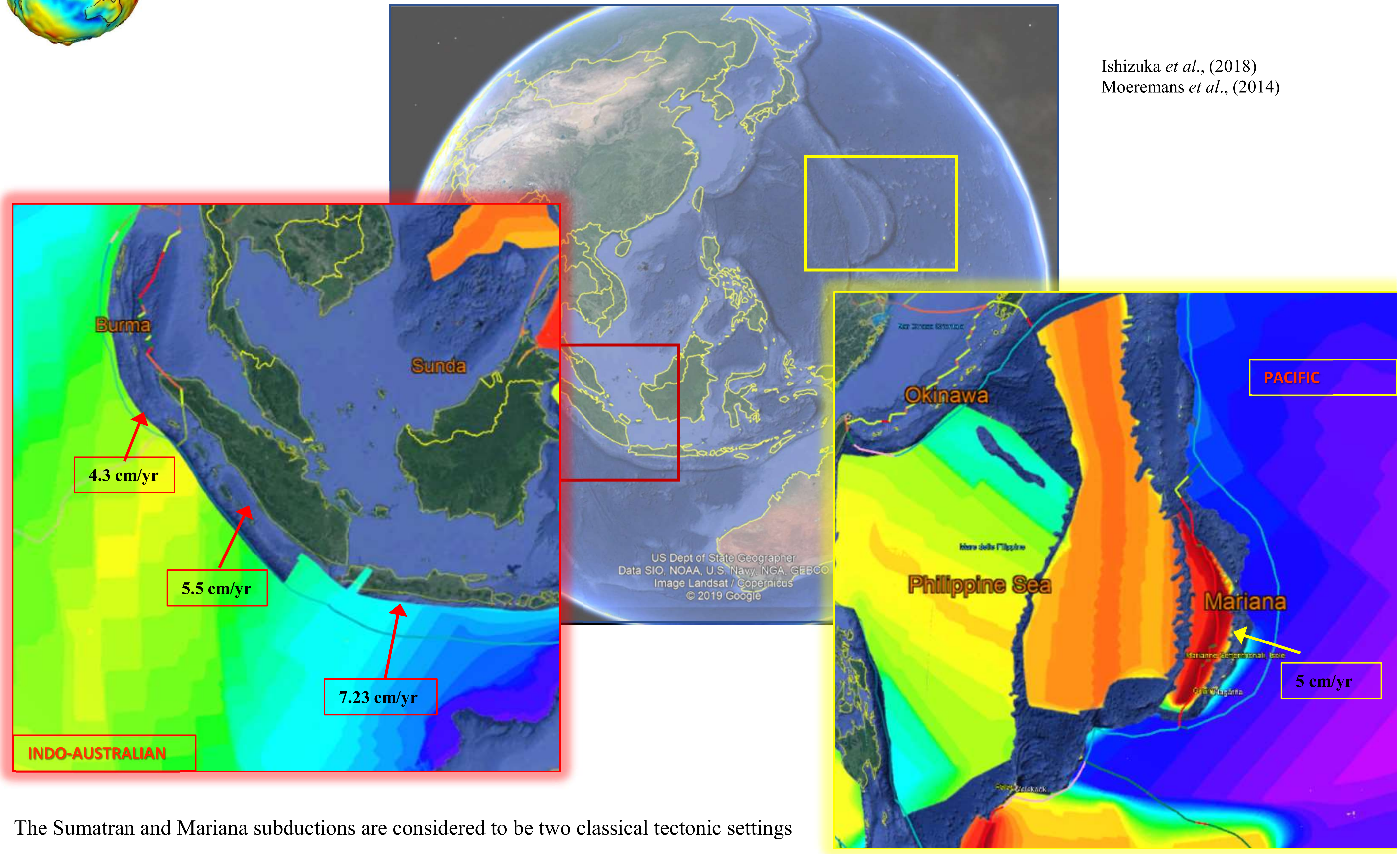
$$\rho C_p \left(\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T\right) = \nabla (K \nabla T) + H$$

IMPLEMENTED MECHANISMS

- Plate coupling
- Phase changes
- Mantle hydration and serpentinization
- Sedimentation/erosion

3. CASE STUDIES: SUMATRA AND MARIANA COMPLEXES

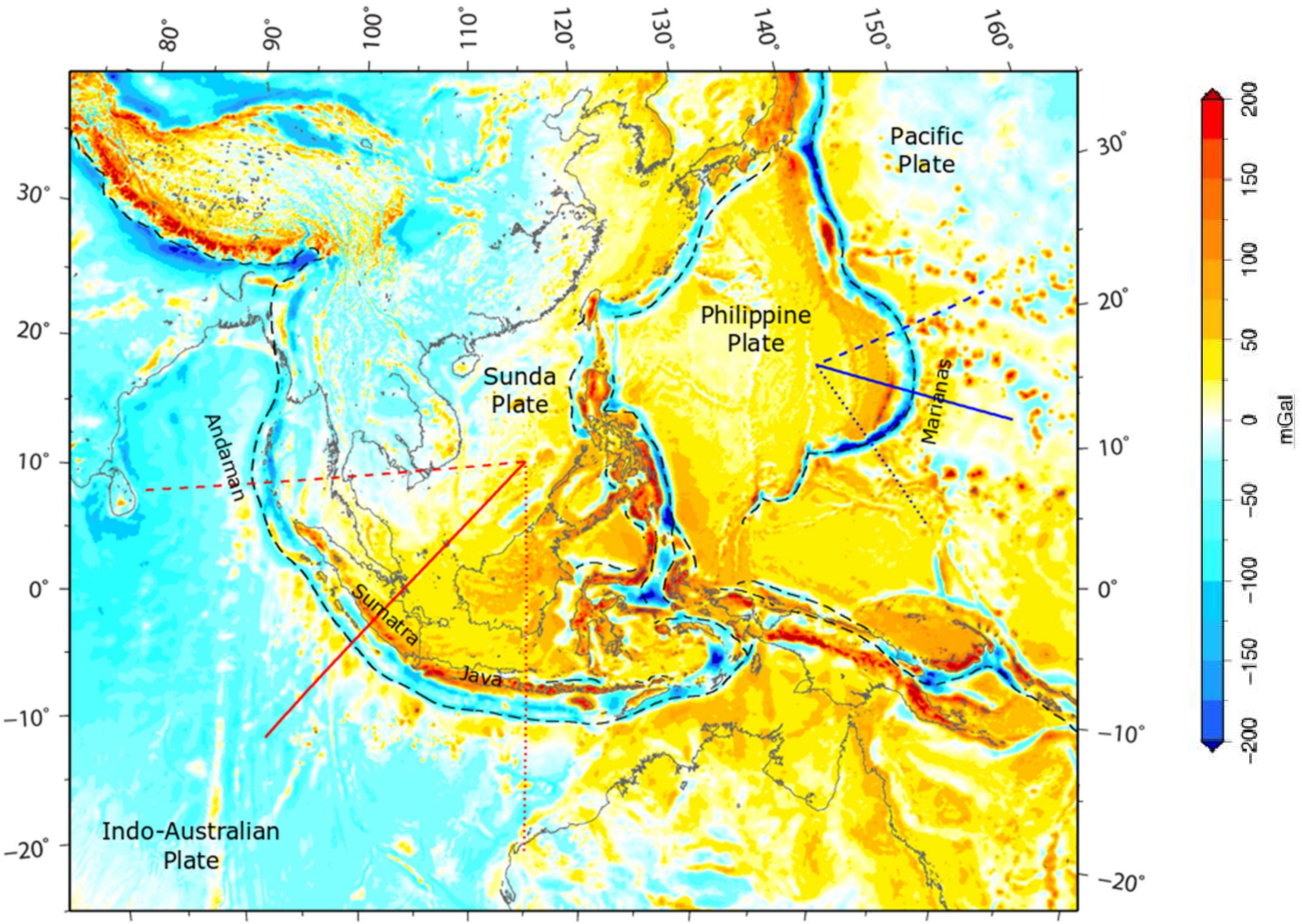
Ishizuka *et al*., (2018)
Moeremans *et al*., (2014)



The Sumatran and Mariana subductions are considered to be two classical tectonic settings representative of an ocean–continent subduction and an ocean–ocean subduction.

3. CASE STUDIES: SUMATRA AND MARIANA COMPLEXES

- Regional gravity pattern



Marotta *et al*., 2020 based on EIGEN 6c4 (Förste *et al*., 2014)

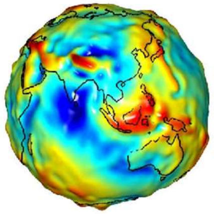
EIGEN 6c4 gravity disturbance: $\delta g(h,\lambda,\phi) = g(h,\lambda,\phi) - \gamma(h,\phi)$

3. CASE STUDIES: SUMATRA AND MARIANA COMPLEXES

- Comparative analysis

- For the Sumatra subduction, we consider all the ocean-continent models with a subduction velocity of 5 cm/yr, compatible with the tectonic information of previous slide, and we calculate the gravitational contribution of the mass distribution predicted after approximately 40 Myr from the beginning of the subduction, accounting for a 4 km thick ocean overlying the subducting plate. Below the discussion will be limited to the only model that shows the best agreement with the data, namely, model *OC*3

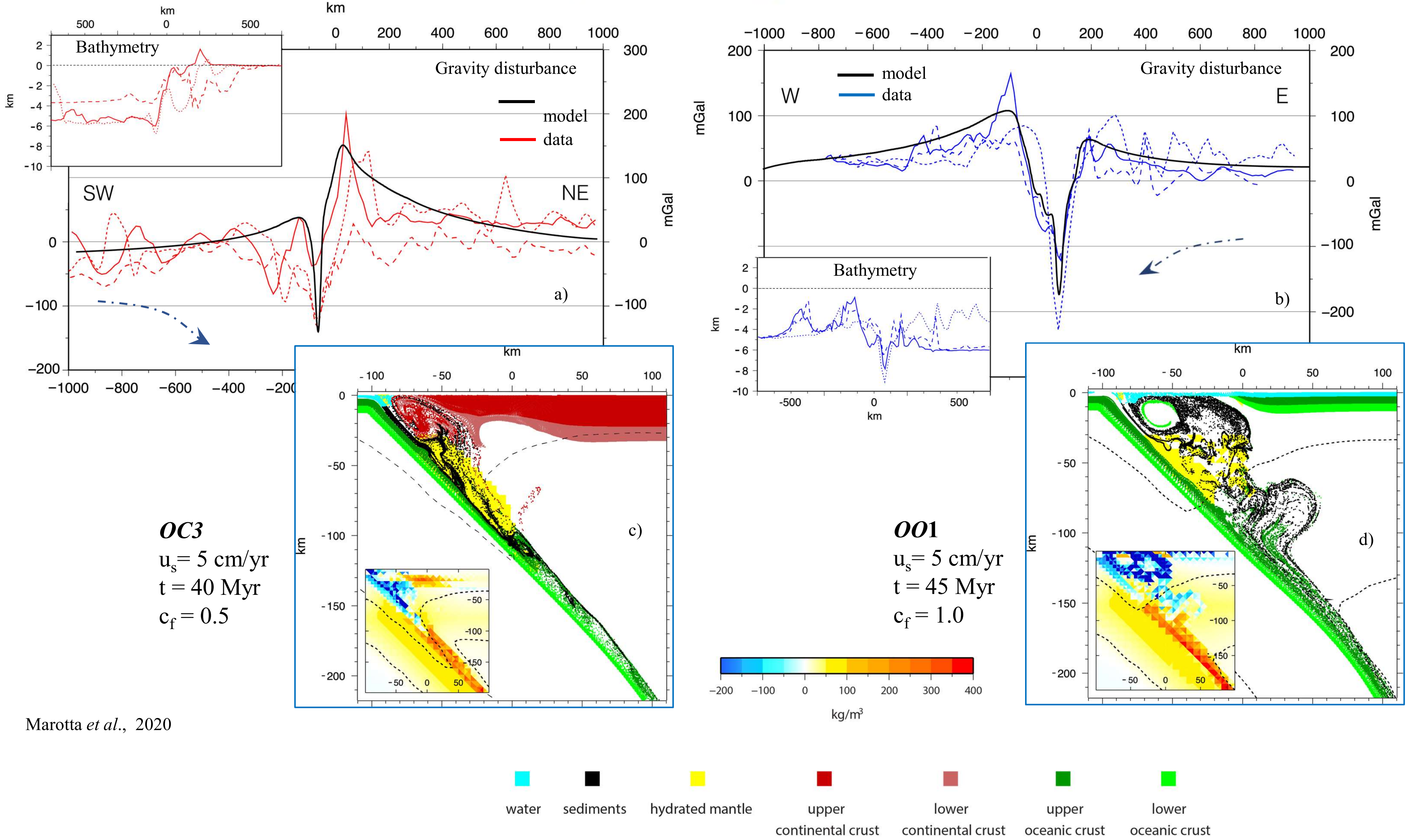
- For the Mariana subduction, we consider all the ocean-ocean models with the same value of subduction velocity of 5 cm/yr as for Sumatra, and we calculate the gravitational contribution of the mass distribution after 45 Myr, compatible with Sumatra, accounting for 5 km thick ocean overlying the subducting plate and a 4 km thick ocean overlying the overriding plate. Below the discussion will be limited to the only model that shows the best agreement with the data, namely, model *OO*1.



3. CASE STUDIES: SUMATRA AND MARIANA COMPLEXES

- Comparative analysis

Model gravity disturbance: $\delta g^{model}(h,x,t) = g^{model}(h,x,t) - \gamma^{model}(h,x,t)$

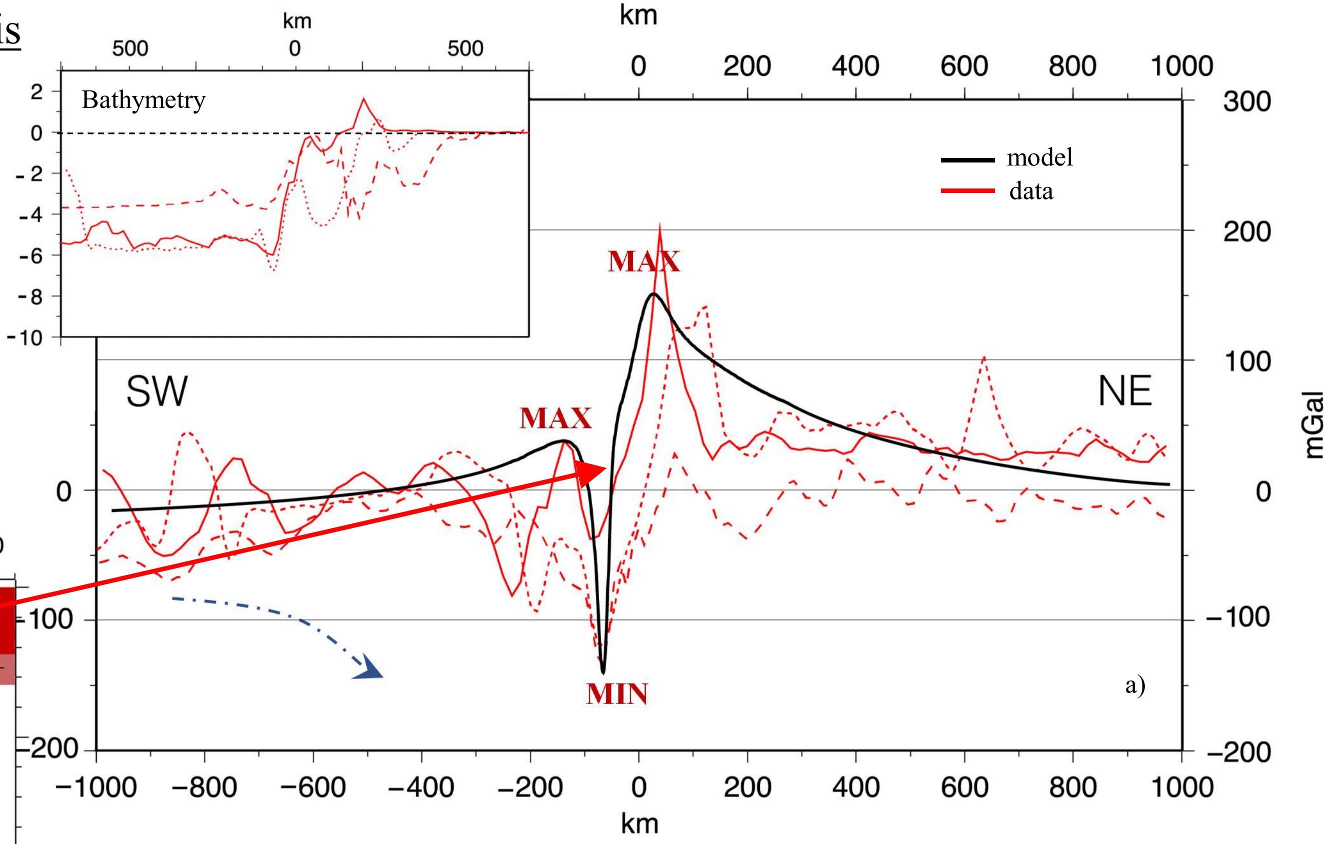


Marotta *et al.*, 2020

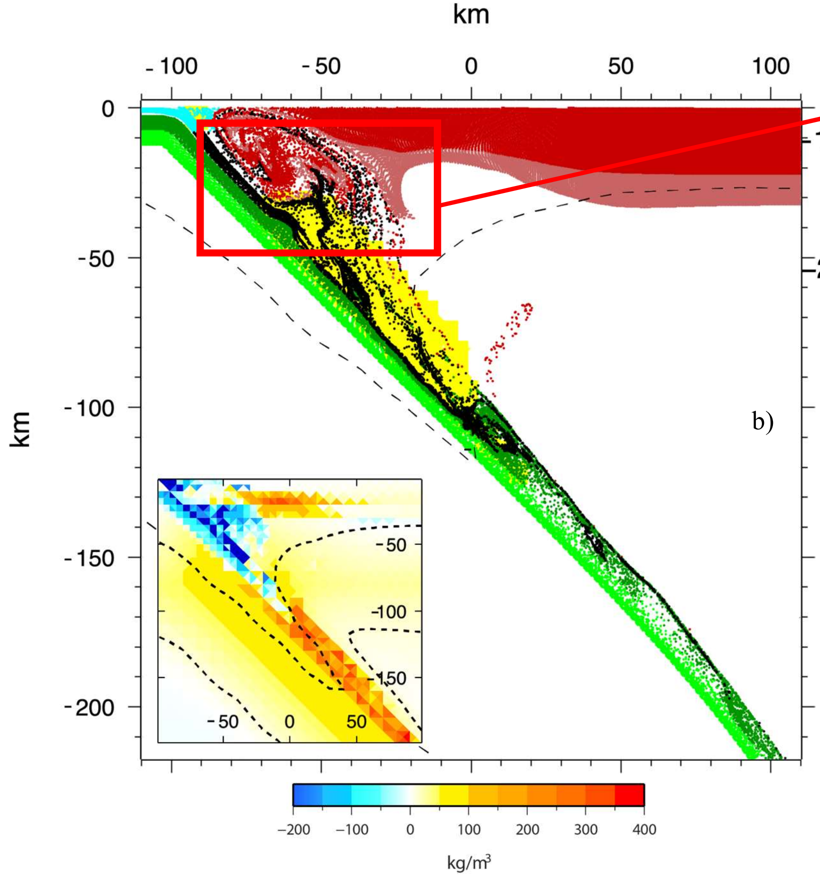
3. CASE STUDIES: SUMATRA AND MARIANA COMPLEXES

- Comparative analysis

- **SUMATRA → ocean-continent subduction**



Marotta *et al.*, 2020

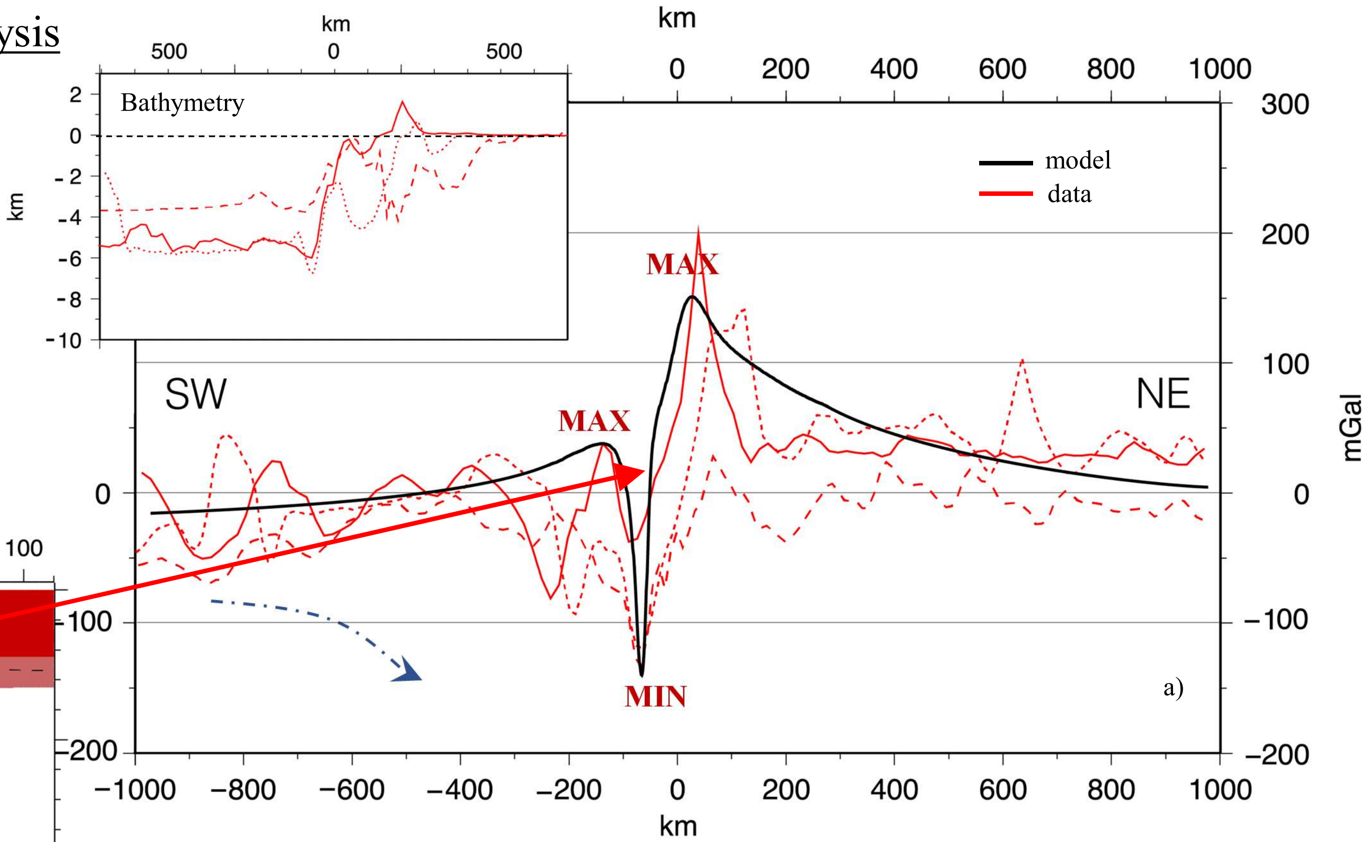


The model (solid black curve) fits the envelope of the profiles well in terms of positioning and height of the maxima of 30 and 200 mGal with a depth of the trough or gravitational disturbance minimum of -120 mGal.

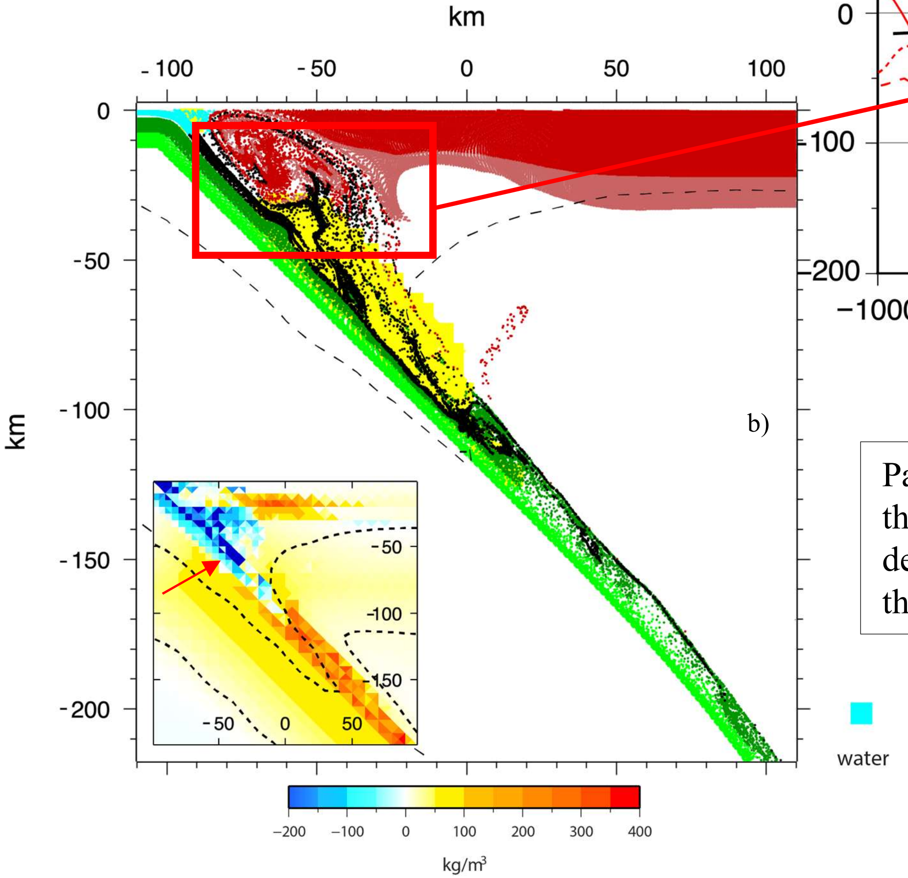
3. CASE STUDIES: SUMATRA AND MARIANA COMPLEXES

▪ <u>Comparative analysis</u>

- **SUMATRA** → **ocean-continent subduction**



Marotta *et al*., 2020

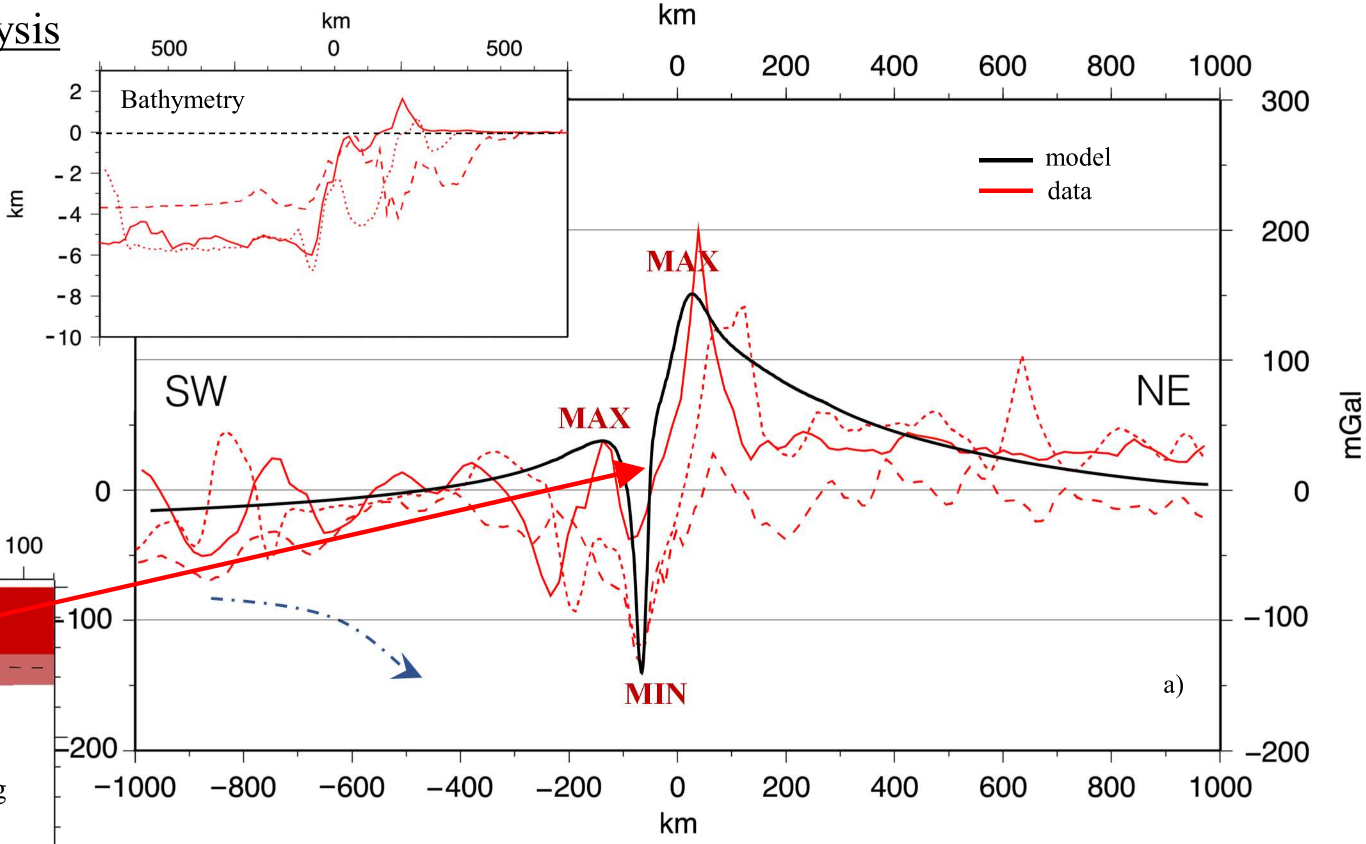


Panel b) provides the explanation for this gravitational disturbance pattern due to the narrow region of negative density contrast, as large as 80 km at most, to a depth of approximately 80 km, embedded between the subduction cold plate and the upwelled lithospheric mantle.

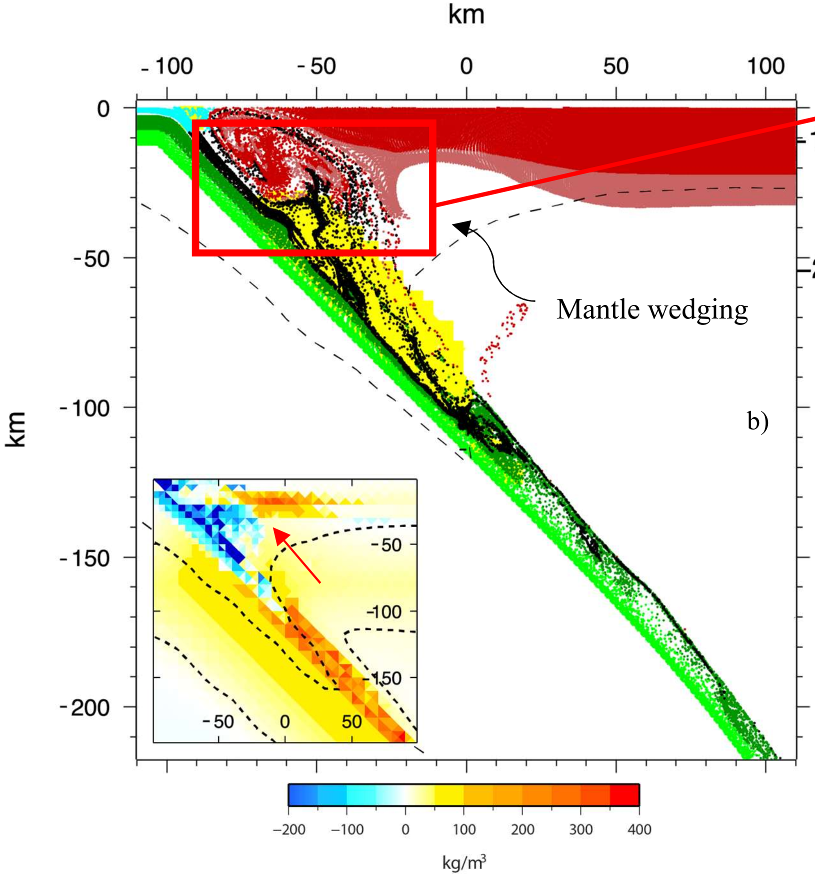
3. CASE STUDIES: SUMATRA AND MARIANA COMPLEXES

- Comparative analysis

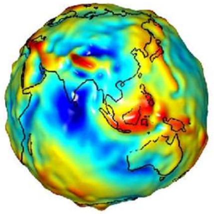
- **SUMATRA → ocean-continent subduction**



Marotta *et al.*, 2020



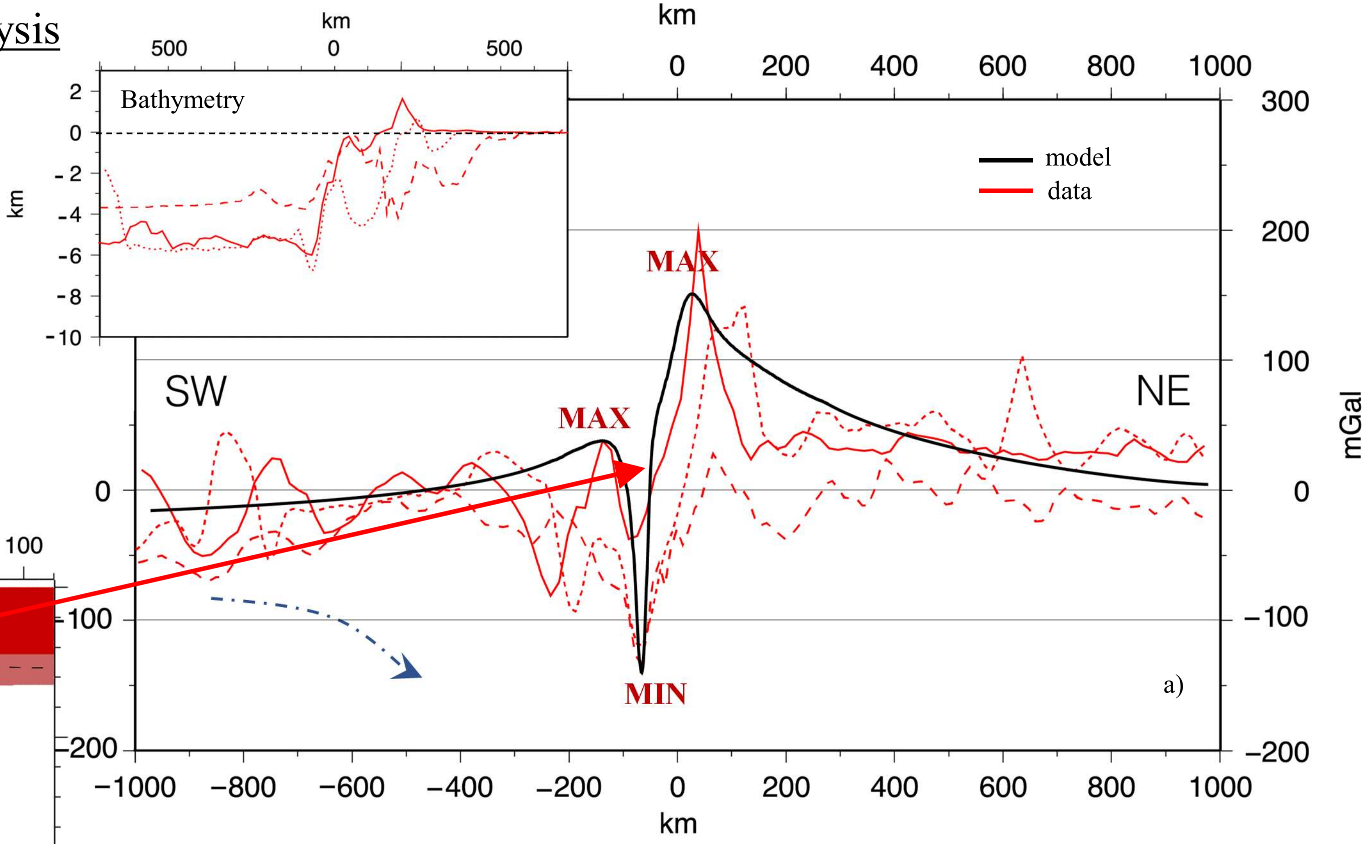
This mantle substitutes the less dense continental crust, as indicated by the white region below the thinned crust thus producing a positive density contrast, portrayed by the shallow red zone in the inset of panel b).



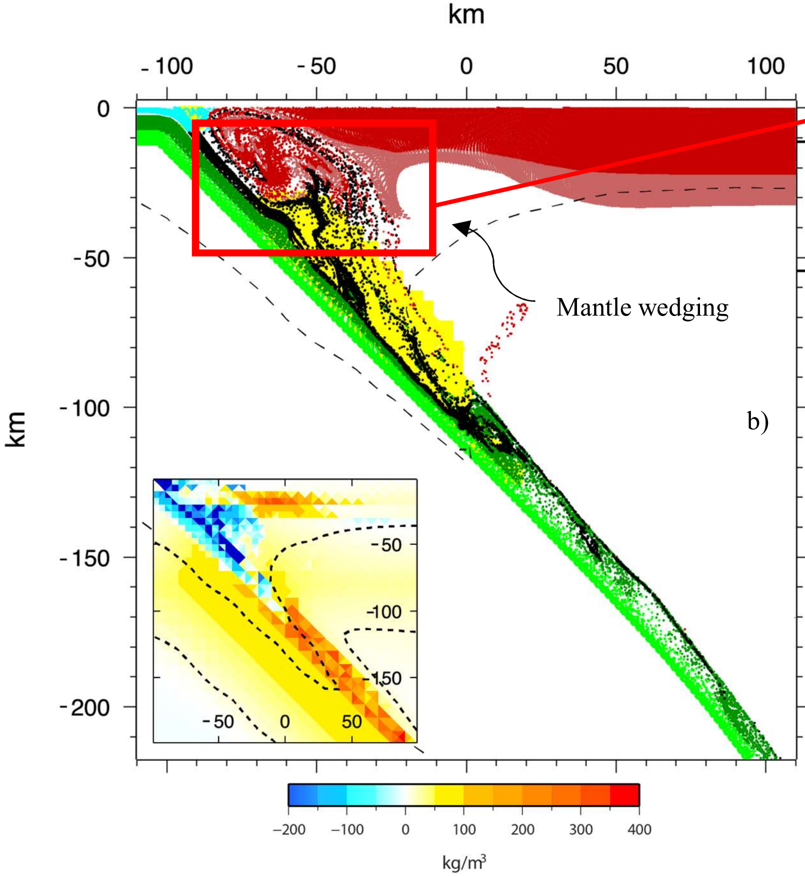
3. CASE STUDIES: SUMATRA AND MARIANA COMPLEXES

- Comparative analysis

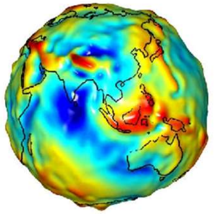
- **SUMATRA → ocean-continent subduction**



Marotta *et al.*, 2020



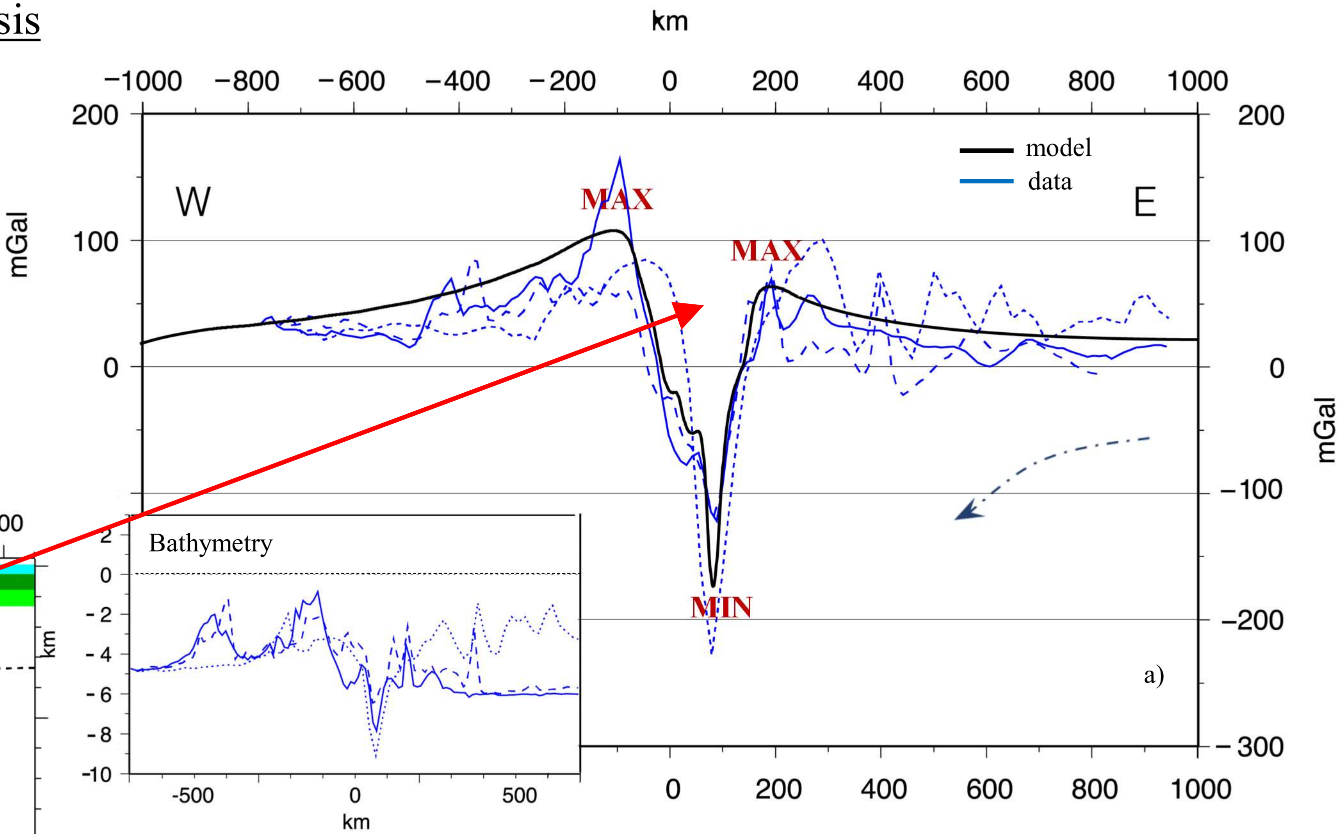
This shallow positive density contrast is thus effective in the thinning of the trough in the ocean-continent subduction. Furthermore, this positive density contrast has the effect of increasing the positive gravitational peak located on the continental side.



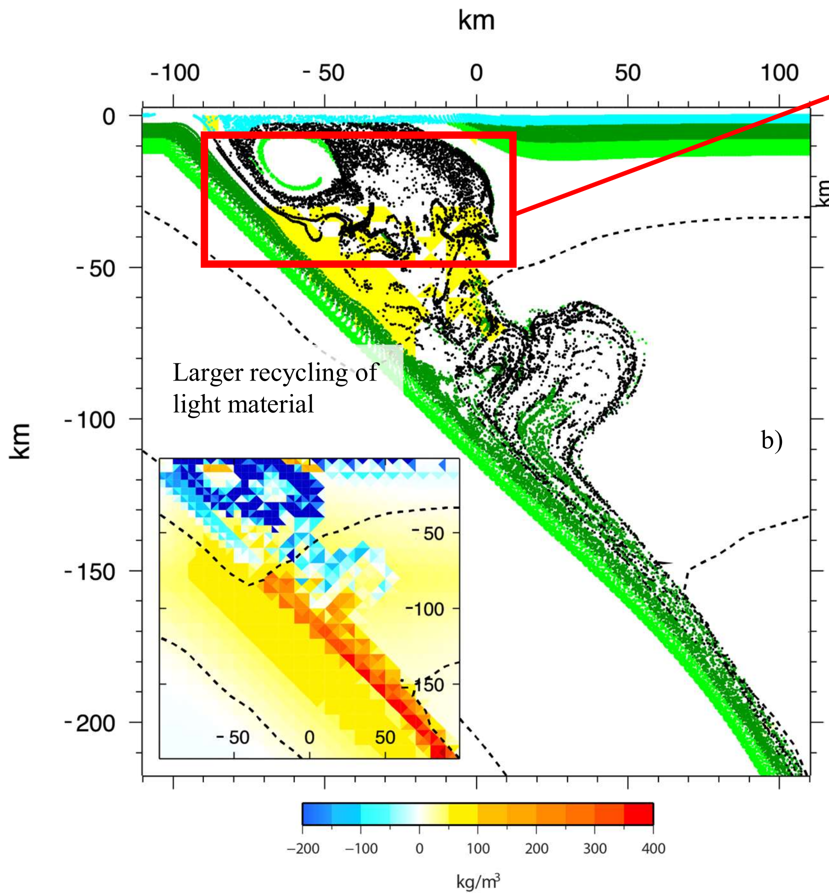
3. CASE STUDIES: SUMATRA AND MARIANA COMPLEXES

- Comparative analysis

• **MARIANA → ocean-ocean subduction**



Marotta *et al*., 2020

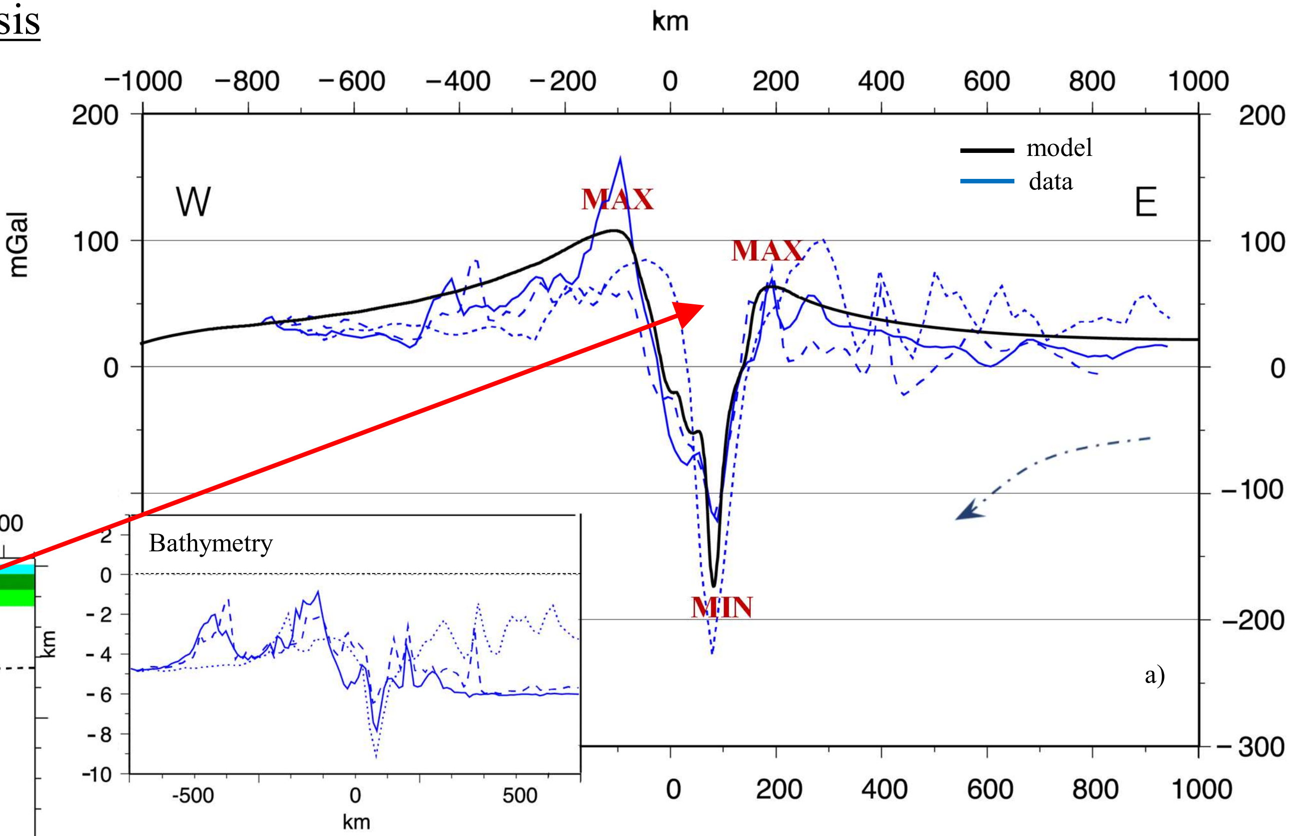


The ocean-ocean subduction is characterised by a large recirculation of light material in the mantle wedge, which is responsible for the wide region of negative density contrasts in blue in the inset of panel b), encompassing a region in the horizontal direction as large as approximately 150 km and leading to the prediction of a large gravity trough in agreement with the data.

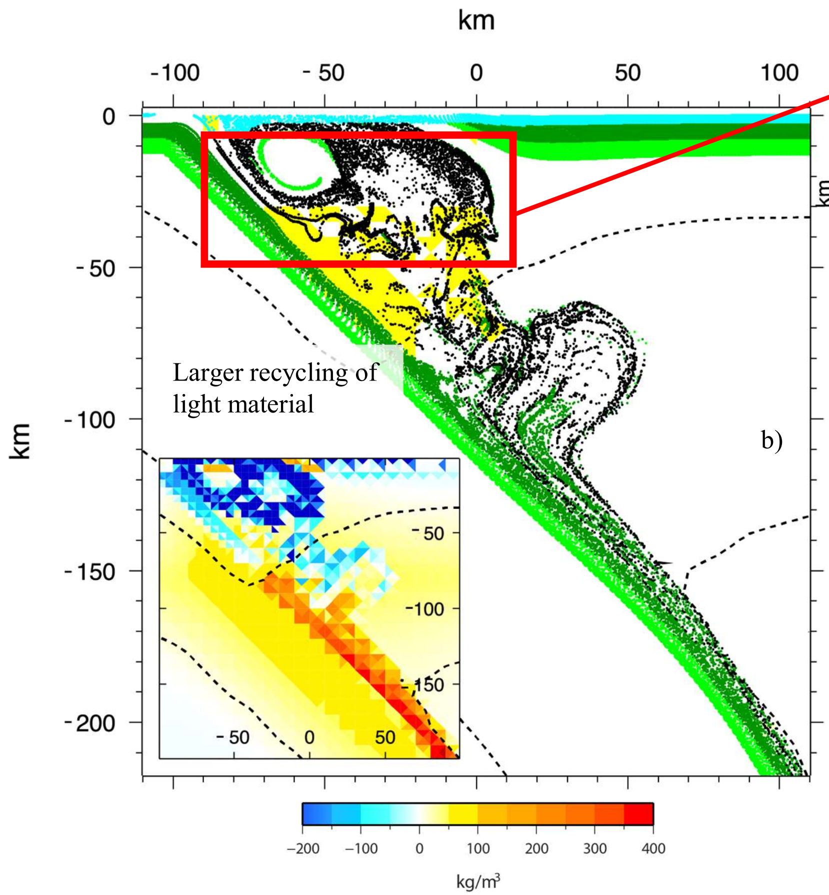
3. CASE STUDIES: SUMATRA AND MARIANA COMPLEXES

- <u>Comparative analysis</u>

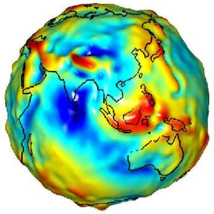
- **MARIANA → ocean-ocean subduction**



Marotta *et al.*, 2020



Another major difference that makes the distribution of light material more effective in the ocean-ocean subduction in the formation of a pronounced and wide gravitational trough relies on the fact that in this type of subduction, in contrast to the ocean-continent one, the dense mantle does not substitute the lighter continental crust.

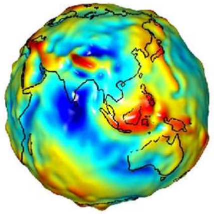


4. CONCLUSION

- Our modelling is able to reproduce the gravity disturbance difference of 250-300 mGal well between the maximum and the minimum, characterising both types of subduction. In the same way it reproduces the fundamental differences highlighted by the EIGEN-6C4 data:
  - the width of the trough (larger for the ocean-ocean subduction than for the ocean-continent one);
  - the symmetry, in terms of the different amplitudes of the two positive gravity peaks facing the trench.

- Our study provides a physical explanation for the broadness of the negative gravitational contribution for mature subductions (as the Mariana) compared to immature ones.

- Finally, our results have allowed us to strengthen the analysis of the gravitational signature in ocean-continent and ocean-ocean subductions, providing important information not only on their anomalous density structure but also on the dynamics of the subduction process.



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ACKNOWLEDGEMENTS

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Thanks for your attention !