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Solid Earth
Discussions

Interactive comment on "Gravity Effect of Alpine Slab Segments Based on Geophysical and Petrological Modelling" *by* Maximilian Lowe et al.

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General Comments

The study can be described a sensitivity analysis of the gravity field to the density variations in the depth range between 70 and 200 km below the Alps and surrounding areas. Several experiments are made to define the expected density variations. First a tomography model of percentage velocity variations respect to a reference model is converted with a constant conversion factor to expected densities contrasts respect to background model, leading to a density range +- 350 kg/m3. The corresponding gravity field extends over a range of 400 mGal, dominated by long wavelengths of several hundreds of km. Then the geometry of a number of lithospheric slabs is assumed to be present

below the Alps, and the possible slab geometries are defined from a selection of seismic tomography models. The depth range which is modelled goes from 40 to 220 km, and a fixed density contrast against the mantle of the slabs is defined. The thickness of the slabs varies between 60 and 100 km, density varies between 20 and 80 kg/m3, and the signal varies from a minimum of 30 mGal to a maximum of 140 mGal, depending on the density contrast and assumed slab thickness, with greater signal for thicker slab and greater density contrast. The effect of composition, temperature and pressure are considered when calculating the probable densities through the Litmod software. Essentially two mantle compositions, the Tecton and the Proterozoic type compositions are used for the two-layer background model of the mantle and for the subducting slabs, in different combinations of lithospheric mantle and sub-lithospheric mantle. The reference model has a lithosphere 100km thick, overlying the sub-lithospheric mantle, which should be equivalent to the asthenosphere. Here the slab is divided into a lithospheric and sub-lithospheric slab. Conceptually this is strange, since the subducting slab is made of lithosphere, and the asthenosphere would not rigidly participate in the subduction process. In the study, the subducting slab is divided into a lithospheric slab and a sub-lithospheric slab segment-with different compositions, and in some cases a reduction in temperature in the sub-lithospheric slab. I wonder whether this distinction is necessary, if it would not be sufficient to define a subducting slab of composition of different types, against the mantle reference model. In the Litmod modeling of the slabs, observing the vertical section of the model (Figs. 8 and 12), the slabs seem to be vertical columns, extending from the Moho down to over 200 km depth. Since in the first part of the study the slab geometries were defined through the seismic tomography, I wonder whether also the same inclined slab geometries were used in the Litmod model- from the figures it is not clear.

In Fig. 1 the simple Bouguer anomaly is shown in map, but the field is not used in the remainder of the manuscript, not in the comparison to the simulated fields nor in defining the residuals with the simulated fields, nor in the discussion. The estimation of the correctness of the simulated fields requires comparison with the observed gravity field, which is presently lacking in the study. The only statement made, is that the observed amplitude of 200 mGal is not too much larger than the modelled slab effect of 40 mGal. Alternatively, the manuscript could clearly state that it is a sensitivity analysis to slab geometries through the gravity field in the Alpine area, without the target of formulation a realistic density model, since the verification with the observed field is lacking.

The sensitivity analysis as such is of value and is potentially of interest to scientists interested in defining slab geometries through geophysical modeling.

Detailed comments

Here first the text from the manuscript is copied, and comments start with the symbol "->"

L.10: The opposing slab configurations. -> This sentence is disconnected from previous one- better introduce the opposing slabs before.

L. 12: reflects or results? L.14-15: Therefore, we define the geometry of the upper slab interface by using the crustal thickness at 40 km depth as upper starting point -> This sentence is difficult to understand and the picture is not clear. If the slab is not resolved, why this would lead to defining upper slab interface? Starting point for what? Please reformulate abstract.

L. 16: the slab interface. -> Not clear which interface of slab is meant.

L. 17: -> the slab configuration is defined by the tomography or by the gravity modeling? Make it clear what the focus of the study is. The models consist in different assumed densities or also in slab geometries? If you mention configuration the reader expects different geometries, but above you claim you cannot resolve the geometry.

->I think the abstract should be reformulated to make the focus of the study clear from the beginning, and mention the given starting configuration. From the abstract it is not clear if the study contributes to the improvement of knowledge in slab geometry. It

seems the study is rather a sensitivity analysis, without conclusions on the real density structure from gravity modeling. This should be made clearer.

L. 42-43: In the Western Alps, Lippitsch et al. (2003) propose a slab break-off, which is in line with the findings of Beller et al. (2018) and Kästle et al. (2018)... -> Mention assumed depth of break-off.

L. 66: -> maybe you could add Tadiello and Braitenberg 2020, discussion paper.

L. 67 subduction-> subduction. ....dominated -> Crustal thickness variations and...

L. 68: subducting slabs have a higher density.. -> Give reference and justify. Is this always? Can it depend on lithospheric mantle composition and on the amount of subducting crustal thickness? What is ambient mantle- can you be more specific? For instance, below in your manuscript the density difference results to be either positive or negative.

-> Fig.1: red faults hardly seen in figure. For Bouguer anomaly specify topographic reduction chosen and maximum degree of the model.

L. 75: strength-> strengths

L. 75: Hereby, we convert seismic velocities to density. We also use seismic crustal thickness estimations and upper mantle tomographic models to define slab geometries -> The "also" is misleading- if not tomography what else can you use for the seismic velocities?

L. 83- -> give more details on how you make the correction of topography- how do you exactly calculate the simple Bouguer correction? Justify why you do not use the available complete mass effect of topography, which is available from the ICGEM homepage. Estimate what error you introduce by using simple Bouguer against the realistic mass correction. You mention the Etopo1 model with 1 minute resolution, how do you equalize frequency content in the topography mass correction and the gravity disturbance model which has a lower spatial resolution of 25 km?

L. 86 constant station height of 6040 m. -> Above geoid or above ellispoid or above a sphere? L. 88 indicating an isostatic compensation -> Compensation of what? Explain a bit better to make it clearer for non-specialists.

L. 89 gradients at 225 km height- -> justify why you also calculate gradients, and why you calculate them at a height different than gravity disturbance. Mention if you correct the mass effect on gradients.

L. 93: crustal thickness estimates based on the receiver function study by Spada et al. (2013), supplemented by the Moho depth model of the European plate by Grad et al. (2009) -> Show in fig.2 which areas come from Grad et al., and which from Spada, and which areas you have overlapping data-values. Do the two models agree in depth? At the western border of Po basin the Moho is shallow as in the Tyrrhenian sea, but this is not reflected in the gravity field. May there be a problem in the definition of Moho here?

L. 105 in the depth range from 70 to 200 km are calculated with respect to a depth-dependent average shear-wave velocity 1-D model - Explain how you deal with the layers from 70 km depth to the Moho, as you mention that you correct gravity for the crust effects, that is from surface to the Moho. - Explain the values you choose for the 1D reference model and justify it. Does a different choice affect the results and in which respect? Add this point to the text. - Define relative velocity variations- I assume these are percentage values?

L. 125: relative densities -> Please make it clear what you intend with relative densities- e.g. density differences with respect to the reference density model divided by the density of the reference model?. Which is the reference model and how do you define it? Please specify. And as above, discuss the effect of a particular choice of the model. -> the conversion factor is a simplification of reality- mention which are the limits of this assumption. A linear function would be more general, that is delta_rho=a+b delta _V. You imply a=0, which probably is a parameter absorbed in the reference model. Please add some comments in the text to make it clear.

L. 126: conversion factor: from 0.1 to 0.45, as it is adimensional, the relative density and velocity is expressed in percentage? Make it clear in the text- see above comment.

L. 130: converted relative density distribution varies between -240 and 350 kg/m3. -> See previous comment: the relative density variation is not in percentage values, so the conversion factor must be expressed in correct units. Please make the text consistent.

L.131: High correlations between the structural pattern in the converted density distribution and the relative seismic velocities are observed -> This is obvious, as you imposed the linear relation.

L. 132: The converted 3D relative density distribution includes all heterogeneities in the Alpine lithosphere and not only structures of the potential slab segments to which the tomography is sensitive -> This is not clear- since the calculated density variation is just the seismic velocity variation multiplied by a factor, it represents exactly the variations sensed by seismic tomography, not more, not less. L. 142 In the gravity field, -> specify that you mean the modelled field or the observed field

L. 144 graity -> gravity -> Figure 4: at this point it would be interesting to learn how close this modelled field is to the observed field cleaned from the crustal contribution and the masses above 70 km depth. If the field cleaned from the crustal contribution is unavailable, you could maybe compare the modelled field with a low-pass filtered gravity field, or a field to which you have subtracted the greater crustal effects as those from the crustal thickness variation, for which you showed the model in Fig. 2.

L. 162 We define two alternative slab configurations based on a model of crustal thickness and different tomographic studies -> Two alternative configurations from two tomographic studies or several alternative configurations from several tomographic results? Please make it clear.

L. 163: Increasing crustal thickness is used as a direct indication for a subducting slab. -> Make this concept clearer. This is a model you use based on what assumptions?

Can I have crustal thickness increase without a subducting slab? Make your concept clear. -> In Fig. 5 would it make sense to show the Moho 44 km isoline contour which defines the onset of the slab?

L. 168 -> I have a question on nomenclature of slab front- Is the slab front intended as the top boundary of the subducting slab and could this be a valid alternative to name it to make the picture clearer? Furthermore, I do not understand what you mean with vertical interpolation of isolines- I would understand the interpolation of the isolines defining the upper boundary of the slab to define its upper continuous surface- would this be correct? In Line 168 you define the slab front isoline at 200 km- so this would be the slab front, as the extreme of the slab. But if this is so, I find the term slab front for the upper boundary misleading. In Line 172 you mention the lower boundary of the slab, so the counterpart would be the upper boundary? L. 182: features a north subducting slab segment in the Eastern Alps -> Is it not NE-directed subduction?

L. 184: Central Alpine slab subducting in southeast direction -> rather SSE directed?

L. 185: southeast directed western alps slab -> rather ESE directed subduction?

L. 187: supporting the idea of slab break-off at about 100 km depth -> is the broken off segment still present or has it been absorbed and no velocity and density variations are seen?

L. 199: tesseroids modeling the slabs extend from 40 km to 220 km depth -> justify choice, as you say above that the slab starts at 44 km depth and extends to 200 km depth?

L. 201 constraint -> constrained

L. 215 signal -> signals

L. 224- constant slab volume of 100 km, -> you mean slab thickness?

L. 245 the perplex algorithm by -> the perplex algorithm of

L. 251 homogene -> homogeneous

L. 263 fix -> fixed

L. 270 Slab segments are introduced stepwise for the lithosphere and sub lithosphere domains into the model as well as thermal anomalies for the sub lithospheric model part -> Clarify at this point if the slabs you introduce have a different temperature than the surrounding lithosphere and sub-lithosphere mantle. The temperature anomaly is in the slab but only in the part of the slab that dips into the sub-lithospheric mantle? Please make it clearer in the text.

L. 272 a slab segments -> a slab segment

L. 283: Additional to the density contrast within the sub lithosphere, a temperature anomaly of – 100 K is introduced for the sub lithospheric part. -> Please make it clear if this last sentence refers to slab or surrounding mantle. -> The density variation is a consequence of the composition, temperature and pressure, so it is not clear why you mention that you introduced a density variation and a temperature variation- is the density variation not dependent on temperature?

L. 313- -> Fig. 10b. Define in caption which model it is (in text you mention M9). Slab is limited to Technical LAB depth? Make it clear in caption.

L. 317 - at surface height -> on topographic surface level?

L. 322, forward calculated gz gravity signal at. . .-> forward calculated gz gravity signal of Lithospheric slabs at. . . -> Make it clear in the text and maybe also in the caption that the gravity effect of topography and crustal thickness variations have been nulled.

L. 326 is in the order of 40 mGal -> is in the order of -40 mGal Fig. 13 A -> should be Fig. 12 A,

L. 334 Fig. 1 b -> should be Fig. 12 b

L. 335 Fig. 13 c -> should be Fig. 12 c,

L. 338 gravity response within the gravity field caused by the density distribution -> gravity response caused by the density distribution ?

L. 363- check grammar of sentence.

L. 364: as gravity modelling is a non-unique solution (Fig. 7). -> the forward model is exact and has one unique solution- the point is, that there is a tradeoff between density and volume, and the same gravity signal can be achieved with different combinations of density and geometry. Please change the sentence.

L. 368 In case, the. . . -> In the case that. . .

L. 372 mantel -> mantle

L. 377 from the the -> from the

L. 399 If the slab contribution is not considered, a significant part of the gravity field is attributed to crustal thickness or intra-crustal sources. -> This sentence is misleading, since it is not the identification of a specific geometry of one or more slabs that contributes to the signal, but in general the density variations in the depth range between 70 and 200 km, if identified as slabs or not. For instance, in the density model of the mantle of Fig. 3, the slabs have not been identified as such, but the mantle has a variable density. Therefore, it would be more correct to write that the subcrustal density variations contribute to the observed Bouguer field to an amount which is non-neglectable when modelling the crustal densities.

L. 424 All three modelling approaches suggest a positive gravitational effect of the Alpine slab segments up to 40 mGal -> from the gravity field of the first model, that converts the seismic model to density variations, the slab signal cannot be really identified. Maybe a positive modelled gravity is seen above the positive density variations in the center of the Figure, but amplitude with respect to the surroundings is much higher, more like 75 mGal. (taking difference from yellow isolines of -50 mGal to light red color of about +25 mGal).

L. 425 Previous studies compensated this effect by lithosphere thickness and/or intra-crustal sources, future studies should incorporate the structures in order to provide a meaningful representation of the geodynamic complex Alpine area -> As far as I can see, other studies concerned with the crustal modeling have taken the sub-crustal density variations into account of the mantle, so it is not a big surprise that the density model must take into account both mantle and crust to reproduce the observations correctly. It could be mentioned at this point in the text that small scale density variations in the crust generate different wavelengths in the gravity field than deep slabs. Furthermore, it could be mentioned that a significant conclusion on the slab density structure requires a correct crustal density and crustal thickness model.

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