Response to comments by Dr. Carla Braitenberg on the manuscript "Forearc density structure of the overriding plate in the northern area of the giant 1960 Valdivia earthquake" (se-2021-53)

We thank the detailed revision on our work from Dr. Carla Braitenberg (https://doi.org/10.5194/se-2021-53-RC3). In this document we write responses in blue after the reviewer's comments (black). Numerous writing corrections annotated by the reviewer in an attached pdf file were included in the new version of the manuscript (highlighted in green).

Sincerely

The authors

The research aims at defining a density structure of the continental forearc in the northern segment of the 1960 Valdivia earthquake, to date the highest magnitude event ever recorded with seismologic and geodetic instruments. The area of study is of general interest due to this landmark event, which generated free oscillations of the earth observed for the first time. The authors present a density model that aims to explain the observed terrestrial and satellite gravity data and to demonstrate a segmentation of the continental wedge, both along and across the subduction margin. The authors propose that the inhomogeneous structure of the overriding plate controls the process of stress loading during the interseismic period, due to rigidity variations. This point is interesting, but at the present stage of the work the link between the density structure and the rigidity variations and stress pattern is suggested qualitatively, but lacking a quantitative estimate. The general assumption made in the

Discussion chapter is, that denser crust is more rigid. This assumption could be supported by some numbers, so as to define what the expected changes in elastic parameters are and which the uncertainties. In the discussion it is mentioned that in the northern profile, P1_Toltén, the density model can be compared with the velocity model reporting Vp values- the authors could use density and velocity along the profile to calculate the elastic parameter changes, in order to support their hypothesis.

R.- We interpret that the general increase of density from MWU (and CC domains) to the east can be related to an increase of rigidity and/or a decrease of fracturing. This interpretation is supported by the correlation between high density anomaly increase of Vp, decrease of Vp/Vs ratio (Dzierma et al., 2012a), and also, high electrical resistivity of MT studies (Kapinos et al., 2016). Inside the region highlighted by white contour in Fig.4b (P1_Toltén profile), Dzierma et al. (2012a) shows Vp/Vs values lower than 1.74, contrasting with values higher than 1.78 eastward and westward. In same region Vp and Vs models reach values ~4% and ~8% higher than surrounded regions, respectively. Then, at least at the profile P1_Toltén, the correlation between D1 high density anomaly and changes in the elastic properties is clearly observed. Considering this Vs velocity anomaly and moderate increase of density of associated to D1 anomaly of about 0.05 gr/cm3 (Fig4a and 7), we estimated an increase of shear modulus asociated to D1 at the order of 20% in comparison to surrounded regions (at the same depth). These values were included in the new version of the manuscript. Unfortunately, the calculation of a grid of shear modulus based on our density grid and the velocity values is not a direct procedure because Dzierma et al., 2012a did not include the velocity grid values in tables (only colored figures are available). However, it is and interesting suggestion, and should be included in future works in zones where Vs models of forearc are available.

The authors further propose that the varying width along the margin of the MWU and CC domains could be due to varying friction at the interpolate boundary. Since friction at a sliding interface is the product of the normal stress component to the surface and the friction coefficient, I wonder if the authors could use the density model to calculate the normal stress and then make implications on the frictional coefficient and possible presence of fluids.

R.- We propose that "the widening of MWU and CC domains to the north of ~42ºS could favoured high friction in the deep region of interplate boundary (bellow CC domain) and a relatively low friction in the seaward portion of MWU", due to a possible dewatering of the deep region associated to deformation style of basal accretionary complexes in MWU and CC domains (Menant et al., 2019). Then, we did not interpret that the deformation style (or width) of MWU and CC domains is due to friction variation at the interplate boundary.

As in our previous works in the Chilean margin (northward from the study zone, Maksymowicz et al, 2015; 2018) it is possible to calculate the total vertical load over the interplate boundary, as an estimation of normal stress component. However, the frictional coefficient (effective basal friction coefficient, Dahlen, 1984) is estimated from the morphology of the continental wedge but it is virtually independent of the continental wedge density (Maksymowicz, 2015). On the other hand, as the shear stress along the interplate boundary cannot be determined independently, the friction coefficient cannot be derived from estimations of vertical load over the contact. This makes impossible (or highly speculative) to link mathematically the estimations of effective basal friction coefficient with the estimations of vertical load. However, these independent models (density models and models of effective basal friction coefficient) are suggesting changes in the friction variations and fluid migration along the megathrust.

Concluding, I propose the authors use their density model to quantitatively support their implications on the seismotectonics. In the following some specific problems are addressed.

Specific problems

It is discussed that gravimetric lineaments have been defined, partly based on previous publications, partly defined in the present paper. At first sight these lineaments are not seen the BGA, so the authors need to define how the determine the presence of a lineament.

R- These lineaments were visually interpreted, which in our opinion is a valid procedure to provide a qualitative description of the gravity signal. Similar qualitative exercise is often used in bathymetric/topographic, earth magnetic field, gravity and seismic studies, and other geophysical/geological analysis to highlight linear features in the signal that could be related (or not) with hidden structures and other geological features at depth. To make easier this qualitative interpretation, it is a common practice to generate set of derivative filters of the original signal to highlight short wavelength features. A set of figures with the interpreted gravity lineaments and derivative filters (first derivative to the west, first de first derivative to the north, directional derivative to the northeast, slope gradient and analytical signal) is presented in the new version of the supplementary material.

In Figure 3b the interpreted gravity lineaments are drawing with dotted lines on the CBA grid and Figure 3a shows also the CBA grid without these interpreted features in order to facilitate the direct evaluation of our interpretation by the reader. Regarding the relation of interpreted gravity lineaments with structure published in the zone we explicitly state that "The gravity lineaments confirm the location of fault zones previously identified at the surface (SERNAGEOMIN, 2003; Melnick and Echtler, 2006), suggesting their continuity through the forearc and, in some cases, their seaward extension (e.g., Valdivia-Futrono lineament, VFL in Fig. 3b)". In fact, published fault and structures and their names are presented in Figure 3 (blue lines). The clear relation between previously identified crustal faults with some of the interpreted gravity lineaments is a primary reason to show this qualitative interpretation, because some of these lineaments could be confirmed (or not) as crustal structures in future works. In the new version of the text, we explicitly clarify the visual/qualitative type of this interpretation.

The English Grammar must be improved- I attach a pdf with many small corrections

R.- We appreciate the detailed revision. Numerous writing corrections annotated by the reviewer in an attached pdf file were included in the new version of the manuscript (highlighted in green).

The relation between the gravity field and the mega-faults for the Andean Subduction margin has been discussed before, but these papers are missing- I propose these findings shall be included in the introduction. They have been produced by Researchers as Orlando Alvarez and co-authors (https://scholar.google.com/citations?user=MDsDjEcAAAAJ&hl=en). These have also demonstrated the interaction of the morphology of the subducting topography on the angle of subduction.

R.- Álvarez et al., 2014 is cited in the new version of the manuscript.

Line 92: give a few words on how the right lateral strike slip system relates to the oblique subduction. Give some more details on the crustal seismic fault mechanisms present in the area.

R.- Added in the new version of the manuscript.

Line 139:" normal gravity correction (subtracting the theoretical gravity of the WGS-84 ellipsoid), Free-Air, Bouguer, and Terrain corrections": give more details, as different standards exist. Give the formulas for the corrections. GPS give elliposidal heights, which geoid was used to obtain normal heights? Did you define gravity anomlay or disturbance? up to which radius did you make the topographic correction? Did you first calculate simple Bouguer and then terrain correction? did you use a higher resolution DTM for the near field? What is the estimated error on the final gravity acquisition?

R.- The paragraph was modified to include details of the process of gravity data reduction and estimated data error.

We applied the process broadly used in geophysical studies to derive the Complete Bouguer Anomaly from direct surface gravimetric measurements (Blakely, 1995; Lowrie, 2007). It is clear that in geodesy studies there are different definitions of gravity anomalies and corrections (Hackney and Featherstone, 2003). According to these authors, the subtraction of normal gravity of the ellipsoid (calculated in the surface of the ellipsoid) from the absolute gravity registered in the surface of the earth is defined as scalar disturbance, and is one of the firs step applied in the process of gravity data reduction.

R. I. Hackney, W. E. Featherstone, Geodetic versus geophysical perspectives of the 'gravity anomaly', *Geophysical Journal International*, Volume 154, Issue 1, July 2003, Pages 35–43, https://doi.org/10.1046/j.1365-246X.2003.01941.x

Did you have coincident old and new datapoints and what is the mean difference and standard deviation? What is the standard deviation compared to the GOCE field? Notice you must low-pass filter your data to make the differences with GOCE.

R.- As is mentioned in the text, the new gravimetric data were distributed to fill in some observed gaps in onshore studies, and to complement and validate gravity and topographic information from old stations. The new gravity measurements were tied to the absolute gravity stations available in the study zone (International Gravimetric Bureau (BGI), https://bgi.obs-mip.fr/). The average difference in absolute gravity values between new stations and every old station located closer than 1 km is 0.29 mGal, reflecting that old data are consistent with new data, even considering changes of elevations between not coincident points in rough topography areas.

We include satellite derived data in the merged gravity database. In fact, the last version satellite derived data of Sandwell and Smith (https://topex.ucsd.edu/cgi-bin/get_data.cg) is used to cover marine gaps and regions to the south of 42ºS. In a previous work, Maksymowicz et al. (2015) confirmed that the shape and amplitude of this satellite data (i.e., all relevant features for the modeling scale) are preserved in comparison with the Free-air data obtained by the direct acquisition of marine gravimetric lines. This favore the use of this satellite grid to be merged with marine and onshore surface gravity measurement. As is pointed by the reviewer, GOCE provide a low-frequency gravity anomaly, providing less information of density structure of the subsoil, which in turns is the primary objective of this work.

Line 170: "This linear regional gravity trend is mostly related to a deep continental root below the Andes, eastward from inverted gravity" Linear trend of gravity field: do you mean crustal root and subducting lithospheric plate? You could at least calculate an isostatic root and calculate its gravity field to show that the linear plane resembles the isostatic field. The effect of the subducting plate has been calculated before and could be used or at least mentioned to estimate its effect on your field.

R.- This sentence was removed in the new version of the manuscript. While 2D models provide a possible solution of the density structure of the subduction zone (under the available independent constraints), the 3D local inversion can be seen as an automatic solution (independent of the forward 2D method). As is pointed in the new version of the text: “The 3D inversion modelled the input Residual Bouguer Anomaly (Fig. 5a) with high precision, as is observed in Fig. 5b, where differences between modelled and observed data are, in general lower than ± 1 mGal. The results show density contrast anomalies to about 20 km depth (Fig. 6, 7 and supplementary material), which means that deeper anomalies are mostly contributing to regional linear trend of the CBA at the scale of 3D local inversion”. It is important to highlight that the 3D inversion method is completely different in numerical approach to 2D forward method, but the obtained density structure is similar (at common depths), which reinforce the modeled characteristics of density distribution in the upper crust and the considered linear regional trend.

Line 184: define density background model

R.-. The modeling of residual gravity provides contrasts of density respecting to the background density. Theoretically, above the reference level considered to perform the Bouguer Correction (0 m respecting to ellipsoid in this case), the background density is equal to the reference density (or reduction density), i.e. 2.67 gr/cm3 in this case. To clarify the point, we include the value in the corresponding sentence.

Line 195: here you mention the geophysical models for slabs and crustal thickness- it is not clear why previously you claim to subtract a plane that represents crustal roots of the Andes- the longest period field should be explainable by the slab and crustal thickness variation. Could you use these models to correct for the longest gravity field wavelengths?

R.- As was pointed before, the independent information of slab structure and geometry was used as a constraint for 2D density models. With a different modeling approach, 3D inversion considers the previous subtraction of a linear regional trend to generate a Residual Bouguer Anomaly. Then, all gravity signals, different from the linear trend, generated in the slab, lower continental crust and/or upper mantle are included in this Residual Bouguer Anomaly. Accordingly, as the results of the inversion show density contrast anomalies to about 20 km depth, and a mostly homogeneous layer below (see supplementary material), the deeper anomalies are mostly contributing to regional linear trend of the CBA at the scale of 3D local inversion. On the other hand, the 3D inversion present similar density structure in comparison with 2D model (at common depths) which means that the gravity signal of the deeper anomalies modeled in 2D profile (whit the original Complete Bouguer Anomaly) are well approximated by the linear regional trend.

In general, use SI units, that is kg/m^3

R.- We change the density unit to standard gr/cm3