A mantle related gravity anomaly map for the Paraná, Pantanal and Chaco-Paraná basins

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Abstract

In this work, we integrate terrestrial gravity data with the South America Gravity Model 2004 (SAGM04) to derive a new Bouguer anomaly map for the Pantanal, Paraná, and Chaco-Paraná basins and surroundings. Then, we estimate the effect of known masses on the gravity field as sediments, basalts and Moho depth variations to isolate the contributions of mantle sources on the residual Bouguer map. For this, we use the Parker method and rectangular prisms. The estimated effects can be as large as 250 mGal. The result is a mantle gravity anomaly map that reflects the density lateral variation from the crust and mantle beneath southwest South America. The mantle gravity map, which varies from -250 mGal to 150 mGal, can be used to model mantle density variations for providing additional constraints on past and current tectonic events in the study area. The most prominent features are two high amplitude gravity anomaly of about 150 mGal along the central Andes. We also observe positive gravity anomalies underneath the Paraná and Pantanal Basins, whereas the residual anomalies for Chaco-Paraná Basin are not superior to ~30 mGal, with a low amplitude anomaly of about -40 mGal in the north part of this basin. A high amplitude gravity of about 80 mGal between the Paraná and Chaco-Paraná basins is most likely an artefact caused by imprecise Moho depth values used in our estimates.

Introduction

The gravity acceleration measured on the Earth's surface results from the influence of several components. Those components can be simply divided into non-geological and geological. The non-geological ones are equipment drift, lunisolar attraction, and centrifugal force, with the last one usually estimated by the calculation of the so-called Normal Earth. The geological components on the gravity field are due to Earth’s density variations. Usual corrections as free-air and Bouguer ones are intended to reflect density anomalies beneath the geoid. Besides the usual corrections, there are components resulting from the attraction of other anomalous masses, for example, sediments within basins, large volumes of volcanic rocks, and the density contrast between crust and mantle rocks due to topography variations at the Mohorovicic discontinuity. After removing all cited components from the observed value of gravity acceleration, we assume that the residual gravity anomaly map is the result of the attraction of unknown masses within Earth's crust and mantle.

In this work, we use ground gravity data and, for the areas without data, the SAGM04 model to derive a Bouguer anomaly map. SAGM04 is a regional geopotential model for the South America plate with a maximum resolution of 5’ calculated with ground, marine and satellite data by Sá (2004).

The three basins of this study are intracratonic, and geographically near, although there are significant differences between their gravity anomalies. To analyze the source of these anomalies, we remove from the Bouguer anomaly the influence of some known masses and the effect of the Mohorovicic discontinuity topography on the gravity field. The result is a mantle related gravity map for the region of these three basins. Thus, from this residual map, we can obtain a mantle density anomaly model to infer the compositional and thermal state beneath the Paraná, Pantanal and Chaco-Paraná for a better understanding of the origin of past and current tectonic events that have been affecting the study area.

Method

The data set used in this study has a total of 81078 ground points, 66707 provided by the Potential Methods Laboratory (IAG-USP), 6860 by the Topography and Geodesy Laboratory (LTG-USP-POLI), and 7511 by the National Geographic Institute of Argentina (IGN) (Figure 1). We integrate the ground data with the SAGM04 model by blending the grids, filling the data gaps with the regional model.

After non-geological corrections, we evaluate the data and remove the components of gravity acceleration from equation 1, starting with the total g (Figure 2):

g = attraction of the rotating reference ellipsoid (Normal Earth)
+ effect of elevation above the geoid (free-air)
+ normal mass effect above the geoid (Bouguer)
+ effect of the sedimentary masses
+ effect of basalt masses from the Paraná Magmatic Province (PMP)
+ effect of the Mohorovicic discontinuity topography
+ effect of density variation on the crust and upper mantle

(eq. 1)

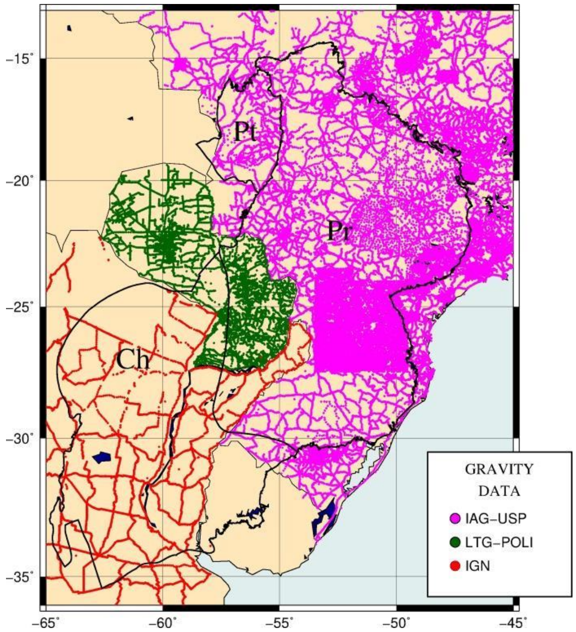

***Figure 1:** Measured gravity data within the study area. Pr: Paraná Basin, Pt: Pantanal Basin, and Ch: Chaco-Paraná Basin.*

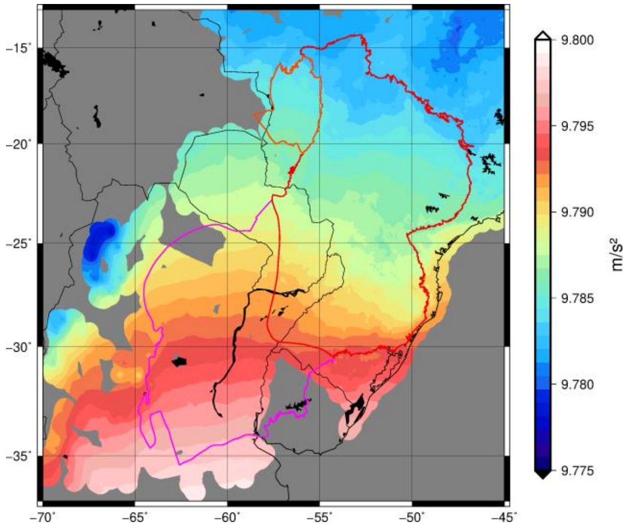

***Figure 2:** Gravity acceleration for the study area. Note that it is higher as long as it gets apart from the Equator, because of the centrifugal force. Basin contours - red: Paraná Basin, orange: Pantanal Basin, and magenta: Chaco-Paraná Basin.*

The first three terms of the eq. 1 are calculated as follows: we use the 1967 International Gravity Formula for the rotating reference ellipsoid and the usual 2670 kg/m³ for the density in the Bouguer correction.

The fourth and fifth terms of equation 1 are estimated using the Parker method (Parker, 1973). The influence of the sedimentary thickness and the PMP basaltic layer on the gravity field are from the CRUST1.0 model (Laske et al., 2013) and Molina et al (1987), respectively. The density contrast considered for these two estimates are -200 kg/m³, for the sediments, and 200 kg/m³, for the PMP basalts.

The sixth term of the equation 1, the effect of the Mohorovicic discontinuity topography, is calculated using rectangular prisms (Nagy et al., 2000) through the "Fatiando a Terra" package (Uieda et al., 2013). We adopt the Moho depth map derived by Rivadeneyra-Vera et al. (2019) for most of the region and we add the model of Rosa et al. (2016), from surface-wave tomography, for the Chaco-Paraná area (Figure 3) due to a lack of homogeneous receiver function estimates of Moho depth from the model of Rivadeneyra-Vera et al. (2019). The larger difference between these two models is about of 7 km, with the depth error from the receiver function of about +/- 3 km.

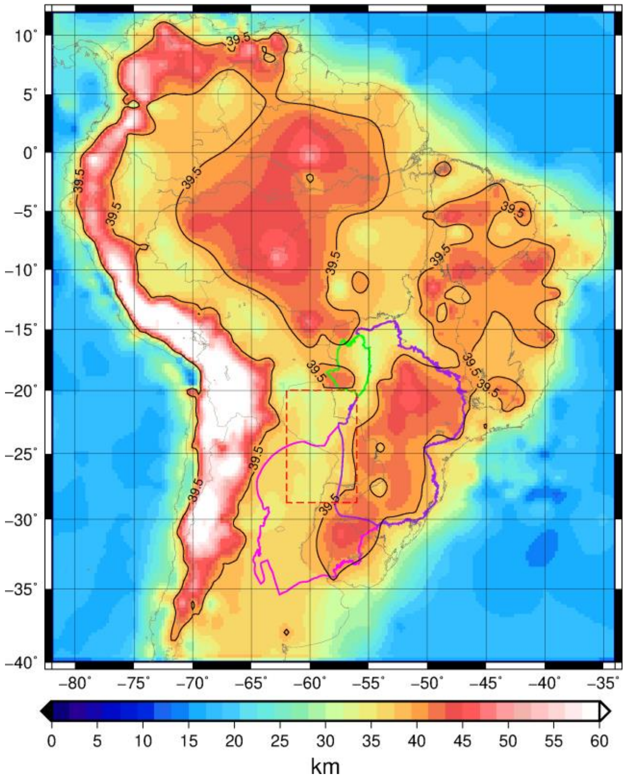

***Figure 3:** Mohorovicic depth topography used in this work. The 39.5 km depth is highlighted. The dotted red contour in the altered region of the model by Rivadeneyra-Vera et al. (2019), through the combination of the model by Rosa et al. (2016) for the Chaco-Paraná basin region. This grid was calculated using the grdblend program from the "Generic Mapping Tools" package (Wessel et al., 2013), with weights of 0.4 and 0.6 for the Rivadeneyra-Vera et al. (2019) and Rosa et al. (2016), respectively, only in the common region between the models. Basin contours - purple: Paraná Basin, green: Pantanal Basin, and magenta: Chaco-Paraná Basin.*

To calculate the effect of the Moho topography on the gravity field, it is necessary to define a mean crustal depth, which is 39.5 km for the study area (Figure 3). Such a step is necessary to take into account the density contrast between mantle and crust due to Moho depth variations. For our estimates, we use the density contrast from the CRUST1.0 model (Figure 4). Above the depth of 39.5 km, the density contrast is considered positive, and below, negative.

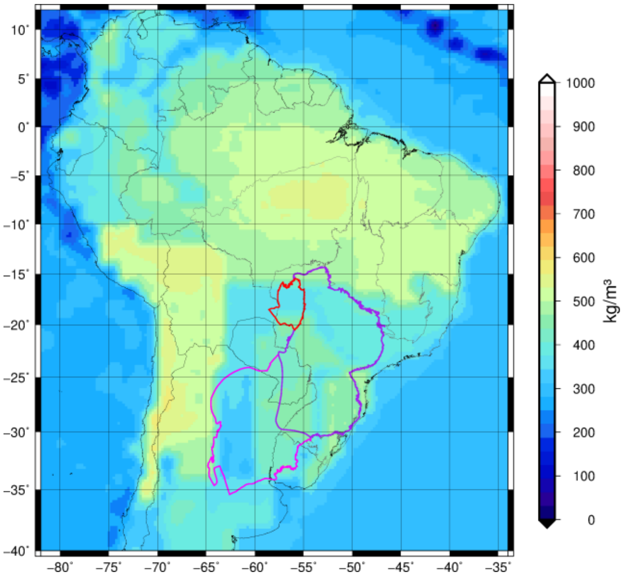

Figure 4: *Density contrast map between the mantle and the lower crust according to the CRUST1.0 model. The values of the CRUST1.0 density are estimated by their model of the age and composition for the crust and upper mantle. Basin contours - purple: Paraná Basin, red: Pantanal Basin, and magenta: Chaco-Paraná Basin.*

Results

In Figure 5, we show the free-air map, with mean values of 12.4, -6.8, and 11 mGal for the Pantanal, Paraná, and Chaco-Paraná basins, respectively.

A new Bouguer anomaly map for the area is presented in Figure 6, with the gaps from measured gravity data in Figure 1 completed with values of the South America model SAGM04 (Sá, 2004). The Bouguer anomaly map presents a distinctive pattern, partitioning the study area in a very low Bouguer anomaly in the central Andes region of about -250 mGal, a positive gravity anomaly of about 30 mGal along the Pantanal, Chaco-Tarija and Chaco-Paraná basins, and a predominantly negative gravity of about 100 mGal within the Paraná Basin. The Bouguer anomaly difference between the Paraná and the surrounding basins has been already noticed before by Dragone et al. (2017), which have delimited this feature using gravity and MT data and have named it as Western Paraná suture/shear zone (WPS),.

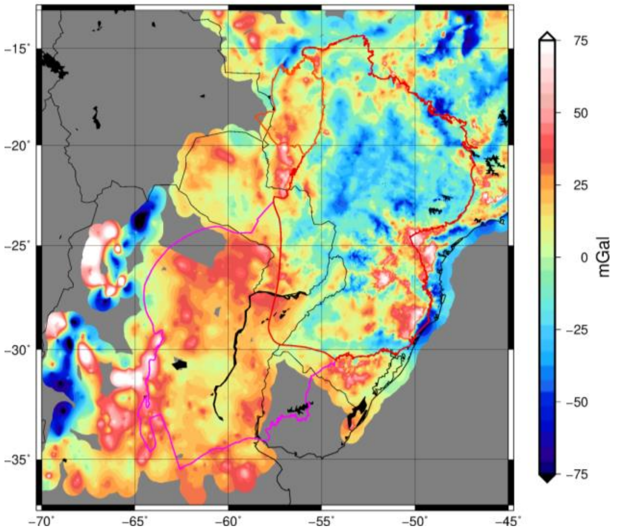

Figure 5: *Free-air anomaly map for the study area. Basin contours - red: Paraná Basin, orange: Pantanal Basin, and magenta: Chaco-Paraná Basin.*

The gravitational effect from the sedimentary cover has a minimum of -30 mGal, and the PMP basalt masses, a maximum of 12 mGal (Figure 7).

The last mass effect calculated in this work is due to the density contrast between crust and mantle caused by Moho depth variations. The estimated effect has the same range values as the Bouguer anomaly (Figure 6 and 8). As expected, it follows the topography of the Moho depth (Figure 3), with few variations, since the used density contrast varies more than 200 kg/m³ among the basins (Figure 4).

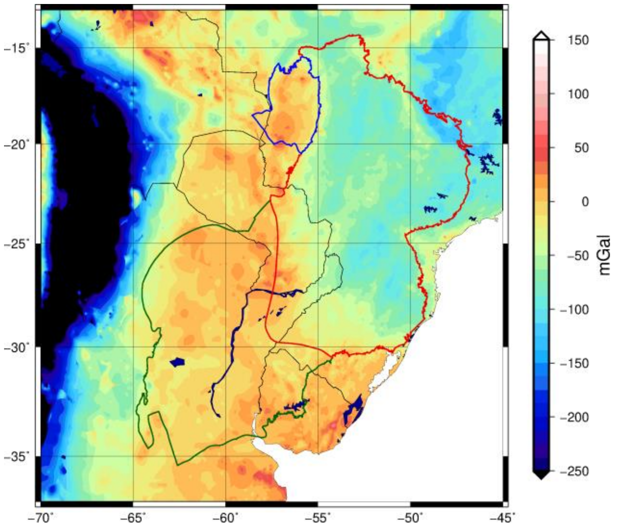

Figure 6: *Bouguer anomaly map from combining the ground data of Figure 1 with the SAGM04 model (Sá, 2004). Basin contours - red: Paraná Basin, blue: Pantanal Basin, and green: Chaco-Paraná Basin.*

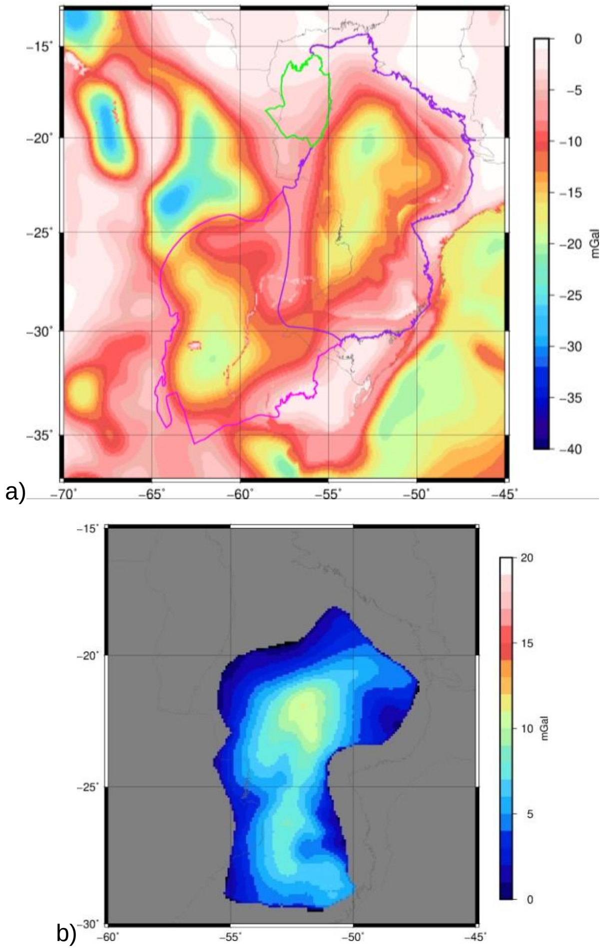

Figure 7: *The gravity components of the known masses in the area, (a) sedimentary cover and (b) PMP basalts. Basin contours - purple: Paraná Basin, green: Pantanal Basin, and magenta: Chaco-Paraná Basin.*

The mantle related gravity anomaly map (Figure 9), which is obtained after removing the gravity effect of known masses from the Bouguer anomaly map, highlights several structures with important lateral density variations. We are still evaluating the residual gravity map since the Moho topography variation effect has an important contribution on the gravity field and the uncertainties from the Moho map we use can be as higher than 5 km in some regions, which can result in a gravity signal of about 40 mGal. This is not the case for the whole area, but only for places with sparse distribution of seismic station or where they have just started their operation. Thus, we highlighted that the observed positive anomaly among Brazil, Argentina, and Uruguay, may be an artefact caused by spurious Moho depth estimates. Therefore, we are not interpreting this gravity anomaly as a geological feature.

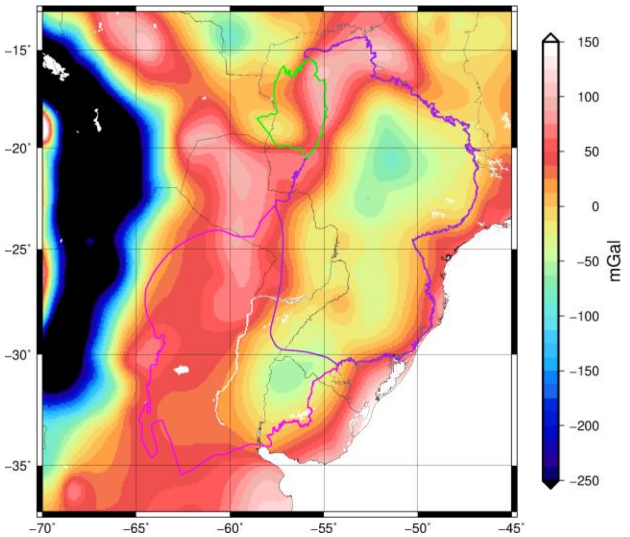

Figure 8: *The gravity effect of the Mohorovicic topography on the gravty field within the study area. Basin contours - purple: Paraná Basin, green: Pantanal Basin, and magenta: Chaco-Paraná Basin.*

The positive anomaly in the central part of the Paraná Basin has already been highlighted in previous studies (e.g., Mantovani et al., 2005; Mariani et al., 2013; Chaves et al. 2016): (Mantovani et al. 2005) interpreted this feature as a cratonic lithospheric block although this interpretation has been challenged by the geoelectrical model of Padilha et al. (2015) and also by the density and velocity tomography models of Chaves et al. (2016). There is another positive gravity anomaly in the south of the Paraná basin, centered on 28ºS – 53ºW, which is most likely related to a fragment of the Paraná Basin lithosphere, as proposed by Milani and Ramos (1998).

The positive anomaly in the south of the Pantanal Basin is coherent with shear-wave velocity models for the area that suggests its lithosphere to be thinner compared to the adjacent lithospheres (Feng et al., 2007). The thinning can be even related to the formation of the lithosphere itself, as proposed by Assumpção et al. (2004).

Northwest the Paraná basin, there is a negative gravity anomaly, which may be associated with Goiás magmatic arc, the Paraguai-Araguaia belt, and the Transbrasiliano lineament since they are geographically near. The negative anomaly seems to continue in the north of the Chaco-Paraná basin, based on the geology, it can also be a continuation of the Paraguai-Araguaia belt and the Transbrasiliano lineament.

Northeast the Paraná basin, we can observe another negative anomaly that can be related to the São Francisco cratonic lithosphere. Connected to this negative anomaly, bordering the coast, between 20ºS and 30ºS, there is a negative gravity anomaly, probably related to the Ribeira belt.

The positive anomaly in most of the Chaco-Paraná basin can be associated with a lithospheric thinning, or an enrichment of the mantle related to a subducting plate.

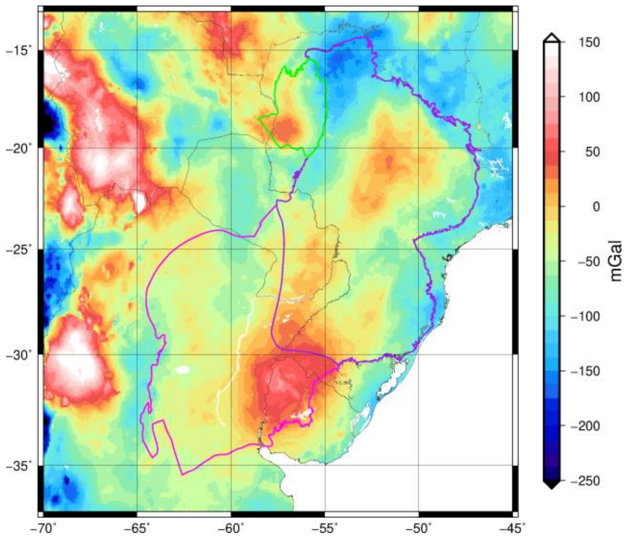

Figure 9: *Mantle related gravity anomaly map, after all the known mass effects are removed from the Bouguer anomaly map. This maps reflects lateral density anomalies within the crust and upper mantle. Basin contours - purple: Paraná Basin, green: Pantanal Basin, and magenta: Chaco-Paraná Basin.*

In the central Andes, we also observe two interesting positive residual gravity anomaly , which may be related to a subduction process of the Nazca plate.

Conclusions

We present a new Bouguer anomaly map for the Paraná, Pantanal and Chaco-Paraná basins, built with recently collected ground data and the South America Gravity Model 2004 (SAGM04). We also present an application of this map, by removing the effect of known masses on the gravity field from it as sediments, the basalts from the PMP, density contrast of Moho depth variations. The result is a mantle related gravity map that highlights gravity anomalies most likely related to crustal and mantle density variations. From this residual map, we observe a positive residual gravity anomaly in the central part of the Paraná basin, extensively discussed in the literature. Possible news based-gravity interpretations about geologic features have also been presented, requiring a more detailed study. As this work is part of a PhD project, this detailing should be done in the next steps.

Acknowledgments

Denise Moura would like to thank FAPESP for the Ph.D. scholarship (number 2018/19562-2), part of the thematic project number 2013/24215-6, and CAPES for maintaining the graduate program.

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