Articles

MORPHOGRAVIMETRIC CHARACTERIZATION OF THE EASTERN AND SOUTHEASTERN REGIONS OF THE BRAZILIAN CONTINENTAL SHELF

By F. Pereira Batista; G.L. Galvão Teixeira and L. C. Torres

Abstract

The use of satellites in the acquisition of geophysical variables has allowed the advancement of joint analysis of bathymetry and gravimetry fields in marine regions where these data are scarce or insufficient, which allows a detailed description of the geomorphology and mass distribution of different provinces of a continental margin. In Brazil, although there is a great effort in the execution of marine geophysical surveys by ships, there is a great difficulty in filling some gaps, due to the size of its continental margin. Therefore, this article aims to analyse the joint spatial data of the bathymetric and gravimetric fields (Free-air and Bouguer) of the eastern and southeastern Brazilian marine region from the TOPEX database, using the tools developed in Python computer language. The results obtained were integrated gravimetric and bathymetric profiles, maps correlating such geophysical fields and diagrams that allowed the combined application of quantitative and qualitative statistical methods on the Bathymetric and gravimetric data. Anomalies of 100 mGal were observed along the Brazilian continental margin, with the largest variations recorded along the Vitoria-Trinity Ridge in the order of 200 mGal, and the remarkable correlation between free-air gravity and bathymetry profiles could also be observed.

Keywords: Brazilian Continental Margin ; Gravimetric anomalies.

Résumé

L'utilisation des satellites dans l'acquisition de variables géophysiques a permis de faire progresser l'analyse conjointe des champs bathymétriques et gravimétriques dans les zones maritimes où ces données sont rares ou insuffisantes, ce qui permet une description détaillée de la géomorphologie et de la répartition des masses des différentes provinces d'une marge continentale. Au Brésil, bien que de nombreux efforts soient déployés pour l'exécution de levés géophysiques maritimes par les bâtiments, il est très difficile de combler certaines lacunes, en raison de la taille de la marge continentale du pays. Cet article vise donc à analyser les données spatiales communes des champs bathymétriques et gravimétriques (Free-air et Bouguer) de la zone maritime de l'est et du sud-est du Brésil provenant de la base de données TOPEX, en utilisant les outils développés en langage informatique Python. Les résultats obtenus ont été des profils gravimétriques et bathymétriques intégrés, des cartes corrélant ces champs géophysiques et des diagrammes qui ont permis l'application combinée de méthodes statistiques quantitatives et qualitatives sur les données bathymétriques et gravimétriques. Des anomalies de 100 mGal ont été observées le long de la marge continentale brésilienne, les variations les plus importantes étant enregistrées le long de la dorsale Vitoria-Trinité, de l'ordre de 200 mGal, et la corrélation remarquable entre la gravité à l'air libre et les profils bathymétriques a également pu être observée.

Mots clés : marge continentale brésilienne ; anomalies de gravité.

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Resumen

El uso de satélites en la adquisición de variables geofísicas ha permitido avanzar en el análisis conjunto de campos de batimetría y gravimetría en regiones marinas, en las que estos datos son escasos o insuficientes, lo que permite una descripción detallada de la geomorfología y la distribución de masas de diferentes provincias de un margen continental. En Brasil, aunque los buques hacen un gran esfuerzo en la ejecución de levantamientos geofísicos marinos, existe una gran dificultad para llenar algunos vacíos, debido al tamaño de su margen continental. Por lo tanto, este artículo tiene por objeto analizar los datos espaciales conjuntos de los campos batimétricos y gravimétricos (Aire libre y Bouguer) de la región marina del Brasil oriental y sudoriental a partir de la base de datos TOPEX, utilizando las herramientas desarrolladas en el lenguaje informático Python. Los resultados obtenidos son perfiles gravimétricos y batimétricos integrados, mapas que correlacionan esos campos geofísicos y diagramas, que han permitido la aplicación combinada de métodos estadísticos cuantitativos y cualitativos sobre los datos batimétricos y gravimétricos. Se observaron anomalías de 100 mGal a lo largo del margen continental de Brasil, registrándose las mayores variaciones a lo largo de la cresta Vitoria-Trinity del orden de 200 mGal, y también se pudo observar la notable correlación entre la gravedad al aire libre y los perfiles batimétricos.

Palabras clave: Margen continental brasileño ; anomalías gravimétricas.

1. Introduction

The importance of studying the surface and subsurface of the marine floor is directly related to the planning of human activities, regarding mainly economic and strategic factors, such as the exploration of mineral sea bed resources, the development of coastal and oceanographic engineering projects related to offshore activities, the exploration of living resources, and the various research activities that occur in these regions (SOUZA, 2006 and NADIM *et al.*, 2006).

The effective study of gravimetry is characterized as a potential geophysical method of great applicability for the identification of many distinct geological formations, for the exploration of minerals, oil and gas, as well as in a great number of geodetic applications (LUIZ & SILVA, 1995 ; KEAREY, et al., 2009). In this context, major scientific advances in the field of geophysics since the 1970s (GIBSON & MILLEGAN, 1998), along with the advent of the space age and high-precision satellite positioning, have enabled the development of airborne geophysics, enabling data acquisition by using global mapping from space.

The delineation of the many diverse marine floor features can be obtained by means of bathymetry and the identification of gravimetric anomalies. This is accomplished by combining satellite-based altimetry with the implementation of various filtering techniques and parameter corrections, for example, the adjustment of radar space track densification and the correction of "non-geological" noise in the gravimetric field, in order to increase the accuracy and precision of this field, so allowing an estimate of the topographic data in a given region of interest (SANDWELL & SMITH, 2009; SANDWELL *et.al*, 2013 ; SANDWELL *et al*, 2014).

The importance of gravimetric field research to the various sectors of exploration activities is widely known, but there are still few completed studies on the Brazilian marine extension. This fact is directly related to the high operational efforts involved to mobilize and execute such task using research ships. In this context, the motivation for this work includes the study and spatial analysis of the morphogravimetric variability present in the Brazilian Continental Shelf (BCS).

The present study expects to contribute to the integrated spatial analysis of bathymetric fields and gravimetric anomalies (free-air and Bouguer) related to the Brazilian East and Southeast oceanic regions, with emphasis on the continental shelf. The bathymetric data have been used to reproduce the seabed morphology surface and the gravimetric data have been used to identify the subsurface depth caused by the differences in the region's density distribution. This analysis, carried out after processing geophysical data from satellites, allows the profiling of the physiographic characterization of the seafloor of this region, as well as the statistical qualitative evaluation among geophysical parameters. For this purpose, bathymetric and gravimetric data from a public domain database have been used, and a computing routine has been developed to process these data, using the Python programming language, a technique that is widely used in the academic environment. The use of such tool in support of geophysical information acquisition activities becomes a reliable reference, given the projected purposes, for future studies in this area.

2. Area of study

The present work will pay attention to the description and characterization of the Eastern and Southeastern extensions of the coast, whereas the selected study area has been delimited between the 5º S and 25º S parallels and the 026ºW and 049ºW meridians, off the oceanic region of this area.

The Brazilian continental margin is classified as Atlantic type, comprising an area around 5.003,397 Km^2, that represents to 59% of the Brazilian emerged territory (COUTINHO, 2005). This characteristic is noteworthy when observing the extension of its continental shelf, mainly in areas that present great sedimentary contribution, as the mouth of the Amazon River, for example (COUTINHO, 2005). Remobilization and sedimentary deposit are dynamic processes, which, considered on a global scale, are consequences of the ocean transgression-regression process, and it is characterized by the shallower strip of the surrounding continental rim existing in most continents. The formation of the continental shelf is generally based on the processes of weathering and erosion that take place along the continental margin, as well as the deposit of minerals in coastal regions (MARINO, 2006). The morphological study of the coastal area is of vital importance for understanding the morphology of the underwater relief, as will be observed in the current paper.

According to Coutinho (2005), the maximum extension of the continental shelf, off the Caravelas region (in the state of Bahia), stands out, followed by its size decrease due to the presence of volcanic intrusions that favour the formation of reefs, protecting the Regencia region coast (in the state of Espírito Santo). From this region on, the shelf gradually widens again due to the sedimentary contribution increased by the Rio Doce river delta, between the Vitória and the Cabo Frio regions.

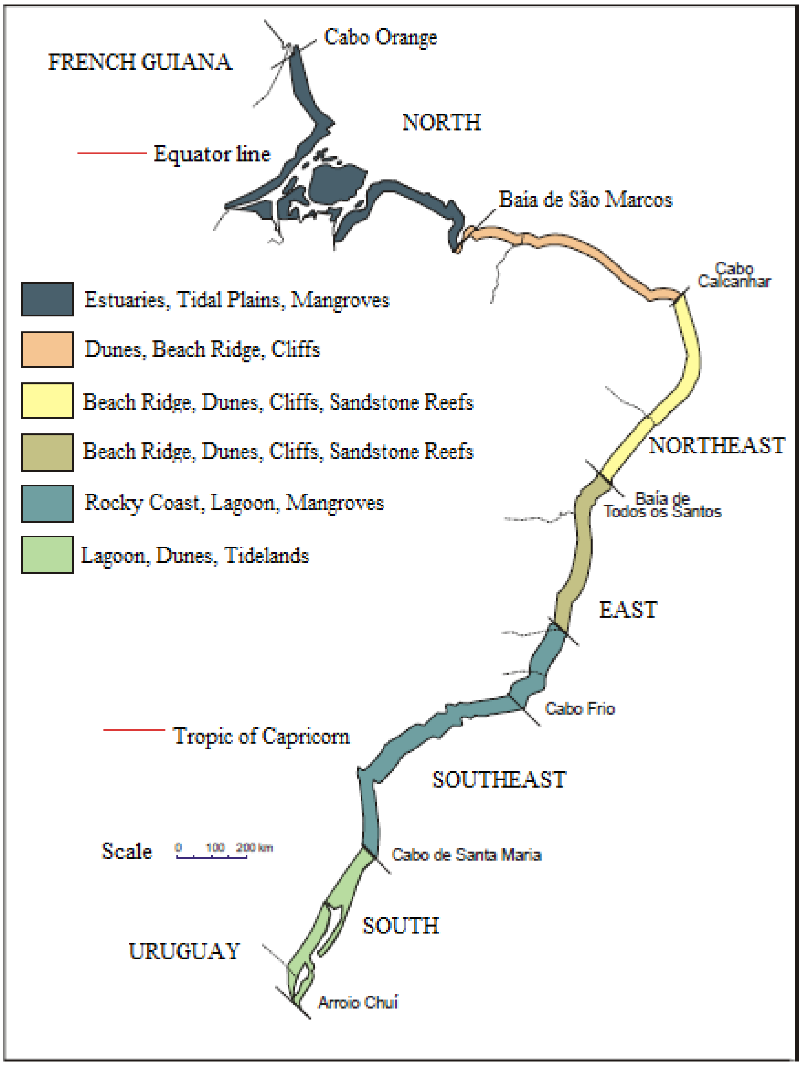


Figure 1 *: Subdivision of the Brazilian continental margin into sectors proposed by Silveira (1964) modified by Villwock (1994). Only the oceanic regions adjacent to the Eastern and Southeastern sectors will be used in this paper. Source: Modified version by Coutinho (2005).*

The Southeast sector is characterized by the widening of its continental shelf, with maximum width near the Santos region and minimum width between Cabo de São Tomé and Cabo Frio regions nearby area (COUTINHO, 2005).

In general, the great diversification observed on the Brazilian Continental Shelf morphology can be noticed, mainly in terms of its longitudinal extension, as it is narrower in the Central and Northeast quadrants, and wider in the North and South sectors, with width values ranging from 90 to 320 km. Such diversification can be observed around the shelf gradient, as it also varies in the different sectors, with shelf break depths ranging from 40m to 200m (GOES & FERREIRA JR., 2017).

3. Methods

In an integrated way, this work aims to explore the joint analysis of the bathymetric and gravimetric fields of the southeastern and eastern sectors of the Brazilian continental margin. As consequence, it was necessary to adopt a method that allows to infer the correlations between these fields in terms of space and through normal profiles taken from the coastline to the deep sea.

The method adopted throughout this study has at its core the characterization of the gravimetric data related to the acquisition of bathymetry and free-air gravimetry data extracted from the TOPEX database webpage located at http://topex.ucsd.edu/cgi-bin/get_data.cgi. The data used are freely accessible and made available in ASCII format, and they are characterized by the geographical positioning and parameter magnitude to be analyzed in those coordinates, and they have been interpolated for a one-minute degree spatial resolution and 1 mGal accuracy. In order to effectively compile and interpret the data, it was necessary to use several tools and libraries available in the semi-interpreted Python programming language, and then to reorganize the bathymetry and gravimetry data vectors referenced to a matrix field, which allowed correlation of the data and production, as results, integrated gravimetric and bathymetric profiles and maps, as listed in ***Table 1***. For the effective study of the spatial distribution of these geophysical fields, statistical methods such as dispersion diagrams and determination of correlation coefficients were used, in order to relate both the bathymetric and gravimetric fields obtained.

Table 1 - Representation of results and parameters generated.

FIGURE	GEOPHYSICAL REPRESENTATION
Figure 3	Altimetric field and Gravimetric free-air field
Figure 4	Gravimetric free-air field of the study area
Figure 5	Bathymetric field of the study area
Figure 6	Transverse bathymetric profile near LAT 24°S
Figure 7	Overlap of free-air gravity anomaly fields on isobaths
Figure 8	Free-air anomaly and bathymetry data cross profile at LAT 20°S
Figure 9	Dispersion diagram *free-air* gravitational anomalies x Bathymetry at LAT 20°S
Figure 10	Overlap of the bouguer gravity anomaly fields over the isobaths.
Figure 11	Transverse profile integrating free-air anomaly data, Bouguer anomaly and Bathymetry at LAT 20°S
Figure 12	Dispersion diagram Bouguer x Bathymetry at LAT 20°S
Figure 13	Spatial dispersion diagram free-air x Bouguer gravitational anomaly at LAT 20°S

In many different applications of gravimetric prospection, the measured gravity (g) values are subject to different types of reduction, according to their purpose. Thus, the gravity anomaly is adopted as the value of "g" on the surface of the geoid, where the gravity reduction at sea level can be obtained (GEMAEL, 2002). The generic definition of the gravity anomaly may be seen as:

Equ 3.1 $$\Delta g = g_0 - \gamma$$

Where g_o would be the reduced gravity to the geoid, and γ the representation of theoretical gravity on normal Earth related to the reference ellipsoid. In order to bring the observed gravity down to the "mean sea level", and to compensate the effects of the altitude difference from the geoid, we have applied the free-air correction C_f (also known as Faye reduction) and the anomaly obtained from such a correction receives the same name (GEMAEL, 2002).

Equ 3.2 $$\Delta g_f = g - \gamma + C_f$$

The general free-air correction (C_f) for a known orthometric altitude gravimetric station (h) is given by the equation 3.3, where the value of the correction equals the product between the vertical gradient and the orthometric altitude. In Geodesy and Geophysics studies the mean gradient of normal gravity for the WGS84 reference ellipsoid is used as the value of 0.3086 (GEMAEL, 2002; CARREIRA, 2015)

Equ 3.3 $$C_f = \frac{\delta g}{\delta h} h \quad \therefore C_f = 0{,}3086h$$

The gravimetric data from satellite radar observations are already compensated for the free air correction but have to be corrected for the excess or deficiency of mass of the observation points located at elevations higher or lower than the elevation datum (sea level or the geoid); and for variations in the observed gravitational acceleration caused by variations in topography near each observation point. The type of correction, which is characterized by the suppression of the external masses to the geoid or removal of topographic masses, is called the Bouguer correction (C_b), where the Bouguer anomaly is obtained from the free-air correction by adding the C_b factor, and where the resulting anomaly is expressed by:

Equ 3.4 $$\Delta g_b = g - \gamma + C_f + C_b$$

To determine the general simplified Bouguer correction, according to Carreira (2015), it should be considered that the external masses to the geoid are distributed on a hypothetical horizontal plateau of infinite length and thickness equal to the height of the point to be observed, with homogeneous density and approached to a curved plateau called Bouguer plateau. The Bouguer correction will have an alternating signal dependent on the location of a given point in relation to the reference surface – the geoid in this case. As the study area is in the marine domain, the Bouguer correction will have a positive signal and usually includes the topographic correction because the Bouguer plate is assumed to have density of the water and the thickness of the water depth. The Bouguer gravimetric anomaly can be described by equation 3.5, where $\Delta\rho$ represents the density contrast between the water and substituted material, "G" the universal gravitation constant and "h" the water depth in meters:

Equ 3.5 $$\Delta g_b = \Delta g_f + C_b \quad \therefore \quad \Delta g_b = \Delta g_f + 2\pi\rho G h$$

4. Results and discussion

The information was processed using the Python computer language, that produced, on the spatial domain, profiles and integrated gravimetric and bathymetric maps, enabling the correlation and spatial analysis of these fields for the study region (***Figure 2***).

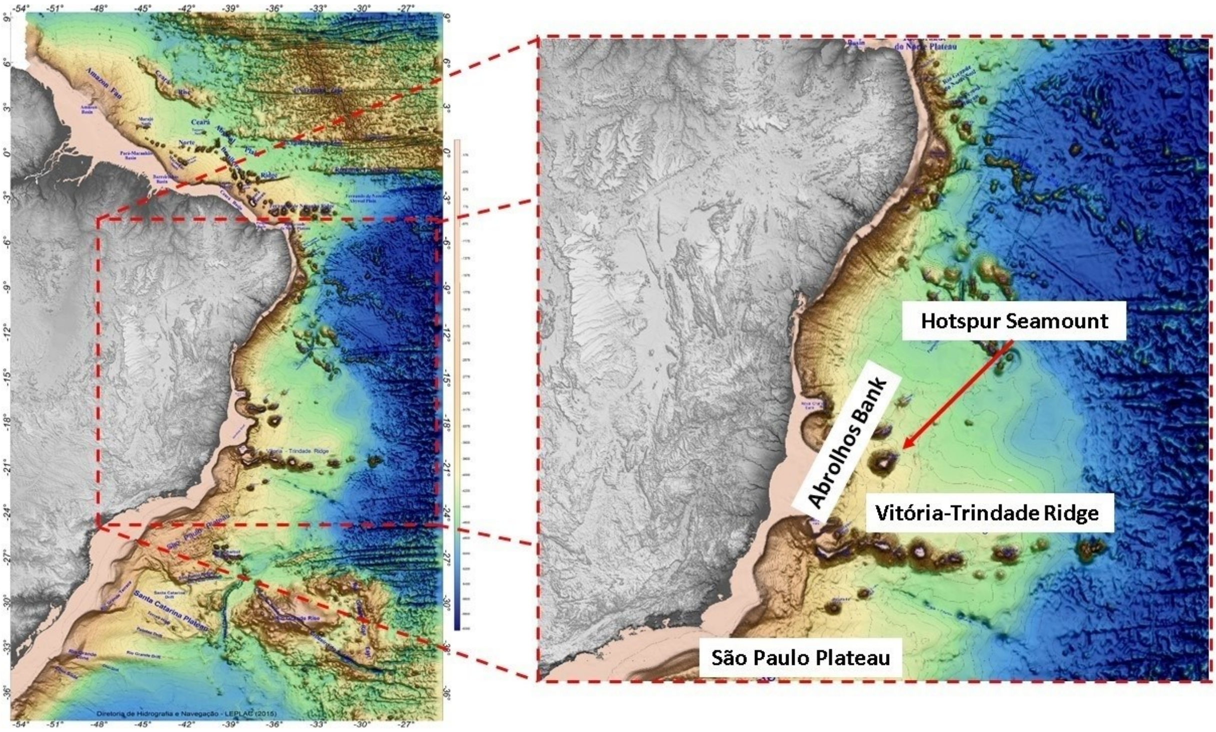
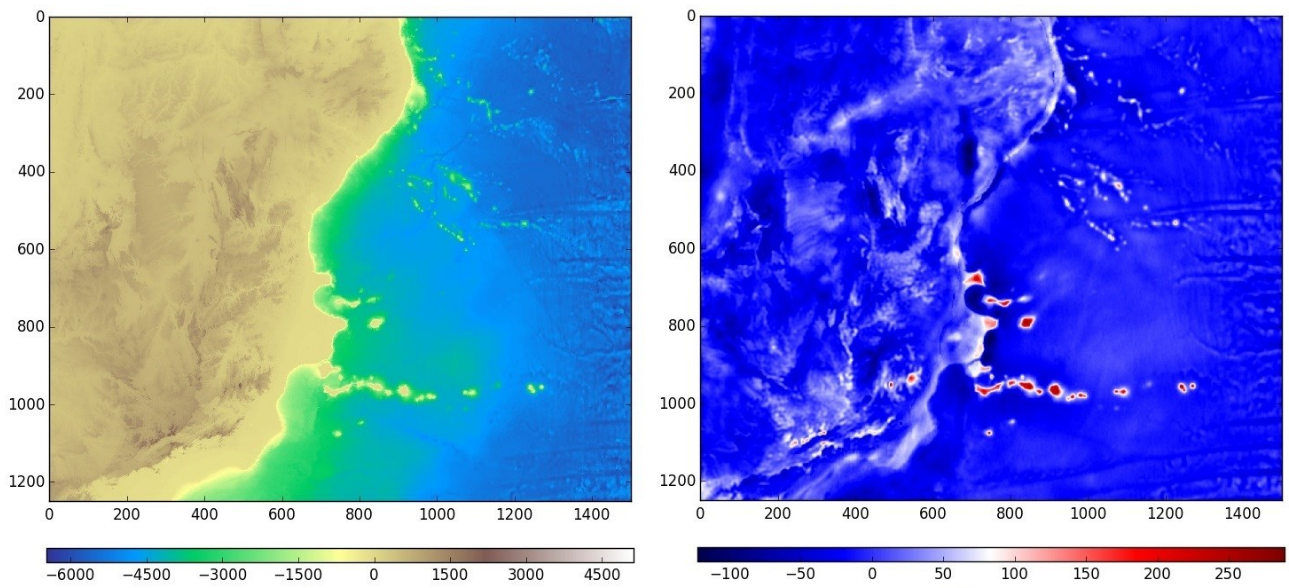


Figure 2 *– Physiographic map of the Brazilian continental margin showing the study area outlined in red in the left image and in higher detail in the right image. Source: Directorate of Hydrography and Navigation (DHN, 2019).*

In the eastern and southeastern ocean regions of Brazil, complex geomorphologies can be observed, represented by Figure 2, where the continental shelf is characterized by large longitudinal spatial variations, where it is also observed the great variability of the sea floor physiographic features, which are of great importance for the understanding and study of the local geology, as well as the morphodynamical processes acting on a large scale. Among such features, the Vitória -Trindade Ridge, the São Paulo Plateau and the Abrolhos Bank stand out in spatial terms.

The altimetry field is shown in the Figure 3a and the free-air field of gravimetric anomalies is illustrated in Figure 3b. Such images display a pixel-matrix composition of the fields in question, from the available data. It should be noted that the representations are not georeferenced, and it is difficult to interpret them in terms of discrimination of the effective continental area of the oceanic region. In the field of altimetry, the brown coloration expresses both the continental area and its extension over the coastal region up to the continental shelf. Secondly, it should be noted that in the scope of both representations, geophysical parameter magnitudes of each field are not directly expressed, and the most accentuated values have been inferred from different digital values based on a color palette.



(a) (b)

Figure 3 *: Altimetric field (3a) and Free-air Gravimetric field (3b); only the data acquired in digital levels are shown. The vertical and horizontal axes are expressed in pixels.*

After the spatial arrangement of the information at the digital level, it was necessary to obtain georeferenced matrices in order to promote a better visualization and analysis of these fields, as illustrated by ***Figures 4*** and ***5.*** Such representations allow production of the geophysical values associated with each point of the geographical coordinate grid. Additionally, the masking of the continental region has been done, so that the study can focus on the marine portion only. In both figures, the horizontal and vertical axes represent the latitude and longitude values for the geographic grid, with the meridians and parallels equally spaced on a regular grid of 2º; in order to make for easier visualization and interpretation of the location of the physiographic provinces along the marine region in question.

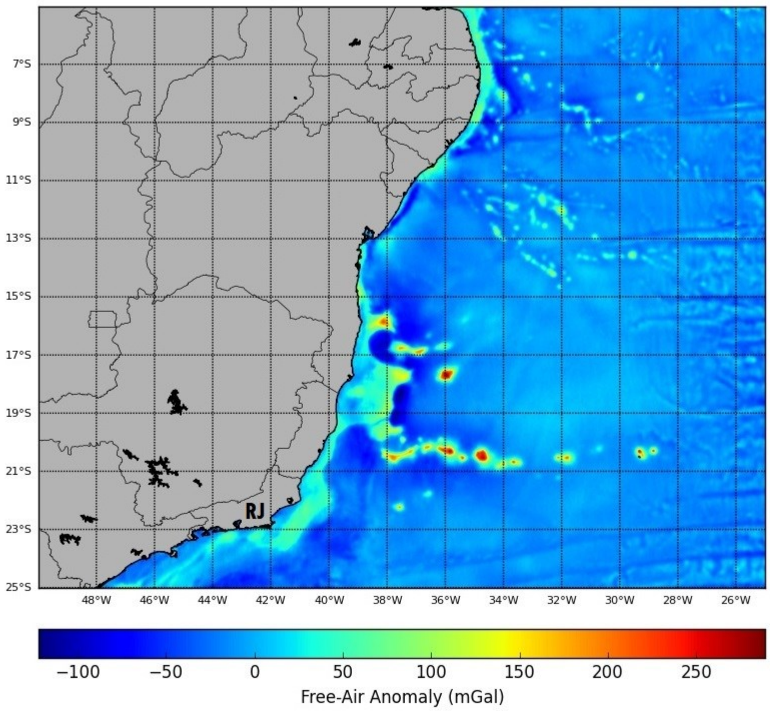


Figure 4 **;** Marine physiographic plotting and gravitational anomaly, with gravimetric values ranging between -100 and 250 mGal, with depths ranging from 0 to 5000m. The Figure was georeferenced in order to present the geophysical parameters inserted in a grid of geographic coordinates. A filter has been used in order to mask the gravimetric anomalies on the continental domain.

In the marine portion, one notices variations of free-air gravitational anomalies in the order of -100 to 250 mGal. The lowest values, in blue color, are associated with the scope of the ocean basin in general, with more pronounced values related to the fracture zones and seamounts present in the eastern and northeastern quadrants of the study region. The values observed between -20 and 80mGal are distributed along the continental shelf, and there is also some uniformity in the distribution of the anomaly values observed in this region, due to the plain structure of the continental shelf, mainly in the southeastern quadrant (***Figure 5***). On the other hand, in the eastern quadrant, one can notice a narrowing of the shelf that is associated with the bathymetric gradient towards the deep-sea basin, which consequently will be related to a greater variation in the observed free-air gravimetry values.

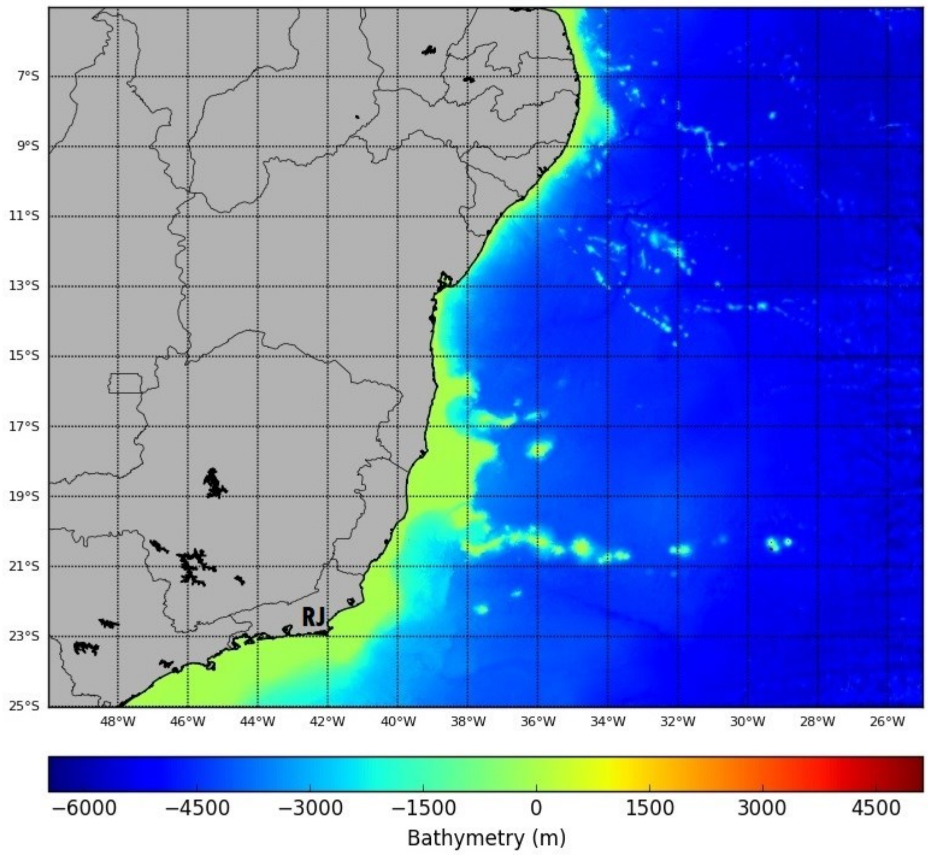


Figure 5 **:** Representation of the bathymetric field of the study area. The smallest depths are represented along the continental shelf, growing progressively up to the ocean basin.

When analysing the free-air gravimetry and bathymetry gradient profiles, represented by ***Figures 4*** and ***5***, respectively, typical features of an "Atlantic" margin can be identified, mainly between the latitudes of 16ºS and 25ºS, with the “wider shelf (represented by greenish tones), strong bathymetric gradient between the shelf break slope and the base of continental slope, continental rise and finally, the deep sea basin. Such fragmentation of the physiographic provinces that represent a typically passive margin can also be observed in the transverse bathymetric profile extract from the southern portion of the Rio de Janeiro (RJ) that is represented in ***Figure 6***, near the latitude of 24ºS and extends between the longitudes of 33ºW and 39ºW.

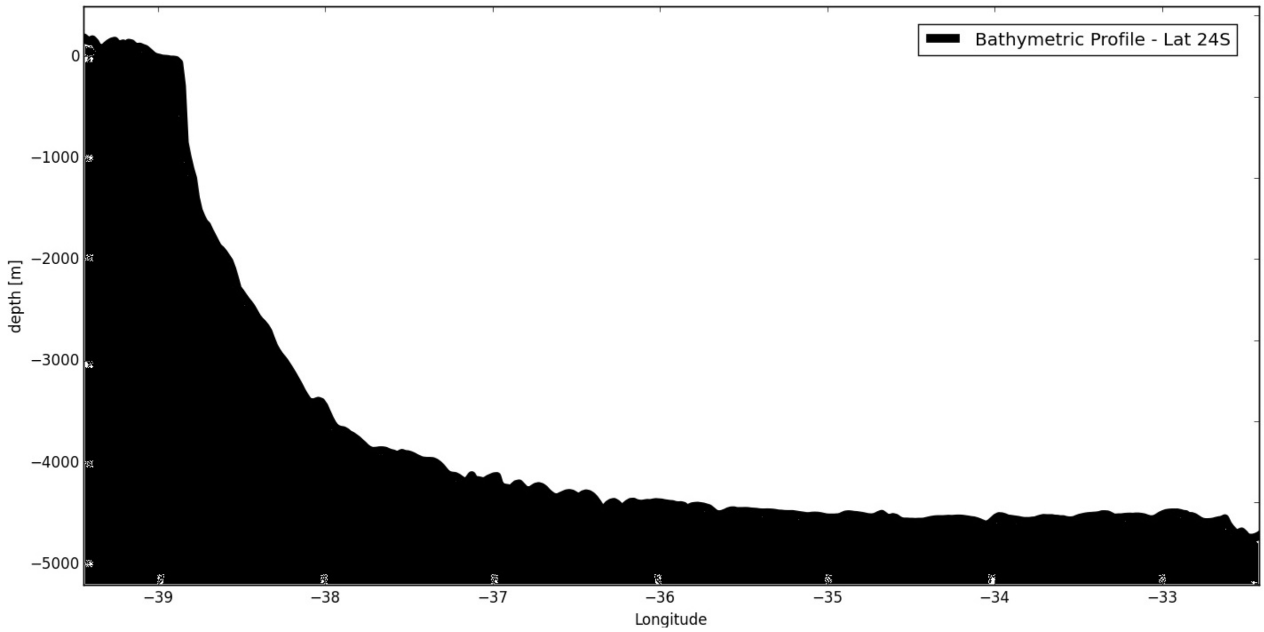


Figure 6 *: Transversal bathymetric profile on the Brazilian continental margin in the latitude of 24°S extended between the longitudes 33°W and 39°W. The profile was extracted from the bathymetric map represented by* ***Figure 5.***

In the bathymetric field, close to latitude of 21ºS, the Vitória-Trindade Ridge can be seen, represented by smaller bathymetries, with estimated depths varying between -2500 to -20m. Between latitudes 16ºS and 19ºS extending between longitudes 35ºW and 38ºW, the Abrolhos Bank and the Bahia Plateau near the Abrolhos Marine National Park are apparent, with deptsh ranging from -50m to -1500m.

In the field of gravimetric anomaly free-air (***Figure 4***), large variations are observed across the continental margin, this fact is justified by the complexity of the region's physiographic features. Peaks of anomalies, 0 and 80 mGal, are noted mainly in the continental shelf region where the São Paulo Plateau and the Abrolhos Bank stand out. The most accentuated peaks of gravimetric field are observed mainly in the Vitória-Trindade Ridge and in the Hotspur seamount, with anomalies ranging from 150 to 250 mGal.

Data processing and analysis of the isobath overlapping of gravimetric anomalies free-air, illustrated by the ***Figure 7***, generated an integrated map of these parameters. This map allows the correlation of the peaks of anomalies found with the geomorphology of the region. There is a strong relation between these parameters, where accentuated peaks of anomalies are directly related to intense topographic gradients. In this analysis, only the morphology of the submarine relief is considered, without simultaneously analysing the fields of mineralogy, constitution/ thickness of sedimentary layers, and rock compositions.

This analysis highlights the gradient of the bathymetric field around the continental shelf, followed by the slope and rise, presenting a correlation with the gradual free-air gravimetric anomaly present throughout the east and southeast marine regions. In addition, the presence of the Abrolhos Bank, the Hotspur Seamount, and the Vitória-Trindade Ridge, stands out, once again, with their respective anomalies also associated with the topographic gradient. Such physiographic provinces are illustrated in a very expressive way from the representative observation of free-air gravimetric variations through a colour palette, which makes the interpretation of the image simpler and more elucidative.

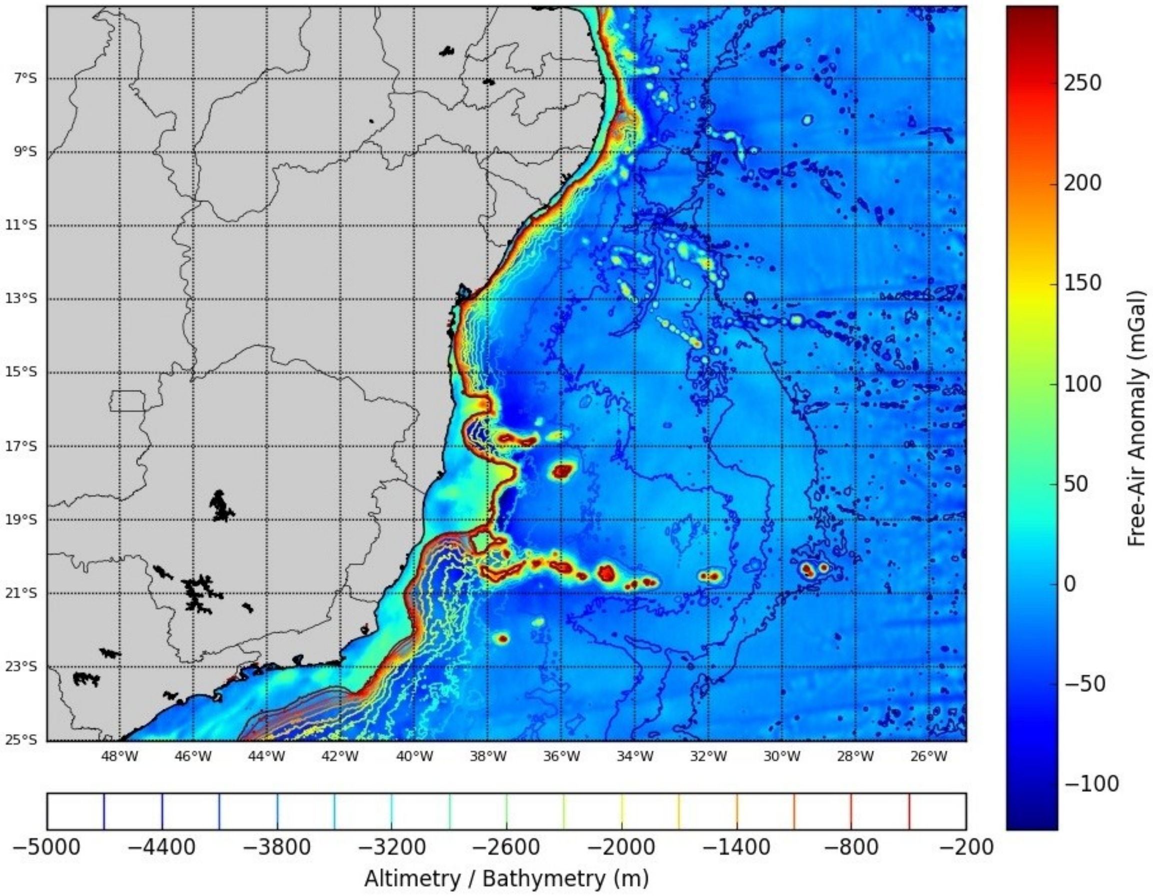


Figure 7 *: Plotting of isobaths over the gravimetric anomalies free-air field. The map allows the analysis of the simultaneous correlation between the parameters, showing the direct correlation between both variables.*

The correlation between the profiles of free-air gravimetry and bathymetry gradients, represented by ***Figure 7***, can also be observed from a transversal view of the parameters, by the longitudinal mass distribution of the Vitória-Trindade Ridge, represented by the graphic of ***Figure 8***, where this profile was traced near to the 20ºS latitude extending between the 29ºW and 40ºW longitudes. In this representation, the direct relationship between the topography and the free-air anomaly is clearly observed. In the vicinity of the 35ºW longitude, an inversion can be observed between the lines of the gravimetric and bathymetric profiles, further SE are observed greater depths with greater anomalies and further NE it is possible to observe shallower bathymetry depth with smaller gravimetric anomalies. Such free-air anomalies can be explained by the inhomogeneity of the crust, varying in thickness and composition, with the continental region presenting an average thickness of 35km and granitic composition (ρ_m= 2,65 g/cm^3), and the oceanic crustal region having a basaltic nature (ρ_m= 3,0 g/cm^3) and thickness ranging from 5 to 8 km. (GUERRA & CUNHA, 2013)

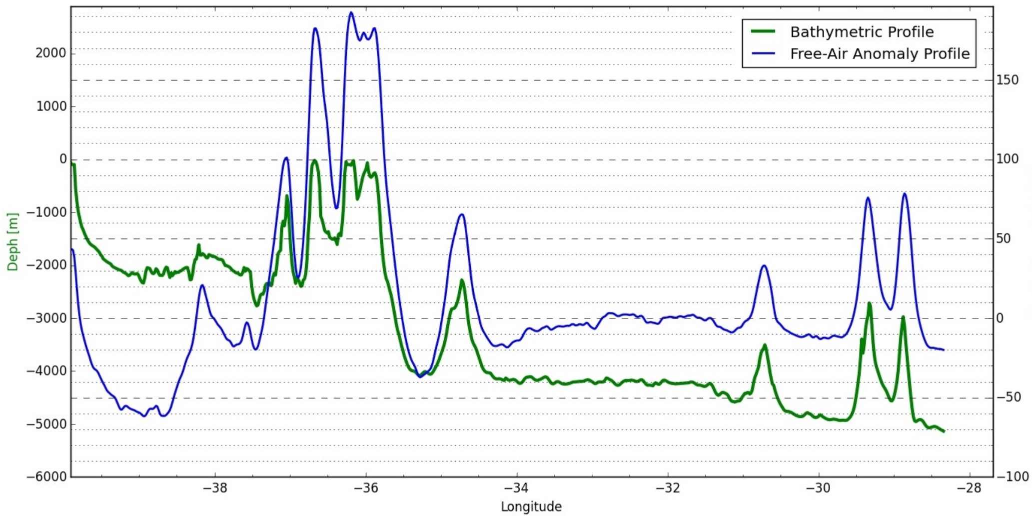
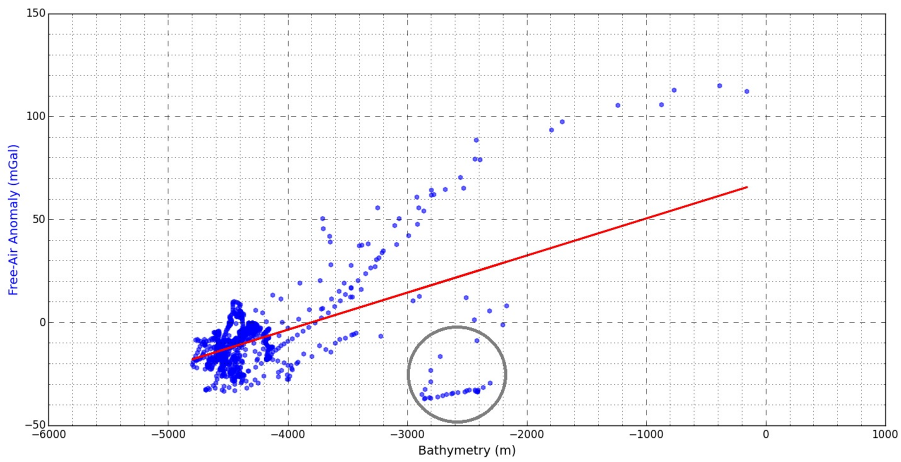


***Figure 8** – Transversal profile integrating free-air gravimetric anomaly and bathymetry data at approximately 20ºS latitude, demonstrating the strong correlation in the spatial field between the bathymetric and gravimetric parameters.*

In order to validate the direct spatial relation between bathymetry and free-air gravimetry, under a statistical perspective, a dispersion/correlation diagram was traced between these variables, utilizing as reference the data present in the vicinity of 20ºS latitude (***Figure 9***). According to Moore (2003), a dispersion diagram presents the shape, direction and measures the degree of relation between two quantitative variables.

The simultaneous graphical representation of the ordered pairs of bathymetric and gravimetric values were investigated, using Pearson's linear correlation coefficient (r), in order to estimate the standard and the intensity of association between the variables. The following "r" values are used as references: Between $0.10 \le r \le 0.29$ as considered a weak correlation; $0.30 \le r \le 0.49$ as moderate correlation; and $0.50 \le r \le 1$ can be interpreted as strong correlation (COHEN, 1988). For this evaluation, the correlation coefficient was calculated with its magnitude equal to 0.5473, characterizing a moderate correlation between the variables. It can be seen in Figure 9 the intensification of the points sampled in the geographic grid, and the positive linear correlation, where the same trend, of growth or decay, is expected between the values of bathymetry and gravity free-air. Such visualization is presented by the orientation of the line obtained from the linear regression processing of the sampled points, characterized by the following equation y= 0,01802x + 68,42.

***Figure 9** : Dispersion diagram representing the spatial variations of the free-air gravitational anomaly with the bathymetry in the vicinity of Latitude 20ºS. The positive correlation between the variables stands out and observed from the linear regression of the sampled points allowing to trace a line that summarize the general trend.*



For the Bouguer correction, listed by equation 3.5, the simplified Bouguer correction was implemented, where "h" would be the bathymetry obtained from a certain point over the geographic mesh, or also designated as orthometric height, and "ρ" would be an average of the variation density of water in the oceans, with a adopted value of 1.046 g / cm3 as a reference for the reduction of the Bouguer plateau. The value used for the water density was obtained from the average between the water density on the surface as similar to the presented by PICKARD & EMERY (1990). From these adjustments, the spatial overlap of the field of gravimetric anomalies was performed with the Bouguer correction over the field of isobaths, represented by ***Figure 10***. Such a map, as well as the one listed in Figure 8, allows the spatial correlation of anomalies found with the submarine relief. The representation of the Bouguer anomaly map allows one to analyze the information of the gravimetric field in a deeper way, allowing evaluation of the oceanic and continental interface crust depth, disregarding the influence of the underlying topographic masses.

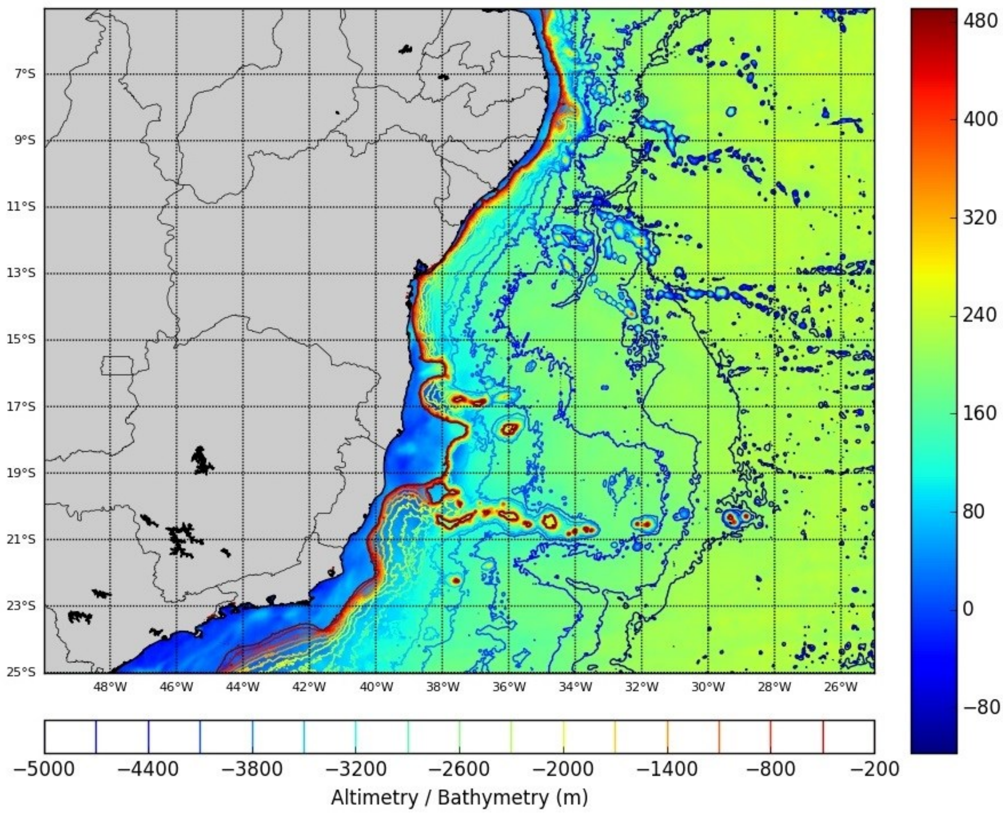


Figure 10 - *Overlapping the fields of gravity anomalies corrected of the Bouguer anomaly over the isobath, allowing to analyse the relation between the variables.*

The greatest changes observed between the free-air and Bouguer anomalies are analysed throughout the ocean basin, and they are more significant according to the distal advance in the direction to greater depths. Under this assessment, when comparing the maps in ***Figures 7 and 10***, it is noted that, at depths around -4000m, where anomalies were previously observed in the range of -100 to 50 mGal (***Figure 7***), variations are now observed between 160 and 260 mGal (***Figure 10***). This difference between values of Bouguer and free-air anomalies is due to the fact that the latter anomaly has a significant and positive correlation with topographic variations, as shown by the dispersion diagram ***(Figure 9***). In general, the gravimetric profiles related to the Bouguer anomaly show a marked increase in its magnitude as the coastline towards the ocean basin is observed, with greater depths. Such analysis can be interpreted based on the transversal spatial profile, the parameters of bathymetry, free-air gravimetry anomaly and gravimetry with Bouguer correction for the proximity of latitude 20ºS (***Figure 11***).

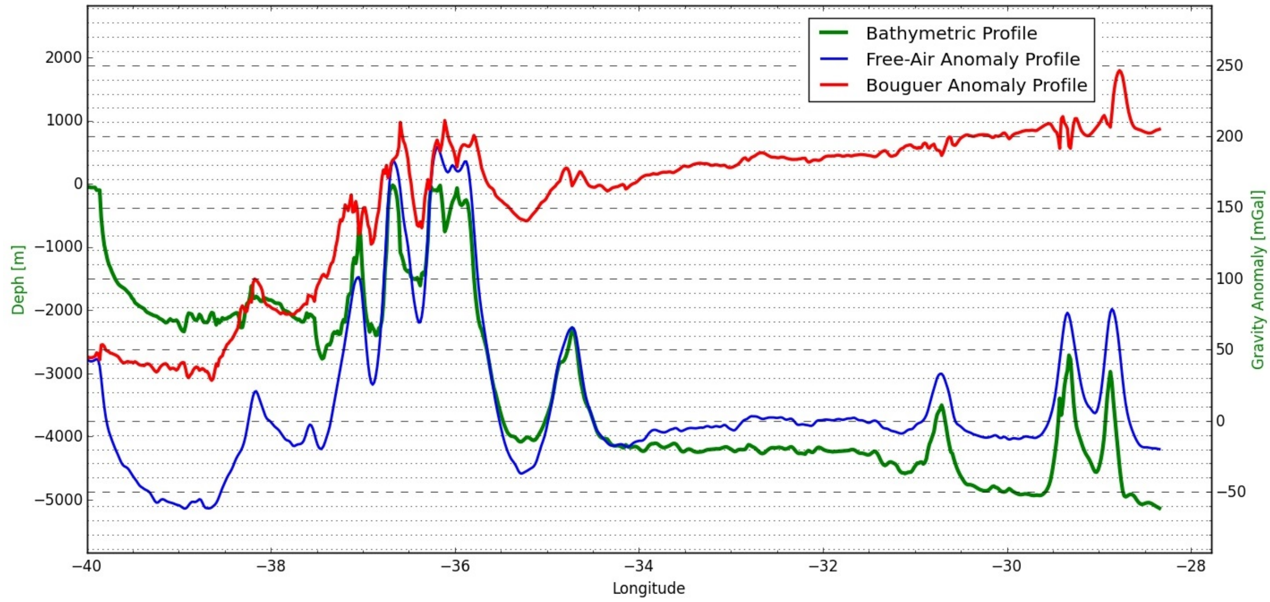


Figure 11 : Transverse profile integrating data on free-air gravimetric anomaly, Bouguer anomaly and bathymetry at approximately 20ºS latitude, demonstrating the strong correlation in the existing spatial field between bathymetry and free-air gravimetry, and the inverse trend of the Bouguer anomaly in relation to bathymetry with the distal advance of the continental margin.

Another interpretation of this profile would be the observation of the progressive increase in the magnitude of the Bouguer anomaly related to the thinning of the oceanic crust in relation to the continental crust (GUERRA & CUNHA, 2013). In order to verify the spatial relation between Bouguer anomalies and bathymetry, under a statistical perspective, a dispersion diagram between these variables was also traced, utilizing as reference the data present in the proximity of 20ºS latitude (***Figure 12***). For this evaluation, the correlation coefficient (r) was determined, with its magnitude equal to -.6838, thus showing a strong negative correlation between the fields, which shows the inverse behaviour, of growth or decay, between the values of Bouguer anomaly and bathymetry. Such interpretation can be made by analysing the behaviour of the line obtained from the linear regression, where y = -0.0258x + 68.42. It is important to note that the coefficient obtained between bathymetry and Bouguer anomaly is greater than that related to free-air anomaly and bathymetry.

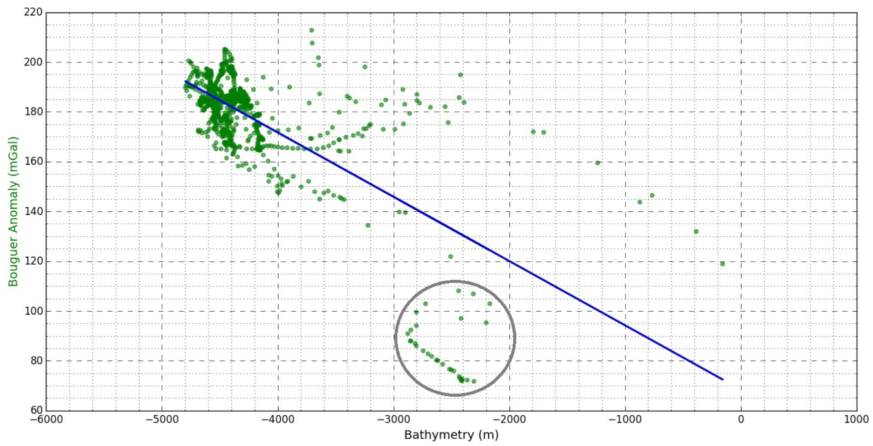


Figure 12 : *Dispersion diagram representing the spatial variations of the Bouguer gravitational anomaly with the bathymetry in the proximity of latitude 20ºS. The negative correlation between the variables stands out, interpreted based on the linear regression of the sampled points allowing to trace a line and analyse its behavior.*

Following the same line of reasoning as to the implementation of a qualitative statistical analysis, the dispersion diagram was traced between the gravimetric parameters of Bouguer anomaly and free-air anomaly, represented by the ***Figure 13***, for the region near 20ºS latitude. The correlation coefficient was calculated with a value of 0.2365, which characterizes a weak correlation between the variables, despite the intensification of the points sampled in the geographic grid. From the linear regression processing of the sampled data, it was possible to obtain the line that would characterize the concomitant trend of the variables, and this line is expressed by: $y = 0.2713x + 181.21$. Based on the weak correlation verified between these variables, it is concluded that the correction implemented was satisfactory, effectively removing the influence of the relief on the gravimetric Bouguer anomaly values.

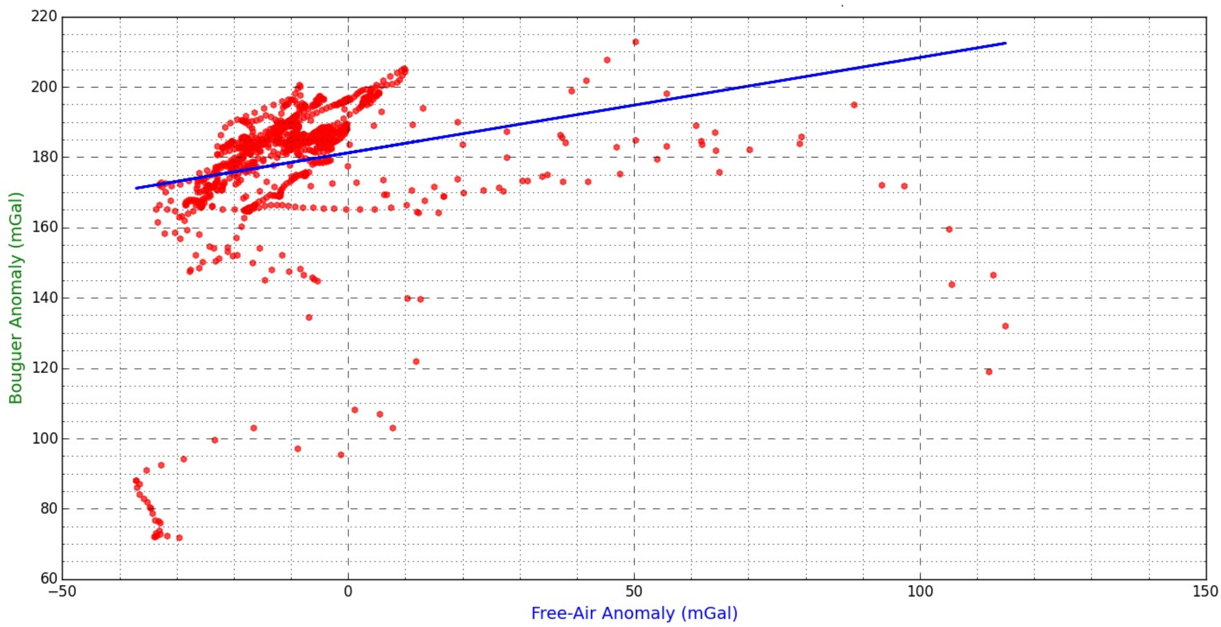


***Figure 13** : Dispersion diagram representing the spatial variations of the free-air and Bouguer gravitational anomaly in the vicinity of latitude 20ºS. The weak correlation between the variables is highlighted, characterized by the low inclination of the line obtained through the linear regression of the sampled points.*

Finally, regarding the correlations between the Free-air and Bouguer gravimetric anomalies present in ***Figures 9 and 12***, one is able to determine the presence of a set of data that significantly influences the inclination of the line. These set of data, delimited by the gray circle, are located at depths between -2000 and -3000m. In the correlation of gravitational anomaly free-air and bathymetry (***Figure 9***), it was possible to verify that these data are responsible for reducing the correlation and decreasing the inclination of the line. In the Bouguer gravitational anomaly and bathymetry correlation (***Figure 12***), it was verified that these data are responsible for increasing the inclination of the line and contributing to the increase in the correlation. Thus, it is verified that the variation of these correlations is caused by these data located in the region of the continental slope and its adjacencies.

5. Conclusion and final considerations

The development of this work proposed the integrated spatial analysis of the bathymetry fields and gravimetric anomalies related to the Brazilian east and southeast marine regions. This allowed a trace of a profile on the physiographic characterization of the region's sea floor, as well as the qualitative statistical evaluation between geophysical parameters. The importance of using the Python computer programming language is highlighted, as a facilitating agent in the processing and presentation of data, since it offers several free tools and libraries that allowed an interface for the treatment of gridded data and the production of analysis and results such as: graphics, interactive profiles, maps and diagrams. The altimetry and gravimetry data from the TOPEX database were presented as viable for qualitative use, and the parameters were interpolated for a resolution of 1 minute of degree and accuracy of 1 mGal. With regard to quantification in the geophysical scope, it is noted the complexity of the arrangement of gravimetric anomalies in the studied region, where in the field of free-air anomalies, it values in the order of 100 mGal were found to distributed along the continental shelf, and largest peaks, on the order of 250 mGal, were associated with the Vitória-Trindade Ridge, the Abrolhos Bank, and the Hotspur Seamount. In this same field, the lowest values, around -100 to 60 mGal, were found in the ocean basin, with smaller values in the fracture zones and seamounts present in the east and northeast quadrants.

In the field of Bouguer gravimetric anomalies, the modification of the geophysical parameter in question is notable, with the greatest changes observed with the distance of the continent towards the greater depths of the oceans, in which anomalies at depths of -4000m, which previously varied from - 100 to 50mGal (free-air), can now be observed between 160 and 260 mGal (Bouguer). Such changes in geophysical parameters would be associated with the crustal “thinning” of the oceanic part in relation to the continental crust.

The spatial analysis of the fields of free-air gravimetry, Bouguer gravimetry and bathymetry through statistical parameters was presented in a satisfactory and significant way, where, with the analysis of the dispersion diagrams in the bathymetric and free-air gravimetry fields, it is possible to observe a moderate positive linear correlation (r = 0.5473) between the variables. For the Bouguer bathymetry and gravimetry fields, a strong negative linear correlation (r = -0.6838) can be observed between the parameters. When analysing the dispersion fields of Bouguer and free-air gravimetry, a weak linear correlation (r = 0.2365) is observed for the region in the proximity of 20ºS latitude, and this relation is best seen from the observation of the trend of the line that supports the correlated variables.

For future work, it is recommended to reduce the geographic mesh to support analysis at much higher spatial resolution. Another suggestion would be to carry out the analysis of geophysical parameters from different data acquisition platforms, whether acquired *in loco* or remotely, in order to compare the information with a goal to increase the accuracy of the data and allow the determination of necessary adjustments.

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