Characterization of the Rio Grande Rise from elements of the terrestrial gravity field

Marília T. Dicezare (IAG-USP) & Eder C. Molina (IAG-USP).

Abstract

Satellite altimetry data are important tools in mapping tectonic structures in oceanic regions such as faults, fracture zones and seamounts, especially when information from ship is scarce. In order to investigate the structural characteristics of the Rio Grande Rise in South Atlantic, we used sea surface height (SSH) values and its gradients (SSG) from ERS1, Geosat and Seasat altimetric missions. The main structures of the rise were identified in the analysis of SSH variation along satellite tracks with good precision, whereas smaller scale features, such as fracture zones and seamounts, were observed in the analysis of SSG variation, showing its potentiality to identify these structures.

Introduction

The Rio Grande Rise (RGR) is an aseismic ridge located in the southern region of the Atlantic Ocean, near the Brazilian coast (Figure 1). According to Gamboa & Rabinowitz (1984), the area is divided into two units, an eastern (ERGR) and a western (WRGR) one. Its top reaches a bathymetry of less than 1000 m above the ocean floor, presenting an average depth of 4000 m (Mohriak et al., 2010).

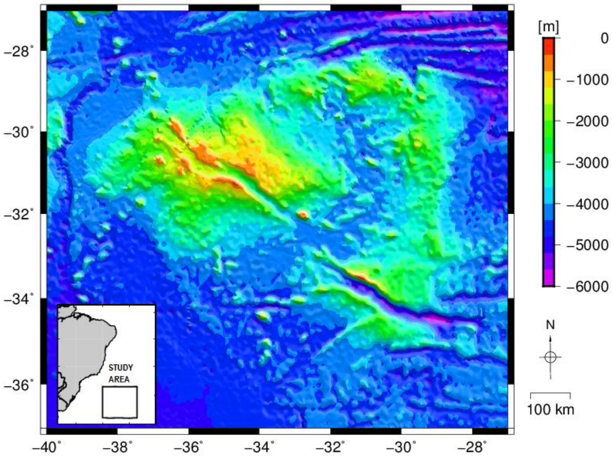

Figure 1 - Bathymetric map of the study area comprising the Rio Grande Rise.

The western portion of the RGR is an elliptical protuberance with a crest that reaches an average depth of 2000 m below sea level, where there are guyots and seamounts with up to 700 m of water depth, mainly concentrated in the central part of this unit (Gamboa & Rabinowitz, 1984). It consists of two flanks and a central trough, where the top exceeds 2000 m depth and is partially filled by sediments, also presenting increasing subsidence southeast. Its northern and southern limits present east-west fracture zones (Mohriak et al., 2010).

The eastern part of the rise has a north segment with N-S direction and a southern one similar to WRGR (Ussami et al., 2013). It is about 600 km long and has an average elevation of 2000 m below sea level, presenting fracture zones in its northern and southern limits. It has a depression with 800 m of sediments.

Gamboa & Rabinowitz (1984) still report that the troughs of the two units are 10-20 km wide extending over 1500 km, with WNW-ESE direction. Between them, there is a narrow and deep abyssal plain, where some seamounts are present.

The origin and evolution of the Rio Grande Rise is not certain; some authors defend the relationship with a deep mantle plume or with the melting of an enriched and heterogeneous sub-continental lithospheric mantle (Ussami et al., 2013). Mohriak et al. (2010) provide a number of alternative interpretations for the origin of RGR, among them, that the rise is the result of a hotspot or thermal anomaly in the mantle, excess volcanic activity due to the differentiation of the mantle by adiabatic decompression, or a piece of continental crust left in the ocean during the drift phase.

The knowledge of its tectonic characteristics is important to better understand the processes of the opening of the South Atlantic, to which they are related. In addition, RGR is an area with great potential for mineral resources, mainly cobaltiferous crusts rich in iron and manganese, as well as nickel, platinum, cobalt and others.

The aim of this study is to investigate structural features of the Rio Grande Rise through gravity field elements, mainly from satellite altimetry of several missions, in order to identify in the region seafloor structures such as seamounts, fracture zones, faults, among others, obtaining new details by combining different types of data. Satellite altimetry measurements provide uniform and global coverage, allowing the determination of gravity field elements with good accuracy in oceanic regions.

Method

The main element of the gravity field used in this study is the directional derivative of sea surface height (SSH) along satellite tracks known as SSG (Sea Surface Gradient). The methodology follows the same procedure of Molina (2010) regarding data processing, corrections and calculations of SSG.

Satellite altimetry tracks data from Seasat, ERS1-GM and Geosat-GM missions were used in the Rio Grande Rise and adjacent areas, from -40° to -27° longitude and from -37° to -27° latitude.

After corrections, sea surface height values were obtained for each satellite measurement point, with a total of 151892 points. Then, the directional derivative of SSH was calculated along-track.

Before calculating SSG values it is necessary to separate satellite tracks in ascending (79071 points) and descending (72821 points), when then the directional derivative is obtained through the approximation by the slope of the line between two consecutive points:

$$\varepsilon(\alpha) = \frac{SSH_2 - SSH_1}{d} \qquad (1)$$

where d is the distance between points, which can't exceed 2 s, equivalent to ~ 15 km (Paolo & Molina, 2010).

Along-track SSG should provide more detail on the ocean floor structures and will be analyzed in this study.

Results and Discussion

Preliminary results showed a good distribution of data throughout the study area and a good correlation with the position of the structures in the ocean floor. In Figure 2 it is possible to observe the distribution of SSH corrected values of the three altimetric missions in the study region and adjacencies, and in Figure 3, the separation in ascending and descending tracks.

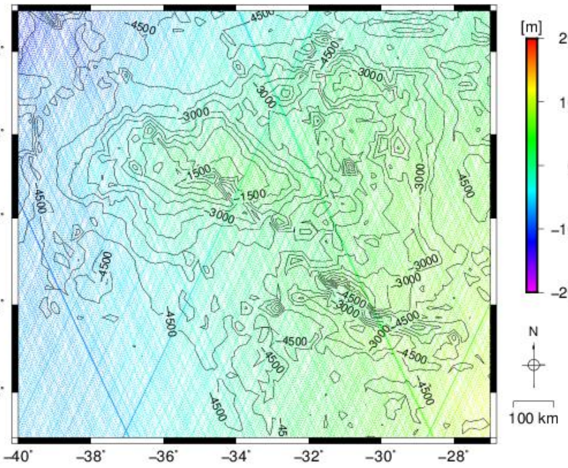

Figure 2 - Distribution of SSH values from the altimetric missions ERS1, Geosat and Seasat.

After separation of satellite tracks in ascending and descending (Figure 3), the directional derivatives (SSG) of sea surface height along-tracks, represented in Figure 4 along with bathymetry, were calculated. The gradients allow to visualize the main features of the ocean floor, especially fracture zones and seamounts, and it is possible to observe a correspondence with local bathymetry in both units (WRGR and ERGR) of the rise.

Another way to represent the two magnitudes is through curves with the variation of along-track SSH and SSG values (wiggles). With sea-surface height values (Figure 5), it is possible to clearly determine major features such as the two flanks and the central trough in the west and east portions of the rise. Structures such as fracture zones and small seamounts are not visible on SSH curves.

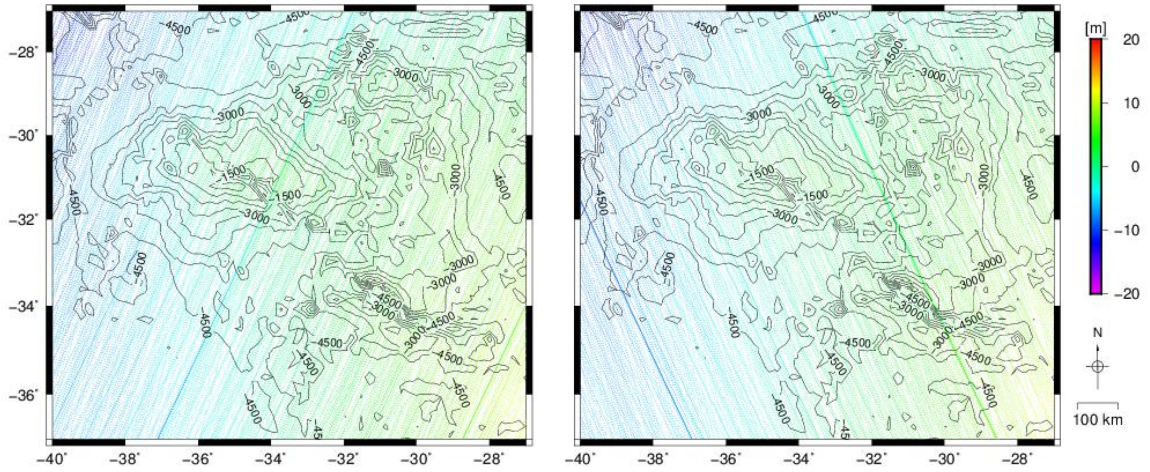

Figure 3 - Distribution of SSH values from altimetric missions ERS1, Geosat and Seasat, separated in ascending (left) and descending (right) tracks.

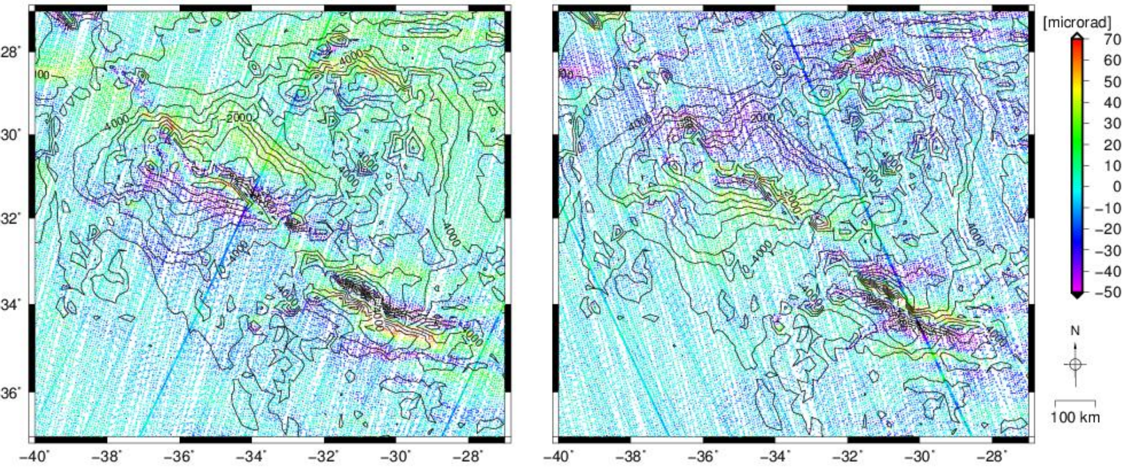

Figure 4 - Distribution of SSH directional derivative values along satellite tracks from ERS1, Geosat and Seasat altimetric missions, separated in ascending (left) and descending (right) tracks.

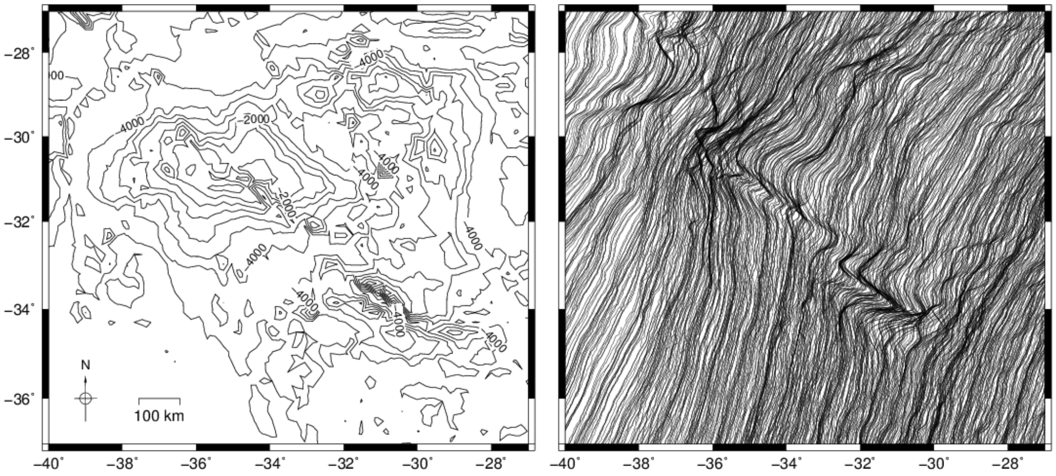

Figure 5 - Bathymetric contour of the study area (left). Variation of SSH values along ascending tracks (right).

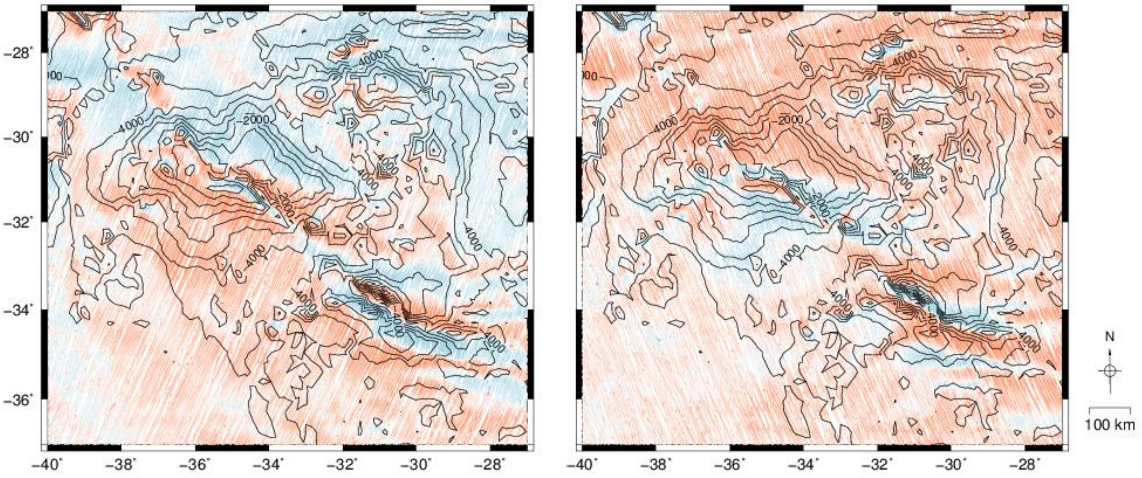

Figure 6 - Variation of SSG values along ascending (left) and descending (right) tracks. Positive values in relation to the track are represented in blue, and negative values in red.

SSH gradient wiggles (Figure 6 - left) highlight, as well as Figure 5, two positive features (blue) and one central negative (red) of NW-SE direction corresponding to the two flanks and the trough of the two units of the rise. In comparison with Figure 1, it is also possible to observe the fracture zones in the upper and lower parts of the right side of the maps in Figure 6, and other structures corresponding to seamounts and guyots.

The analysis of SSH and SSG values in wiggles showed a good correlation with the position of the structures in relation to the bathymetry in the Rio Grande Rise, with negative values of them corresponding to the depressions and positive values, to the elevations. It is important to perform a joint analysis of the maps of the two groups of SSG tracks, ascending and descending, because they complement each other.

With the analysis of each individual track, it is expected to obtain new details of ocean floor structures, as Marks and Smith (2007) did by identifying underwater features through satellite altimetry, especially for seamounts and guyots with characteristic radius greater than 14 km (based on the radius of a straight circular cylinder), because there is attenuation of the altimetric amplitude for smaller seamounts, probably due to the use of filters in data processing. Wessel et al. (2015) have identified, through satellite altimetry data, patterns in the signals that represent fracture zones and even allow the semi-automatic detection of some of these features.

Conclusions

The integrated use of gravity field elements from various satellite altimetry missions provides a good distribution of data throughout the study area. Both SSH and SSG values proved to be important for the identification of seafloor structures. SSH wiggles showed the contour of large features of both units of the Rio Grande Rise while SGG values showed potentiality to determine other smaller scale structures as well. Both magnitudes correctly positioned the identified structures, in relation to the bathymetry of the area. By analyzing the tracks individually it is expected to find new details of seabed features.

Acknowledgments

To CAPES (Coordenação de Aperfeiçoamento de Pessoal de Ensino Superior) for the master’s scholarship.

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