Correlation between bathymetric and free-air gravity anomaly maps of south-east Brazilian coast

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Abstract

We present the results of evaluating correlations between maps of geophysical properties based on their morphology. This method uses angles between gradients and cross-products values as criteria of correlation between maps. Applied to gravity anomaly and bathymetry this method was used to determine sources of gravity anomalies. We tested this method on synthetic model and applied to investigate the relation between free-air gravity anomaly and bathymetric maps of South-East Brazilian coast. Resulting maps were coherent with existing Bouguer anomaly and isostatic models. Method and results are discussed.

Introduction

There is a variety of approaches to determine the relation between bathymetry and gravity anomalies and isostatic compensation, for example the use of wavelet transforms (Audet et. al., 2006; Keller, 2004), computed isostasy based on Airy-Heiskanen and Pratt-Hayford models (Gottl et al., 2009; Heiskanen, W. 1953) or Bouguer correction. All those methods are based on models and density assumptions.

Our idea is to evaluate correlations between bathymetry and FA from their original maps morphologies. The advantage of using a morphological approach is that no actual isostatic compensation or Bouguer correction is computed to derive the conclusions.

To numerically interpret map morphologies we used gradient direction and magnitudes to compute angles between them and their cross-product. We used those morphological parameters to determine levels of correlation between maps. Correlation between maps determined by their morphological properties will be referred as *morphologic correlation*. Preliminary results were presented on the SEG-Annual Meeting in Denver (Jilinski et al, 2010).

Method

Correlation between bathymetry and free-air gravity anomaly (FA) provides important information on regional lithosphere isostasy and reflects its thermo-mechanical state. For a tectonically stable region we can expect bathymetry to be the main source of observed FA. Local bathymetric structures within a scale of 100 km can be supported by lithosphere and will have a corresponding FA while larger structures are *isostatically* compensated and gravity anomaly over them is influenced by deeper structures (McKenzie, 1976; Watts, 2001). FA directly reflects the state of isostatic compensation (Audet, P., Mareschal J.C., 2007; Dehlinger, 1978; McKenzie, 1976; Torge, 2003; Watts, 2001) and are strongly correlated with local, uncompensated bathymetry (Franziska and Rummel, 2009). Exceptions could be found in regions with crustal or deeper density inhomogeneities.

In our research we used angles between gradients directions and cross-product values as qualitative and quantitative criteria to estimate correlation between maps. Our hypothesis is that a strong morphological correlation between FA and bathymetry indicates that the main source of the observed gravity anomaly is the local bathymetry. Accessing the overlapping influence of deeper crustal structures is important for a precise Bouguer correction.

Gradient directions are determined according to Moore et al. (1993). Angles between gradients are obtained by subtraction of individual gradient direction and range from 0º to 180º. From statistical and spatial distribution of angles we can access morphologic correlation between maps. Statistical distribution of angles can be made to evaluate correlation by specific criteria (ex. depth, magnitude, etc). Resulting map of angles will allow us to find correlated and not-correlated regions. We can distinguish direct and inverse correlation.

Map morphologies can be directly correlated - dominated by angles close to 0º or inverse correlated - domination of values close to 180º. Not-correlated regions will appear as spots of values and statistical distribution of angles will be equal over the interval.

On maps morphologically correlated regions or structures will appear dominated by angles close to 0º or 180º. Not correlated regions should be characterized by angles close to 90º.

The use of cross-product values for image correlation interpretation was developed by Gallardo and Meju (Gallardo, Meju et al., 2003; 2004; 2005; 2007).

Cross-Product formulae:

$$\mathbf{a \times b = |a| \cdot |b| \cdot sen(\alpha);} \qquad (1)$$

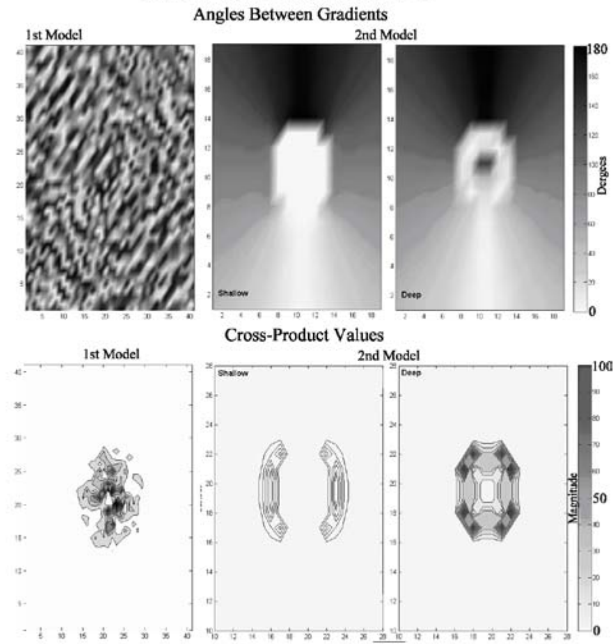
where *a* and *b* are gradients magnitudes and α is the angle between them.

Cross-product values depend on gradient magnitudes and sine of the angle between them (1). In theory, regions where product of gradient magnitudes becomes zero after multiplication by the sine of the angle are correlated. Higher cross-product values point out morphologically distinct regions. Small cross-gradient values can be generated by small value of one of the gradients or small angles between. Only values generated by small sine values are an indicator of morphological correlation. For real data we can not expect exact match of maps shapes. Cross-product is highly susceptible to small divergences is shape between anomalies. Also its results can not be compared for regions with different gradient magnitudes. It is important to perform magnitudes normalizations and use different scales for visualization when analyzing correlations. Cross-product performs better with smoothed or sparse grids or for region with structures of similar magnitudes. Cross-product is a valuable tool to interpret level of correlation over specific structures.

Examples

To test this method of determining correlations between bathymetry and FA were created synthetic models simulating gravitational effect vertical component distribution. The first model – not-correlated case - is of the gravitational effect of a crust punctual density inhomogeneity not correlated with bathymetry. The second model – correlated case - is of the gravitational effect of a prismatic bathymetric structure. For the second model we used two different depths from the estimation level in order to evaluate how the dispersion of the gravitational effect affects morphological correlations.

Figure 1. Syhtnetic Models



The results of these models indicated some properties of the applied method. It had shown the importance of using different criteria to make the interpretations more reliable. Figure 1 present the resulting maps.

First model (Figure 1, a) shows random spots of angles values indicating that original maps are not correlated. Spots of higher cross-product values were located closer to the body – region with higher magnitudes - indicating strong morphological divergences.

The second model (Figure 1, b, c) showed that with increasing distance from the structure morphological correlation decrease. Angles show a strong correlation by contouring structures borders with small values. Correlation is stronger for the shallow case (Figure 1, b) than for the deep case (Figure 1, c) as expected. Higher cross-product values are created in the corners of the structure while magnitudes are minimized over straight borders because gravitational gradients point to the center of mass. Cross-product also showed stronger correlation for shallow depth.

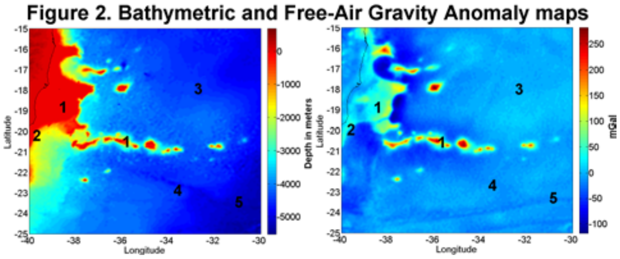
Those models showed that we cannot expect a complete morphologic correlation even in originally correlated case for bathymetric and FA maps.

This experiment allowed us to make the following conclusions. Morphologic correlation between maps should be accessed first by constructing maps of angles between gradients. Map of angles localize correlated regions. Afterwards cross-product maps can be constructed to evaluate levels of correlation for those regions. Cross-product maps should be analyzed together with angles and magnitudes maps.

Results

We applied this method to investigate correlation between bathymetry and FA maps of the South-East Brazilian coast. The studied area is limited by 20°W and 30°W meridians and 15°S and 25°S parallels. Western part is dominated by shelf and continental slope. It is a passive transition zone from oceanic to continental crust. This segment is characterized by regions with active and passive tectonics. Western part presents a sequence of fractures extending eastward. Vitoria-Trindade Fracture Zone (VTFZ) with a corresponding seamount chain extends from east to west (Alves et al, 2006). Abrolhos bank is responsible for the uncommon width of the shelf zone adjacent to VTFZ. Bathymetry is complicated by smaller volcanic seamounts and banks. Those types of structures are expected to have a corresponding FA (Zembruscki, S.G. 1979). Bathymetry is represented by isostatically compensated and uncompensated structures. Bathymetric data was derived from ETOPO2v2 grid (NGDC/NOAA; http://www.ngdc.noaa.gov). Marine gravity data from the Satellite Geodesy at the Scripps Institution of Oceanography, UCSD (Smith & Sandwell, 1997; http://topex.ucsd.edu).

Figure 2. Bathymetric and Free-Air Gravity Anomaly maps



On Figure 2 bathymetric and FA maps are presented in normal and log scales. The use of log scaled maps makes small structures affecting angles maps visible. Log maps show that ocean floor is all covered by small magnitude FA and bathymetric structures. Angles are not dependent of magnitudes but those structures if not correlated will generate small spots of angles indicating weak correlation for the region. Due to small magnitudes of both gradients they will not appear on regional cross-product map. Those structures indicate the need for a separate statistical analysis of structures by their magnitude. We marked regions of special interest with numbers on Figure 2:

1- Abrolhos Bank and VTFZ;
3- Shelf, continental slope and continental rize;
3- Abyssal plane north of VTFZ;
4- Abyssal plane south of VTFZ;
5- Fracture zones.

Figure 3. Angles Between Gradients

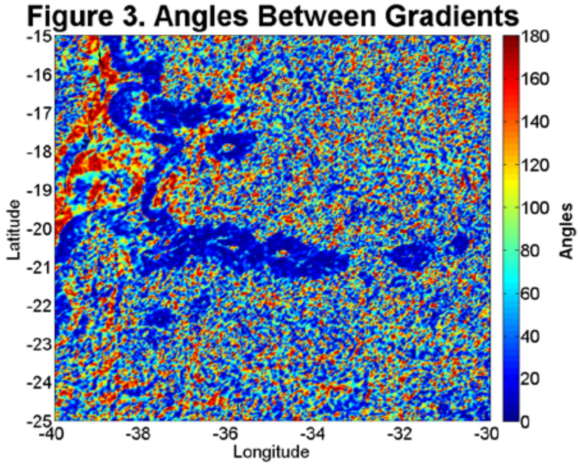


Figure 3 shows the resulting map of angles between bathymetric and FA gradients. Statistical distribution of angles between bathymetric and FA gradient is given in equal intervals. 22.5% of values are smaller 20°. If we only analyze most prominent bathymetric structures (with magnitudes larger than standard deviation from the mean value) this number increases to 65.2% indicating correlation. From figure 3 we can see that correlated areas are concentrated on slopes of major bathymetric – seamounts and continental slope (respectively regions 1 and 2). Shelf zone is characterized by dominance of inverse correlation. Abyssal plane shows uncorrelated spots indicating no common tendencies between bathymetry and FA (regions 3 and 4). Fracture zones show strong correlation (region 5). Map of angles shows strong correlation between bathymetry and FA. Especially over seamounts.

Figure 4. Cross-Product map - VTZF

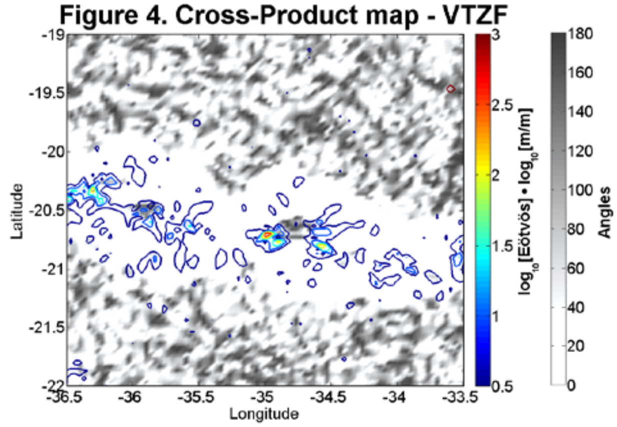


Figure 4 presents the resulting cross-product map over a segment of VTZF. It shows small spots of higher cross-product magnitudes following bathymetry and FA angles and magnitude isolines (as shown in second model). Cross-product shows high levels of correlation. Higher values are generated by slightly larger angles in regions with high magnitudes. The same behavior can be observed over other seamounts. According to these results for the studied areas cross-product values distribution shows strong correlation suggesting that seamounts are the main source for the observed FA.

Conclusions

We used different gradient properties to analyze correlation between bathymetry and free-air gravity anomaly. We created synthetic models to test the method and analyzed maps of the South-East Brazilian coast. Angles between gradients proved to be a good indicator of correlation between maps as show using our synthetic models and real data. Maps of angles can be used to find areas with direct and inverse correlation between mapped properties and contour areas of influence of anomalies outside actual structure borders. A statistical analysis of the distribution of angles by magnitudes is a good criterion for evaluating correlation.

Cross-product alone can not be used to interpret correlation. Cross-product performs better combined with angles and magnitudes maps gives information about levels of correlation and for smaller scale structures. Maps of angles and cross-product map indicate a strong correlation between bathymetry and FA. Based on our results we can conclude that for South-East Brazilian coast bathymetry is the main source of the observed free-air gravity anomalies. Results were coherent with existing models and Bouguer anomaly maps of the region.

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