ISSN:1984-2295

Revista Brasileira de Geografia Física

Homepage: www.ufpe.br/rbgfe

Solução de baixo custo para correção de variações de maré no mapeamento de ambientes costeiros

Leonardo Lara de Carvalho¹, Fabio Ferreira Dias^{2,3,4}, Vanessa dos Santos Mariano de Souza⁵, Alberto Luis da Silva³, Paulo Roberto Alves dos Santos³, Ruan Vargas⁶, Roberto Campos Villaça²

¹Programa de Pós-Graduação em Biologia Marinha e Ambientes Costeiros – Universidade Federal Fluminense, autor correspondente: leonardolara1@yahoo.com.br. ²Professor, Programa de Pós-Graduação em Biologia Marinha e Ambientes Costeiros – Universidade Federal Fluminense, fabiofgeo@yahoo.com.br, robertocv@id.uff.br. ³Professor, Depto. Análise Geo-Ambiental – Instituto de Geociências - Universidade Federal Fluminense, albertosilva@vm.uff.br, paulorobertoalvess@gmail.com. ⁴Professor, Programa de Pós-Graduação em Engenharia de Biossistemas – Universidade Federal Fluminense. ⁵Geógrafa – Universidade Federal Fluminense, vanessa2mariano@gmail.com. ⁶Mestrando, Programa de Pós-Graduação em Engenharia de Biossistemas – Universidade Federal Fluminense, ruanvargas@id.uff.br.

Artigo recebido em 29/11/2017 e aceite em 05/03/2018

RESUMO

As constantes modificações no ambiente costeiro marinho, sejam causadas por agentes naturais ou antrópicos, impõe a necessidade de se conhecer a morfodinâmica e morfografia costeira de maneira a auxiliar na conduta de utilização desse ambiente para fins de navegação, projetos de engenharia ou conservação do mesmo a partir de estudos ecológicos. A metodologia sugerida, neste trabalho, pode ser utilizada com pequenas embarcações comerciais, um GPS geodésico e um ecobatímetro, destinada a avaliar os relevos submersos de regiões costeiras rasas, principalmente costões rochosos e zonas recifais. O levantamento hidrográfico foi feito em três praias de Armação dos Búzios, a partir da associação dos valores de profundidade registrados por um ecobatímetro monofeixe associado a um rastreador geodésico, processado pelo método relativo cinemático. A técnica mostrou ser mais eficiente que o uso de correções de redução batimétrica clássicas. O trabalho também enfatiza a importância do pós-processamento dos dados para melhoramento dos modelos gerados. A partir dos mapas bidimensionais, as diferenças topográficas quanto à inclinação e profundidade puderam ser evidenciadas, enquanto que os modelos tridimensionais destacaram os afloramentos formados por recifes rochosos. Este trabalho oferece subsídios para estudos futuros de levantamentos hidrográficos de regiões costeiras rasas e caracteriza-se como importante ferramenta de gerenciamento costeiro.

Palavras chaves: batimetria, ecobatímetro, GPS, costão rochoso, recifes rochosos

Low-cost solution for correction of tidal changes in the mapping of coastal environments

ABSTRACT

Constant changes in the marine coastal environment caused by natural or anthropic agents lead to the need of knowing the coastal morphodynamic and morphography in order to assist its use for navigation purposes, engineering projects, or its conservation by means of ecological studies. The methodology suggested in this study can be used with small commercial vessels with a geodesic GPS and an echo sounder and it is used to assess submerged reliefs of shallow coastal regions, mainly rocky shores, and reef zones. The hydrographic survey was carried out on three beaches of Armação dos Búzios by associating depth values registered by a single-beam echo sounder associated with a geodesic tracker, processed by the kinematic relative method. This technique was more efficient than the use of classical bathymetric reduction corrections. Our study also emphasizes the importance of post-processing of data to improve the generated models. From two-dimensional maps, topographic differences in slope and depth could be evidenced, while three-dimensional models showed outcrops formed by rocky reefs. This study offers support for future studies on hydrographic surveys of shallow coastal regions and it is an important coastal management tool.

Keywords: bathymetry, echo-sounder, GPS, rocky shore, rocky reefs

Introduction

Coastal environments are considered highly complex because they are constantly modified by the action of continental and marine agents, which are responsible for the different physiographies that compose the coastal zone. However, the anthropic action in this environment has contributed to significant changes, not only in the landscape but also in their dynamics. The coastline is an example of instability resulting from changes due to natural and anthropic effects, resulting in changes in sediment availability, wave climate, and relative sea level (Muehe, 1995). In addition, the intensification of demographic occupation and use of the coastal environment for economic purposes often disregard its dynamics.

Thus, the need for in-depth research on the coastal morphodynamic and morphography has grown in order to assist its use for navigation purposes, engineering projects, or its conservation by means of ecological studies. Therefore, there is an increase in scientific and academic research, whose object of study refers to changes and morphodynamic studies of this environment. However, this is a topic of recent scientific interest and there are many questions to be answered on the coastal dynamics. For this, the integration of measurement techniques with precision positioning equipment and use of geo-technologies have brought very positive results to the knowledge of the coastal environment. Many of these studies have collaborated in the moments of decision making, especially in creating means to manage the coastal areas in an environmentally correct manner.

In this context, knowing the submarine bottom and identifying its morphology is necessary. The bathymetric survey associated with relief modeling techniques constitutes an efficient methodology for mapping and knowing sea-floor morphology. Identifying the depth of coastal environments has significant relevance since they collaborate for an environmentally correct management, vessel safety in coastal navigation, and various constructions. In addition, knowing the submarine topography in this environment provides support for understanding the distribution patterns of benthic organisms. Several studies on bathymetry have already been carried out addressing a variety of topics, also assisting in conservation and reconstruction of the coastal environment, such as beach recovery (Osilieri et al., 2013). From hydrographic surveys it is possible to map coastal areas, collecting position

and depth data for describing the submarine relief, being also important for navigation as it provides safety and support to other activities such as research, environmental protection, and predictions (Leandro et al., 2008).

In this sense, from geo-technologies as tools, the focus of this study is to contribute and encourage future research studies of the submerged morphology of shallow coastal areas from the generation and analysis of two- and three-dimensional models that are, in many cases, spaces delimited by rocky or coral reef ecosystems.

Methodology

Bathymetric survey

This study was conducted in four beaches on the coast of Cabo de Armação dos Búzios, in the State of Rio de Janeiro, Brazil. The area is located between the coordinate vertices, in UTM, 7480409.44 mN, 201342.59 mE; 7482559.26 mN, 204741.11 mE (horizontal datum WGS 1984, zone 24K). The sampled regions (Figure 1) were delimited by polygons and their trajectories were previously established. The mapped areas on the beaches of João Fernandes/João Fernandinho (hereinafter referred to as João Fernandes), Tartaruga, and Canto/Bardot (hereinafter referred to as Bardot cove) is equivalent to 241,310, 284,813, and 844,473 m², respectively.

A single-beam echo sounder (521S – Garmin, Figure 2) coupled to a probe fixed to the draft of a vessel was used for sounding and obtaining gross bathymetric measurements. The previously established trajectory of sounding was guided by using a second portable GPS. The data obtained by the echo sounder were processed together with the positioning data from a pair of geodesic GPS receivers (Zenith 2 L1/L2 – TechGeo) in order to determine the sampling point accurately and correct errors of readings due to tide variation. We used two GPS receivers to ensure continuous data collection even if one of the receivers lost the communication with the satellites for a certain period. The sounding of all sampled areas was carried out on October 22, 2014, for a period of approximately 5h, starting during low tide in the flood process and ending at high tide peak. The distance between the echo-sounder probe and the GPS receiver was registered for further correction of tidal changes as shown in the diagram.

Figure 1. Location of the study area highlighting the beaches where the bathymetric surveys were carried out.

Figure 2. Equipment used on board. On the left, echo sounder displays the real-time bathymetric survey and auxiliary GPS used to guide the sampling trajectory. On the right, geodetic GPS receivers.

After data collection in the laboratory, a pre-treatment of the data recorded by the echo sounder was performed, and null values or values obtained outside the pre-established area were eliminated. In addition to the bathymetric data, the exact positioning of the GPS receiver in three-dimensional space was obtained from the post-processed kinematic relative method. This method takes as reference the geodetic data acquired concomitantly from a fixed ground point at the RIOD station (located in the city of Rio de Janeiro, Brazil), belonging to the Brazilian Network for Continuous Monitoring, and another

mobile point, fixed in the vessel (Monico, 2000; Seeber, 2003). The positioning data obtained by the geodetic GPS at moments different from those obtained by the echo-sounder were excluded from the analyses (Table 1), thus leaving only the positioning values correlated with the exact moment of obtaining the values of bathymetry (Ferreira et al., 2014). GPS data was combined with bathymetry information in the software GTR Processor. Each point obtained by GPS and correlated with depth measure was investigated regarding the interpretation of mode of obtaining the data (kinematic or static), carried out automatically by the program. The points erroneously considered as landmarks (static mode) were corrected for kinematic mode since the entire survey was performed during a trajectory.

After the data was treated, depth values related to the local reduction level were estimated from the bathymetric reduction calculation in order to eliminate the effects of sea level rise by tide and oscillations produced by waves (Figure 3). The real depth value (D_r) at a time t was calculated based on the relation between antenna ellipsoidal heights $h(t)$ and the ellipsoid GRS80, on the ratio (R) between local reduction level (NR) and the ellipsoid, on the distance (a) between GPS receiver and the probe, and on the

depth [$D_e(t)$] obtained by the echo sounder from the distance between the probe and the seabed.

The equation used in the bathymetric reduction

Table 1. Data preprocessing example. The table shows the data of the GPS receiver excluded from the analysis (in bold) because in some moments there was no capture of depth values (D_e), obtained by the echo sounder.

Tempo hh:mm:ss	Receptor GPS						Ecobatímetro			Eq.
	E (m)	S (m)	H+a (m)	E(rms)	N(rms)	H(rms)	E (m)	S (m)	D_c (m)	
14:54:40	203693.815	7481103.990	5.894	0.0363	0.0416	0.0891	203694	7481102	3.5	2.539
14:54:41	203693.417	7481101.248	5.891	0.037	0.0422	0.0948	--	--	--	--
14:54:42	203693.197	7481098.483	5.885	0.0372	0.0423	0.0971	203694	7481098	3.5	2.53
14:54:43	203693.119	7481095.684	5.916	0.0371	0.0428	0.0974	203693	7481094	3.5	2.561
14:54:44	203693.258	7481092.943	5.894	0.0372	0.0427	0.0979	--	--	--	--
14:54:45	203693.588	7481090.229	5.896	0.037	0.0422	0.097	203694	7481089	3.4	2.441

Figure 3. Scheme of the bathymetric survey method. On the left, a representation of the measures used to obtain the depth relative to the local reduction level (NR). On the right, a photograph indicating the positioning of the GPS receiver and echo-sounder probe. R – coefficient of the ratio between the ellipsoid and reduction level; h(t) – ellipsoidal height of the antenna; (a) – distance between antenna and probe; $D_e(t)$ – depth measured by the echo-sounder; $D_r(t)$ – real depth in relation to the local reduction level.

Depth prediction in places not sampled by the echo sounder was obtained from computational models. For this, the geoprocessing software ArcGIS 10.2 was used with the interpolation Top to Raster within the areas delimited by predefined polygons. The comparative work between interpolators to generate bathymetric maps by Nogueira and Amaral (2009) indicates that the method by Topo to Raster is more advantageous than the kriging method for bathymetric studies, offering more details of topography. In order to estimate the error obtained in models without correction for bathymetric reduction, an estimate of accretion and volume reduction was performed from the difference between modeling with depths corrected at the level of local reduction and those not corrected. Three-dimensional models were produced from surface models by using the

was:

$$D_r(t) = D_e(t) + [h(t) + (a)] - R \quad (1)$$

software ArcScene 10.2 with factor 15 of exaggeration so that relief features could be highlighted. The images of beaches confronted with three-dimensional models were obtained by the satellite WordView-2, kindly provided by DigitalGlobe™.

Results

Sounding registered 7261 times (depth values collected every second) among the three mapped regions. A large number of times collected allowed generating more robust surface digital models. Associated with the dense sampling, the use of high precision geodesic positioning system resulted in more accurate reduction corrections at the mean sea level. The difference between the classical corrections and the use of the geodesic system was, on average, 0.05 m (Figure 4).

Figure 4. Comparison between bathymetric reduction methods. The graph shows an example of depth differences (negative values) after a bathymetric reduction on a 100-m route. Correction by classical method (gray line and square marker) and kinematic relative method by GPS (black line and round marker). Markers indicate the estimated values.

The maps of products of the differences between the bathymetric profile with and without

reduction allowed observing a continuous overestimation of depth due to the effect of tide increase and an underestimation of some small areas probably due to prediction errors in less densely sampled areas (Figures 5, 6 and 7). However, the sum of these underestimated areas did not exceed 0.2% of the total sampled area. The reduced volumes by geodesic system on the beaches João Fernandes, Bardot cove, and Tartaruga were equivalent to 158,431, 840,851, 388,204 m³, respectively. From the generated digital models, we observed that João Fernandes cove presented a higher slope, reaching depths of up to 17 m (Figure 5). The coastal zone that borders the waterline is at least 1 m deep. Thus, this region is home to benthic organisms that remain constantly submerged, not desiccating, except for a narrow strip that is exposed during low tide but it could not be reached by the vessel during sampling. The opposite was found in the northeast portion of Bardot cove. This region is delimited by the Environmental Protection Area of the Coral Park of Armação dos Búzios and presents an extensive area of depths ranging from 0 to 1 m.

In regions closer to the coast, depth tends to zero and the substrate remains exposed to the air during periods of low tide (Figure 6). In these areas, resident organisms remain exposed for a few hours and, if exposure occurs during the daytime period, these organisms suffer from rising temperatures. On this beach, the slope is softer than in João Fernandes and extends on average about 200 m from the coastline to the sea, reaching 4 m deep.

The deepest region found in this zone was also lower than that observed in João Fernandes beach, reaching up to 13 m. However, the shallowest region was observed in Tartaruga Beach, reaching a maximum depth of 8 m and a sloping even softer than the other beaches, extending about 300 m from coastline to the sea, reaching depths higher than 4 m (Figure 7). As the Bardot cove, Tartaruga beach has areas exposed to the air during periods of low tide in the northeast portion, in which there are rocky outcrops inhabited by algae, corals, and other benthos. An extensive sand strip characterizes the south-west side of this beach.

Figure 5. Bathymetric maps (left) and areas altered by the bathymetric reduction (right). Beaches of João Fernandes

Figure 6. Bathymetric maps (left) and areas altered by the bathymetric reduction (right). Beach of Bardot.

Figure 7. Bathymetric maps (left) and areas altered by the bathymetric reduction (right). Beach of Tartaruga

From the digital surface models, the submerged relief form could be observed in detail (Figures 8, 9 and 10). The images obtained by the satellite WorldView-2 confirmed the presence of discontinuity of rock outcrops (reefs) detected in the bathymetric survey of João Fernandes beach and an increase of depth in the central region, represented by darker tones (Figure 8). The areas near the coast exposed to the air during periods of low tide and rocky elevations around Caboclo Island were observed in Bardot cove (Figure 9).

Similarly, the rocky shore at Tartaruga beach could be observed in the central region and in its northeast portion (Figure 10). In addition, topographical elevations were also observed in the southwest portion of this beach. However, although the probe used in this study is not able to identify the type of substrate, previous studies carried out in this region (Carvalho, 2016) indicated that the elevations observed in the southwest portion are submerged sandy dunes.

Figure 8. Image of João Fernandes beach obtained by the satellite WorldView-2 and its respective three-dimensional model.

Figure 9. Image of Bardot beach obtained by the satellite WorldView-2 and its respective three-dimensional model.

Figure 10. Image of Tartaruga beach obtained by the satellite WorldView-2 and its respective three-dimensional model.

Discussion

The use of a geodesic reference allowed characterizing the submerged relief with a higher accuracy since we considered the coastal processes then active of the bathymetric survey, in addition to being able to identify outcrop regions characterized by rocky reefs.

Souza (2015) used the same database of our study to estimate the real topographic profile of João Fernandes beach. Although this author has succeeded in producing digital surface models with bathymetric reduction, the data obtained here reached a higher accuracy after reprocessing the data interpreted by the program as being obtained in static mode for the kinematic model. This improvement is found from the uniformity of

removal of estimated volume after processing. This result was expected since during the sounding tide was above the local reduction level. Modeling without bathymetry reduction results in the information of low relevance and makes decision-making impractical regarding, for example, route planning for vessels or studies of sedimentary balance processes (Ferreira et al., 2014). Moreover, reduction estimates by the classical method do not consider variations in measurements due to wave oscillations on vessels (Ramos and Krueger, 2009).

The sampled beaches do not show large ripples due to the low hydrodynamics (Oigman-Pszczol et al., 2004), and thus the method advantage on this effect in the northern portion of Búzios is insignificant in deeper areas. However,

variations produced by waves in very shallow and sloped regions, close to the coast, even if they are of low intensity, can make the correlations between benthic organism zonations and depth unfeasible if soundings are not measured correctly. Therefore, the method used in this study is justified due to the large mapped area of rocky shore be less than 1 m deep.

The different degrees of inclination were detected by the bathymetric mapping, showing a continuous increase from the beaches Tartaruga to João Fernandes. Although the entire northern region of Búzios presents a low hydrodynamicity (Bulhões and Fernandez, 2011), the formation of deeper regions on João Fernandes beach may indicate a more marked hydrodynamicism in this region when compared to the other mapped areas. However, much of the mapped area resembles other beaches regarding depth and differs only in its portion closer to the cove entrance. Thus, this characteristic may be the result of its positioning towards open oceanic areas, in which the highest hydrodynamicity may be restricted to these deeper regions. According to Oigman-Pszczol and Creed (2004), the wave exposure index in João Fernandes is about twice as high as in Tartaruga beach. This result is in accordance with the less sloping relief on Tartaruga beach observed in the bathymetric map. Thus, a deeper understanding of submerged reliefs can support studies on sediment transport process and hydrodynamics, which are essential for a good coastal management.

Conclusion

The bathymetric mapping performed on the beaches of Búzios provided detailed information with an efficient bathymetric reduction at the local relative level since post-processing corrections encompassed coastal dynamics at the time of the survey. This technique might be used for ecological and coastal management studies in a fine scale of space, mainly in shallow and sloping areas due to a greater precision of values obtained by the geodesic GPS.

In this sense, the presented methodology is aimed at the bathymetric survey of shallow coastal regions such as beaches, rocky shores, and coves since this study proposes the use of a simple set of equipment, but with limitations. Thus, we recommend the use of more sophisticated equipment, such as multi-beam probes, for future studies with a larger sampling scale performed in deeper regions. In addition, surveys conducted in oceanic areas whose water turbidity is lower than

in coastal areas may be associated with the concomitant use of remote sensing by satellite imagery when classifying underwater features and understanding geological events.

The importance of performing manual data processing in a cautious and systematic way, in order to eliminate mistakes and misinterpretations, is emphasized in this study since the generated models showed a significant improvement when compared with a previous work carried out in the region.

The use of geo-technologies associated with in situ surveys for small coastal areas proved to be efficient and possible to be carried out by using small vessels. Thus, this study encourages future studies to use the proposed methodology and contribute to the knowledge of underwater features of marine coastal environments. This information will serve as powerful coastal management tools.

Acknowledgements

We are grateful to the Coordination for the Improvement of Higher Education Personnel (CAPES) and the Rio de Janeiro Research Foundation (FAPERJ) for the financial support. We are also grateful to the authorities for the research permission in the Environmental Protection Area of the Coral Natural Park of Armação dos Búzios, issued by the Municipal Government of Armação dos Búzios (#006/2014) and by the Chico Mendes Institute for Biodiversity Conservation (#35309-3). Lastly, we are grateful for the images of the satellite WordView-2, courtesy of DigitalGlobe™.

References

- Bulhões, E., Fernandez, G., 2011. Analysis of shallow water wave propagation and coastal response in embayed beaches. case study in Cape Buzios, Rio de Janeiro, Brazil. *Journal of Coastal Research* SI 64, 2022-2026.
- Carvalho, L.L., 2016. Estudo das comunidades bentônicas de Armação dos Búzios (RJ) com ênfase nas relações entre corais e macroalgas, *Biologia Marinha*. Tese (Doutorado). Niterói, Universidade Federal Fluminense.
- Ferreira, A.T.d.S., Amaro, V.E., Santos, M.S.T., Lopes, A.B., 2014. Geodésia aplicada à integração de dados topográficos e batimétricos na caracterização de superfícies de praia. *Revista Brasileira de Cartografia* 66, 167-184.

- Leandro, D., Huinca, S.C.M., Krueger, C.P., Ramos, A.M., 2008. Análise da qualidade do posicionamento de uma embarcação em um levantamento hidrográfico, in: Superintendência de Ensino da DHN (Ed.), Anais Hidrográficos: Revista Anual de da Diretoria de Hidrografia e Navegação. Diretoria de Hidrografia e Navegação, Rio de Janeiro, pp. 75-85.
- Monico, J.F.G., 2000. Posicionamento pelo Navstar-GPS, 1 ed. Unesp, São Paulo.
- Muehe, D., 1995. Geomorfologia costeira, in: Guerra, A.J.T., da Cunha, S.B. (Eds.), Geomorfologia: uma atualização de bases e conceitos. Bertrand Brasil, Rio de Janeiro, pp. 253-308.
- Nogueira, J.d., Amaral, R.d., 2009. Comparação entre os métodos de interpolação (Krigagem e Topo to Raster) na elaboração da batimetria na área da folha Touros-RN. Anais XIX Simpósio Brasileiro de Sensoriamento Remoto, Natal, Brasil, 25-30.
- Oigman-Pszczol, S.S., Creed, J.C., 2004. Size structure and spatial distribution of the corals *Mussismilia hispida* and *Siderastrea stellata* (Scleractinia) at Armacao dos Buzios, Brazil. *Bulletin of Marine Science* 74, 433-448.
- Oigman-Pszczol, S.S., Figueiredo, M.A.D., Creed, J.C., 2004. Distribution of benthic communities on the tropical rocky subtidal of Armacao dos Buzios, southeastern Brazil. *Marine Ecology-Pubblicazioni Della Stazione Zoologica di Napoli I* 25, 173-190.
- Osilieri, P.R.G., Dias, F.F., da Silva, A.L., da Silva, A.C., de Alencar Castro, J.W., 2013. Uso de modelos digitais de terreno no monitoramento da Praia do Forno, Armação dos Búzios, RJ, Brasil. *Quaternary and Environmental Geosciences* 4, 01-08.
- Ramos, A.M., Krueger, C.P., 2009. Aplicação de reduções batimétricas GPS em levantamentos hidrográficos. *Boletim de Ciências Geodésicas* 15, 615-635.
- Seeber, G., 2003. *Satellite geodesy: foundations, methods, and applications*, 2ed. Walter de Gruyter, Berlin.
- Souza, V.S.M., 2015. Levantamentos batimétricos associados a geotecnologias na investigação de relevo submerso na praia de João Fernandez – Búzios - rj. Monografia (Trabalho de Conclusão de Curso). Niterói, Universidade Federal Fluminense.