CILAMCE 2017
Florianópolis - Santa Catarina - Brazil

WAVE ENERGY ATTENUATION OVER A PLANE SLOPE ACTING AS A COASTAL PROTECTION STRUCTURE ON THE SOUTHERN BRAZILIAN SHELF

Thaísa B. Trombetta

Phelype H. Oleinik

Bruno V. Lopes

Ricardo C. Guimarães

Wiliam C. Marques

Liércio A. Isoldi

thaisa_bt@hotmail.com

phe.h.o1@gmail.com

lopesbruno13@gmail.com

ricardo_guimaraes@hotmail.com

wilianmarques47@gmail.com

liercioisoldi@gmail.com

Universidade Federal do Rio Grande

Av. Itália, 99500-000, Rio Grande do Sul, Brasil

Abstract. *The erosion study over Santa Catarina shore, caused partially by the high intensity energetic waves, lead to problematic and shocking issues to the environment. Therefore, the present study aims to analyze the wave action over the Santa Catarina shoreline in addition to characterize the most energetic area using numerical models. From the data obtained, the insertion of a ramp was proposed, with the ambition to work as a coastal protection structure, attenuating the wave energy impact. Thus, through data and computational simulations for the year 2014, it was verified that Cape of Santa Marta region in Laguna has the most energetic wave values, and that with the utilization of the ramp it was possible to mitigate almost 98% of the wave height that approached the coast, and nearly 90% of the energetic potential. In this way, the installation of the ramp proved to be a valid alternative for the coastal protection in* *the Cape of Santa Marta region, demonstrating that this system could serve as an alternative to prevent the coastal erosion problem.*

Keywords: *Waves, Erosion, TOMAWAC, Coastal protection, Coastal zone.*

INTRODUCTION

Climate changes emerging from factors related to the global warming have been an extremely alarming circumstance to the society and the environment in the last years. According to Vallega (2001), the so called greenhouse effect, considered the most influent factor over the global warming theory, has caused alterations in the ocean level. With that in mind, the coastal dynamics ends up to suffer modifications, being able to suffer erosion, silting, crumbling dunes, and even damages to sea and port structures.

Scientists esteem that 70% of the shorelines over the world suffer from erosion (Lira, 1997) and around 40% of the 8,500 km of the Brazilian coast suffers a severe erosive process (Muehe, 2006). The main coastal erosion cases are due two factors (MMA, 2000): dispersion and sediments transport at the coastal zone, and human interventions (encouraged by the development of activities such as tourism, fishing, industry and commerce).

The sandy beaches present a unique dynamic because of their sediment mobility, carried by the constant effect of the waves, coastal currents, tides and wind, resulting in a process of beach addition and/or erosion (MMA, 2000). The erosion can also be related to the anthropic action, which through constructions over the coastal surroundings intensifies the erosive processes, making the occupations near the beach ambience vulnerable to wave action at more intense events (Horn *et al.*, 1998).

In Brazil, a high range of coastal areas, where the process of environmental change has become highly harmful, is requiring costal protection and reconstruction measures. Particularly at the Santa Catarina state, where nearly 68% of the population is situated at the coastal areas (Pollete *et al.*, 1995), the erosion has been causing serious environmental and socioeconomic damages to the counties.

Aiming to restrain the sea breakthrough and protect the coast from the erosive action, public and private investments are commonly requested, focusing at the construction of structures with different technological levels to protect the coastal zones. Airoldi *et al*. (2005) and Bruun (2013) stand out that the constructions can protect urban equipments, recover the shoreline and consolidate urban structures. Koerner *et al.* (2013) attracted attention to the effect of containment structures of coastline erosion, as a result for badly planned coastal areas. Eventually highly technological constructions do not guarantee high efficiency, being necessary an elaborated evaluation of the region, to define the suitable structure that ensures the expected results. In this way is verified the importance of study, planning and investment in new technologies, to assure the protection of the coastal dynamics and prevent the occurrence of bigger environmental problems at the determined region.

Inserted in this context, the present article consists in performing an analysis of the Santa Catarina shore, to identify the energetic wave action over the coast and then define the area that most suffer from the wave impacts. Next, a coastal structure capable to attenuate the wave action will be proposed, avoiding in this way a higher degradation of the environment.

1 STUDY AREA

The Santa Catarina coast extends itself for 561.40 km, between the latitudes of 25˚58”S and 28˚37”S and the longitudes of 48˚25” and 48˚49”W (Moraes, 1995) has 36 coastal counties, totalizing approximately 9,094.40 km^2 of land area and 5,894 km^2 of oceanic area (Scherer *et al.*, 2006).

The Santa Catarina coastline is oriented in the N-S direction from the border with Paraná state until Cape of Santa Marta, while the extreme south is oriented SW-NE up to the border of Rio Grande do Sul (Scherer *et al.*, 2006).

Oleinik *et al.* (2017) evaluated the wave's energetic potential in the south-southeastern Brazilian shelf and concluded that the most energetic wave places are Cape of Santa Marta in Santa Catarina, Ilhabela in São Paulo and Farol Island in Rio de Janeiro.

At Cape of Santa Marta, Oleinik *et al*. (2017) observed a considerable increase in significant wave height in the months of May and September, which are approximately the transition months between the cold and warm seasons, also the energetic potential present greater values at autumn and winter while smaller at spring and summer, having a considerable increase in May.

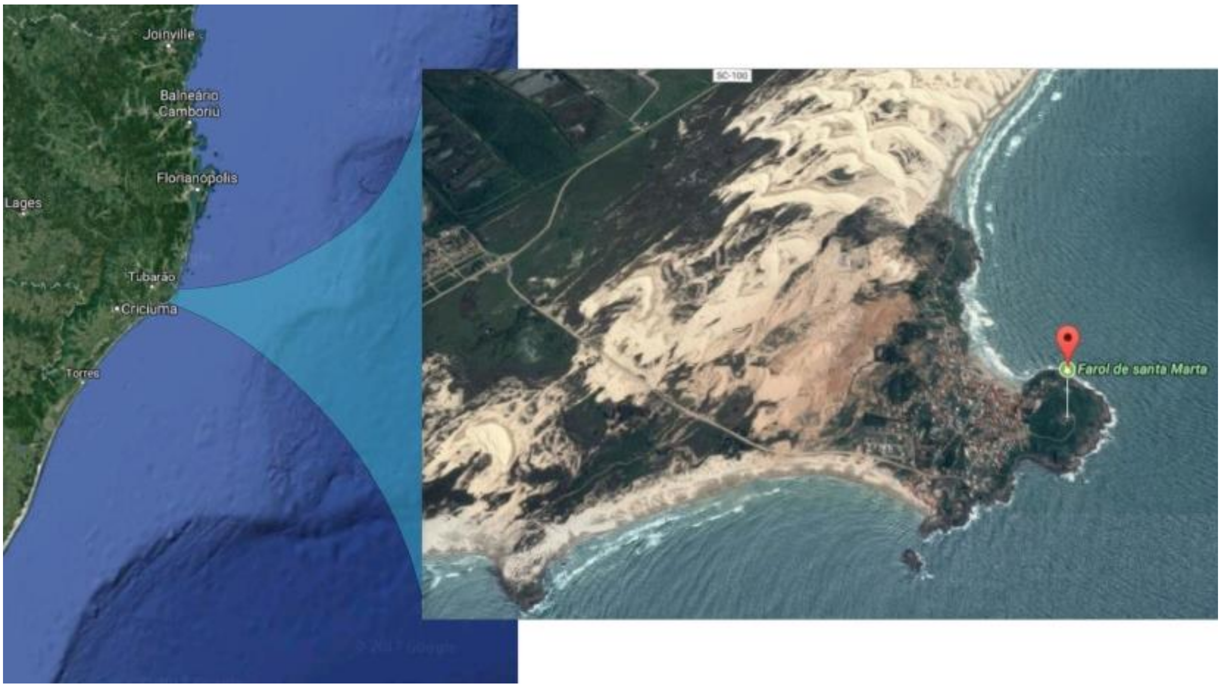

Figure 1. Location of the Cape of Santa Marta - Laguna/SC (Source: Google Maps, 2017).

2 METHODOLOGY

The numerical model TOMAWAC was used to perform the simulations. This model is part of the TELEMAC modeling system (www.opentelemac.org). TOMAWAC is a third generation wave model that computes the sea state by solving the equation of conservation of wave action density (Eq. (1)) for the wave directional spectrum:

$$\frac{\partial N(f,\theta)}{\partial t} + \frac{\partial \acute{x} N}{\partial x} + \frac{\partial \acute{y} N}{\partial y} + \frac{\partial \acute{k}_x}{\partial k_x} + \frac{\partial \acute{k}_y}{\partial k_y} = Q\left(k_x, k_y, x, y, t\right) \qquad (1)$$

where N is the directional wave spectrum, k_x and k_y are the components on the x and y directions of the wave number vector and t is time. Equation (1) represents that, in a general situation of waves propagating in a non-homogeneous and unsteady environment, the wave action density is preserved within the source and sink terms, defined by Q.

TOMAWAC calculates wind-driven waves taking into account most of the main physical processes involved such as, shoaling, whitecapping, bottom friction-induced dissipation, non-linear interactions between waves and depth-induced refraction. TOMAWAC, however, does not take diffraction and reflection into account.

To solve Eq. (1), TOMAWAC splits the directional spectrum of wave action (N) into a finite number of wave frequencies (f_i) and directions (θ_i) and solves Eq. (1) for each component (f_i,θ_i). The directional spectrum of wave energy, denoted by E(f,θ), can be associated with N(f,θ) through Eq. (2).

$$E(f,\theta) = N(f,\theta)\rho g \tag{2}$$

where ρ is the specific mass of water, g is the gravity acceleration and σ is the angular frequency of the waves given by σ = 2πf. The integration of E(f,θ) along the discretized frequencies and directions yields the energy per unit area of the random multi-directional waves (Eq. (3)).

$$\sum_{f}^{f+df} \sum_{\theta}^{\theta+d\theta} \frac{1}{2}\rho g a_m^2 = E(f,\theta) df d\theta. \tag{3}$$

The superficial conditions, correspondents to the year of 2014, were produced using global atmospheric data from NOAA (National Oceanic and Atmospheric Administration), with temporal resolution of 6 h and spatial resolution of 0.5 degrees. The boundary conditions were forced with significant height, peak period and peak direction of the waves, obtained through the forecast wave model WAVEWATCH III, with a temporal resolution of 3 hours and spatial of 0.5 degrees, also for the year 2014.

To generate the computational grid, the *software* BlueKenue (developed by CHC – *Canadian Hydraulic Centre*) was used, with boundary limits properly georeferenced, covering all the Santa Catarina coast extension and the north region of the Rio Grande do Sul coast. The unstructured mesh was generated with triangular elements, which enables the presentation of the domain from non uniform levels of refine, facilitating the achievement of higher resolutions over specific areas (Lynch *et al.*, 1996). The spatial domain is represented by a 195,436 nodes mesh, where the distance of the vertices of the triangular elements is of 15,000 m at the oceanic zone, 500 m at the coastal zone, and 80 m at the region of study.

3 RESULTS AND DISCUSSION

Through a simulation using waves forced by the wind over the year of 2014, was verified that the region with the more intense energetic values and therefore the more pronounced significant wave height, if compared to the adjacent regions at the coast of Santa Catarina, is Cape of Santa Marta situated in Laguna (Fig. 2).

Situated 120 km apart to the south of the capital Florianópolis, Laguna has a population of 51,562 (IBGE, 2016), being the city that most grown in this region of the state. The center-south shore of Santa Catarina presents a considerable demographic growth caused by the disordered and accelerated urbanization, culminating in significant environmental impacts over the region, such as the pollution of water bodies, erosive processes at the dune region and loss of the coastal vegetation (Scherer *el al.,* 2006).

By simulating the behavior of the waves at Cape of Santa Marta between 1997 and 2014, Oleinik *et al.* (2017) found values of significant wave height of from 1.25 to 1.5 m and from 7.5 to 10 kW/m of energetic potential close to the coastline. In the current study, which considers the year 2014 for analysis, values between 1.2 and 1.4 m were obtained for the significant wave height and approximately 8 kW/m of energetic potential. Thus, a similarity can be observed between the two studies.

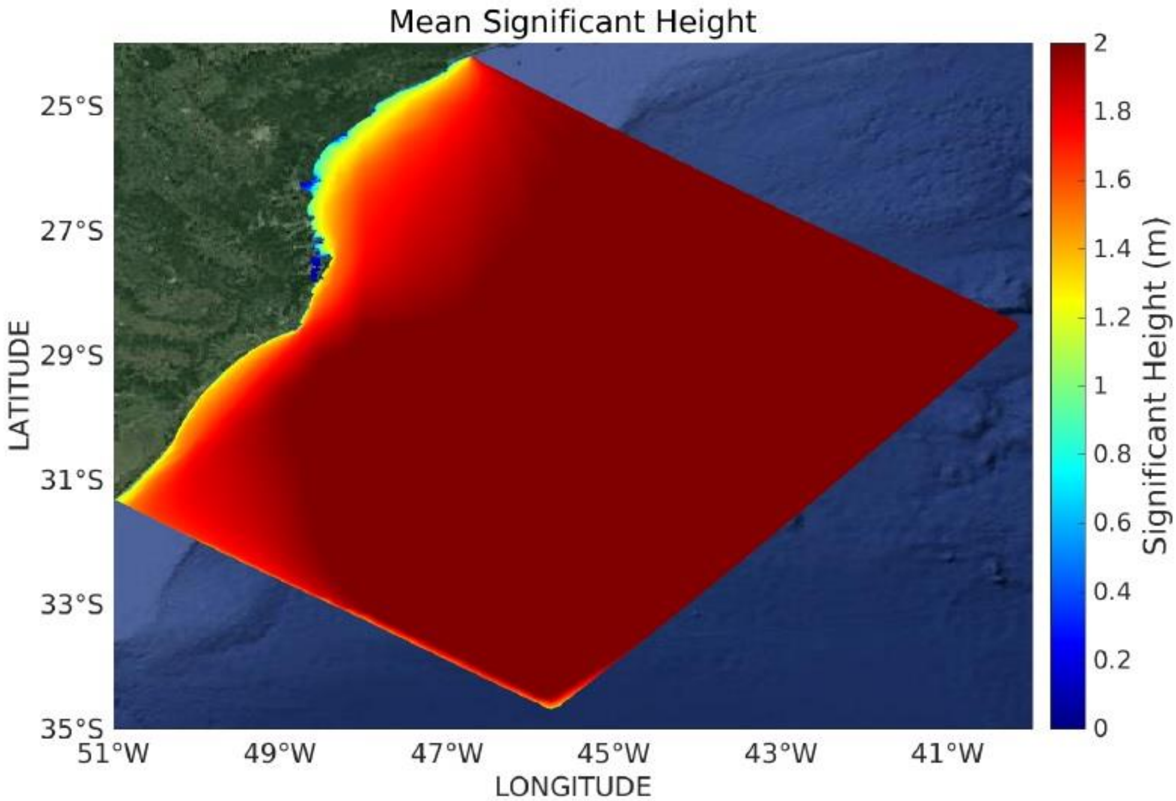

Figure 2. Significant mean wave height over the Santa Catarina coast in the year of 2014.

Due to the extension of the affected area by the wave action at Cape of Santa Marta, it was determined the use of a structure with ramp cross section, in a way that attenuated continuously the wave energetic potential. The ramp used for numerical simulations was defined with 7,000 m in length towards the ocean and 3,000 m of width along the coast, so that it wrapped completely the area that suffers the wave action (Fig. 03).

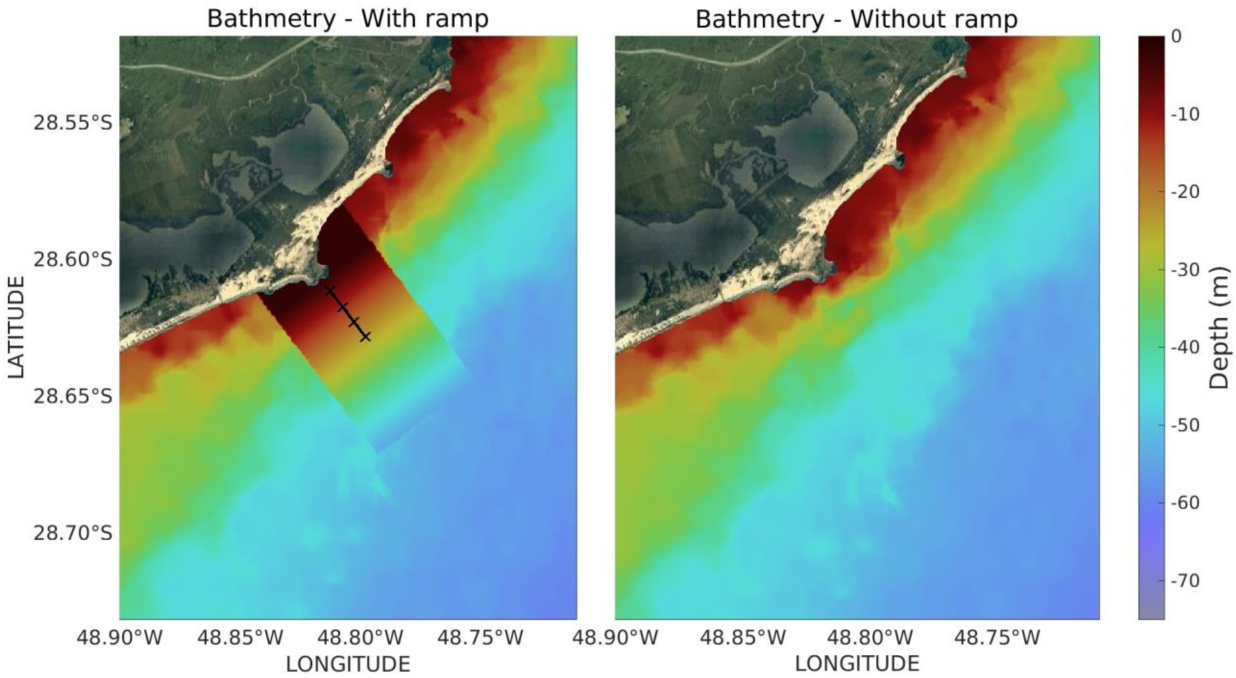

Figure 3. Bathymetry of the study area before and after the installation of the ramp. The points represent the position where the time series of significant wave height and energetic potential were extracted.

After the simulations, an analysis of the result could lead to the efficiency of the installation of the ramp at the studied area. In the normal scenario, without the ramp, the significant wave height and the energetic potential were in a way accented reaching 1.2 m and 8 kW/m respectively, nearby the coast. However, after the installation, the wave parameters decreased significantly due to the interaction of the waves with the ramp, which caused a greater dissipation of the wave energy as they approached the coast, resulting in values in the range of 0.1 m of significant height and below 2 kW/m of energetic potential.

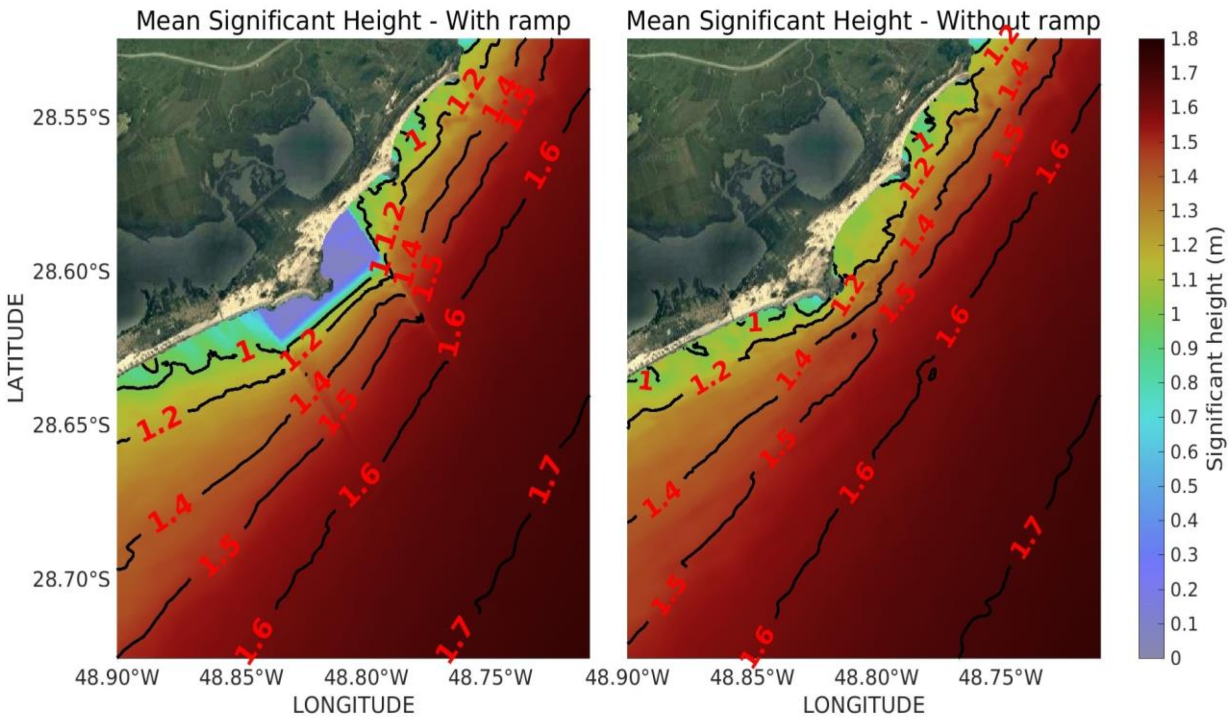

Figure 4. Temporal mean of significant wave height in the study area over the year of 2014.

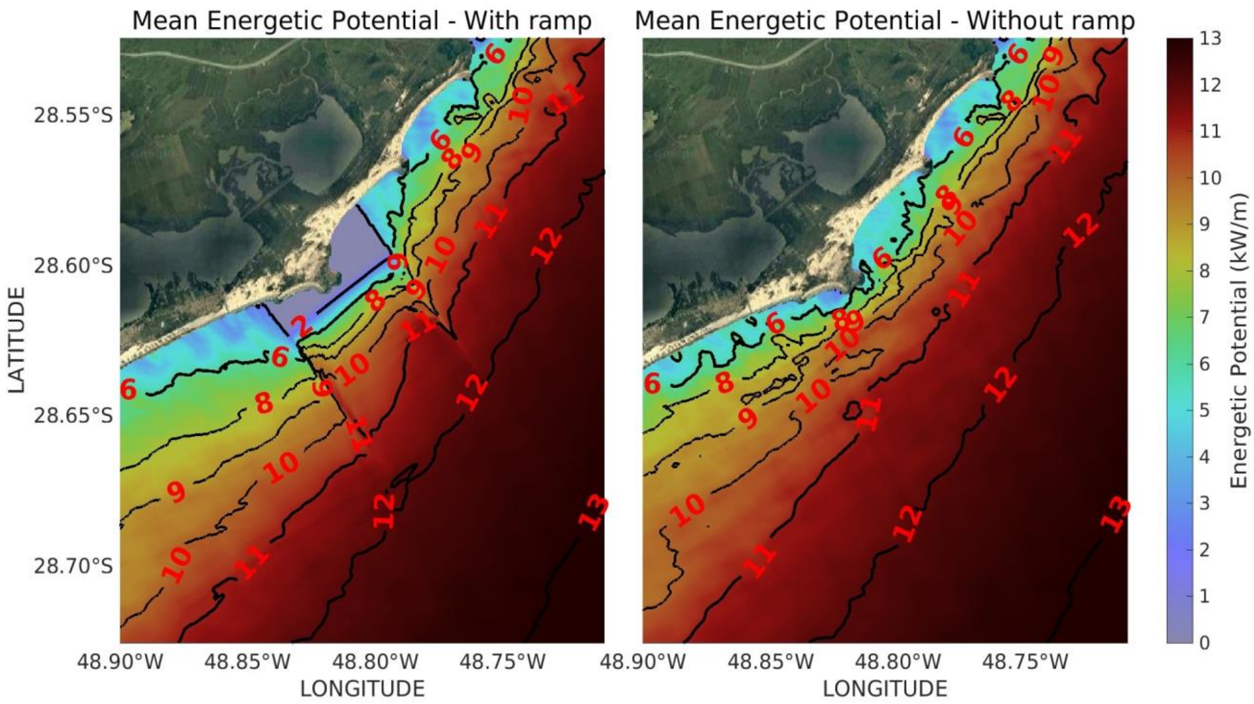

Figure 5. Temporal mean of wave energetic potential in the study area over the year of 2014.

For a better understand of the results, a time series analysis of significant height and energetic potential was conducted over the year of 2014 (Fig. 6 and 7).

In the normal scenario, without the ramp, a noticeable rise in significant wave height in the months of March/April and August/September was observed that are approximately the months that mark the transition between cold and warm weather. This fact was also observed in the study published by Oleinik *et al.* (2017). Time series of energetic potential shows a similar behavior to significant height but with higher differences between colder and warmer months.

It leads to some observations, because with the utilization of the ramp it was possible to mitigate almost 98% the wave height that approached the coast, and nearly 90% of the energetic potential. Thus, is becomes evident that through an analysis of the results, as the waves approach the coast and its energy is dissipated, the extreme events of significant height and energetic potential that occurred mainly in the months of March/April and August/September, were virtually abolished after the insertion of the ramp.

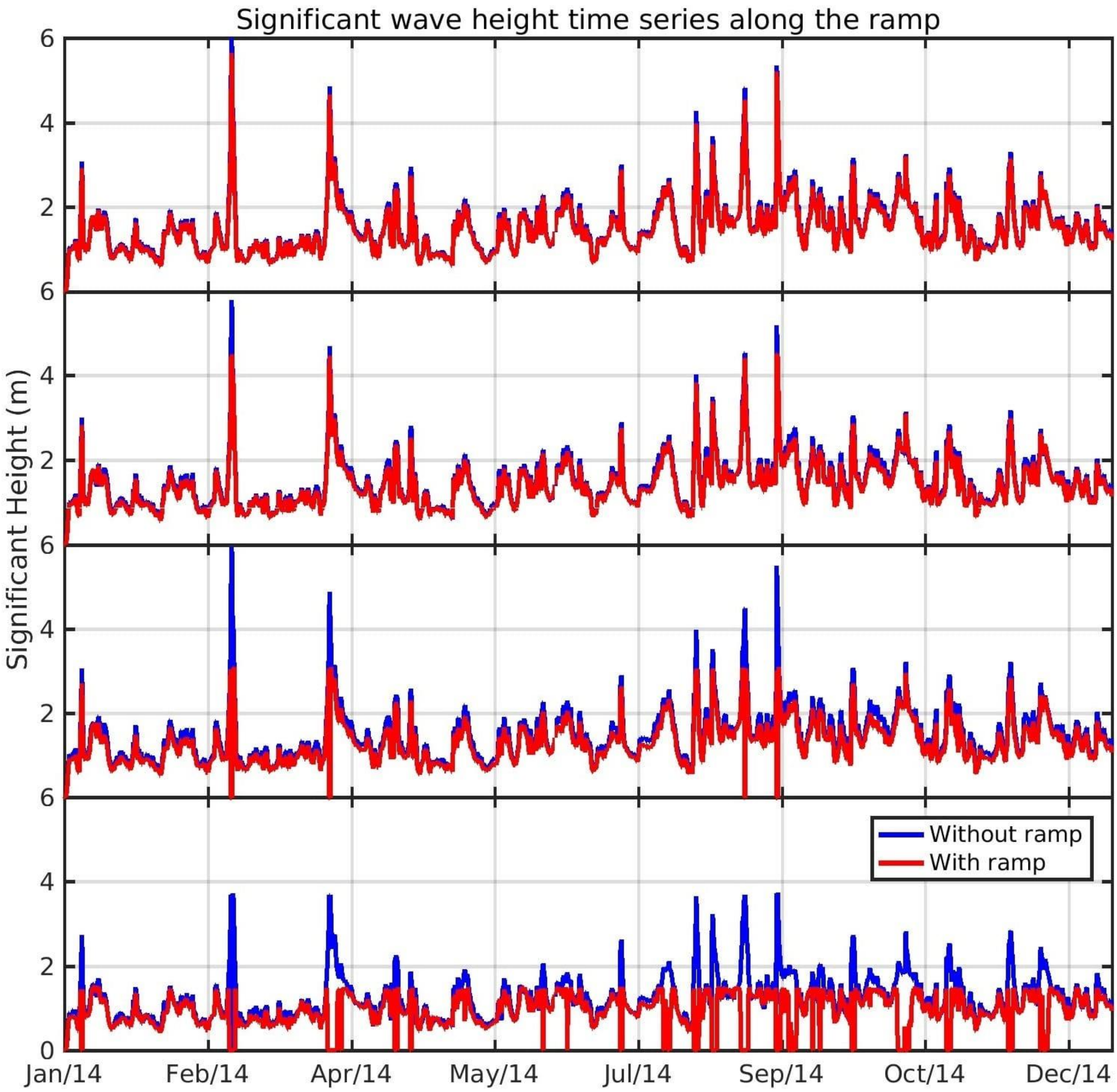

Figure 6. Time series of significant wave height over the ramp over the year of 2014.

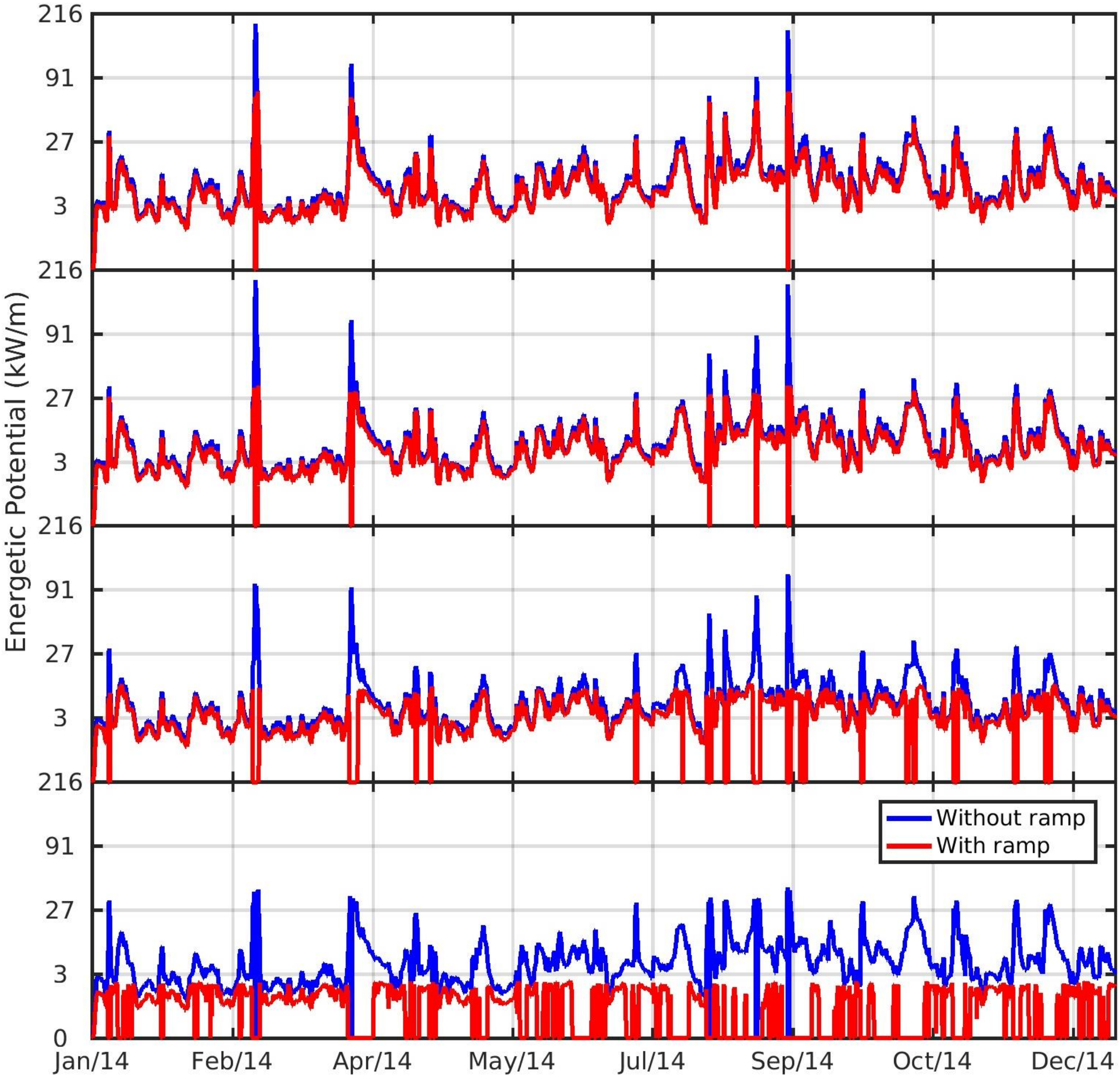

Figure 7. Time series of the wave energetic potential over the ramp for the year of 2014.

For purposes of understanding and to facilitate the visualization of the results, Figures 8 and 9 demonstrate the mean difference for the significant height and energetic potential for the scenarios with and without ramp, resulting in negative values over the study region and, thus, conferring validity of the data presented above.

It is also possible to notice, that due the predominant energy flux direction of the waves, the southern region of the structure also had a slight reduction of the significant wave height of the incident waves. Although this effect could also be noticed at northern region of the structure, the reduction was considerably lower. This shadowed area in the south direction provides, to future studies, an indicative that if the ramp slope was oriented further north, perhaps the reductions could be more efficient.

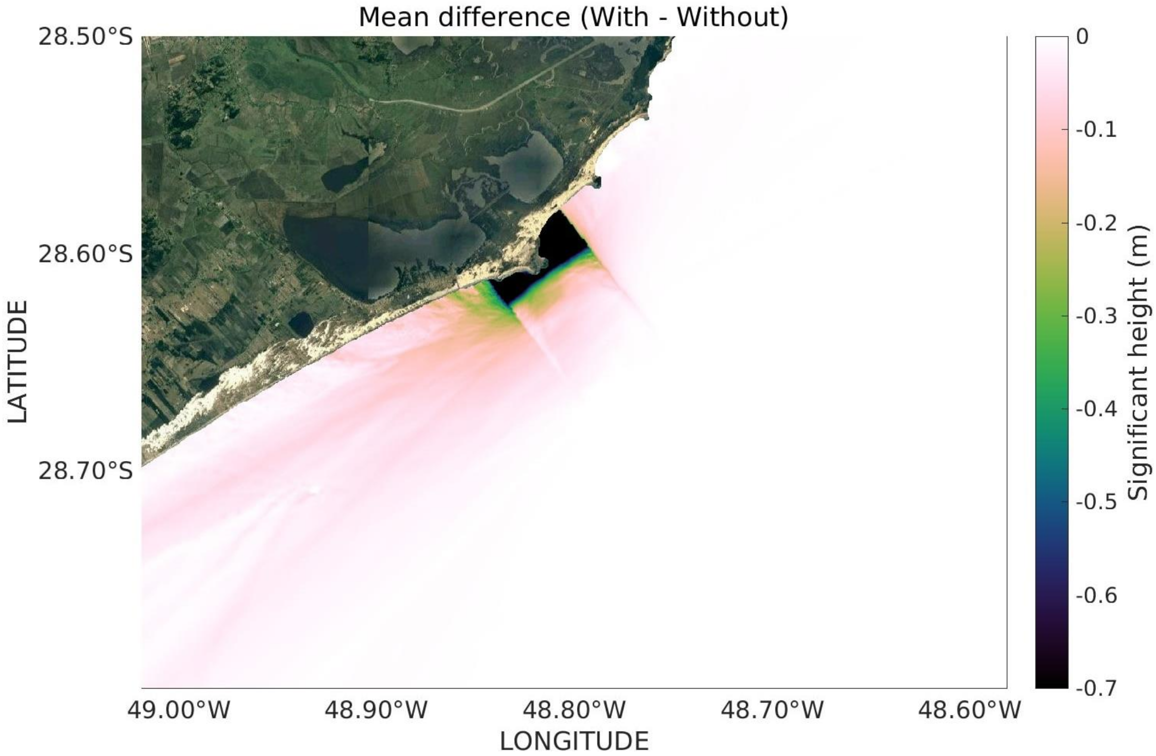

Figure 8. Temporal mean of the wave significant height difference considering the scenarios with and without ramp.

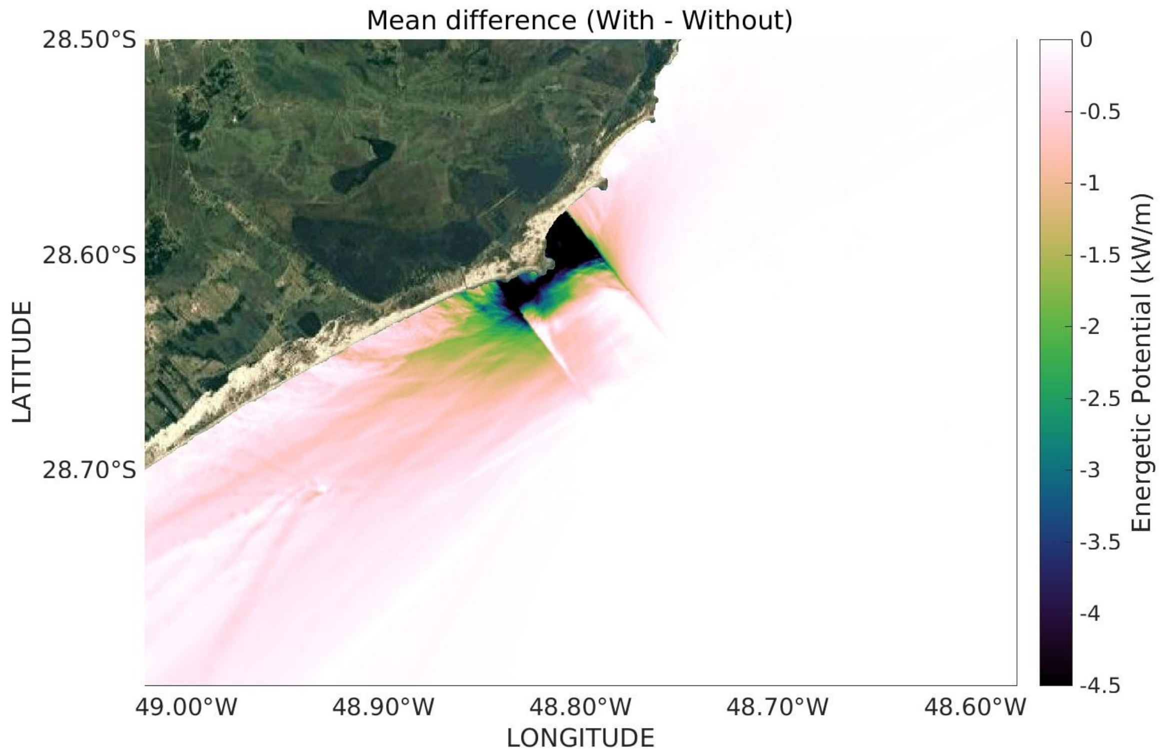

Figure 9. Temporal mean of the wave energetic potential difference considering the scenarios with and without ramp.

4 CONCLUSION

With the accomplished results by the computational simulations, it was possible to perform a comparative analysis between the natural scenario and the scenario after the installation of the ramp. In this way, sharp reductions in significant wave height and wave energetic potential were identified.

Previously to the installation of the ramp, the wave energy was dissipated, in most part, near the shoreline, making possible that waves with greater heights reached the coastline, occasioning great impacts on the coastal zone. However, after the installation of the ramp, the wave energy was gradually reduced throughout the whole extension of the structure, allowing the wave's height decreases continuously as it approached the coast, reaching the coastline with relatively small energetic potential values. Thus, the results obtained for these parameters were positive, since the dissipation of the energy of gradual form causes that the impact on the beach is much smaller than the sudden dissipation of all the energy of the wave.

Lastly, the installation of the ramp proved to be a valid alternative for the coastal protection in the Cape of Santa Marta region, considering that it attenuates effectively the wave effects, what potentially result in lower erosion rates of the beaches, reflecting directly in the decrease of the annually spent values for coastal protection.

For future studies it is intended to modify the dimensions of the ramp, aiming to define the most effective way to dissipate the wave energy, and that less demand material for its construction. Thereby, the study will have goal to define the ramp with the best cost benefit, prioritizing the decrease of the erosive action of the waves on the coastal area.

ACKNOWLEDGEMENTS

The authors are grateful to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for conceding the fellowships, to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the sponsor contract 304227/2016-1, to the Centro Nacional de Supercomputação (CESUP) of the Universidade Federal do Rio Grande do Sul (UFRGS) which supported in the development of this work. The authors also grateful for the meteorological and ocean data provided by NOAA, to the openTELEMAC-MASCARET consortium to provide the TELEMAC system free of cost and the Laboratório Nacional de Computação Científica (LNCC) that makes available the Santos Dumont Supercomputer.

REFERENCES

Airoldi, L., Abbiati, M., Beck, M.W., Hawkins, S.J., Jonsson, P.R., Martin, D., Moschella, P., Sundelof, A., Thompson & R.C. and Aberg, P., 2005. An ecological perspective on the deployment and design of low-crested and other hard coastal defence structures. Coastal Engineering, vol. 52, pp. 1073-1087, 2005. Doi:10.1016/j.coastaleng.2005.09.007.

Bruun, P., 2013. Design and Construction of Mounds for Breakwaters and Coastal Protection. *Elsevier Science Publishing Company*, vol. 3, pp. 931.

Horn Filho, N.O., Bonetti Filho, J, Gré, J.C.R., & Porto Filho, E., 1998. Uma visão geológica e geomorfológica do domínio costeiro da ilha de Santa Catarina, Santa Catarina, Brasil. *In: Simpósio Nacional De Geomorfologia.* Florianópolis.

IBGE - Instituto Brasileiro de Geografia e Estatística, 2017. Dados gerais do município – Laguna.

Koerner, K. F., Oliveira, U. R., & Gonçalves, G., 2013. Efeito de estruturas de contenção à erosão costeira sobre a linha de costa: Balneário Hermenegildo, Rio Grande do Sul, Brasil. *Revista da Gestão Costeira Integrada*, vol. 13, pp. 457-471. Doi: 10.5894/rgci405

Lira, A. R., 1997. *Caracterização morfológica e vulnerabilidade do litoral entre as praias de Enseadinha e Marinha Farinha – Paulista (PE).* Recife, Pernambuco, Thesis - Universidade Federal de Pernambuco.

Lynch, D. R., Ip, J. T. C., Naimie, C. E., & Wermer, F. E., 1996. Comprehensive coastal circulation model with application to the Gulf of Maine. *Continental Shelf Research*, vol. 16, n. 7, pp. 875-906. Doi: 10.1016/0278-4343(95)00028-3.

MMA - Ministério do Meio Ambiente e da Amazônia Legal, 2000. *Gestão dos Recursos Naturais, Subsídios à elaboração da Agenda 21 Brasileira.*

Moraes, A. C. R. de, 1995. *Os impactos da política urbana sobre a zona costeira*. Brasília: Ministério do Meio Ambiente e da Amazônia Legal.

Muehe, D., 2006. E*rosão e Progradação do Litoral Brasileiro.* Brasília: Ministério do Meio Ambiente e da Amazônia Legal.

National Oceanic and Atmospheric Administration, 2016. “Historical data from the NOAA WAVE WATCHIII global and regional ocean wave models”.

Oleinik P. H., Marques W. C., & Kirinus E. de P., 2017. Estimate of the Wave Climate on the Most Energetic Locations of the South-Southeastern Brazilian Shelf. *Defect and Diffusion Forum*, vol. 370, pp. 130-140.

Polette, M., 1997. *Gerenciamento Costeiro Integrado: Proposta metodológica para paisagem litorânea da Microbacia de Mariscal, Município de Bombinhas, (SC), Brasil.* Thesis - Universidade Federal de São Carlos.

Scherer, M., Ferreira, C., Mudat, J., & Cataneo, S., 2006. Urbanização e gestão do litoral centro-sul do estado de Santa Catarina. *Desenvolvimento e Meio Ambiente*, vol. 13, pp. 31-50. Doi: http://dx.doi.org/10.5380/dma.v13i0.4873

TELEMAC-MASCARET Consortium, 2016. “openTELEMAC-MASCARET - The mathematically superior suite of solvers”.

Vallega, A., 2000. *Sustainable Ocean Governance:* A Geographical Perspective. Abingdon (Reino Unido): Routledge.