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Coastal Erosion Case at Candeias Beach (NE-Brazil)

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ABSTRACT

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The present work is a study of changes in longshore sediment circulation due to the presence of a breakwater which interferes with the beach morphology. The study was done using the SMC software (Sistema de Modelado Costero) as the main tool for simulating the coastal dynamics for the different configurations, as well as for determining the wave climate to be applied at the simulations. The beach environment is a complex dynamic system responsive to the impact of waves and currents through a series of changes that can occur at different time scales and the intervention of human constructions. The focus of the present work is the application of SMC to investigate beach erosion in an area of Candeias Beach, in the metropolitan region of Recife (NE-Brazil), after installation and further modification of a hard coastal structure (breakwater), as well as in a scenario without the breakwater at the same area.

ADDITIONAL INDEX WORDS: *Numerical wave modeling, nearshore wave processes, coastal erosion.*

INTRODUCTION

Beaches are of great significance as recreational areas, but from a geological perspective, the beach has a value as a natural defense system for the coast, which is exposed to the constant risk of erosion due to the action of waves and tides.

Problems of beach erosion have become prevalent in northeast Brazil as a result of unplanned coastal development. Urbanization in conjunction with historic soil occupation and use, including the landfill of mangrove areas, the practice of soil sealing (which prevents drainage), combined with the local meteo-oceanographic characteristics, have caused a growing erosion problem and have contributed to a reduction in the resilience of the beaches.

This study investigates the sediment dynamics in an area of Candeias Beach, located in the metropolitan region of Recife, Pernambuco state, northeast of Brazil (Figure 1), where a hard structure (breakwater) was originally installed to prevent beach erosion and more recently it was modified to address resulting sediment trapping and beach erosion downdrift.

The main objective of this study is to analyze and compare the coastal dynamics of different configurations of the breakwater, as well as creating a simulation scenario without the breakwater, using numerical modeling to determine which minimizes the erosion impact in the area.

First, the study area is described and the beach erosion problem in the area is presented. Second, the structure is detailed, as well as the modules and numerical tools included in the Coastal Modeling System (SMC) software package are described. The third part summarizes a discussion of the regional model configuration. And finally the simulation results are presented. The conclusion assesses the software application and discusses future perspectives of coastal erosion in the study area.

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CANDEIAS BEACH

The Candeias Beach is known as one of the greatest beaches in northeastern Brazil where approximately 3 km supports a high population density (Figures 1 and 2). In 2013 the population density registered in Jaboatão dos Guararapes municipality was 2,491.82 inhabitants per square kilometer (http://cod.ibge.gov.br/A62), with an even higher concentration in the coastal zone, which is the preferred area for living.

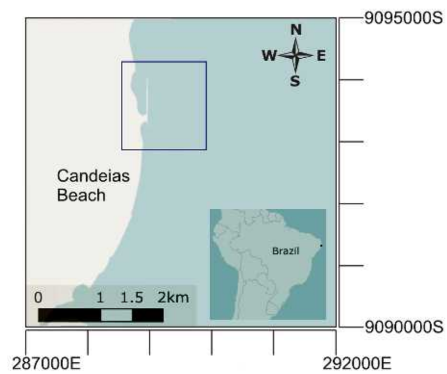

Figure 1. Location of the study area, at the coastline of Jaboatão dos Guararapes municipality, metropolitan region of Recife, Pernambuco state, NE Brazil. The rectangle delineates the breakwater study area.

There are some geographic features of this region that make it highly susceptible to the action of the sea including: low altitudes (between 2.0 m and 4.0 m of the Mean Sea Level-

MSL); flat areas, bordered by coastal plains; large surface drainage with the presence of rivers, streams and lakes, and areas of permanent flooding, due to the shallow groundwater level (FINEP/UPFE, 2009).

Figure 2. Candeias Beach showing the studied breakwater (A) still being modified to its present configuration, (B) the patch reef known as abreus, (C) the Abreus bar and (D) the fringing reef formation which protects most part of the beach (source: Google Earth. July, 2013).

There is also an overall trend of coastline retreat in this region, mostly caused by sea level rise, as well as the increasing number of significant storm events registered (Neves and Muehe, 1995).

This trend prevails along several stretches of the coast of Pernambuco, and is felt mostly in the municipalities of the Recife metropolitan area due to its high population density and the resulting pressure on real estate in the coastal zone (FINEP/UPFE, 2009; Marroni and Asmus, 2005).

Natural Reef Protection

Natural reef formations, where they exist, counter the trend of coastal erosion in this region and are abundant in the shallow waters of the northeast Brazilian coastline (Maida and Ferreira, 1997).

By generating abrupt changes in wave characteristics and consequent reduction of their energy, natural reef formations, such as coral reefs and sandstone reefs, act as submerged wave barriers and thus protect against costal erosion (Dally *et al.*, 1985; Kench and Brander, 2006; Roberts *et al.*, 1975; Sallenger and Holman, 1985).

In some areas of the metropolitan region of Recife coastline, the wave energy is mostly dissipated over the reefs, consequently creating weak wave-induced currents in shallow waters near the beach (Longuet-Higgins, 1970). However, in other areas where the reefs crests are not shallow enough or this natural reef protection does not exist, the wave energy reaching the beach slope is almost the same registered in deeper waters outside the reefs (Costa, 2010).

In these unprotected areas, the extreme wave events create strong wave-induced currents which consequently transport bigger amounts of sediments. In these areas the post-beach sand ridges work as a natural sediment reserve to avoid depletion, otherwise this high rate of sediment transport can cause beach erosion.

While Candeias Beach is mostly protected from extreme wave events by a large fringing reef formation (shown in Figure 2), in its northern area there is a natural gap known as "Abreus Bar" (Figure 2-C). This deep water channel is located between a big fringing reef formation to the south (Figure 2-D), and a smaller patch of submerged reef to the north known as "Abreus" (Figure 2-A).

Because of the Abreus Bar channel high depth (Figure 2), deep water wave energy can propagate almost without any obstacle towards the shore. Wave shoaling and bottom friction dissipate only a small fraction of the wave energy, thus exposing the beach area in front of the Abreus Bar to a high level of wave-current sediment transport.

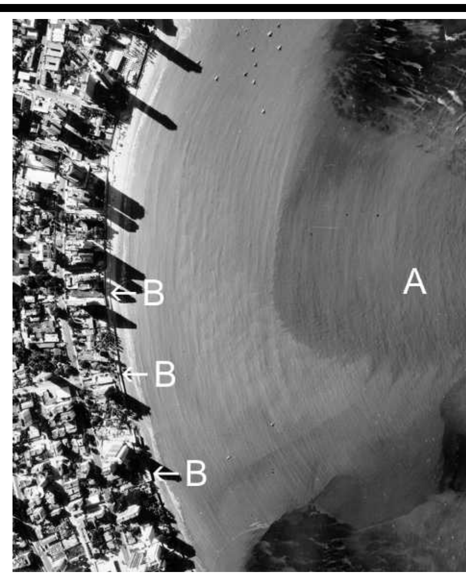

Figure 3. Jaboatão dos Guararapes coastline in 1997 (A) at the Abreus bar region and (B) showing a small post-beach area and seawalls to protect the buildings which invaded the beach zone. (photo: Fidem)

Coastline Invasion

Beach morphology is affected by human constructions installed in the post-beach area, because these constructions tend to stabilize the sand which once would serve as natural sediment reserve to highly dynamic system. With the increasing real estate pressure and a non-integrated management of coastal urbanization (Muehe, 2004), which allowed the buildings to advance into the beach area towards the sea (Figure 3), many coastal sand ridges were destroyed, with urbanization getting even closer to the waterline (Borba, 1999).

In addition to the beach invasion by urban constructions, hard structures like groins and seawalls were installed. These coastal structures were implemented without any in-depth knowledge of local coastal dynamics (FINEP/UPFE, 2009) and usually cause erosion downdrift, as a consequence of the dynamic equilibrium interruption of sediment transport in the area.

In 2004 a detached breakwater measuring 700 meters of length was installed 20 meters from the beach in a wave exposed area (Figure 4-A). While detached breakwaters are usually constructed as a way to protect a coastline from erosion caused by wave action, their installation, even with a previous study and simulations of the local coastal dynamics, can lead to erosion in adjacent areas (Brandon and Steven, 2011). This has occurred in the study area.

Figure 4. Jaboatão dos Guararapes coastline, showing the high density occupation of the study area (A) the detached breakwater, installed in the region in its first configuration, (B) the small groin, (C) the already sand depleted areas with seawall protections, (D) the trapped sand salience and (E) the eroded area to the north. (photo: Roberto Angelo).

In 2013, nine years after the breakwater installation, it was modified to its present configuration by opening four 100 m gaps along its length thereby retaining five smaller sections of the original breakwater in place (Figures 2-A and 5-A).

This planned breakwater reconfiguration was executed in conjunction with a nourishment along the entire Candeias Beach in an effort to reestablish typical beach morphology. The latest observations show that the wave-induced currents have promoted a sediment rearrangement at the site (Figure 5), but since this new configuration has yet to weather the more extreme wave currents of the winter season no conclusion can be made about the resulting impact on beach morphology besides performing simulations.

COASTAL MODELING SYSTEM (SMC-BRAZIL)

The SMC is a Windows based package developed by the Environmental Hydraulics Institute of Cantabria (IH Cantabria) at the University of Cantabria, Spain. It was adapted and transferred to the Brazilian federal government in 2011 through the project entitled "Transfer of methodologies and tools for management support of the Brazilian coast" (http://www.mma.gov.br/gestao-territorial/gerenciamento-costeiro/smc-brasil).

The SMC numerical package includes a hydrodynamic module, which simulates water level variation and flow in response to wave interactions in shallow waters, and a module for the assessment of sediment transport rates and seabed level changes resulting from combined wave-current flows. It also contains a 61 year wave climate database for the Brazilian coast. In order to apply the SMC-Brazil model to the enormous number of sea states propogated towards the coast without losing the variability represented, a statistical classification technique, called maximum inequality (MaxDiss), was used to organize and classify multidimensional spaces in order to seek the most distinct groups in a data set (Snarey *et al.*, 1997).

Figure 5. Breakwater configuration in a low spring tide (march 31, 2014) (A) three of the remaining breakwater sections, (B) a salience and (C) a bay formed by the wave-current sediment rearrangement just a few months after the breakwater reconfiguration.

The wave model incorporated into the SMC, called Oluca, uses the Booij (1981) procedure. Refraction, diffraction and shoaling of wave discrete components are assumed to be governed by the wave-current parabolic approach of the mild slope equation (Kirby, 1994), expanded to include the effects of current by Booij (1981) and Kirby (1983). The model also predicts the energy losses due to breaking waves by using three different statistical models of dissipation.

The Copla module solves the depth-averaged mean flow equation due to breaking waves from results of the Oluca model. Copla is the two-dimensional model of beach currents deducted from the Navier-Stokes equations; it uses the radiation stress tensors (Longuet-higgins and Stewart, 1964) already calculated from Oluca as input, and is incorporated into the SMC package, as well as the Mopla program, which is the morphodynamic modeling tool for calculating the sediment transport and evolution of the bathymetry of a beach. It uses the currents calculation from Copla as input.

The sediment transport module called Mopla uses three formulations: CERC (Shore Protection Manual, 1984), Kamphius and Bayram. The CERC formula was elaborated by U.S. Army engineers for sediment transport calculations and is widely adopted and calibrated (Komar and Inman, 1970; Kraus *et al.*, 1982). It relates the rate of sediment transport along the beach with the flow of the wave energy per unit length of the coast. The CERC formula using the Del Valle *et al*., (1993) coefficient are the options adopted in this study.

Considering the database availability of wave climate reanalysis, and the integrated tools for statistical analysis, wave propagation, wave-generated current flows and sediment transport, the SMC package was adopted as the simulation tool for this study, and also with regards to the scope of the SMC-Brasil project of the Brazilian government (MMA), which aims to apply it as the primary tool for integrated management of the coastal zone in Brazil, generating important planning information for decision-making.

Model databases

The IH-Data module has three databases: One is associated with time series of waves called DOW points (Downscaled Ocean Waves). The other two are associated with sea level time series: one for astronomical tides, called GOT points (Global Ocean Tides), and another for meteorological tides, called GOS points (Global Ocean Surge). These wave climate and sea level databases were built by a 61 year reanalysis (from 1948 to 2009) of wind fields and satellite data processed using state of the art numerical models, such as Wavewatch III (polar.ncep.noaa.gov/waves), Swan (www.swan.tudelft.nl), TPXO (volkov.oce.orst.edu) and Roms (www.myroms.org), and TPXO (Reguero *et al.*, 2012).

For the wave climate, wind field data, provided by the NCEP/NCAR reanalysis project, are first modelled in deep waters using Wave Watch III, version 2.2 (Tolman, 1989) in a 0.25º resolution grid, generating the so called GOW (Global Ocean Waves) data, and then calibrated to avoid possible biases in the results. The methodology used for calibration is described in Mínguez *et al*., (2011).

The second step is downscaling to provide regional characteristics to this database. To accomplish this, a series of numerical simulations were performed by applying the SWAN model (Booij *et al.*, 1999), using a more detailed bathymetry and regional wind fields. These simulations were performed in 17 grids with 1 km resolution distributed along the Brazilian coast, generating the DOW data.

REGIONAL MODEL CONFIGURATION

Wave Climate

The wave climate in this area is described by using a module called IH-AMEVA statistical tool from SMC-Brasil. A DOW point over 15.6 m depth at the average spring low-tide (MSLW), located at coordinates 290687E and 9093096S, is used as reference to extract the data from the IH-data database, and is also used to calculate the series of most representative DOW sea states, using the MaxDiss technique to be propagated to the coast.

The wave climate at the DOW point (Table 1 and Figure 6) has more than 75% of probability of waves coming predominantly from East-Southeast direction, and waves from Southeast with 24% of probability. The other 0.5% of waves arrive from East direction and an insignificant percentage come from South-Southeast (0.08%).

Since the East-Southeastern incident waves predominate, those are the ones to be most considered when describing the wave climate for this location.

The wave height statistical table shows the mean (or typical) wave height, the ones registered 50% of the time ($H_{s50\%}$), and the storm (or extreme) wave height, which are the ones registered in an extreme event that occurs during 12 hours of a year (H_{s12}), as well as the typical and extreme wave period values (Table 1).

Table 1. *The wave climate probability calculated by AMEVA component. ESE waves are predominant with more than 75% of probability.*

Direction	Probabilty (%)	$H_{s50\%}$ (m)	H_{s12} (m)	$T_{p50\%}$ (s)	T_{p12} (s)
ENE	0.00	1.11	1.13	9.51	10.98
E	0.55	0.90	1.78	7.06	10.97
ESE	75.25	1.37	2.59	7.46	12.12
SE	24.11	1.37	2.48	6.65	8.41
SSE	0.08	1.25	1.86	5.36	11.04

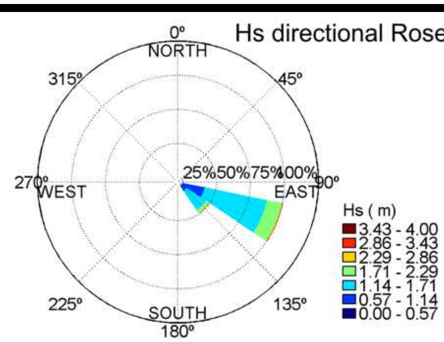

Figure 6: The Hs directional Rose, calculated by the Ameva component.

Sea Level Characterization

The astronomical tide data found at GOT database were generated using the harmonic constants from the global tidal model TPXO (version 7), developed by Oregon State University.

The TPXO model is a tidal inverse model that assimilates the sea information derived from the observations of the TOPEX/Poseidon level sensor.

The database used to characterize the meteorological tide is called GOS reanalysis, also incorporated at IH-data. Both astronomical and meteorological tides were validated by IH Cantabria, with instrumental data obtained from tide gauges from University of Hawaii Sea Level Center (uhslc.soest.hawaii.edu).

The tidal regime in the region is of semidiurnal type, with a shape number F = 0.09 and an average of 12.42 hours, presenting two high tides and two low tides per lunar day and with small diurnal inequality. Hayes (1979) has classified the tides of Pernambuco state as strong mesotidal, ranging from -0.2 m to 2.6 m.

For astronomical tides a GOT database point with coordinates 332466E 9118711S was used, and for meteorological tides a GOS database point with coordinates 307266E 9082111S.

The results show that the sea level oscillation regime (Figure 8) is mostly governed by the astronomical tide, with oscillations between ±1.4 m (Figure 7) while meteorological tides oscillate between ±0.1 m, with nearly negligible influence.

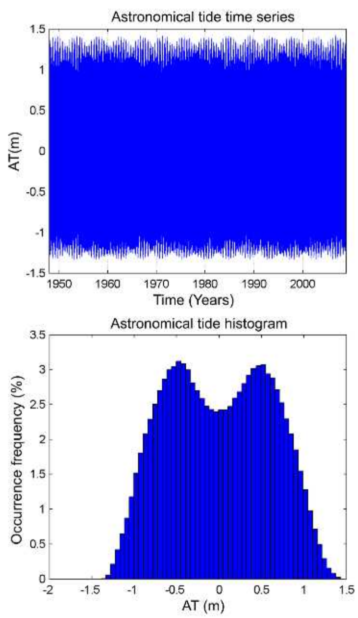

Figure 7: Astronomical tide characterization.

Sediment Characteristics

According to Borba, 1999, the granulometric analysis of sediment at the shore and upper shore of the study area reached a value of D_{50} between 0.25 mm and 0.125 mm. This is classified as fine grain sand.

Topography Dataset

The topography is derived from the Bathymetry dataset and a database of digitized nautical charts of the whole Brazilian coast. This is a low resolution bathymetric source for a general application, but in a particular project, data generated by local high resolution measurements can be added, improving the bathymetric resolution. In this study, the detailed data provided by the MAI project (FINEP/UFPE, 2008) was used as the primary source of bathymetry. The latest bathymetry measurements of the beach protected by the breakwater was executed on March 2, 2014, during a 0.0 m low spring tide, and the measurements results are represented in Figure 9-B.

Table 2 summarizes all the configurations used in this study: The former continuous breakwater, the present divided breakwater, and a breakwater absent scenario.

Table 2. *Study area configurations and scenario simulated in this study.*

Breakwater Name	Breakwater Parts and Length	Year Completed
Former	One piece of 750 m	2004
Present	Five pieces of 50 m each separated 100 m	2013
Without	None	Scenario

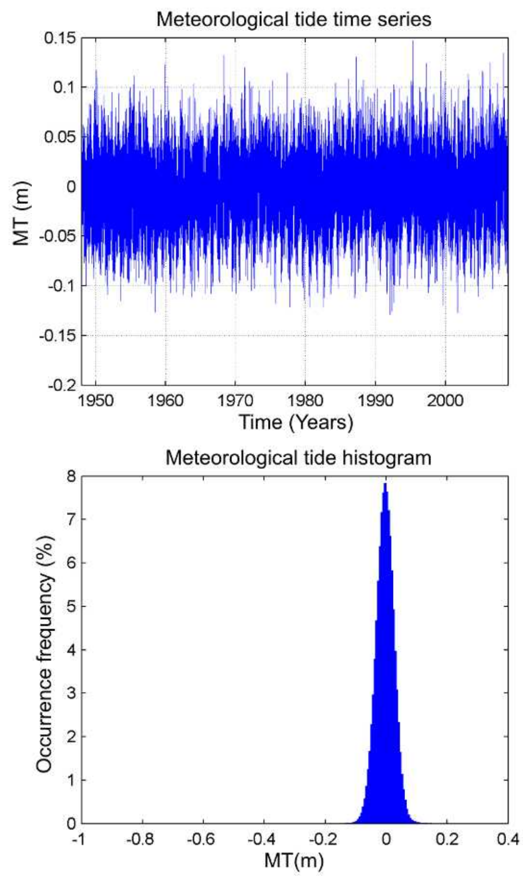

Figure 8: Meteorological tide characterization.

RESULTS

Wave, Current and Sediment Transport Results

As described in statistical analysis, the predominant wave directions are from East-Southeast, with 75% of waves coming from this direction, for both the typical and the extreme wave climates. The second most probable direction of waves arrive from the Southeast at 24% of probability, and the least probable wave direction from the East.

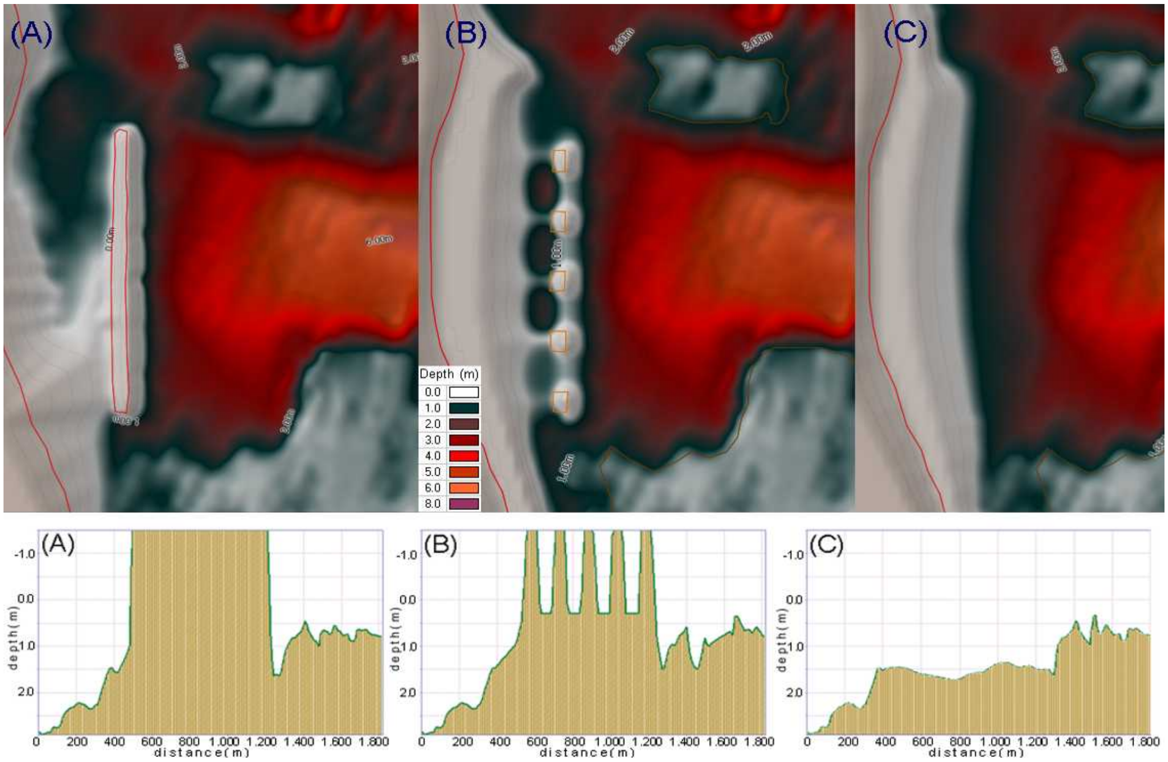

Figure 9. Three different configurations and a scenario of the study area (A) former breakwater configuration, (B) present breakwater configuration and (C) without breakwater scenario.

To comply with the criterion determined by the Booij (1981) method, which applies to the Oluca wave model, the waves propagated need to be at the range of ±50° from the main propagation direction.As both the Southeast and East directions are inside the range of ±30° from the main East-Southeast direction, only one grid created to propagate the predominant East-Southeast direction was enough to cover more than 99% of all incoming wave directions.

For best simulation results, the width of grid is chosen in such a way that the interference at the lateral boundaries do not affect the area of interest since some wave reflection at the lateral boundaries is an undesired side effect usually present in wave simulation. To best simulate the conditions, a grid measuring 6,380 m wide, centered at the study area, was created.

The most representative sea levels to be considered, as discussed in section above, should account only for the astronomic tide, as the meteorological tide is negligible. For this study the sea levels considered are the 2.5 m high spring tide and 0.0 low spring tide, as well as the middle spring tide of 1.25 m.

Simulations were performed for the three configurations of the study (Table 2), considering the two cases of waves (typical and extreme – Table 1) and for the three spring tides levels.

The importance of sea level characterization for the numerical simulation is related to the fluctuations resulting in changes of the boundary conditions in which the incident waves are propagated. These modifications change the bathymetric depth, which changes the wave interaction with the seabed, and results in variations of wave heights at the surf zone, consequently changing wave-current patterns and sediment transport.

Model results over the former breakwater show a tendency to accumulate sediment between breakwater and shoreline (Figure 10). This is the situation observed in the years after the construction of the structure and may validate the statistical modeling analysis used in this study.

Other simulation results without the breakwater structure demonstrate that the beach has a tendency to erosion, and a comparison with the results of the present breakwater structure configuration can be best interpreted in the next section (Figures 11 and 12).

Annual Mean Sediment Transport

For the annual mean sediment transport calculations, the most relevant sea states must be selected. For this purpose the MaxDiss technique is used. About 150 sea states were selected, downscaled to the coast for three tide levels: low (0.0 m), mid (1.25 m) and high tide (2.5 m), using the Oluca wave model.

For extracting sediment transport data, beach profiles are traced perpendicular to the coastline in selected points of interest.

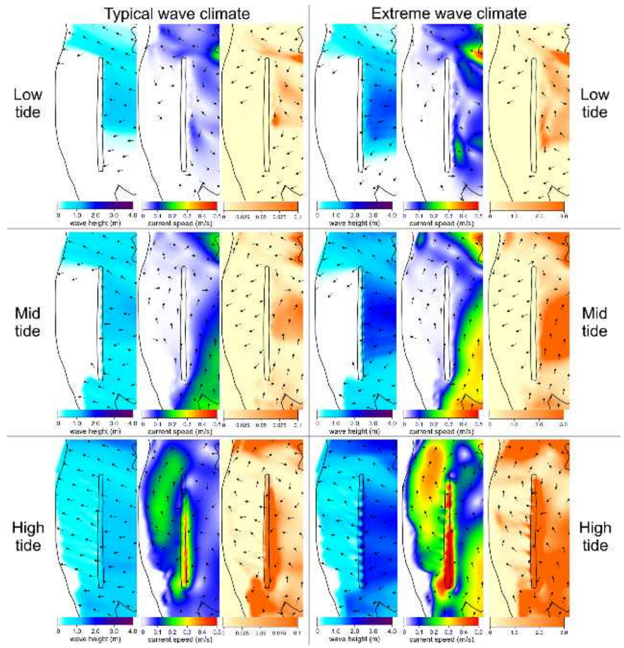

Figure 10: Simulation results for the former breakwater configuration, in both typical (left side) and extreme (right side) wave climate conditions (table 1). From top to bottom the lines show the low tide, mid tide and the high tide results. For each half line side it is displayed the wave height, current speed and sediment transport results for each wave climate condition.

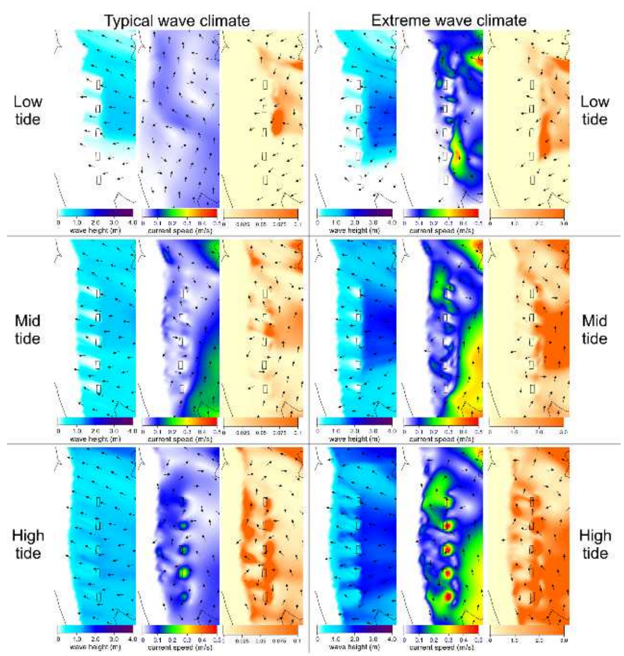

Figure 11: Simulation results for the present breakwater configuration, in both typical (left side) and extreme (right side) wave climate conditions (table 1). From top to bottom the lines show the low tide, mid tide and the high tide results. For each half line side it is displayed the wave height, current speed and sediment transport results for each wave climate condition.

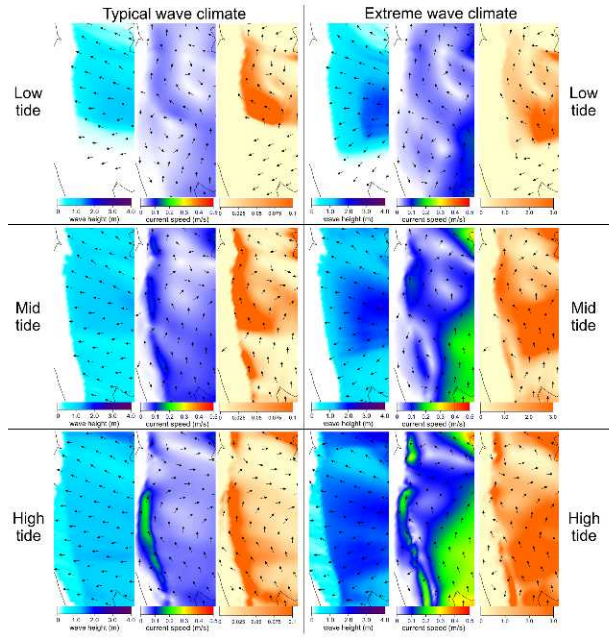

Figure 12: Simulation results for the scenario without a protective breakwater, in both typical (left side) and extreme (right side) wave climate conditions (table 1). From top to bottom the lines show the low tide, mid tide and the high tide results. For each half line side it is displayed the wave height, current speed and sediment transport results for each wave climate condition.

For the present breakwater configuration and the scenario without a breakwater, the selected profiles are at the same position. For the former breakwater configuration, the profiles were traced both outside and inside the breakwater shaded area to show the difference in sediment transport of these regions.

Sediment transport is represented by arrows drawn by the sides of the traced beach profiles over the satellite picture of the study area. Using the standard convention of an observer positioned at the beach looking out to the sea, the sediments transported to the right are attributed positive values. The transport values shown in Table 3 apply this convention: the southward sediment transports are positive, and northward are negative.

The values are reported in a position order of the beach profiles from north to south, as in Figures 14 and 15.

The sediment transported through a beach profile can occur in both directions during the year, depending on wave characteristics each day. As the wave change characteristics vary throughout the year, there will be a total amount of sediments transported for both directions, and the mean annual value will be the difference of these values.

The values displayed in Table 3 are the mean sediment transported during one year computed for both directions (Q+ and Q-). The total mean value transported (Q) is calculated as the difference between the two.

The mean annual sediment transport calculated for the three study cases (Figures 13, 14 and 15) show differences among patterns of transport, but similarities are evident in the present breakwater configuration (Figure 14) and the scenario without the breakwater (Figure 15).

Table 3. *Calculated transport values for the present breakwater configuration and without the breakwater scenario, for the beach profiles disposed in an order from north to south, measured in 1,000 m³ per year (rounded values).*

Profile	Present Breakwater Configuration			Wihtout Breakwater Scenario		
	Q	Q+	Q-	Q	Q+	Q-
1	626	647	-22	380	394	-13
2	-33	44	-77	-413	858	-414
3	77	95	-18	-133	0.4	-133
4	158	164	-6	11	24	-12
5	225	226	-1	228	233	-4
6	531	533	-1	392	392	-0.6
7	803	831	-28	248	248	-0.5

Comparing values displayed in Table 3, we can observe that, except at the profile 2, a southward sediment transport is predominant at the present breakwater configuration, and in comparison with the scenario without breakwater protection, the amount of sediment transport to the south is much higher, except at the profile 5, where the values have the same order of magnitude.

In contrast, the northward sediment transport values are bigger in most of the wave exposed coastline scenario, compared with the present breakwater configuration. And these values increase to the north, where the exposure to waves coming from east-southeast increases, because the areas to the north are less protected by the outside fringed reef (Figures 9 and 12). The present breakwater configuration apparently provides fair protection from waves (Figure 11) with less sediment transport to the north being registered in the central and northern areas.

The border profiles 1 and 7 register big southward transport in both cases, as there is a big influence of the reefs in front of them to create wave diffraction.

The mean sediment transport calculated with the former breakwater configuration (Figure 13), shows that there is a clear barrier to the longshore current in this area, which led to erosion at the coastline to the north.

At the unshaded area in front of the former breakwater the transport diverged in direction, presenting exceptionally high opposed values at the borders of the breakwater, thus causing a permanent barrier to sediments.

At the shaded area of the former breakwater, there are small amounts of transport values registered, and in opposite directions, with a predominant tendency of sediments to move south, toward the salience area. Thereby this area works as a trap, capturing and accumulating all the sediment that moves to the inside this region, and not allowing it to move to the outside anymore.

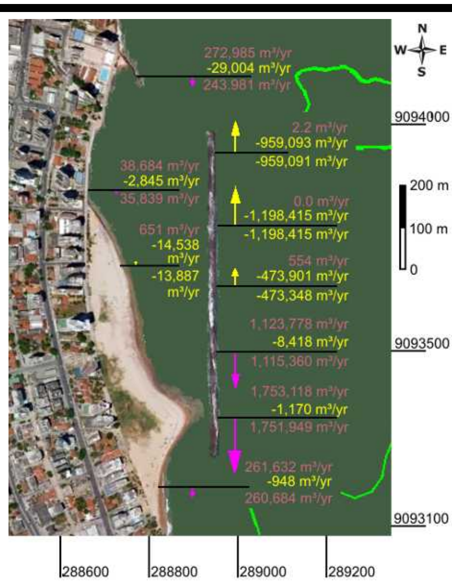

Figure 13. Calculated annual mean sediment transports in selected beach profiles along the studied area for the former breakwater configuration. By convention, the south bound transport is defined as positive, which are represented with a magenta arrow. The negative transports to the north are represented in yellow. The numbers to the right show the annual transport for each direction, with the mean transport shown below of each beach profile line.

CONCLUSIONS

The results of numerical simulations for the different breakwater configurations responded well for the observations of coastal dynamics in the study area (sediment dynamics, coastal erosion). The numerical tool used in this study contributes to studies aimed to minimize the impacts of coastal erosion.

Comparing the simulation results of the present breakwater configuration with the scenario of no breakwater, it is not clear that the present configuration will act as an efficient protection against the wave-current induced erosion.

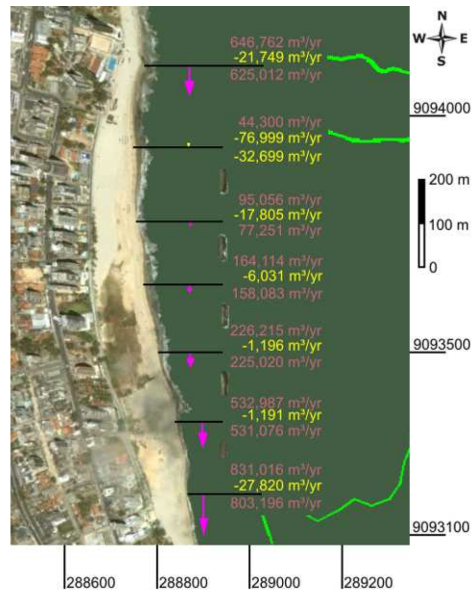

Figure 14: Calculated annual mean sediment transports in selected beach profiles along the studied area for the present breakwater configuration. By convention, the south bound transport is defined as positive, which are represented with a magenta arrow; the negative transports to the north are represented in yellow. The numbers to the right show the annual transport for each direction, with the mean transport shown below of each beach profile line.

In fact, comparing with the scenario of exposed coastline, the simulations show that at the present breakwater configuration, there is a great reduction in sediment transport at the northern area, however the divergence of sediment transport observed in the middle area shall result in erosion in a long term.

Using the simulation methods presented, we made the same observation in the southern area of the breakwater. In fact, the sediment transport to the south is even greater than if there was no protection to the coastline because there is no sediment source in the area that could replace the sediment that is being moved to the south. As a result, this could dramatically reduce the sediment availability in the area, leading to more beach erosion in the future.

On the other hand, there is an improvement related to modifying the former breakwater. By opening up the gaps, wave-current transport was restored thereby eliminating the sediment trap created by the installation of the original breakwater.

With the longshore circulation restored there still exists the possibility that the coastline could reach an equilibrium shape in the short term, since the present configuration had little exposure to the winter waves with greater energy impact. This may potentially reshape the coastline towards an equilibrium.

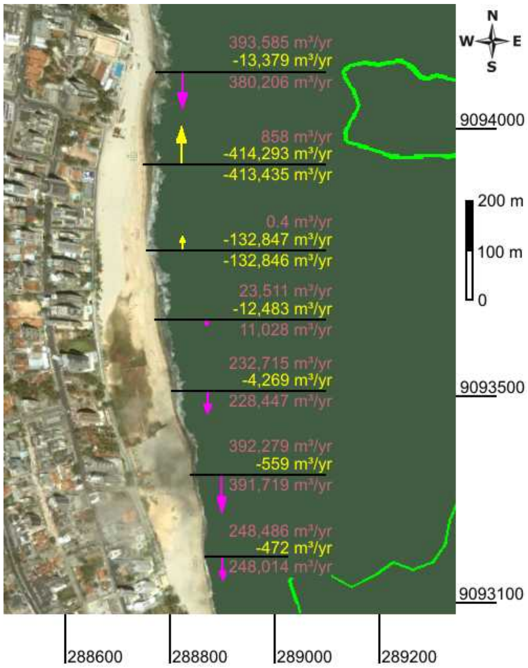

Figure 15. Calculated annual mean sediment transports in selected beach profiles along the studied area for the scenario without breakwater. By convention, the south bound transport is defined as positive, which are represented with a magenta arrow; the negative transports to the north are represented in yellow. The numbers to the right show the annual transport for each direction, with the mean transport shown below of each beach profile line.

This article validates the numerical modeling presented to predict changes in beach morphology as a result of modifying the former breakwater at Candeias Beach. It also demonstrates the value of coastal modeling to predict changes in beach morphology as a result of planned costal development and invites future simulation modeling prior to undertaking further development.

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