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Assessment of Wetland Functions considering Climate Change

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ACQUISITION OF WAVE DATA AND MODELING IN SANTOS BAY, SÃO PAULO, BRAZIL

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ABSTRACT

The access channel of the Santos Harbor has been dredged to increase its capacity for larger ships. The main objective of this project is to analyze the sediment transport along of Santos Beach, focusing in the eastern portion of Santos Beach, called Ponta da Praia, before and after dredging the channel, using the Delft3D model. A ten-year wave simulation was performed to obtain the typical wave climate in the region. Eight most-frequent conditions were chosen based on H_s and direction to simulate scenarios with two different bathymetries, before and after the deepening dredging. In addition to these eight conditions, a further five conditions were selected to represent high waves. Delft3D-SED module was incorporated with the coupled waves and currents. The results before and after deepening the channel were compared to analyze the impacts along Santos Beach. The modeling of hydrodynamics, wave and sediment transport indicated an intensification of wave heights after the deepening of the channel in eastern portion of Santos Beach. In general, the waves from south and south-west have a higher impact than waves from south-east. The direction of waves did not present significant difference before and after dredge at the end closest to the channel. At the Ponta da Praia, where erosion naturally occurs, the deepening of the channel did not cause significant differences in the sediment transport pattern for bed load, just for suspended sediment that do not influence the erosion process.

1. INTRODUCTION

The City of Santos, Brazil, is heavily populated and has the largest harbor in South America. The access channel of the harbor has been dredged by approximately 2 meters to increase its capacity for larger ships. The process of dredging to deepen the channel could be one of the processes that cause the erosion on eastern portion of Santos Beach, Brazil (Figure 1). The eastern portion of Santos Beach is called Ponta da Praia, the focus of this project (Figure 2).

Santos Beach is a west-east beach and the sediment supply is located inside the Bay (Farinaccio, *et al.* 2009). The circulation in the estuarine system of Santos and São Vicente consists of four compartments, determined by the existing circulation pattern: Santos Bay, Santos Channel, São Vicente Channel and Bertioga Channel. The tidal wave is semidiurnal and spreads by both channels of Santos and São Vicente and the Bertioga Channel, so that the amplitudes vary from 27 cm in the neap tide and 123 cm in the spring tide (Harari *et al.*, 1990; Fukumoto, 2007).

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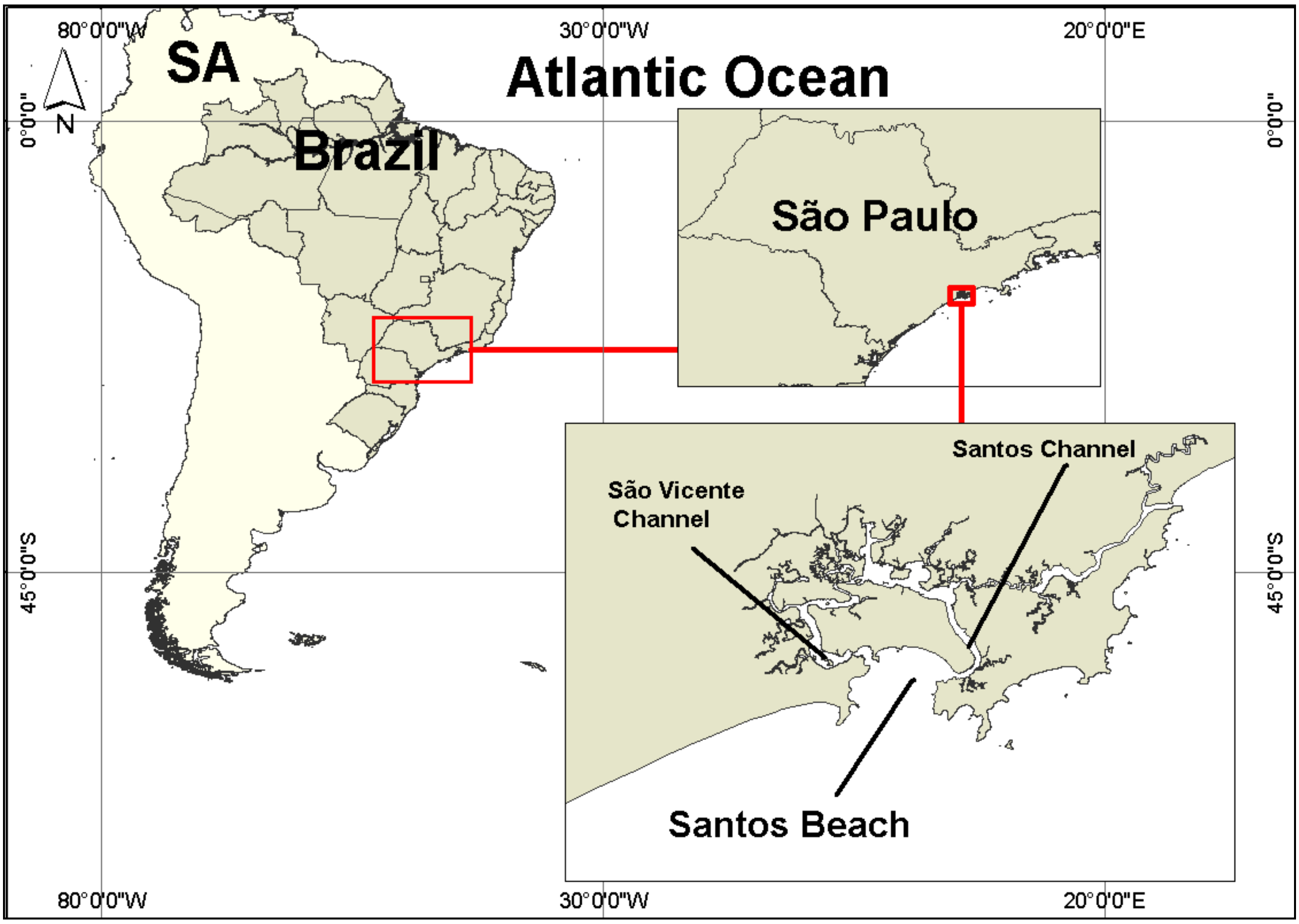

Figure 1 Study area: SA, South America, Brazil, São Paulo state and Santos beach.

Figure 2 Focus in Ponta da Praia, Santos Beach, Brazil.

According Fúlgaro & Ponçano (1976; Fukumoto, 2007), the Estuarine System of Santos and São Vicente is a region of great balance with regard to sedimentation, where high rates occur only locally, including the district of harbor, next to mouth of the Bay.

Sediment transport refers to the combined movement of sediment as bedload and suspension. In the surf zone the velocity field is oscillatory. The long shore currents are continuous shore-parallel flows within the surf zone. These currents are powerful sediment transport agents and they are associated with problems concerning long-term beach erosion and harbor/inlet shoaling (Short, 1999).

Wave height is the single most important process in controlling beach type and change. Wave sources and wave generation are naturally highly variable producing regular fluctuations in wave height at frequencies ranging from hours to seasonal to longer term. Natural influences on wave height including all topographic controls that affect wave shoaling, refraction and breaking (Short, 1999).

The main objective of this project is analyze the impact on sediment transport due the deepening the Santos Bay entrance channel at Ponta da Praia Beach. To analyze the possible influence of the deepening of the channel on the sediment transport in the Ponta da Praia Beach, Santos Beach, it was necessary simulate two scenarios, one with the bathymetry before channel deepening and the other after channel deepening.

2. METHODS

Wave data were collected in the middle of the Santos Bay with an ADCP for six months. These data were used to understanding the wave climate and validated the wave modeling. There are no data in the region.

To analyze the hydrodynamic, wave and sediment transport, Deflt3D modeling was used. The Delft3D suite is composed of several modules, grouped around a mutual interface, while being capable to interact with one another. In this project was used Delf3d Flow module, Wave module and sediment transport module.

The Delft3D WAVE modeling is performed trough SWAN (Holthuijsen *et al.*, 1993; Booij *et al.*, 1999; Ris *et al.*, 1999). The SWAN model is based on the discrete spectral action balance equation and is fully spectral (in all directions and frequencies). The latter implies that short-crested random wave fields propagating simultaneously from widely different directions can be accommodated (e.g. a wind sea with super-imposed swell). SWAN computes the evolution of random, short-crested waves in coastal regions with deep, intermediate and shallow water and ambient currents. The SWAN model accounts for (refractive) propagation due to current and depth and represents the processes of wave generation by wind, dissipation due to whitecapping, bottom friction and depth-induced wave breaking and non-linear wave-wave interactions (both quadruplets and triads) explicitly with state-of-the-art formulations (Deltares, 2011a).

Delft 3D-SED is a sediment transport and morphology module that supports bed-load and suspended load transport of non-cohesive sediments and suspended load of cohesive sediments. For cohesive sediment fractions the fluxes between the water phase and the bed are calculated with the well-known Partheniades-Krone formulations (Partheniades, 1965): For non-cohesive sediment (e.g. sand), we follow the method of Van Rijn (1993) for the combined effect of waves and currents. The transfer of sediment between the bed and the flow is modeled using sink and source terms acting on the near-bottom layer that is entirely above Van Rijn's reference height. Three-dimensional transport of suspended sediment is calculated by solving the three-dimensional advection-diffusion (mass-balance) equation for the suspended sediment. The settling velocity of one particle is reducing due to the other particles in high concentration mixtures. The local flow velocities and eddy diffusivities are based on the results of the hydrodynamic computations (Deltares, 2011b).

To force Delft3D WAVE, global modeling was performed using WW3 (Wave Watch 3) from NOAA (National Oceanic and Atmospheric Administration) and these results were used at SWAN (Simulating Waves Nearshore) boundaries and SWAN results were used in the Delft3D WAVE boundaries.

To characterize the wave climate inside the Santos Bay, ten-year wave simulations were performed with SWAN and the results were extracted to force Delft3D WAVE. The wave data collected in the Santos Bay were used to validate Delft3D hydrodynamic and wave model. The ten-year wave simulations indicated the typical wave climate in the region.

Eight most frequent conditions were chosen based on H_s and the direction to simulated scenarios with two different bathymetries, before and after dredging channel. In addition to these eight conditions, further five conditions were selected to represent waves during cold fronts. These thirteen conditions of wave climates, eight most frequent and five during cold fronts, correspond approximately 84 % of the frequency for the last ten years.

The hydrodynamic and wave modeling were run with 2 grids for each model. The bigger grid, encompassing adjacent coastal areas of Santos in estuary and a smaller grid with better resolution in the interested areas.

Delft3D-SED module was incorporated with the coupled waves and currents, considering a D50[4] of 0.1 mm for the region. Geophysical data indicated that the region is homogenous. The results before and after the deepening of the channel were compared to analyze the impacts along Santos Beach. As extreme events have low frequencies, the simulations were accomplished separately to identify the possible influence on wave climate and sediment transport.

3. RESULTS

The wave data collected indicated two periods with high waves, higher than 3 m, but most of the time the H_s was less than 2m. The main direction was from SSE, S and SSW, and the period of waves was 6 s (Figure 3).

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[4] Median Diameter of Sediment

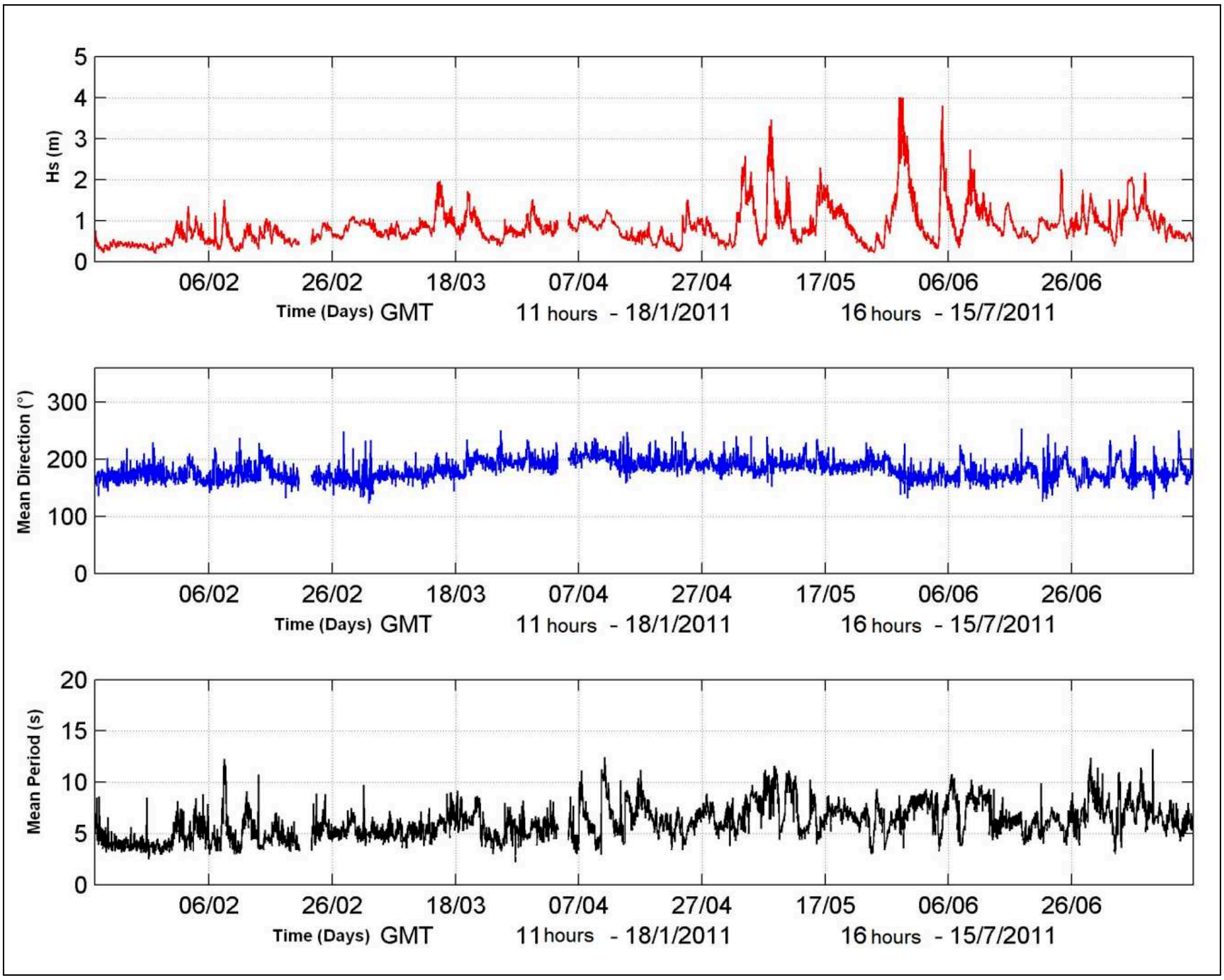

Figure 3 Temporal series of waves from 18th of January till 18th of July 2011.

The wave data were used to validate Delft3D WAVE. The validation of wave modeling are presented in Figure 4: (A) the waves height for wave data in the left side of the figure and (B) the waves height by the model on the right. In both A and B the direction of waves is in the range of 150° to 210°, with height ranging from 0.5 to 1.0 m.

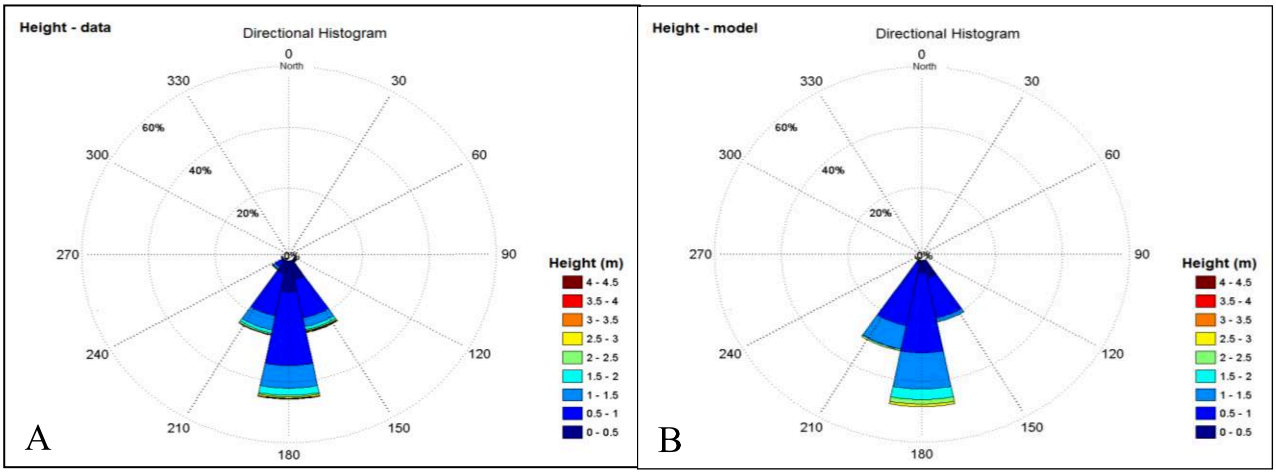

Figure 4 Height waves in the ADCP point: (A) height wave for ADCP data and (B) height waves obtained by modelling.

Ten-year waves were simulated using SWAN to obtain the wave climate. The statistical analysis of wave climate for ten years was obtained at a point next to the Santos Bay (Table 1). In Table 1 are thirteen conditions highlighted of height and direction waves. Eight conditions of the highlighted represent most frequent waves: south-southeast waves with H_s ranging 0.00 to 0.50 m (5.2%), 0.50 to 1.0 m (17.9%) and 1.00 to 1.50 m (3.3%); waves from south has H_s ranging 0.50 to 1.00 m (16.9%) and 1.00 to 1.50 m (8.1%) and south-southwest waves with H_s ranging 0.5 to 1.0 m (14.1%), H_s 1.0 to 1.50 m (12.9%) and H_s 1.5 to 2.0 m (3.1%). The sum of this directions and H_s most frequent, correspond to 81.5%. The others 5 conditions highlighted represent the largest high of waves to south-southwest waves, 3.50 to 4.0 m of H_s, and 4.0 to 4.5 m this high were uncommon and occurs during cold fronts.

Table 1 Percentage of occurrence of the height and direction of waves in Santos Bay between 2001 and 2010.

	Percentage of occurrence (%)																
Hs.(m)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	**Perc.**	**Mean Direc.**
0.00-0.50	0	0	0	0	0	0	0.9	**5.2**	2.7	1.2	0.3	0	0	0	0	0	10.3	168
0.50-1.00	0	0	0	0	0	0	0.4	**17.9**	**16.9**	**14.1**	2.7	0.1	0	0	0	0	52.2	181
1.00-1.50	0	0	0	0	0	0	0	**3.3**	**8.1**	**12.9**	4.1	0	0	0	0	0	28.4	194
1.50-2.00	0	0	0	0	0	0	0	0.2	1.2	**3.1**	0.9	0	0	0	0	0	5.3	200
2.00-2.50	0	0	0	0	0	0	0	0	0.8	**1.3**	0.2	0	0	0	0	0	2.3	197
2.50-3.00	0	0	0	0	0	0	0	0.1	0.2	**0.7**	0.3	0	0	0	0	0	1.3	202
3.00-3.50	0	0	0	0	0	0	0	0	0	**0.1**	0	0	0	0	0	0	0.2	204
3.50-4.00	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0.1	202
4.00-4.50	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	198
Porc.	0	0	0	0	0	0	1.3	26.7	29.9	33.5	8.4	0.2	0	0	0	0		
Alt.med	NaN	NaN	0	0	1	NaN	0.4	0.7	0.9	1.1	1.2	0.8	0.8	0.9	NaN	1		
Alt.max	0	0	0	0	1	0	0.8	3.1	3.9	4.1	3.4	1.1	1	0.9	0	1		

The hydrodynamics and wave modeling were simulated by coupling. The thirteen wave conditions were simulated according to the frequency and height of the wave climate.

For each condition of wave climate (thirteen conditions), two scenarios were simulated: one before channel dredge and other after channel dredge, totalizing twenty six simulations. Figure 5 presents the difference between the results (after minus before deepening channel) for height of waves equal to 1.25 m and 4.25 m to south-southwest waves. For the others H_s simulated the results were similar.

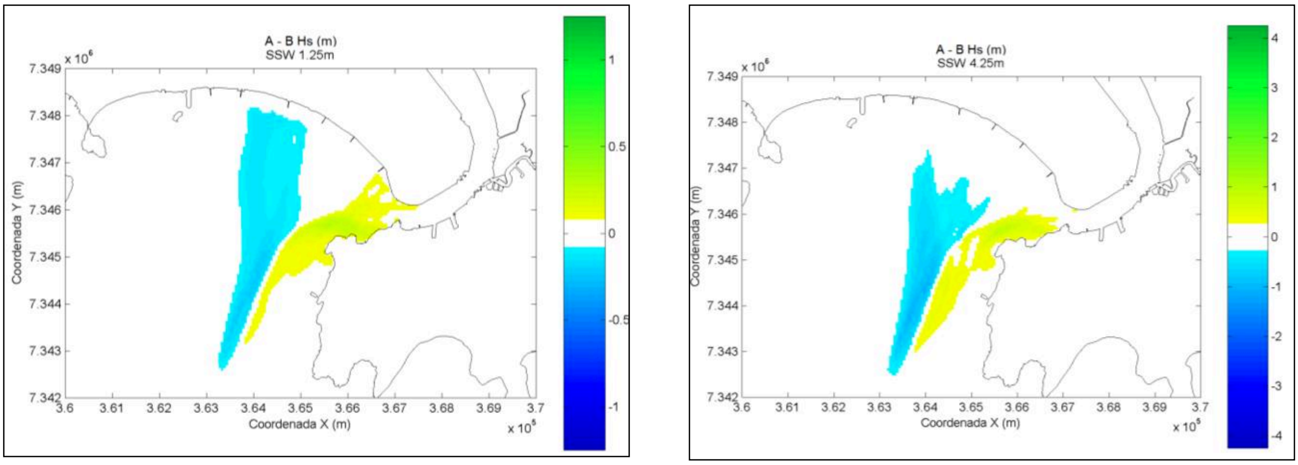

Figure 5 Difference between the wave height from south-southwest direction obtained in the simulations with the bathymetry after dredging (A) minus the simulation with the bathymetry before dredging (B) to H_s equal 1.25 m (left side) and 4.25 m (right side).

The figures of difference in H_s before and after dredging show that in the Ponta da Praia of Santos Beach the waves are higher after dredge for some conditions. A bifurcation occurs in the waves and in the middle of the beach the H_s is smaller after dredging and in the Ponta da Praia is higher. For lower H_s, the results were similar. For SSE, S and SSW incident waves the changing in the pattern of wave climate were similar, lower waves in the center of the Beach and higher waves at the extremity.

The results of bed sediment transport modeling indicated few differences after dredging for the three directions simulated (SSE, S and SSW). The results are presented to 1.25 m, Figure 6, and 4.25 m, Figure 7, wave heights of south-southwest waves. The results are qualitative due unavailable sediment data to quantify.

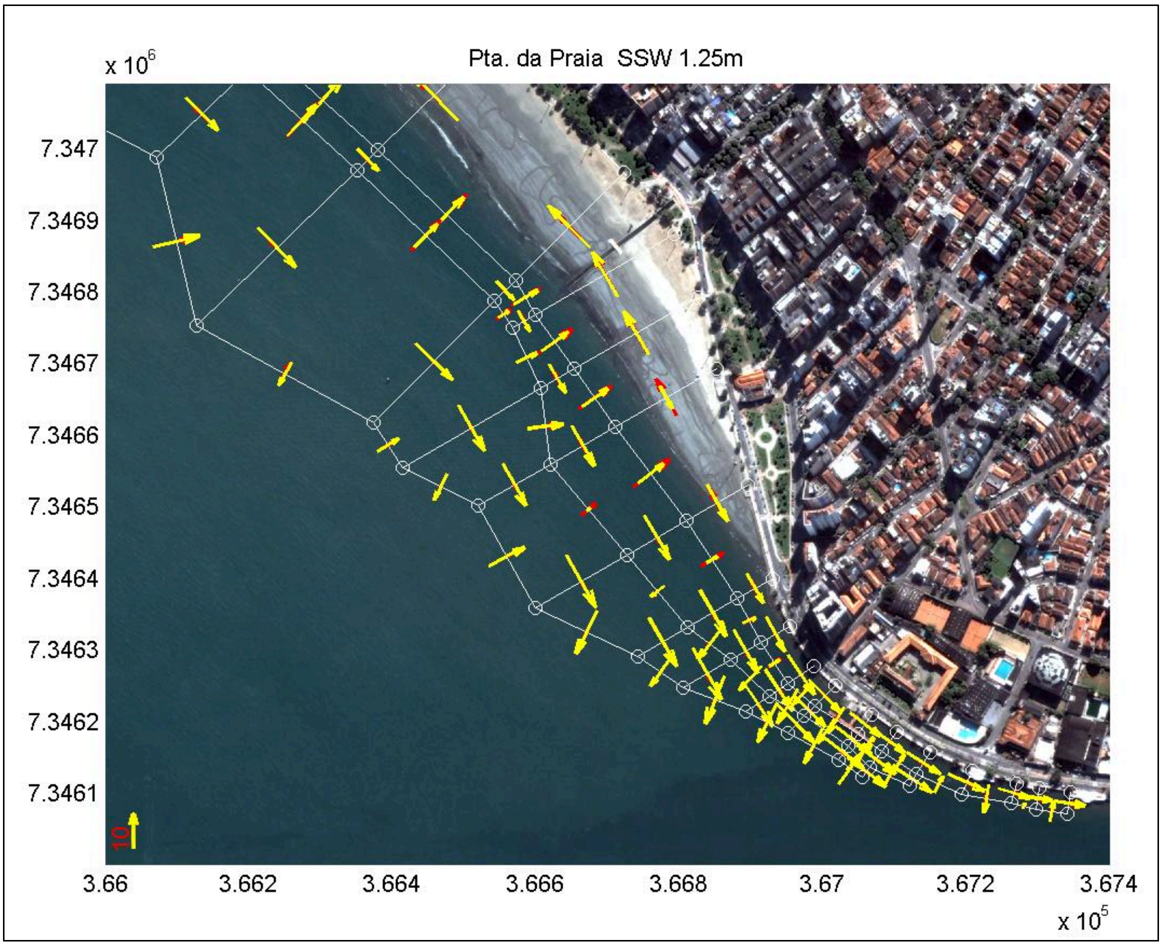

Figure 6 Bed sediment transport in the Ponta da Praia Beach, Santos, Brazil. The yellow arrows indicate the sediment transport before dredging and the red arrows indicate the sediment transport after dredging.

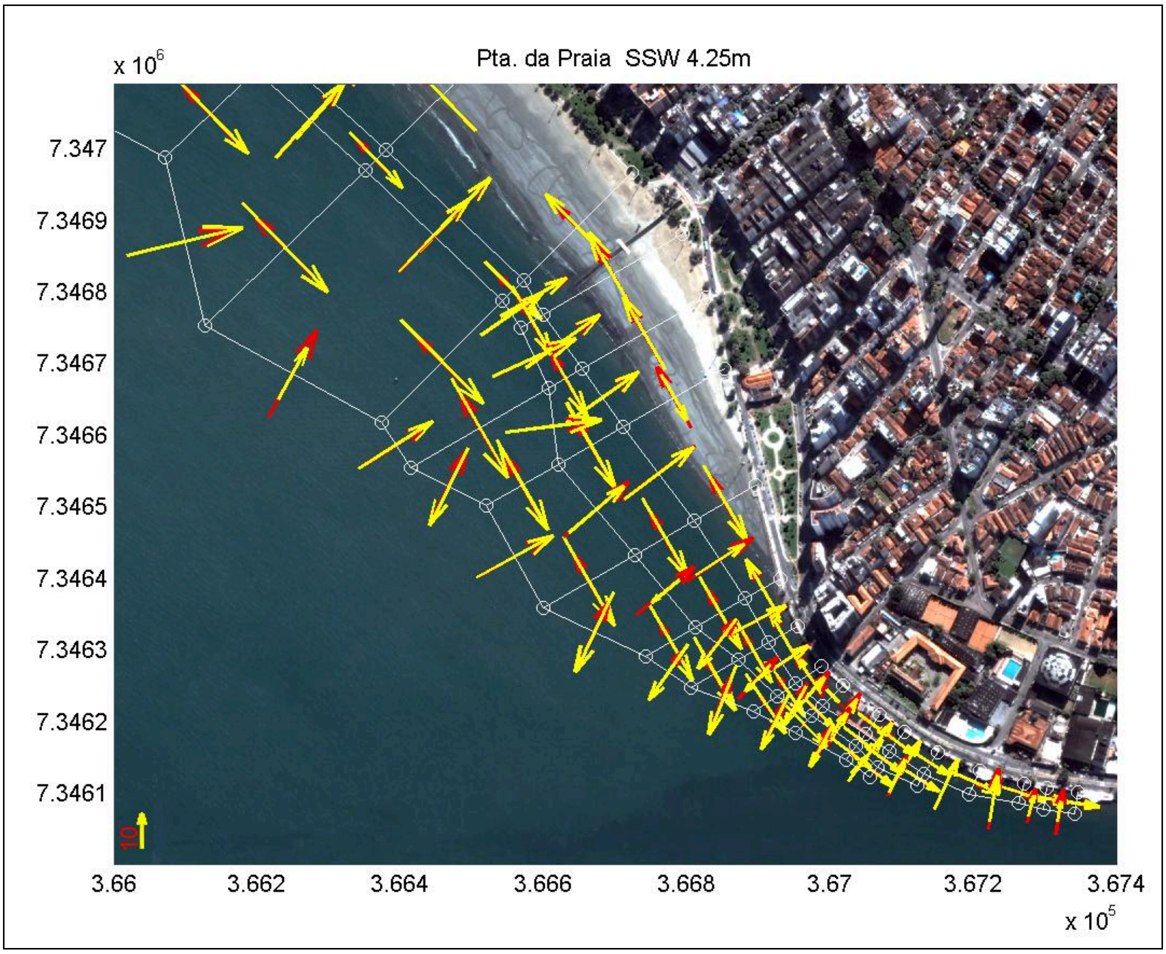

Figure 7 Bed sediment transport in the Ponta da Praia Beach, Santos Brazil. The yellow arrows indicate the sediment transport before dredging and the red arrows indicate the sediment transport after dredging.

The direction of sediment transport was to east to west according to Magini *et al.* (2007) and Rocha (2003) that used granulometric parameters. At the Ponta da Praia, east of Santos Beach, where erosion naturally occurs, the deepening of the channel did not cause significant differences in the sediment transport pattern for bed load, just for suspended sediment that do not influence the erosion process.

4. CONCLUSION

The modeling of hydrodynamics, wave and sediment transport indicated an intensification of wave heights after the deepening of the channel in Ponta da Praia, Santos Beach. The pattern of the incident waves do not present a difference. In the middle of the beach, the pattern is that waves are smaller compared to the east part, Ponta da Praia, independent of the dredging. This pattern is just intensified with the deepening of the channel.

In general the waves from south and south-west were more impacting than waves from south-east. This happens because of the geography of the Santos Bay that refracts more south-east waves. The direction of the wave does not present significant difference between before and after dredging. The transport of sediment did not show difference in the direction in the Ponta da Praia Beach.

Regarding the erosion that occurs normally in the Ponta da Praia, Farinaccio *et al.* (2009) studied the Ponta da Praia beach and identified a backward constant shoreline after 1977. The cause for this regression was the absence of input sediment that are held by the outfall that exists in the middle of the Bay. In this project it was possible to observe that after channel deepening, for large H_s, the sediment transport did not present difference in the direction of transport pattern for bed transport, just for suspended sediment and it does not influence the erosion process. However, the erosion could be accelerated after dredging but it is a natural process in this area and is not due the dredging.

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