EVALUATION OF PROPOSED JETTIES FOR PORT OF SANTOS NAVIGATION CHANNEL DEPTH MAINTENANCE

by

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ABSTRACT

In order to become a hub port in South America, Port of Santos intends to deepen and widen its Navigation Channel to support New Panamax vessels. Some authors proposed jetties geometries and evaluated the variation of currents velocities along Navigation Channel of Port of Santos. Five jetty options, previously proposed by other authors, were simulated with 2DH model and compared with a baseline scenario (without jetties). Flood and ebb current maps of each scenario with jetty were compared to flood and ebb current maps of baseline scenario, respectively. In addition, the siltation rate along Navigation Channel of Port of Santos was considered in this evaluation. Among the five jetties options (J1 and J3 with one jetty, J2 and J5 with two spaced jetties and J4 with two jetties with narrow channel), J4 has the best performance. For all options no significant current velocity variations were observed in the inner part of the estuary, so the jetties would only soften siltation in Stretch 1 (outer part of Navigation Channel). Moreover, the option J4, if implemented, would block the longshore induced current in Bay of Santos. Moreover, it is likely that the construction of jetties would increase the time required to renew water in bay of Santos, which would be a concern considering that Bay of Santos has a submarine outfall.

Keywords: Port of Santos, Jetties, Dredging, New Panamax, Coastal Engineering

INTRODUCTION

Background

The Panama Canal expansion has been an important pressure for Port of Santos improvements. Panama Canal Authority (ACP) announced the Panama Canal expansion project in 2006, and the works started in the following year (ACP, 2016a). The main purposes are the widening and deepening of existing channels, and the construction of Post Panamax dimension locks on the Pacific and Atlantic sides, also known as Third Set of Locks (URS, 2007). The expanded locks were inaugurated in 25th June 2016 (ACP, 2016b), and the new locks dimension established new vessel reference for Panama Canal, also known as “New Panamax” (Table 1).

Vessel Reference	Draught (m)	Beam (m)	Length Overall (m)
Panamax	13.2	32.2	290.0
New Panamax	15.2	49.0	366.0

Table 1: Vessel size references for Panama Canal. Source: PIANC (2014).

Therefore, São Paulo State Docks Company (CODESP) released in 2006 a Zoning Directive Plan (PDZ) aiming the expansion of Port of Santos and operation efficiency (CODESP, 2006). The plan foresaw the construction of new terminals, the deepening dredging of the Access Channel, Navigation Channel and berths, improvements in port and nearby infrastructure, and the perspective of Port of Santos assuming a role of Hub Port in South America due to its vast hinterland (Figure 1 – Map of Port of Santos hinterland).

In response to external pressures and port bottlenecks, Brazilian Federal Government published the law N 11.610/2007 (BRASIL, 2007). This law instituted the National Dredging Program (PND 1), which aimed the deepening dredging of Brazilian ports, allowing several ports to receive larger vessels with deeper drafts (BRASIL, 2007). PND 1 summed an investment of R$1.6 bi, and dredged about 73 million m³ of sediments from 16 ports (BRASIL, 2015).

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Figure 1: Port of Santos hinterland. Source: Adapted from IPEA (2009).

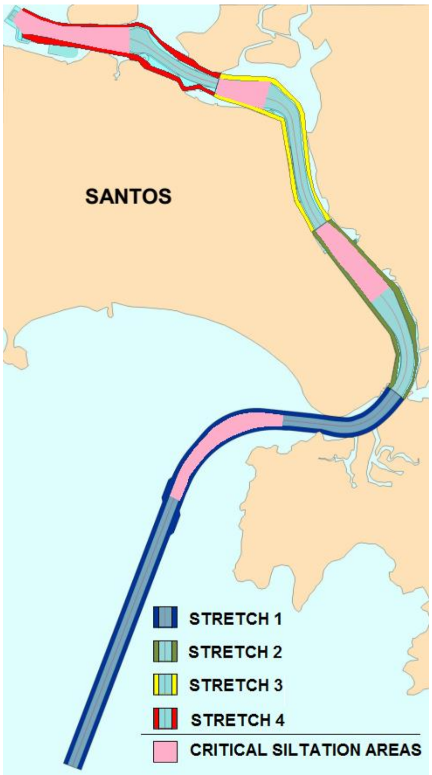

Figure 2: Port of Santos navigation channel dredging stretches 1 (blue), 2 (green), 3 (yellow) and 4 (red), with siltation critical areas (magenta) (based on Carvalho, 2016).

Thus, CODESP took advantage of PND 1 investments to manage its deepening dredging. INPH (2007) projected three phases for the deepening and widening dredging (see Table 2 with Port of Santos channel dimensions for each phase and Figure 2 with a map showing the different dredging stretches). Despite Phase 1 is fully accomplished, Port of Santos is one step behind from Panama Canal, because it does not support the traffic of large draft vessels, such as New Panamax.

Stretch	Extent	Depth (m)			
		Before Deepening Dredging	Phase 1	Phase 2	Phase 3
1- Access Channel until "Entreposto de Pesca"	9.5	14.0	15.0	16.0	17.0
2- From "Entreposto de Pesca" to "Torre Grande"	4.5	13.0	15.0	16.0	17.0
3/4- From "Torre Grande" to "Alemoa"	8.5	12.0	15.0	15.0	16.0
Minimum Channel width (m)		150.0	220.0	220.0	250.0*

*Except from Ponta da Praia to Ferry-Boat (220.0 m).

Table 2: Port of Santos projected channel dimensions for each phase (INPH, 2007).

Current Scenario

Currently, Port of Santos navigation channel is 15 m deep and 220 m wide, with two navigation lanes (Phase 1 – Table 2), and CODESP depth target is 17 m deep and 250 m wide (Phase 3 – Table 2). This deepening dredging would allow the traffic of New Panamax vessels in Port of Santos. Gireli & Vendrame (2012) estimated the Access Channel (contained in stretch 1) siltation evolution using monthly siltation records from May 1997 to March 2003. According to their estimates, the Phase 3 deepening depth would significantly increase siltation rate along navigation channel, requiring larger maintenance dredging volume (GIRELI & VENDRAME, 2012). Carvalho (2016) estimated the monthly siltation along Port of Santos navigation channel by comparing bathymetries from October 2010 to November 2013 (Table 3). The navigation channel has four critical siltation areas (Figure 2); according to Carvalho (2016), these areas are responsible for 19%, 12%, 6%, and 14% of total siltation in stretches 1, 2, 3, and 4, respectively.

Stretch	**1**	**2**	**3**	**4**
Siltation rate (m³/month)	248,597	103,871	80,566	108,629
Percentage of total siltation (%)	45.90%	19.18%	14.87%	20.05%
Mean vertical accretion (cm/month)	8.7	5.9	7.3	9.9

Table 3: Port of Santos navigation channel mean monthly siltation rate from October 2010 to November 2013 (Carvalho, 2016).

Moreover, the Federal Public Ministry (MPF) claims that Port of Santos deepening dredging has aggravated the progressive erosion of *Ponta da Praia*, an adjacent beach to the Port, due to wave heightening and longshore current acceleration (MPF, 2015). Indeed, the Environmental Impact Assessment (EIA) of Port of Santos deepening dredging (FRF, 2008) has a gap, since the beaches were not included in the Direct Impact Area (DIA). Thus, CODESP signed a Term of Conduct Adjustment (TAC) recognizing the impact on the beach erosion, and committing themselves to design and afford a structure, which cannot be rigid and must be submerse, that mitigates *Ponta da Praia* beach erosion.

Therefore, this study evaluates jetties previously proposed for depth maintenance of Port of Santos navigation channel (REIS, 1978; ALFREDINI et al., 2013), based on the variation of currents velocities along the navigation channel and the siltation on each stretch.

METHODOLOGY

Port of Santos has been facing challenges with depth maintenance of navigation channel for a long time. In order to minimize siltation along the navigation channel and decrease the volume of dredged sediments, Reis (1978) proposed several geometries of jetties for Port of Santos (Figure 3), and tested them with small-scale physical model.

This physical model had a movable-bed filled with cellulose acetate, horizontal scale of 1:600 and vertical scale of 1:100, and its domain comprised only part of the Bay of Santos. The bathymetry of the physical model was based on nautical chart no. 1701 DHN (Directory of Hydrology and Navigation) and bathymetric data collected by INPH in 1974, when the navigation channel was dredged up to -14 m deep. Reis (1978) proposed six options of jetties, but two were discarded, the four remaining options have distinct geometry and length (J1, J2, J3, and J4), as shown in Figure 3 and described in Table 4. Later, Alfredini et al. (2013) proposed another geometry of two curved jetties (J5 as described in Table 4 and shown in Figure 3) for depth maintenance of Port of Santos navigation channel.

Jetty Options	No. of jetties	Type (right/left)	Extension (r/l)	Depth of head (r/l)
(J1)	Single jetty	Straight	2,900 m	-9 m
(J2)	Two jetties	Straight/ Straight	2,900 m/ 700 m	-9 m/ -9 m
(J3)	Single jetty	Curved	2,910 m	-9 m
(J4)	Two jetties	Curved/ Straight	4,350 m/ 1,590 m	-11 m/ -11 m
(J5)	Two jetties	Curved/ Curved	4,360 m/ 2,150 m	-12 m/ -12 m

Table 4: Description of each jetty option (Source: Reis, 1978 and Alfredini et al., 2013).

The evaluation consisted of comparing velocity maps of each jetty option (J1, J2, J3, J4 and J5) during ebb and flood (in the instant of maximum velocity at Santos estuary inlet) for a Spring tide with the Baseline Scenario (BS), as described in Figure 4.

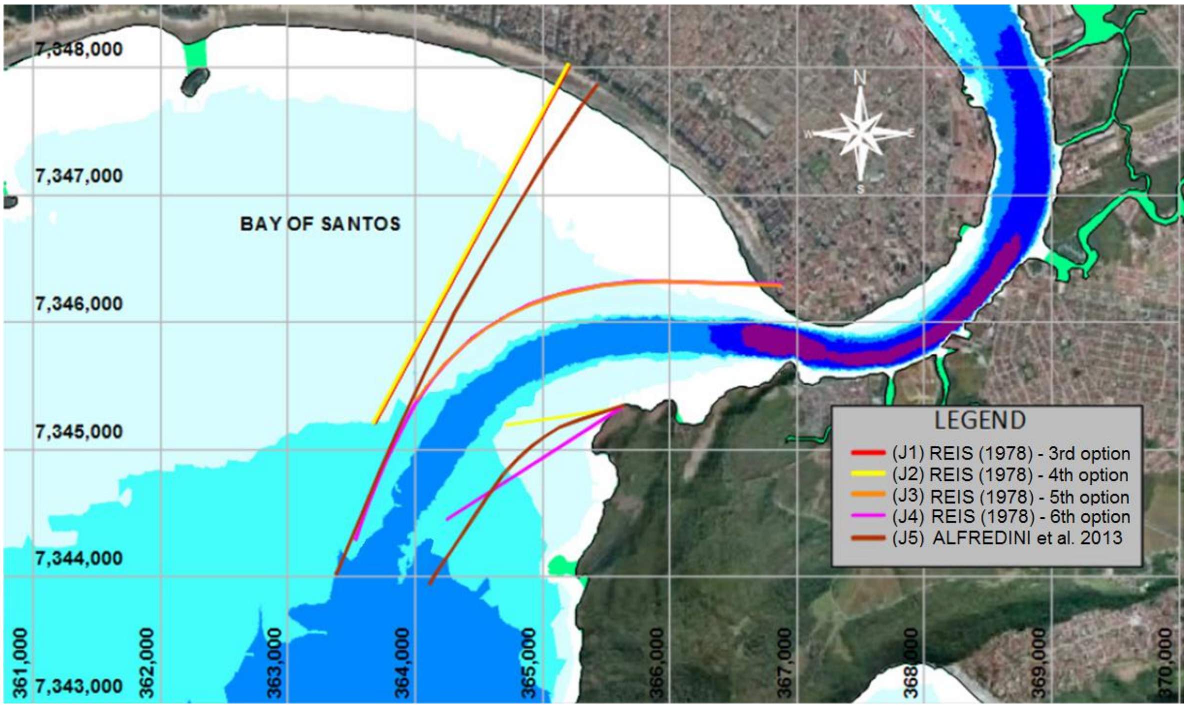

Figure 3: Proposals of jetties for Port of Santos marine Sandbar transposition (Source: Adapted from Gireli et al. 2017).

Calibration and validation of 2D hydrodynamic model for baseline scenario with field data (tide elevation and current measurements along Port of Santos navigation channel), as described in the next section. The baseline is set for 2006, before the Phase 1 of deepening dredging

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Simulation of five modified scenarios for each jetty option (J1, J2, J3, J4 and J5), the only difference to baseline scenario was the introduction of jetties, all forcing still the same

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From each scenario were retrieved two currents velocities maps, one for Spring ebb tide and another for Spring flood tide, along Port of Santos navigation channel

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All flood and ebb current maps of scenarios with jetty were compared to flood and ebb current maps of baseline scenario, respectively. This comparison consisted of subtracting the current velocities map from a scenario with jetty with a current velocity map of baseline scenario

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Evaluation of each jetty option based on the comparison of critical siltation areas along Port of Santos navigation channel and currents velocities maps

Figure 4: Evaluation process of each jetty option, considering current velocities maps for Spring ebb tide and Spring flood tide.

HYDRODYNAMIC NUMERICAL MODEL SET UP

The current study applies a 2DH model with flexible mesh (Mike 21 Flow Model FM). This hydrodynamic module solves two-dimensional shallow water equations (the depth-integrated incompressible Reynolds averaged Navier-Stokes equations), the spatial discretization of equations is performed using a cell-centered finite volume method, and in the horizontal plane an unstructured grid is adopted comprising triangles or quadrilateral elements (DHI, 2015).

Data set

Due to data availability, the baseline of this study is set for 2006, before the deepening dredging. The Port of Santos Access and Navigation Channel are retrieved from bathymetric data of the baseline year (INPH, 2007). Parts of the estuary are from older surveys (MARMIL, 2015; GARCIA et al., 2002) or are interpolated values (SOUZA, 2017), and the nearshore area and some parts of the estuary are retrieved from nautical charts and DHN bathymetric data, which the scatter data is composed of data from 1969 to 2004 (MARMIL, 2015; GARCIA et al., 2002). Figure 5 shows the bathymetry from 2006 interpolated with older surveys using Mike Mesh Generator.

The major model forcing is tidal elevation, Santos estuary has tides with diurnal inequalities and tidal range up to 1.5 meter (HARARI & CAMARGO, 2003), so the sea boundary consists of nine nodes and eight segments (Figure 5). The tidal forcing for each node were computed using the nine most energetic tidal constituents in Santos region (Q1, O1, P1, K1, N2, M2, S2, K2 and M3). Each node has amplitude adjustment and phase lag, based on a shelf model with observations during 46 years in the Port of Santos, from 1944 to 1989, for these nine constituents (HARARI & CAMARGO, 1994). The hydrodynamic model has nine points of river discharge along the estuary (Figure 5), considering long-term river discharges retrieved from Roversi et al. (2016).

The elements of the mesh are triangular, with angles smaller than 30° (degrees), and each polygon has a local maximum area element. The model consisted of an unstructured mesh with 31,897 nodes and 57,039 elements.

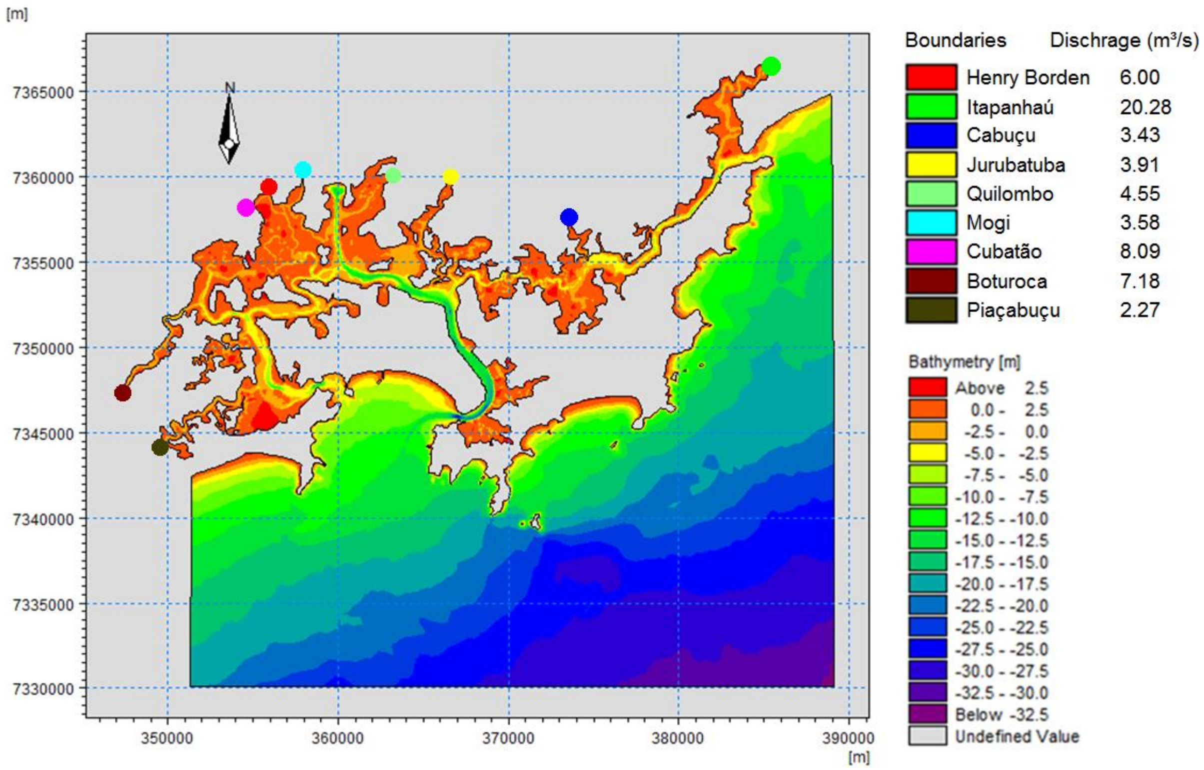

Figure 5: Model of Santos Estuary System and nearshore region 2006 bathymetry interpolated using Mike Mesh Generator and long-term river discharges (m^3/s).

Model calibration and validation

The model period of simulation covers 13 days, from 4th to 17th March of 2006. The calibration consisted on adjusting the bed roughness to minimize the errors in five tide gauge stations (Figure 6), and validation consisted of comparing current measurements in eight sections (INPH, 2007) along the estuary (Figure 7) with current velocities retrieved from model simulation.

Calibration showed good agreement with field data. The comparisons between harmonic analysis and simulated results are shown in Figure 8 and the Root Mean Square Error (RMSE) (equation 1) is acceptable. Due to lack of data, the period of validation covers only 8 days, from March 9th to 17th of 2006, and the model had no adjustment in the validation process. Figure 9 shows comparison between flow measurement and simulation. The validation results show good or acceptable agreement with measured values from flow stations along Santos Estuary. Skill score (equation 2) for S07 and S09 flow stations may be lower because the bathymetry has coarser scatter data in this area.

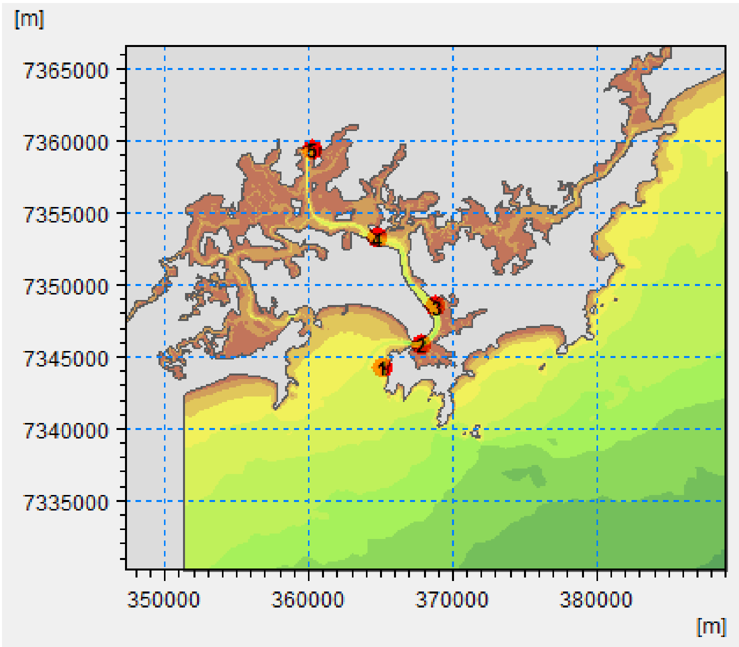

Figure 6: Tide gauge stations along Santos estuary used to calibrate the hydrodynamic model. 1-Ilha das Palmas, 2-Praticagem, 3-Conceiçãozinha, 4-Ilha Barnabé and 5-Cosipa.

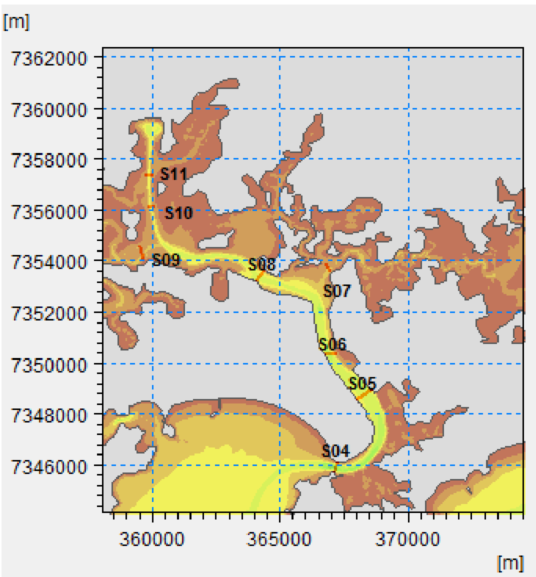

Figure 7: Eight flow stations (S04, S05, S06, S07, S08, S09, S10, S11) along Santos estuary used to validate the hydrodynamic model for currents.

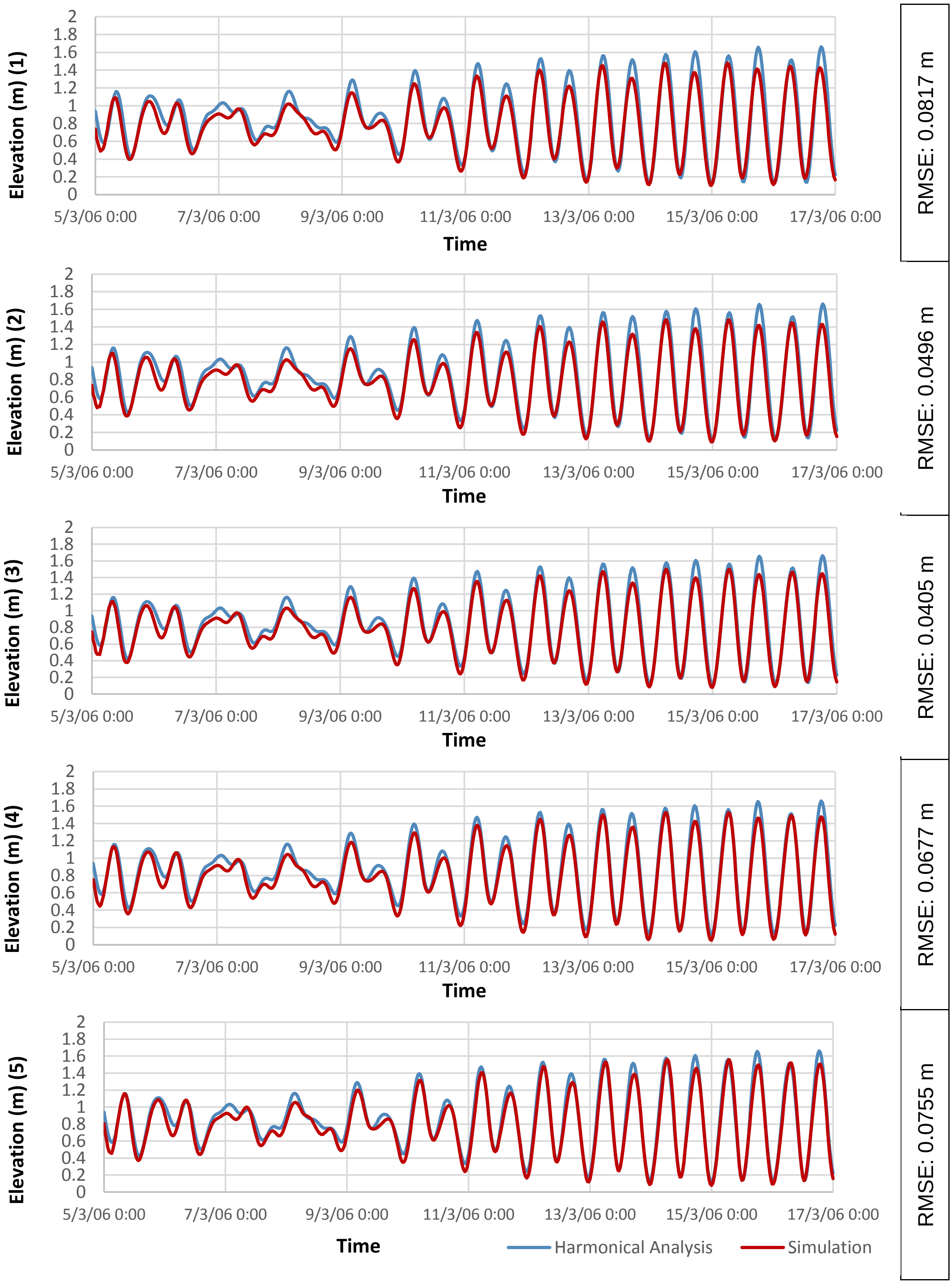

Figure 8: Time series comparative between harmonic analysis (blue) and simulation (red) for tide gauge station (1) Ilha das Palmas, (2) Praticagem, (3) Conceiçãozinha, (4) Ilha Barnabé e (5) Cosipa.

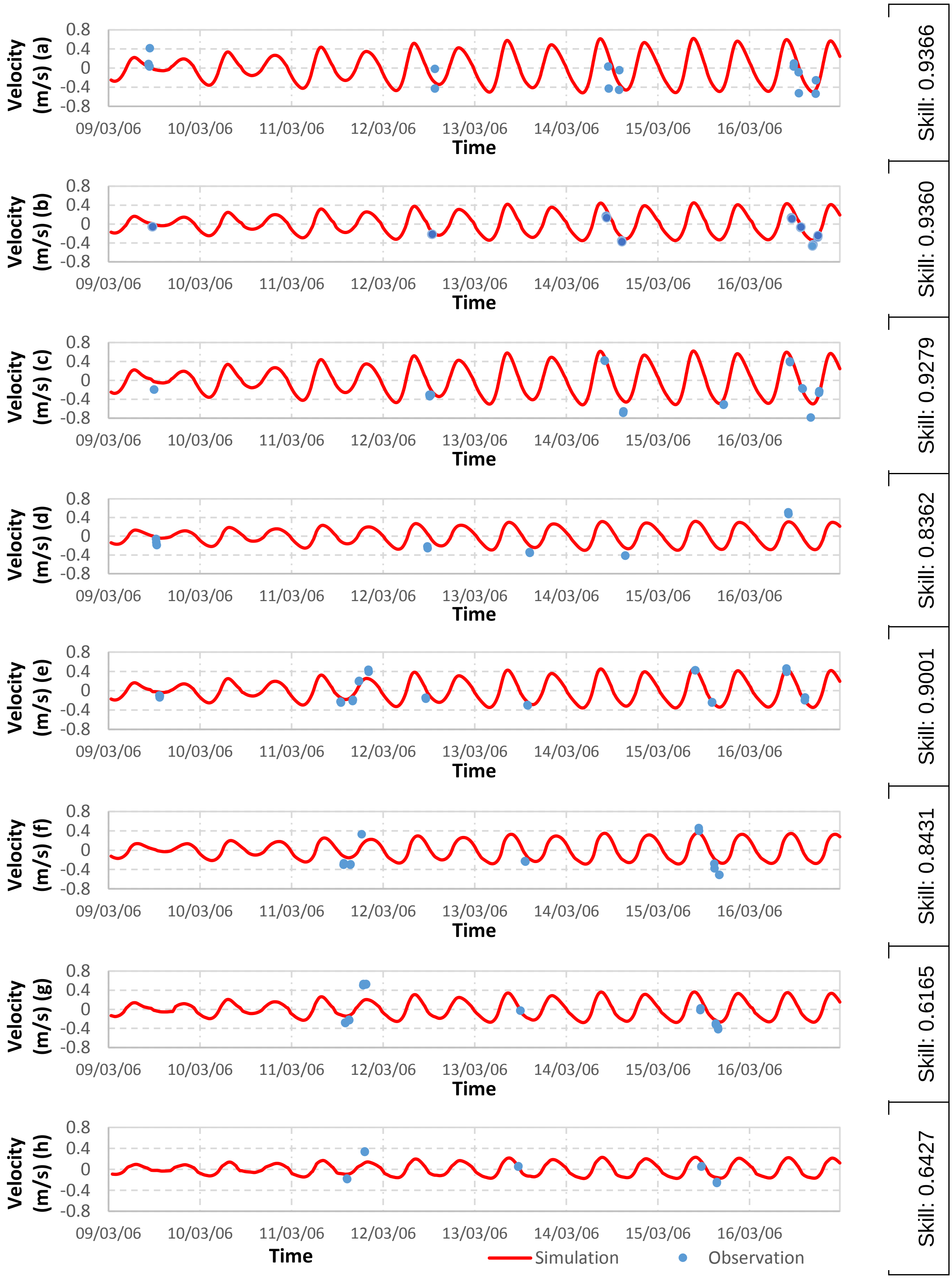

Figure 9: Model validation for flow stations S04 (a), S05 (b), S06 (c), S07 (d), S08 (e), S09 (f), S10 (g), S11 (h). Comparative between flow measurement (blue) and simulation (red). Skill score for current measurements in each section (0 – poor agreement and 1 – good agreement)

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n}(S_t - O_t)^2}{n}} \quad (1)$$

where: t is the time step, n is the amount of data acquired or the sample size, S are the simulated values, and O are the observed values. RMSE is easy to understand because it has the same metric as S and O (Willmott, 1981)

$$SKILL = 1 - \frac{\sum_{t=1}^{n}(S_t - O_t)^2}{\sum_{t=1}^{n}(|S_t - \overline{S_t}| + |O_t - \overline{O_t}|)^2} \quad (2)$$

where: t is the time step, n is the amount of data acquired or the sample size, S are simulated values, O are observed values and O is the average of observed values (Willmott, 1981).

RESULTS

Baseline Scenario

During the flood, in the outer part of Stretch 1, the currents reach up to 20 cm/s in the straight part of the navigation channel and between 30 cm/s and 55 cm/s in the curvy part of the navigation channel. In the inner navigation channel, the currents reach up to 70 cm/s in the end of Stretch 1, varies between 30 cm/s and 6 cm/s in the Stretch 2, varies between 30 cm/s and 50 cm/s in the Stretch 3, and reach up to 45 cm/s in the Stretch 4 (Figure 10). During the ebb, in the outer part of Stretch 1, the currents reach up to 25 cm/s in the straight part of the navigation channel and between 40 cm/s and 60 cm/s in the curvy part of the navigation channel. In the inner navigation channel, the currents reach up to 90 cm/s in the end of Stretch 1, varies between 40 cm/s and 75 cm/s in the Stretch 2, varies between 30 cm/s and 70 cm/s in the Stretch 3, and reach up to 60 cm/s in the Stretch 4 (Figure 10).

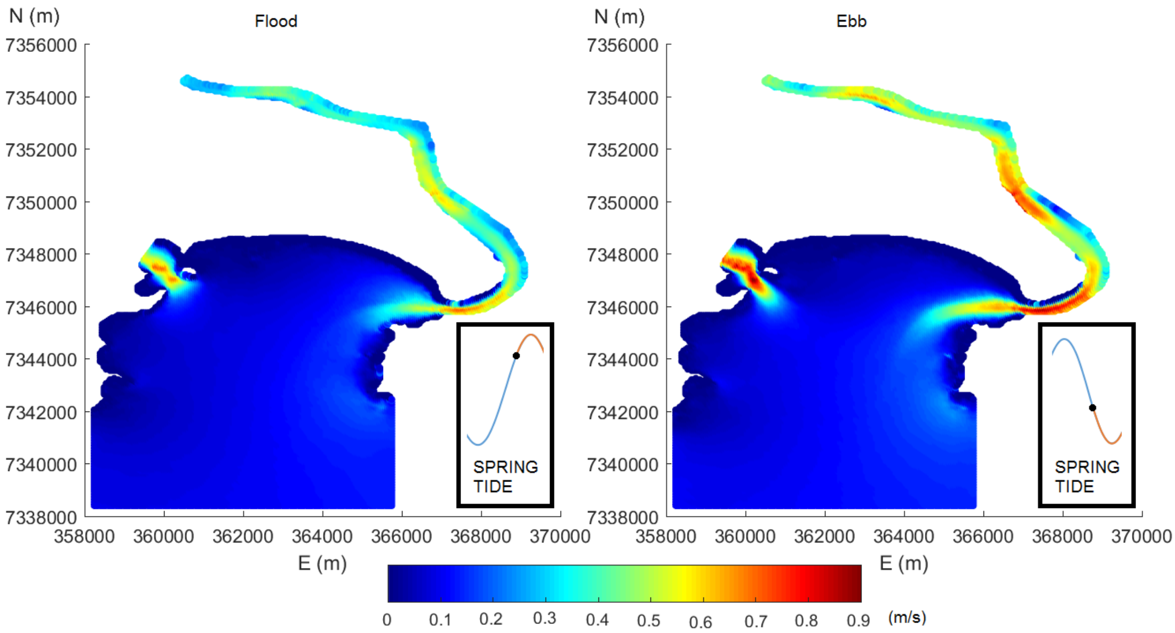

Figure 10: Currents velocities maps of Baseline Scenario (BS), without jetty, for Spring tide (flood) at 14/3/06 4:00 (left) and Spring tide (ebb) at 15/3/06 9:38 (right).

J1

Comparing the current velocity maps of option J1 (Figure 11) with BS (Figure 10), is possible to notice that near the jetty head, in the straight part of navigation channel near the curvy part, the option J1 increases the current velocity up to 15 cm/s during flood and ebb (Figure 12). Furthermore, no significant current velocity variations were observed in the inner part of the estuary.

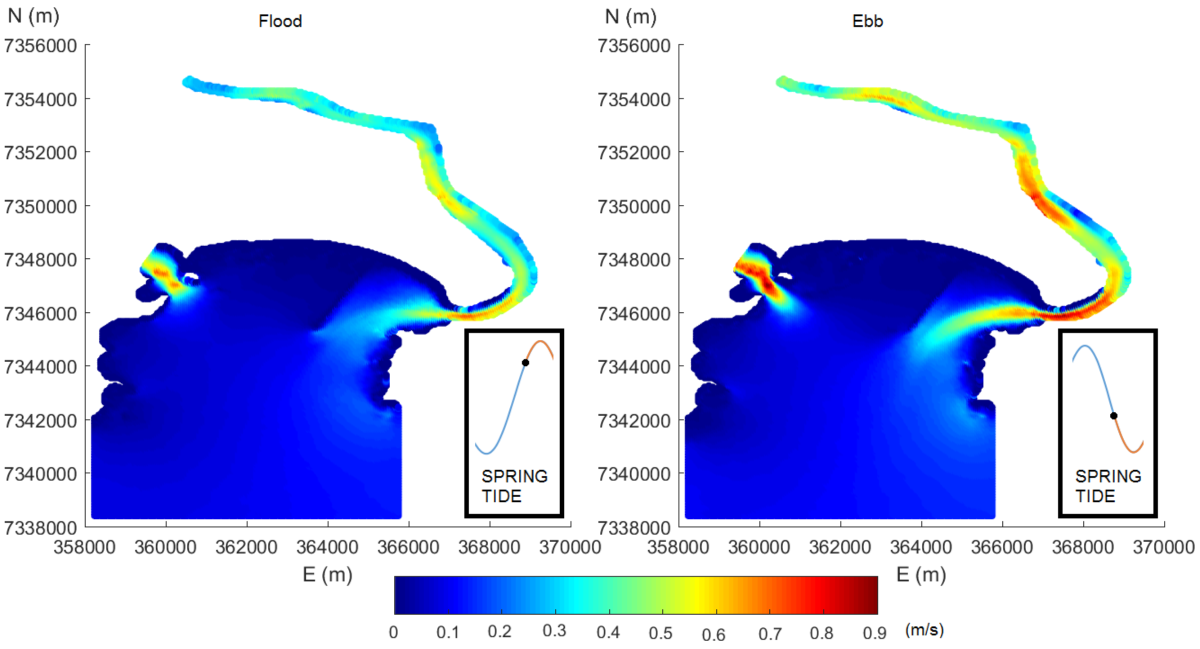

Figure 11: Currents velocities (m/s) maps of Jetty option no. 1 (J1), with one jetty, for Spring tide (flood) at 14/3/06 4:04 (left) and Spring tide (ebb) at 15/3/06 9:38 (right).

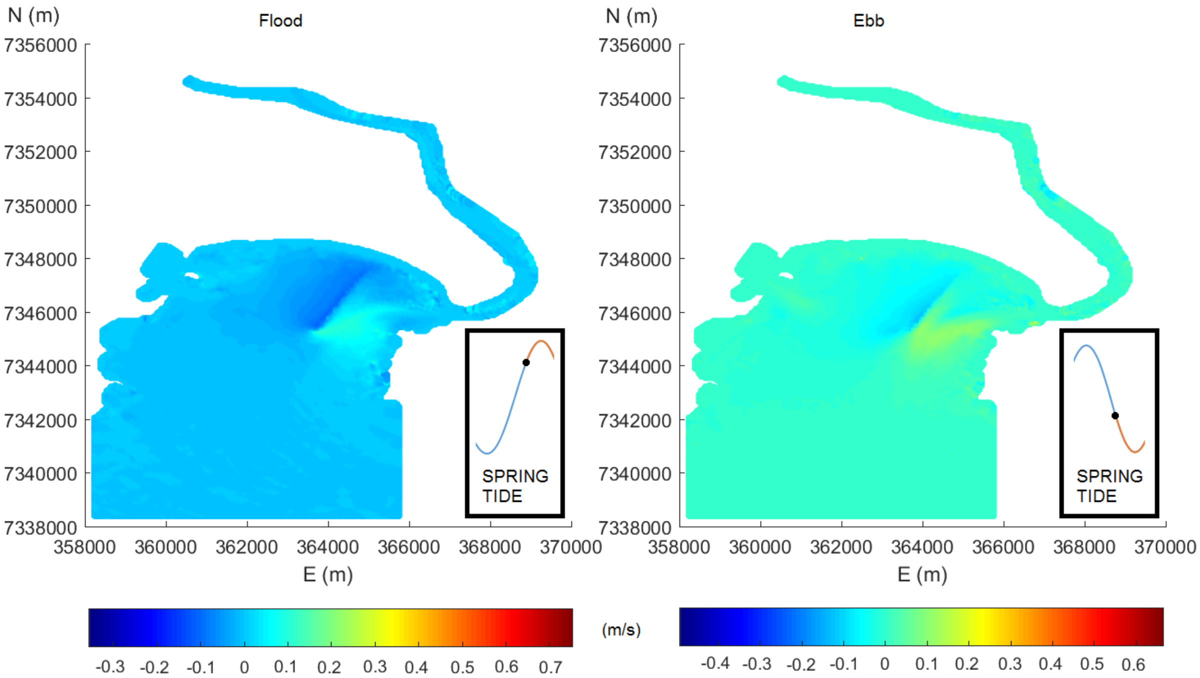

Figure 12: Maps with absolute difference of currents velocities (m/s) between Jetty option no. 1 (J1), with one jetty, and BS for Spring tide - flood (left) - and Spring tide - ebb (right).

J2

Comparing the current velocity maps of option J2 (Figure 13) with BS (Figure 10), is possible to notice that between the jetties walls, in the straight part of navigation channel near the curvy part, the the current velocity increases by more than 10 cm/s during flood, and increases up to 15 cm/s during ebb (Figure 14). Near the jetties head, the current velocity increases up to 40 cm/s during flood and ebb (Figure 14). Furthermore, no significant current velocity variations were observed near the estuary mouth and in the inner part of the estuary.

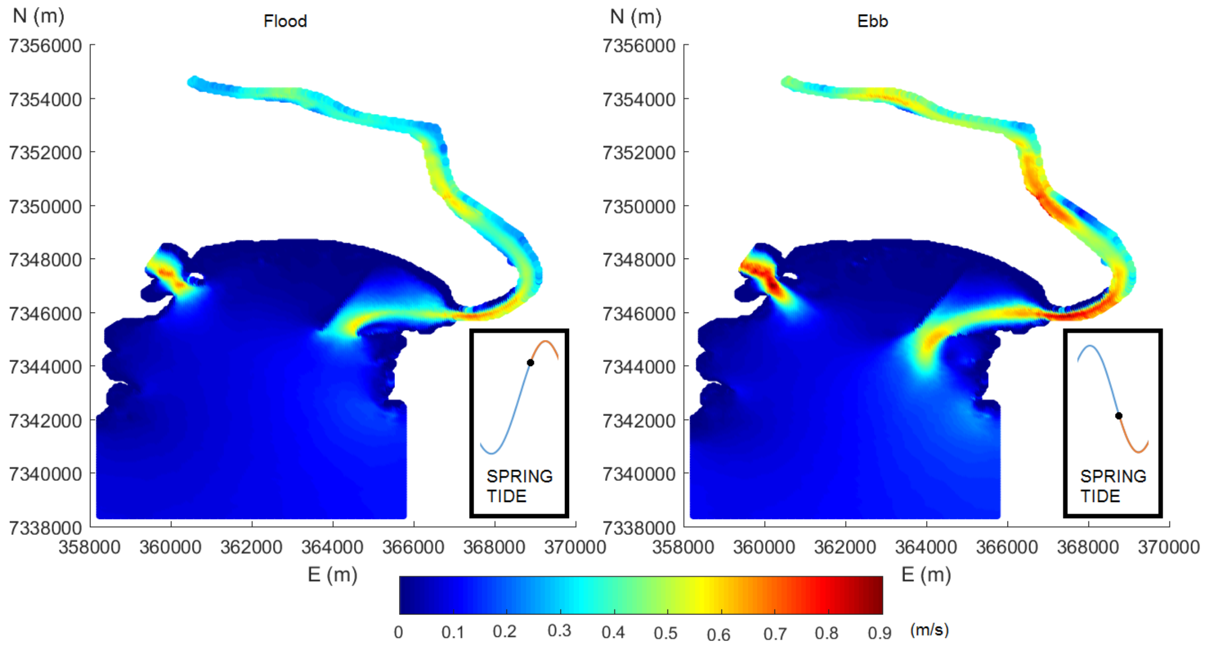

Figure 13: Currents velocities (m/s) maps of Jetty option no. 2 (J2), with two jetties, for Spring tide (flood) at 14/3/06 4:18 (left) and Spring tide (ebb) at 15/3/06 9:38 (right).

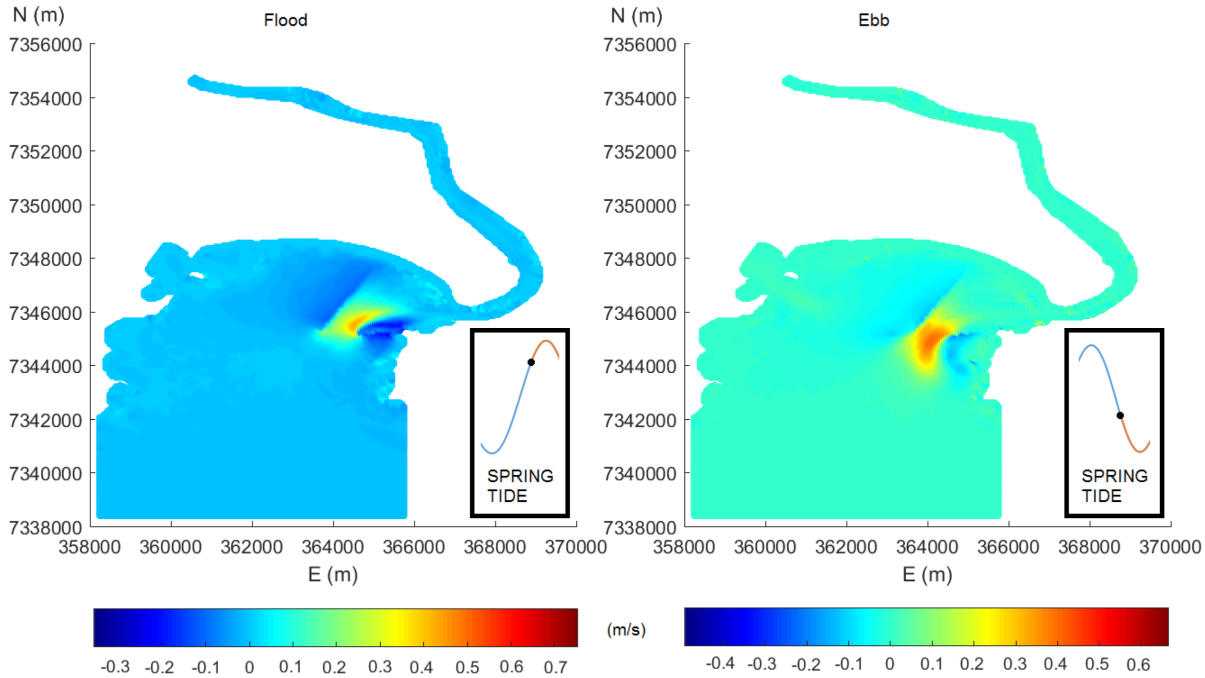

Figure 14: Maps with absolute difference of currents velocities (m/s) between Jetty option no. 2 (J2), with two jetties, and BS for Spring tide - flood (left) - and Spring tide - ebb (right).

J3

Comparing the current velocity maps of option J3 (Figure 15) with BS (Figure 10), is possible to notice that near the jetty structure, the current velocity increases up to 10 cm/s during flood and up to 15 cm/s during ebb (Figure 16). Furthermore, no significant current velocity variations were observed in the inner part of the estuary.

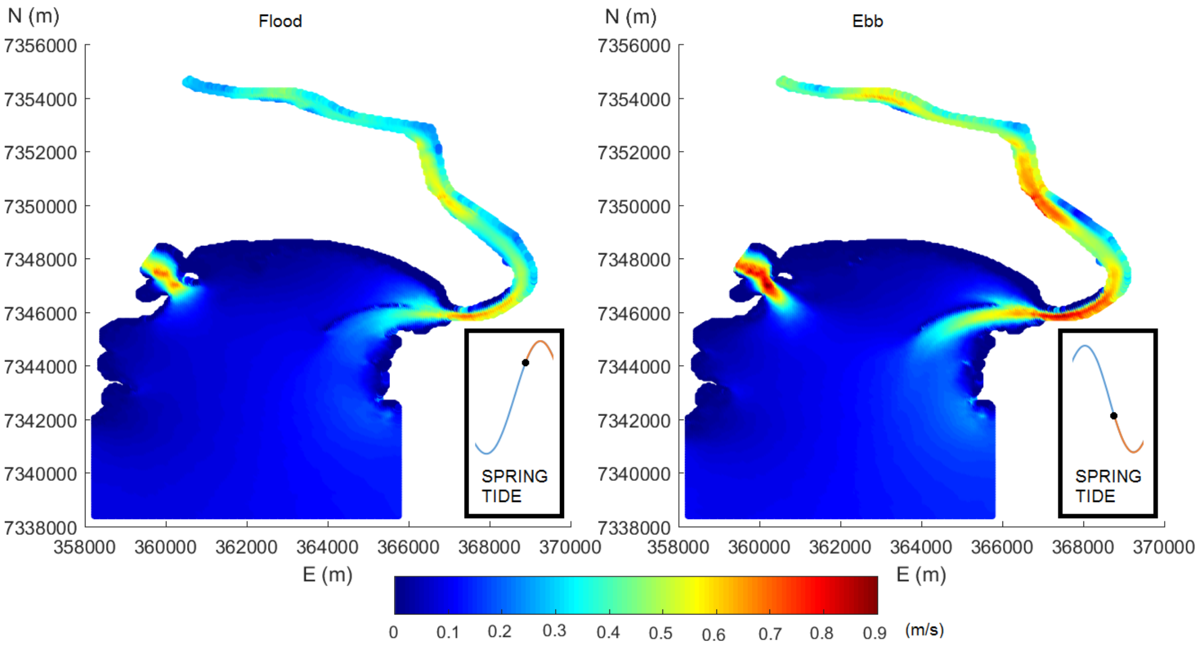

Figure 15: Currents velocities (m/s) maps of Jetty option no. 3 (J3), with one jetty, for Spring tide (flood) at 14/3/06 4:06 (left) and Spring tide (ebb) at 15/3/06 9:40 (right).

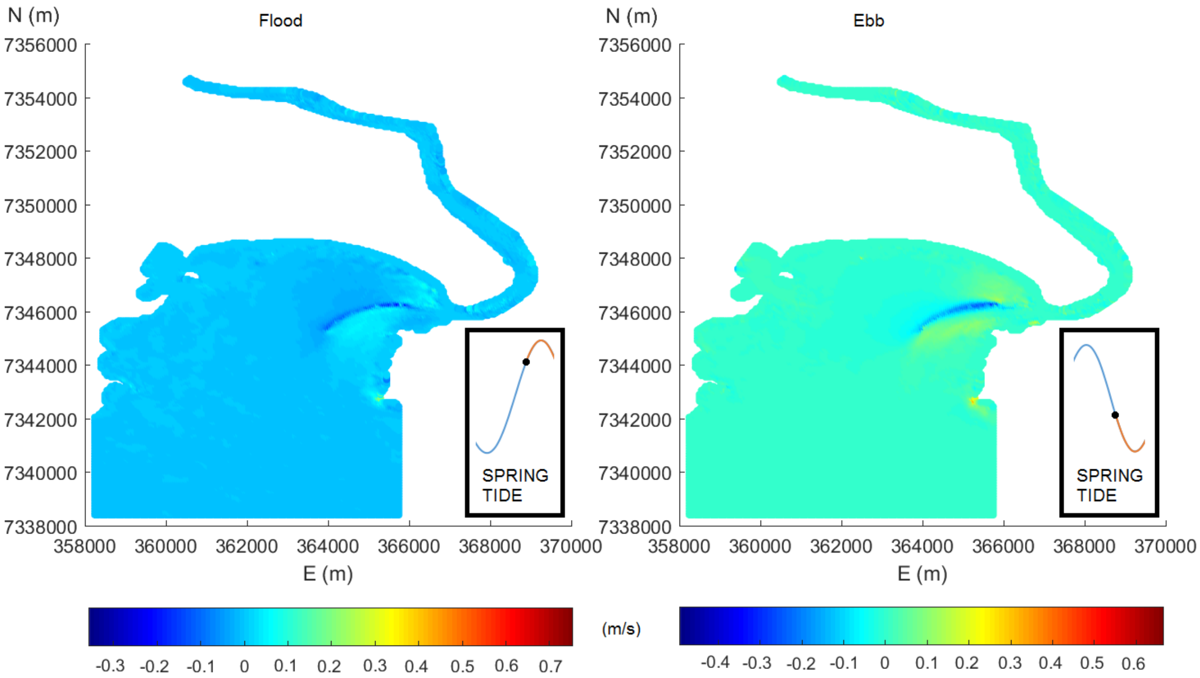

Figure 16: Maps with absolute difference of currents velocities (m/s) between Jetty option no. 3 (J3), with one jetty, and BS for Spring tide - flood (left) - and Spring tide - ebb (right).

J4

Comparing the current velocity maps of option J4 (Figure 17) with BS (Figure 10), is possible to notice that between the jetties walls, the current velocity increases by more than 30 cm/s during flood and ebb (Figure 18). Near the jetties head, the current velocity increases up to 60 cm/s during flood and increases up to 65 cm/s during ebb (Figure 18). Furthermore, no significant current velocity variations were observed in the inner part of the estuary.

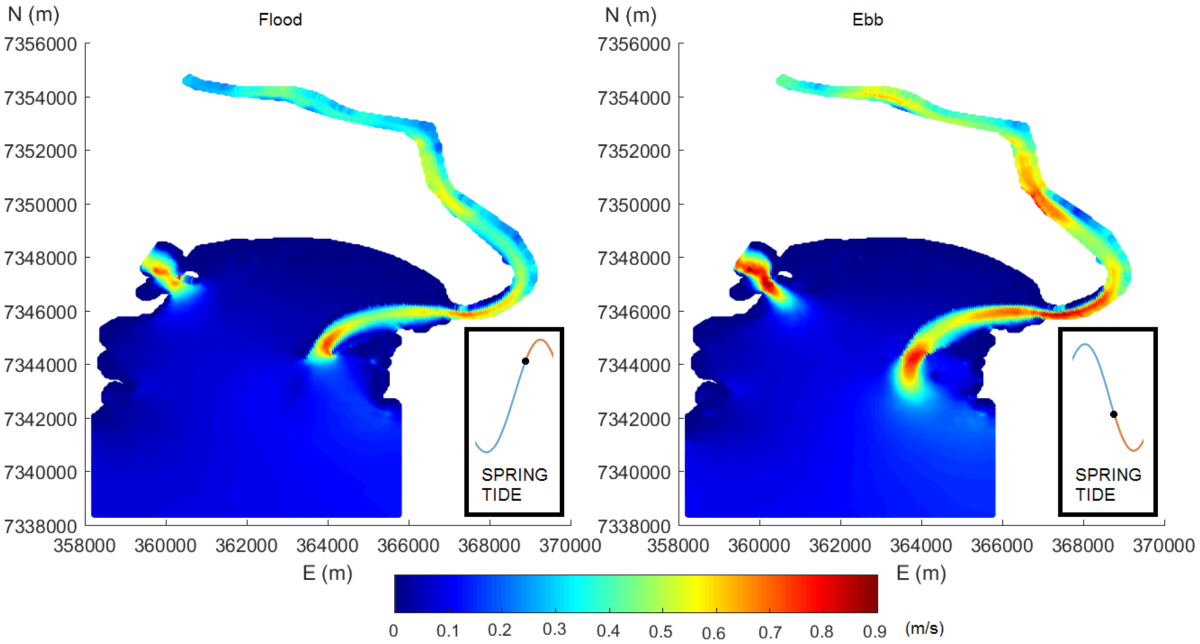

Figure 17: Currents velocities (m/s) maps of Jetty option no. 4 (J4), with two jetties, for Spring tide (flood) 14/3/06 4:20 (left) and Spring tide (ebb) at 15/3/06 9:32 (right).

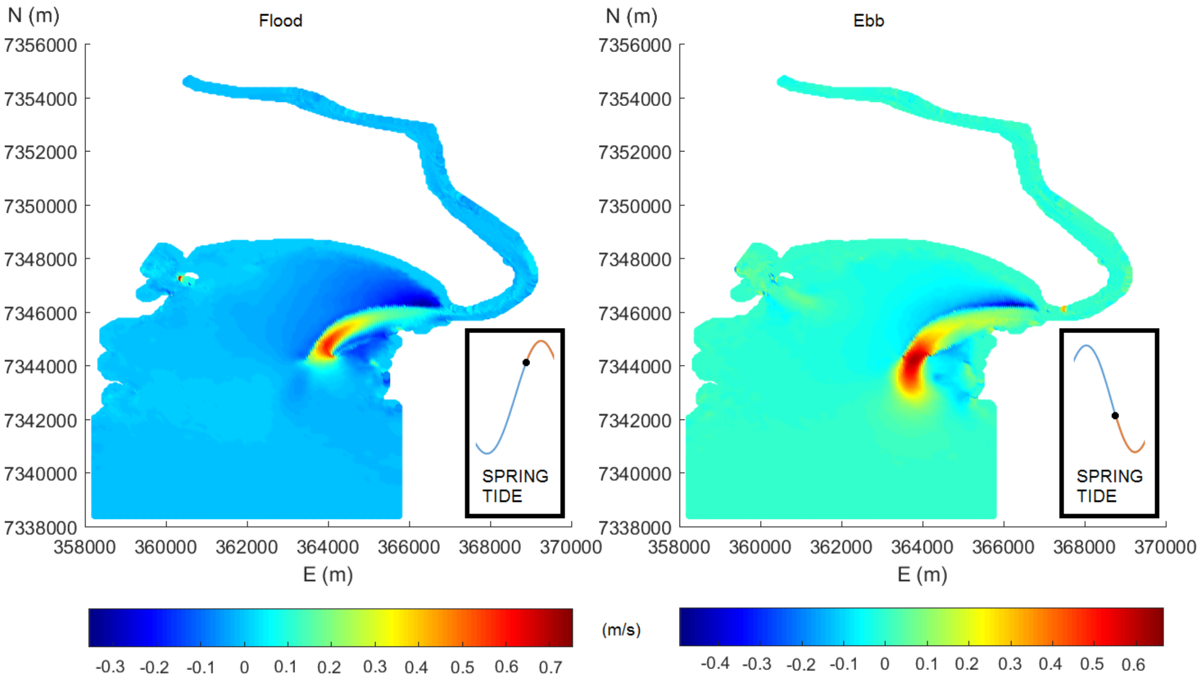

Figure 18: Maps with absolute difference of currents velocities (m/s) between Jetty option no. 4 (J4), with two jetties, and BS for Spring tide - flood (left) - and Spring tide - ebb (right).

J5

Comparing the current velocity maps of option J5 (Figure 19) with BS (Figure 10), is possible to notice that between the jetties walls, in the straight part of navigation channel near the curvy part, the the current velocity increases by more than 15 cm/s during flood and ebb (Figure 20). Near the jetties head, the current velocity increases up to 40 cm/s during flood and increases up to 50 cm/s during ebb (Figure 20). Furthermore, no significant current velocity variations were observed near the estuary mouth and in the inner part of the estuary.

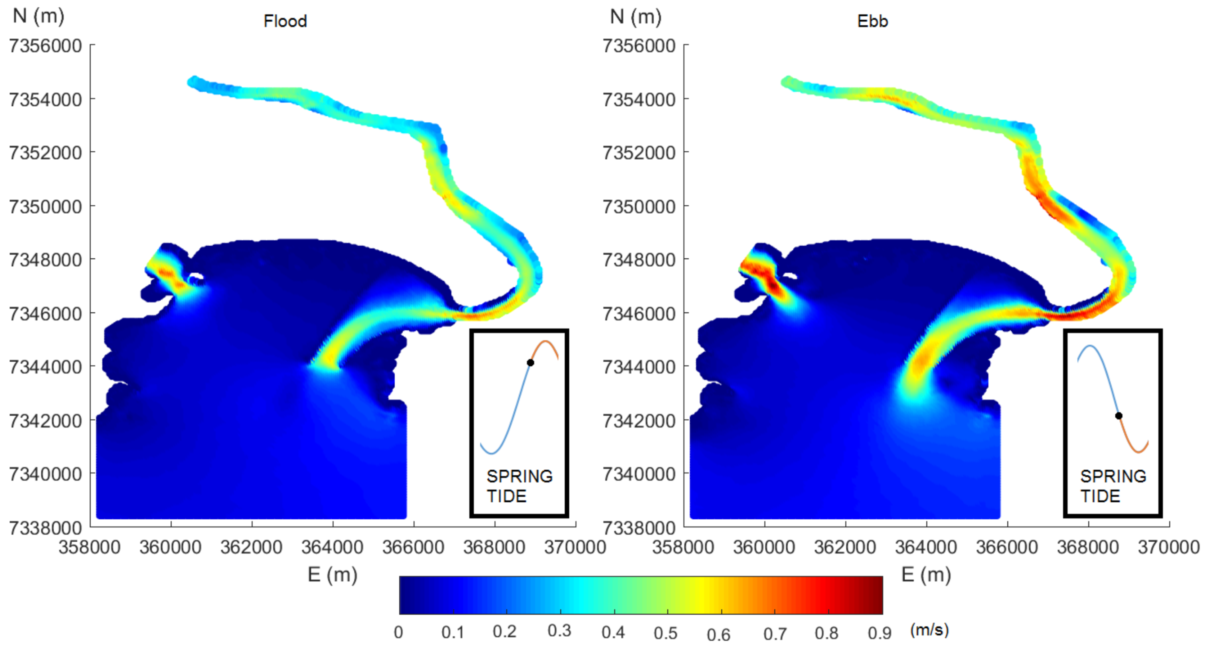

Figure 19: Currents velocities (m/s) maps of Jetty option no. 5 (J5), with two jetties, for Spring tide (flood) at at 14/3/06 4:18 (left) and Spring tide (ebb) at 15/3/06 9:40 (right).

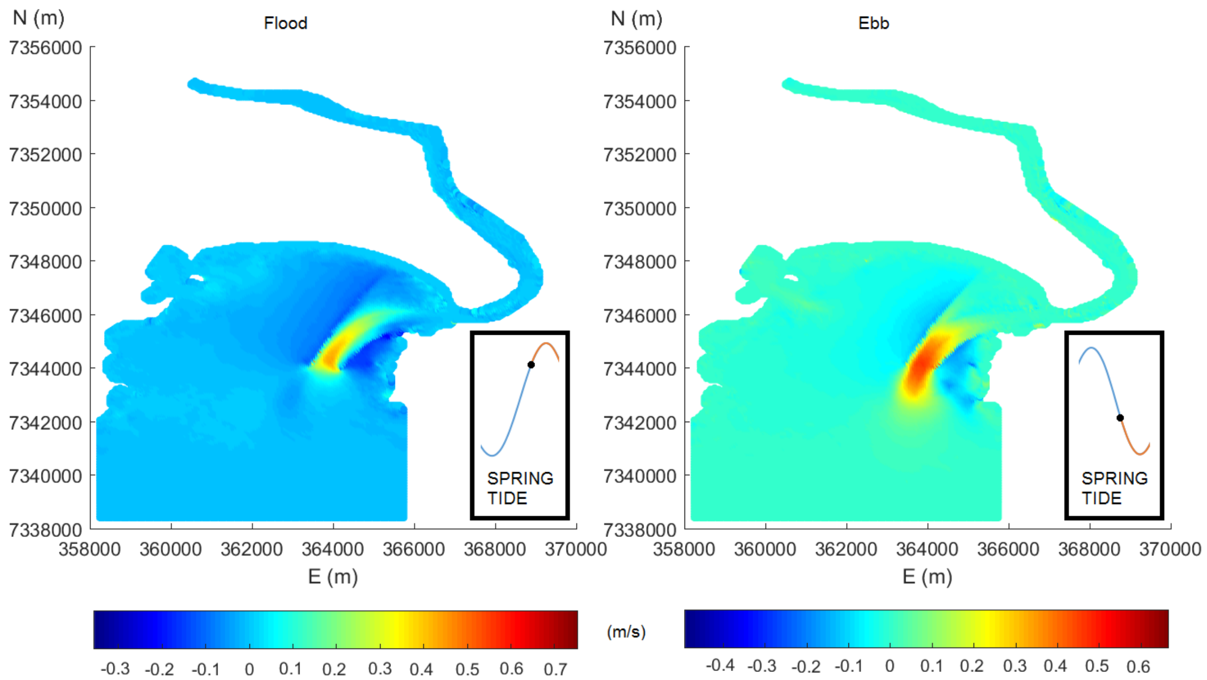

Figure 20: Maps with absolute difference of currents velocities (m/s) between Jetty option no. 5 (J5), with two jetties, and BS for Spring tide - flood (left) - and Spring tide - ebb (right).

DISCUSSIONS

Considering the critical siltation areas of Navigation Channel of Port of Santos defined by Carvalho (2016) (Figure 2) and the currents velocities variation of all five jetty options (Figures 12, 14, 16, 18 and 20), only Stretch 1 critical area would have its siltation softened. For all options, no significant current velocity variations were observed in the inner part of the estuary.

Among all options, J4 (two jetties with narrow channel) provides the highest velocity increment in Stretch 1, and its currents velocities increment area coincides with the siltation critical area in Stretch 1. Indeed, this observation is in accordance with Gireli et al. (2017) results. They have proposed jetties with similar geometry to J4, and the areas of current velocity increment are similar as well. Options J1 and J3 (with only one jetty in the right margin of Santos estuary) do not increase velocity significantly, while options J2 and J5 (two spaced jetties) provide considerable velocity increment in Stretch 1, but only in the straight area of Stretch 1.

Nevertheless, J4 reduces the currents velocities along Bay of Santos beaches, especially during flood. Magini et al. (2007) studied the circulation of currents in Bay of Santos before the deepening dredging (Phase 1). As shown in Figure 21, the Navigation Channel of Port of Santos induces currents alongshore and seawards (Magini et al., 2007). Therefore, the construction of J1, J2, J4 and J5 would block the longshore induced current in Bay of Santos, so the coastline morphology shall be studied too.

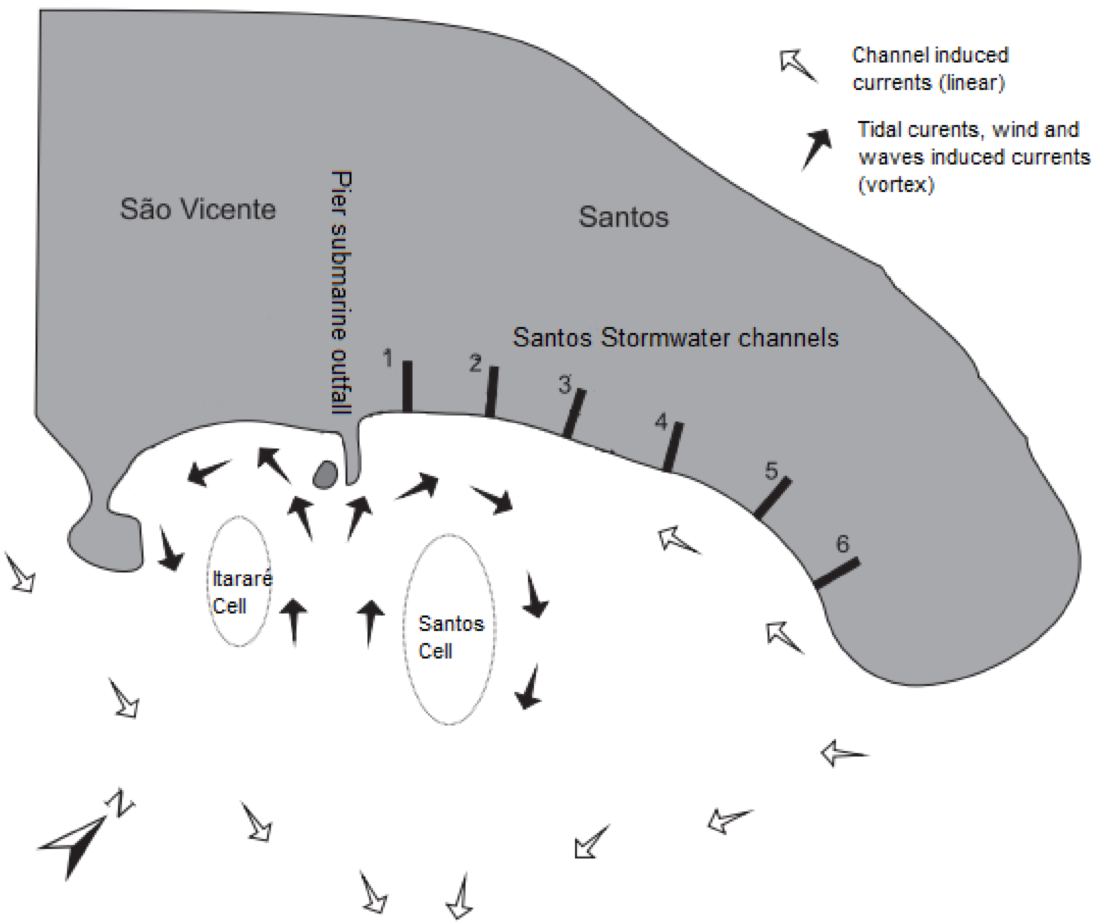

Figure 21: Currents pattern in Bay of Santos (Source: Adapted from Magini et al., 2007).

Moreover, this reduction in tide currents velocities in Bay of Santos combined with the blocking of the longshore current induced by Navigation Channel would reduce water renewal in the bay. According to Roversi et al. (2016), before the deepening dredging (Phase 1) the Bay of Santos used to take approximately 15 days to renew 95% of water. It is likely that the construction of jetties would increase the time required to renew water in bay of Santos.

Reis (1978), who simulated J1, J2, J3 and J4 in movable bed model, warned about the difficulty to discharge pollution in Bay of Santos with the construction of any of simulated options (J1, J2 and J3), and recommended an environment study on the combined impact of the submarine outfall (Figure 22) and the jetties. Therefore, another concern is the submarine outfall, which is 4 km long and discharges approximately 3 m³/s of sewage effluent in the bay of Santos (Gregorio, 2009). Further studies must be conducted to assess the combined impact of submarine outfall and jetties in the Bay of Santos pollution.

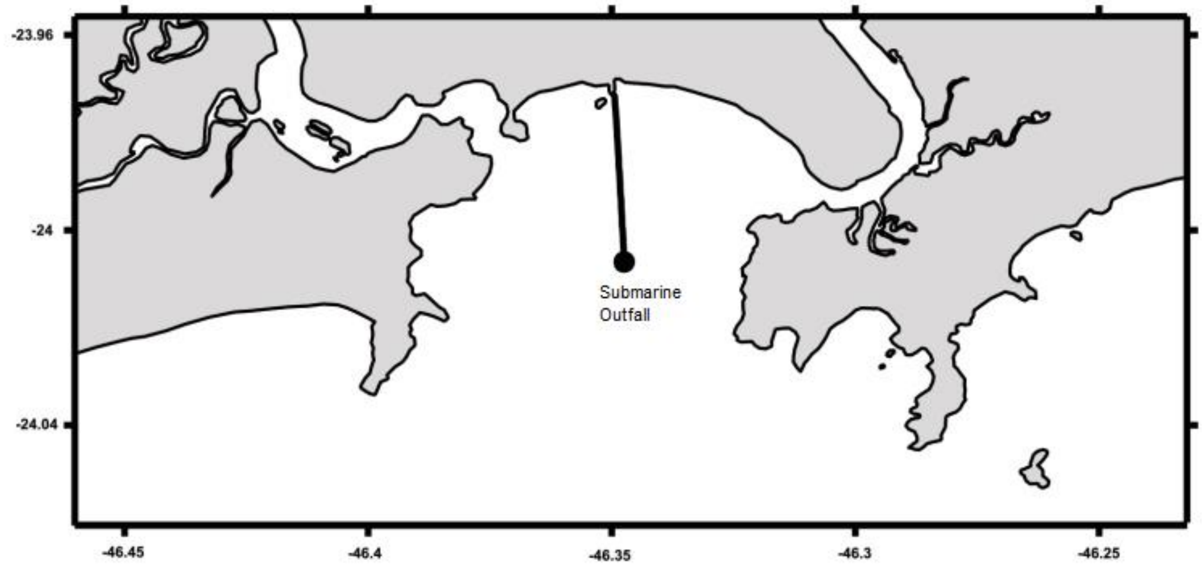

Figure 22: Location of Santos' Submarine Outfall (Source: Adapted from Gregorio, 2009).

None of previous studies that proposed jetties for Santos (Reis, 1978; Alfredini et al., 2013; Gireli et al. 2017) assessed the impact of these structures in coastline morphology, sediment transport, currents circulation, wave height, refraction and diffraction, water renewal, or water quality. The objective of these studies was strictly the evaluation of currents velocity variation. Moreover, the lack of updated bathymetric data in Bay of Santos, and the unequal distribution of tide gauges and flow measurement stations in the region give insufficient field data to validate Bay of Santos area results in hydrodynamic models.

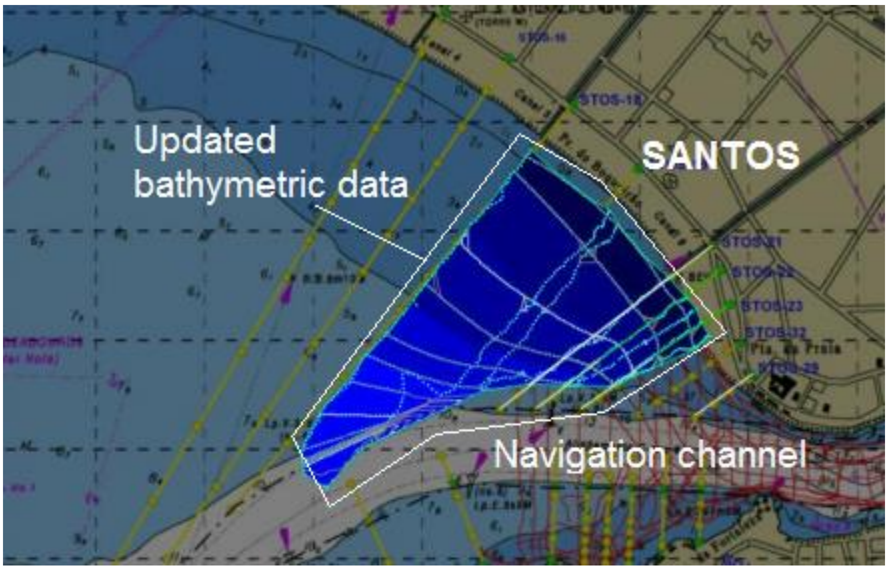

Figure 23: Updated bathymetry polygon near *Ponta da Praia* beach (Source: Adapted from Venancio, 2018).

According to Garcia et al. (2002), Bay of Santos last bathymetry dates back from 1982, since then only Port of Santos Navigation channel has been updated. Simulations with minor bathymetric updates near the northeastern beach *Ponta da Praia* (Figure 23), which currently is under an erosion process, have identified soft induced vortex currents between the beach and the curvy area of Stretch 1 (Venancio, 2018). This result is in accordance with FUNDESPA (2014), which measured residual longshore sediment budget in Bay of Santos. Moreover, all the permanent tide gauges are located along Navigation Channel of Port of Santos (Figure 6).

CONCLUSIONS

In order to become a hub port in South America, Port of Santos intends to deepen and widen its Navigation Channel to support New Panamax vessels. Some authors proposed jetties geometries and evaluated the variation of currents velocities along Navigation Channel of Port of Santos.

Hydrodynamic model results show that options with one jetty (J1 and J3) do not increase the velocity significantly, and options with two spaced jetties (J2 and J5) provide considerable velocity increment in the straight part of Stretch 1, which is only part of a critical siltation area. Only options with two jetties with narrow channel (J4) provide velocity increment in the critical siltation area of Stretch 1. However, considering that Stretches 2, 3, and 4 mean monthly siltation volume is 293,066 cubic meters (54.10% of total volume, as shown in Table 3) and that the jetties would only soften siltation in Stretch 1, even with the construction of J4 the monthly dredged volume along Navigation Channel would still huge. Thus, the construction of jetties alone would not allow Port of Santos to become a hub Port.

Hence, the chosen option must seek balance between low impact in Santos Bay beaches, water renewal, sediment transport, wave regime, and depth maintenance in Navigation Channel of Port of Santos. The option J4, if implemented, would block the longshore induced current in Bay of Santos, which is an important tide current for sediment dynamics in Bay of Santos. Moreover, it is likely that the construction of jetties would increase the time required to renew water in bay of Santos.

Field data in Bay of Santos are outdated, and tide gauges and flow stations are concentrated in Port of Santos Navigation Channel. Thus, before the implementation of any jetty option is highly recommended a comprehensive field data collection that includes currents measurements and tide gauge stations in different location of Bay of Santos, updates in Bay of Santos bathymetric data, and measurements of sediment budget. Moreover, a suitable Environmental Impact Assessment must include all beaches in the Direct Impact Area, because the construction of jetties changes wave refraction and diffraction, which impacts coastline morphology. Also, a sediment transport model should be used to evaluate new siltation trends along the Navigation Channel of Port of Santos, and alongshore.

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