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D2.3 – Calibration of the hydrodynamic model for the Santos Estuary

Ramiro Neves, PhD.
MARETEC — Marine & Environment Technology Center
Instituto Superior Técnico
Secção de Ambiente e Energia — Dep. De Mecânica

Avenida Rovisco Pais
1049 - 001 Lisboa PORTUGAL
Tel: (+351) 218 417 397
Fax: (+351) 218 419 423

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1 Introduction

This report aims to describe the main processes that drive the hydrodynamics of the Santos Estuary (SP, Brazil) and its coastal zone. Due to the well marked differences between the processes inside the estuary and outside, in the coastal zone, each of these areas is treated separately.

The report starts with a description of the estuary and its location. Afterwards, a short description of the conceptual model is presented, where processes that drive the circulation are depicted.

In the next chapter, data is analyzed and the processes described in the conceptual model are illustrated. This analysis in divided in two: (1) focus on the coastal zone of Santos and (2) focus on the inside of the Santos Estuary.

Based on the conceptual model, the hydrodynamic model was implemented for the estuary. The MOHID system (www.mohid.com) was used, as described in the Technical Annex of the contract. This modeling system was originally developed at Instituto Superior Técnico. The MOHID modeling system allows the adoption of an integrated modeling philosophy, not only of processes (physical and biogeochemical), but also of different scales (allowing the use of nested models) and systems (estuaries and watersheds), due to the adoption of an object oriented programming philosophy.

The validation of the model was made using sea level and current data measured in several different places of the estuary. The mesh of the implemented model has about 20000 computational points and spatial steps between 100 and 400 m.

2 Santos Estuary

2.1 General remarks

The Santos Estuary, in Brazil (**Figure 1**), is a highly changed ecosystem, after 500 years of urban, industrial and port use (it's the biggest port in Latin America with an annual movement of cargo in 2004 around $70x10^6$ ton). It has extensive areas of mangrove, partially degraded. Nevertheless, there are still some well preserved areas and the region is an important tourism area for the population of São Paulo. It is located roughly at 24º S latitude.

Figure 1 – Santos Estuary

Sea access to the Santos Port is through a dredged channel, with project drafts ranging from 14 m in the outside access channel, to 12 m in the innermost part the estuary. The maintenance of these depths is done with dredging services and the mud is deposited outside of the estuary.

The estuary receives the flow from several small rivers that develop on the slopes of Serra do Mar, at hights of 700 m. These rivers regime have average flows between a few and some tens of cubic meters per second.

Mangroves play an important role in the biotic and the abiotic environment of the estuary. They span over vast areas of the estuary, as can be seen in the satellite picture of Figure 1. Mangroves have an area of approximately 120 km², part of which degraded due to anthropogenic activities. These mangroves are also important deposits of sediments originated in the watershed.

2.2 Sea Level.

Sea level data are the most important element for the estuary model calibration. The most significant available data are presented in Table 1. An example of the sea level variation is presented in Figure 2. The existence of two important forcing mechanisms can be seen in the sea level data: the characteristic variation due to astronomical tide and atmospheric forced events with time scales that vary between 4 and 8 days. The sum of these two forcing mechanisms create the sea level variation that in turn force the water flow in and out of the estuary

The scale of these forcing mechanisms is much larger than the area of interest to the present study. Therefore, these are considered as boundary conditions to local models. With respect to the calibration of the model, the astronomical tide will be the most used in the comparisons due to its predictability and to the set of data available.

Table 1 - Available sea level measurements in Santos

Author	Period	Frequency	Location	Comments
Instituto Nacional de Pesquisas Hidroviárias – INPH	1/7/76 to 17/12/76	Hourly	Ilha das Palmas, Clube de Pesca, Torre Grande, Base Aérea, Ilha Barnabé, Cosipa, Tumiaru, Casqueiro.	There are some doubts on the time reference of the gauges.
SONDOTÉCNICA	23/8/76 to 26/8/76	Five minutes	Ilha das Palmas, Clube de Pesca, Torre Grande, Base Aérea, Ilha Barnabé, Cosipa, Tumiaru, Casqueiro.	
Companhia Docas de Santos	1944 to 1989	Hourly	Torre Grande	
Instituto Nacional de Pesquisas Hidroviárias - INPH	12/3/73 to 3/4/73	Five minutes	Ilha das Palmas, Ponte Club Pesca, Club Tumiaru, Cosipa	

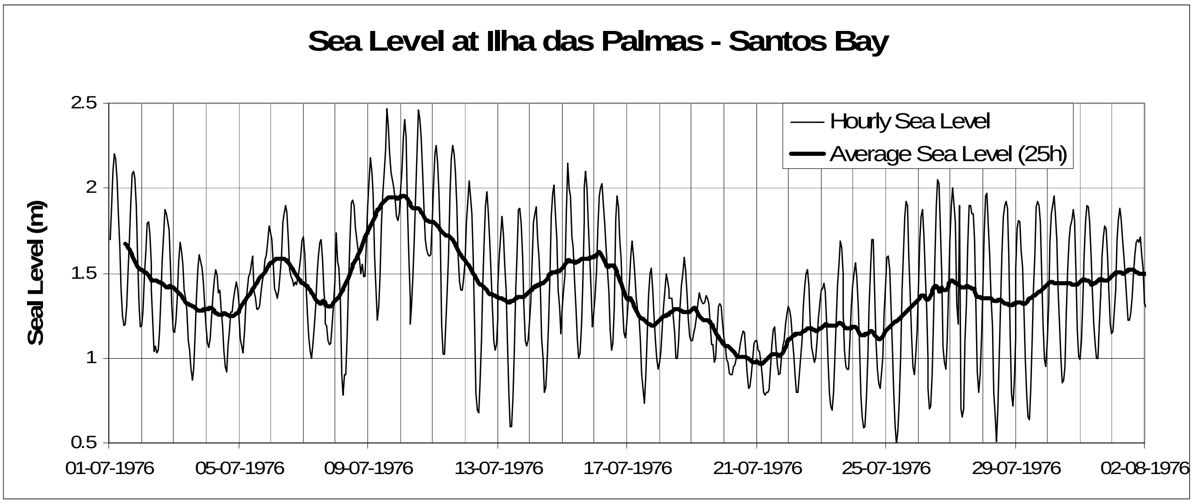


Figure 2 – Hourly and 25h average of sea level measurements in Ilha das Palmas, in the bay of Santos

Due to some doubts on the time reference of the sea level measures done between 1/7/76 and 17/12/76, a set of measurements were done by SONDOTÉCNICA from 23/8/76 to 26/8/1976, specifically to investigate the changes in tidal amplitude and phase along the estuary. The measures were taken around spring tide conditions and the reference tidal station was at Ilha das Palmas.

These variations were computed and are described in Table 2 and Table 3. These differences show that:

- Tidal amplitudes at Torre Grande, Base Aérea, Ilha Barnabé, COSIPA and Casqueiro are equal or 10% greater than those at Ilha das Palmas;
- Tidal amplitudes at Clube de Pesca and at Tumiaru are equal or less than those at Ilha das Palmas;
- Tidal phase increases as a function of the distance to Ilha das Palmas.

Table 2 – Tidal Phase differences (High and low water average) along the estuary (values in minutes with reference to Ilha das Palmas)

DATA	I. Palmas	C. Pesca	T. Grande	B. Aérea	I. Barnabé	COSIPA	Tumiaru	Casqueiro
23/8/76	0	10	15	37	40	63	10	35
25/8/76	0	10	20	30	32	50	15	50
26/8/76	0	10	25	30	40	55	25	50
Average	0	10	20	32	36	56	16	45

Table 3 – Tidal amplitudes along the estuary (values in metre)

DATA	I. Palmas	C. Pesca	T. Grande	B. Aérea	I. Barnabé	COSIPA	Tumiaru	Casqueiro
23/8/76	1.36	1.26	1.37	1.38	1.36	1.38	1.04	1.38
25/8/76	1.58	1.52	1.60	1.76	1.66	1.76	1.54	1.54
26/8/76	1.47	1.48	1.54	1.62	1.55	1.62	1.47	1.51
Average	1.50	1.39	1.56	1.62	1.55	1.62	1.39	1.51

3 Conceptual model

Transport processes inside the estuarine system of Santos are mainly controlled by sea level where tide (with a maximum amplitude around 1.5m) and meteorological effects outside the estuary are the most important components (the average sea level may vary more than 1 m due to those meteorological effects).

In the coastal zone of São Paulo, outside the estuary, the dynamics of sub-inertial atmospheric forced events is dominant, with time scales that vary between 4 and 8 days (see Figure 2). The variation of sea level induced by those events adds to the astronomical tide creating a sea level variation that forces the water in and out of the estuary.

Due to those forcing mechanisms, there is a distinct difference in the hydrodynamics inside and outside the estuary:

Inside the estuary, the variability is dominated by the astronomical tide, although in neap tide the outside level variation induced by remote or local metheorological may be important. The intensity of the currents in the estuary is a balance between the bottom shear stress and the sea level gradient. The meteorological induced level variation outside the estuary manifests itself inside the estuary mainly in the form of a variation in the mean sea level (due to the time scale of this mechanism), on top of which the astronomical tide evolves. This meteorological induced variation in the mean sea level (that may be up to one metre) indirectly changes the force balance inside the estuary and, hence, the currents (mainly in the shallower mangrove areas). The main exchanges between the upper zone of the estuary and the outside are through the Porto Channel (between Ponta da Praia and Ilha Barnabé).

In the coastal zone, the astronomical tide has a minor influence in the hydrodynamics when compared to the remote and local meteorological induced effects. For 20 m depth, outside the estuary, there are frequent records of 50 cm/s currents in the whole water column, associated to the sub-inertial level perturbation. Castro e Lee (1995) have put forward the hypothesis that this sub-inertial perturbation, detected in the sea level records in Ilha das Palmas, is generated further South, in the Atlantic, by the action of the wind and tends to propagate North in the form of a continental shelf wave. This kind of waves has an exponential decay of the sea level, perpendicular to the coast, with the maximum level near the coast. The level gradient is balanced by the coriolis force, resulting in currents parallel to the coast and strongly correlated tho the mentioned sub-inertial oscillations. The direct action of the wind is only important for local hydrodynamics during very strong wind episodes, which are not very frequent.

4 Modeling setup

4.1 Introduction

The hydrodynamic modeling of the Santos Estuary was done with the MOHID system (www.mohid.com). The main objective of this model setup is to support the transport processes required by the water quality and ecological model.

The previously defined conceptual model showed that sea level variation, and namely tide, is the main forcing mechanism of the hydrodynamics. Therefore, this was also the main forcing used to calibrate de model. A 2D barotropic approach was used to calibrate the model once the estuary is well mixed most of the time.

4.2 Bathymetry

Water circulation in an estuary is controlled by its geometry. Therefore, the bathymetric information is the most important one for the setup of the model. In the case of the Santos Estuary, several hydrographic and topographic charts were digitized to get a set of bathymetric points and the land contour.

The charts and other depth related information that was used were:

- Hydrographic charts N. 1701 and 1711 from Brazilian Navy (scales 1/15000, 1/23000 and 1/80000);
- Several hydrographic surveys from 1996 made available by Companhia Docas de Santos (scale 1/5000);
- Topographic charts from the *Baixada Santista* area produced by IGBE at the scale of 1/50000 (Ns. SF.23-Y-D-IV-3 / SG.23-V-B-I-1 / MI-2794-3 / MI-2815-1);
- Environment chart of Baixada Santista produced by CETESB at the scale of 1/50000;
- A new set of soundings gathered during this project.

The gaps detected in some areas of the estuarine system were filled using the knowledge of the area. The west area of the Estuary (Canal de S. Vicente and adjoining areas) is the least known in term of depth, once it is not used for navigation.

The computation of depth in each cell of the mesh is obtained by triangulation using the points defined with the digitalization of the charts. The mesh has variable cell dimensions in both directions and the smallest cells have 100*100m^2. Therefore, the detail that is expected to be solved in the model is of that order of magnitude or larger. As characteristic dimensions of particularities in the bathymetry (mainly channel's width) get smaller then 100 m, they disappear in the mesh. On the opposite side, as characteristic dimensions inside the estuary get bigger then 100 m, they are better represented in the mesh. For that reason, variable cell size was used to shorten the computation time, while keeping the main features of the bathymetry.

The model results for tidal propagation inside the estuary also induced corrections in the bathymetry of the model in places where tidal amplitude or phase was wrong. This is therefore an iterative procedure between calibration and mesh setup.

Some examples of corrections that had to be done in the bathymetry of the model are:

- Channels with widths of the order of the local cell sizes had to be manually corrected to guarantee water flow. Also, in areas where depth information is scarce or bellow the local mesh resolution (i.e., mangrove areas, roads, hydraulic connections), manual correction of cell's depths was made;
- To keep the water flow as it should through a set of rectangles that represent a 3D continuum bathymetry, in some places the channel's transversal area was evaluated and the depth of the cells was corrected so that this area would remain the same in the model as it is in the Estuary;
- Scarcity of bathymetric information some times generates plateaus in the mesh (large areas with the same depth), which are not real and must be corrected giving the area more or less gentle slopes and, eventually, drainage channels.

One of the difficult problems with bathymetric information is that it is necessary to use information from different sources and time references (it is common in hydrographic charts). This difference is not easy to relate to tidal characteristics measured in precise dates (as was presented in earlier sections). For instance, the available bathymetric information was not all for the year of 1976, when the most extensive set of sea level measures was made. The same applies to currents measurements. The main point result of this is that calibration must be done cautiously (this topic will be further developed in the later sections).

The bathymetry of the model is made of 137x147 points, with variable spatial steps of 100 to 400 m and an output of the bathymetry used in the calibration of the model is presented in Figure 3.

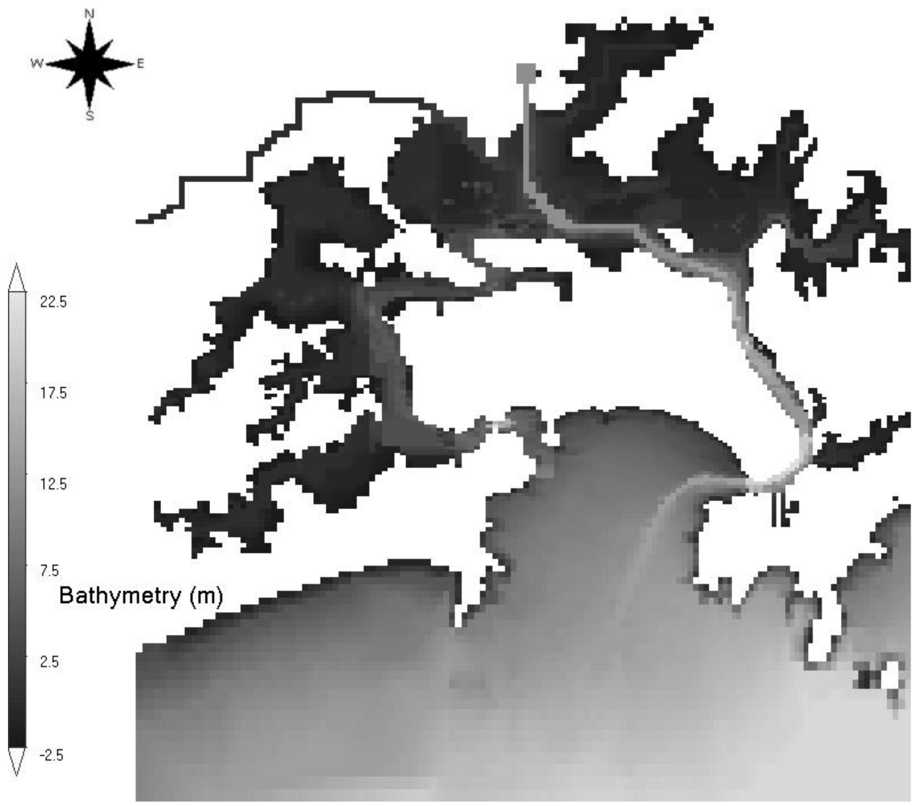


Figure 3 - Bathymetry used in the calibration phase

4.3 Boundary conditions

The boundary conditions for the model were tidal harmonics in the sea boundary and river flow in the land boundary.

The tidal harmonics were computed for a tidal gage in the Bay of Santos (Ilha das Palmas). The components were imposed with a phase lag in order to have a good match between the computed sea level and the measured sea level in Ilha das Palmas. The average sea level used was 1.4 m, which was obtained with the same measures used to compute the tidal harmonics.

A manning coefficient of 0.02 was used for the bottom shear stress parameterization.

5 Calibration

5.1 Introduction

5.2 Sea level

The calibration of the Santos Estuary hydrodynamic model was made using mainly the measures presented in SONDOTÉCNICA, 1977. Measured sea level heights (synthesized from the harmonic constituents of the each tidal gauge) were compared against model results.

Figure 4 – Tidal gauges location

To obtain the synthesized sea level in each location of the tidal gauges, a specific program, based on CALDWELL, 1991, was used. 36 harmonic constituents for each location were calculated based on 5 months of hourly measures.

As expected, in Ilha das Palmas the comparison is excellent (Figure 5). In Clube de Pesca, at the entrance of the Port's main channel, the comparison shows a good agreement, with some differences in the amplitude and phase (Figure 6). At Base Aérea and Ilha Barnabé, Figure 7 and Figure 8, computed tidal amplitude is, respectively, slightly bigger and slightly smaller than the ones resulting from the measures. Once both locations are quite close to each other, the model results seem to be more plausible than the measured ones. It is noticeable in both places that there is a good agreement in phase of the two comparisons.

The results in COSIPA have some noticeable differences in phase and amplitude. This must be due to the influence of the vast intertidal mangrove area of the innermost part of the estuary, where bathymetric information is of very poor quality.

In the West part of the Estuary, although there are some lacks of bathymetric information, the results that are shown in Figure 10 and Figure 11 show a very good agreement between model results and measures.

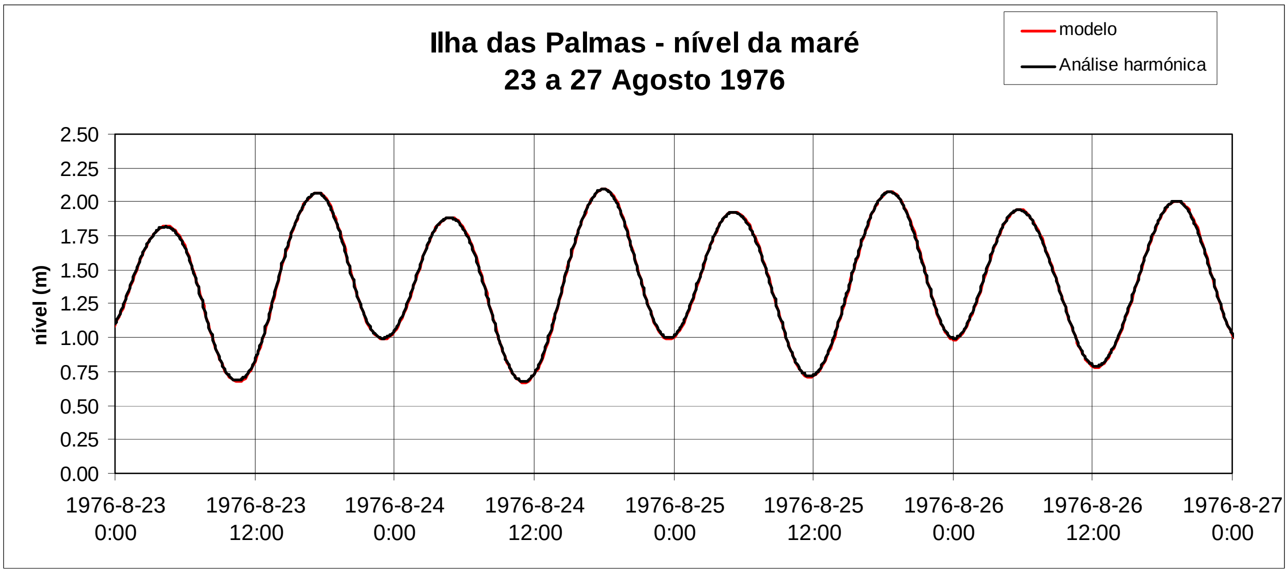


Figure 5 – Comparison of sea level height at Ilha das Palmas

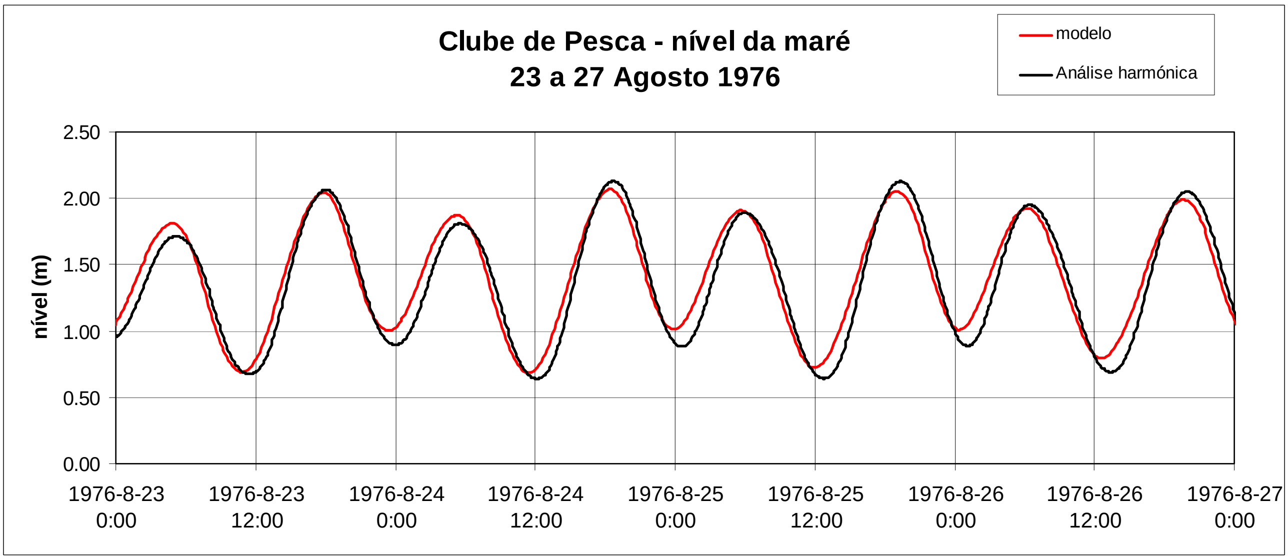


Figure 6 - Comparison of sea level height at Clube de Pesca

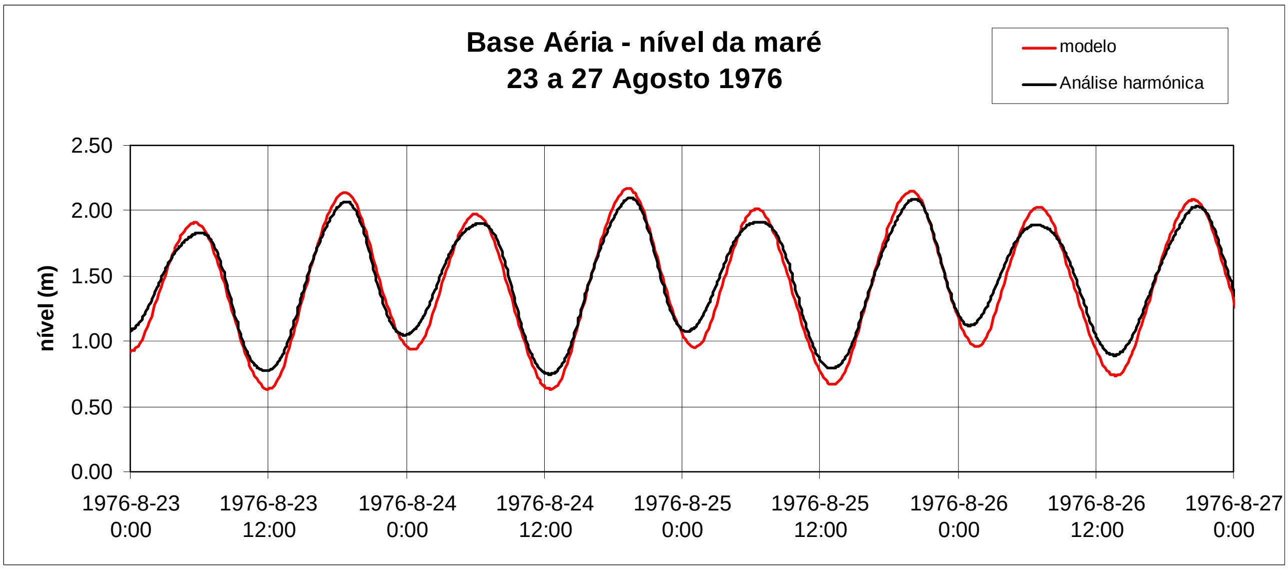


Figure 7 - Comparison of sea level height at Base Aérea

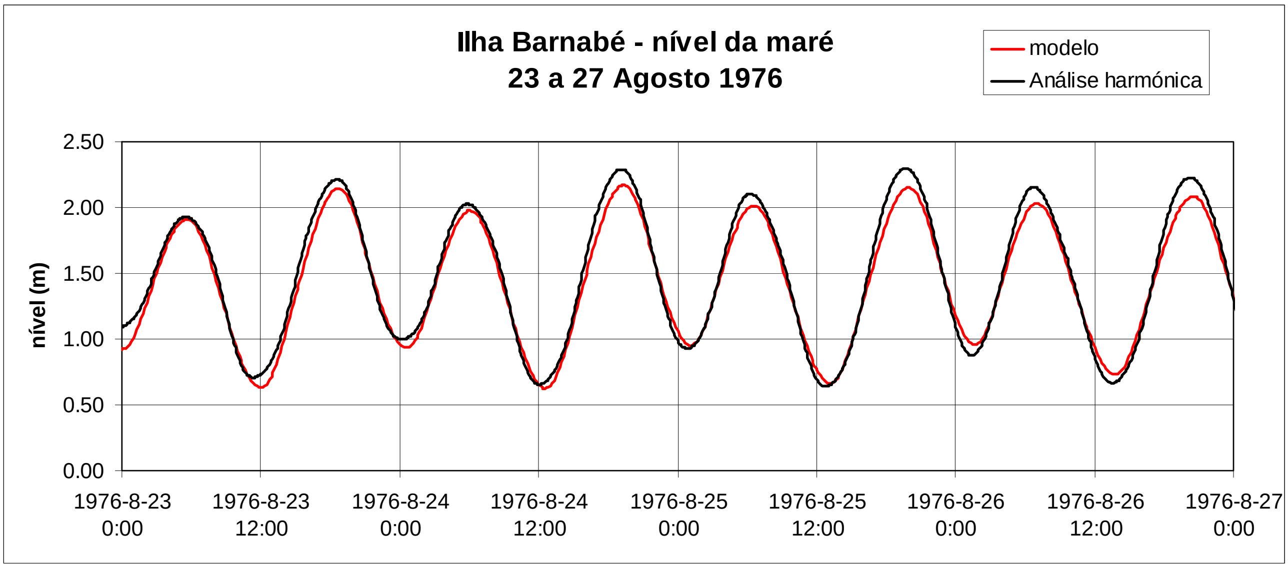


Figure 8 - Comparison of sea level height at Ilha Barnabé

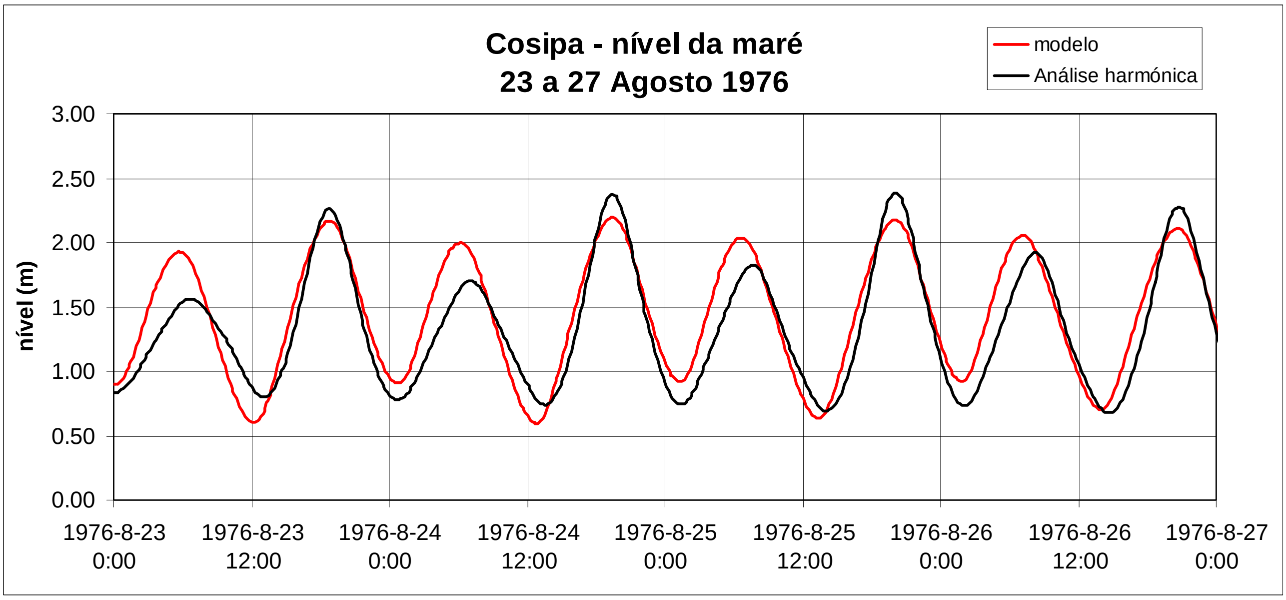


Figure 9 - Comparison of sea level height at Cosipa

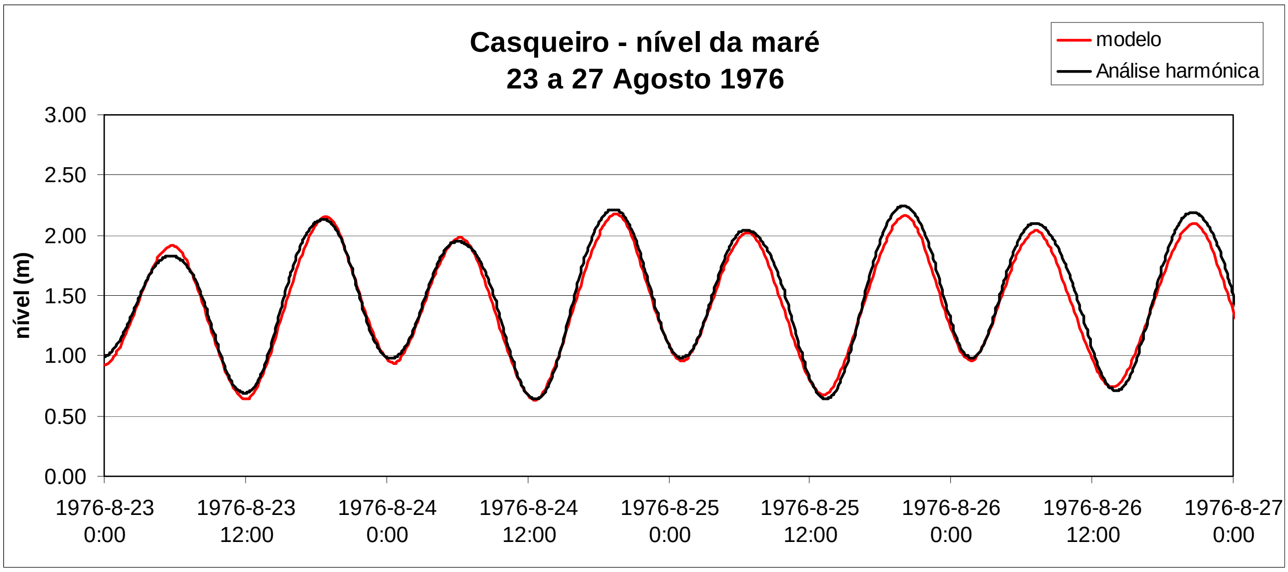


Figure 10 - Comparison of sea level height at Casqueiro

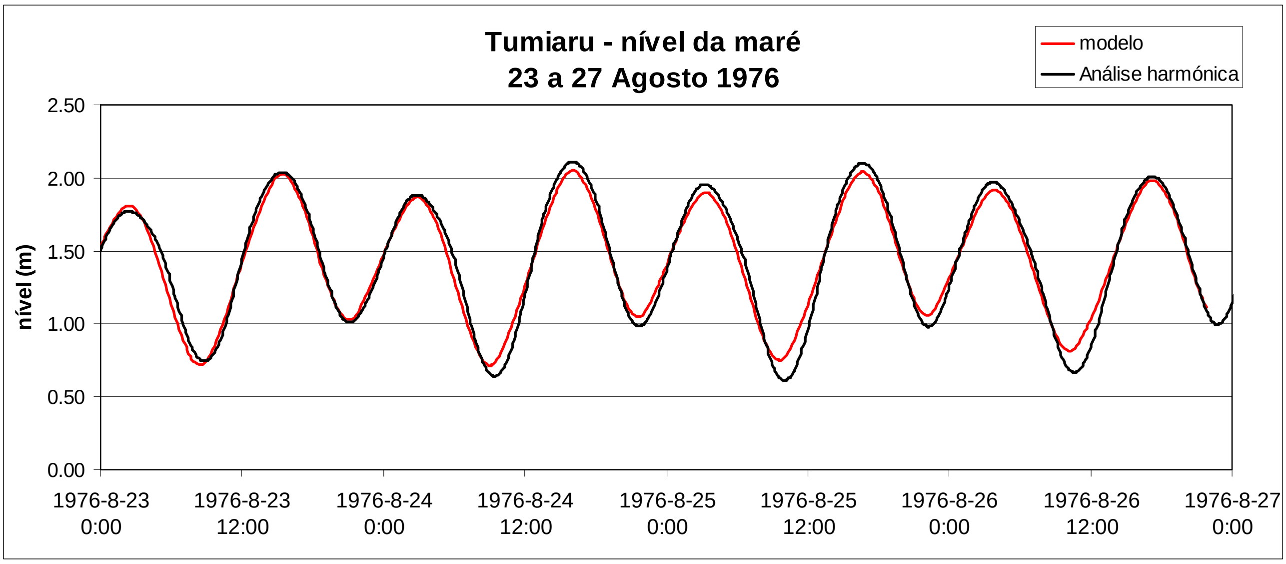


Figure 11 - Comparison of sea level height at Tumiaru

In Figure 12 the changes on amplitude and phase of the tide, as it propagates inside the estuary can be seen. As the sea level in the boundary was forced using synthesized sea level data from the tidal harmonics, average tidal amplitude computed during the simulation is lower than the average measured values. Nevertheless, the most important result is that the increase/decrease tendencies are present, except for the "Clube de Pesca" station.

The phase comparison is also quite good once the simulated average phase delays are quite similar to the measured values (see Figure 12).

5.3 Currents

The currents validation was made using measures made by "Directoria de Hidrografia e Navegação" from the Brazilian Navy inside the estuary and in the Bay, near the entrance of the main channel (Figure 13).

When comparing velocities, it must be taken into account that the velocity in nature may have large variations in space (horizontally and vertically), mainly in places like the channels of the Santos Estuary. Therefore, care must be taken when a velocity computed by the model (which is an average in the 3D space) is compared with field measures. In the specific case of the channel of Santos Estuary, cells of the model inside the main channel have dimensions close to 100x100 m^2. Horizontal velocity gradients below these spatial scales are not solved by the model. The same for vertical gradients, once the model was applied with just one layer in the vertical.

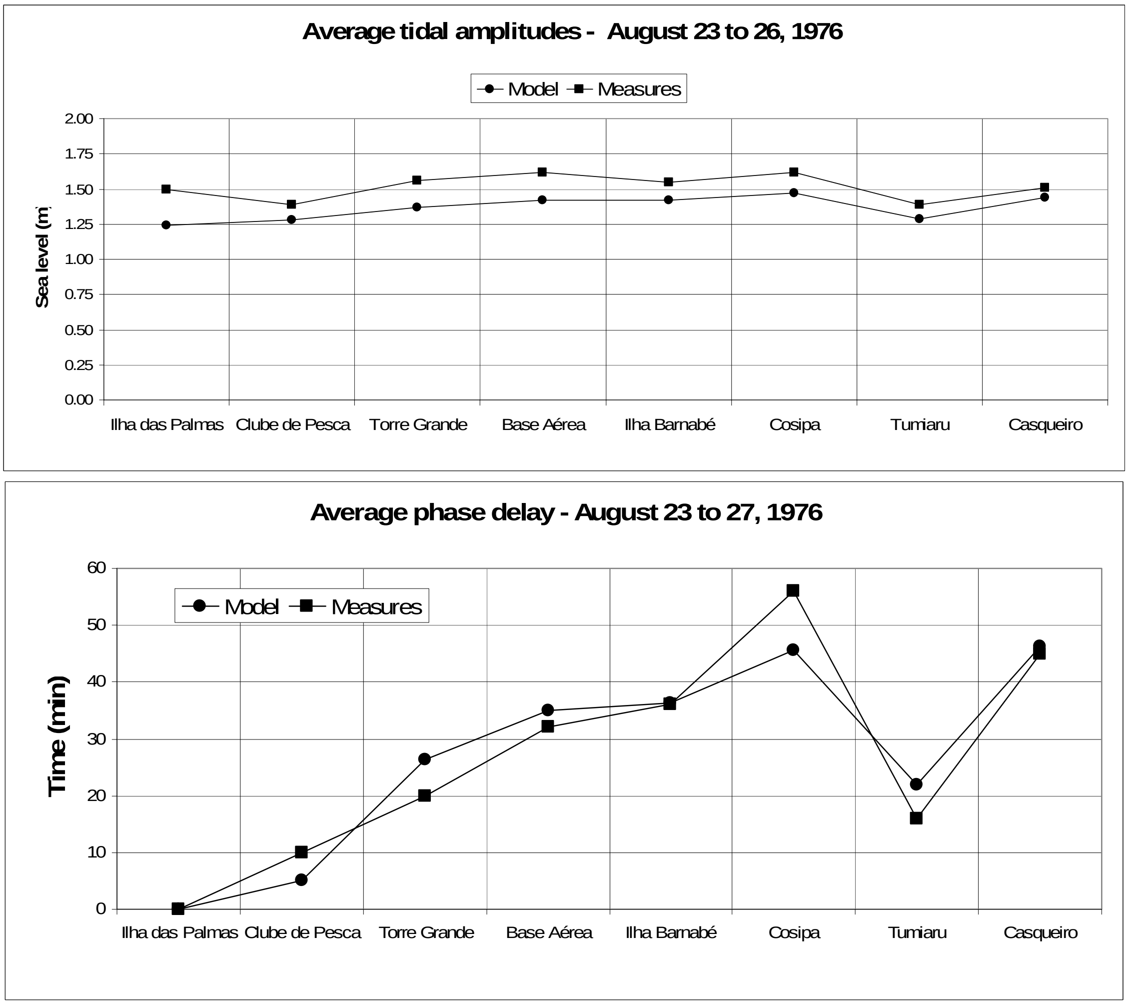


Figure 12 - Tidal amplitude and phase variation along the estuary

A comparison between model results and measures can be seen in Figure 14 and Figure 15. Taking into account the previous considerations, this comparison shows a reasonable approach between the measures and the simulations. In the first comparison (Figure 14), currents computed by the model are a bit higher that the measures. In the second period (Figure 15), values are quite similar.

In Figure 16 results are shown for a different location in the Port Channel (near Torre Grande). For this place, the time interval is larger. The results show good agreement for both the velocity and the direction of the currents. The model results are a bit higher for some tidal cycles. Measured values are much more irregular due to the influence of meteorological effects on the estuary's hydrodynamics. Model results are much more regular once they are driven only by tidal circulation.

In the Bay of Santos, the comparison is also reasonable (Figure 17). In the measures there are some evidences of different directions of currents at different depths. These must be due to the existence of density effects of the water flowing in and out of the inner part of the estuary. When lower density water flows out of the channel, into the bay, more dense water will start to flow in, during flood, preferably near the bottom. This may generate a stratified flow, with different directions, for some periods, which is increased in the case of higher values of fresh water input in the upper part of the estuary. These considerations explain why there are some periods with good comparisons and others which are not so good.

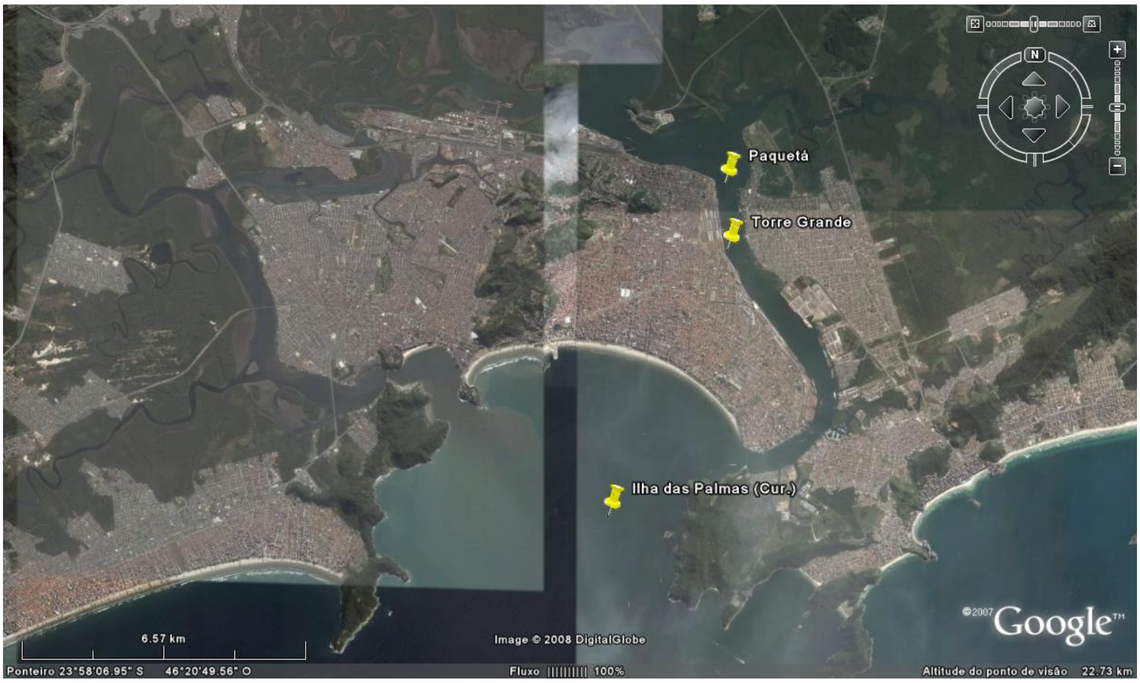


Figure 13 - Current measurements

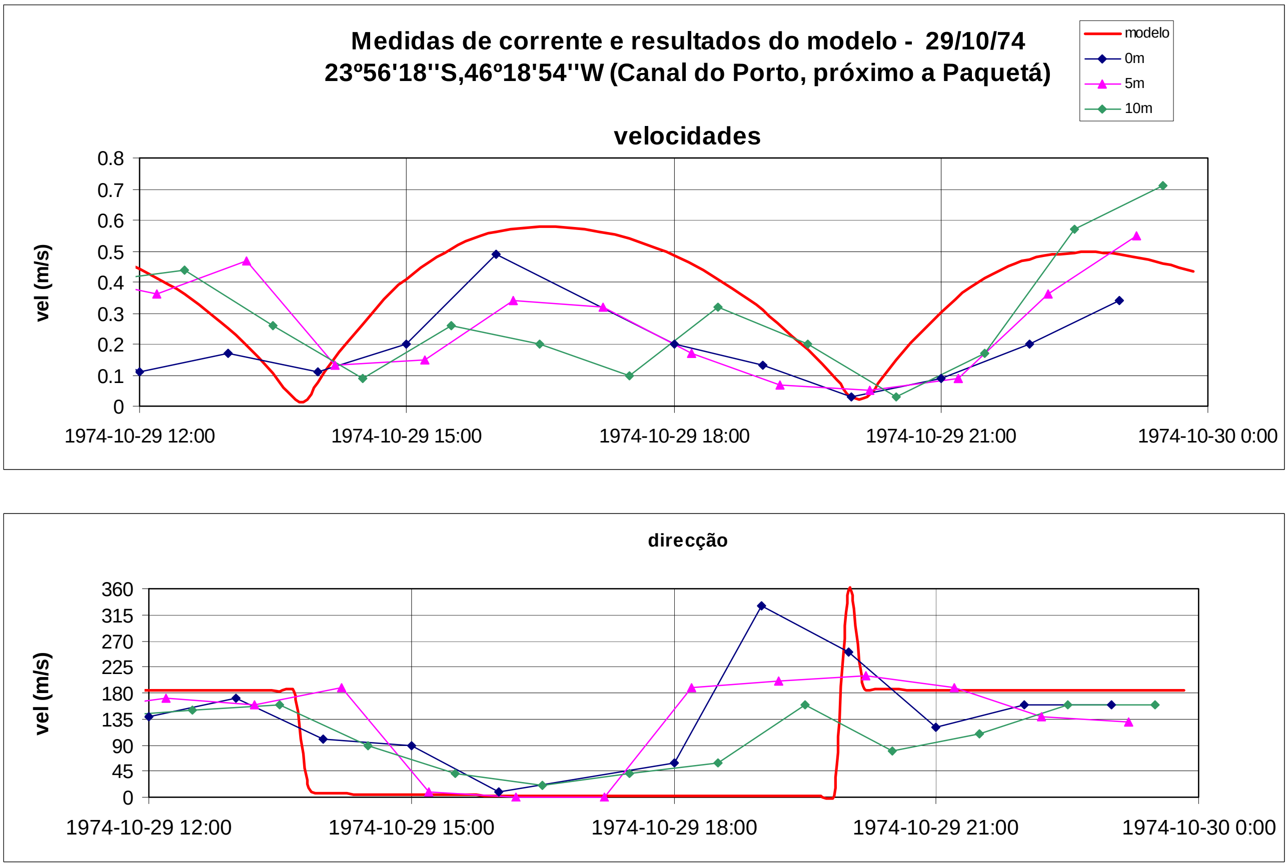
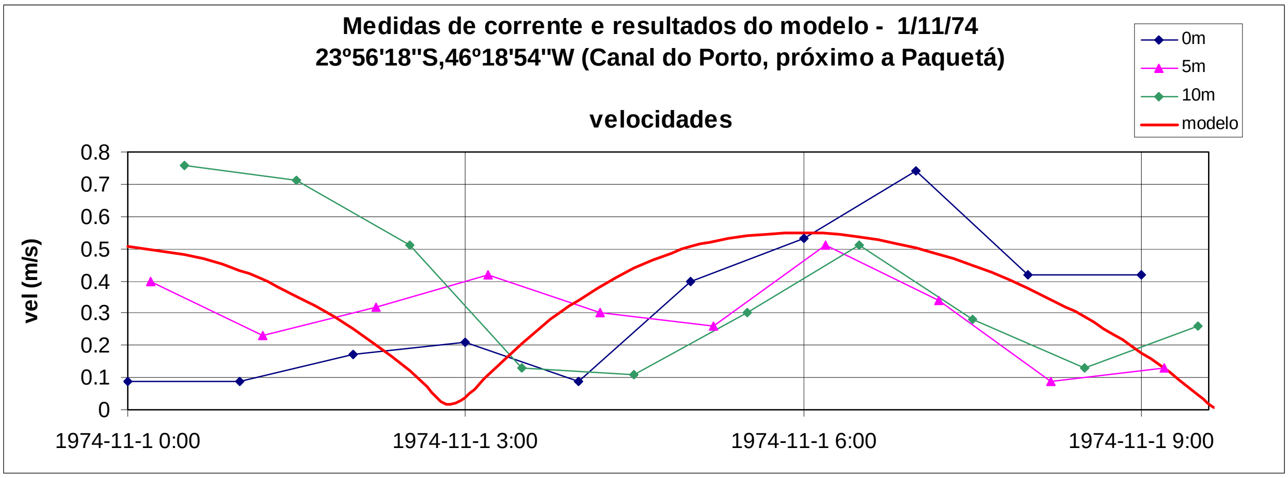


Figure 14 – Comparison between measures and model results for currents on the Port Channel near Paquetá (23º56'18''S,46º18'54''W)



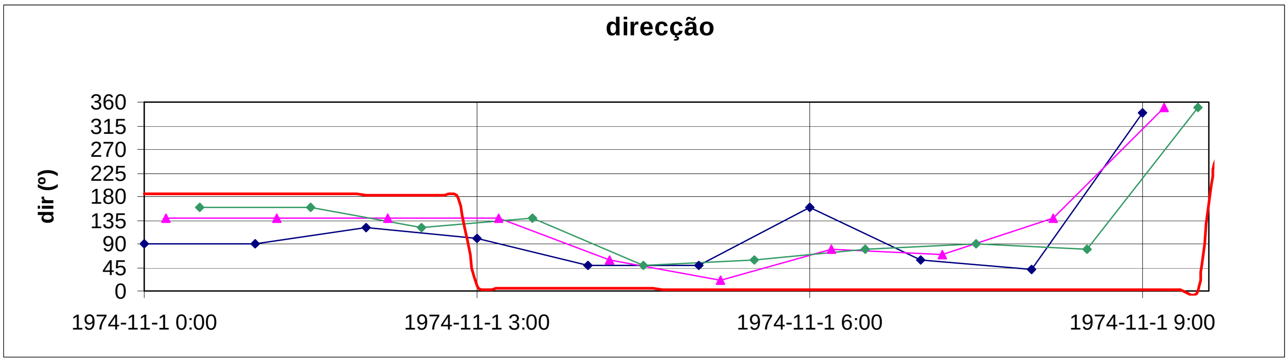


Figure 15 - – Comparison between measures and model results for currents on the Port Channel near Paquetá (23º56'18''S,46º18'54''W)

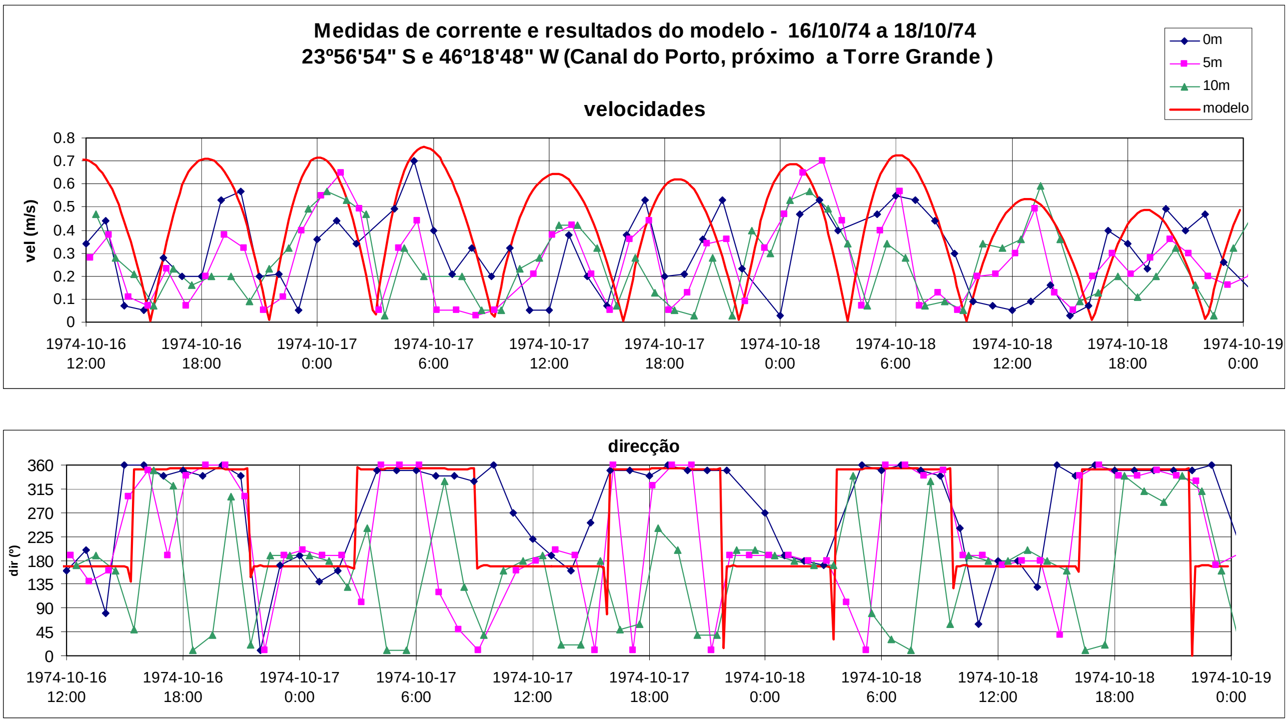


Figure 16 - Comparison between measures and model results for currents on the Port Channel near Torre Grande (23º56'54" S e 46º18'48" W)

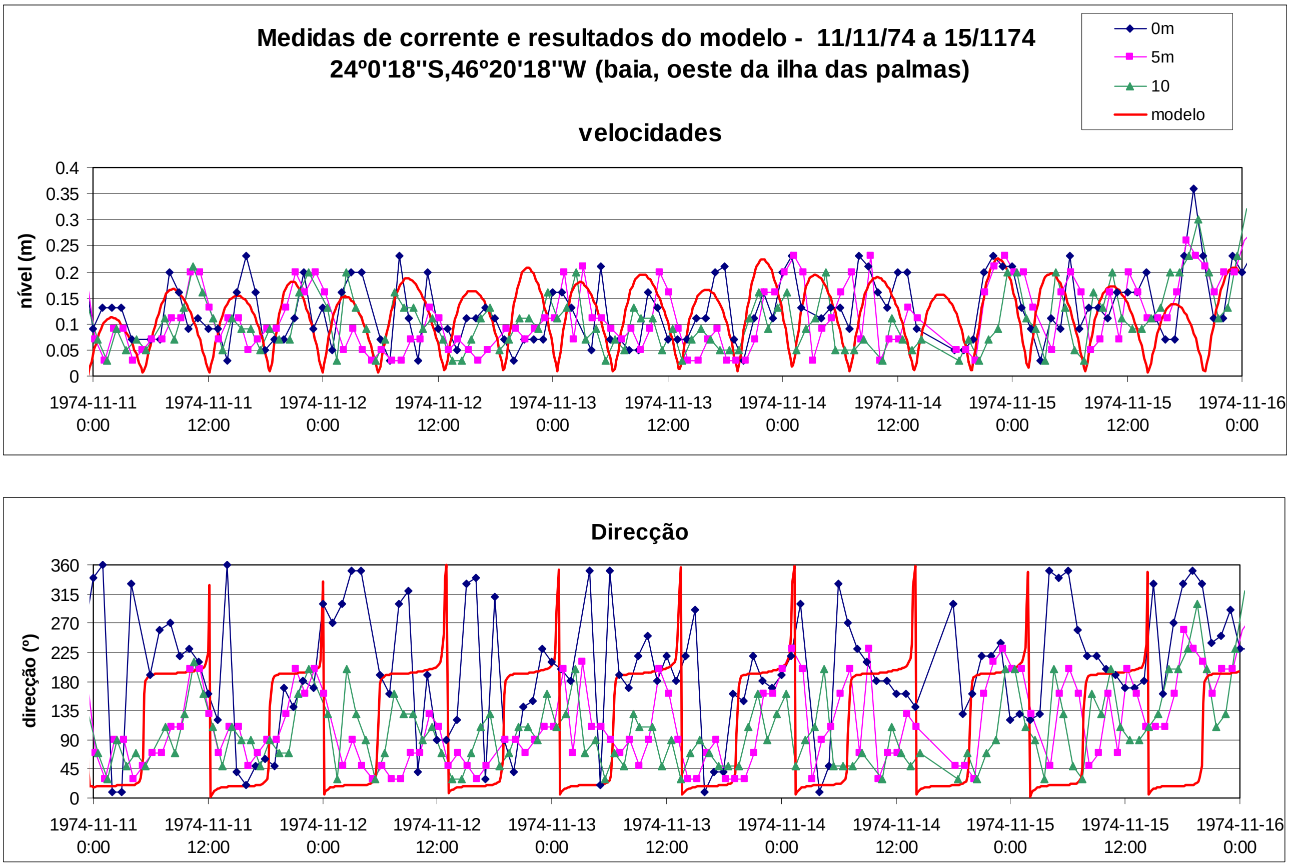


Figure 17 - Comparison between measures and model results for currents on Santos Bay, west of the Palmas Island (24º0'18" S e 46º20'18" W)

6 Residence time

6.1 Introduction

For practical applications, the residence is considered complete when a small amount of residual water is still in the region. The residual water is usually defined in a subjective way as a certain fraction of the original water mass. Tartinville et al. (1997) show that this problem can be overcome considering that the water mass evolution in the region follows the exponential law:

$$m(t) = m(0) \exp(-t/\tau) \qquad \text{(eq. 1)}$$

The residence time can thus be determined by adjusting an exponential regression to the model results and defining τ as the residence time. This characteristic time τ is used to quantify residence times in the Santos Estuary. An integrated renewal time scale, the integrated water fraction, is also used to understand the history of water renewal in each region. The model results used were obtained using the MOHID primitive equation hydrodynamic model, coupled to its Lagrangian transport module. Since the Lagrangian tracers can carry explicitly the information of its origin, this property is used to build a dependency matrix that helps to understand the fate of water masses inside the estuary. Residence times and water history are then interpreted together.

6.2 Methodology

In this study the residence time was calculated for different regions of the estuary. For this purpose, the estuary was divided into seven boxes where the high resolution model results are integrated. It must be noted that these boxes are used only for monitoring purposes and no box model was applied. Each box covers a given area and is composed of several cells of the underlying grid. The boxes are used in two functionalities: (1) to release Lagrangian tracers and (2) to examine the Lagrangian tracers passing through them.

The boxes were placed in such a way as to cover the whole estuary. Figure 18 shows their configuration. The number and location of the boxes was based on prior knowledge of physical and biological characteristics of the estuary. Boxes 1, 3, 4 and 6 are placed over tidal flats and are located in the inner part of the estuary, characterized by relatively shallow channels, where the freshwater influence in the renewal process is high, boxes 2 and 5 covers two relatively deep with high velocity channels, and box 7 is located near the coast in the region of the estuary plume’s influence.

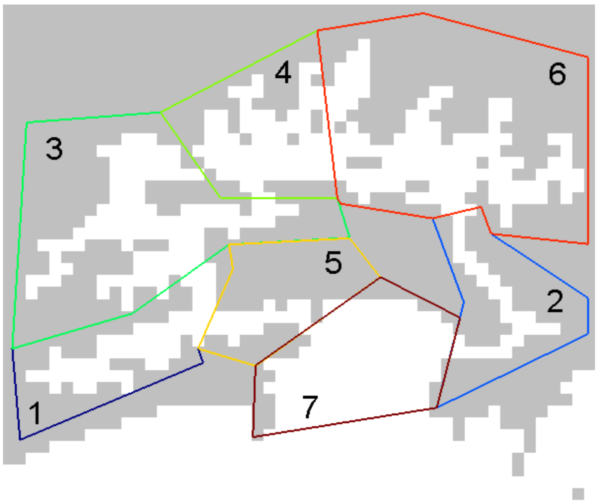


Figure 18 - Configuration and localization of the boxes in the Santos Estuary.

The box's average residence time is defined as the time needed until the water volume initially in a given region is replaced by new water. This can be applied to the estuary as a whole or to a single box. Using the Lagrangian approach, this parameter can be computed releasing an amount of tracers with a volume equal to the entire water body. The water fraction inside box i in each instant of time, with origin from box j ($f_{i,j}$) is calculated as:

$f_{i,j}$ (t) = $V_{i,j}$ (t)/ Vi,j (0) (eq. 2)

where Vi,j(t) is the volume of tracers emitted in box j, present inside box i at time t and Vi,i(0) represents the water volume in box i at the beginning of the simulation.

For the especial case i=j the average residence time for a given box can be computed. When Vi,j(t) reaches zero, all the box's water is renewed and the box's average residence time is found. In some regions a residual fraction of particles tends to stay inside the box for a long time. Consequently, Vi,j(t) approaches zero very slowly. This definition of residence time would then lead to excessively high values. An expedite way of solving this problem is to use a limiting residual fraction below which the box is considered completely renewed. This, however, brings some subjectivity in the choice of the residual fraction. In this article an alternative approach was chosen using the method proposed by Tartinville et al. (1997). In this method results are adjusted to Eq. (1) using an exponential regression. The residence time is obtained as the value of s in that equation, without the need of any subjective parameter.

6.3 River discharges

Six discharge points are defined inside the modelled domain (Figure 19), corresponding to the main rivers in the system and one channel: a joint discharge of rivers Cubatão, Pereque and Henry Borden effluent, rivers Boturoca, Moji e Piaçaguera (joint in one discharged), Quilombo, Jurubatuba, and Bertioga channel.

River discharges are defined by a flow value (Figure 20) with a characteristic temperature and salinity. Mean monthly values are provided for the flow and a constant value of temperature (21ºC) and salinity (0.4 PSU) are assumed for all discharges.

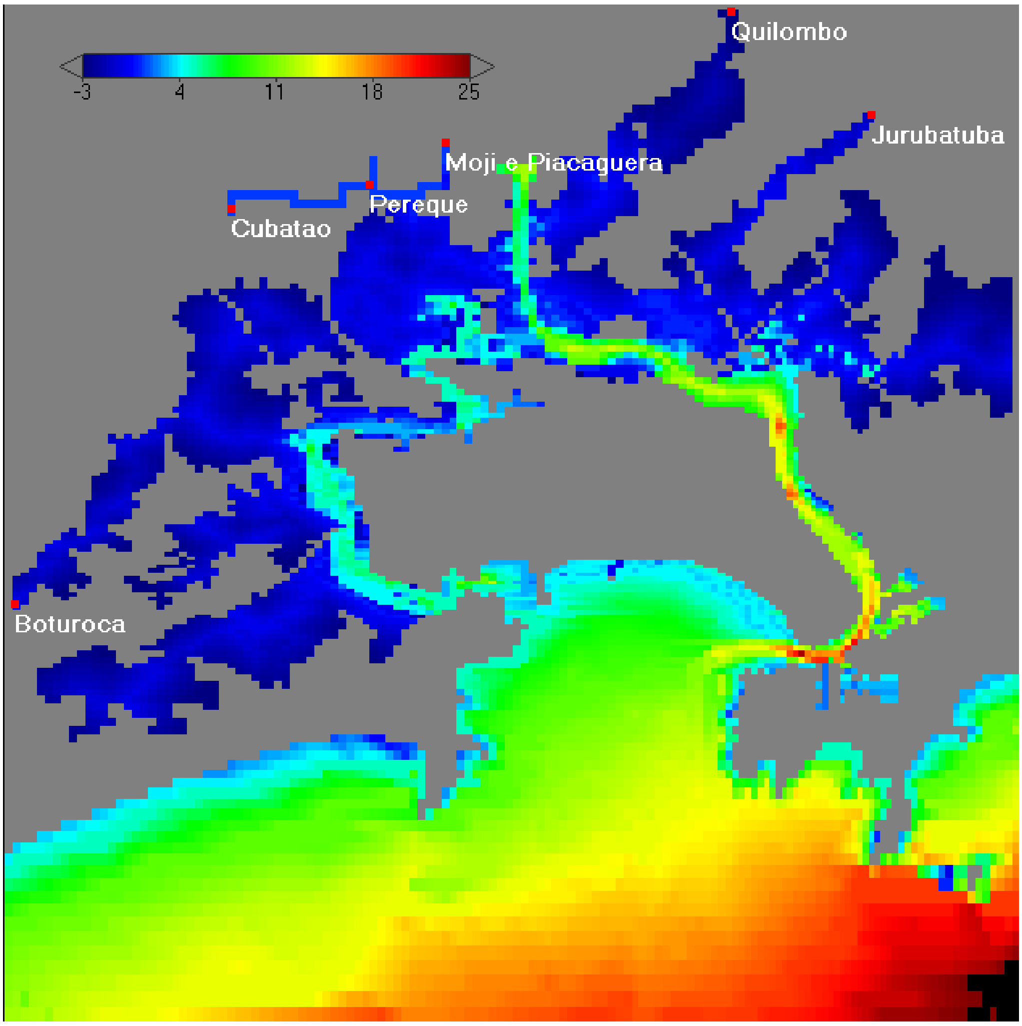


Figure 19 - Modeled domain with the red dots marking the discharge points: (1) river Butoroca, (2) rivers Cubatão, Pereque and Henry Borden, (3) rivers Mogi and Piaçaguera, (4) river Quilombo, (5) river Jurubatuba, and (6) Bertioga channel.

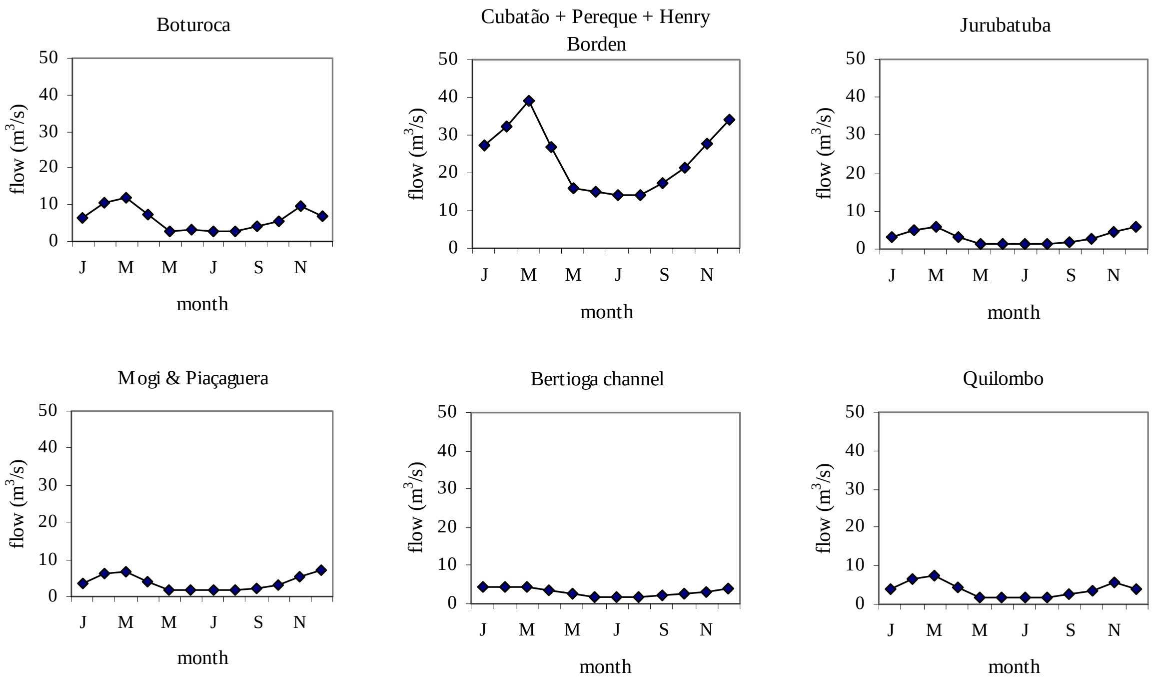


Figure 20 - Monthly mean flow assumed for each river discharging inside the model domain.

6.4 Results

The residence times estimated over a period of two months for winter and summer conditions are presented in Table 4. The results show clear differences that range across the estuary and seasonally. The comparison between winter and summer estimations shows the renewal times to be higher during summer. This is expressed in the lower values of the mean residence time in this period of year. The seasonal difference is linked with the estuaries' flushing capacity, i.e., with the amount of water entering the estuary via rivers. As seen in Figure 20, river flow is always higher in summer months because this is the rainy season, a typical feature of the austral summer at these latitudes. The fluctuation of the total mean flow entering the estuary is portrayed in Figure 21, showing the significant increase in river discharge during summer months.

The most expressive variation in the residence time among seasons is seen in boxes 2 and 5, corresponding to the Santos and Sao Vicente channels, respectively. Considering that the residence time is dependent on the volume and hydrodynamic regime, this is not a surprising outcome. Regional differences are also a typical pattern in this system, with the inner areas (box 6) or more secluded sections (box 1 and 3) having higher residence times. Curiously, the residence time in the bay (box 7) does not vary significantly among seasons, which can be explained by the extensive open ocean boundary.

The different size of the boxes and intricate coastline geometry adds some difficulties in the interpretation of results if the intention is to have a detailed compare of the residence time among different sections of the system. However, this results aim at providing a temporal scale for the different areas of the estuary, with possible implications for the management decisions and results analyses from the study of processes such as pollutant dispersion and dilution, sediment transport (sedimentation or accretion), etc.

Table 4 – mean residence time estimated for the Santos Estuary over a period of two months: results for the seven boxes (winter and summer conditions).

	Mean residence time (days)	
Box	**Winter**	**Summer**
1	22.9	14.3
2	4.8	0.3
3	22.9	15.3
4	11.4	9.6
5	1.7	0.2
6	48.7	29.8
7	15.6	13.7

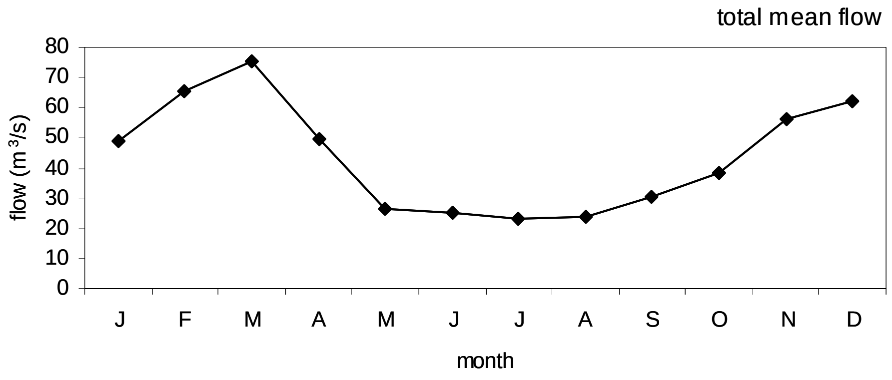


Figure 21 - Annual variations of the total mean flow entering the estuary via river discharge. Green areas denote the flow corresponding to both the winter (J, J) and summer months (N, D)

7 Grid resolution and model performance

Numerical models stand as a way to look at real systems and to translate then into compartments, identifying the connection between them. They are versatile tools that enable an in-depth look at natural systems incapable to be achieved by the simple combination of analytical methods. The first step to model a natural system is to set up a numerical tool that is able to simulate the dynamics of the circulation over the domain. This is achieved by setting up an accurate domain geometry and topography and by defining a correct forcing. The spatial resolution of the domain is dependent on the model implementation aims, available bathymetric data and computing power.

The improvement of numerical codes allied with the increase in available computing power allows hydrodynamic models to simulate efficiently and robustly circulation patterns with high spatial resolution (Haidvogel and Beckman 1998). While more resolution adds spatial detail to the solution, its benefits must be balanced against the available resources and the effective need for the resolution. For short interval hydrodynamic simulations this poses no problem, but if the intention is to simulate large periods (at the scale of months or years) or to have coupled ecological or water-quality models, such computational demands can hinder the modelling exercise by requiring a impractical computation time.

Faced with limited computational resources, there is a need to optimize model runs to achieve feasible running times. This is particularly relevant when models are used as management tools or as part of a decision support system. In both cases the users of the model may need to run the model intensively, which implies the necessity of fast runs. This is in part explained by the need to run different sets of scenarios for long time periods to assess the long term impact that policies and decisions will have on the systems. The need for faster runs is still aggravated by the fact that many of this implementation addresses the ecological aspects of the system.

This means that the tool must be optimized for consuming less computer resources, including running time. A way to achieve this is by reducing the resolution of the grid, thus decreasing the number of calculation points in the mesh. However, the level of detail in a low-resolution grid must still be sufficient to allow a proper characterization of the system. The main features and dynamics of the system must still be reproduced with a coarse geometric and bathymetric rendering of the system. Also, the spatial description needs to maintain the scales and proportions of the system, as well as a coherent geographical reproduction.

The primary purpose of this section is to present a methodology based on a benchmark high resolution mesh that allows researchers and stakeholders to model the main features of the Santos estuary using standard computational facilities. The aim of this exercise has been to test different grid resolution to investigate the influence of grid resolution on the model outcome and to determine if the systems dynamics can be achieved.

7.1 Spatial resolution

The model domain was extended to encompass the adjacent coastal area outside the estuary, as well as some sections of the inner channels. The geographic location of the domain is defined by grid origin coordinates are 46.505º S and 24.135º W (Southwest corner of the grid).

Both a low- and a high-resolution grid are configured (Figure 22), both with the topography derived from sets of bathymetric data. The coarse grid is based on a fixed rectilinear square grid where each cell covers approximately 0.25 km², while the fine grid admits cells of variable size with higher resolution inside the estuary and in channel areas. The variable horizontal step of the high-resolution grid was set to allow a more realistic topography in the inner areas. The low and fine-resolution grids have 48x50 and 147x147 computations points respectively.

Both grids are supposed to capture the general features of the system that vary from the wide and deeper bay area to the inner meandering channels with variable width, mostly bordered by shallow areas. While retaining the same general features of the high resolution grid, the coarse resolution loses spatial definition, especially in depth and coastline contour. Model results using both grids were compared for several stations scattered inside the system (Figure 23) for a period of one month (July 2005).

7.2 Model results

The behavior of the model solution was analyzed focusing on the modeled water levels variability in the outputs of the high-resolution model and those of the low-resolution scheme. The results (Figure 24) show that a generally reasonable agreement was found between the simulations with low and high resolution grids at different places of the system. Generally, the decrease in resolution of the model domain does not seem to compromise the capacity of the model to reproduce the observations.

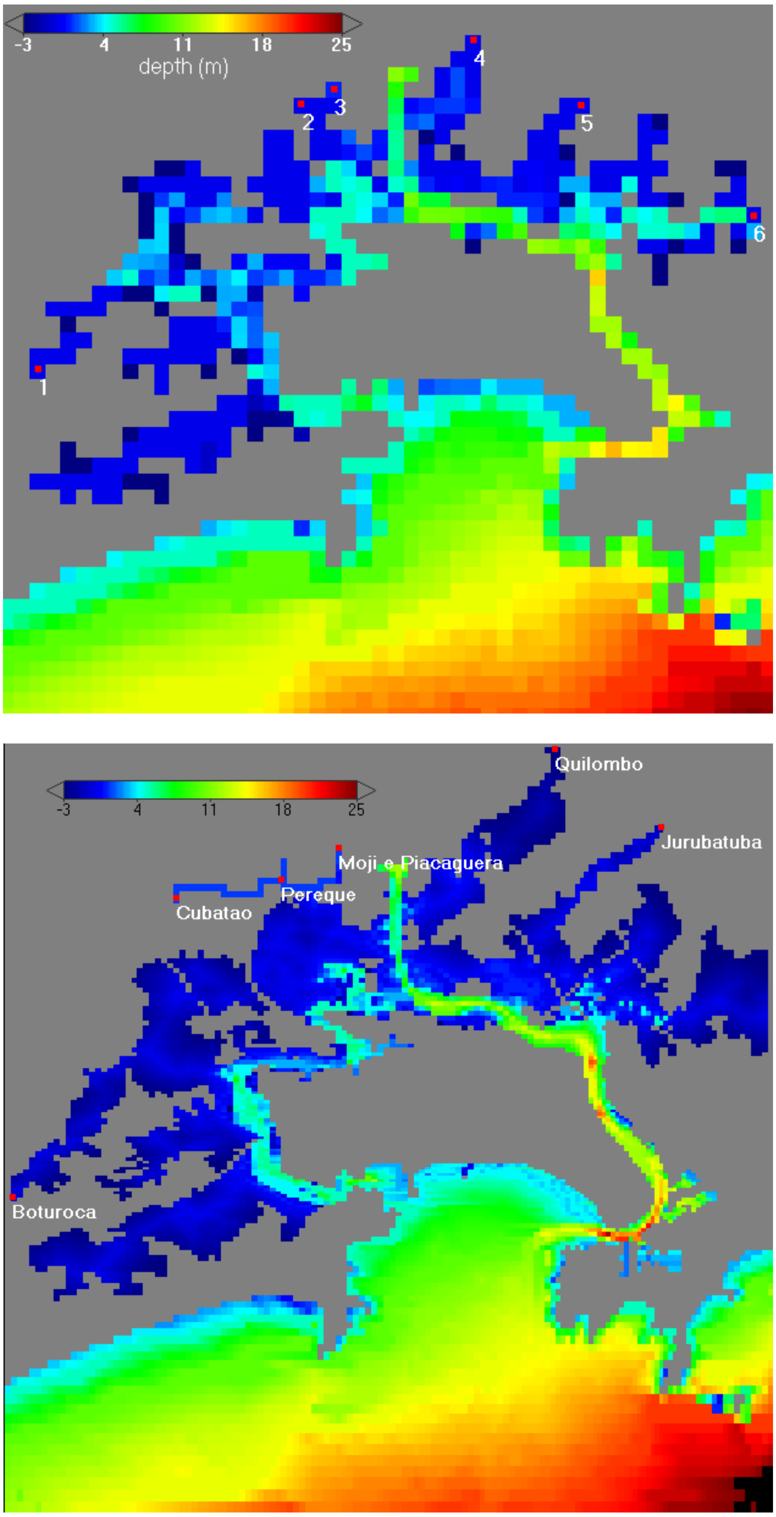


Figure 22 - The low resolution grid (top) and high resolution grid (bottom) used to model the Santos Estuary hydrodynamic processes.

Although these results are encouraging and indicate that the model using the low-resolution grid is able to simulate sea level variations, there will be slight differences in some aspects of the dynamics of the system like small circulation processes in some areas of the estuary. Low resolution means less cells and a rough geometry of the meandering channels. This, in turn, will mean that the modeled circulation in this case will not be as detailed as in the case of the high resolution bathymetry. In summary, the low resolution grid might be too coarse for a detailed depiction of some features like the circulation in the inner and narrow channels and intertidal flats.

The coarse resolution grid was adopted to optimize the running time for testing purposes (scenarios, different sets of conditions, etc.). The loss of grid resolution in the representation of any model domain can only be an option when it is not expressed in the loss of representatively of the system. This means that major features, whether physical or ecological, must be retain in coarse grid resolution and that the global solutions cannot give a different scenario than the fine grid. The need for a high-resolution estuary model of Santos is only justified if localized circulation patterns inside the estuary have to be considered in a simulation or there is a special interest in depicting a detailed geometry of the area. However, when facing limited computer resources, the use of grids with detailed spatial resolution is impaired.

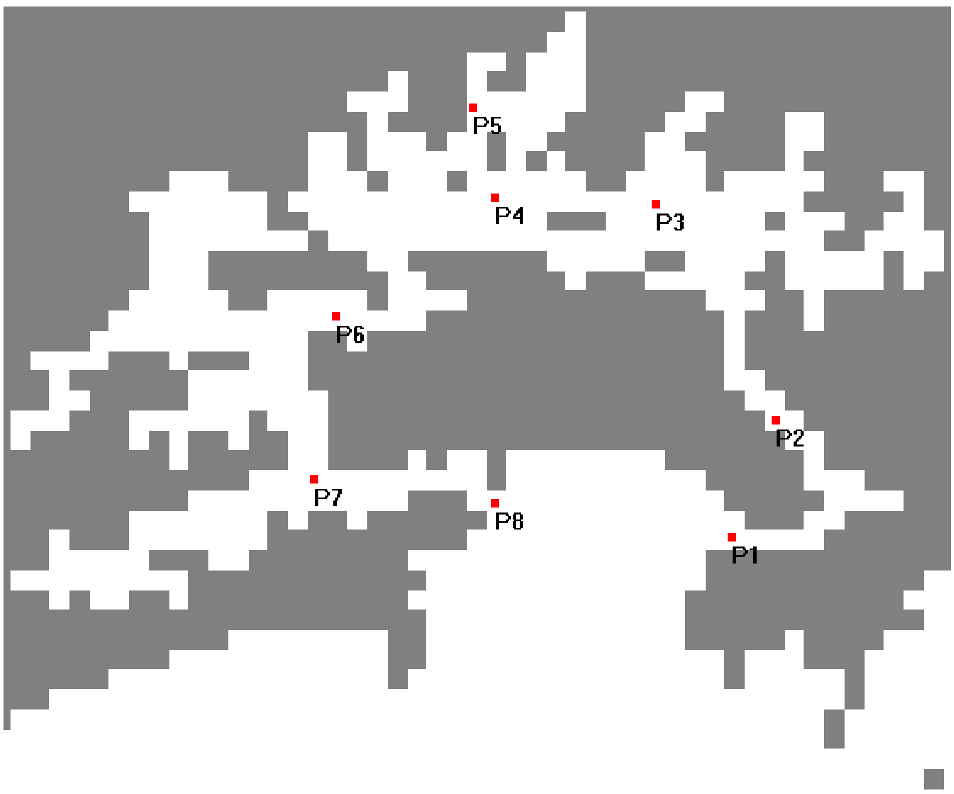
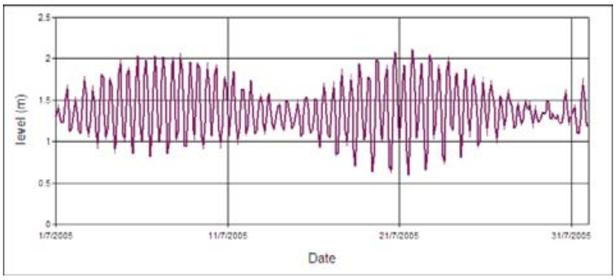
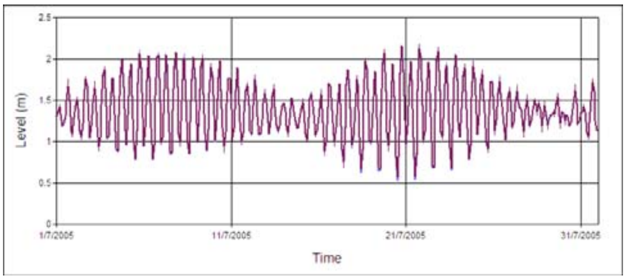


Figure 23 - Monitoring points used in the model results comparison between low- and high-resolution grids.

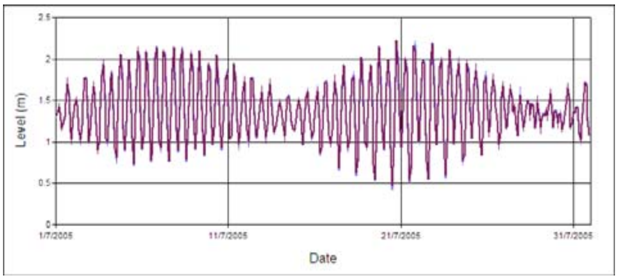
Station 1



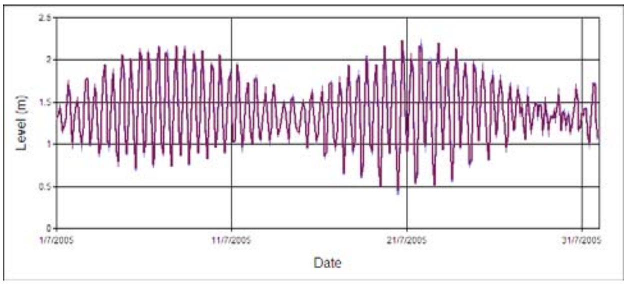
Station 2



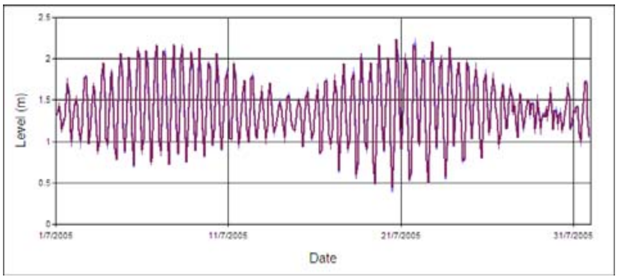
Station 3



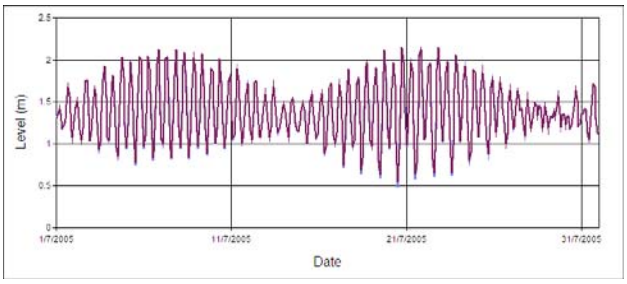
Station 4



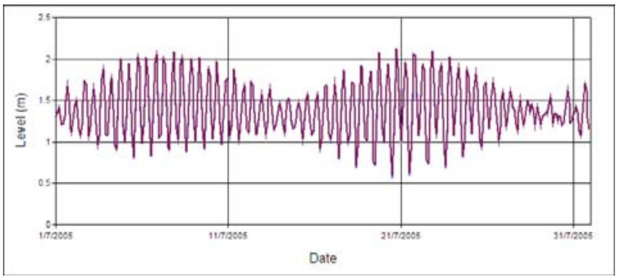
Station 5



Station 6



Station 7



Station 8

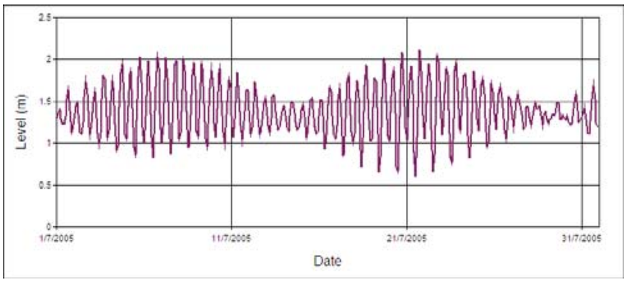


Figure 24 - Sea level comparison at eight different stations scattered inside the Santos Estuary. Model results for simulation with a high resolution grid (blue) and a low resolution grid (magenta).

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