SEASONAL HYDRODYNAMICS AND TRANSPORT TIMESCALE OF A COASTAL ISLAND

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INTRODUCTION

Santa Catarina Island, situated at the city of Florianopolis has over 450000 people and is the 2nd most populous island in Brazil, with 88km of sandy beaches. Located between the island and the continent are the North and South Bays, with an average depth of 5m. Most of its economy depends on the aquaculture, therefore coastal management has a key role in the economic development of the city. For this reason, analyses of coastal hydrodynamics and transport processes in this region are essential for enabling new ventures and the expansion of existing ones.

The Southeastern Brazilian coast is constantly affected by the passage of frontal systems remotely generated on the Argentine continental shelf. These remote signals can induce shelf waves with periods of several days, playing a key role in mean sea level (MSL) variations (Castro & Lee, 1995). Remote winds blowing parallel to the Southeastern Brazilian coast from the south quadrant tend to increase the mean sea level, while winds from the north quadrant induce a lowering of the MSL. Consequently, these sea level fluctuations may generate coastal currents that are dissociated from the astronomical tide, with heights in the same order of magnitude as the astronomical components (Melo et al., 2016; Dottori & Castro, 2018).

Eulerian approaches are commonly used in numerical models to assess water transport timescales (Huguet et al., 2019; Aguilera et al., 2020). These transport timescales are applied to quantify the efficiency of water renewal and transport processes in coastal areas, especially regarding water quality (Lucas & Deleersnijder, 2020; Tang et al., 2021)

To provide useful information, this paper aims to describe the coastal hydrodynamics and assess the transport timescales of Santa Catarina Island, including the North and South Bays. To represent seasonality, two scenarios comprising 3 months each - winter and summer - were defined, with different meteorological and hydrological conditions.

METHODS

Santa Catarina Island was modeled using the numerical models of SisBaHiA® - Base System of Environmental Hydrodynamics (Rosman, 2022), which included two-dimensional depth-integrated and three-dimensional hydrodynamic models, with wave generation models running coupled. The hydrodynamic model of SisBaHiA® solves the Navier-Stokes equations, considering shallow water approaches (hydrostatic pressure approximation) and Boussinesq approximation (Rosman, 1987).

The generation of wind-driven waves was simulated with a wave model based on the method described by the U.S. ARMY (2012), that determines whether wind-wave growth will be limited by fetch or duration, allowing the calculation of wave parameters, such as significant wave heights, peak periods, and orbital velocities. Wave generation models run coupled with hydrodynamics models, allowing waves to change the hydrodynamic circulation in shallower areas and close to shorelines.

A Eulerian advective-diffusive transport model was used to support the analysis of characteristics hydraulic times in the form of a Water Age (WA) parameter and a Water Renewal Rate (WRR).

Both models are useful to understand water exchanges within the domain. The WA model calculates the first-order decay time of a passive substance, accounting the time in which the water remains in different sectors of the modeling domain. As the waters mix, the concentration decays while the water age increases. Meanwhile, the WRR model describes the mixture of the water incoming the domain through the open boundaries. which have and WRR index of 100%. New waters are marked with a WRR index of 100%, while the water at the initial conditions within the domain has a WRR index of 0%.

Water Renewal Rate and Water Age parameter allow detailed estimates of water exchanges in each region of the modeled domain. Thus, it is possible to locally assess whether the kinetic processes of eutrophication, involving concentrations of nutrients, are relevant or not for water quality. The lower the WRR and the higher the WA, the greater the importance of kinetic reactions in the region.

METOCEAN DATA

The bathymetry shown in Figure 1 was obtained by the digitalization of nautical charts produced by the Brazilian Navy Hydrographic Center. The set of 33 harmonic constants obtained from the Finite Element Solution (FES) was used to calculate the astronomical tides (Lyard et al., 2014). The non-astronomical sea level variations were obtained from reanalysis in the South Atlantic through the Hybrid Coordinate Ocean Model (HYCOM).

The wind data used to drive the model was obtained by the atmospheric reanalysis model ERA5, from the European Centre for Medium-Range Weather Forecasts (ECMWF). Rainfall data from the Brazilian National Institute of Meteorology (INMET) was used to calculates river streamflow in each sub-basin that reaches the North and South Bays. During summer, due to increased rainfall, streamflow is higher than in winter.

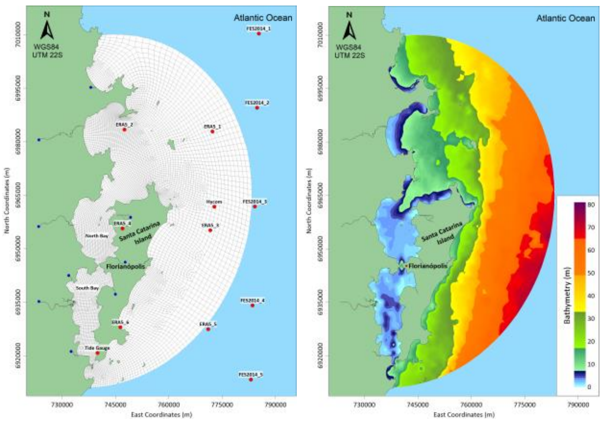

Figure 1 – a) Biquadratic finite element mesh used for the domain discretization, with 2131 elements and 9083 calculation nodes, and b) bathymetry in meters relative to local chart datum. Blue dots are inputs of river flow data and red dots are metocean data, as astronomical and meteorological tides, coastal currents, and winds.

SEASONAL HYDRODINAMICS

Especially in shallow waters, wind effects are important for hydrodynamic circulation and transport processes. Results showed that in several places, vertically averaged and free surface currents present different velocities and opposite directions. When winds blow towards the shores, wind set-up induces a flow near the bottom with opposite directions to the free surface flow. In general, velocities are higher at the surface and directions changes, mainly on the east coast of the island and at the South Bay.

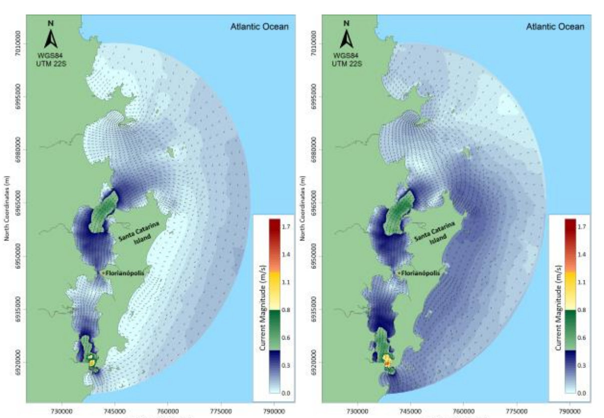

Figure 2 - Results of vertically averaged currents (left) and free surface currents (right). Both results are at the same time step, with southerly winds blowing and close to the MSL, in which maximum speeds occurs.

For the selected scenarios, meteorological tides from N quadrant occurs with the same intensity in both seasons, however, they are more common than the passage of southern frontal systems. Therefore, the main direction of transport around the island is to the south, according to the direction of the Brazilian Current.

To understand the influence of these events on the circulation, two typical meteorological tides conditions were selected, both lasting 7 days and representing the lowering (negative) and rising (positive) of the MSL. Results of residual currents and mean sea levels showed that, under the effect of negative meteorological tides, water levels are higher in the north of the island, inducing a transport to South Bay. Otherwise, positive meteorological tides tend to change currents directions: the more common N/NE currents are commonly shifted to an S/SW direction. Furthermore, the south of the island, including the South Bay, presented a higher MSL than the north of the island.

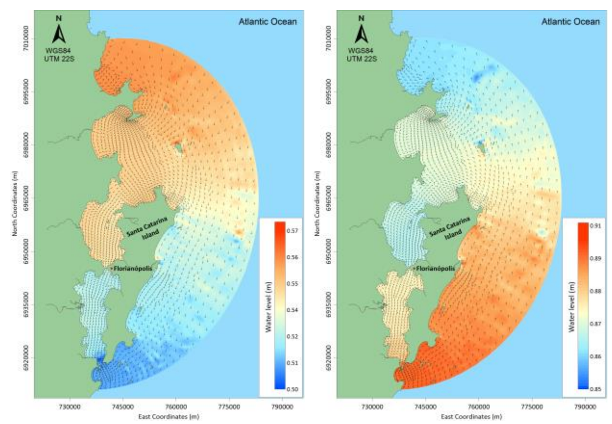

Figure 3. Mean water level during 7 days of simulation considering a) a negative meteorological tide propagating to S, and b) a positive meteorological tide propagating to N. The arrows stand for the residual current directions.

Hydrodynamics results showed that, regardless of seasonality, the volume of water that enters the North Bay is slightly greater than the volume that leaves. The opposite occurs at the South Bay entrance, in which ebb volume is greater than flood volume in both seasons. In summer, greater differences between ebb and flood were observed at both tidal inlets, indicating the effect of a higher streamflow entering the bays during this season, which increases ebb flows in both bays, especially in South Bay.

SEASONAL TRANSPORT TIMESCALES

Water exchanges between inner water and the open sea control the water mixing of the domain. In both scenarios, WA results showed that the east cost of the island presents lower age than the west coast, due to the direct influence of the ocean. During summer conditions, river flows are greater and WA in North and South Bays tends to decrease, while in winter scenario, when rainfall is less intense, the water age becomes greater. In addition to less intense river flows, positive meteorological tides induce a lowering of the sea level in the North Bay.

Water age at the surface is lower than vertically averaged and bottom results, however, the spatial distribution remains the same. This wind-induced surface transport has an important effect on water quality and can dominate the direction of transport, thus generating the accumulation of floating debris in certain regions of the coast.

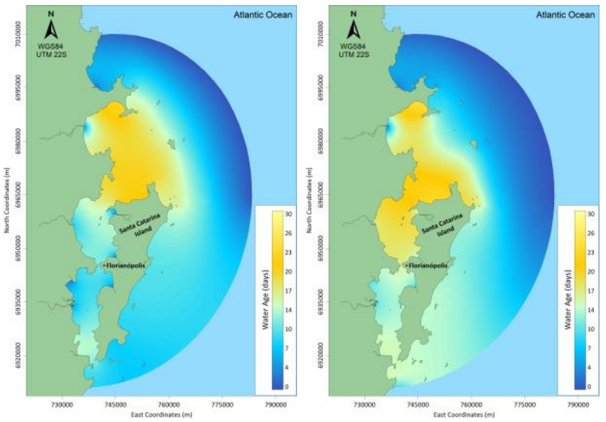

Figure 4 – Spatial results of vertically averaged WA at the end of 3 months of simulation for a) summer and b) winter scenarios.

In both scenarios, the WRR of the South Bay is greater than of the North Bay, due to rivers with higher flows that reaches this bay. The decrease of the MSL in the North Bay and the presence of vortices in the tidal inlet also decreases the water exchanges in this region, which reduces the mixing processes and the WRR.

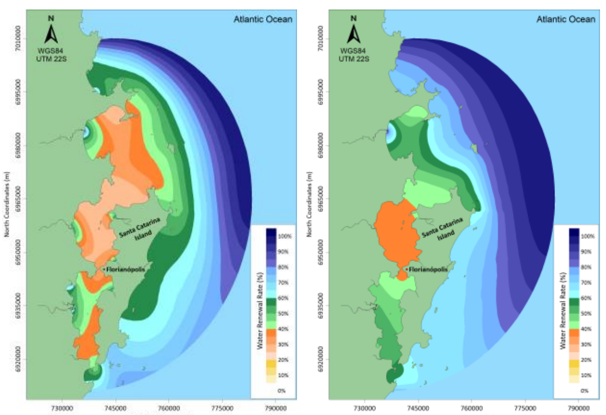

Figure 5 – Spatial results of vertically averaged WRR after 3 months of simulation for a) summer and b) winter.

CONCLUSIONS

Due to intense aquaculture activity in the surroundings of Santa Catarina Island, coastal hydrodynamics and transport processes play an important role for local coastal management, since water quality is directly influenced by the water exchanges occurring in the tidal inlets of the North and South Bays.

Depending on the intensity, wind stress acting in the water surface may generate surface currents with different directions and intensities from the water column. But local winds are not the only mechanism that causes changes in coastal hydrodynamics. Astronomical tides are often overwhelmed by meteorological tides in Southeastern Brazilian Coast. These sea level oscillations with periods between 3 and 30 days can dominate the residual transport within the bays, which affects the transport timescales of the island.

Under different meteorological and hydrological conditions, the hydrodynamic circulation within the bays showed a lower WRR and a greater WA. Several aspects influence the water renewal results, such as streamflow intensity, meteorological events, as well as the tidal inlets characteristics. For the selected period, meteorological tides had a greater influence on water mixing than river streamflow.

However, to better understand the meteorological effects on transport timescales, the hydrodynamic models need to run scenarios in which astronomical, meteorological, and hydrological variables are isolated, thus, assessing the importance of each one in the hydrodynamic circulation.

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