CHARACTERISTIC HYDRAULIC TIMES OF WATER AGE AND RENEWAL RATES IN THE LOWER AMAZON

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INTRODUCTION

The analysis of characteristic hydraulic times (CHT), Times of Renewal Rates (TRR%), and Water Age (WA) have been used as important diagnostic tools in tracking the scale of kinetic reactions as water masses move downstream. These analyses are helpful to track the water mass exchange (Monsen et al., 2002), giving us an important knowledge of the hydrodynamics processes that helps water bodies to recover from local pollution. Currently, transport models are the main tool used worldwide to develop CHT analysis (Bacher et al., 2016). One can find numerous examples in the literature of CHT studies on water bodies pressured by the surrounding population or by the presence of industrial activity, that usually present environmental risks.

The lower reaches of the Amazon are extremely complex, with 2 large and several small tributaries entering, an extensive floodplain, multiple channels, and islands. To represent the dynamics of this region, we have selected models that are part of SisBaHiA - Environmental Hydrodynamics Base System, which has been continuously expanded and improved at COPPE/UFRJ since 1987 through several master's and doctoral theses as well as research projects. http://www.sisbahia.coppe.ufrj.br

METHODS

Flows with horizontal movement scales at least 20 times larger than the depth can be considered as shallow water flows, Dean and Dalrymple (2001). The amazon estuary fits in this case, in addition, it tends to be vertically homogeneous. It justifies the application of a vertically integrated hydrodynamic model, that is, two-dimensional horizontally, also known as 2DH. In these situations, the differential equations of movement, called shallow water equations, are deduced from the general equations of flows in turbulent regime, known as Navier-Stokes equations, which express the principles of mass conservation and balance of movement quantity via Newton's second law. Following the usual hierarchy of the models, a Eulerian Transport Model that calculates TRR% receives information directly from a hydrodynamic model. In this article, we explored the main aspects of the TRR% and the WA as hydrodynamic circulation of the Lower Amazon progresses considering typical dry season scenario (October to December 2020) and rainy season scenario (April to June 2020). The hydrodynamic model considers the digital terrain model, bathymetry, and bottom roughness derived from nautical charts provided by the Brazilian Navy. Oceanographic data on astronomical tides were obtained from FES-2014, while meteorological tide data were acquired through the HYCOM reanalysis platform (www.hycom.org). Hydro-meteorological data, including wind, evaporation, precipitation, salinity, temperature, and river discharge, were also incorporated into the model. Figure 1 shows the modeling domain, the land and sea contours that delimit the modeled water body. The domain was discretized into a finite element mesh with 23,700 calculation nodes and spans 1250 km from the upstream section near Parintins to the open border.

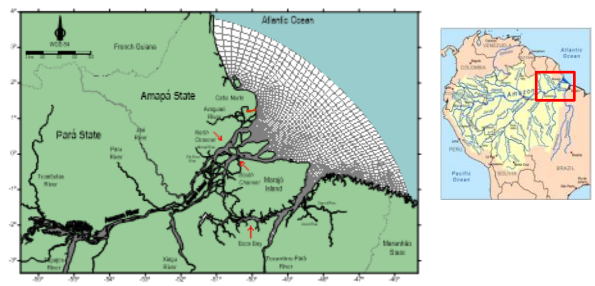

Figure 1 – Base map with finite element mesh.

WATER AGE (WA)

The Water Age, (WA), reflects the time elapsed for dissolved substances to be transported from one point to another, making it a useful timescale for describing the complex hydrodynamic and biogeochemical processes in large shallow water body (Li et al., 2011). The WA indicates, for a given position of the domain, the average time the water parcels that are in that position remain in the domain of interest as the flow circulates through the domain.

During the WA simulation, as hydrodynamic circulation progresses, parcels of newer waters are mixed with older ones. Advection, diffusion, and decay processes continue varying WA in space and time, so the value of WA becomes varied and variable.

TIMES OF RENEWAL RATES (TRR%)

Times of Renewal Rates (TRR%) represents the time it takes to attain a water renewal of X% in different regions of the water body. To analyze the characteristic time for water renewal, it is recommended that the Times of Renewal Rates (TRR%) be computed directly at different points over time, to obtain the time evolution of the renewal rates at different points of the study domain (Roversi et al., 2016; Rosman, 2022). The TRR% simulation assumes a reference value of Water Renewal Rate, WRR, equal to 0% for the waters that are inside the domain of interest at the initial simulation instant. For renewal purposes, incoming waters, i.e., waters that enter the domain by the open boundaries or through other inflows, such as rivers, have a reference value equal to 100%. As new water with 100% reference value mixes with initial water of 0% reference value an intermediary value is computed, indicating the percentage of mixing at any given point in time (Aguilera et al., 2020).

To represent these two conditions, a generic substance with concentration C is used as a tracer for new water.

Consequently, at the beginning of the simulation, all the water enclosed within the domain of interest is considered old and is prescribed with concentration C = 0. All new water inflows in the domain after the initial time are considered new water with concentration C = 100.

Then, due to the advection, dispersion and diffusive processes, the percentage of fresh or new water in the domain will be directly proportional to this generic substance concentration, varying from 0% to 100%. The values resulting from these simulations represent the percentage of the mixing of new and old waters in each position of interest, delimited by the predefined domain. The TRR% will be different at each point of the domain because it depends on the magnitudes of the currents and turbulence in different places and times, as a function of the advective-diffusive transport.

The Times of Renewal Rates, TRR%, are the characteristic hydraulic times associated with the concept of water renewal. It means the necessary time, with respect to the initial modelling time, for a water parcel to reach a specific value of Water Renewal Rate, WRR. When running the Renewal Rate model for a "sufficiently long" period, concentrations tend to reach 100% throughout the domain.

RESULTS AND DISCUSSION

The results of WA and TRR% will be presented in the form of contour maps or graphs. The riverine part of the estuary is dominated by incoming flows and exhibits low WA and TRR% close to 100%. Newer water is also observed in the region near the open border. During the rainy season, with higher river discharges, the waters of the Lower Amazon River are renewed more rapidly than during the dry season.The estuary of the Pará River, with a much lower river flow compared to the Amazon, exhibits a region with a water age of around 50 days and a renewal rate of 70%, demonstrating sensitivity to environmental issues. The same is observed in the region of the large lakes (Figure 2).

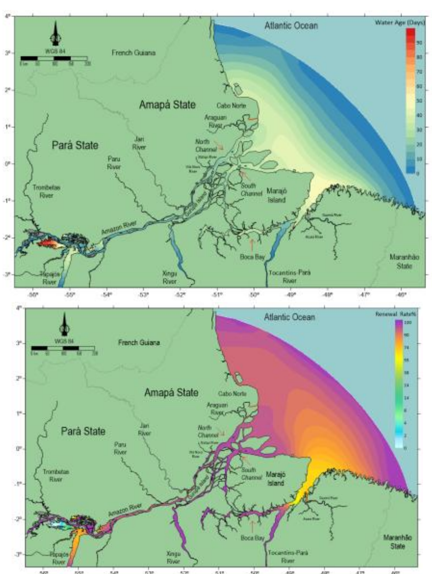

Figure 2 – Map of isolines of Water Age (top) and Renewal rates (above) at the end of the three-month simulation for the dry season.

The water age graph for the dry season in the river section indicated by the red arrow shows that even 500 km from the mouth of the Amazon River, tidal influence still affects the flow. The most pronounced fluctuations are related to the spring and neap tide periods.

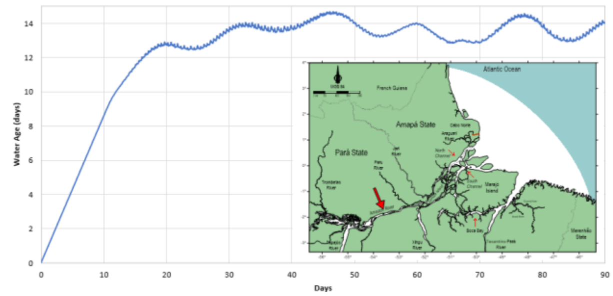

Figure 3 – Water Age at river section indicated by the red arrow of the three-month simulation for the dry season.

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