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Research Paper

Evaluation of hydrologic influence on water quality variation in a coastal lagoon through numerical modeling

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ABSTRACT

The present study was developed for the Patos Lagoon, a coastal lagoon located in southern Brazil. Due to operational limitations, most of water quality studies in Brazilian coastal lagoons are conducted through field sampling at specific stations, providing limited spatial and temporal resolution. Particularly in the Patos Lagoon, studies were conducted through sampling at specific stations at the northern area of the lagoon and/or focusing on its estuarine area. The lagoon has a major importance for the south of Brazil in both environmental and economic aspects, being subject to several human activities, which affect its water quality. Studies indicate that hydrological variations at different spatial scales could affect the Patos Lagoon dynamics, especially those variations resulting from El Niño and La Niña events, promoting wet and dry conditions, respectively. This work presents the spatial and temporal variability of chlorophyll-a and dissolved inorganic nutrients (ammonium, nitrate and phosphate) throughout the Patos Lagoon in two distinct situations: one typical of La Niña event (represented by the 2006 year), and the other, typical of El Niño event (represented by the 2011 year), in order to evaluated if the hydrological variability affects water quality variables throughout the system. Differences between the two situations are concentrated on the main physical forcing, the river flow discharge at the north of the system (Guaiba River) and wind magnitude, being both more intense in 2011 than in 2006. The study was conducted using the MOHID2D numerical model, since it overcomes the field and costs limitations. Results showed that the analyzed concentrations of the main variables were higher in wet condition (2011), with exception of phosphate. The spatial and temporal variations of all water quality variables, however, were similar in both conditions. Thus, different hydrological conditions could affect the magnitude of the concentration of the main water quality variables, but that does not affect significantly its spatial and temporal variability. In addition, it is evident that the numerical modeling application provides a systematic evaluation of a complex coastal system, as the Patos Lagoon, becoming an important tool for its environmental management.

1. Introduction

Coastal lagoons are important in environmental and economic aspects. Therefore, the study of their dynamics and water quality becomes critical for their understanding, maintenance and management. It is known that hydrological forces such as wind and river flow, may constrain the dynamics of these systems. Hence, this study attempted to evaluate the implication of these physical forcing variations on a set of variables which indicate the water quality. The study was conducted at the Patos Lagoon, located in southern Brazil (Fig. 1), a natural reserve of fauna and flora subject to the influence of several human activities. From the environmental perspective, the Patos Lagoon estuarine region houses species of fish and shrimp of great commercial importance (Castello, 1985), while from the economical point of view, it presents growing industrial and urban development. Furthermore, in its estuarine region it is also installed the Port of Rio Grande, one of the most important in South America (http://portoriogrande.com.br/).

Due to operational limitations related to the extension of the Patos Lagoon system and financial resources available, few studies considering the entire system were carried out until now (Odebrecht, 2003; Odebrecht et al., 2005; Niencheski et al., 2006; Seiler and Fernandes, 2013). These studies were conducted through field sampling in specific stations, generating spatially and temporal limited information. Thus, working with numerical modeling

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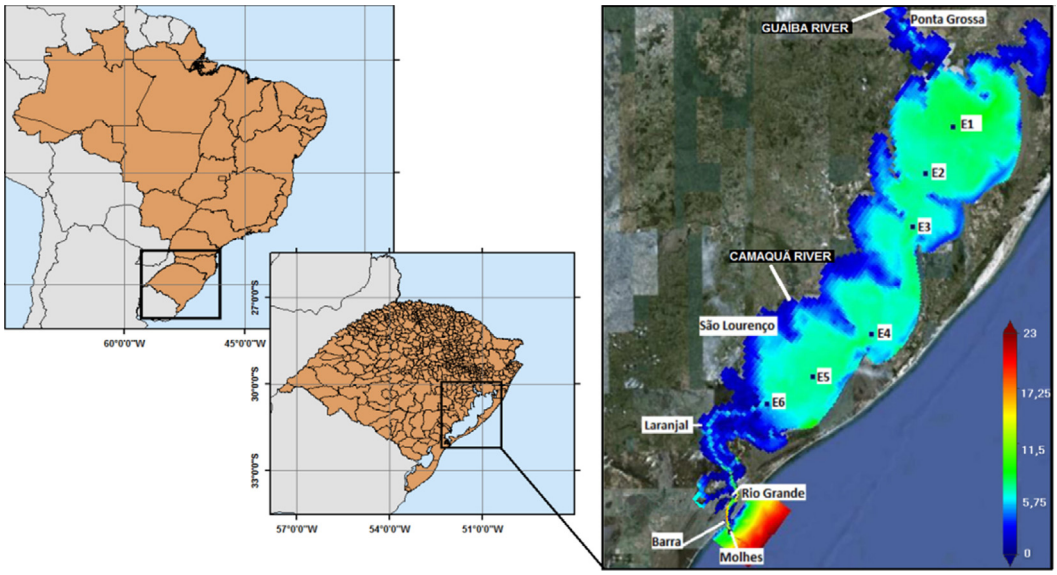

Fig. 1. Location of Patos Lagoon and of the output points for the hydrodynamic simulations, chlorophyll-a and nutrients.

tools figured as an excellent option to overcome these limitations. This not only allows the simulation of different scenarios, but also the prediction of the subsequent environmental response in the short, medium and long term, but also helps with the prevention and management of environmental issues. The use of field data, however, is essential in the numerical model application, since it is used in the calibration and validation of the model results.

Previous studies indicated that the Patos Lagoon circulation is strongly influenced by hydrological variables, particularly the river discharge and the winds acting parallel to the coast (Möller et al., 1996, 2001; Fernandes et al., 2002). Studies also indicate that the inter-annual variability of these hydrological factors, which are mainly observed during El Niño and La Niña events, leads to changes in the estuarine circulation (Möller et al., 1996; Fernandes et al., 2002), in fishing activity (Möller et al., 2009), in determining the recruitment of marine or freshwater fish species (Garcia et al., 2003), in the distribution of salt marshes (Marangoni and Costa, 2009), in the recruitment and distribution of macrozoobenthos (Colling et al., 2007), in nutrient availability, and consequently, in the distribution and growth of phytoplankton (Abreu et al., 2010).

During El Niño events, the precipitation in southern Brazil is intense, therefore changing the river discharge contribution at the northern end of the Patos Lagoon (Möller et al., 2009). This promotes a consistent decrease in salinity within the estuarine region (Fernandes et al., 2002) and an increase in the ebb fluxes toward the coast (Pasquini et al., 2012). Moreover, when the precipitation is excessive (over 1500 mm of rain per year), the concentration of chlorophyll-a in the estuary decreases sharply due to the effect of 'wash' caused by high ebb fluxes (Abreu et al., 2010). In contrast, precipitation is low during La Niña events, resulting in drought condition in the region (Seeliger, 2004). It is known that factors such as the availability of nutrients and light, water temperature and hydrological variables constrain the spatial and temporal variations of phytoplankton in one system (Odebrecht et al., 2005; Bonato et al., 2015). Thus, the variations of hydrological parameters not only strongly affect the lagoon circulation, but also the dynamics of organisms.

Based on data from pluviometric stations of the National Water Agency (ANA) and the National Institute of Meteorology (INMET), it was observed that in 2006 there were 138 days of rain, summing 1160 mm of precipitation, with a maximum of 65.1 mm. In 2011 there were 153 days of rain, summing 1350 mm of precipitation, with a maximum of 77.2 mm. With this information it was possible to infer that 2006 was drier than 2011, presenting a characteristic behavior of a weak La Niña event, while 2011 showed an El Niño characteristic behavior.

This study aims to present an evaluation of the spatial and temporal variability of a set of water quality variables (chlorophyll-a and inorganic nutrients) in two different hydrological situations: one with high precipitation rate and consequently high river discharge (characteristic of El Niño events, represented by the 2011 year) and the other with low precipitation rate, thereafter a low river discharge (characteristic of La Niña events, represented by the 2006 year).

The research goals were achieved through the application of the MOHID (Water Modelling System) numerical model, a modern numerical tool that allows the simulation of a variety of physical, chemical and ecological processes in the water, sediment and air interfaces, being so, considered a powerful tool for dynamic ecosystems studies (Deus et al., 2013). The model was developed to support the management of aquatic ecosystems (Martins et al., 2001), and is in constant improvement in order to better describe the real ecological processes occurring in the water and your interfaces (Deus et al., 2013). MOHID has been successfully applied in numerous studies involving the hydrodynamics and the variation of water quality variables in coastal environments (Trancoso et al., 2005; Malhadas et al., 2009; Cancino and Neves, 1999; Deus et al., 2013; Fossati and Piedra-Cueva, 2013). The model reliability was highlighted in several studies through extensive calibration exercises (Vaz et al., 2007; Moreno Navas et al., 2011; Lopes et al., 2005; Fossati and Piedra-Cueva, 2013).

2. Methodology

2.1. The numerical model MOHID

MOHID is integrated modelling software which allows the simulation of a variety of physical, chemical and ecological processes occurring at the sediment, water and atmosphere. The model was developed by the Marine and Environmental Technology Research Center (MARETEC) at the Instituto Superior Técnico (IST), from the Technical University of Lisbon. The system was programmed in ANSI FORTRAN 95 using the object-oriented philosophy.