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Three-dimensional modeling of the lower trophic levels in the Ria de Aveiro (Portugal)

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ABSTRACT

The water and the ecosystem dynamics of the Ria de Aveiro, a shallow, multi-branch lagoon located on the northwest coast of Portugal, are simulated using a new fully coupled 3D modeling system. This model couples the hydrodynamic model SELFE (semi-implicit Eulerian-Lagrangian finite element) and an ecological model extended from EcoSim 2.0 to represent zooplankton dynamics. The model application is based on an unstructured grid spatial discretization, which is particularly appropriate for this system given its complex geometry. The baroclinic circulation is calibrated and validated for different environmental conditions, leading to velocity errors smaller than 5 cm/s across the lagoon. Ecological simulations, focused on zooplankton dynamics represented by a site-specific formulation, are then presented and compared against field data for two contrasting environmental conditions: Autumn 2000 and Spring 2001. Results show that the fully coupled model is able to reproduce the dynamics of the ecosystem in the Spring 2001, fitting the model results inside the range of data variation. During this period zooplankton differences between data and model results are of about 0.005 mg C/l (60%), while other ecological tracers' differences are generally smaller than 20–30% along the several branches of the lagoon. In the Autumn 2000, the model tends to overestimate zooplankton by a factor of 10 and to underestimate phytoplankton and ammonium, with discrepancies of about 0.1 mg C/l and 4.8 μmol N/l, respectively. Factors like the ecological conditions imposed at the boundaries, the input parameters of the ecological model and the simplification of the ecosystem structure, since phytoplankton is the only primary producer considered, may explain the observed differences.

1. Introduction

The Ria de Aveiro is a shallow temperate coastal lagoon located on the Northwest (NW) coast of Portugal (40°38′N, 8°45′W). The lagoon is about 45 km long and 10 km wide (Fig. 1) and has an average depth of about 1 m (Dias et al., 2000). It is separated from the ocean by a sand spit, interrupted by an artificial tidal inlet about 20 m deep. The artificial inlet channel is connected to four main branches, the Mira, Ílhavo, Espinheiro and S. Jacinto channels (Fig. 1), through which the main sources of freshwater flow into the lagoon. The rivers Vouga and Antuã discharge to the Espinheiro channel, being the major sources of freshwater to the lagoon (Dias et al., 2000; Dias and Lopes, 2006). Smaller sources of freshwater flow into the system through other channels, namely the Boco river in the Ílhavo channel, the Caster River in the S. Jacinto channel and several small rivers in the Mira channel. Freshwater flows are poorly known due to a severe lack of data: Dias and Lopes (2006) refer average annual flows of 50 and 5 m^3/s, while Dias et al. (2000) refer average annual flows of 29 and 2 m^3/s, respectively, for the Vouga and the Antuã rivers; for the Vouga river, Vaz and Dias (2008) refer an average annual flow of 31.45 m^3/s, based on field measurements in the Espinheiro channel from September 2003 to August 2004. Tides at the mouth of the lagoon are semi-diurnal, with a mean tidal range of about 2 m (Dias et al., 2000). More detailed descriptions of the lagoon can be found in Dias et al. (2000) and references herein.

This lagoon plays an important ecological role, being the habitat of several species of flora and fauna (Hermoso et al., 2001) that are supported by the dynamics of the lagoon. In the lower trophic levels, in particular, zooplankton is a very important biological community. Zooplankton is responsible for the secondary productivity

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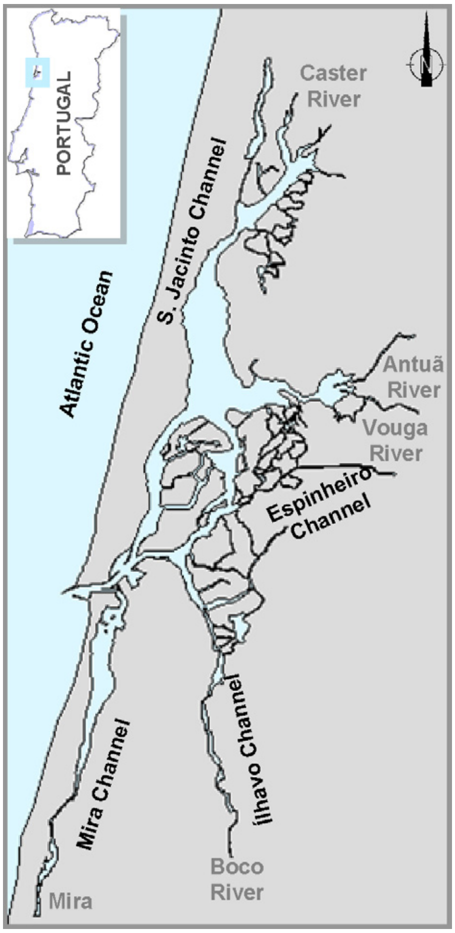

Fig. 1. Synthetic map of the Ria de Aveiro.

of the estuaries, which supports several vital functions for fishes or shrimps. The study of the factors that affect this community is thus fundamental for the management of the ecosystem (David et al., 2006). In the Ria de Aveiro, the copepoda community represents 62% of the total zooplanktonic biomass, playing an important role in the secondary production of the lagoon (Leandro, 2008).

There are also several economic and social activities (e.g. industries, agriculture) in the Ria de Aveiro and it supports a population of about 250 000 habitants (Ferreira et al., 2003). In the last few decades, these activities have reduced the ecological quality of the lagoon (Lopes and Silva, 2006; Lopes et al., 2005). Some human interventions, like the construction of a submarine outfall, reduced the nutrient loads and improved its quality (Silva et al., 2000), but there are still problems.

There is, thus, a need to develop strategies that contribute to an integrated management of the Ria de Aveiro, supported by a detailed and updated knowledge of the system and by tools and monitoring programs that improve this knowledge. In particular, it is important to assess the impact of the human interventions in this water system (e.g. outfall construction). Numerical models, integrated and validated with field data, are important tools for supporting management policies.

Most of the past ecological and water quality studies in the Ria de Aveiro were based on field data. The focus of these studies include the oxygen consumption (e.g. Cunha et al., 1999), the variability of nutrients and chlorophyll *a* along the lagoon (e.g. Almeida et al., 2005, 2007; Lopes et al., 2007), the effects of the mercury contamination (Válega et al., 2008; Pato et al., 2008) and the zooplankton (Leandro et al., 2006a). The studies based on water quality and ecological models (e.g. Lopes et al., 2005, 2008; Saraiva, 2005; Trancoso et al., 2005; Lopes and Silva, 2006) are still scarce. The hydrodynamics of the lagoon has been characterized through both field data (e.g. Dias et al., 1999; Vaz and Dias, 2008) and numerical modeling (e.g. Dias et al., 2003; Oliveira et al., 2006), but past numerical applications were limited by insufficient horizontal or vertical resolution. Indeed, among these studies, only one uses unstructured grids, which are fundamental to solve the complex geometry of the lagoon and the relevant spatial scales. However, this study, from which was build the 3D model presented here, is based on a depth-averaged approach (Oliveira et al., 2006). An integrated analysis that is able to tackle the adequate spatial scales is yet to be performed both to increase the knowledge of the system and to create the basis for an operational forecast system to support the lagoon's management.

The present work aims at implementing a new, fully coupled, three-dimensional hydrodynamic and ecological model, ECO-SELFE (Rodrigues et al., 2008), in the Ria de Aveiro and validate it with field data measured in the several branches of the lagoon under different environmental conditions. This model allows for the representation of the hydrodynamic and the biological processes at the relevant time and space scales, through the use of unstructured discretizations of the domain. The ecological model allows the simulation of the cycles of carbon, nitrogen, phosphorous, silica and iron, and includes a site-specific formulation for zooplankton, based on the field work of Leandro et al. (2006a,b) in the Ria de Aveiro. This application of ECO-SELFE constitutes its first validation in a real system.

2. Methodology

A two-stage methodology is adopted in this study. First, the hydrodynamic model is calibrated with field data, in order to establish the numerical conditions of the simulations (e.g. horizontal and vertical grids, time step). This approach optimizes the computational time as the coupled model is twice more CPU demanding than the hydrodynamic module alone. The implementation of the 3D hydrodynamic model builds on the work of Oliveira et al. (2006). Secondly, the fully coupled 3D hydrodynamic and ecological model is validated. This validation is performed for two contrasting environmental conditions, also allowing the analysis of the effects of the seasonal conditions on the ecosystem dynamics. For both stages, the simulation periods were defined based on the data available for the validation of the coupled model. Thus, the structure of the paper reflects the methodology adopted: the description of the model and its set-up for both stages are presented in the following subsections. Section 3 presents and discusses the results for the hydrodynamic model assessment and the ECO-SELFE model application together with a preliminary analysis on the importance of the environmental factors; the main conclusions and the directions for further research are summarized in Section 4.

2.1. The 3D coupled numerical model ECO-SELFE

ECO-SELFE is a fully coupled three-dimensional hydrodynamic and ecological model. The hydrodynamic model, SELFE (semi-implicit Eulerian–Lagrangian finite-element; Zhang and Baptista, 2008, serial version 1.5k2, available at http://www.stccmop.org/CORIE/modeling/selfe/), solves the three-dimensional shallow-waters equations and calculates the free-surface elevation and the 3D water velocity, salinity and temperature. The ecological model results of an extension of the model EcoSim 2.0—ecological simulation (Bisset et al., 2004, available at http://www.myroms.org/) to account for the simulation of several groups of zooplankton (Rodrigues et al., 2008). The model includes the cycles of carbon (C),