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A process-oriented model of pelagic biogeochemistry for marine systems. Part II: Application to a mesotidal estuary

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ABSTRACT

The main goal of this study is to use an integrated ecosystem model to study the role of physical, chemical and environmental parameters on the biogeochemistry of the Tagus estuary, the main estuarine system in Portugal. This work was developed as part of EU-funded INSEA project and tried to accomplish two major aims: (1) the development and implementation of a coupled modeling system capable of reproducing all the major characteristics both in physical and biological environments, and (2) to create a coastal management system based on the efficient integration of observations and biophysical models. Our results suggest that both aims were met. In this study we have used a 2D hydrodynamic application coupled to a complex ecological model presented in a companion paper which captures the state of the art of marine ecological models, and also developed during the project. Special emphasis is given to the processes governing temporal and spatial patterns of both phytoplankton and bulk properties, and the physical–biological interactions shaping their variability. The results shown in this paper are indicative of a reasonable performance of the model. It captures the complexity of the Tagus estuary and provides reasonable estimates of the biomass trends of a highly dynamic and interactive community.

1. Introduction

Estuaries are highly dynamic environments because of the high spatial–temporal variability of its biotic and abiotic conditions. For many years the complexity of these coastal systems have been tackled with numerical models constructed around simplified assumptions about the functioning of marine ecosystems. Most of these models fail to simulate important biogeochemical processes by not considering features such as the explicit carbon cycle modeling, the microbial loop dynamics, the role of key functional groups and multiple nutrient limitation to primary production. Recent developments have increased the number of processes resolved by these models (Denman, 2003; James, 2002; Moore et al., 2002; Vichi et al., 2003, 2007), and while this approach brings an overall complexity increase of the modeling tools, it provides additional knowledge on the dynamics of the systems.

This study is a preliminary attempt at implementing this approach for coastal eutrophication problems as addressed in the Data Integration System for Eutrophication Assessment in Coastal Waters (INSEA) project. Two major aims of the INSEA project were (1) the development and implementation of a coupled modeling system capable of reproducing all the major characteristics both in physical and biological environments, and (2) to create a coastal management system based on the efficient integration of observations and biophysical models.

Following this rationale we have used an integrated ecosystem model to assess the influence of some physical, chemical and environmental parameters on the biogeochemistry of the Tagus estuary (Portugal). A two-dimensional hydrodynamic model provides the physical background for an ecosystem model implemented in the same area. This work is an application of the model presented in a companion paper in this issue (Mateus, 2012-this issue), where the biogeochemistry model details and options are fully described.

This paper is organized in the following order. In Section 2 we present a description of the study area. Section 3 gives the details of the numerical experiment setup, with a brief description of hydrodynamic and pelagic biogeochemistry models, and specification of boundary conditions, initialization and forcing. Model results are presented in Section 4 and discussed in Section 5. Some final remarks are summarized in Section 6.

2. The study area

The Tagus estuary (38°44′N, 9°08′W) is the largest estuarine system on the Portuguese coast (Fig. 1), and the main estuary in terms of human occupation and use. It is a relatively shallow mesotidal system (mean tidal range of 2.2 m) with semi-diurnal tidal regime with an amplitude range between 1 and 4 m. It has a surface area of about 320 Km^2 and a mean volume of 1900×10^6 m^3. The intertidal areas

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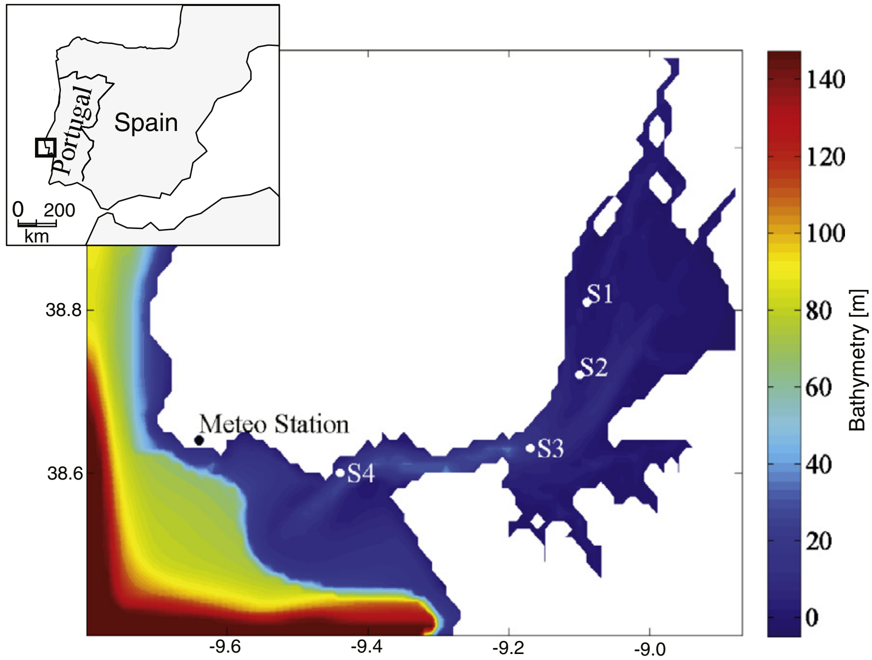

Fig. 1. The Tagus estuary: geographical location (inner caption), modeled domain (main frame) and monitoring stations (marked with dots).

are composed mainly of mudflats occupying an area of about 20 to 40% of the total estuarine area.

The hydrographic conditions of the estuary are mainly determined by the inflow of the saline water from the Atlantic and a considerable riverine input of freshwater with a clear seasonal pattern. From March to December the Tagus river has a rather constant monthly average flow of around 330 m^3s^{-1}. Higher values are recorded from January to March, sometimes above 900 m^3s^{-1}. The Tagus river is the major fresh water contributor to the estuary, but two other smaller rivers, Sorraia and Trancão, also contribute with fresh water inputs and effluent discharges from urban (over 10 WWTP), industrial, and agricultural sources.

The seasonal variability of meteorological conditions and river discharges confers to the estuary strong seasonal variability of both hydrodynamic and biogeochemical conditions. There is also a strong horizontal pattern as a result of the hydrodynamic conditions. Lower estuarine areas are characterized by a high variability, while the inner part of the estuary, with higher residence times, has more stable and homogenous conditions. The relatively high flow associated with the shallow depth prevents the formation of a late-spring thermocline, characteristic of temperate waters. Hence, there is no thermal stratification inside the estuary during spring and summer months. The system is, in general, vertically well-mixed all year around, and has a mean tidal prism of 600×10^6 m^3, about a third of the mean volume.

Limiting nutrients (nitrogen and silica) are never depleted inside the estuary, and bloom are shaped by a combination of several biotic and abiotic factors such as grazing, light ambient, residence time, etc. Several groups of primary producers can be found inside the estuary and also in the surrounding coastal waters. Despite the different composition in phytoplankton communities inside the estuary (specially Bacillariophyceae, Chlorophyceae, and Dinophyceae), diatoms dominate the phytoplankton in the entire estuary (Cabrita et al., 1999).

3. Methodology

3.1. Hydrodynamic model

The MOHID model (Coelho et al., 2002; Santos et al., 2002) was used to simulate the hydrodynamic conditions of the study area. The MOHID system employs a 3D finite-volume approach (Martins et al., 2001) using a horizontal Arakawa-C grid (Arakawa and Lamb, 1977) to perform the computations. The hydrodynamic governing equations are the momentum and the continuity equations. The hydrodynamic model solves the primitive equations in Cartesian coordinates for incompressible flows, and the horizontal and vertical advection of momentum, heat and mass is computed using a TVD-Superbee method (Vincent and Caltagirone, 1999). The MOHID system is coupled to the General Ocean Turbulence Model (GOTM) from Burchard and Bolding (2001).

3.2. Ecological model

The ecological model implemented in this study is fully described in a companion paper (Mateus, 2012-this issue). It is a biomass-based pelagic biogeochemical model based on the ERSEM biochemical modeling philosophy (Baretta-Bekker et al., 1995, 1997). The model has twelve major components: producers, consumers, decomposers, organic matter (particulate, dissolved labile and semi-labile), nutrients (nitrate, ammonium, phosphate, silicate), biogenic silica and oxygen. Trophic interactions are expressed in terms of material flow of carbon and nutrients. The model has a decoupled nutrient and carbon dynamics with explicit parameterization of carbon, nitrogen, phosphorus, silica and oxygen cycles. All living groups have variable stoichiometry of the basic constituents and chlorophyll synthesis is accounted for in producers, allowing variable C:Chla ratios. Carbon and nutrient content in non-living organic matter varies.

The model considers producers, consumers and decomposers using the Living Functional Groups (LFG) approach (Baretta and Ruardij, 1987), but instead of a fixed trophic structure, the Generic Type Model (GTM) concept developed in the model enables the user to define the types inside each LFG. While LFGs are a theoretical construct used to relate measurable biogeochemical properties with model state variables, the GTM is a model routine that allows the simulation of several types inside each LFG (Mateus, 2012-this issue). For this simulation we have considered two types of primary producers, diatoms and autotrophic flagellates, bacterioplankton and a single group of consumers (microzooplankton). The division between the