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Coupling physical and biogeochemical processes in the Río de la Plata plume

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Abstract

A coupled three-dimensional physical–biogeochemical model was developed in order to simulate the ecological functioning of the Río de la Plata estuary and plume. The biogeochemical model reproduces the nitrogen cycle between five compartments: dissolved inorganic nitrogen, phytoplankton, zooplankton, detritus and dissolved organic nitrogen. The coupling is tested in seasonal climatological configurations and for the particular year 1999. The circulation is forced with Paraná and Uruguay rivers discharges, NCEP wind and tide. The biogeochemical model includes loads of inorganic and organic nitrogen from both rivers. The model reproduces the correct tidal amplitudes in the estuary, as well as the most outstanding features of the observed horizontal and vertical structures of the salinity plume. Simulated surface chlorophyll *a* concentrations exhibit maximum values all year long seaward of the turbidity front, between the 0.5 and 15 isohalines, in agreement with SeaWiFS images of the area. The model simulates well the low primary production in the light-limited highly turbid tidal river (20 gC/m^2/yr), the high production area in the frontal zone where it can reach 500 gC/m^2/yr, and the nutrient-limited production in the outer estuary and inner shelf (300 gC/m^2/yr), with realistic values in each case. According to the 1999 model simulation, the tidal river is the location of organic nitrogen remineralization with a consequent increase of the inorganic pool. At the entrance of the frontal zone, inorganic nitrogen represents about 75% of the whole nitrogen pool, it is reduced to 50% at its sea end-member. The outer estuary has the same sink role for inorganic nitrogen, suggesting that organic nitrogen is the major form exported to the shelf.

Keywords: Physical–biogeochemical modelling; River plumes; Chlorophyll; Primary production; SeaWiFS; Río de la Plata

1. Introduction

The Río de la Plata estuary, located along the South East coast of South America, between

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Argentina and Uruguay, drains the second largest basin of the South American continent. The Paraná and Uruguay rivers are the main tributaries with more than 97% (Nagy et al., 1997) of the 22,000 m^3/s long-term mean runoff (the sixth largest in the world, Shiklomanov, 1998). Both Capitals, Buenos Aires and Montevideo, lie on either shore of the estuary. This is also a valuable system for fisheries, with its outer part being the spawning and nursery area of many fish species (Nion, 1997). The Río de la Plata system is highly sensitive to changes in nutrient loading and freshwater input, which may modify the ecosystem structure by the development of harmful algal blooms and consequent eutrophication (Nagy et al., 2002). Both Paraná and Uruguay rivers are sensitive to ENSO-induced variability in flow (Depetris and Kempe, 1990; Mechoso and Iribarren, 1992), which results from coherent ENSO-related precipitation over Southeastern South America (Ropelewski and Halpert, 1987). Over the 1983–1992 period, a noticeably increased trend in the mean river discharge, which has reached 25,000 m^3/s, has been associated to stronger ENSO events (Nagy et al., 1997).

The Río de la Plata system, as many coastal zones, is specially vulnerable to climate change. Developing adaptation and mitigation strategies to cope with such changes requires modelling as a predictive tool for the system evolution. Within the IGBP/LOICZ (Land-Ocean Interaction in the Coastal Zone) core project, two budget models have been adapted to the outer estuary (Smith, 1997) and to the frontal region of the Río de la Plata (Nagy, 2000). Such box models provide robust estimates of the variable fluxes (N and P in their case) at steady-state across boundaries, from mean in situ values of these variables. However they do not allow to study the variability of these fluxes, neither to comprehensively understand the internal coupling between physical and biogeochemical processes of the system.

Here we made a step forward by developing a system model of the area, referring to the LOICZ classification (Gordon et al., 1996). Constant increases in computer power has led to the development of fully three-dimensional (3-D) coupled physical–biological models at the shelf, coastal, and estuarine scale (see James (2002) for a review of coastal model applications and present capabilities). Such models are particularly necessary when modelling systems with strong vertical structures such as the Río de la Plata. A 3-D modelling work of the Río de la Plata has already been implemented to study the plume dispersion in climatological situations (Simionato et al., 2001). In the present paper, we coupled a biogeochemical model to a hydrodynamical model of the estuary and shelf. We used the MARS-3D circulation model developed by Lazure and Salomon (1991) to investigate coastal hydrodynamics, with an application to the Loire and Vilaine estuaries in France. Further applications of this model have been performed, one to simulate the dynamics of river plumes in the Bay of Biscay (Lazure and Jegou, 1998), and another to investigate the forcing effects on the subtidal circulation of Patos Lagoon, Brazil (Moeller Jr. et al., 2001).

Many ecosystem models, with different levels of functional complexity have been coupled to 3-D box or fine-grid physical models over coastal areas. They often include phytoplankton functional groups and multiple limiting nutrients, such as the NORWECOM model with seven prognostic variables which was used to estimate the impact of the nutrient reduction in the North Sea (Skogen et al., 1995). Models of increasing complexity were used in the investigation of eutrophication process in the Bay of Seine (Guillaud et al., 2000) or in the Chesapeake Bay (Cerco and Cole, 1993). ERSEM (Baretta et al., 1995) is one of the most complete of the actual ecosystem models, with coupling to a benthic submodel; it has been implemented for different applications in European regional seas (Allen, 1997; Paetsch and Radach, 1997; Lenhart et al., 1997; Petihakis et al., 2002). This increasing complexity has however a major drawback, which is a dramatic increase in the number of degrees of freedom combined with the lack of data for a complete validation of the different variables. For that reason and because this is one of the first attempts to model the biological activity of the Río de la Plata, we chose to keep the model structure as simple as possible, i.e. representing only the major biogeochemical pelagic variables that can be validated by available data. Consequently, major