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A modeling study examining the impact of nutrient boundaries on primary production on the Louisiana continental shelf

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ABSTRACT

Nutrient inputs to the Louisiana continental shelf (LCS) from lateral ocean boundaries can be significant, but the effect of these nutrients on LCS primary production has not been examined. Herein, we apply a three-dimensional physical-biogeochemical model to calculate nitrogen and phosphorus mass balances on the LCS and quantify the contributions of riverine and offshore nutrient inputs to primary production. A model sensitivity analysis to different offshore nutrient concentrations indicated that modeled primary production was most sensitive to boundary nitrogen concentrations, whereas changing boundary phosphorus concentrations had little effect. The primary production response also varied spatially and temporally, with its greatest response being to changing boundary nitrogen concentrations in areas furthest from the river plume, and during the late summer for all regions of the shelf when Mississippi River discharge approaches its annual minimum. These results indicate that even for river-dominated shelves like the LCS, uncertain boundary condition nutrient concentrations are likely to contribute significantly to uncertainty in modeled primary production. The modeling study highlights the need for further observational studies to understand the sources and variability of nutrients at LCS offshore boundaries and the impacts to LCS primary production.

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1. Introduction

Large seasonal discharges of nitrogen and phosphorus from the Mississippi-Atchafalaya River Basin (MARB) stimulate phytoplankton growth and accrual of phytoplankton derived organic matter on the inner Louisiana continental shelf (LCS) (Lohrenz et al., 2008; Le et al., 2014; Fry et al., 2015), which contributes to hypoxia in this system (Rabalais et al., 2002; Bianchi et al., 2010). While Mississippi River loadings to the northern Gulf of Mexico have been measured over several decades (United States Geological Survey, 2013; Battaglin et al., 2010; Aulenbach et al., 2007), much less is known about the nutrient loads flowing across the open shelf boundaries. These boundary inflows and outflows of nutrients can represent a significant source or sink for the LCS (Walsh et al., 1989; Sahl et al., 1993; Lehrter et al., 2013) and may support primary production on the middle and outer shelf (Chen et al., 2000; Lehrter et al., 2009).

Further, whereas primary production in the river plume of the LCS is correlated with river nutrient loads (Lohrenz et al., 2008), primary production in non-plume regions of the shelf is not positively correlated with river loads (Lehrter et al., 2009). These observations have led to speculation that non-river nutrient sources may be important for fueling primary production away from the river plumes and during periods of low river discharge (Chen et al., 2000). Thus, quantifying the significance of the non-river nutrient inputs to phytoplankton production is important for teasing out the impacts of land-based nutrients on this system and for elucidating the factors contributing to primary production dynamics.

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Numerical ecosystem models have proven useful for understanding the relationships between river nutrient loads and primary production on the LCS. Bierman et al. (1994) demonstrated the importance of river nutrients and light availability on the spatial and temporal distribution of phytoplankton biomass. Green et al. (2008) explored the role of nitrogen limitation in regulating primary production in the river plume, and a key conclusion was that physical dilution of river nitrate due to mixing with offshore surface water is one of the main regulators of the amount of primary production. Fennel et al. (2011) and Laurent and Fennel (2014) have also examined the roles of nitrogen and phosphorus limitation on the LCS. In all of these studies, lower nutrient concentrations resulted in less primary production and thus a reduction in the sedimentation of organic matter to the benthos. However, the potential contribution of boundary condition nutrient inflows to the shelf nutrient regime and primary production has not yet been evaluated.

In this study, we have applied a three-dimensional physical-biogeochemical model to quantify and compare the contribution of shelf boundary nutrient fluxes and river nutrient loads to LCS nutrient concentrations and primary production. The main conclusion is that the modeled nutrient concentrations and production were sensitive to changes in nutrient boundary conditions. Thus, model uncertainty due to the lack of spatial and temporal understanding of boundary nutrient dynamics is significant.

2. Methods

2.1. Model description

The Gulf of Mexico Dissolved Oxygen Model (GoMDOM) is a process-based numerical model of the northern Gulf of Mexico. The model domain encompasses the LCS and a small area east of the Mississippi River delta (Fig. 1). The model grid has an approximately 6 km by 6 km horizontal resolution and 26 vertical sigma layers. The sigma layer fractions range from 0.01 to 0.04, with higher resolution at the top two sigma layers to better account for wind and heat effects.

GoMDOM has 19 state variables: diatoms and non-diatoms phytoplankton groups; one zooplankton grazer; labile and refractory particulate organic carbon; labile and refractory particulate organic phosphorus and labile and refractory particulate organic nitrogen; dissolved organic carbon, dissolved organic phosphorus and dissolved organic nitrogen; biogenic and dissolved silica; soluble reactive phosphorus; ammonium; nitrate + nitrite; dissolved oxygen and salinity. The kinetics equations used in GoMDOM are based on the LM3-Eutro eutrophication model that was applied to Lake Michigan (Pauer et al., 2008, 2011; Melendez et al., 2009). Several new features, as described below, were made to the LM3-Eutro kinetics, namely adding dissolved oxygen as a state variable, changing the sediment equations, and improving the representation of the zooplankton and light formulations. A one-dimensional variation of this model, GoMDOM-1D, has been applied to a number of sites on the LCS (Pauer et al., 2014).

2.2. Dissolved oxygen

Dissolved oxygen was not included in the original LM3-Eutro model, but was added as a state variable in GoMDOM. Sources of dissolved oxygen are photosynthesis and exchange with the atmosphere (reaeration), while algal and zooplankton respiration, dissolved organic carbon oxidation, nitrification and sediment oxygen demand are oxygen sinks. Detailed equations used to describe these sources and sinks can be found in Pauer et al. (2014).

2.3. Zooplankton

The zooplankton mortality formulation used in the original LM3-Eutro model was replaced with a quadratic dependency on the zooplankton concentration to simulate predation by higher trophic levels (Banas et al., 2009; Cerco and Meyers, 2000). As noted by Cerco and Noel (2004), the use of a quadratic dependence reduces the phytoplankton–zooplankton biomass oscillations, providing a higher degree of stability to the phytoplankton standing crop.

2.4. Sediment fluxes

Sediment nitrate fluxes and sediment oxygen demand (SOD) were modeled using relationships developed by Lehrter et al.

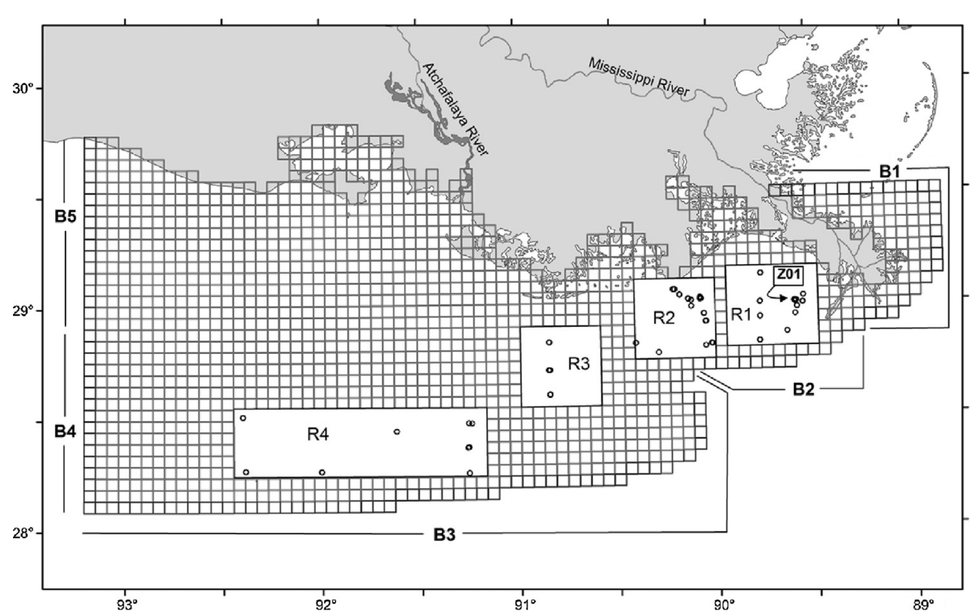

Fig. 1. The Louisiana continental shelf of the northern Gulf of Mexico study area showing the GoMDOM computational grid, the spatial regions with the sampling stations, and the boundaries. The four spatial regions are the Mississippi Plume (region 1, R1), Mississippi Intermediate (region 2, R2), River Transition (region 3, R3) and Outer Continental Shelf (region 4, R4). The five boundaries are Eastern (B1), Trench (B2), Offshore (B3), Outer western (B4) and Inner western (B5).