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Water column oxygen dynamics within the coastal gradient in the northeastern Gulf of Mexico inner shelf

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ABSTRACT

This study quantified the coastal gradients of salinity, temperature, nutrients, chlorophyll and oxygen along a transect from 5 to 18 m depth in the northeastern Gulf of Mexico (NEGOM) through measurements of water column profiles over 4.5-years and recordings of probes mounted at 0.5 m above the seafloor over 2-years. The main goal was to determine the influences of the coastal gradients on water column oxygen concentration distributions. Apalachicola River discharge affected the study region as reflected in low-salinity surface layers. Decreasing rates of oxygen production and consumption from the shallowest station to the deepest station were attributed to measured coastal gradients of nutrients and the decreasing influence of seafloor processes with increasing distance from shore. Water column photosynthetic oxygen production at a realistic irradiance of 200 $\mu E\ m^{-2}\ s^{-1}$ ranged from 0.5 to 4.5 mmol $O_2\ m^{-3}\ h^{-1}$, and dark consumption rates from 0.2 to 2.6 mmol $O_2\ m^{-3}\ h^{-1}$. Based on July irradiance profiles and associated production and consumption rates, the water column in July 2009 produced 0.9 (1SD=0.2) $g\ C\ m^{-2}\ d^{-1}$ with rates remaining relatively constant over the length of this coastal transect. Benthic boundary layer production reaching 26–43% of the surface layer production underlines the role of the benthic boundary layer for production in the inner shelf. Oxygen in the benthic boundary layer never decreased below 73% air saturation, and hypoxic zones, as reported from shelf areas west of the study region, did not occur. Oxygen production exceeded consumption suggesting a net autotrophic system.

1. Introduction

Understanding the oxygen dynamics and controls of production and consumption processes in the coastal zone is central for assessing the functioning of the shelf in the cycles of matter and for identifying trends that may indicate fundamental changes in the ecosystem (Canfield et al., 1993; Glud, 2008). Oxygen is an indicator of the fate of carbon and carbon flux, of system metabolism in a changing climate, and a respondent to external forcing functions. Oxygen thus is also an important indicator of ecosystem health, e.g. coastal eutrophication fueled by riverine runoff of fertilizers and the burning of fossil fuels caused an exponential spread of coastal hypoxic zones since the 1960s (Diaz and Rosenberg, 2008). Oxygen concentrations determine the ability of an ecosystem to sustain fisheries or whether harmful sulfides may be produced. Bottom waters are of particular interest in terms of oxygen because the settlement of decaying plankton can cause high oxygen consumption rates at the seafloor, a process that is most pronounced in upwelling areas and coastal waters prone to planktonic blooms resulting from eutrophication (Lohrenz et al. 1997, Rabalais et al., 1996). Understanding the current drivers of oxygen dynamics therefore can enable us to identify and quantify other anthropogenic influences in the future as those that may result from ocean warming, increases in carbon dioxide, changes in nutrient discharge to the ocean or catastrophic events (McQuatters-Gollop et al., 2009). A key requirement for the evaluation of change in oxygen and its magnitude is the availability of baseline data that can be used as reference (Duarte et al., 2009). In light of the recent major crude oil spill in the northern Gulf in 2010, it has become apparent that a record of baseline oxygen dynamics in this coastal region did not exist. Here we present results of a long-term study that focused on water column and boundary layer oxygen dynamics in the coastal gradient of the northeastern Gulf of Mexico (NEGOM) inner shelf.

Abbreviations: NEGOM, Northeastern Gulf of Mexico; dw/dw, dry weight to dry weight ratio; PAR, photosynthetically active radiation; Chl, chlorophyll a; NTU, nephelometric turbidity units; SD, 1 standard deviation

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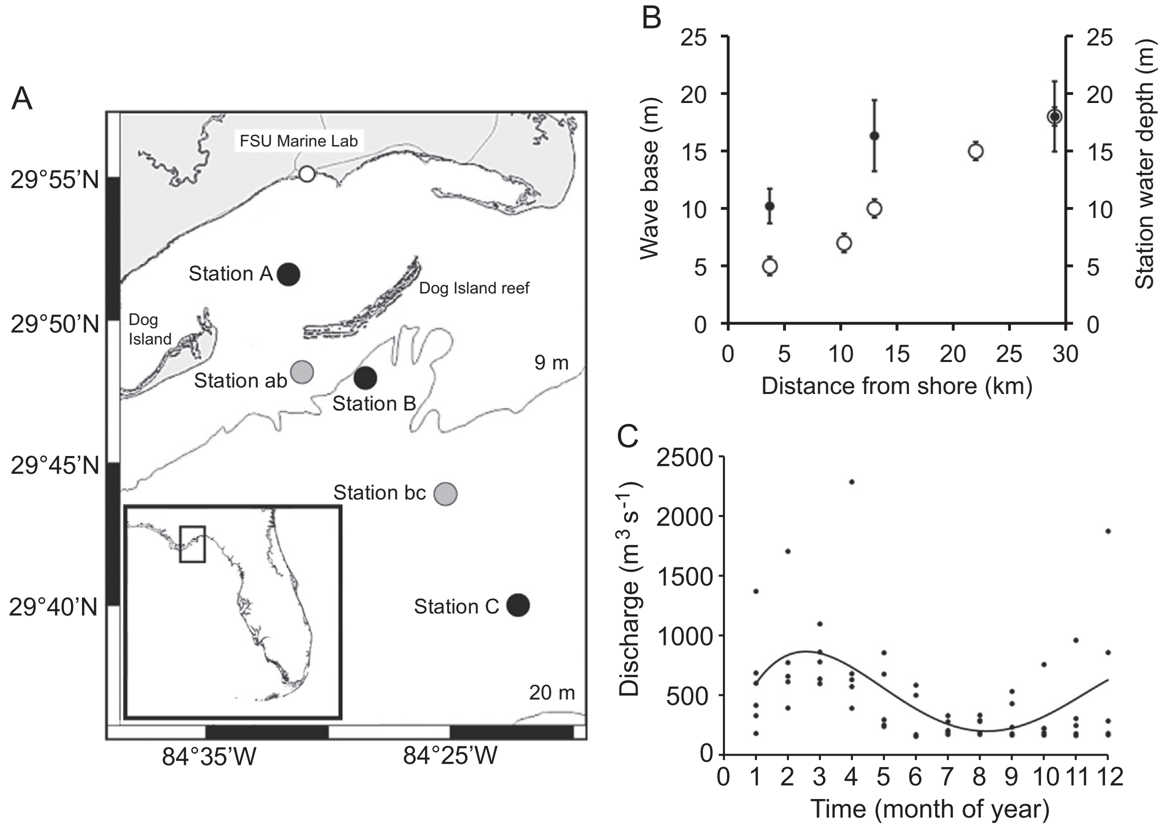

Fig. 1. A. Locations of the stations along the study transect. Bottom mounted instruments were placed at Stations A, B and C (black circles). Additional vertical water column profiling was done at Stations ab and bc (gray circles). B. Station mean water depth (open circles) and mean depth of the wave base (solid circles) with distance from shore. The wave base is defined as the depth at which the wave orbital water movement decreased to $e^{-\pi} \approx 0.04$ or 4% of the surface value (Dean and Dalrymple, 1991) and is estimated as wavelength/2. Whiskers denote 1SD. C. Apalachicola river discharge 2007–2011: Maximum March 800 $m^3 s^{-1}$, minimum August 180 $m^3 s^{-1}$, data from USGS http://waterdata.usgs.gov/nwis/; black line indicates best fit 4th-order polynomial function.

The NEGOM, which includes the northern section of the West Florida Shelf (Fig. 1), is a shallow, broad continental margin that is about 300 km wide at Florida's Big Bend coast (Weisberg et al., 2005). Little information is available on the processes that affect oxygen in the shelf waters of the NEGOM, in contrast to the well-studied northwestern Gulf of Mexico, where the Mississippi outflow causes large oxygen fluctuations and coastal hypoxic zones (Rabalais et al., 2007, 2002; Turner et al., 2006). The NEGOM is influenced by the Apalachicola River, the largest river in Florida, which drains a watershed of approximately 50,000 km^2, including the Atlanta metropolitan area, and discharges 140 to >5000 m^3 s^{-1} into the Gulf of Mexico (Livingston, 2000). Occasionally Mississippi River water moves eastward and can affect the NEGOM and West Florida Shelf (He and Weisberg, 2002b). Currents in the NEGOM shelf are driven mainly by tidal forces and wind (Marmorino, 1983a, 1983b). During fall and winter, southeasterly winds produce downwelling, while in spring and summer, the wind regime is predominantly northwesterly favoring upwelling (He and Weisberg, 2002a). River discharge and upwelling supply nutrients to the NEGOM shelf, and the ensuing algal blooms can periodically extend from the Big Bend region far into the eastern Gulf of Mexico (Gilbes et al., 2002; Morey et al., 2009). Nonetheless, the reported water column primary productivity rates south of this study region on the West Florida Shelf are relatively low, as reflected in oxygen production rates ranging from 0.02 to 0.21 mmol O_2 ml^{-3} h^{-1} (Vargo et al., 1987; Wanninkhof et al., 1997).

This study was initiated to address the lack of oxygen concentration data and information on oxygen dynamics in the inner shelf of the NEGOM. The main goal of this work was to determine the influences of the coastal gradients (in salinity, temperature, nutrients, chlorophyll) on water column oxygen concentration distributions, because so far, the dynamics of oxygen in the NEGOM and the factors influencing these dynamics were poorly quantified. Oxygen measurements in the water column were conducted over 4.5-years, and over 2-years at 0.5 m above the seafloor to determine magnitudes and the spatial and temporal changes of dissolved oxygen along a transect from the nearshore (3.7 km off shore, 5 m water depth) to 29 km offshore (18 m depth). Our results provide baseline data for future studies in the NEGOM, a region anticipating rapid coastal development.

2. Methods

2.1. Study transect

Our measurements were conducted along a transect in the NEGOM extending 29 km in a southeastern direction from the coast off St. Teresa, FL, to K-Tower, a retired US Air Force tower that now is used as a hydrographic and meteorological measurement station (Fig. 1; White et al., 2011). The transect was located approximately 50 km east of the mouth of Apalachicola River that discharges into Apalachicola Bay, an estuary enclosed by barrier islands. Due to this proximity, the Apalachicola River and Bay waters influenced the water composition at the transect. During the study period (2007–2011), the average nutrient concentrations in the bay were 11.8 (1SD=12.1) μmol l^{-1} inorganic nitrogen, 0.15 (1SD=0.10) μmol l^{-1} orthophosphate, and 21.5 (1SD=12.5) μmol l^{-1} silicic acid (Apalachicola National Estuarine Research