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Composition and fluxes of particulate organic matter in a temperate estuary (Winyah Bay, South Carolina, USA) under contrasting physical forcings

Miguel A. Goñi [a,*], George Voulgaris [b], Yong H. Kim [c,1]

[a] College of Oceanic and Atmospheric Sciences, Oregon State University, 104 Ocean Admin. Building, Corvallis, OR 97331, USA
[b] Department of Earth and Ocean Sciences, Marine Science Program, University of South Carolina, Columbia, SC 29208, USA
[c] Horn Point Laboratory, University of Maryland Center for Environmental Science, Cambridge, MD 21613, USA

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ABSTRACT

To understand the role that physical processes play on the biogeochemical cycles of estuaries, we conducted intense field studies of the turbidity maximum region within a partially mixed estuary (Winyah Bay, SC, USA) under contrasting conditions of river discharge, tides and wind. Water samples and hydrographic data were collected at different depths and locations along the main channel over several tidal cycles during several cruises to Winyah Bay. Tidal variations in current speed, salinity, total suspended solid concentrations were measured within each cruise and were consistent with estuarine circulation processes. Salinity and total suspended solid concentrations ranged from 0 to 32 and from 20 to over 500 mg L^{-1}, respectively, with the highest salinity and total suspended solid values measured during periods of low river discharge. In fact, comparison of tidally averaged salinity and total suspended solid concentrations revealed marked differences among cruises that were negatively correlated to river discharge and SW wind speed. Moreover, significant contrasts in the chemical compositions of suspended particles were evident among periods of contrasting river discharge and wind regime. For example, the weight percent organic carbon content of suspended particles ranged from 1 to over 6% and displayed a positive correlation with river discharge. Similarly, both the molar carbon to nitrogen ratios (10 to 20 mol:mol) and stable carbon isotopic compositions (−25 to −29‰) of the suspended organic matter varied significantly as a function of discharge and wind. Such trends indicate that in Winyah Bay low river discharge and steady SW winds promote resuspension of bed sediments from shallow regions of the estuary. These materials contain highly altered organic matter and their incorporation into the water column leads to the observed trends in suspended particle concentrations and compositions. Furthermore, these conditions result in net landward fluxes of salt, sediment and particulate organic matter throughout most of the water column, promoting efficient trapping of materials within the estuary. Our results illustrate the fundamental connection between physical forcings, such as discharge and wind, sediment transport processes and the cycling of biogeochemical materials in estuarine environments.

1. Introduction

Placed between continents and oceans, estuaries are critical interfaces in the exchange of biogeochemically relevant materials (e.g., freshwater, sediment, nutrients, organic matter) between the land and the sea. The cycling (i.e., production, transport and degradation) of organic matter (OM) in estuaries fundamentally affects the net fluxes of chemical constituents (e.g., carbon, nitrogen, trace metals) across the land/sea interface (e.g., Smith and Hollibaugh, 1993; Turner and Millward, 2002). Understanding what factors control the overall fate (i.e., mineralization, export and sequestration) of OM in these systems is challenging because estuaries are extremely dynamic both physically and biogeochemically (e.g., Geyer et al., 2004; Hoffman and Bronk, 2006; Middelburg and Herman, 2007; Jay et al., 2007a,b). A salient feature of estuaries is the estuarine turbidity maximum (ETM), which forms as a result of gravitational circulation, tidal asymmetries and stratification and can act as an efficient trap for particulate materials (e.g., Allen et al., 1980; Geyer, 1993; Jay and Musiak, 1994; Sanford et al., 2001; Chant and Stoner, 2001). In the ETM, particles are subjected to periodic resuspension that facilitates sorption/

* Corresponding author.
E-mail address: mgoni@coas.oregonstate.edu (M.A. Goñi).
[1] Present address: Applied Science Associates, South Kingstown, RI, USA.

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desorption reactions as well as the re-oxidation of metal-oxide phases, which can enhance the degradation of OM (e.g., Aller, 1994, 1998; Hedges and Keil, 1999; Murrell and Hollibaugh, 2000; Abril et al., 2002).

The forcings that control general estuarine circulation and ETM dynamics, including river discharge, tidal amplitude and wind, are highly variable both spatially (i.e., within and among estuaries) as well as temporarily over a broad range of time scales (e.g., semi-diurnal, seasonal, inter-annual). Such variability leads to marked differences in the processing of materials within a given estuary or among different estuarine systems (see Geyer et al., 2004 and references therein). Furthermore, the input of OM to these systems can be highly heterogeneous both in magnitude and composition over the same period (e.g., Hopkinson et al., 1998; Goñi et al., 2003; McCallister et al., 2004, 2006). Hence, the inherent reactivity of OM in these systems is also highly variable over both spatial and temporal scales. Combined, the physical and biogeochemical heterogeneity displayed by estuaries can lead marked contrasts in the net fluxes of OM and associated materials (e.g., nutrients, inorganic carbon) measured at any given point or time (e.g., Cai and Wang, 1998; Raymond et al., 2004; Goñi et al., 2005).

To assess the biogeochemistry of estuaries, process-based studies need to take into account both the temporal and spatial variability that characterizes these systems. Given the complexity of the processes described above, the goal of this field-based study is to elucidate the role that physical processes play on the cycling of particulate OM in the vicinity of the ETM within Winyah Bay (SC, USA). Specifically, our objectives are to identify the characteristics and estimate the transport of particulate OM in Winyah Bay under contrasting river discharge, tidal amplitude and wind regimes. We focus our interpretations on the mechanisms and factors that explain the spatial and temporal variability in net material fluxes in this system. Our study expands on the results from previous investigations of OM composition and fluxes (e.g., Goñi et al., 2003, 2005) and physical oceanographic characteristics of Winyah Bay (e.g., Kim and Voulgaris, 2005, 2008) by presenting new biogeochemical compositional data in the context of estuarine dynamics.

2. Materials and methods

2.1. Physical setting

Winyah Bay, South Carolina (see Fig. 1) is a partially mixed estuary with a longitudinal salinity gradient of approximately 1 km^{-1} and with absolute salinities controlled by river discharge and by wind-induced coastal setup/down processes (Kim and Voulgaris, 2005). It is one of the largest estuarine systems on the eastern coast of the U.S., with a drainage area of 47,060 km^2, a total length of

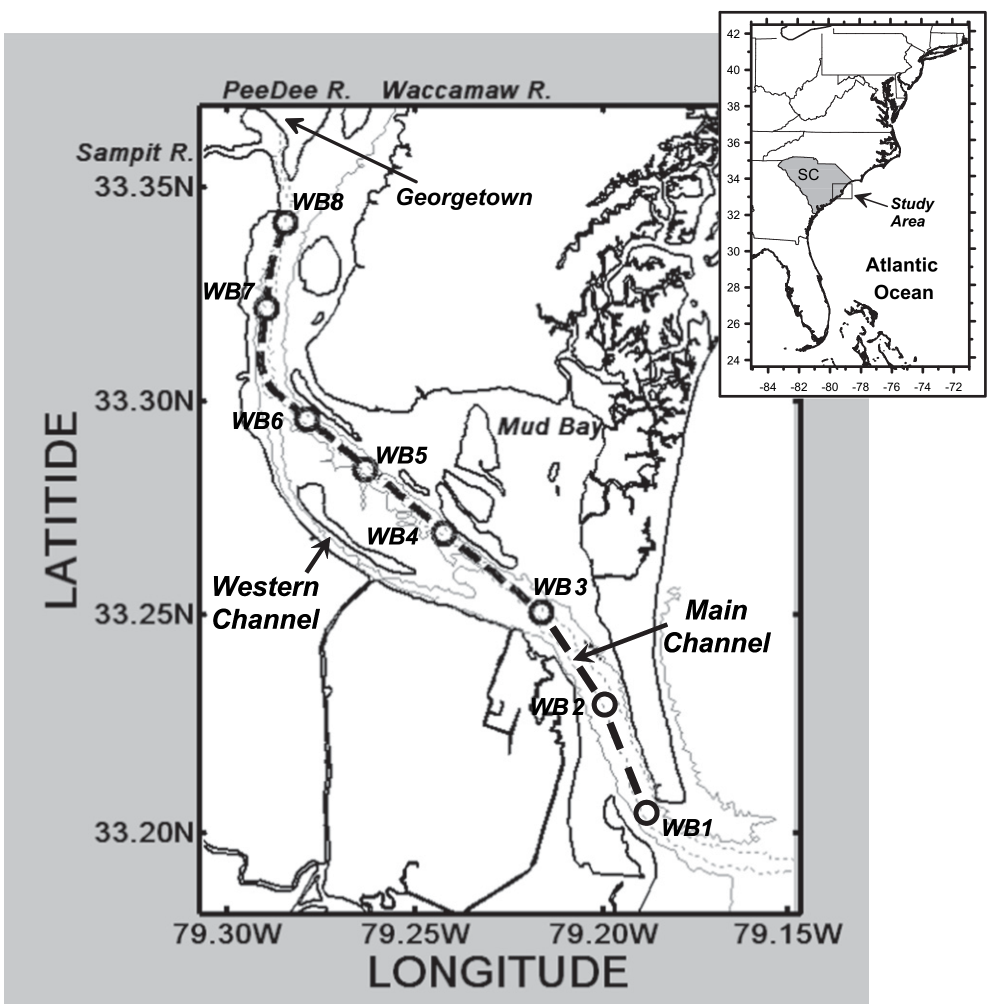

Fig. 1. Map of Winyah Bay. The locations of the main channel, the western channel, Mud Bay and the city of Georgetown are indicated along with those of stations (WB1–WB8) occupied during the various cruises.