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Hydrodynamics and sediment transport in a southeast Florida tidal inlet

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Abstract

A three-dimensional ocean circulation model is used to investigate the hydrodynamics of a tidal inlet and deltas system in Southeast Florida, and to understand the consequences for suspended and bedload sediment transport patterns. The model reproduces observed tidal currents and provides insight about residual currents caused by spatial asymmetries in the inlet throat and tidal deltas during ebb and flood flows. A particle-tracking approach for suspended and bedload sediment transport is used to simulate deposition patterns for different particle sizes. The simulation results qualitatively correlate with the distribution of sediment characteristics within the tidal inlet and deltas system and demonstrate sensitivity to the choice of advection velocities (e.g., near-bottom versus depth-averaged) and regions of sediment origin. Furthermore, the distinction between suspended and bedload transport as a function of particle size indicates significant differences in deposition patterns and their potential connection to geomorphologic features of the tidal inlet and deltas system.

Keywords: tidal inlets and deltas; tidal currents; residual flow; sediment transport; sediment distribution; numerical circulation model

Regional index term: USA; Southeast Florida; Miami; Biscayne Bay; Bear cut

1. Introduction

Flows in tidal inlets have been extensively studied, particularly along the east coast of the United States (e.g., Kana et al., 1999) and in the North Sea (e.g., van de Kreeke et al., 1997). Since tides are typically the dominant hydrodynamic forcing, considerable effort has been invested in understanding the impact of tidal asymmetry and residual currents in inlets and estuaries, as well as their linkages to geomorphology and sediment transport (e.g., van Leeuwen et al., 2003; van de Kreeke and Himba, 2005). Hydrodynamic and sediment transport models have further demonstrated the importance of spatial asymmetries and residual flows associated with tidal currents on sediment relocation in inlets and estuaries (e.g., Ridderinkhof, 1988, 1989; Mallet et al., 2000; van Leeuwen and de Swart, 2002). In parallel, dynamical models have been used to investigate initial seabed changes and long-term morphological development in tidal inlets (e.g., Wang et al., 1995). Simulations of barotropic (i.e., depth-integrated) tidal flow in idealized and realistic inlet systems have also been used to quantify the temporal and spatial variability of along- and cross-stream momentum balances (Hench and Luettich, 2003).

Since previous modeling studies have generally concentrated on the two-dimensional characteristics of the tidal currents and used depth-averaged velocities to compute sediment transport, the focus of the present study is to incorporate the full three-dimensional characteristics of the tidal

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and wind-driven currents into the computation of suspended and bedload transport mechanisms. As such, this work contributes to emerging efforts targeted towards the use of three-dimensional hydrodynamic models to predict sediment transport and morphodynamics in realistic configurations (e.g., Lesser et al., 2004). Here, the fundamental hydrodynamic characteristics of a Southeast Florida tidal inlet are investigated using a three-dimensional coastal ocean model. The spatial and temporal variability of the simulated fields is analyzed to describe the full vertical structure of the flow. In addition, a Lagrangian particle-tracking approach is used to model suspended and bedload sediment transport as a function of grain size attributes. Deposition patterns from the particle transport model are qualitatively compared to observed distributions of sediment characteristics and geomorphologic features in the tidal inlet and deltas system.

2. Study domain

Located on the southeastern coast of Florida just offshore Miami, Bear Cut is a naturally occurring inlet, formed within a break of the Key Largo Limestone between two barrier islands, Virginia Key and Key Biscayne (Fig. 1A). The tidal inlet and associated deltas are situated on a narrow continental shelf, 7 km landward of the deep Straits of Florida. Landward of the barrier island complex is the broad (ca. 6 km near Bear Cut), shallow (2 to 3 m on average) lagoon of Biscayne Bay. Historically, while no significant southward migration of the inlet has been observed, sediment accretion has narrowed Bear Cut by ca. half of its width over the past two centuries. Erosion most noticeably occurred near the northeastern tip of Key Biscayne and along the seaward coastline of Virginia Key. Erosion related to dredging, filling, and seawall construction activities near the southern tip of Virginia Key have also contributed to the creation of a new flood channel.

The Bear Cut tidal inlet (Fig. 1B) includes the geomorphic elements analogous to those documented in other tidal inlet and deltas systems: flood delta, inlet throat, and ebb delta (terminology of Hayes, 1980). The flood delta includes numerous broad sub-lobes cut by narrow channels, whereas the ebb delta has one large central lobe with a main channel and a marginal channel on each side of the lobe. The inlet throat comprises a main channel and two sinuous channel margin bars rising 2 to 4 m above the bottom. The length (measured from flood delta

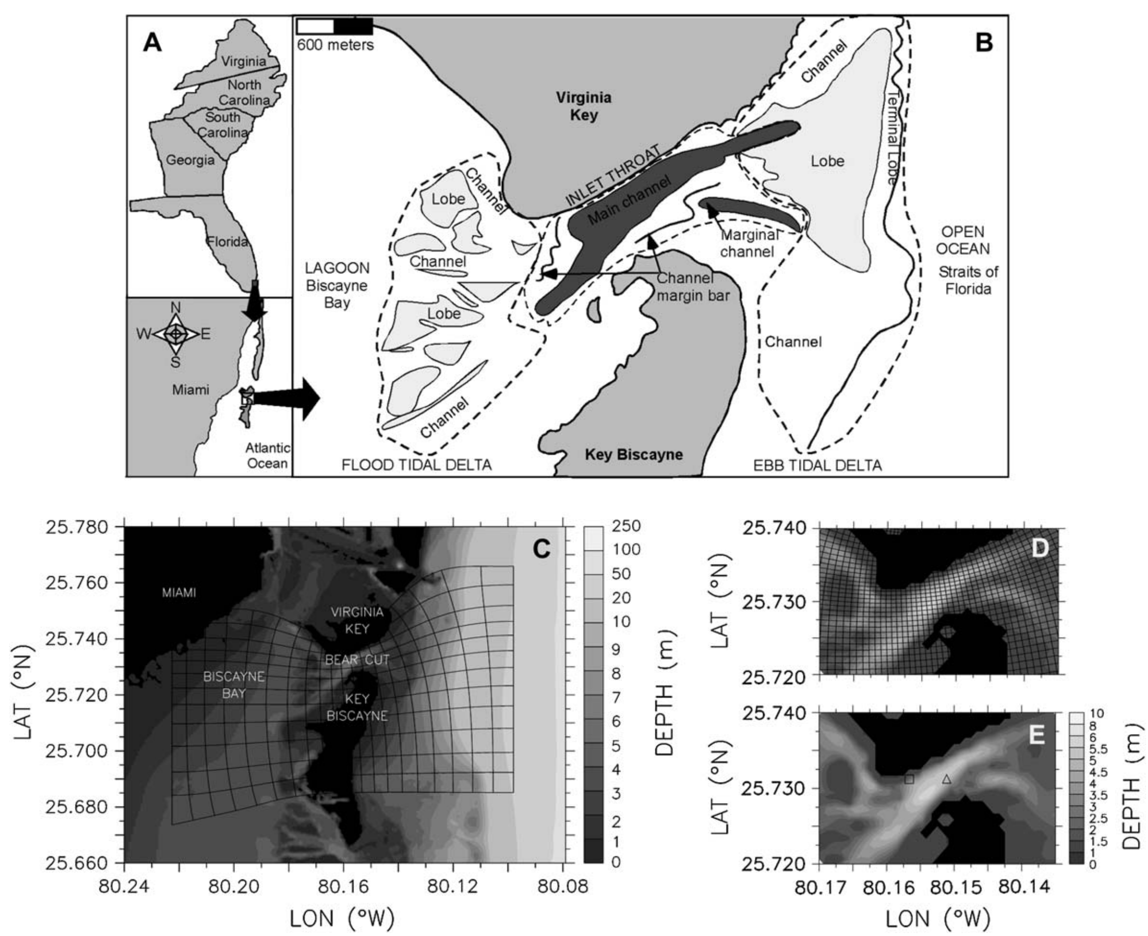

Fig. 1. Bear Cut tidal inlet and deltas system. (A) Location map of the southeastern coast of the United States, Florida, and Miami-Dade County (Bear Cut is located just offshore of Miami between Virginia Key and Key Biscayne). (B) Schematic map of the general geomorphic attributes for Bear Cut and associated ebb and flood tidal deltas. (C) Model domain and computational grid (subsampled by 5 for clarity) with bottom topography (grayscale: depth in meters) for Bear Cut tidal inlet system and surrounding region. (D) Details of computational grid (full resolution) in Bear Cut tidal inlet with bottom topography (grayscale: depth in meters). (E) Locations of in-situ observations: Virginia Key tide gauge (square) and bottom-mounted ACDP (triangle).