[5] In only a few studies, process-based models have been used to study the dynamics of ebb-tidal deltas. Most of these studies focus on the hydrodynamics [*Stommel and Farmer*, 1952; *Awaji et al.*, 1980; *van Leeuwen and de Swart*, 2002; *Hench and Luettich*, 2003]. These studies identified and explained the observed asymmetry in flow patterns seaward of tide-dominated inlets during flood and ebb. They also demonstrated the existence of residual circulation cells at the seaward side of the tidal inlet.

[6] The morphodynamics of ebb-tidal deltas have been studied less extensively. Symmetric deltas are believed to form when the ebb jet removes sediment from the entrance of the inlet and deposits it on the seaward side [*Oertel*, 1972; *FitzGerald*, 1996]. State-of-the-art process-based models have been used to study the morphodynamic evolution of asymmetric ebb-tidal deltas under various forcing conditions [*Wang et al.*, 1995; *Ranasinghe and Pattiaratchi*, 2003; *van Leeuwen et al.*, 2003; *Siegle et al.*, 2004]. However, in these studies the concepts as discussed by *Oertel* [1972] and *FitzGerald* [1996] were not reproduced and the exact mechanisms that cause and maintain ebb-tidal deltas were not identified.

[7] In view of the aim of the present study, the results of *van Leeuwen et al.* [2003] are of special interest, since they suggest that ebb-tidal deltas can be interpreted as morphodynamic equilibrium solutions (no evolution in time of the bottom), even in the absence of waves. They simulated the temporal evolution of the bathymetry of a tidal inlet system, starting from a state without a delta. During the simulation an asymmetric ebb-tidal delta developed and after a long time ($\sim$500 yr) the bathymetric changes decreased. Because of numerical resolution problems a true morphodynamic equilibrium was not reached.

[8] Motivated by these results, the specific objectives of the present paper are twofold. The first is to develop a morphodynamic model that contains only the physical processes that are essential for the existence of an equilibrium bathymetry that resembles an ebb-tidal delta. The bottom pattern together with the corresponding hydrodynamics and sediment transport patterns comprises a so-called morphodynamic equilibrium. The second objective is to investigate the characteristics of the modeled bottom patterns (e.g., channel-shoal pattern, sand volume, etc.) and compare them with field data of ebb-tidal deltas. Since the focus of this study is on gaining fundamental knowledge rather than a detailed simulation of the features, an idealized model will be developed and analyzed. The idealized model describes explicit feedbacks between the water motion and the sandy bottom in case of symmetric tide-dominated inlets. All processes that cause asymmetry (Coriolis force, obliquely incident waves, and large-scale pressure gradients in alongshore direction) are ignored.

[9] To obtain equilibrium solutions of the model a continuation technique is used. This technique is often used in dynamical systems theory to explore the dependence of solutions on parameter values [*Manneville*, 1990]. It was successfully applied by *Schuttelaars and de Swart* [2000] and *Schramkowski et al.* [2004] to compute morphodynamic equilibria in sheltered tidal embayments.

[10] The results of the idealized morphodynamic model are compared with both the observations and the results of a hydrodynamic modeling study of the Beaufort Inlet (North Carolina, United States) [*Hench and Luettich*, 2003]. The bathymetry of Beaufort Inlet is shown in Figure 1. The inlet has a width of B = 1 km. The ebb-tidal delta is almost symmetric with respect to the midaxis through the inlet. The ebb channel is maintained at a depth of 10 m. The region of the ebb-tidal delta is shallow with typical depth of 2–10 m. Maximum M_2 cross-shore currents are in the order of 1 ms^{-1}.

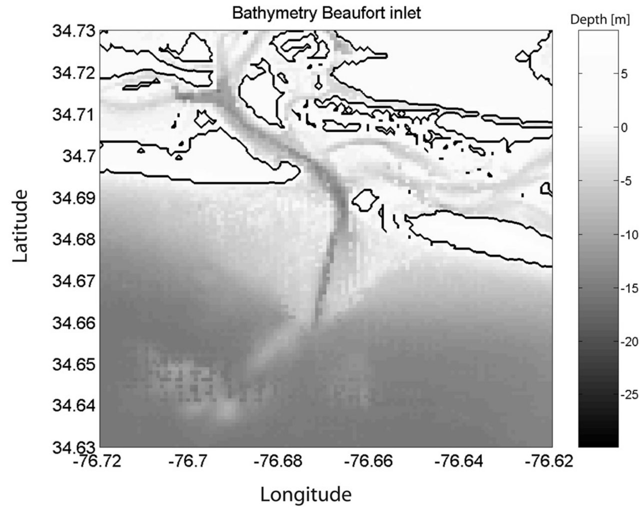

Figure 1. Bathymetry of Beaufort Inlet, North Carolina, United States. The depth is in meters. The solid lines denote the zero contour line. The width of the inlet is B = 1 km. The data are taken from NOAA's coastal relief model (available at http://www.ngdc.noaa.gov/mgg/gdas).

[11] The paper is organized as follows. In section 2 the physical model is described. The methods that are used to calculate the morphodynamic equilibria are introduced in section 3. In section 4 the results are presented. The sensitivity of results to model parameters is studied in both sections 4 and 5. The physical mechanisms are studied in section 6. Section 7 contains the discussion and the conclusions.

2. Model

2.1. Domain

[12] The model domain consists of a coastal sea that is bounded by a straight coast bisected by one inlet with width B. A Cartesian coordinate system is chosen, with the x, y, and z axes pointing in the cross-shore, alongshore and vertical direction, respectively. The coastline is located at $x = 0$, while the center of the inlet is located at $(x, y) = (0, 0)$ (Figure 2a). The location of the bottom is denoted by $z = -H$, where H is the water depth with respect to $z = 0$. In the regions far away from the inlet the water depth is assumed to be alongshore uniform with a constant depth H_0 at the coast and increasing exponentially to $H_s > H_0$ at the shelf break (Figure 2b). Figure 3 shows three cross-shore profiles taken along stretches of the U.S. east coast that are relatively far away from any tidal inlet. The profiles can be approximated by

$$H_R(x) = H_0 + (H_s - H_0)\left(1 - e^{-x/L_s}\right). \quad (1)$$