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Two-dimensional hydrodynamic modeling of circulation in Great South Bay and New York Bight

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ABSTRACT

A two-dimensional depth-averaged boundary-fitted hydrodynamic model is used to study circulation in Great South Bay and New York Bight Region. The model domain included portions of New York Bight from Cape May, New Jersey to Montauk Point at the end of Long Island Sound, New York Harbor, Great South Bay and the adjoining rivers in New York and New Jersey. The model forcing functions consisted of tidal elevations along the open boundaries and winds. Model predictions of surface elevations at Fire Island Inlet and Moriches Inlet Coast Guard Stations showed good comparison with observations, with correlation coefficients exceeding 0.960. The simulated tidal currents showed good comparisons with observations with root mean square errors less than 10% and correlation coefficients exceeding 0.910. The model predicted low-frequency currents showed favorable comparison with observations, with correlation coefficients of 0.808 and 0.605, respectively for the east–west and north–south components. Observations and model simulations show that the subtidal currents with speeds of 10–20 cm/s are generated due to alongshore wind over the continental shelf.

1. Introduction

Great South Bay (Fig. 1) is about 40 km long with widths varying between 2.5 km to 8 km with an average depth of 1.3 m at mean low water. Fire Island Inlet, 6 km long, serves as a major passage for exchange of water between Great South Bay and Atlantic Ocean. Great South Bay also exchanges small amounts of water through Jones Inlet and Moriches Inlet. The average fresh-water discharge into Great South Bay is 12 m^3/s (Wong, 1982). Great South Bay is vertically well-mixed due to the shallowness of the bay and the small fresh water input. Wong (1993) applied the Coastal Area Finite Element model (CAFÉ), one of the earliest finite element shallow water circulation models (Wang and Connor, 1975) to study the exchange between Great South Bay and its surrounding waters.

A two-dimensional (vertically averaged), tide and wind-driven hydrodynamic model is undertaken in the present study, since Great South Bay is well mixed (Wong, 1993). However, other areas of the modeling domain may not be well mixed. Hence, depth-averaged modeling used in this study is an approximation that appears to be sufficient for tide driven circulation modeling but less so for wind and buoyancy-driven circulation. The model domain for the present study encompasses portions of New York Bight from Cape May, New Jersey to Montauk Point in Long Island Sound, New York Harbor, Great South Bay and the adjoining rivers in New York and New Jersey. The boundary-fitted hydrodynamic model (Muin and Spaulding, 1996, 1997a), which has the capability to use a variable grid resolution with fine resolution in the areas of interest, is used to model the circulation in the study area. The model used in this study has been successfully used to simulate hydrodynamic circulation in Mount Hope Bay (Swanson et al., 2006), Providence River (Muin and Spaulding, 1997b), Bay of Fundy (Sankaranarayanan and McCay, 2003a) and San Francisco Bay (Sankaranarayanan and McCay, 2003b) and Buzzards Bay (Sankaranarayanan, 2007). The model solves a coupled system of partial differential prognostic equations describing conservation of mass, momentum, salt and temperature in a generalized non-orthogonal boundary-fitted coordinate system. The equations of continuity and motion on a spherical coordinate system are given below.

Continuity equation

$$\frac{\partial \zeta}{\partial t}+\frac{1}{R\cos\theta}\frac{\partial UD}{\partial \phi}+\frac{1}{R}\frac{\partial VD}{\partial \theta}-\frac{VD}{R}\tan\theta=0 \quad (1)$$

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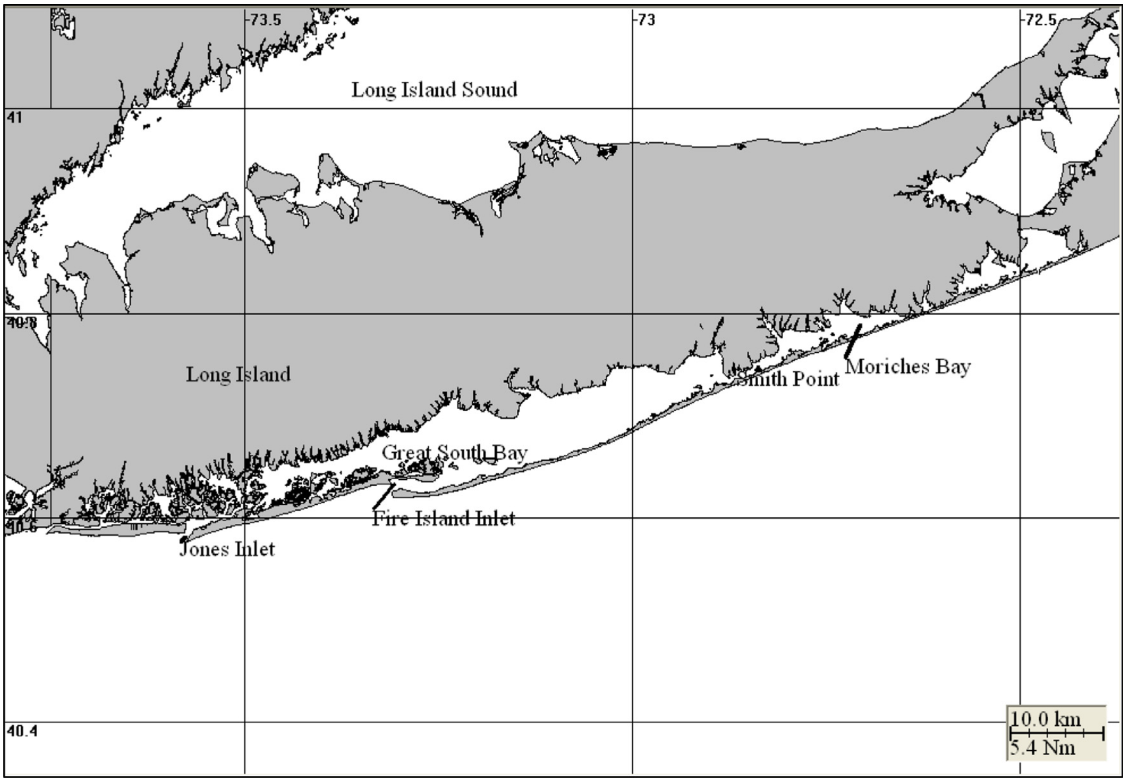

Fig. 1. Study Area Showing Great South Bay, New York.

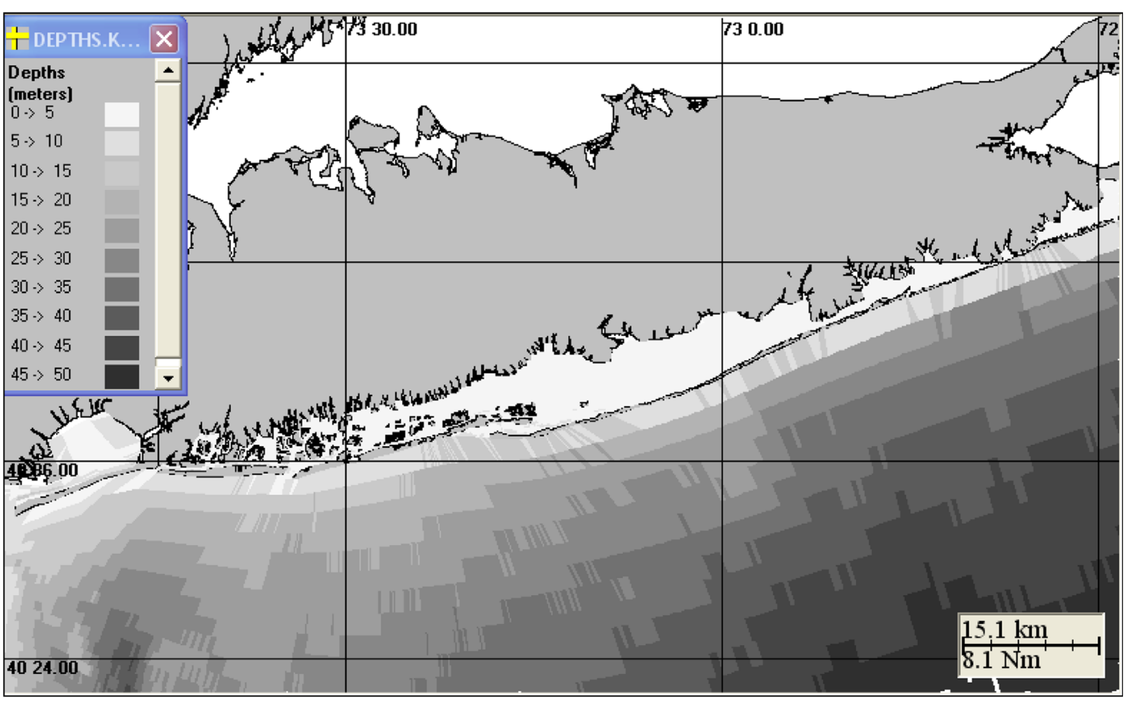

Fig. 2. Bathymetry of the study area.

Momentum equation in the ϕ-direction

$$\frac{\partial UD}{\partial t}+\frac{1}{R\cos\theta}\frac{\partial UUD}{\partial\phi}+\frac{1}{R}\frac{\partial UVD}{\partial\theta}-\frac{UVD}{R}\tan\theta-fVD=-\frac{gD}{R\cos\theta}\frac{\partial\zeta}{\partial\phi}+\frac{\tau_{s\phi}-\tau_{b\phi}}{\rho_0} \quad (2)$$

Momentum equation in the θ-direction

$$\frac{\partial VD}{\partial t}+\frac{1}{R\cos\theta}\frac{\partial UVD}{\partial\phi}+\frac{1}{R}\frac{\partial VVD}{\partial\theta}-\frac{UUD}{R}\tan\theta+fUD=-\frac{gD}{R}\frac{\partial\zeta}{\partial\theta}+\frac{\tau_{s\theta}-\tau_{b\theta}}{\rho_0} \quad (3)$$