CHAPTER 328

Modeling Tidal Circulation in Florida Bay

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Abstract

A preliminary modeling study on tidal circulation in Florida Bay has been conducted, based on a set of high resolution (20 meters x 20 meters) bathymetric data and a comprehensive set of water level data for Florida Bay obtained by the Everglades National Park in 1993 and 1994. Using thc data and a 3-D curvilinear-grid model developed by Sheng (1989, 1994), we conducted preliminary model simulations of tidal, wind-driven and density-driven circulations in Florida Bay (Sheng et al. 1995). This paper presents some results of tidal simulation and comparison with tidal data. The results indicate that the 3-D model is capable of simulating many of the observed circulation features in Florida Bay, including tidal amplitude, tidal phase and residual circulation. Additional work is being conducted with the use of a very fine 50m grid and a robust wetting-and-drying scheme.

Introduction

Florida Bay is a shallow coastal water body located at the southern tip of Florida. It is adjacent to the western Florida Shelf and is separated from the deep Florida Strait by the Florida Keys. In the past few years, Florida Bay has undergone substantial changes in the form of major seagrass die-off and massive algal bloom. Due to the lack of understanding of the extremely complex ecosystem, it is unclear presently as to how Florida Bay can be restored (Johnson and Fennema 1989). One restoration plan, which is based on the assumption that reduced freshwater supply and increase in hypersalinity (salinity reaching up to 35-50 ppt) has caused the seagrass die-off and algal bloom (Figure 1), is to increase the inflow of freshwater into Florida Bay from its northeastern shore. In order to determine the soundness of this

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restoration plan, it is essential to have a quantitative understanding on the circulation and salinity transport in Florida Bay. This paper presents a preliminary study on tidal circulation in Florida Bay. In addition to a comparison between simulated and measured water levels in Florida Bay, we also examine the exchanges between Florida Bay and Florida Strait through the tidal channels along the Florida Keys.

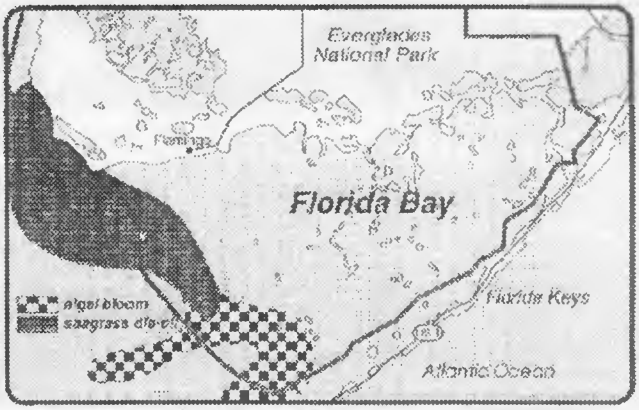

Figure 1. Florida Bay Map with Areas of Massive Algal Bloom and Seagrass Die-off.

Field Data

As a first step, we reviewed a comprehensive set of data which includes the high resolution bathymetric data for Florida Bay and hydrodynamic and hydrographical data at numerous stations in Florida Bay during 1993 and 1994, both compiled by the National Park Service (Sheng et al. 1995). As shown in Figure 2, much of the eastern Florida Bay is less than 1 m deep. Figure 3 shows that mudbanks in Florida Bay actually divide the Bay into numerous lakes during low water. Field data collected in Florida Bay include water level, water temperature, conductivity, rainfall, and evaporation. Water level data were taken at the 27 stations shown in Figure 4. Using these water level data, Smith (1995a) obtained the co-amplitude chart and co-phase chart for the M_2 tide as shown in Figure 5. As can be seen from Figure 5, M_2 tide enters the Florida Bay from both West Florida Shelf and Florida Strait. Diurnal tides such as O_1 and K_1 constituents primarily enter into Florida Bay from West Florida Shelf. Some tide data are from the offshore waters to the south of Florida Keys (Smith 1995b). Wind data are available from 1-2 offshore CMAN stations only. Freshwater discharge data and current meter data are lacking. High evaporation rate often leads to hypersalinity of more than 50 ppt inside Florida Bay even during the wet season.

Using the data indicated above and a 3-D curvilinear-grid model developed by Sheng (1987, 1989, 1994), we conducted model simulations of tidal, wind-driven and density-driven circulations in Florida Bay (Sheng et al. 1995). In this paper, we present some results of preliminary simulation of tidal circulation. model results.

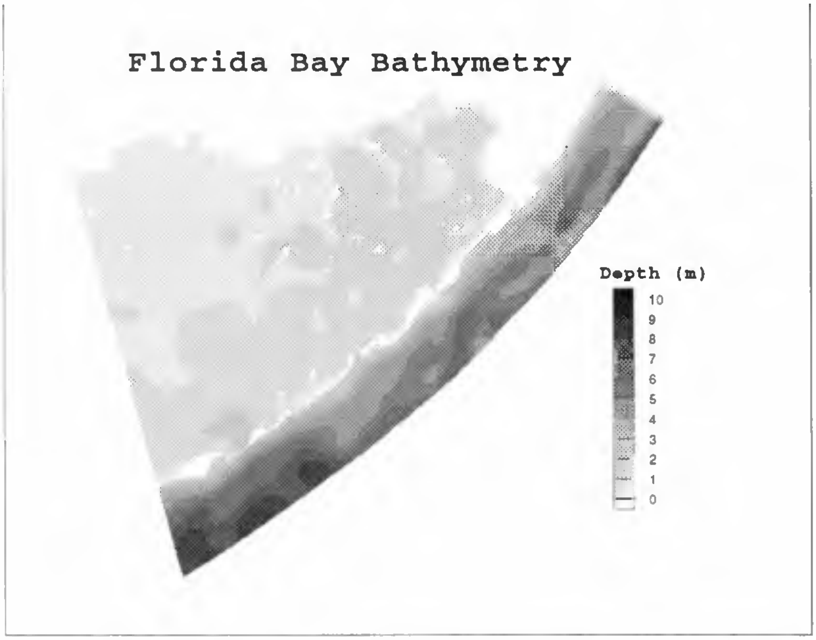

Figure 2. Bathymetry contours in the entire finer-grid model domain. All depths inside the Bay are less than 1-2 meters.

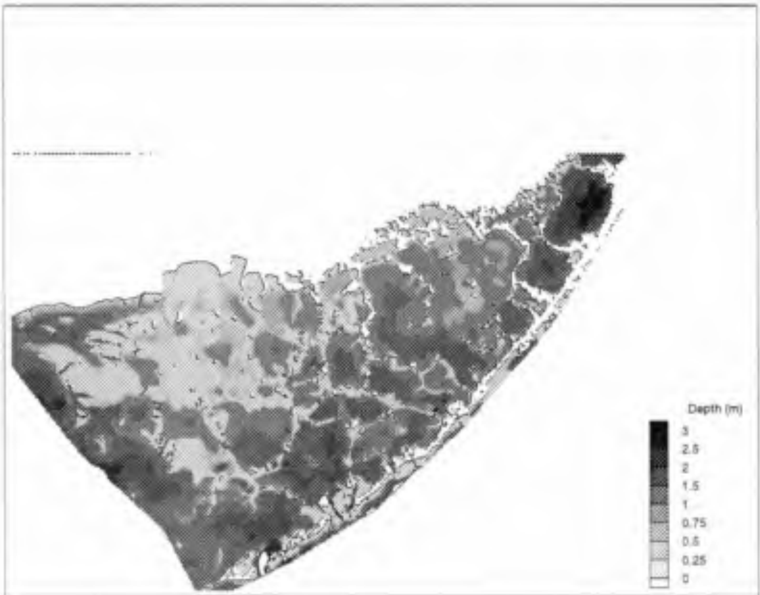

Figure 3. Florida Bay bathymetry provided by Everglades National Park.

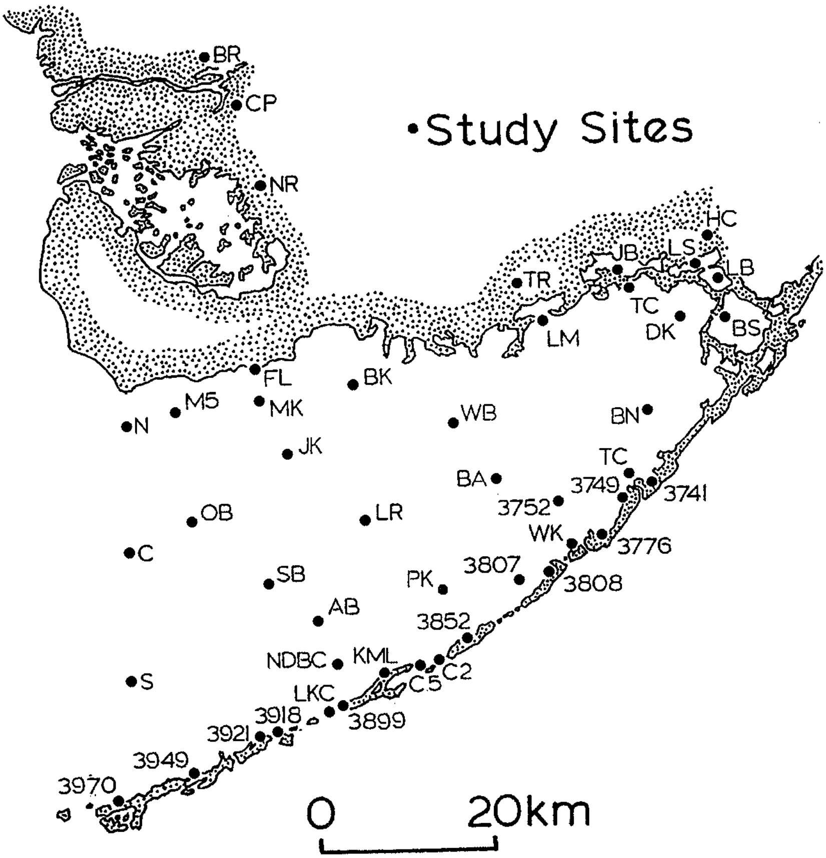

Figure 4. A Map of Monitoring Stations in Florida Bay.

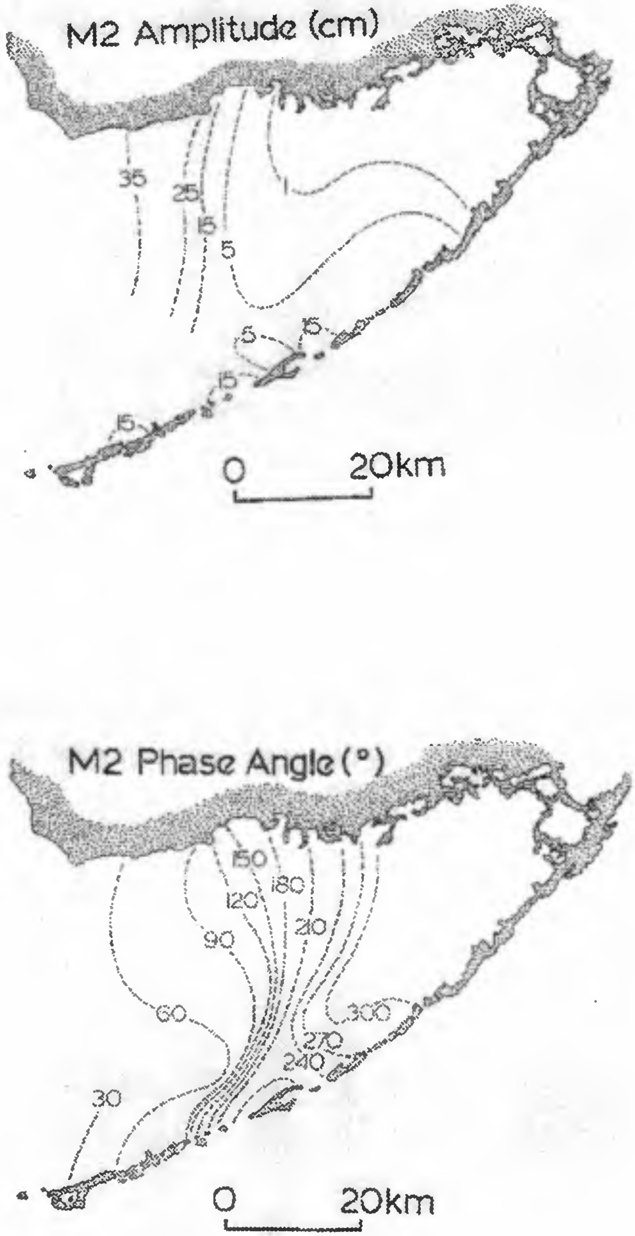

Figure 5. Co-Amplitude and Co-Phase Lines of M_2 Tide in Florida Bay.

Model and Grid

CH3D, the 3-D curvilinear-grid circulation model developed by Sheng (1989, 1994) is modified for application to Florida Bay. In the past few years, through numerous research projects (Chesapeake Bay, James River, Sarasota Bay, Lake Okeechobee, Indian River Lagoon, and Tampa Bay), we have significantly improved the model's features/capabilities for simulating stratified flow, effect of vegetation on circulation, ocean-estuary coupling, and wind-induced flow. The model solves for the three-dimensional equations of motion in terms of the water level and contravariant velocity components. The model solves the vertically-integrated equations of motions as well as the vertical structures of the flow field. Since the same time step is used for the solution of the external mode and the internal mode, the model solutions are consistent with each other and converge. A robust vertical turbulence model (Sheng and Villaret 1989) is used to represent the vertical turbulent mixing. The model allows the use of boundary-fitted grid which can accurately represent the complex shoreline in Florida Bay. In the vertical direction, the sigma grid is used. Sheng et al. (1995) used several boundary-fitted grids to resolve Florida Bay.

The grid shown in Figure 6 includes all the area covered in the detailed bathymetry map in Figure 3 plus the offshore area between the Florida Keys and the reef tract. A total of 98 by 75 grid points are contained in this grid. For 3-D simulations of tidal circulation, a total of 4 vertical cells are generally used.

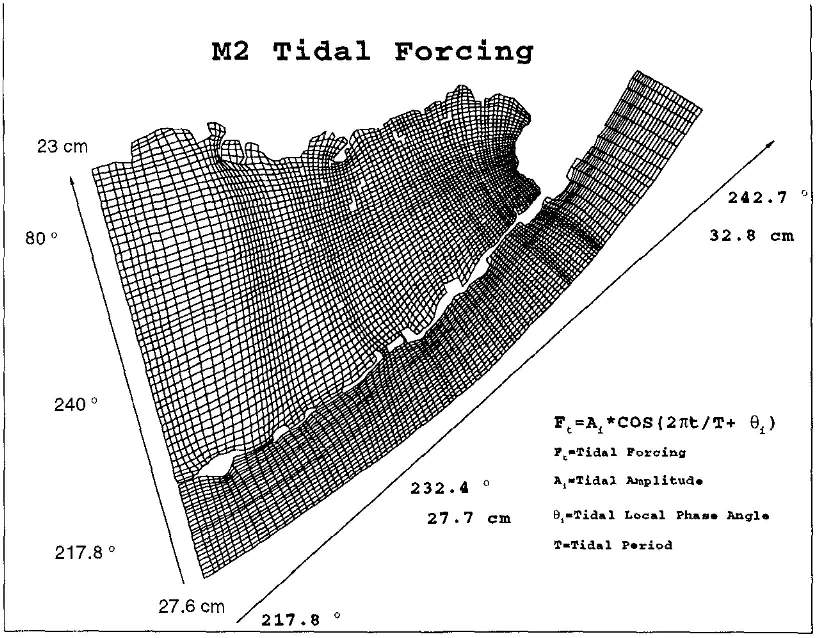

Figure 6. A model grid with 98x75 cells and open boundary conditions for M_2 tide in Florida Bay.

Simulation of Tidal Circulation

Using the horizontal numerical grid shown in Figure 6 and a vertical sigma-grid with 4 cells, we conducted simulations of tidal circulation in Florida Bay with CH3D (Sheng et al. 1995). The major objectives of tidal simulation is to examine the model's ability to simulate tide propagation and dissipation inside Florida Bay, and to examine the simulated residual flow inside the Florida Keys. For the first objective, detailed comparison between model results and data have been made (Sheng et al. 1995). For the second objective, model results can be compared qualitatively with preliminary flow measurement by Smith (1995b) which showed persistent southerly residual flow inside the Florida Keys.

To simulate the tidal dynamics in Florida Bay, it is essential to include part of the offshore water in the numerical grid as shown in Figure 6, since tides in Florida Bay are influenced by tides from the Gulf of Mexico and the Florida Strait. Tidal data along the reef tract were taken at Carysfort Reef, Alligator Reef, Tennessee Reef, Sombrero Key and Sand Key Light. These data were analyzed to produce the amplitudes and phases for various tidal harmonic constituents. Using these data and the tidal data inside Florida Bay, we produced the boundary conditions for the M_2 simulation as shown in Figure 6.

Using the open boundary conditions for M_2 tide described above, the 3-D model CH3D was run for 5 days. The result during the last tidal cycle was then analyzed to produce the maximum water level chart and a corresponding co-phase chart. The simulated maximum water level chart for M_2 tide in Florida Bay is shown in Figure 7. Amplitude in the extremely shallow eastern Florida Bay, where the depth is generally less than 50 cm, is on the order of 1-5 cm only.

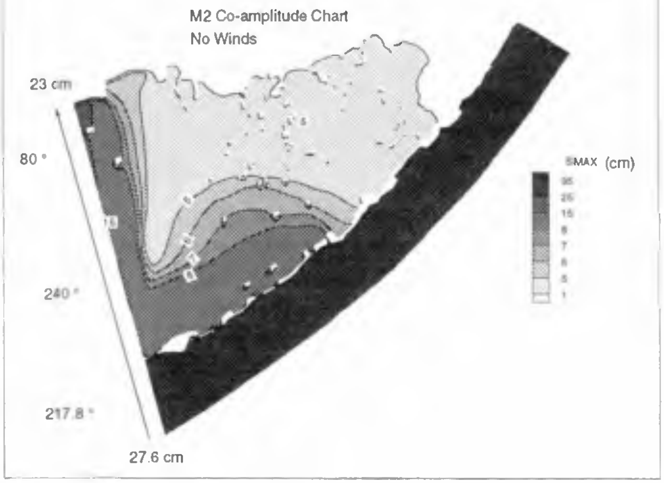

Figure 7. Co-amplitude chart of M_2 tide simulated by the 3-D model.

The results shown in Figure 7 compare favorably with the co-amplitude chart produced from data as shown in Figure 5. The simulated peak water level in the eastern Florida Bay is larger than the observed amplitude, suggesting insufficient tidal dissipation in the model. The simulated co-phase chart, which is presented in Sheng et al. (1995), showed that tides propagated further eastward. This is partly due to the fact that the complicated mudbanks, extremely shallow depths, and narrow Florida Keys in the eastern Florida Bay are not accurately represented in the 3-D model grid and bathymetry. The minimum horizontal grid spacing is approximately 100 meters while a spacing of 20 m may be necessary to represent the detailed bathymetry.

Other reasons for discrepancy between model results and data are that wind and wetting-and-drying were not included in the preliminary simulations. In the absence of wind, the residual (tidally-averaged) water level in the eastern Florida Bay is about 2 cm plus. By including a mild summer wind from the southeast, simulated maximum water level chart as shown in Figure 8 agrees better with the co-tidal chart based on data. In the presence of a summer wind, the residual water level in eastern Florida Bay became approximately -0.5 cm. A robust wetting-and-drying scheme has recently been implemented in CH3D. With the wetting-and-drying scheme and a fine grid (50m minimum grid spacing), we are able to produce much better results with 1 cm tidal amplitude in the eastern Florida Bay.

The tidally-residual vertically-averaged flow field as shown in Figure 9 exhibits significant southerly flow in the Florida Keys, in agreement with recent flow measurement by Smith (1995b). The southerly residual flow results from the higher residual water level in eastern Florida Bay.

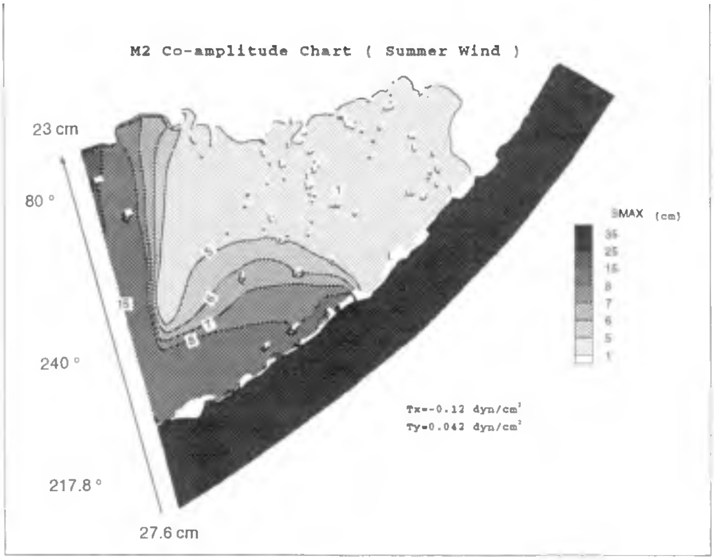

Figure 8. Co-amplitude chart of M_2 tide simulated by the new fine grid model with average summer wind condition.

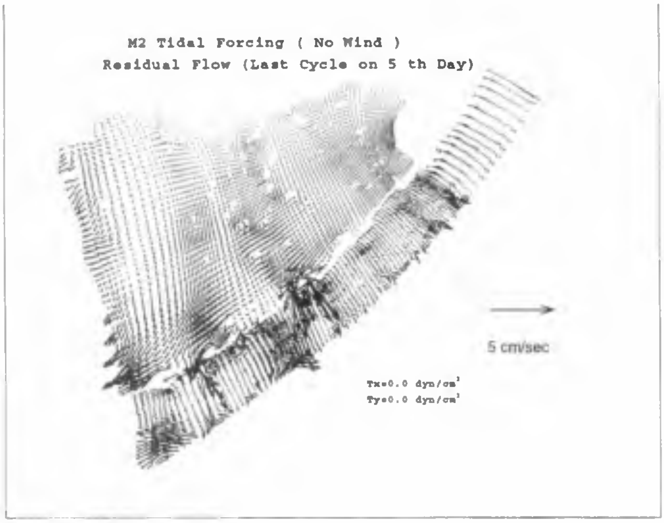

Figure 9. Simulated tidal residual currents in Florida Bay with forcing by pure M_2 tide.

To examine the influence of tides from the southern open boundary, we made a model run with closed Florida Keys. As shown in Figure 10, the maximum water level compares poorly with that in the co-amplitude chart based on the 1-year data. These results also suggest that simulated results in Figure 8 exhibit stronger influence from the southern open boundary than that shown in the data. This could be improved by more accurate representation of the Florida Keys and more accurate open boundary conditions along the southern open boundary.

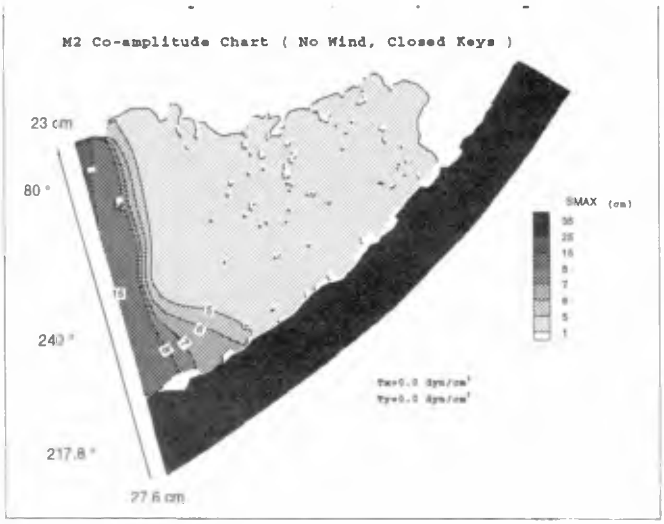

Figure 10. Simulated maximum water level of M_2 tide in Florida Bay with the Florida Keys closed.

Discussion

A curvilinear-grid 3-D circulation model developed by Sheng (1987, 1989, 1994) has been modified to simulate the tidal circulation in Florida Bay. Tide data collected at 27 stations inside Florida Bay during 1993 and 1994 plus offshore tide data during earlier time periods were analyzed in terms various diurnal (O_1 and K_1) and semi-diurnal (M_2) constituents. Using the tidal constituent data to construct open boundary conditions along the southern and western open boundaries, we conducted numerous model simulations with a number of numerical grids and various forcing conditions: first with tide only, then with tide and wind, and finally with tide, wind and salinity field (Sheng et al. 1995). Due to the dominance of M_2 tide from both the Gulf of Mexico and the Florida Strait, this paper focuses on the simulation of M_2 tide. The simulated maximum water level and co-phase chart compare reasonably well with the co-amplitude and co-phase charts produced from the 1-year tide data. Significant dissipation due to the mudbanks and extremely shallow water depths result in very small tidal amplitude on the order of 1-5 cm in the eastern Florida Bay. The residual (tidally-averaged) model results indicate that there is a setup in the eastern Florida Bay which causes southerly residual flow inside the channels along the Florida Keys, which has been found by recent flow measurement.

Additional model simulations of K_1 and O_1 tides and baroclinic circulation have been conducted by Sheng et al. (1995). Model results suggest that data gap in freshwater inflow and evaporation data prevents longterm (from 1 month to 1 year) simulation of Florida Bay circulation at the present time.

We have continued with the modeling effort. Recently, a robust wetting-and-drying scheme has been implemented in CH3D. A very fine grid, with a minimum grid spacing of 50m, has also been used in recent simulations. This grid gives much better representation of the mudbanks and the complex bathymetry. Using the very fine grid and the wetting-and-drying scheme, we are able to significantly improve the model results in the eastern Florida Bay. Maximum M_2 tidal amplitude in the eastern bay was reduced to 1 cm. Details of the wetting-and-drying scheme and the improved model simulations will be reported in two upcoming papers.

Acknowledgement

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