NOAA Technical Report NOS CS 11

GENERATION OF TIDAL DATUM FIELDS FOR TAMPA BAY AND THE NEW YORK BIGHT

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noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Coast Survey Development Laboratory

Office of Coast Survey
National Ocean Service
National Oceanic and Atmospheric Administration
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GENERATION OF TIDAL DATUM FIELDS FOR TAMPA BAY AND THE NEW YORK BIGHT

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May 2001

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ABSTRACT

As part of a joint National Oceanic and Atmospheric Administration (NOAA) - U.S. Geological Survey project to develop a unified topographic/bathymetric data set referenced to a common vertical reference frame, tidal datum fields for Tampa Bay, Florida, and the New York Bight were generated by the combination of a circulation model and spatial interpolation. The tidal datums were mean lower low water (MLLW), mean low water (MLW), diurnal tide level (DTL), mean tide level (MTL), mean sea level (MSL), mean high water (MHW), and mean higher high water (MHHW). For Tampa Bay, the model was run for a 1-year period, and the water levels saved at 6-min intervals. The datums were computed from analysis of individual water level time series at each cell of the hydrodynamic model grid, and adjusted to represent the 1960-1978 epoch. Datum fields for an area outside the Tampa Bay model grid were generated by spatial interpolation of values at a few coastal gauges. For the New York Bight, the model was run for 2 months since accuracy requirements were less. All datum fields were interpolated to a uniform grid and referenced to MLLW. The data fields were used by NOAA's National Geodetic Survey to create a datum transfer tool for land and sea bottom elevations in the Tampa region and New York Bight.

1. INTRODUCTION

Spatially-varying tidal datum fields were developed as part of the Topographic/Bathymetric Demonstration Project, a joint National Oceanic and Atmospheric Administration (NOAA) - U.S. Geological Survey (USGS) project to develop a Digital Elevation Model (DEM) with a single vertical datum reference (NAVD88, Geoid, GPS Ellipsoid, etc.) for the land and waters near Tampa, Florida (Parker et al., 2000), and in the New York Bight. The National Ocean Service's (NOS') historical depth data in U.S. coastal areas are given relative to either mean low water (MLW) or mean lower low water (MLLW), so a method of re-referencing them to other datums was needed. The tide datums selected were MLLW, MLW, diurnal tide level (DTL), mean tide level (MTL), mean sea level (MSL), mean high water (MHW), and mean higher high water (MHHW).

The primary problem addressed herein is how to generate the spatially-varying tidal datum fields. At present, tidal datums, which are elevations referenced to a mark on the tide staff, are known for specific locations (i.e., NOS' water level gauges) along the coast. But in general, tidal datum fields vary in elevation over horizontal space. The datum fields for Tampa Bay and the New York Bight were generated in the Coast Survey Development Laboratory (CSDL) by two methods: (a) a numerical hydrodynamic circulation model of the region and (b) spatial interpolation using values at the water level stations. When the circulation model was used, four steps were involved in the process:

- Making hydrodynamic model runs to generate time series of water levels for each point in the model grid,
- Tidal analysis of the model-generated water levels to identify the times and amplitudes of high and low waters and from these the datums (MHHW, etc) at each point in the model grid,
- Generation of the uniform regional grid and interpolation of the model-generated datum fields to this new grid (for VDatum), and
- Generation of datums for the offshore area.

In addition, some selected fields were generated by spatial interpolation for comparison purposes. These steps are discussed in detail in the following sections.

Once generated, the regional datum fields were used by NOS' National Geodetic Survey to create a datum transfer tool (VDatum) for land and sea bottom elevations in the regions of interest.

This study relied heavily on tidal data in the form of time series, tidal datums, and water level gauge locations, which were provided by NOS' Center for Operational Oceanographic Products and Services (CO-OPS). Some of these data are unverified, and therefore should not be used for other purposes without prior approval. The locations of water level stations in Tampa Bay used in this study are shown in Figure 1.1. and in the New York Bight in Figures 1.2 and 1.3.

Section 2 describes tidal elevation data, tidal datums, and methods for obtaining datums. Section 3 describes the hydrodynamic model for Tampa Bay, and Section 4 discusses how the model was used to obtain tidal datum fields. Section 6 covers the generation of the datum transfer fields used by VDatum.

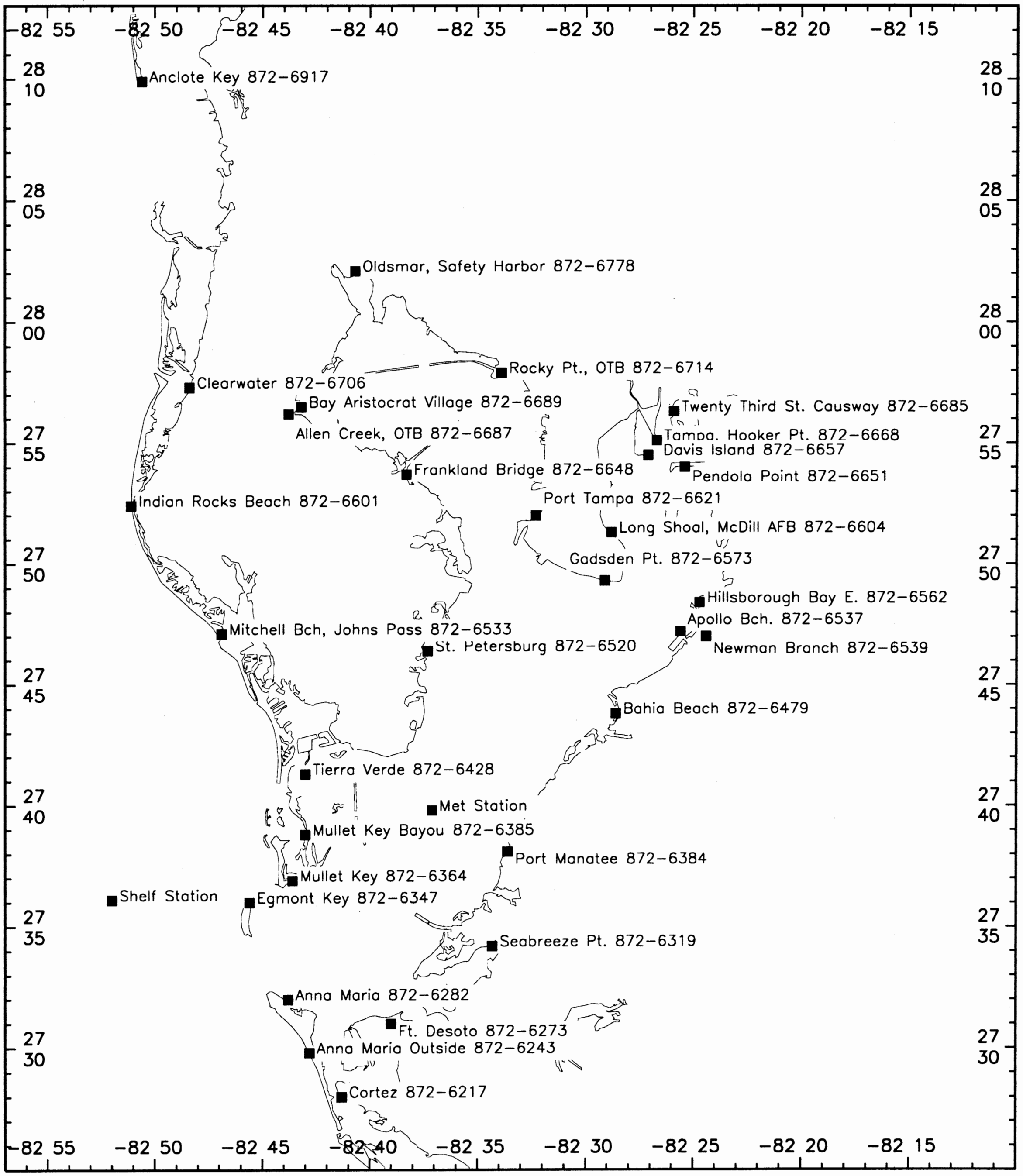

Figure 1.1. Locations of NOS water level gauges in Tampa Bay used in the Bathymetric-Topographic Demonstration Project.

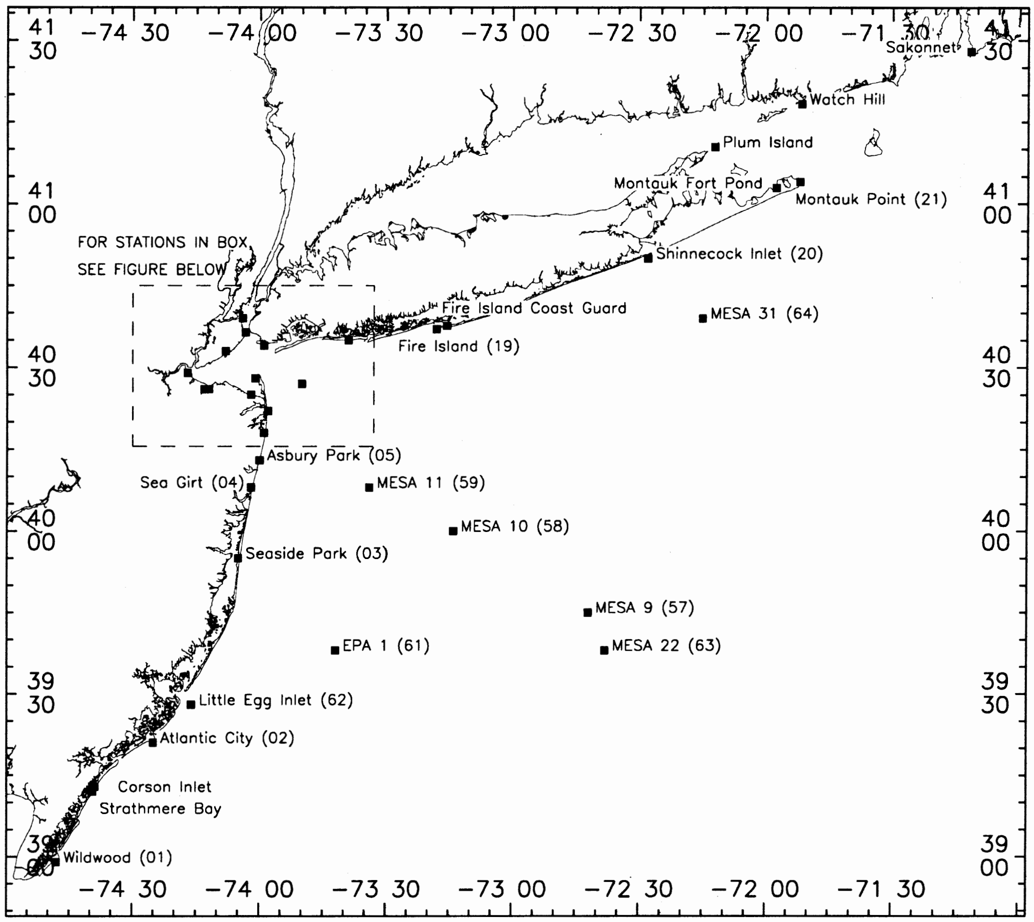

Figure 1.2. Water level stations in the New York Bight used in the data interpolation. The numbers in parentheses refer to the MESA stations (Appendix D). For New York Harbor station names, see Figure 1.3.

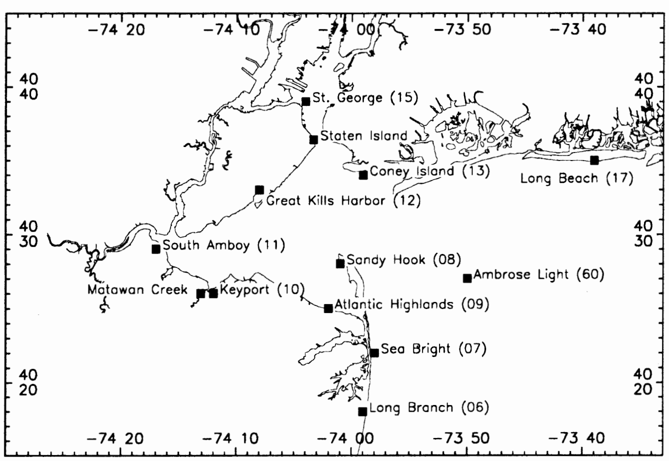

Figure 1.3. Water level stations in the New York Harbor used in the data interpolation. The numbers in parentheses refer to the MESA stations (Appx. D).

2. TIDAL ANALYSIS

Tidal datums were computed from time series of 6-minute values for each hydrodynamic model grid cell. This section discusses the methods used in the generation of the datums. See also Gill and Schultz (2001).

2.1. Definitions

Tidal datums at a single location are based on the identification of all the tidal extrema (highs and lows), and the selection (in a 25-hour or so time period) of the higher of the two highs and the lower of the two lows (Figure 2.1).

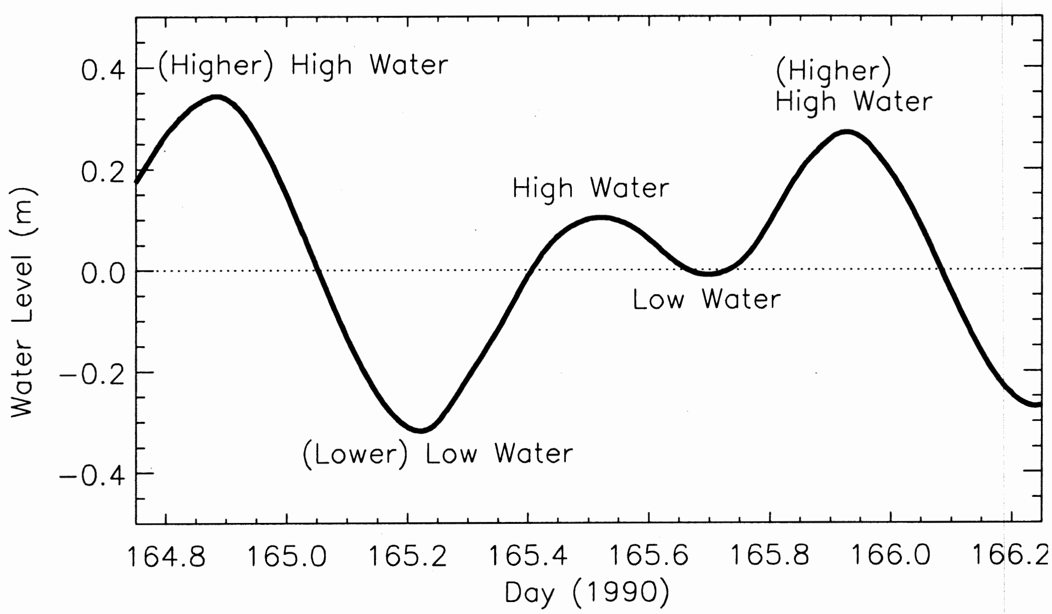

Figure 2.1. Schematic showing a typical water level curve in a 35-hr period. The high and low waters are identified.

The average of all the highs and higher highs is called the Mean High Water (MHW), and the average of just the higher highs is called the Mean Higher High Water (MHHW). Similarly for the lows and lower lows. The average of the MHW and the MLW is called the Mean Tide Level (MTL) and the average of the MHHW and the MLLW is called the Diurnal Tidel Level (DTL). Mean Sea Level (MSL) is the average of the hourly water levels. Observations made in a limited time period are adjusted to represent the values for a 19-year National Tidal Datum Epoch; at present, the epoch used is 1960 to 1978.

The datum values at NOS water levels gauges are routinely computed by CO-OPS and are available to the public on the station benchmark sheets. A portion of a typical benchmark sheet is shown in Figure 2.2.

```
                    FLORIDA  872 6520

           ST. PETERSBURG, TAMPA BAY

Tidal datums at ST. PETERSBURG, TAMPA BAY are based on the following:

    LENGTH OF SERIES                = 19 YEARS
    TIME PERIOD                     = 1961-1979
    TIDAL EPOCH                     = 1960-1978
    CONTROL TIDE STATION            =

Elevations of tidal datums referred to mean lower low water (MLLW) are as
follows:

    HIGHEST OBSERVED WATER LEVEL (06/18/1982)          =   5.98 FEET
    MEAN HIGHER HIGH WATER (MHHW)                      =   2.24 FEET
    MEAN HIGH WATER (MHW)                              =   1.96 FEET
    MEAN TIDE LEVEL (MTL)                              =   1.17 FEET
    *NATIONAL GEODETIC VERTICAL DATUM-1929 (NGVD)      =   0.79 FEET
    MEAN LOW WATER (MLW)                               =   0.39 FEET
    MEAN LOWER LOW WATER (MLLW)                        =   0.00 FEET
    LOWEST OBSERVED WATER LEVEL (01/16/1972)           =  -2.27 FEET
```

Figure 2.2. Portion of the tidal datum benchmark sheet for St. Petersburg, Florida.

2.2. Extraction of Tidal Extremes

A computer program was developed in CSDL to select the high and low waters from a time series of water level values. The program used the 25-hour rule to pick out first the highs and lows, then the higher high and lower low. The program computes the precise time and elevation by cubic interpolation. MSL is computed by saving and averaging all 87,841 values. The data can be filtered, but was not for these purposes. Since the method differs slightly from that used by CO-OPS, the program was tested on St. Petersburg, Florida, 6-minute data (start of June 1 to end of July 5, 1999). Results (Table 2.1) show that the two methods are reasonably similar.

Table 2.1. Comparison of datums (m) at St. Petersburg, Florida, for observed, 6-minute water level data from May 30 to July 6, 1999, using the methods of CO-OPS and CSDL.

Datum	CO-OPS Method	CSDL Method	Difference
MHHW	1.738	1.752	-0.014
MHW	1.627	1.632	0.005
MSL	1.407	1.408	-0.001
MTL	1.407	1.413	0.006
DTL	1.386	1.391	0.005
MLW	1.118	1.194	0.006
MLLW	1.035	1.029	-0.006

A typical time series of water levels and the picks of highs and lows is shown in Figure 2.3.

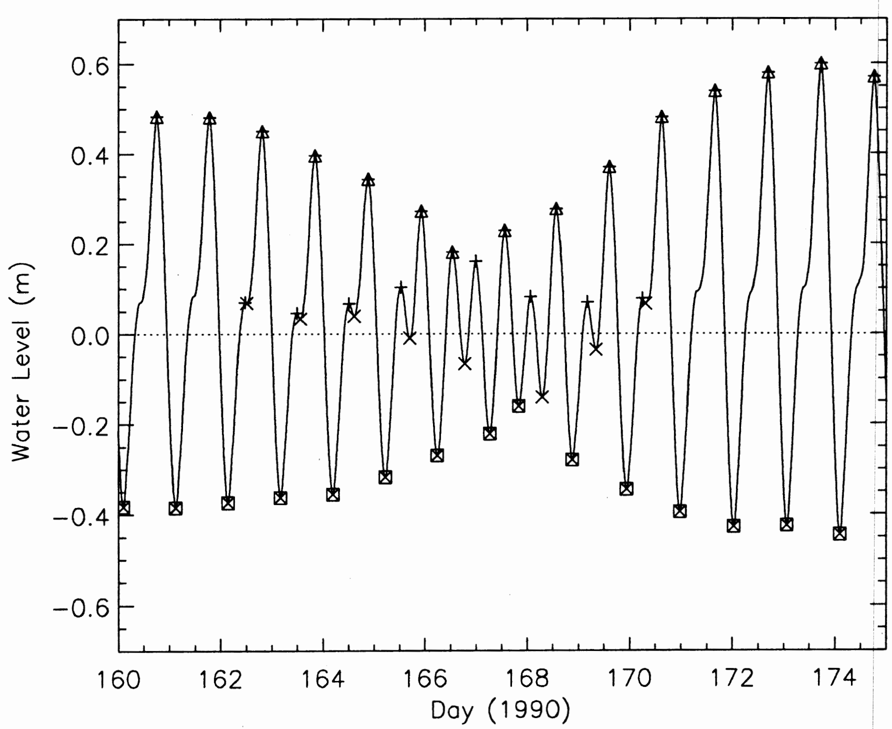

Figure 2.3. Portion of a modeled water level time series showing the selected higher high waters (triangle), high waters ("+"), low waters ("X"), and lower low waters (square).

3. THE TAMPA BAY HYDRODYNAMIC MODEL

The numerical circulation model is a version of the Princeton Ocean Model (POM) (Blumberg and Mellor, 1987) that was previously applied to Tampa Bay by NOS (Hess, 1994; Hess, 1993; Hess and Bosley, 1992). The POM has been under development and refinement for nearly 10 years and has been widely applied to many estuarine and coastal regions, so it has become a standard tool in the oceanographic research community. The model uses a terrain-following vertical sigma coordinate and orthogonal curvilinear coordinates in the horizontal to depict currents, salinities, and temperatures over depth and at numerous locations throughout the Bay. Typical grid spacing is from 100 to 1000 m. A plot of the grid appears in Figure 3.1.

For the development of the tidal datum fields, the model was run for a 385-day period covering June 1, 1990, to June 21, 1991. The entire field of water levels was saved every 6 minutes. Model forcing and the accuracy of the model are described below.

3.1. Model Forcing

The model was forced by (a) coastal water levels, (b) winds and air temperatures from one meteorological station (3-hr values), (c) coastal salinity and temperature (daily values), and (d) flows from seven rivers (daily values). Observational data for the model run were collected during NOS' Tampa Bay Oceanography Project (TOP) during 1990 and 1991 (NOS, 1992).

Coastal Water Levels

Water levels at the Shelf Station (Figure 1.1) located near the deep-water boundary of the hydrodynamic model (Figure 3.1) were measured by a bottom-mounted pressure sensor. The data (at 6-minute intervals) were low-pass filtered and applied to all cells forming the model's coastal (up-shelf, deep water, and down-shelf) boundaries.

Atmospheric Forcing

Momentum flux is added to the water across the surface by winds, and the atmosphere adds (or removes) heat. Winds at the real-time Meteorological Station near Port Manatee (Figure 1.1)were used to estimate the wind stress for the entire Bay. A data file using 10-minute values were filtered to produce a time series of 3-hourly values of wind speed, wind direction, and air temperature. Periods of missing data were filled in with data from the Tampa International Airport .

The heat flux across the surface is expressed as a function of air temperature, water temperature, wind speed, solar radiation, and several other variables. Details of the calculation are given in Hess (1994). Net precipitation and evaporation are neglected when computing surface salinity.

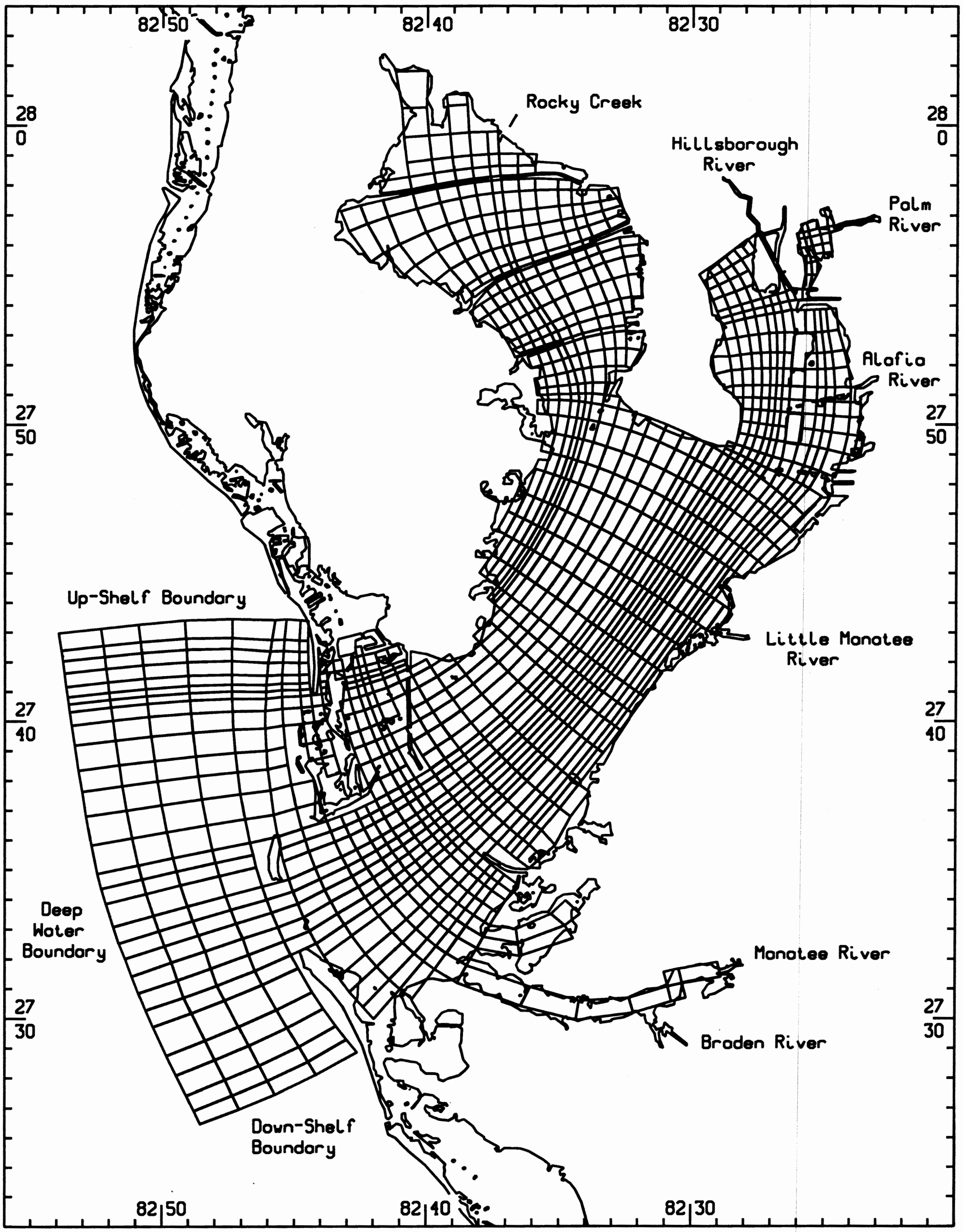

Figure 3.1. Grid used by the Tampa Bay numerical circulation model. Locations of the coastal boundaries and the rivers that provide fresh water are also shown.

Coastal Water Salinity and Temperature

A long series of salinity and temperature measurements at two levels at the Shelf Station were collected during TOP (Figure 1.1). For the hydrodynamic model, a time series of depth-varying ocean boundary salinities and temperatures were generated using bottom measurements, with values over the vertical chosen to give a realistic (i.e., weakly stratified) density profile. Monthly averages were used to eliminate small time-scale variations and to fill in data gaps.

River Inputs

River input to Tampa Bay, while relatively small compared to that in other estuaries, is large enough to create significant horizontal density gradients and hence to drive an estuarine circulation. Daily averaged river discharge data were obtained for the major tributaries (Alafia, Bullfrog Creek, Braden River, Hillsborough River, Lake Tarpon Canal, Little Manatee River, Manatee River, Rocky Creek, Sulphur Springs, Sweetwater Creek, and Tampa Bypass Canal) from the USGS in Tampa and for the Tampa Bypass Canal from the Southwest Florida Water Management District. Rivers are shown in Figure 3.1. Discharge in 1991 was considerably higher than in 1990.

3.2. Model Accuracy

The model was run in full three-dimensional mode with water temperature and salinity continuously updated. The statistics describing model accuracy of the predicted water levels for this case were discussed in Hess and Bosley (1992) and are summarized in Table 3.1. The average RMS error is 3.3 cm.

Table 3.1. Model RMS error (cm) for NOS water levels stations in and near Tampa Bay, Florida, used in this study.

Station No.	Name	RMS Error (cm)
872-6217	Cortez	3.2
872-6243	Anna Maria	4.0
872-6273	Ft. DeSoto Point	3.1
872-6347	Egmont Key	2.1
872-6364	Mullet Key	2.1
872-6384	Port Manatee	2.8
872-6428	Tierra Verde	2.3
872-6520	St. Petersburg	3.2
872-6537	Apollo Beach	4.0
872-6657	Davis Island	4.5
872-6689	Bay Aristocrat Village	5.0

3.3. Analysis of Modeled Water Levels

Model output water levels for June 15, 1990, to June 15, 1991, were analyzed to generate the datums. For each grid cell, a time series of 6-minute values was constructed from the archived model data, which consisted of sets of instantaneous water level fields for the entire model grid. The time series was then analyzed by the datum extraction method described above. A typical field (MLLW) is shown in Figure 3.2. All the fields generated by the hydrodynamic model are shown in similar plots in Appendix A.

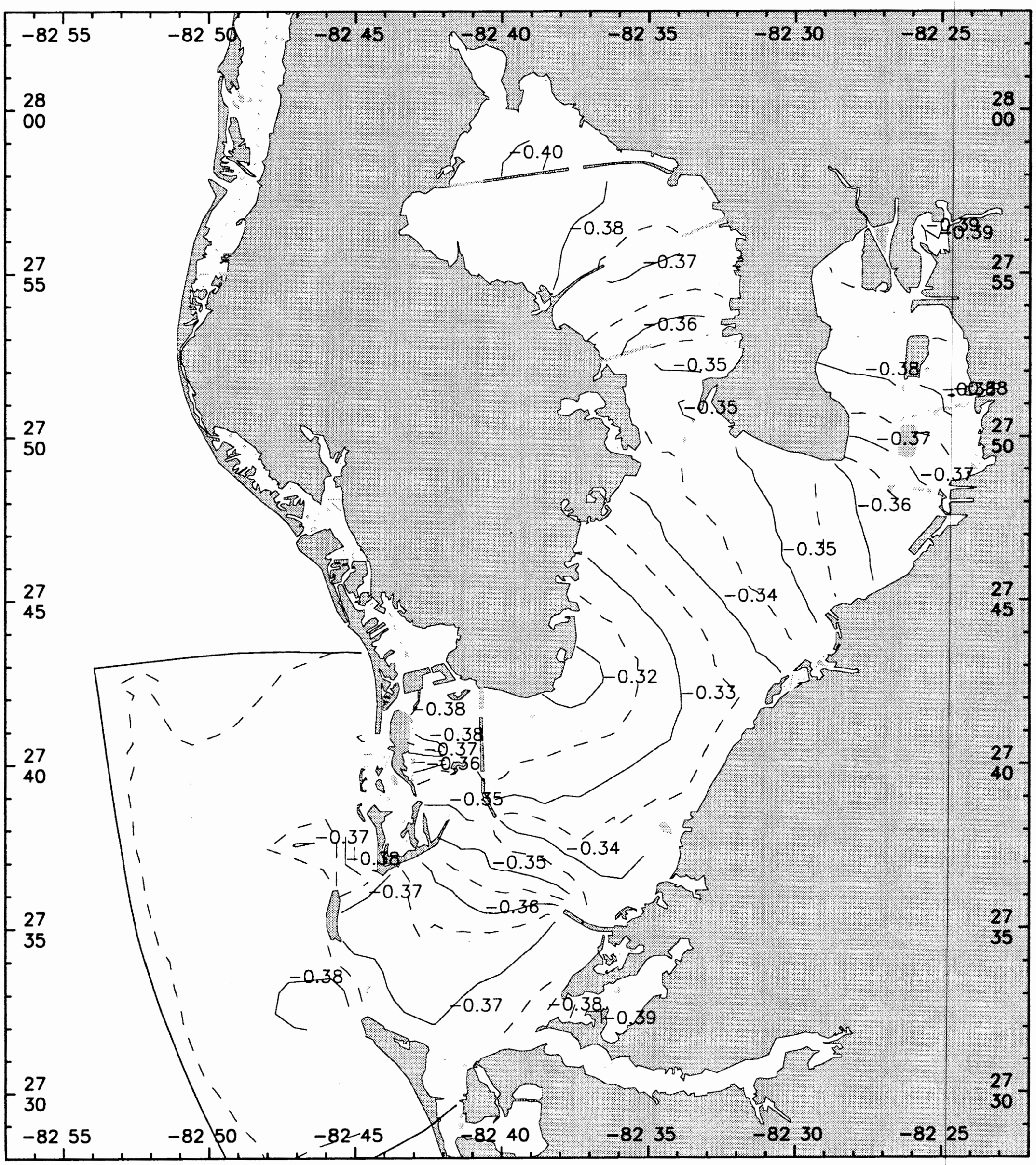

Figure 3.2. Modeled MLLW (relative to model zero level).

As a check, the values for St. Petersburg were examined (Table 3.2). The modeled datums were somewhat less than those derived from the observed values. The average absolute difference was under 2 cm.

Table 3.2. Comparison of datums derived from modeled and observed water levels, and the differences (m) at St. Petersburg, Florida (872-6520), for 365 days of data.

Tidal Datum	Modeled Elevation	Modeled Elevation minus MLLW	Observed (1990 & 1991)	Difference= Model minus Observed
MHHW	0.360	0.690	0.708	-0.018
MHW	0.254	0.584	0.616	-0.032
MSL	0.024	0.354	0.373	-0.019
MTL	0.023	0.353	0.367	-0.014
DTL	0.015	0.345	0.354	-0.009
MLW	-0.209	0.121	0.117	0.004
MLLW	-0.330	0.000	0.000	0.000

4. GENERATION OF REGIONAL DATUM FIELDS FOR TAMPA BAY

To facilitate the vertical datum transfer algorithm, VDatum, to be developed by NGS, a set of regional datum fields was created. The grid for each regional field has uniform spacing of 1 arc minute in the vertical and horizontal. Datum values for each grid cell were computed from the model or by spatial interpolation. The model data were first interpolated to the uniform grid, then the values were adjusted to refer to the 1960-1978 National Tidal Datum Epoch. Datum fields were generated for the region outside the Tampa Bay circulation model using spatial interpolation and values from a few coastal water level gauges.

4.1. Creation of the Uniform Regional Grid

The first step was the creation of the uniform regional grid. This grid covers latitudes from 27.50° to 28.12° and longitudes from -83.00° to -82.36°, with a spacing in each direction of 0.01666°, or 1 arc minute (Figure 4.1).

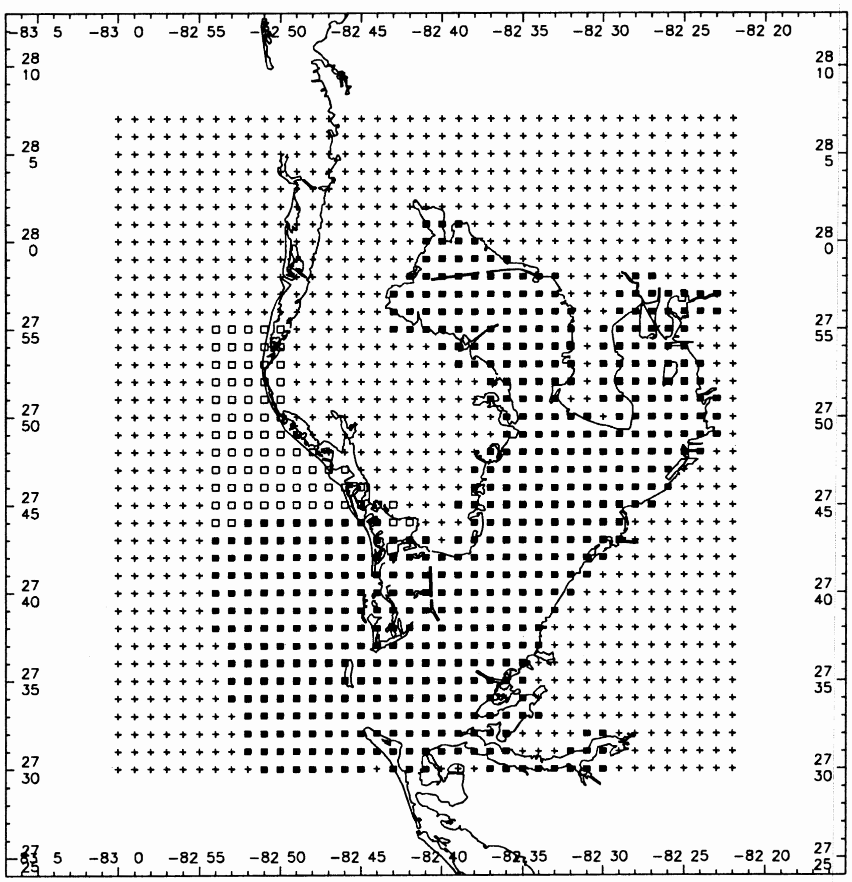

Figure 4.1. Locations of regional datum field grid points, with values created from the circulation model data (filled squares) and from interpolation of data based on observations (open squares). Points with default values are denoted by a plus sign. Spacing of nodes in each direction is 1 arc minute.

4.2. Interpolation of Model Fields

All cells in the regional grid were filled initially with a default value (-88.888) for each tidal datum. Then, locations in the uniform grid within 1 nautical mile of a cell of the hydrodynamic model were filled with a value computed as the average of the values from the four closest model cells.

Tidal datums derived from the water level series covering June 1990 to July 1991 must be corrected to apply to the tidal epoch in use, which is 1960 to 1978. Observations at St. Petersburg (Table 4.1) show that, as compared to the values for the tidal epoch (1960 - 1978), in 1990-1991 all datums were approximately 8 cm higher relative to the station datum and the differences between datums was approximately 3% larger. Therefore, the results derived from the model were corrected by applying a reduction factor for each datum. The reduction factors that were used are shown in the rightmost column in the table below. Note that all ratios are less than 1.0, except for MLW.

Table 4.1. Tidal datums and differences (m) at St. Petersburg (872-6520).

Datum	Elevations (1960-78 Epoch)		First Reduction Elevations (6/90 - 6/91)		Ratio of Epoch Elevation on MLLW to First Reduction Elevation on MLLW
	On Station Datum	On MLLW	On Station Datum	On MLLW	
MHHW	1.649	0.683	1.745	0.708	0.965
MHW	1.564	0.598	1.653	0.616	0.971
MSL	1.329	0.363	1.410	0.373	0.973
MTL	1.323	0.357	1.404	0.367	0.973
DTL	1.308	0.342	1.391	0.354	0.966
MLW	1.085	0.119	1.154	0.117	1.017
MLLW	0.966	0.000	1.037	0.000	-

4.3. Generation of Values in the Coastal Region

Additional transfer field locations in the coastal area outside of Tampa Bay and northward toward Clearwater required datum values. Specifically, transfer field locations were filled if they lie within the region bounded on the south by the numerical model's up-shelf boundary (Figure 4.2), on the west by the westernmost numeric model grid cell, on the east by land, and on the north by latitude 27° 55′. Tidal datums based on observed time series at various locations show a general increase with latitude (Table 4.2). Therefore, cells were filled as follows. For any specific latitude, the value was computed by linearly interpolating between the appropriate pair of datum values selected from the northmost model grid cell, the value at Indian Rocks Beach, and the value at Clearwater Harbor. All grid cells at that latitude, whatever the longitude, were given the same value. Two of the datums were not available, so they were computed as follows: DTL = ½ MHHW and MSL = 2*MTL - DTL.

Table 4.2. Latitudes and tidal datums (feet) at locations representative of the Gulf Coast south and north of the entrance to Tampa Bay.

	Venice (872-5858)	Anna Maria City Pier (872-6282)	Mitchell Bch., Johns Pass (872-6533)	Indian Rocks Beach (872-6601)	Clearwater Harbor (872-6706)	Anclote Key Lighthouse (872-6917)
Latitude	27° 4.3′	27° 32.0′	27° 47.1′	27° 52.4′	27° 57.3′	28° 9.9′
MHHW	2.25	2.22	2.25	2.54	2.74	3.04
MHW	1.99	1.96	1.90	2.17	2.40	2.76
MTL	1.18	1.15	1.18	1.34	1.46	1.59
MLW	0.37	0.34	0.46	0.51	0.51	0.41
MLLW	0.00	0.00	0.00	0.00	0.00	0.00

By agreement with NGS, the final datum fields were referenced to MLLW. A typical plot is shown in Figure 4.3; plots of the final datum transfer fields are shown in Appendix B.

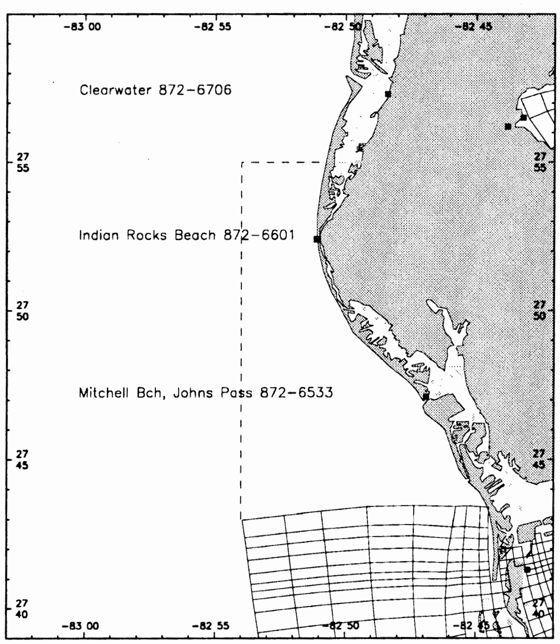

Figure 4.2. Region outside Tampa Bay where tidal datums were spatially-interpolated from gauge values and model values.

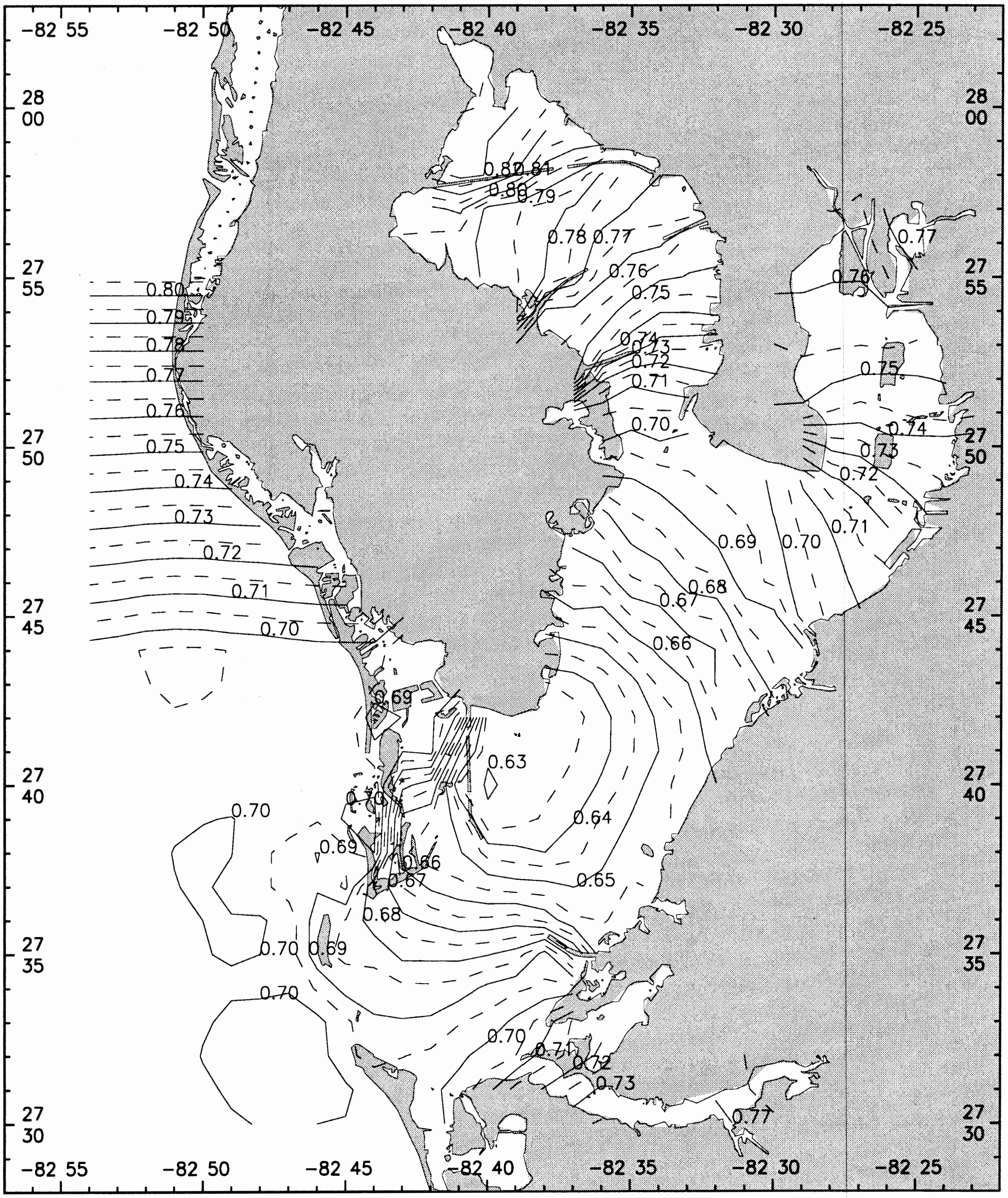

Figure 4.3. The region field of MHHW relative to MLLW (m).

5. DISCUSSION OF TAMPA BAY DATUMS

After review of the process and the data generated, it was decided to further investigate two aspects of the project. These were (1) the relationship between the model-generated MSL and an orthometric datum, and (2) the ability of the model to accurately reproduce the observed datums.

5.1. Reference of Model MSL to Orthometric Datums

In order to connect the bathymetry to the topography, we need to reference the tidal datum to some other, accepted terrestrial datum. If a tidal datum shows a relatively uniform constant offset from another datum (e.g., the North American Vertical Datum of 1988, or NAVD88), and constant offset can be used. Otherwise, interpolation can be used to generate a spatially-varying offset.

Constant Offset Assumption

Tidal datums at many of the water level stations in the Tampa Bay region have been referenced to NAVD88, as shown in Table 5.1. The average NAVD88-to-MSL offset for those station is -0.158 m. Because the range of values is only 0.090 m, it was decided to use a constant offset for the Demonstration project. Using additional data, an mean offset was calculated to be -0.164 m; this value was used to adjust tidal datums to NAVD88.

Table 5.1. Tampa Bay datum relationships (m) for the 1960-1978 epoch. Only the last four digits of the NOS station numbers are shown; the first three are 872. Source: CO-OPS (Stephen Gill, personnel communication).

Datum	6273	6282	6364	6384	6385	6428	6479	6520	6562	6573
MHHW	0.131	0.113	0.108	0.119	0.116	0.147	0.116	0.174	0.196	0.189
MHW	0.055	0.034	0.029	0.036	0.025	0.065	0.055	0.089	0.113	0.113
NAVD88	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MSL	-0.186	-0.210	-0.187	-0.192	-0.188	-0.162	-0.170	-0.146	-0.173	-0.143
MTL	-0.193	-0.213	-0.195	-0.198	-0.198	-0.170	-0.216	-0.152	-0.164	-0.161
DTL	-0.208	-0.225	-0.205	-0.211	-0.198	-0.176	-0.201	-0.167	-0.189	-0.205
MLW	-0.439	-0.460	-0.416	-0.433	-0.423	-0.402	-0.485	-0.390	-0.442	-0.436
MLLW	-0.549	-0.564	-0.520	-0.540	-0.509	-0.505	-0.597	-0.509	-0.573	-0.554
Datum	6539	6604	6621	6648	6651	6668	6685	6687	6714	6778
MHHW	0.195	0.225	0.201	0.259	0.221	0.244	0.235	0.274	0.238	0.271
MHW	0.110	0.158	0.134	0.182	0.121	0.162	0.149	0.198	0.152	0.185
NAVD88	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MSL	-0.180	-0.137	-0.140	-0.120	-0.150	-0.122	-0.143	-0.121	-0.149	-0.143
MTL	-0.171	-0.140	-0.149	-0.113	-0.160	-0.128	-0.152	-0.121	-0.149	-0.146
DTL	-0.192	-0.164	-0.168	-0.125	-0.175	-0.149	-0.174	-0.216	-0.283	-0.164
MLW	-0.451	-0.439	-0.430	-0.405	-0.437	-0.418	-0.454	-0.439	-0.448	-0.488
MLLW	-0.579	-0.554	-0.530	-0.509	-0.568	-0.539	-0.579	-0.549	-0.567	-0.603

Spatially-varying MSL

These data are available only at the water level stations. A way of generating a two-dimensional field using spatial interpolation and the data at the water level stations is described by Hess (in press) and Hess et al. (1999). The method is based on the numerical solution of Laplace's Equation (LE). A plot of the MSL field (relative to NAVD88) generated this way is shown in Figure 5.1a. Notice that there is a general slope downward toward the mouth. This slope is approximately the same as that generated by the model (Figure 5.1b), which is caused by the presence of lighter, fresher water near the upper reaches of the Bay caused by river inflows.

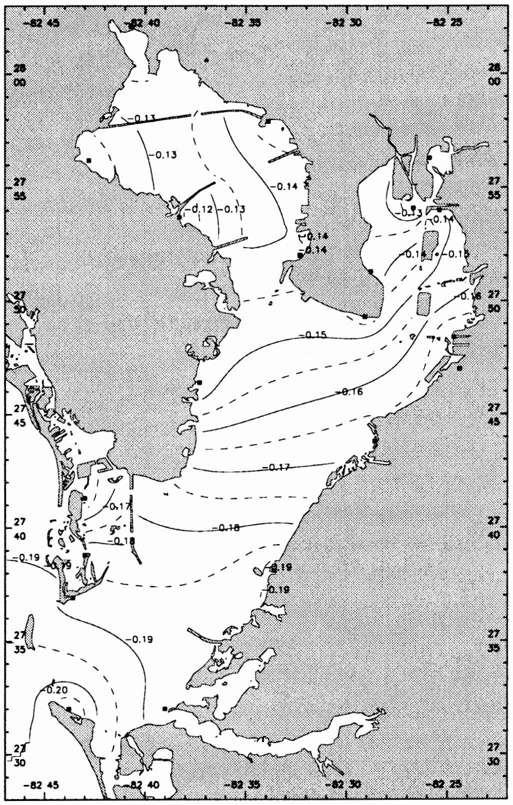

Figure 5.1a. MSL relative to NAVD88 by LE interpolation of gauge data.

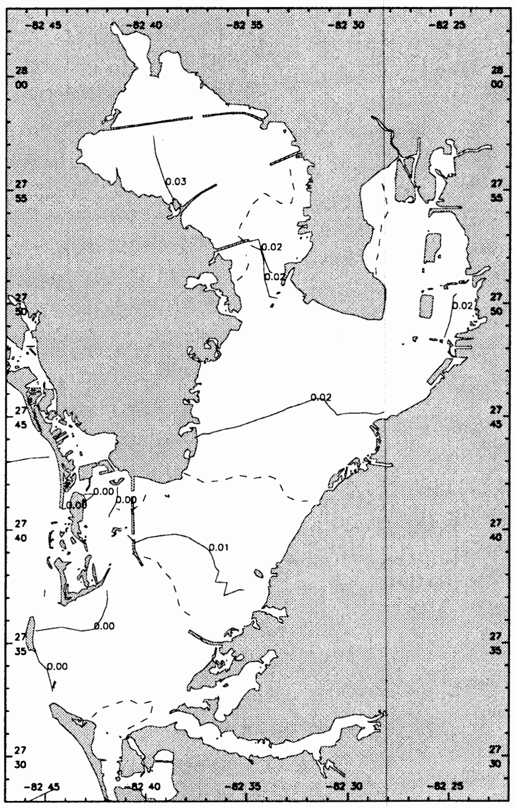

Figure 5.1b. MSL (m) from a 365-day model run.

Spatially-varying Datums by Interpolation

If the spatial interpolation using LE can work on the MSL field, then maybe it could be applied to other datums. A comparison of the MLLW-to-MSL filed generated be each method is shown in Figure 5.2.

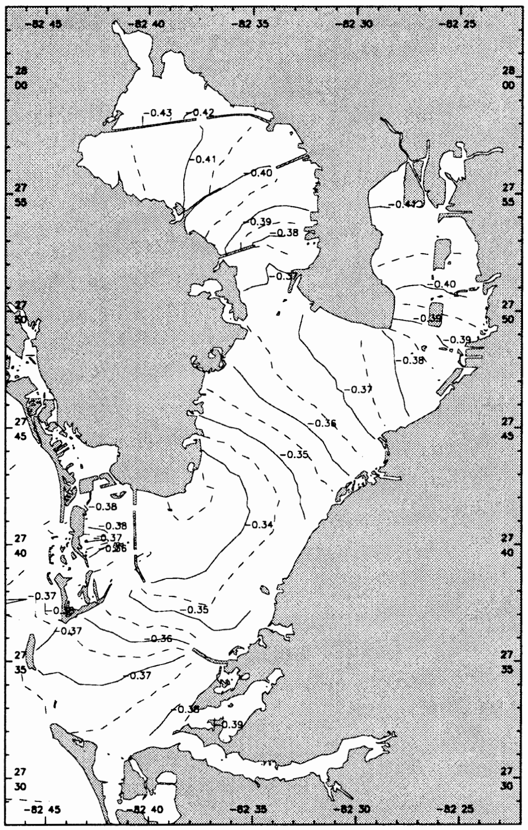

Figure 5.2a. The MSL-to-MLLW field generated by the hydrodynamic model.

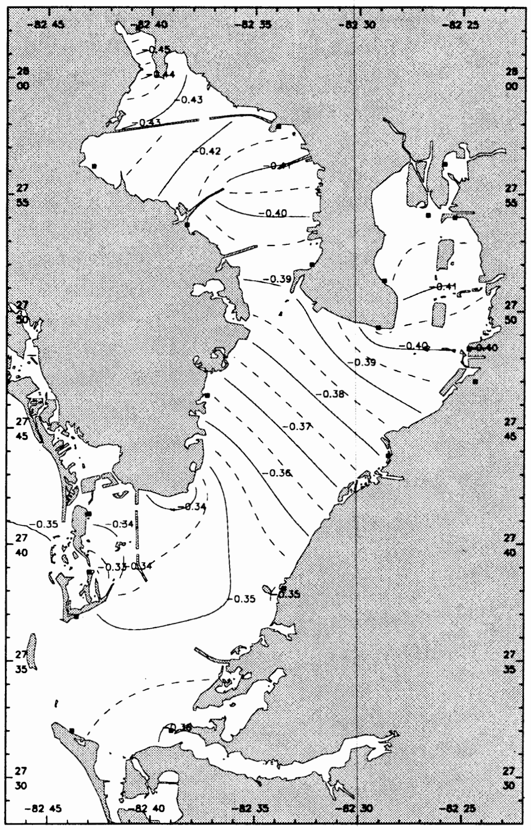

Figure 5.2b. The MSL-to-MLLW field generated by spatial interpolation.

5.2. Inconsistencies in the Modeled Datums

As a check of the consistency of the transfer fields, independent estimates of the MSL relative to NAVD88 were made using four datums and four datum transfer fields. In equation form, this is

$$h_{MSL} = h_{Datum} + \Delta_{DatumTransfer}$$

where h_{MSL} is the estimated MSL relative to NAVD88,

h_{Datum} is the average of the measured level of the datum at the water level stations, and

$\Delta_{DatumTransfer}$ is the datum transfer value as described in Section 4.

For example, an estimate of MSL can be made by starting with the mean MLLW relative to NAVD88 from the tide gauges and applying the MLLW-to-MSL transfer value from the models.

Using local data for 127 locations, four separate average estimates, one each for the four datums MLLW, MLW, MHW, and MHHW were made (Table 5.2). The mean of the estimates was -0.164 m (i.e., MSL was 0.164 m below the NAVD88 surface). The departure from the mean using the MLLW and MHHW was 0.010 m or less, but the departure from the mean usingMLW and MHW was significantly greater, and averaged 0.045 m in absolute value. The results indicate that the MHW values extracted from the modeled water level time series may be too small, and that the MLW values were too large.

Table 5.2. Estimates of MSL relative to NAVD88 using several different datums and datum transfer fields (meters). MSL is calculated as the datum level (relative to NAVD88) based on observations plus the circulation model-based datum difference. The RMS error is based on the deviations of the values at the 127 gauges. Source: NGS (Dennis Milbert, personnel communication).

Datum	Estimated MSL	RMS Error	Estimated - Mean
MHHW	-0.154	0.033	0.010
MHW	-0.123	0.034	0.041
MLW	-0.214	0.020	-0.050
MLLW	-0.163	0.019	0.001
Mean	-0.164	-	-

Preliminary analysis of data and model-generated datums at selected stations shows that, relative to MLLW, MLW tends to be too high in the lower bay, and MHW tends to be too small in the upper bay (Appendix C). The same analysis shows that relative to MLLW, MSL shows the same trend (too high in the lower bay, and too small in the upper bay).

6. TIDAL DATUM TRANSFER FIELDS FOR THE NEW YORK BIGHT

6.1. Introduction

After meeting with representatives of the USGS and U.S. Army Corps of Engineers, it was decided to develop tidal datum fields for the New York Bight and to reference them to some other datum (e.g., NAVD88). Since the Bight is deeper than Tampa Bay, it was agreed that accuracy requirements could be less than for the Bay.

The region to be studied is defined as the continental shelf area (not coastal lagoons) eastward of New York Harbor, bounded on the east by longitude -71° 50' (Montauk Point, New York), and on the south by latitude 38° 55' (Cape May, New Jersey). The area is shown in Figure 6.1. Tide data for coastal stations in the Bight are available from CO-OPS, and for offshore stations from the MESA Project (Swanson, 1976) and the USGS study (Moody et al., 1984).

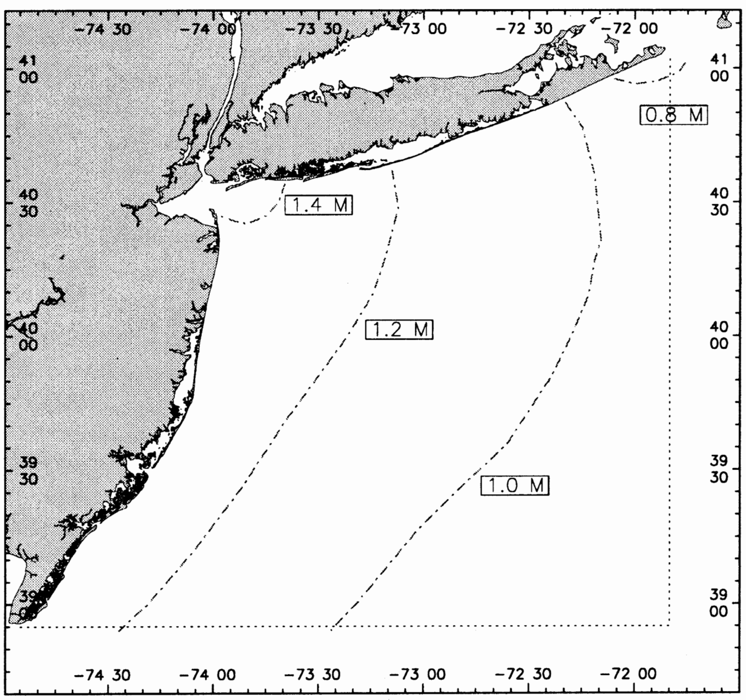

Figure 6.1. New York Bight and mean tide range (dash-dot lines, with range value in meters) from the MESA data. The offshore boundaries of the project are shown as dotted lines.

The Tampa Bay study included the use of an available hydrodynamic model and spatial interpolation. Since spatial interpolation is usually the quicker method, the first test was to compare the distribution of the mean tide range field as generated with the Laplace's Equation approach and the distribution presented in the MESA report (Swanson, 1976), which is based on observed values (Appendix D).

The results (Figure 6.2) indicate that the major characteristics of the distribution are not reproduced. Some of the discrepancies may be due to the presence of a large open boundary. In any case, it was decided to investigate the use of a numerical circulation model to provide tidal datum distributions.

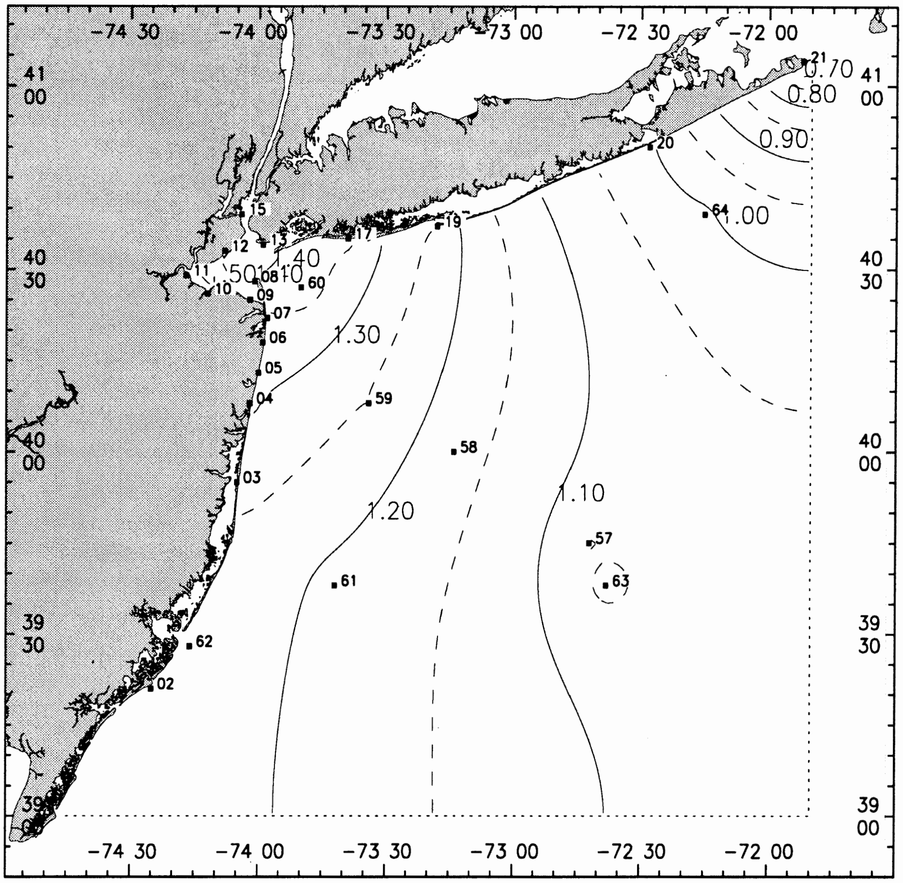

Figure 6.2. Mean tidal range as computed by the LE method. Numbered squares (see Appendix D for values) show the location of the MESA data used.

6.2. Hydrodynamic Model of the Bight

NOS was fortunate that a hydrodynamic model that includes the area of the Bight was being developed in CSDL. The model of the U.S. East Coast (Zhang et al., 1999) has horizontal curvilinear coordinates and a variable grid spacing, which in the Bight is 5 to 6 nautical miles. The grid is shown in Figure 6.3. The model was run in the two-dimensional mode with a time step of 20 s and forced at the open boundaries by a simplified astronomical tide consisting of five constituents (M_2, S_2, N_2, O_1, and K_1). The harmonic constants (i.e., amplitude and phase) for each constituent were determined by data assimilation (Zhang et al., 1999) . Water levels at all grids in the Bight were saved every 6 min during an 80-day run (May 12 to July 31, 2000).

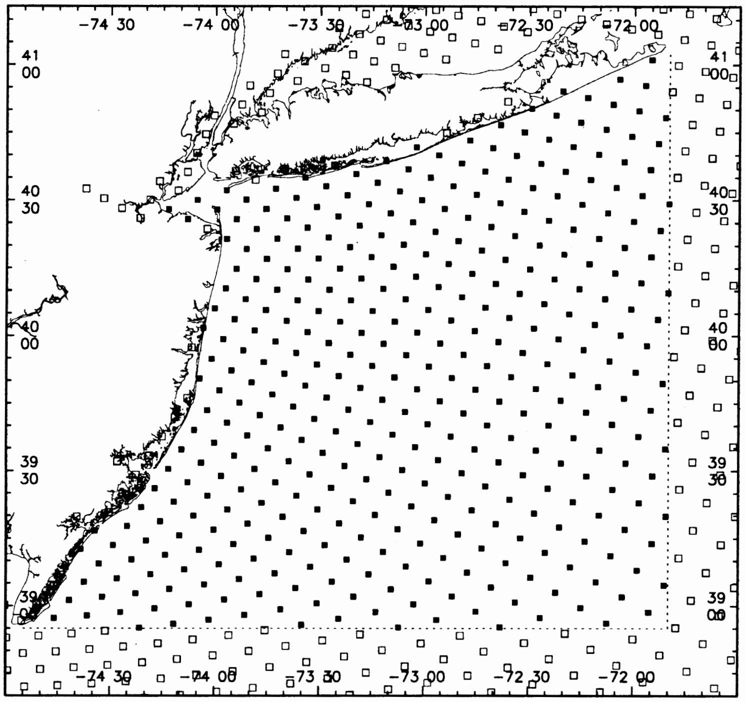

Figure 6.3. The circulation model grid in the New York Bight (Zhang et al., 1999) .

6.3. Generation of Datum and Transfer Fields

The tidal datum fields were generated from the hydrodynamic model in the same way as was done for Tampa Bay. However, an inspection of the mean range (MHW minus MLW) (Figure 6.4) shows that the modeled range is generally lower than the MESA Project's range throughout the Bight. Therefore, a spatially-varying correction function based on the modeled mean tide range was developed and applied to all model fields. The correction field, C, was developed by trial-and-error. The field is a function of tide range, R (meters), latitude, ϕ, and east longitude, λ, and is expressed as

$$\boxed{C(R,\varphi,\lambda) = A(R)B(\varphi,\lambda)} \qquad (1)$$

where

$$A(R) = 1.03 + a(R-0.95) \qquad a = \begin{cases} 0.025 & if \;\; R \geq 0.95 \\ 2.0 & if \;\; R < 0.95 \end{cases}$$

$$B(\varphi,\lambda) = 1.0+b[0.035-0.015(\lambda+73.0)](40.3-\varphi)/1.3 \qquad (2)$$

$$b = \begin{cases} 1.0 & if \;\; \varphi \leq 40.3 \\ 0.0 & if \;\; \varphi > 40.3 \end{cases}$$

The field $C(R, \phi, \lambda)$ is shown in Figure 6.5.

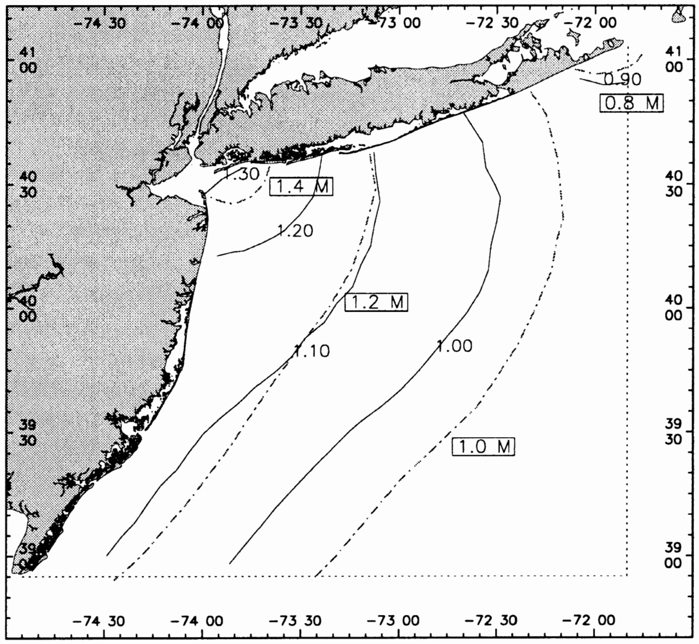

Figure 6.4. Tide ranges from MESA (dash-dot lines, range in box) and from the (uncorrected) circulation model.

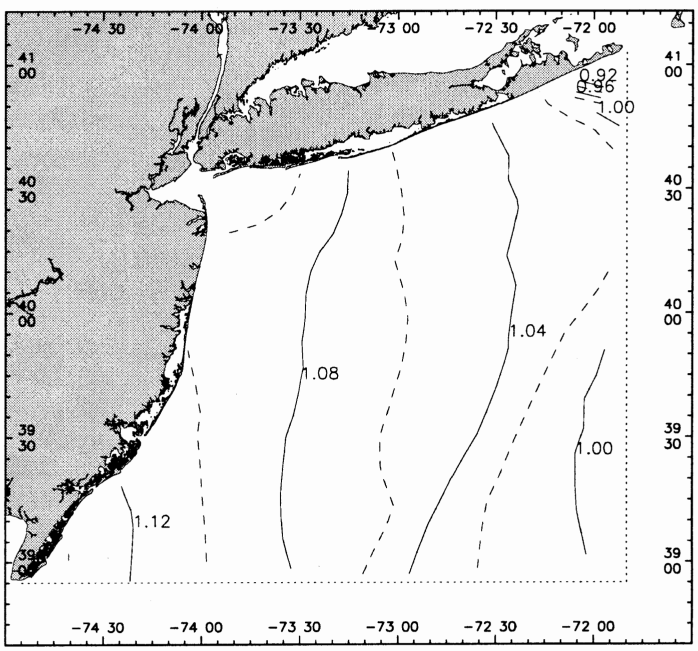

Figure 6.5. The tidal datum correction field, $C(R, \phi, \lambda)$.

The corrected mean tide range (the modeled tide range times the correction field) is shown in Figure 6.6). A comparison of errors in the corrected tide range at the tide gauges is shown in Table 6.1. The error (corrected range minus observed range) at six stations varies from -0.02 to 0.06 m, and averages 0.023 m. Plots of the corrected model datums are shown in Appendix E.

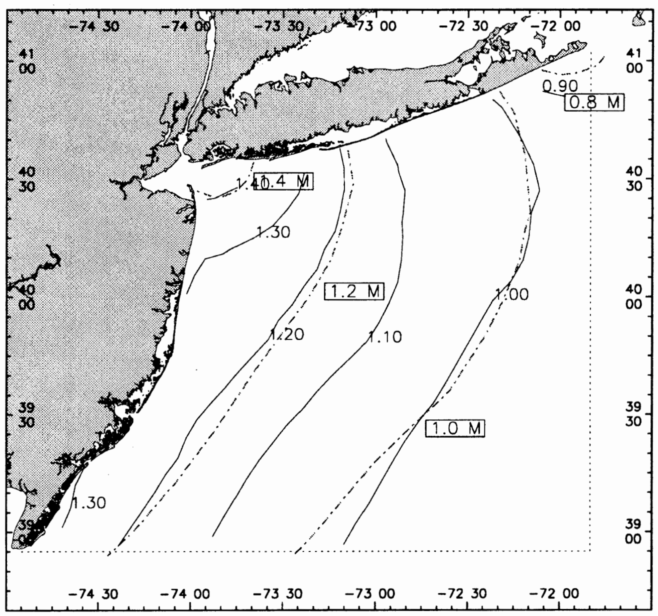

Figure 6.6. Modeled mean tide range (solid lines) after applying correction. The MESA data are dash-dot lines, with range values in boxes.

Table 6.1. Comparison of modeled tide ranges (m) with observed at several locations in the New York Bight. Observed values are from the MESA report (Swanson, 1976).

Location	Modeled Range	Observed Range	Difference (Modeled minus Observed)
Wildwood, NJ	1.31	1.25	0.06
Little Egg Inlet, NJ	1.26	1.23	0.03
Long Branch Pier, NJ	1.37	1.34	0.03
Fire Island, NY	1.28	1.25	0.03
Shinnecock Inlet, NY	1.02	1.01	0.01
MESA 10	1.15	1.17	-0.02

The next step is to interpolate the datum fields to a rectangular grid. For this application, columns of the rectangular grid began at longitude -74.9° and continued at 0.05° intervals to longitude -71.8°. The rows began at latitude 38.9° and continued at 0.05° intervals to latitude 41.08333°. The grid is shown in Figure 6.7. To create the final datum transfer fields, all the modeled tidal datum fields multiplied by the correction value, $C(R,\phi,\lambda)$. Then the modeled tidal datum MLLW field from the model was subtracted from one of the other datum fields, and the result interpolated to the rectangular grid. The interpolation simply computed the mean of all the modeled field values within 7.2 nmi of the location of the rectangular grid point, but excluding the locations that were not in the Bight, such as the coastal lagoons and some of New York Harbor and Long Island Sound.

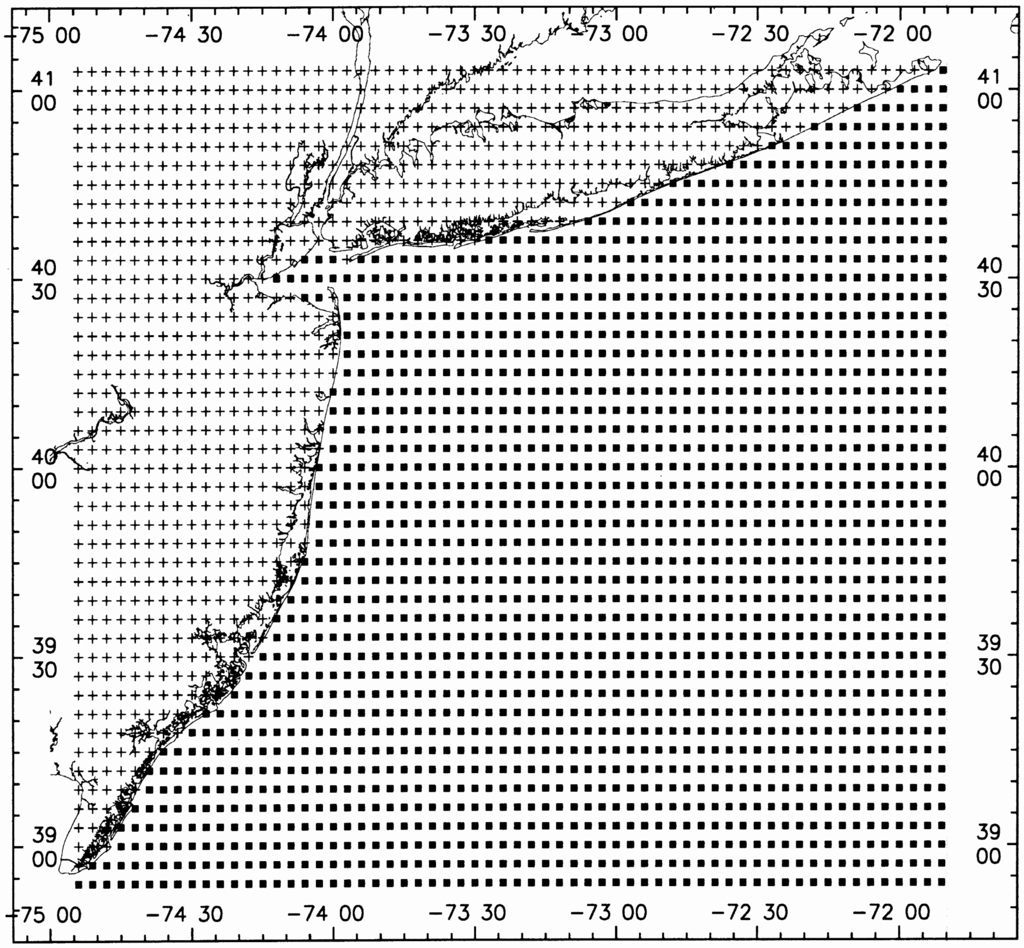

Figure 6.7. The datum transformation grid showing location of points used by VDatum. Filled squares show locations where datum transfer values are valid and locations denoted by a '+' hold only the default value.

Ultimately, some tidal datum transfer field will have to be referenced to a vertical datum. Although there are very little data for the south shore of Long Island, the mean value of the MTL-to-NAVD88 difference at 12 locations in or near the Bight averaged -0.155 m (Appendix F).

7. SUMMARY AND CONCLUSIONS

Tidal datum fields were generated for Tampa Bay, Florida, and the New York Bight. Datums for Tampa Bay, Florida, were generated from (1) the analysis of individual water level time series at each cell of a hydrodynamic model grid, and (2) spatial interpolation of tide gauge data. The model was run for a 1-year period, and the water levels saved at 6-min intervals. The datums were adjusted to represent the 1960-1978 epoch. Datum fields for an area outside the Tampa Bay model were generated by spatial interpolation of values at a few coastal gauges. The datums for the New York Bight were generated by a numerical model, although the modeled water levels were increased after comparison with the MESA Project data.

As a result of this study, there are four main conclusions:

1. Hydrodynamic models, when they exist, are useful in developing tidal datum fields in a region because (a) such models have a known level of accuracy, and (b) most models incorporate the appropriate tidal physics. A major drawback, however, is that such models require relatively long periods of time (months to years) to calibrate and validate to the required level of accuracy (several cm).

2. Spatial interpolation is also useful in developing tidal datum fields in a region because (a) usually there exists data from numerous water level gauges, and (b) methods for interpolating data in regions with irregular coastlines now exist. However, interpolation in open areas such as the New York Bight is difficult because of the presence of the large open boundary.

3. This project makes good use of the extensive tidal data base created by NOS over many years. Two drawbacks are that tidal data is not uniformly accurate for all locations, and sometimes water level stations do not adequately represent a region because they are placed in narrow channels, up rivers, and behind barrier beaches.

4. As compared to the mean of gauge values around the region, the model-generated field for MHW in Tampa Bay (based on a year-long run) appears to be too high by about 4 cm, and for MLW appears to be is too low by about 4 cm. At present, the reason for this is unknown.

ACKNOWLEDGMENTS

Dr. Bruce Parker, Chief of the Coast Survey Development Laboratory, has coordinated the NOS/USGS effort and provided the vision for many aspects of this project. Dr. Stephen Gill, Center for Operational Oceanographic Products and Services, provided the majority of the tidal data for Tampa Bay. Dennis Milbert, Chief Geodesist of the National Geodetic Survey, provided insight on datums and how they could be used for circulation model validation. Dr. Aijun Zhang, Coast Survey Development Laboratory, ran his circulation model for the East Coast of the U.S. (Including the New York Bight) and made the data available for analysis.

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APPENDIX A. TAMPA BAY DATUM FIELDS FROM MODELED WATER LEVELS

Plots of the tidal datum fields in Tampa Bay produced by the numerical circulation model. All elevations are in meters and are relative to the model's zero elevation.

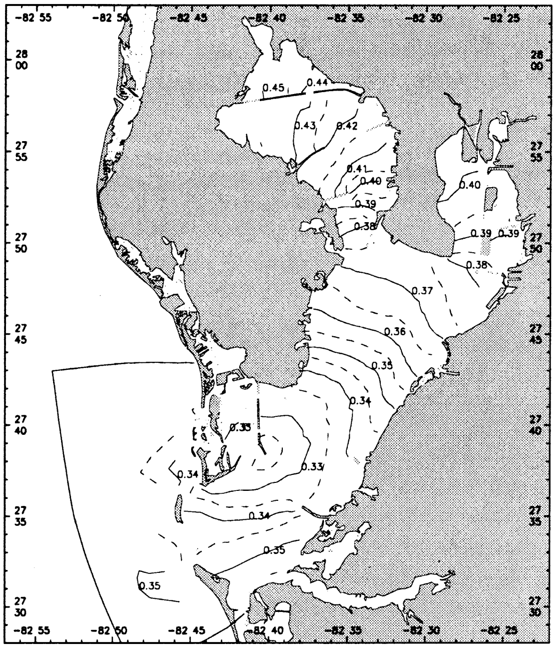

Figure A.1. MHHW.

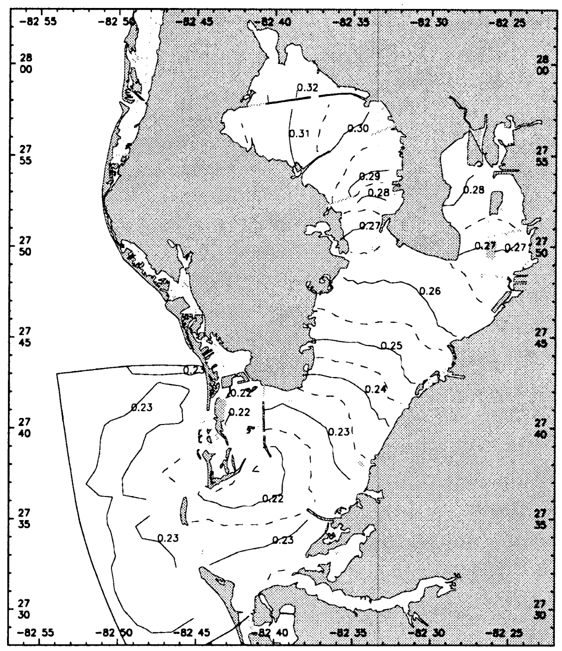

Figure A.2. MHW.

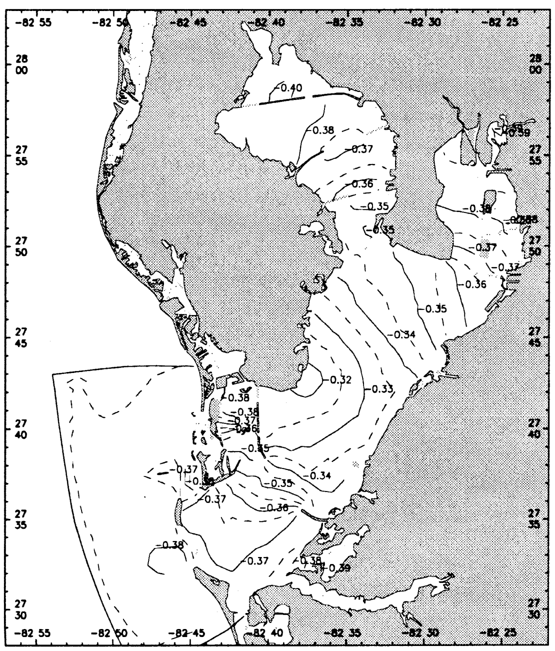

Figure A.3. MLLW.

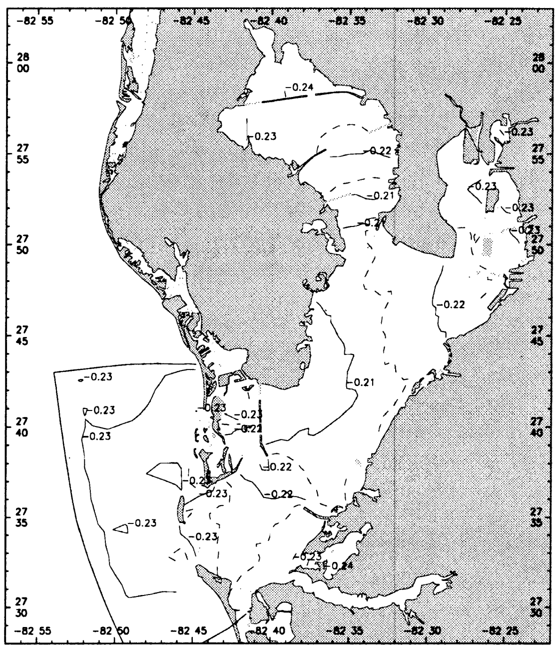

Figure A.4. MLW.

Appendix A. (Continued)

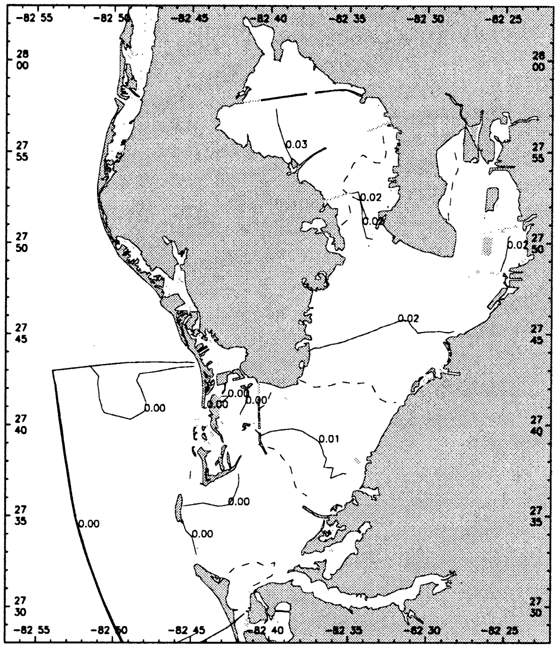

Figure A.5. MSL.

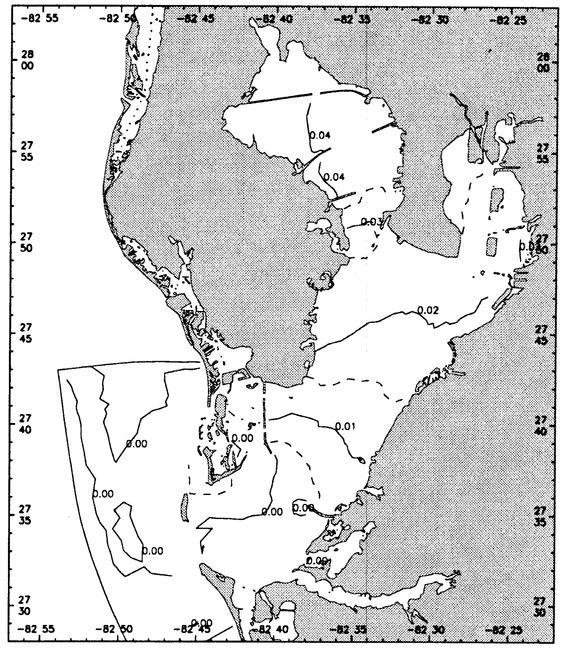

Figure A.6. MTL.

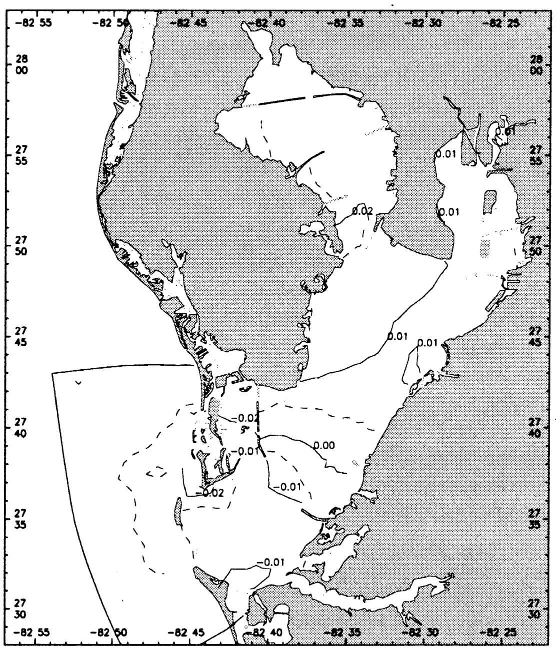

Figure A.7. DTL.

APPENDIX B. DATUM TRANSFER FIELDS FOR TAMPA BAY

Figures show the datum transfer fields as interpolated to the transfer grid (Figure 4.1.).

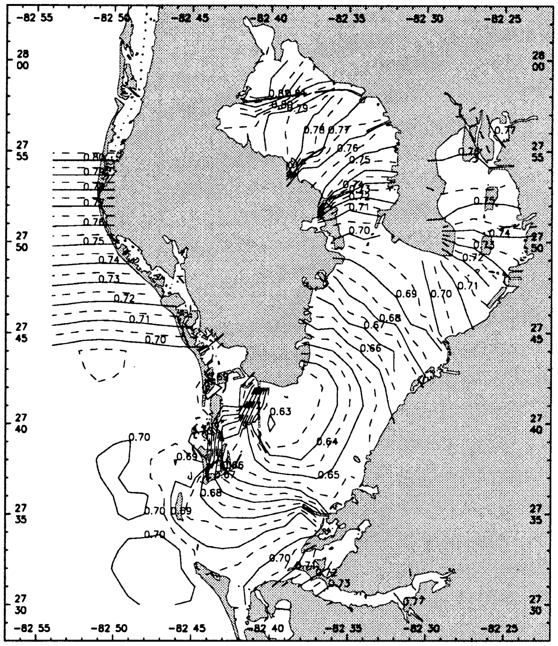

Figure B.1. MHHW (m) relative to MLLW.

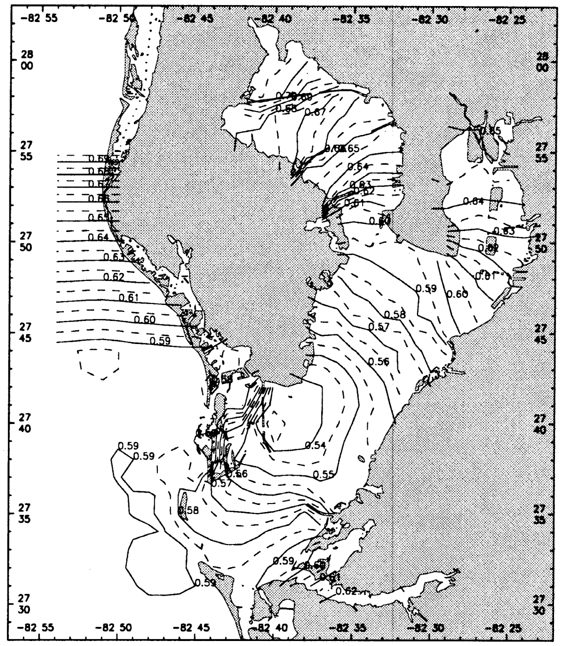

Figure B.2. MHW (m) relative to MLLW.

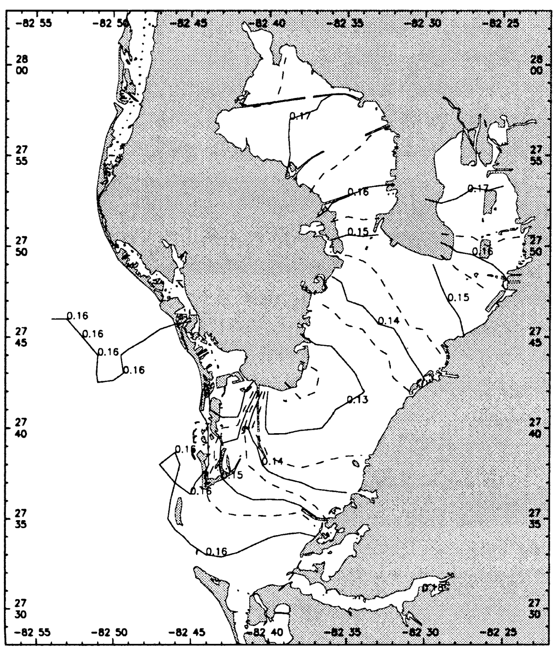

Figure B.3. MLW (m) relative to MLLW.

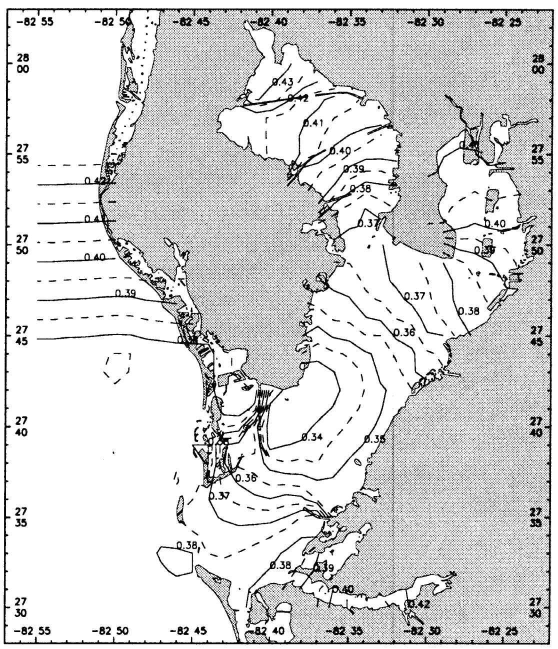

Figure B.4. MSL (m) relative to MLLW.

APPENDIX B. (Continued)

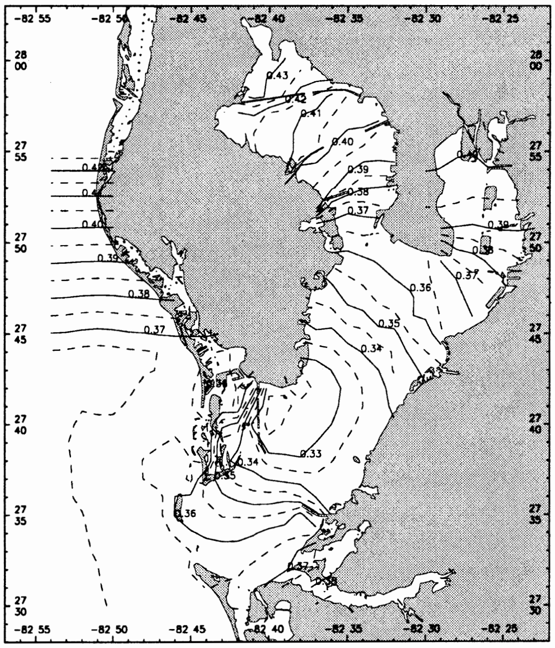

Figure B.6. MTL (m) relative to MLLW.

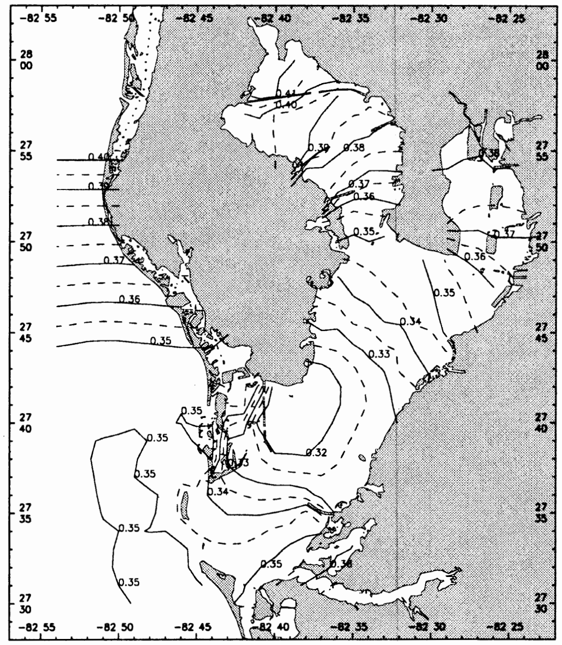

Figure B.6. DTL (m) relative to MLLW.

APPENDIX C. COMPARISON OF OBSERVED AND MODELED DATUMS IN TAMPA BAY

The tables below show a comparison of the observed and circulation model generated datums at selected Tampa Bay NOS tide station locations (8-digit number in parentheses). All datums (m) are relative to MLLW and modeled datums are referenced to the 1960-1978 epoch by the ratio method (see Table 4.1).

Table C.1. Ft. DeSoto Park (872-6273)

Datum	6273	O'=O-MLLW	Model	M'=M-MLLW	R	M' = M*R	R*M'-O'
MHHW	0.131	0.680	0.355	0.733	0.965	0.707	0.027
MHW	0.055	0.604	0.236	0.614	0.971	0.596	-0.008
MSL	-0.186	0.363	0.005	0.383	0.973	0.373	0.010
MTL	-0.193	0.346	0.003	0.379	0.973	0.369	0.023
DTL	-0.208	0.341	-0.011	0.367	0.966	0.354	0.013
MLW	-0.439	0.110	-0.230	0.148	1.017	0.164	0.054
MLLW	-0.549	0.000	-0.378	0.000	1.000	0.000	0.000

Table C.2. Anna Maria City Pier (872-6282)

Datum	6282	O'=O-MLLW	Model	M'=M-MLLW	R	R*M'	R*M'-O'
MHHW	0.113	0.677	0.346	0.717	0.965	0.692	0.015
MHW	0.034	0.598	0.234	0.605	0.971	0.587	-0.011
MSL	-0.210	0.354	0.011	0.382	0.973	0.372	0.018
MTL	-0.213	0.351	0.010	0.381	0.973	0.371	0.020
DTL	-0.225	0.339	-0.013	0.358	0.966	0.346	0.007
MLW	-0.460	0.104	-0.227	0.144	1.017	0.146	0.042
MLLW	-0.564	0.000	-0.371	0.000	1.000	0.000	0.000

Table C.3. Mullet Key (872-6364)

Datum	6364	Obs	Model	M'=M-MLLW	R	R*M'	R*M'-O'
MHHW	0.108	0.628	0.330	0.682	0.965	0.658	0.030
MHW	0.029	0.549	0.217	0.569	0.971	0.553	0.004
MSL	-0.187	0.333	0.004	0.356	0.973	0.346	0.013
MTL	-0.195	0.325	0.000	0.352	0.973	0.343	0.018
DTL	-0.205	0.315	-0.011	0.341	0.966	0.329	0.014
MLW	-0.416	0.104	-0.218	0.134	1.017	0.136	0.032
MLLW	-0.520	0.000	-0.352	0.000	1.000	0.000	0.000

APPENDIX C. (Continued)

Table C.4. Port Manatee (872-6384)

Datum	Obs	O'=Obs-MLLW	Model	M'=M-MLLW	R	R*M'	R*M'-O'
MHHW	0.119	0.659	0.341	0.678	0.965	0.654	-0.005
MHW	0.036	0.576	0.234	0.571	0.971	0.554	-0.022
MSL	-0.192	0.348	0.011	0.348	0.973	0.339	-0.009
MTL	-0.198	0.342	0.000	0.337	0.973	0.328	-0.014
DTL	-0.211	0.329	0.002	0.339	0.966	0.327	-0.002
MLW	-0.433	0.107	-0.214	0.123	1.017	0.125	0.018
MLLW	-0.540	0.000	-0.337	0.000	1.000	0.000	0.000

Table C.5. Tierra Verde (872-6428)

Datum	Obs	O'=Obs-MLLW	Model	M'=M-MLLW	R	R*M'	R*M'-O'
MHHW	0.147	0.652	0.333	0.713	0.965	0.688	0.036
MHW	0.065	0.570	0.219	0.599	0.971	0.582	0.012
MSL	-0.162	0.343	-0.001	0.379	0.973	0.369	0.026
MTL	-0.170	0.335	-0.007	0.373	0.973	0.363	0.028
DTL	-0.176	0.329	-0.023	0.357	0.966	0.345	0.016
MLW	-0.402	0.103	-0.233	0.147	1.017	0.150	0.047
MLLW	-0.505	0.000	-0.380	0.000	1.000	0.000	0.000

Table C.6. Bahia Beach (872-6479)

Datum	Obs	O'=Obs-MLLW	Model	M'=M-MLLW	R	R*M'	R*M'-O'
MHHW	0.116	0.713	0.366	0.716	0.965	0.691	-0.022
MHW	0.055	0.652	0.255	0.605	0.971	0.587	-0.065
MSL	-0.170	0.427	0.018	0.368	0.973	0.358	-0.069
MTL	-0.216	0.381	0.018	0.368	0.973	0.358	-0.023
DTL	-0.201	0.396	0.008	0.358	0.966	0.346	-0.050
MLW	-0.485	0.112	-0.218	0.132	1.017	0.134	0.022
MLLW	-0.597	0.000	-0.350	0.000	1.000	0.000	0.000

APPENDIX C. (Continued)

Table C.7. St. Petersburg (872-6520)

Datum	Obs	O'=Obs-MLLW	Model	M'=M-MLLW	R	R*M'	R*M'-O'
MHHW	0.174	0.683	0.360	0.690	0.965	0.666	-0.017
MHW	0.089	0.598	0.254	0.584	0.971	0.567	-0.031
MSL	-0.146	0.363	0.024	0.354	0.973	0.344	-0.019
MTL	-0.152	0.357	0.023	0.353	0.973	0.343	-0.014
DTL	-0.167	0.342	0.015	0.345	0.966	0.333	-0.009
MLW	-0.390	0.119	-0.209	0.121	1.017	0.123	0.004
MLLW	-0.509	0.000	-0.330	0.000	1.000	0.000	0.000

Table C.8. Hillsborough Bay East (872-6562)

Datum	Obs	O'=Obs-MLLW	Model	M'=M-MLLW	R	R*M'	R*M'-O'
MHHW	0.196	0.769	0.386	0.758	0.965	0.731	-0.038
MHW	0.113	0.686	0.268	0.640	0.971	0.621	-0.065
MSL	-0.173	0.400	0.020	0.392	0.973	0.381	-0.019
MTL	-0.164	0.409	0.021	0.393	0.973	0.382	-0.027
DTL	-0.189	0.384	0.007	0.379	0.966	0.366	-0.018
MLW	-0.442	0.131	-0.227	0.145	1.017	0.147	0.016
MLLW	-0.573	0.000	-0.372	0.000	1.000	0.000	0.000

Table C.9. Gadsden Point(872-6573)

Datum	Obs	O'=Obs-MLLW	Model	M'=M-MLLW	R	R*M'	R*M'-O'
MHHW	0.189	0.743	0.378	0.735	0.965	0.709	-0.034
MHW	0.113	0.667	0.265	0.622	0.971	0.604	-0.063
MSL	-0.143	0.411	0.021	0.378	0.973	0.368	-0.043
MTL	-0.161	0.393	0.022	0.379	0.973	0.369	-0.024
DTL	-0.205	0.349	0.010	0.367	0.966	0.355	0.006
MLW	-0.436	0.118	-0.220	0.137	1.017	0.139	0.021
MLLW	-0.554	0.000	-0.357	0.000	1.000	0.000	0.000

APPENDIX D. MEAN TIDE RANGES AT MESA NEW YORK BIGHT STATIONS

MESA Station Number	Latitude	Longitude	Name	Range (m)
02	39° 21'	-74° 25'	Atlantic City	1.25
03	39° 55'	-74° 05'	Seaside Park	1.28
04	40° 08'	-74° 02'	Sea Girt	1.31
05	40° 13'	-74° 00'	Asbury Park	1.31
06	40° 18'	-73° 59'	Long Branch	1.34
07	40° 22'	-73° 58'	Sea Bright	1.34
08	40° 28'	-74° 01'	Sandy Hook	1.40
09	40° 25'	-74° 02'	Atlantic Highlands	1.43
10	40° 26'	-74° 12'	Keyport	1.52
11	40° 29'	-74° 17'	South Amboy	1.52
12	40° 33'	-74° 08'	Great Kills Harbor	1.43
13	40° 34'	-73° 59'	Coney Island	1.43
15	40° 39'	-74° 04'	St. George	1.37
17	40° 35'	-73° 39'	Long Beach	1.37
19	40° 37'	-73° 18'	Fire Island	1.25
20	40° 50'	-72° 28'	Shinnecock Inlet	1.01
21	41° 04'	-71° 52'	Montauk Point	0.61
57	39° 45'	-72° 42'	MESA 9	1.04
58	40° 00'	-73° 14'	MESA 10	1.17
59	40° 08'	-73° 34'	MESA 11	1.25
60	40° 27'	-73° 50'	Ambrose Light	1.40
61	39° 38'	-73° 42'	EPA 1	1.17
62	39° 28'	-74° 16'	Little Egg Inlet	1.23
63	39° 38'	-72° 38'	MESA 22	1.00

APPENDIX E. NEW YORK BIGHT DATUM FIELDS FROM MODELED WATER LEVELS

The figures show the corrected tidal datum fields based on the fields as generated by the numerical circulation model grid. Water elevations are relative to the model's zero water level.

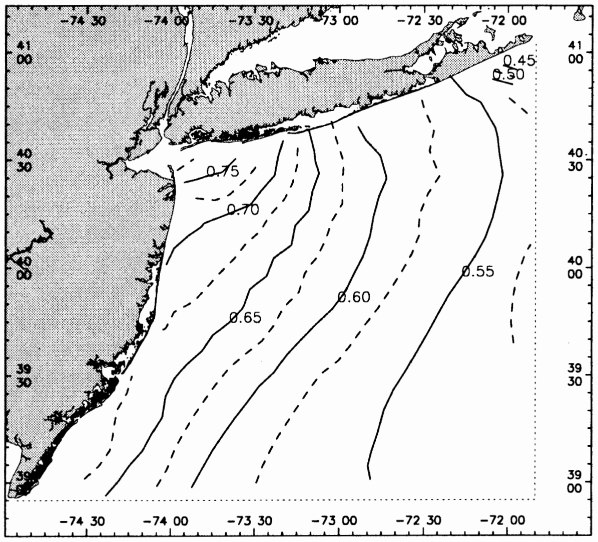

Figure E.1. The MHHW field (m).

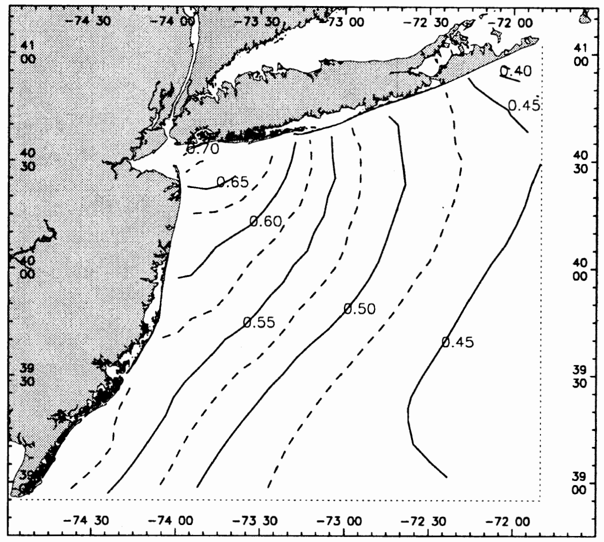

Figure E.2. The MHW field (m).

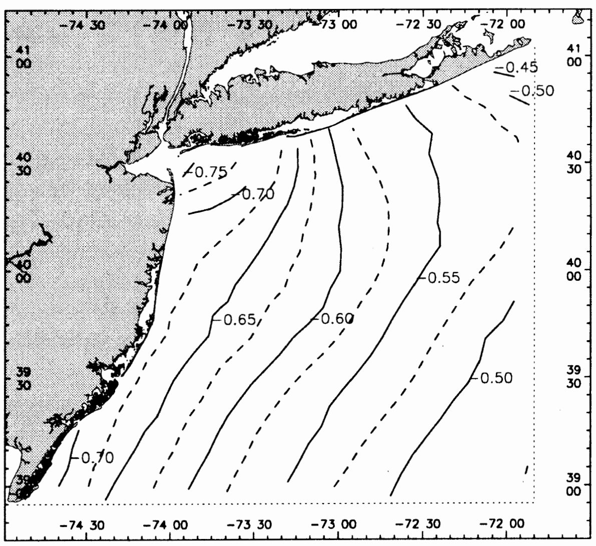

Figure E.3. The MLW field (m).

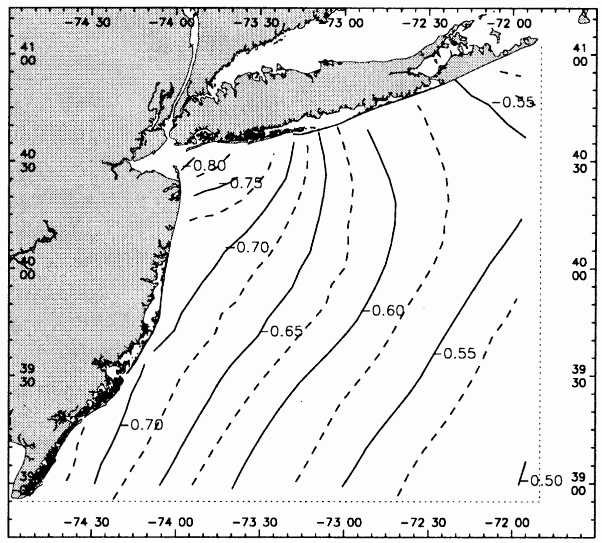

Figure E.4. The MLLW field (m).

APPENDIX E. (Continued)

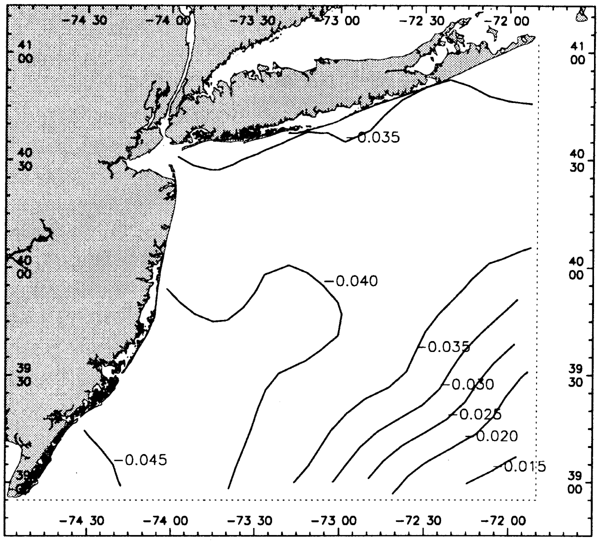

Figure E.5. The MSL field (m).

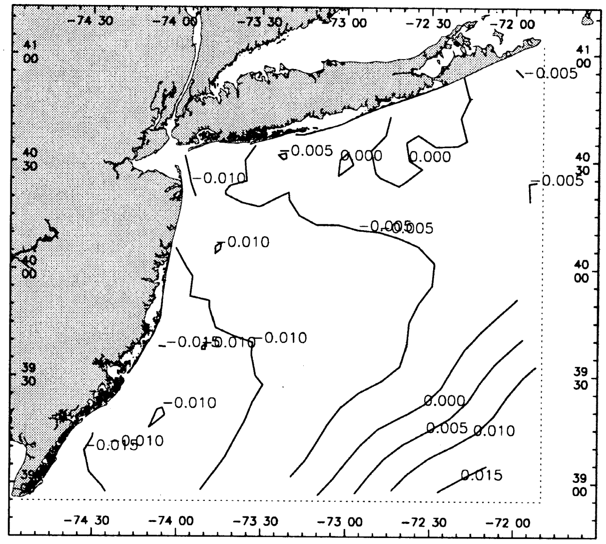

Figure E.6. The DTL field (m).

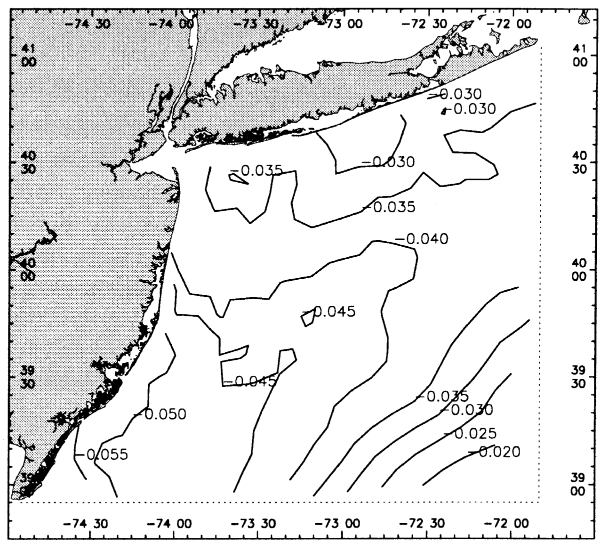

Figure E.7. The MTL field (m).

APPENDIX F. NAVD88 ELEVATIONS AT NEW YORK BIGHT STATIONS

Water Level Station Location	NOS Tide Station Number	Latitude	Longitude	MTL - NAVD88 (ft)
Sakonnet, RI	845 0768	41° 27.9′	-71° 11.6′	-0.40
Watch Hill, RI	845 8694	41° 18.3′	-71° 51.6′	-0.54
Plum Island, NY	851 1236	41° 10.4′	-72° 12.3′	-0.60
Montauk, Fort Pond, NY	851 0560	41° 2.9′	-71° 57.6′	-0.29
Fire Island Coast Guard Station, NY	851 5186	40° 37.6′	-73° 15.6′	-0.50
Staten Island, NY	851 9024	40° 36.4′	-74° 3.3′	-0.38
Matawan Creek, Raritan Bay, NJ	853 1526	40° 26.0′	-74° 13.1′	-0.46
Sandy Hook, NJ	853 1680	40° 28.0′	-74° 0.6′	-0.54
Long Branch Pier, NJ	853 1991	40° 18.2′	-73° 58.6	-0.57
Corson Inlet, NJ	853 5101	39° 12.9′	-74° 38.9′	-0.55
Strathmere Bay, NJ	853 5163	39° 12.0′	-74° 39.4′	-0.57
Cape May, NJ	853 6110	38° 58.1′	-74° 57.6′	-0.68
		Max= -0.29 ft	Min = -0.68 ft	Mean = -0.51 ft = -15.5 cm