# Digital Elevation Model for Montauk, New York: Procedures, Data Sources and Analysis

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# Digital Elevation Model for Montauk, New York: Procedures, Data Sources and Analysis

## 1. Introduction

The National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), has developed a bathymetric–topographic digital elevation model (DEM) of Montauk, New York (Fig. 1)—the northeastern end of Long Island—for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The 1/3 arc-second[1] coastal DEM will be used as input for the Method of Splitting Tsunami (MOST) model developed by PMEL to simulate tsunami generation, propagation and inundation. The DEM was generated from diverse digital datasets in the region (grid boundary and sources shown in Fig. 3) and will be used for tsunami inundation modeling, as part of the tsunami forecast system SIFT (Short-term Inundation Forecasting for Tsunamis) currently being developed by PMEL for the NOAA Tsunami Warning Centers. This report provides a summary of the data sources and methodology used in developing the Montauk DEM.

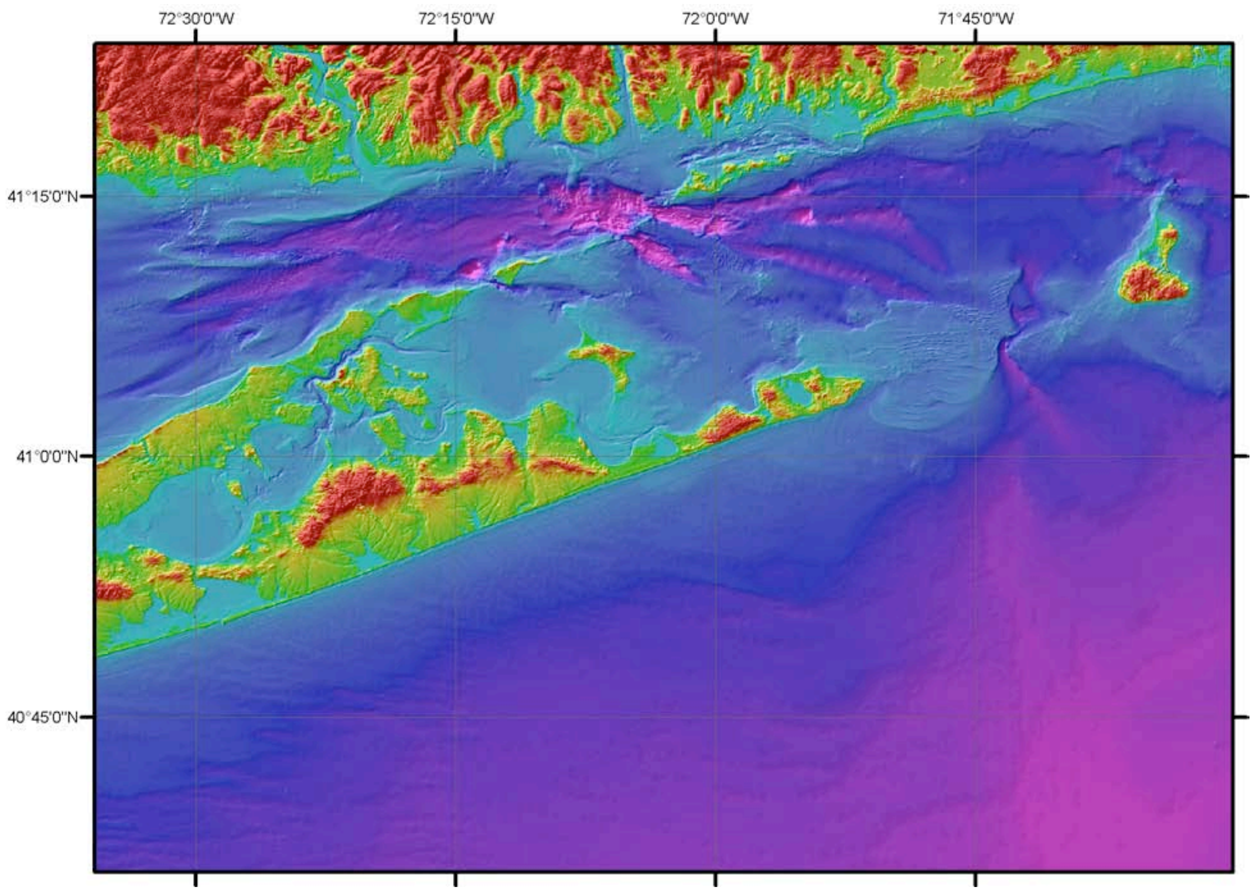


***Figure 1.*** *Shaded-relief image of the Montauk, New York DEM.*

1. The Montauk DEM is built upon a grid of cells that are square in geographic coordinates (latitude and longitude), however, the cells are not square when converted to projected coordinate systems, such as UTM zones (in meters). At the latitude of Montauk, New York (41°02.1′ N, 71°57.3′ W) 1/3 arc-second of latitude is equivalent to 10.283 meters; 1/3 arc-second of longitude equals 7.786 meters.

## 2. Study Area

The geologically young sediments that cover much of the U.S. Eastern Seaboard make up the Atlantic Coastal Plain, which includes Long Island, Fishers Island, Block Island, Martha's Vineyard, Nantucket, and Cape Cod. These islands are parts of glacial moraines—long ridges of clay, sand, gravel, and boulders deposited at the edge of a continental glacier. On Long Island, the Ronkonkoma Moraine marks the southernmost advance of the glacier in this region. During the last ice age, the growing mass of ice on the continents depleted the ocean waters enough to lower sea level by 100 meters. As the ice melted, the rising sea made parts of these moraines into islands. Waves and currents have been modifying them ever since.

The continental shelf, slope, and rise lie seaward of the Atlantic Coastal Plain. The continental shelf is nearly level; the continental slope has a slope of $2^{o}$ to $4^{o}$; the continental rise slopes less than $1^{o}$. They are made of material eroded from the land, carried by rivers to the ocean, and distributed there by marine currents. During the period of low sea level, the continental shelf was exposed as part of the coastal plain, and rivers cut valleys across it to the shelf edge. Most of those valleys have since been filled with sediment, but a vestige of the Hudson Shelf Valley still remains. The Hudson Canyon and other, large canyons are cut into the shelf edge and continental slope. Much of this canyon-cutting occurred when rivers, swollen with glacial meltwater and laden with glacial sediment, flowed across the exposed shelf and met the sea at the top of the continental slope. The sediment that the rivers poured into the ocean at those points formed density currents. These currents cut the canyons into the slope (from Rogers et al., http://gretchen.geo.rpi.edu/roecker/nys/nys_edu.pamphlet.html).

***Figure 2.*** *Boulder-covered beach and moraine cliffs on Long Island's Atlantic Ocean coast. Montauk Lighthouse is in the distance. (Image taken from http://3dparks.wr.usgs.gov/nyc/parks/loc65.htm).*

## 3. METHODOLOGY

The Montauk, New York DEM was developed to meet PMEL specifications (Table 1), based on input requirements for the MOST inundation model. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: World Geodetic System 1984 (WGS84) and Mean High Water (MHW), for modeling of "worst-case scenario" flooding, respectively. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

**Table 1. PMEL specifications for the Montauk, New York DEM.**

| | |
|---|---|
| **Grid Area** | Montauk, New York |
| **Coverage Area** | 72.6º to 71.5º W; 40.6º to 41.4º N |
| **Coordinate System** | Geographic decimal degrees |
| **Horizontal Datum** | World Geodetic System 1984 (WGS84) |
| **Vertical Datum** | Mean High Water (MHW) |
| **Vertical Units** | Meters |
| **Grid Spacing** | 1/3 arc-second |
| **Grid Format** | ESRI Arc ASCII grid |

### 3.1 Data Sources and Processing

Shoreline, bathymetric, topographic, and topographic–bathymetric digital datasets (Fig. 3) were obtained from several U.S. federal, state and local agencies including: NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS) and Coastal Services Center (CSC); the U.S. Geological Survey (USGS); and the U.S. Army Corps of Engineers (USACE). Safe Software's (http://www.safe.com/) FME data translation tool package was used to shift datasets to WGS84 horizontal datum and to convert them into ESRI (http://www.esri.com/) ArcGIS shape files. The shape files were then displayed with ArcGIS to assess data quality and manually edit datasets. Vertical datum transformations to MHW were accomplished using FME, based upon conversion grids created by PMEL from the NOAA tide stations in the area. VDatum model software (http://nauticalcharts.noaa.gov/csdl/vdatum.htm) was used for the region south of Long Island. GMT (http://gmt.soest.hawaii.edu/) and MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/) were used to grid the data and build the DEM.

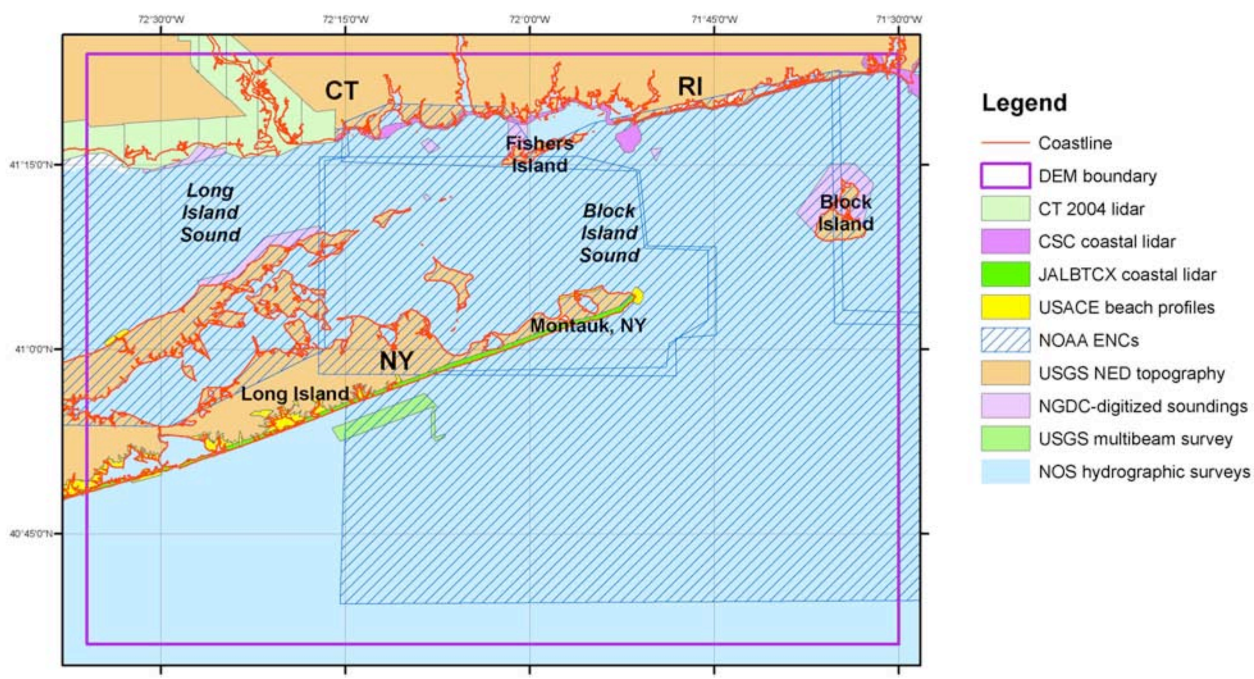


***Figure 3.*** *Source and coverage of datasets used to compile the Montauk DEM.*

### 3.1.1 *Shoreline*

Coastline datasets of the Montauk region were obtained from NOAA's Office of Coast Survey and Coastal Services Center (Table 2).

**Table 2. Shoreline datasets available in the Montauk, New York region.**

| *Source* | *Year* | *Data Type* | *Spatial Resolution* | *Original Horizontal Datum/Coordinate System* | *Original Vertical Datum* | *URL* |
|---|---|---|---|---|---|---|
| OCS ENCs and RNCs | 2006-2007 | Coastline | 1:10,000 to 1:80,000 | WGS84 geographic | Mean High Water | http://nauticalcharts.noaa.gov/ |
| NOAA CSC | 2003 | Vector shoreline of New York | Various | NAD83 geographic | Mean High Water | http://www.csc.noaa.gov/shoreline/data.html |
| NOAA OCS | 1994 | Vector shoreline of U.S. | Avg. 1:70,000 | NAD83 geographic | NGVD29 | |

**1) NOAA Office of Coast Survey nautical charts**

Four of the NOAA nautical charts in the vicinity of Montauk, NY have been released as Electronic Navigational Charts (ENCs) with chart features in digital form. These ENCs (Table 3) were downloaded from NOAA's Office of Coast Survey website (http://nauticalcharts.noaa.gov/mcd/enc/index.htm). The ENCs are available in S-57 format and include coastline data at Mean High Water. Other nautical charts (Table 4) were available as georeferenced raster nautical charts (RNCs; digital images of the charts) and were used for digitizing coastline sections, and for quality control of bathymetric and topographic datasets.

**Table 3. NOAA Electronic Navigational Charts in the Montauk region.**

| *Nautical Chart #* | *ENC ref.#* | *Region* | *Scale* | *Ed. Date* |
|---|---|---|---|---|
| 13205 | US4CN21M | BLOCK ISLAND SOUND AND APPROACHES | 1:80,000 | 1999 |
| 13218 | US4MA23M | MARTHA'S VINEYARD TO BLOCK ISLAND | 1:80,000 | 2001 |
| 12354 | US4NY1GM | LONG ISLAND SOUND-EASTERN PART CONN-NY | 1:80,000 | 2000 |
| 13209 | US5MA22M | BLOCK ISLAND SOUND AND GARDINERS BAY | 1:40,000 | 1999 |

**Table 4. NOAA Raster Nautical Charts in the Montauk region.**

| *Nautical Chart #* | *Region* | *Scale* | *Ed. Date* |
|---|---|---|---|
| 12352 | SHINNECOCK BAY TO MORICHES BAY LONG ISLAND NY | Various | 2006-03-01 |
| 12353 | SHINNECOCK LIGHT TO FIRE ISLAND LIGHT | 1:80,000 | 2003-11-01 |
| 12358 | NEW YORK LONG ISLAND SHELTER ISLAND SOUND AND PECONIC BAYS | 1:40,000 | 2002-09-01 |
| 12372 | LONG ISLAND SOUND - RI CONN | 1:40,000 | 2006-11-01 |
| 12374 | NORTH SHORE OF LONG ISLAND SOUND-DUCK ISLAND TO MADISON REEF | 1:20,000 | 2000-10-28 |
| 12375 | CONNECTICUT RIVER LONG ISLAND SOUND TO DEEP RIVER | 1:20,000 | 2001-02-17 |
| 12377 | CONNECTICUT RIVER-DEEP RIVER TO HIGGANUM CREEK | 1:20,000 | 2001-01-13 |
| 13211 | NORTH SHORE OF LONG ISLAND SOUND - NIANTIC BAY VICINITY | 1:20,000 | 2004-09-01 |
| 13212 | APPROACHES TO NEW LONDON HARBOR | 1:20,000 | 2005-11-01 |
| 13213 | NEW LONDON HARBOR AND VICINITY | 1:10,000 | 2004-03-01 |
| 13214 | FISHERS ISLAND SOUND | 1:20,000 | 2006-04-01 |
| 13215 | BLOCK ISLAND SOUND-PT JUDITH TO MONTAUK PT CONN-RI-NY | 1:40,000 | 2004-08-01 |
| 13217 | BLOCK ISLAND RI | 1:15,000 | 2006-11-01 |
| 13219 | PT JUDITH HARBOR RI | 1:15,000 | 2001-10-06 |

**2) NOAA Coastal Services Center coastline of New York**

A statewide coastline of New York was downloaded from NOAA's Coastal Services Center. These shoreline data represent a vector conversion of a set of NOS raster shoreline maps (often called t-sheet or tp-sheet maps). These vector data were created by contractors to NOS who vectorized georeferenced raster maps using Environmental Systems Research Institute, Inc. (ESRI) ArcInfo's(r) ArcScan(r) software to create individual ArcInfo coverages. The individual coverages were ultimately edge-matched and appended together to form this statewide coverage. The CSC New York shoreline includes man-made features, such as piers (e.g., Fig. 4).

**3) NOAA Office of Coast Survey U.S. coastline**

National Oceanic and Atmospheric Administration's (NOAA) Medium Resolution 1:70,000 scale Digital Vector Shoreline is a high-quality, Geographic Information System-ready, general-use digital vector data set containing the coastline of the contiguous United States of America. It was created by the Strategic Environmental Assessments (SEA) Division of NOAA's Office of Ocean Resources Conservation and Assessment. Compiled from hundreds of NOAA coast charts, this product comprises over 75,000 nautical miles of coastline (nearly 2.5 million vertices). The shoreline was created from data captured (digitized from scanned images of the master separates of the NOS Charts) from over 270 National Ocean Service Navigation Charts and spans some 80,000 nautical miles at an average map scale of 1:70,000. This coastline is at lower resolution than the other NOAA coastlines (e.g., Fig .4).

NGDC extracted the coastlines from the four ENCs available in the Montauk area (Table 3), then digitized sections of coastline from higher-resolution, larger-scale RNCs (Table 4) that do not exist in ENC form. Modifications to the "Montauk" coastline included adjustments to fit the most recent topographic and topographic–bathymetric lidar data and removal of manmade features such as piers. Digitization and coastline modification were done using ArcMap editing tools.

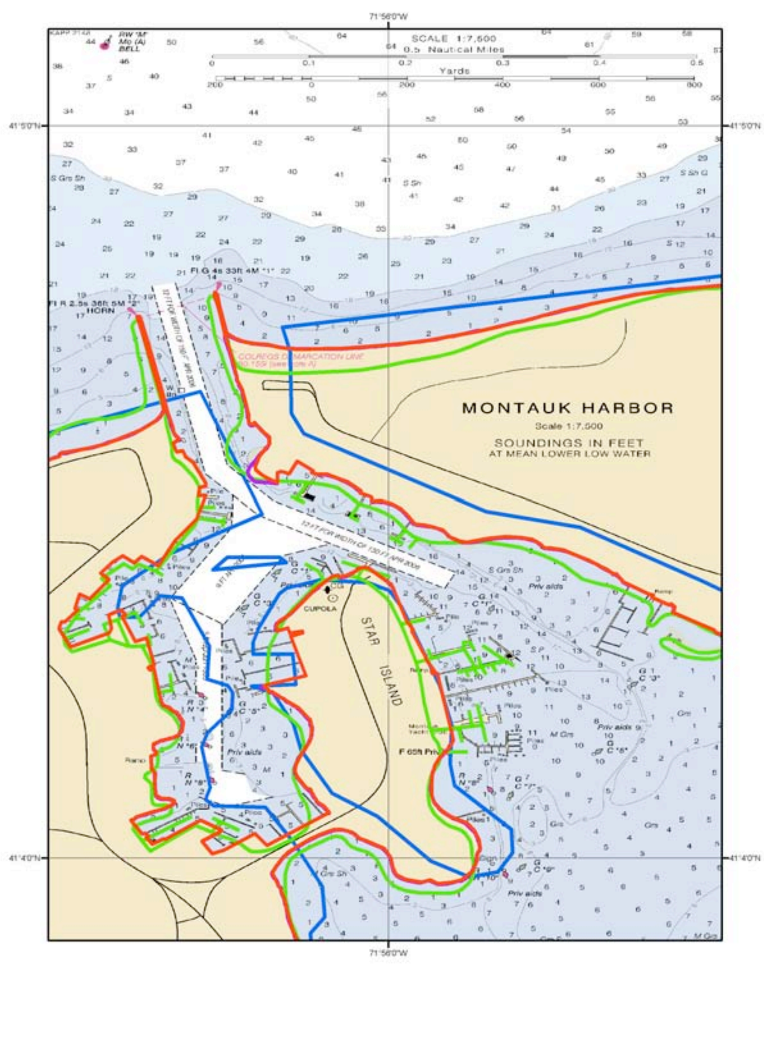


*Figure 4. Digital coastline datasets in Montauk Harbor. Blue–low-resolution OCS shoreline of the U.S.; Green–CSC shoreline of New York, which includes manmade features such as piers; Purple–ENC shoreline from Chart 13209; Red–final 'Montauk' coastline derived from NOAA ENCs and RNCs.*

### *3.1.2 Bathymetry*

Bathymetric datasets used in the compilation of the Montauk DEM include 78 NOS hydrographic surveys, recent NOS and USGS multibeam sonar surveys, and soundings from NOAA nautical charts (Table 5; Fig. 5).

**Table 5. Bathymetric datasets used in compiling the Montauk DEM.**

| *Source* | *Year* | *Data Type* | *Spatial Resolution* | *Original Horizontal Datum/Coordinate System* | *Original Vertical Datum* | *URL* |
|---|---|---|---|---|---|---|
| NOS | 1883 to 2000 | Hydrographic survey soundings | Ranges from 10 m to 1 km (varies with scale of survey, depth, traffic, and probability of obstructions) | NAD27 or NAD83 geographic | Mean Low Water or Mean Lower Low Water | http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html |
| NOS | 2003 | Multibeam sonar survey | 2 meters | NAD83 geographic | Mean Lower Low Water | |
| USGS | 2006 | Multibeam sonar survey | 3 meters | WGS84 geographic | Inferred Mean Lower Low Water | |
| NOAA ENCs | 2007 | Digital chart soundings | 250 to 2000 meters | WGS84 geographic | Mean Lower Low Water | http://nauticalcharts.noaa.gov/ |
| NOAA RNCs | 2007 | NGDC-digitized soundings | 50 to 300 meters | WGS84 geographic | Mean Lower Low Water | http://nauticalcharts.noaa.gov/ |

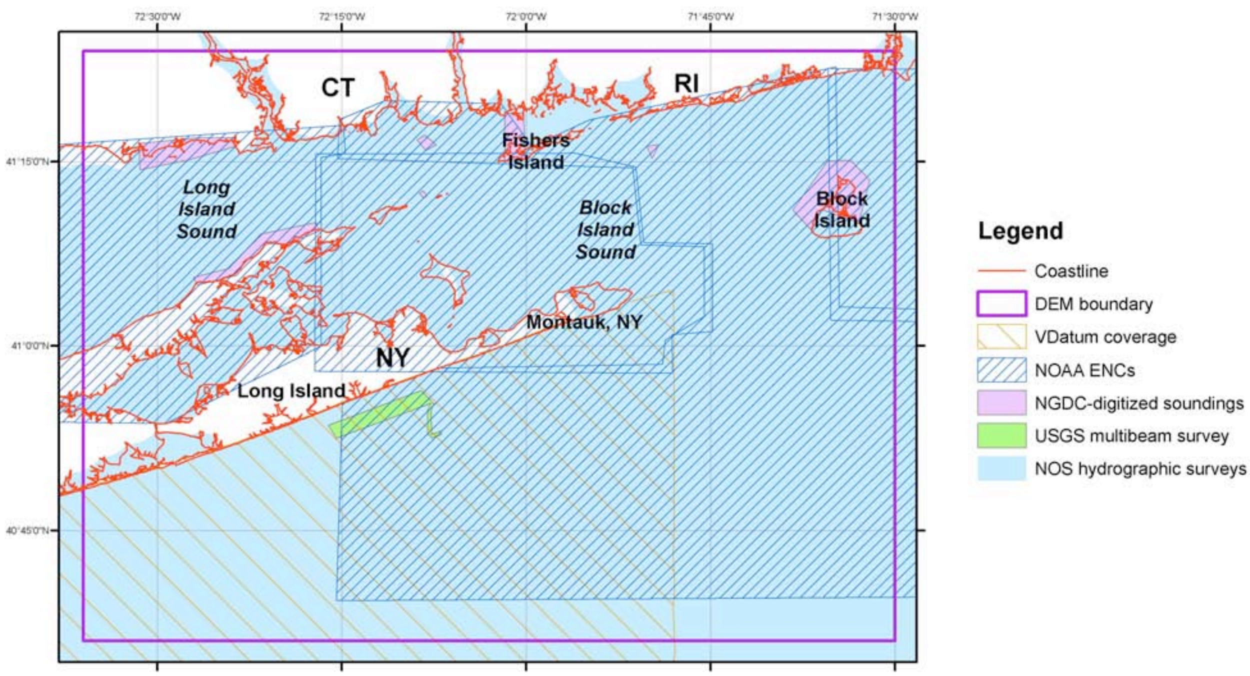


***Figure 5.*** *Spatial coverage of bathymetric datasets used to compile the Montauk DEM.*

### 1) NOS hydrographic survey data

A total of 78 NOS hydrographic surveys conducted between 1883 and 2000 were utilized in developing the Montauk DEM (Table 6; Fig. 6). The digital hydrographic survey data were originally vertically referenced to Mean Lower Low Water (MLLW) or Mean Low Water (MLW) and horizontally referenced to either NAD27 or NAD83 datums.

Data point spacing for the NOS surveys varied by collection date. In general, earlier surveys had greater point spacing than more recent surveys. All surveys were extracted from NGDC's online NOS hydrographic database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html). The data were then converted to WGS84 and MHW using FME software, an integrated collection of spatial extract, transform, and load tools for data transformation (http://www.safe.com). The surveys were subsequently clipped to a polygon 0.05 degree (~5%) larger than the Montauk DEM area to support data interpolation along grid edges.

After converting all NOS survey data to MHW (see Section 3.2.1), the data were displayed in ESRI ArcMap and reviewed for digitizing errors against scanned original survey smooth sheets and edited as necessary. The surveys were also compared to the topographic, bathymetric, and topographic–bathymetric datasets, the Montauk coastline, and NOS raster nautical charts (RNCs). In some areas, significant coastal change has occurred, causing the shallow-water soundings in particular to be inaccurate.

**Table 6. Digital NOS hydrographic surveys used in compiling the Montauk DEM.**

| *NOS Survey ID* | *Year of Survey* | *Survey Scale* | *Original Vertical Datum* | *Original Horizontal Datum* |
|---|---|---|---|---|
| H01603B | 1883 | 10,000 | mean low water | undetermined |
| H01603C | 1883 | 10,000 | mean low water | undetermined |
| H04893 | 1928 | 10,000 | mean low water | NAD1913 |
| H05322 | 1933 | 20,000 | mean low water | NAD27 |
| H05323 | 1933 | 10,000 | mean low water | NAD27 |
| H05324 | 1933 | 20,000 | mean low water | NAD27 |
| H05325 | 1933 | 20,000 | mean low water | NAD27 |
| H05326 | 1933 | 5,000 | mean low water | NAD27 |
| H05344 | 1933 | 20,000 | mean low water | NAD27 |
| H05378 | 1933 | 10,000 | mean low water | NAD27 |
| H05379 | 1933 | 10,000 | mean low water | NAD27 |
| H05380 | 1933/35 | 10,000 | mean low water | NAD27 |
| H05381 | 1933 | 10,000 | mean low water | NAD27 |
| H05382 | 1933 | 10,000 | mean low water | NAD27 |
| H05383 | 1933 | 20,000 | mean low water | NAD27 |
| H05513 | 1934 | 10,000 | mean low water | NAD27 |
| H05514 | 1934 | 20,000 | mean low water | NAD27 |
| H05515 | 1934 | 20,000 | mean low water | NAD27 |
| H05516 | 1934 | 10,000 | mean low water | NAD27 |
| H06328 | 1938 | 40,000 | mean low water | NAD27 |
| H06329 | 1938 | 40,000 | mean low water | NAD27 |
| H06330 | 1938 | 40,000 | mean low water | NAD27 |
| H06331 | 1938 | 80,000 | mean low water | NAD27 |
| H06347 | 1938 | 120,000 | mean low water | NAD27 |
| H06442 | 1939 | 10,000 | mean low water | NAD27 |
| H06443 | 1939 | 40,000 | mean low water | NAD27 |
| H06444 | 1939 | 40,000 | mean low water | NAD27 |
| H06668 | 1941 | 5,000 | mean low water | NAD27 |
| H06828 | 1943 | 5,000 | mean low water | NAD27 |
| H07640 | 1948 | 10,000 | mean low water | NAD27 |
| H08315 | 1958 | 12,500 | mean low water | NAD27 |
| H08615 | 1961 | 10,000 | mean low water | NAD27 |
| H08616 | 1961/62 | 10,000 | mean low water | NAD27 |

| | | | | |
|---|---|---|---|---|
| H08708 | 1962 | 10,000 | mean low water | NAD27 |
| H08709 | 1961/62 | 20,000 | mean low water | NAD27 |
| H08908 | 1966 | 10,000 | mean low water | NAD27 |
| H08926 | 1966/68 | 10,000 | mean low water | NAD27 |
| H08936 | 1967 | 10,000 | mean low water | NAD27 |
| H08996 | 1968 | 10,000 | mean low water | NAD27 |
| H08997 | 1968/69 | 10,000 | mean low water | NAD27 |
| H09051 | 1969 | 10,000 | mean low water | NAD27 |
| H09059 | 1969 | 10,000 | mean low water | NAD27 |
| H09087 | 1969 | 20,000 | mean lower low water | NAD27 |
| H09088 | 1969 | 20,000 | mean low water | NAD27 |
| H09089 | 1969 | 20,000 | mean low water | NAD27 |
| H09093 | 1969 | 10,000 | mean low water | NAD27 |
| H09170 | 1970 | 10,000 | mean low water | NAD27 |
| H09181 | 1970/71 | 20,000 | mean low water | NAD27 |
| H09212 | 1971 | 20,000 | mean low water | NAD27 |
| H09550 | 1975 | 40,000 | mean low water | NAD27 |
| H09551 | 1975 | 40,000 | mean low water | NAD27 |
| H09554 | 1975 | 40,000 | mean low water | NAD27 |
| H09555 | 1975 | 80,000 | mean low water | NAD27 |
| F00264 | 1984 | 20,000 | mean lower low water | NAD27 |
| D00102 | 1989 | 40,000 | mean lower low water | NAD83 |
| F00340 | 1989 | 10,000 | mean lower low water | NAD83 |
| F00341 | 1989 | 10,000 | mean lower low water | NAD83 |
| D00103 | 1990 | 40,000 | mean lower low water | NAD83 |
| F00343 | 1990 | 10,000 | mean lower low water | NAD83 |
| F00345 | 1990 | 10,000 | mean lower low water | NAD83 |
| F00348 | 1990 | 10,000 | mean lower low water | NAD83 |
| H10339 | 1990 | 10,000 | mean lower low water | NAD83 |
| H10350 | 1990 | 10,000 | mean lower low water | NAD83 |
| D00111 | 1991 | 20,000 | mean lower low water | NAD83 |
| F00363 | 1991 | 10,000 | mean lower low water | NAD83 |
| F00364 | 1991 | 10,000 | mean lower low water | NAD83 |
| F00365 | 1991 | 10,000 | mean lower low water | NAD83 |
| H10378 | 1991 | 10,000 | mean lower low water | NAD83 |
| H10424 | 1991/92 | 10,000 | mean lower low water | NAD83 |
| F00377 | 1992 | 10,000 | mean lower low water | NAD83 |
| H10659 | 1995/96 | 10,000 | mean lower low water | NAD83 |
| H10788 | 1997 | 10,000 | mean lower low water | NAD83 |
| H10795 | 1997/99 | 10,000 | mean lower low water | NAD83 |
| H10900 | 1999 | 10,000 | mean lower low water | NAD83 |
| H10930 | 1999 | 10,000 | mean lower low water | NAD83 |
| H10914 | 1999/2000 | 10,000 | mean lower low water | NAD83 |
| H10984 | 2000 | 10,000 | mean lower low water | NAD83 |

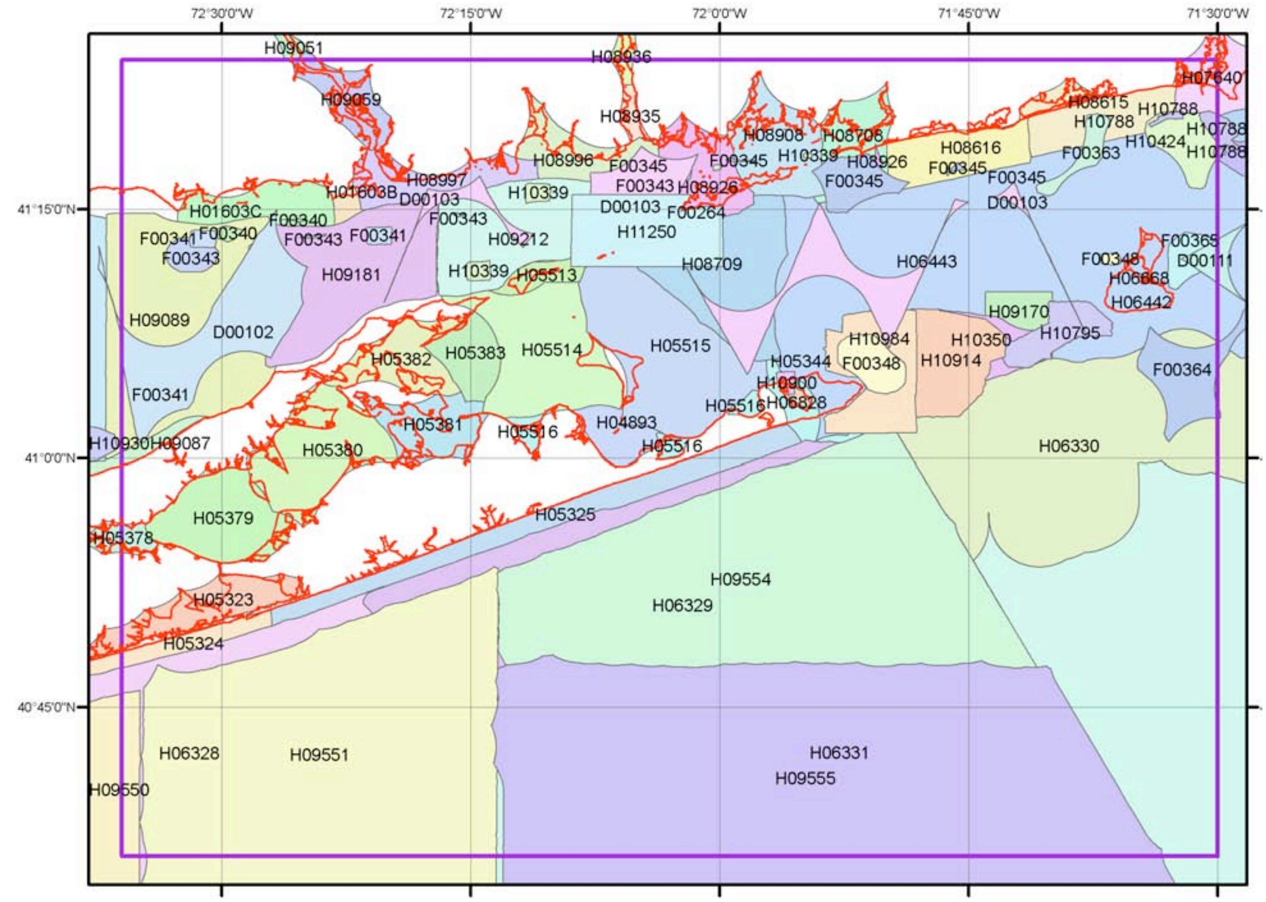


*__Figure 6.__ Digital NOS hydrographic survey coverage in the Montauk region. DEM boundary in purple; Montauk coastline in red.*

**2) NOS multibeam sonar survey**

NOS, in cooperation with USGS, conducted a detailed multibeam sonar survey, H11250 in 2003, in the channel between Plum and Fishers Islands (Fig. 7) for geologic mapping purposes. NOS is still reviewing the survey so it has not been publicly released, though USGS did provide a preliminary grid of the data to NGDC for use in building the Montauk DEM. The bathymetric grid was in WGS84 geographic coordinates, and undefined vertical datum, assumed to be MLLW. Cell size was ~2 meters. Survey results were published in USGS Open File Report 2007-1012 "Geologic Interpretation and Multibeam Bathymetry of the Sea Floor in the Vicinity of the Race, Eastern Long Island Sound" (Poppe et al, 2007; http://woodshole.er.usgs.gov/pubs/of2007-1012/).

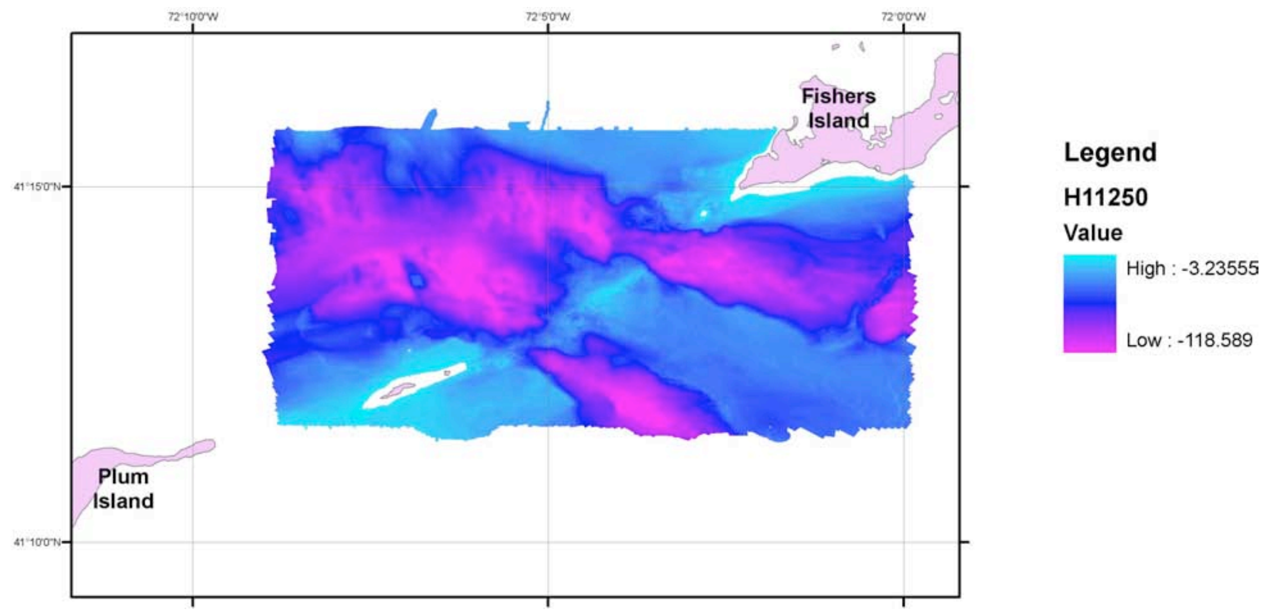


***Figure 7.*** *NOS multibeam sonar survey H11250.*

**3) USGS multibeam sonar survey**

USGS conducted a multibeam sonar survey offshore Georgica Pond, Long Island in 1996 (Fig. 8). Survey results were published in USGS Open File Report 00-243 "Seafloor Sediment Distribution Off Southern Long Island, New York" (Schwab et al, 2000; http://pubs.usgs.gov/of/2000/of00-243/). The bathymetric data were provided to NGDC by Jane Denny, USGS, Woods Hole in xyz format, WGS84 geographic and MLLW datums. Data point spacing is about 3 meters.

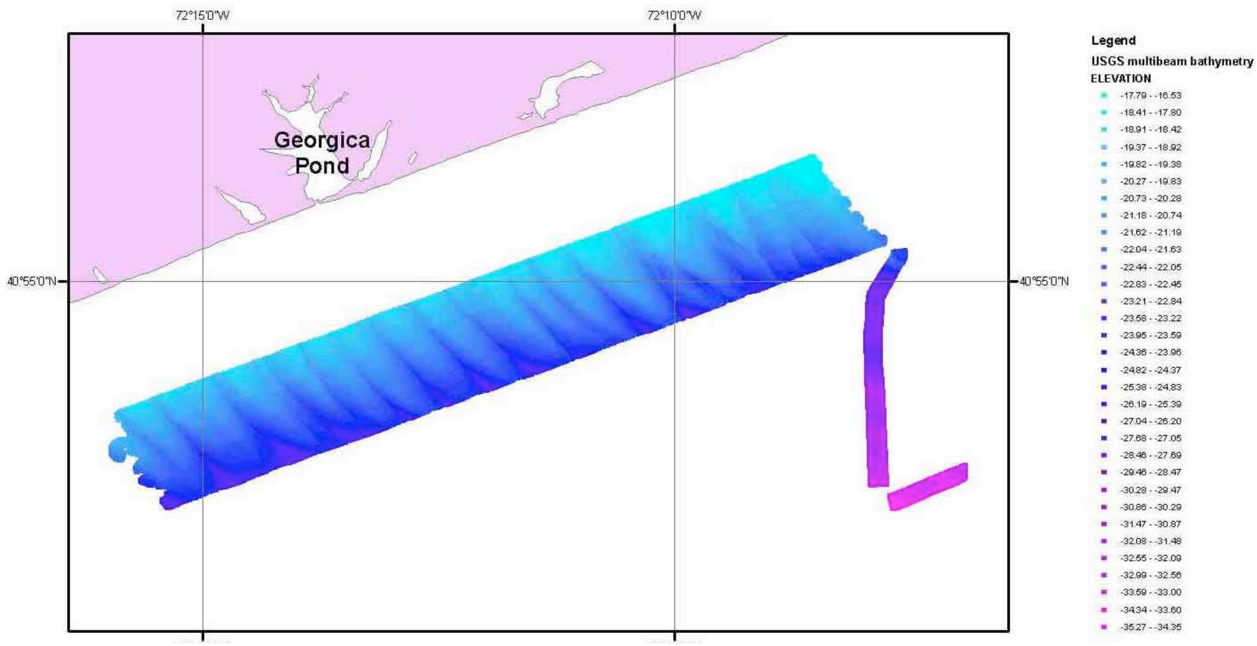


***Figure 8.*** *Coverage of USGS multibeam sonar survey offshore Georgica Pond, Long Island.*

**4) NOAA ENCs**

There are several regions in the Montauk area without digital NOS hydrographic soundings. NGDC extracted the soundings from NOAA Electronic Navigational Charts in the area (Fig. 5; Table 3) for use in building the Montauk DEM. Soundings were in meters, referenced to MLLW and WGS84 datums.

**5) NGDC-digitized soundings from NOAA RNCs**

Remaining gaps in the bathymetry were filled by directly digitizing soundings (Fig. 5) from the largest-scale NOAA Raster Nautical Charts (RNCs) for each area (Table 7). The RNCs are georeferenced to WGS84, with soundings displayed in meters at MLLW. Soundings were digitized using ESRI ArcMAP 9.2.

**Table 7. NOAA Raster Nautical Charts from which NGDC digitized soundings.**

| *Nautical Chart #* | *Region* | *Scale* | *Ed. Date* |
|---|---|---|---|
| 12352 | SHINNECOCK BAY TO MORICHES BAY LONG ISLAND NY | Various | 2006-03-01 |
| 12358 | NEW YORK LONG ISLAND SHELTER ISLAND SOUND AND PECONIC BAYS | 1:40,000 | 2002-09-01 |
| 12372 | LONG ISLAND SOUND - RI CONN | 1:40,000 | 2006-11-01 |
| 12374 | NORTH SHORE OF LONG ISLAND SOUND-DUCK ISLAND TO MADISON REEF | 1:20,000 | 2000-10-28 |
| 12375 | CONNECTICUT RIVER LONG ISLAND SOUND TO DEEP RIVER | 1:20,000 | 2001-02-17 |
| 13212 | APPROACHES TO NEW LONDON HARBOR | 1:20,000 | 2005-11-01 |
| 13213 | NEW LONDON HARBOR AND VICINITY | 1:10,000 | 2004-03-01 |
| 13214 | FISHERS ISLAND SOUND | 1:20,000 | 2006-04-01 |
| 13217 | BLOCK ISLAND RI | 1:15,000 | 2006-11-01 |

### *3.1.3 Topography*

Topographic datasets in the Montauk region were obtained from NOAA's Coastal Services Center (CSC), and the U.S. Geological Survey (USGS; Table 8; Fig. 9).

**Table 8. Topographic datasets used in compiling the Montauk DEM.**

| *Source* | *Year* | *Data Type* | *Spatial Resolution* | *Original Horizontal Datum/Coordinate System* | *Original Vertical Datum* | *URL* |
|---|---|---|---|---|---|---|
| NOAA CSC | 2000 | Coastal LiDAR | ~6 meters | NAD83 geographic | NAVD88 (meters) | http://maps.csc.noaa.gov/TCM/ |
| NOAA CSC | 2004 | Bare-earth LiDAR DEMs of CT | ~2 meters | NAD83 geographic | NAVD88 (meters) | http://maps.csc.noaa.gov/TCM/ |
| USGS | 1999-2000 | NED DEM | 1/3 arc-second | NAD83 geographic | NAVD88 (meters) | http://ned.usgs.gov/ |

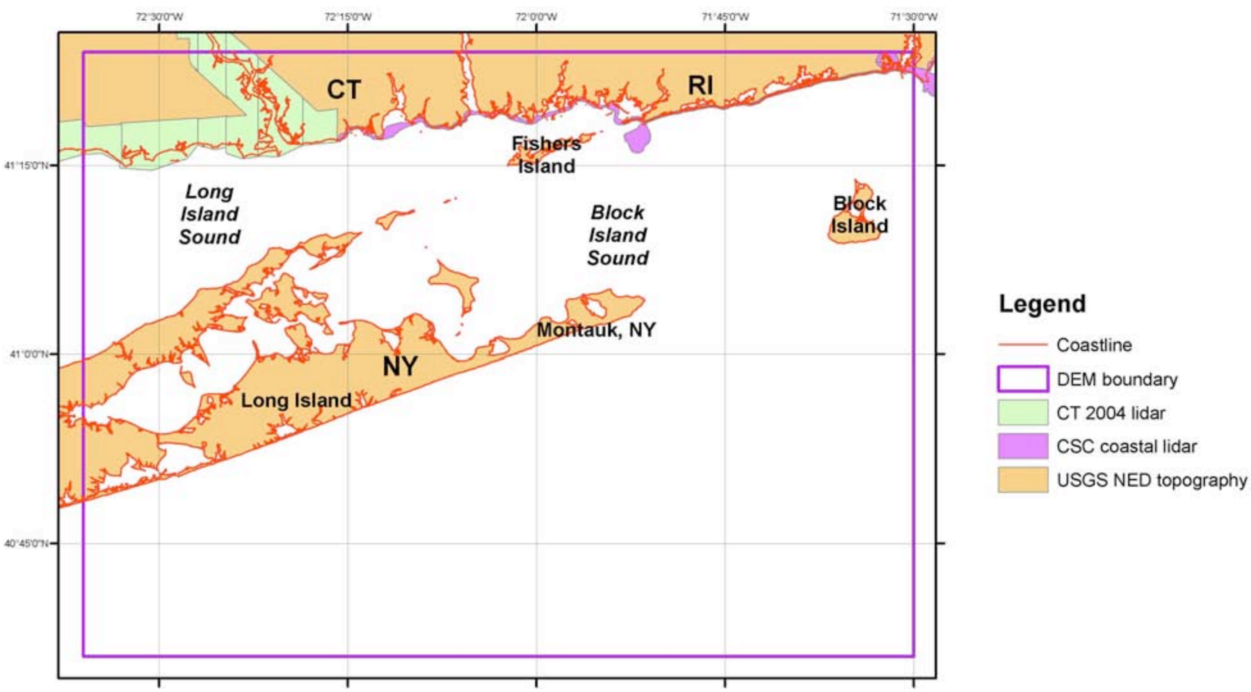


***Figure 9.*** *Source and coverage of topographic datasets used to compile the Montauk DEM.*

**1) Coastal Services Center coastal topographic LiDAR**

A fall 2000 coastal LiDAR survey[2] of the southern coasts of Rhode Island and Connecticut (Fig. 9) was downloaded from NOAA's Coastal Services Center (CSC) web site (http://maps.csc.noaa.gov/TCM/). Data were collected as part of the Airborne LIDAR Assessment of Coastal Erosion (ALACE) project, a partnership between NOAA, NASA, and USGS. Survey data are in NAD83 geographic horizontal datum and NAVD88 vertical datum. The data were downloaded at 5-meter point spacing, and mostly follow the coastline though they also contain elevation values from over the open ocean, which were deleted by NGDC. These data were not processed to bare earth, so some manmade features such as buildings are present in the data. Data were in NAD83 geographic and NAVD88 datums. Horizontal accuracy is 80 cm, and vertical accuracy is estimated at 15 cm.

**2) CSC topographic LiDAR survey of Connecticut**

A 2004 topographic LiDAR survey[3] of southern Connecticut (Fig. 9) was also downloaded from NOAA's Coastal Services Center (CSC) web site (http://maps.csc.noaa.gov/TCM/). The LiDAR data are available as "first return" and "bare earth". NGDC downloaded the bare-earth data at 5-meter point spacing. Data were in NAD83 geographic and NAVD88 datums. Horizontal accuracy is 50 cm, and vertical accuracy is estimated at 5.7 cm for bare-earth data.

**3) USGS NED topographic DEM**

The USGS National Elevation Dataset (NED; http://ned.usgs.gov/) provides complete 1/3 arc-second coverage of the Montauk region[4]. Data are in NAD83 geographic coordinates and NAVD88 vertical datum (meters), and are available for download as raster DEMs. The bare-earth elevations have a vertical accuracy of +/- 7 to 15 meters depending on source data resolution. See the USGS Seamless web site for specific source information (http://seamless.usgs.gov/). The dataset was derived from USGS quadrangle maps and aerial photographs based on topographic surveys; it has been revised using data collected in 1999 and 2000. The NED DEM included "zero" elevation values over the open ocean, which were removed from the dataset by clipping to the Montauk coastline.

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2. This data set was collected with a LIDAR (LIght Detection And Ranging) instrument designed and developed by the Observational Sciences Branch (OSB) of NASA at the Wallops Flight Facility in Virginia. The instrument, originally designed for mapping ice sheets in Greenland, is called the Airborne Topographic Mapper or ATM. The ATM II (the latest version), operates with a Spectra Physics laser transmitter, which provides a 7 nanoseconds long, 250 microjoules pulse at a frequency-doubled wavelength of 523 nanometers in the blue-green spectral region. The laser transmitter can function at pulse rates from 2 to 10 kilohertz (kHz). The laser system with a separate cooling unit weighs approximately 45 kilograms (kg) and requires approximately 15 amperes of power at 115 volts. The transmitted laser pulse is reflected to the surface of the earth with the aid of a small folding mirror mounted on the back of a secondary mirror of a rotating scan mirror assembly mounted directly in front of the telescope. The scan mirror, which is rotated at 20 hertz, is comprised of a section of round aluminum stock, machined to a specific off-nadir angle. A scan mirror with the off-nadir angle of 15 degrees was utilized, producing an elliptical scan pattern with a swath width equal to 50 percent of the approximately 700-meter aircraft altitude. The reflected laser pulse is transmitted to a photo-multiplier assembly that consists of a lens, a narrow bandpass filter, and a single photomultiplier tube. [Extracted from metadata.]

3. LiDAR data collection was performed using a LH Systems ALS50 Light Detection And Ranging (LiDAR) system, 41 flight lines of high density (submeter ground sample distance) data were collected over areas in coastal Connecticut (approximately 300 square kilometers). Two returns were recorded for each laser pulse along with an intensity value for each return. The data acquisition occurred in one (1) mission on October 8, 2004. Three (3) airborne global positioning system (GPS) base stations were used to support the LiDAR data acquisition: Moriches 1 continuously operating reference station (CORS) ARP, NGS point P36, and one station Woolpert located using static GPS positioning methods, Madison CP. In addition, twenty-two control points were surveyed through fast-static GPS methods to support the final accuracy analysis and tied into the National Geodetic Survey (NGS) points Moriches CORS and P36. [Extracted from metadata.]

4. The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the maturation of the USGS effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous U.S. and 1:63,360-scale DEM data for Georgia. The dataset provides seamless coverage of the United States, HI, AK, and the island territories. NED has a consistent projection (Geographic), resolution (1 arc second), and elevation units (meters). The horizontal datum is NAD83, except for AK, which is NAD27. The vertical datum is NAVD88, except for AK, which is NGVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc second (10 m) data covers the U.S., then this will also be a seamless dataset. [Extracted from USGS NED website]

### *3.1.4 Bathymetry–Topography*

Two bathymetric–topographic datasets were available for Long Island, New York: Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX) coastal LiDAR survey and USACE beach profiles (Fig 10; Table 9).

**Table 9. Bathymetric–topographic datasets used in compiling the Montauk DEM.**

| *Source* | *Year* | *Data Type* | *Spatial Resolution* | *Original Horizontal Datum/Coordinate System* | *Original Vertical Datum* |
|---|---|---|---|---|---|
| JALBTCX LiDAR | 2005 | Coastal LiDAR | < 5 meters | WGS84 geographic | MLLW (meters) |
| USACE | 2001–2005 | Beach profiles | profiles up to 650 meters long, spaced 150 to 650 meters apart, with point spacing of 1.5 to 6 meters | NAD83 New York State Plane, Long Island (feet) | NGVD29 (ffet) |

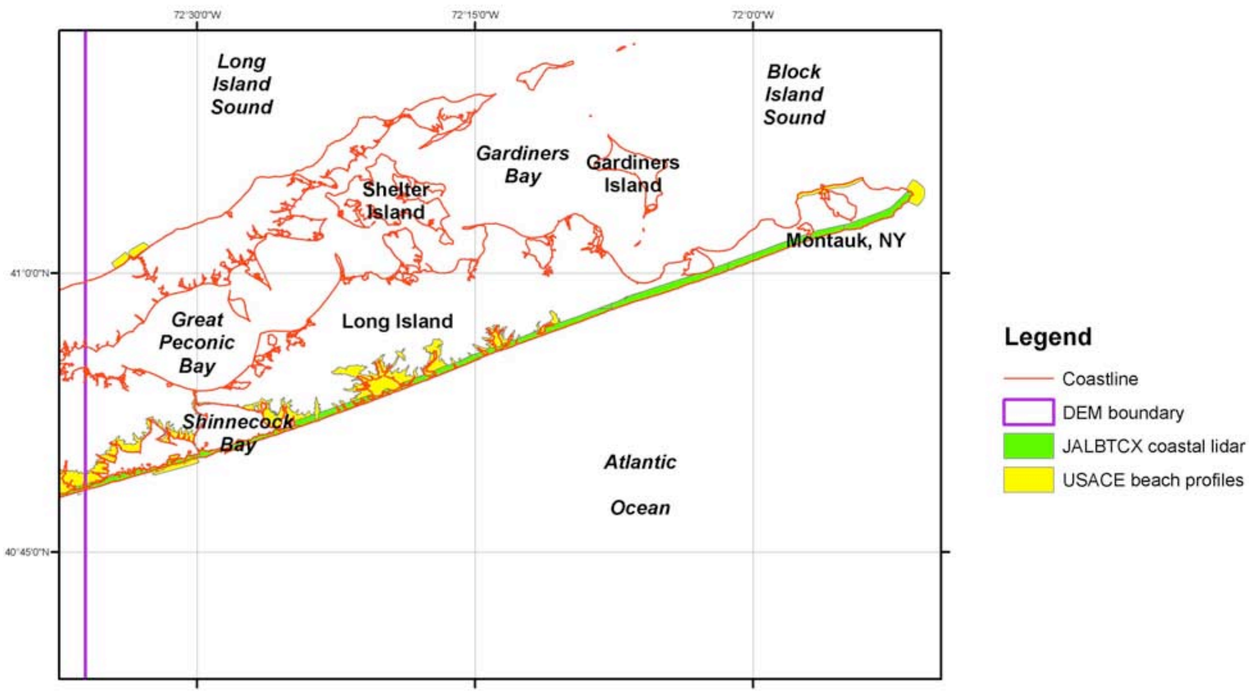


***Figure 10.*** *Source and coverage of bathymetric–topographic datasets used to compile the Montauk DEM.*

**1) JALBTCX coastal LiDAR**

The Joint Airborne Lidar Bathymetry Technical Center of Expertise conducted a bathymetric–topographic LiDAR survey of the southern coast of Long Island in 2005 using the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system[5]. These data are published on the NOAA CSC web site (http://maps.csc.noaa.gov/TCM/) and were downloaded at 5-meter point spacing in NAD83 geographic and NAVD88 datums. Horizontal accuracy is 3 m, and vertical accuracy is estimated at 30 cm. These data have not been processed to bare earth, so buildings and trees are represented in the data. NGDC manually removed elevations derived from returns off of the top of the Montauk Lighthouse (Fig. 2) so that that part of the Montauk DEM approximates bare earth. Bathymetric values represent only a few percent of the elevations in this dataset.

**2) USACE beach profiles**

The U.S. Army Corps of Engineers (USACE) conducts beach monitoring programs of Long Island, New York (Morang, 2002). Data from these monitoring programs were provided to NGDC by Diane Rahoy and John Mraz, USACE, New York District office. Data included beach and bathymetric profiles at Montauk Point, Lake Montauk, W. Shinnecock Bay and the entrance to Mattituck Creek (Fig. 10), as well as topographic measurements and contours. Data were collected between 2001 and 2005 and referenced to NAD83 New York State Plane, Long Island (feet) and NGVD29 (feet). At the entrance to Lake Montauk, the data consists primarily of bathymetric profiles across the harbor entrance spaced 10 to 20 meters apart, with elevations every .3 m. Along the coast at Mattituck and Shinnecock, the beach profiles are 500–650 meters long and spaced 150–650 meters apart, with elevations every 1.5–6 meters.

5. Acquisition data were acquired using a SHOALS-1000T. Sensor orientation was measured using a POS AV 410, while images were acquired at 1Hz using a Duncantech DT4000 digital camera. Prior to survey PDOP was checked and missions planned to avoid PDOP greater than 3.5. During survey the plane was always within 30km of a GPS ground control point, to provide a good quality position solution. Final positions were determined using a post-processed inertially aided Kinematic GPS (KGPS) solution. GPS ground control data were acquired at 1Hz. Data received by the airborne system were continually monitored for data quality during acquisition operations. Display windows showed coverage and information about the system status. In addition, center waveforms at 5Hz were shown. All of this information allowed the airborne operator to assess the quality of data being collected. Data were processed in the field to verify coverage and data quality. Data were processed using the SHOALS Ground Control System (GCS). The GCS includes links to Applanix POSPac software for GPS and inertial processing, and IVS Fledermaus software for data visualization, 3D editing and tie-line analysis. Data were processed in NAD83 horizontal and vertical datum. Data were later converted to the NAVD88 vertical datum using the GEOID03 model. Fugro in-house utilities were used to extract XYZ data from the native LIDAR files and split the data in to pre-defined boxes, each covering approximately 5km of shoreline. ASCII files include Longitude Latitude Elevation Date Time Intensity (Topo) or Depth Confidence (Hydro). [Extracted from metadata.]

## 3.2 Establishing Common Datums

### *3.2.1 Vertical datum transformations*

Datasets used in the compilation and evaluation of the Montauk DEM were originally referenced to a number of vertical datums including Mean Lower Low Water (MLLW), Mean Low Water (MLW), National Geodetic Vertical Datum of 1929 (NGVD29), and North American Vertical Datum of 1988 (NAVD88). All datasets were transformed to MHW to provide the worst-case scenario for inundation modeling. Units were converted from feet to meters as appropriate. PMEL provided NGDC with conversion grids for MLLW to MHW, MLW to MHW and NAVD88 to MHW. Theses grids were derived from vertical datum relationships established at tide stations in the Montauk region.

1) **Bathymetric data**

   The NOS hydrographic surveys, the ENC and RNC soundings, and the USGS and NOS multibeam sonar surveys were transformed from MLLW and MLW to MHW, using FME software, by adding the appropriate conversion grid.

2) **Topographic data**

   The USGS NED 1/3 arc-second DEM and the CSC LiDAR data were originally referenced to NAVD88. Both datasets were transformed from NAVD88 to MHW, using FME software, by adding the NAVD88-to-MHW conversion grid.

3) **Bathymetric–topographic data**

   The JALBTCX topographic–bathymetric LiDAR data were transformed from NAVD88 to MHW by adding the NAVD88-to-MHW conversion grid using FME. The USACE beach profile data were first transformed from NGVD29 to NAVD88 by adding a constant offset of -0.288 (the difference between these two datums as measured at the Montauk tide station, #8510560). This difference is roughly equivalent with other tide stations in the region. The data were then transformed to MHW using the NAVD88-to-MHW conversion grid. All transformations were performed using FME.

**Table 10. Relationship between Mean High Water and other vertical datums at the Montauk tide station, #8510560.**

| *Vertical datum* | *Difference to MHW* |
|---|---|
| NAVD88 | -0.286 meters |
| MSL | -0.306 meters |
| NGVD29 | -0.574 meters |
| MLW | -0.631 meters |
| MLLW | -0.683 meters |

### *3.2.2 Horizontal datum transformations*

Datasets used to compile the Montauk DEM were originally referenced to NAD83 New York State Plane Long Island (feet), NAD83 geographic, NAD27 geographic, or WGS84 geographic horizontal datums. The relationships and transformational equations between these horizontal datums are well established. All data were converted to a horizontal datum of WGS84 geographic using FME software.

## 3.3 Digital Elevation Model Development

### *3.3.1 Verifying consistency between datasets*

After horizontal and vertical transformations were applied, the resulting ESRI shape files were checked in ArcMap for consistency between datasets. Problems and errors were identified and resolved before proceeding with subsequent gridding steps. The evaluated and edited ESRI shape files were then converted to xyz files in preparation for gridding. Problems included:

- Presence of piers in the ENC coastlines, which had to be removed.
- Lack of existing high-resolution coastline files for most of the area, which necessitated digitizing of coastline segments from large-scale NOAA nautical charts.
- Data values over the ocean and rivers in the NED and CSC LiDAR topographic data. The NED dataset required automated clipping to the Montauk coastline. The CSC LiDAR datasets were manually clipped to the coastline.
- The older NOS hydrographic surveys were digitized, under contract, from the original survey sheets. The digital files contained many errors that were recognized and corrected by NGDC during data evaluation, by comparison with the survey sheets.
- Coastal area without digital bathymetric values. NGDC hand-digitized soundings in these areas from large-scale NOAA nautical charts.
- The two coastal LiDAR datasets (JALBTCX bathymetric–topographic and CSC topographic) had not been processed to bare earth. NGDC only removed elevation values that represented the Montauk Lighthouse at Montauk Point. Other elevations representing the tops of buildings and trees were left in the datasets.

### *3.3.2 Smoothing of beach-profile data*

The USACE beach-profile data at Shinnecock Bay and the entrance to Mattituck Creek have high resolution along the profiles (1.5 to 6 meters), but the profiles are spaced some distance apart (150 to 650 meters), much greater than the 1/3 arc-second (~10 meter) resolution required for the Montauk DEM. NGDC gridded these profiles at 1/3 arc-second to create interpolated values between the profiles. Interpolation was performed using the 'triangulate' command in GMT, an NSF-funded share-ware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

### *3.3.3 Smoothing of bathymetric data*

The NOS hydrographic surveys are generally sparse at the resolution of the 1/3 arc-second Montauk DEM: in both deep water and in some areas close to shore, the NOS survey data have point spacing up to 1900 m apart. In order to reduce the effect of artifacts in the form of lines of "pimples" in the DEM due to this low resolution dataset, and to provide effective interpolation into the coastal zone, a 1 arc-second-spacing 'pre-surface' bathymetric grid was generated using GMT, an NSF-funded share-ware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

The NOS hydrographic point data, in xyz format, were combined with the ENC and RNC soundings, and the USGS and NOS multibeam sonar data into a single file, along with points extracted from the Montauk coastline—to provide a buffer along the entire coastline. The coastline points were assigned a -0.5 elevation value so that interpolation into coastal bays without bathymetric values would produce negative elevation values of ~-0.5 meters.

The point data were median-averaged using the GMT tool 'blockmedian' to create a 1 arc-second grid 0.05 degrees (~5%) larger than the Montauk DEM gridding region. The GMT tool 'surface' was then used to apply a tight spline tension to interpolate elevations for cells without data values. The GMT grid created by 'surface' was converted into an ESRI Arc ASCII grid file, and clipped to the Montauk coastline (to eliminate data interpolation into land areas). The resulting surface was compared with original soundings to ensure grid accuracy (e.g., Fig. 11), converted to a shape file, and then exported as an xyz file for use in the final gridding process (see Table 11).

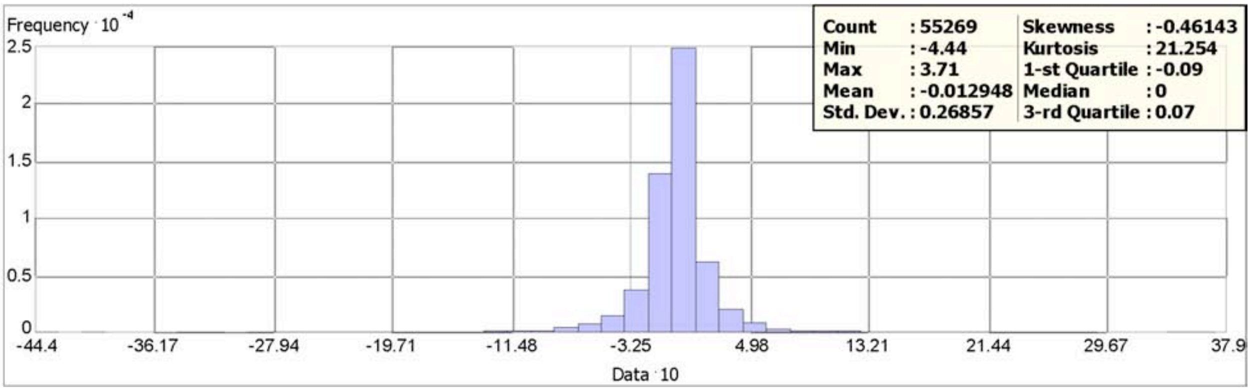


***Figure 11.*** *Histogram of the differences between NOS hydrographic survey H10984 and the 1 arc-second pre-surfaced bathymetric grid.*

### *3.3.4 Gridding the data with MB-System*

MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/) was used to create the 1/3 arc-second Montauk DEM. MB-System is an NSF-funded share-ware software application specifically designed to manipulate submarine multibeam sonar data, though it can utilize a wide variety of data types, including generic xyz data. The MB-System tool 'mbgrid' was used to apply a tight spline tension to the xyz data, and interpolate values for cells without data. The data hierarchy used in the 'mbgrid' gridding algorithm, as relative gridding weights, is listed in Table 11. Greatest weight was given to the LiDAR and multibeam sonar data. Least weight was given to the pre-surfaced 1 arc-second bathymetric grid. Gridding was performed in quadrants, and the resulting Arc ASCII grids were seamlessly merged in ArcCatalog to create the final 1/3 arc-second Montauk DEM.

**Table 11. Data hierarchy used to assign gridding weight in MB-System.**

| *Dataset* | *Relative Gridding Weight* |
|---|---|
| JALBTCX topographic–bathymetric coastal LiDAR | 10000 |
| CSC topographic bare-earth LiDAR | 10000 |
| NOS multibeam sonar survey | 10000 |
| USGS multibeam sonar survey | 10000 |
| CSC topographic coastal LiDAR | 1000 |
| NOS hydrographic surveys: bathymetric soundings | 1000 |
| USGS NED topographic DEM | 100 |
| Montauk coastline | 100 |
| NOAA ENC and RNC soundings | 10 |
| Pre-surfaced bathymetric grid | 1 |

## 3.4 Quality Assessment of the DEM

### *3.4.1. Horizontal accuracy*

The horizontal accuracy of topographic and bathymetric features in the Montauk DEM is dependent upon the datasets used to determine corresponding DEM cell values. Topographic features have an estimated accuracy of up to 10 meters: CSC and JALBTCX LiDAR data have an accuracy of a few meters or less; NED topography is accurate to within about 10 meters. Bathymetric features are resolved only to within a few tens of meters in deep-water areas. Shallow, near-coastal regions, rivers, and harbor surveys have an accuracy approaching that of subaerial topographic features. Positional accuracy is limited by the sparseness of deep-water soundings, potentially large positional uncertainty of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys, and by coastal morphologic change that occurs in this dynamic region.

### *3.4.2 Vertical accuracy*

Vertical accuracy of elevation values for the Montauk DEM is also highly dependent upon the source datasets contributing to DEM cell values. Topographic areas have an estimated vertical accuracy between 0.1 to 0.3 meters for JALBTCX and CSC LiDAR data, and up to 7 meters for NED topography. Bathymetric areas have an estimated accuracy of between 0.1 meters and 5% of water depth. Those values were derived from the wide range of input data sounding measurements from the early 20$^{th}$ century to recent, GPS-navigated sonar surveys. Gridding interpolation to determine values between sparse, poorly-located NOS soundings degrades the vertical accuracy of elevations in deep water.

### *3.4.3 Slope maps and 3-D perspectives*

ESRI ArcCatalog was used to generate a slope grid from the Montauk DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 12). The DEM was transformed to UTM Zone 18 coordinates (horizontal units in meters) in ArcCatalog for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Three-dimensional viewing of the UTM-transformed DEM was accomplished using ESRI ArcScene (e.g., Fig. 13). Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEM. Figure 1 shows a color image of the 1/3 arc-second Montauk DEM in its final version.

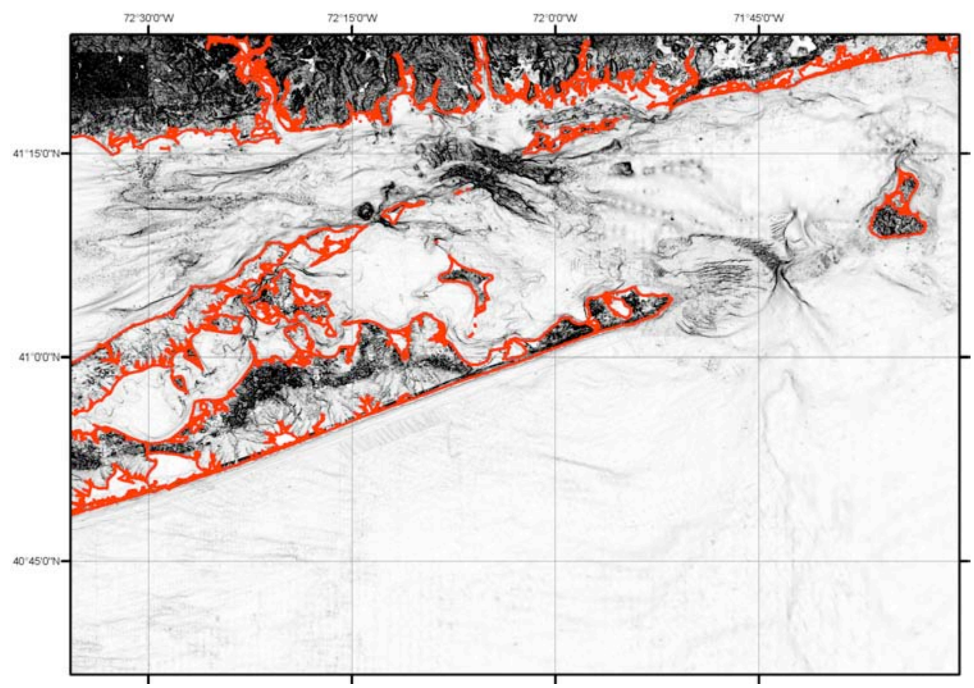


***Figure 12.*** *Slope map of the Montauk DEM. Flat-lying slopes are white; dark shading denotes steep slopes; Montauk coastline in red.*

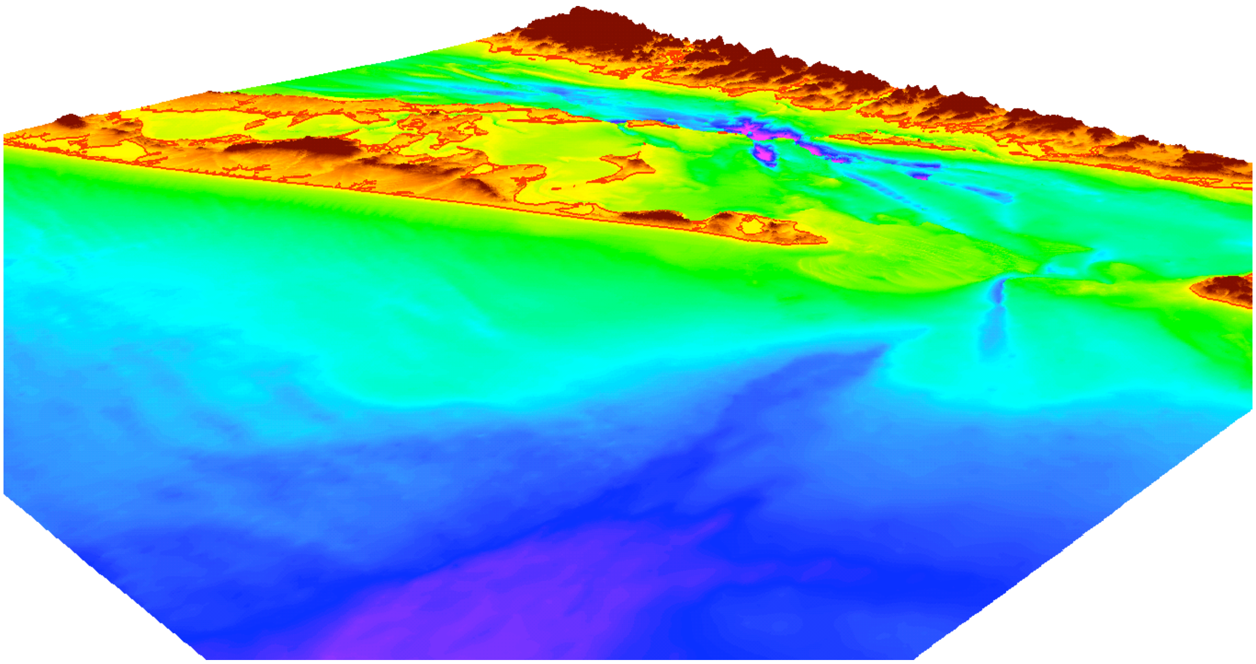

***Figure 13.*** *Perspective view from the southeast of the Montauk DEM. Montauk coastline in red; vertical exaggeration–times 10.*

### *3.4.4 Comparison with source data files*

To ensure grid accuracy, the Montauk DEM was compared to select source data files. Files were chosen on the basis of their contribution to the grid-cell values in their coverage areas (i.e., had the greatest weight and did not significantly overlap other data files with comparable weight). A histogram of the differences between one JALBTCX coastal LiDAR survey file, 5-meter point spacing, and the Montauk DEM is shown in Figure 14. Differences cluster around zero, with only a handful of values, in regions where buildings are present and several elevation values are averaged, exceeding 2-meter discrepancy from the DEM.

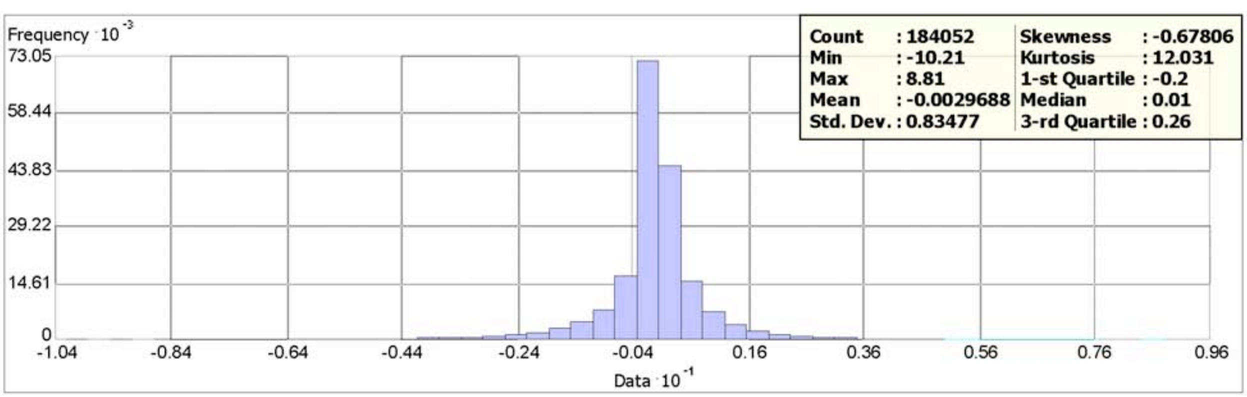


***Figure 14.*** *Histogram of the differences between one JALBTCX coastal LiDAR file and the Montauk DEM.*

### *3.4.5 Comparison with NGS geodetic monuments*

The elevations of 1459 NOAA NGS geodetic monuments were extracted from online shape files of monument datasheets (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl), which give monument positions in NAD83 (typically sub-mm accuracy) and elevations in NAVD88 (in meters). Elevations were shifted to MHW vertical datum (see Section 3.2.1) for comparison with the Montauk DEM (see Fig. 16 for monument locations). Differences between the Montauk DEM and the NGS geodetic monument elevations range from -50 to 14 meters, with the majority of them being within ± 5 meters. Negative values indicate that the DEM is less than the monument elevation (Fig. 15). Large discrepancies from the DEM are from monuments located on the tops of buildings and other such manmade features. Many discrepancies are due to large uncertainties in monument locations (6 arc-seconds/~180 meters).

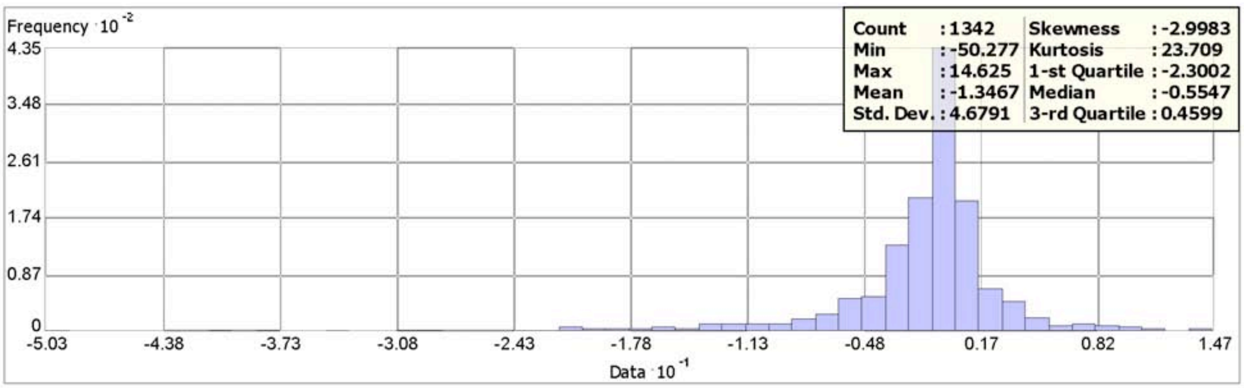


***Figure 15.*** *Histogram of the differences between NGS geodetic monument elevations and the Montauk DEM.*

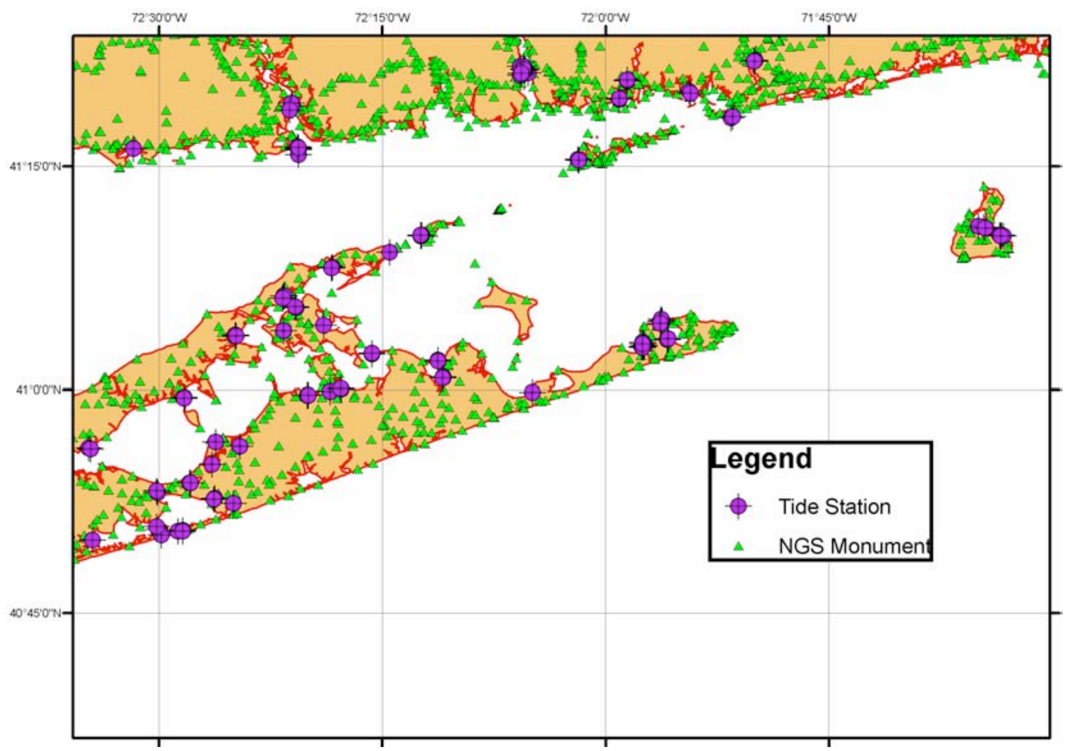


***Figure 16.*** *Location of NGS geodetic monuments and NOAA tide stations in the Montauk region. NGS monument elevations were used to evaluate the DEM.*

## 4. Summary and Conclusions

A topographic–bathymetric digital elevation model of the Montauk, New York region, with cell spacing of 1/3 arc-second, was developed for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research. The best available digital data from U.S. federal agencies were obtained by NGDC, shifted to common horizontal and vertical datums, and evaluated and edited before DEM generation. The data were quality checked, processed and gridded using ESRI ArcGIS, FME, GMT, and MB-System software.

Recommendations to improve the Montauk DEM, based on NGDC's research and analysis, are listed below:

- Conduct topographic–bathymetric LiDAR surveys of the northern coast of Long Island, New York and coastal bays and estuaries.
- Conduct hydrographic surveys for near-shore areas without digital sounding data, mostly around Block Island.
- Conduct complete topographic LiDAR surveying of Long Island, New York.
- Process CSC and JALBTCX coastal LiDAR data to bare earth.

## 5. Acknowledgments

The creation of the Montauk DEM was funded by the NOAA Pacific Marine Environmental Laboratory. The authors thank Chris Chamberlin and Vasily Titov (PMEL), Diane Rahoy and John Mraz (USACE, New York District), and Bill Schwab and Jane Denny (USGS, Woods Hole).

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Schwab, W.C., E.R. Thieler, J.F. Denny, W.W. Danforth, and J.C. Hill, 2000, *Seafloor Sediment Distribution Off Southern Long Island, New York*, USGS Open File Report 00-243, http://pubs.usgs.gov/of/2000/of00-243/

## 7. Data Processing Software

ArcGIS v. 9.2, developed and licensed by ESRI, Redlands, California, http://www.esri.com/

FME 2007 ESRI Edition – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

GEODAS v. 5 – Geophysical Data System, shareware developed and maintained by Dan Metzger, NOAA National Geophysical Data Center, http://www.ngdc.noaa.gov/mgg/geodas/

GMT v. 4.1.4 – Generic Mapping Tools, shareware developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/

MB-System v. 5.1.0, shareware developed and maintained by David W. Caress and Dale N. Chayes, funded by the National Science Foundation, http://www.ldeo.columbia.edu/res/pi/MB-System/