NOAA Technical Memorandum NESDIS NGDC-18

DIGITAL ELEVATION MODEL OF ATLANTIC CITY, NEW JERSEY: PROCEDURES, DATA SOURCES AND ANALYSIS

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1. Introduction

In October 2007, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed a bathymetric–topographic digital elevation model (DEM) of Atlantic City, New Jersey (Fig. 1) 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 Atlantic City DEM.

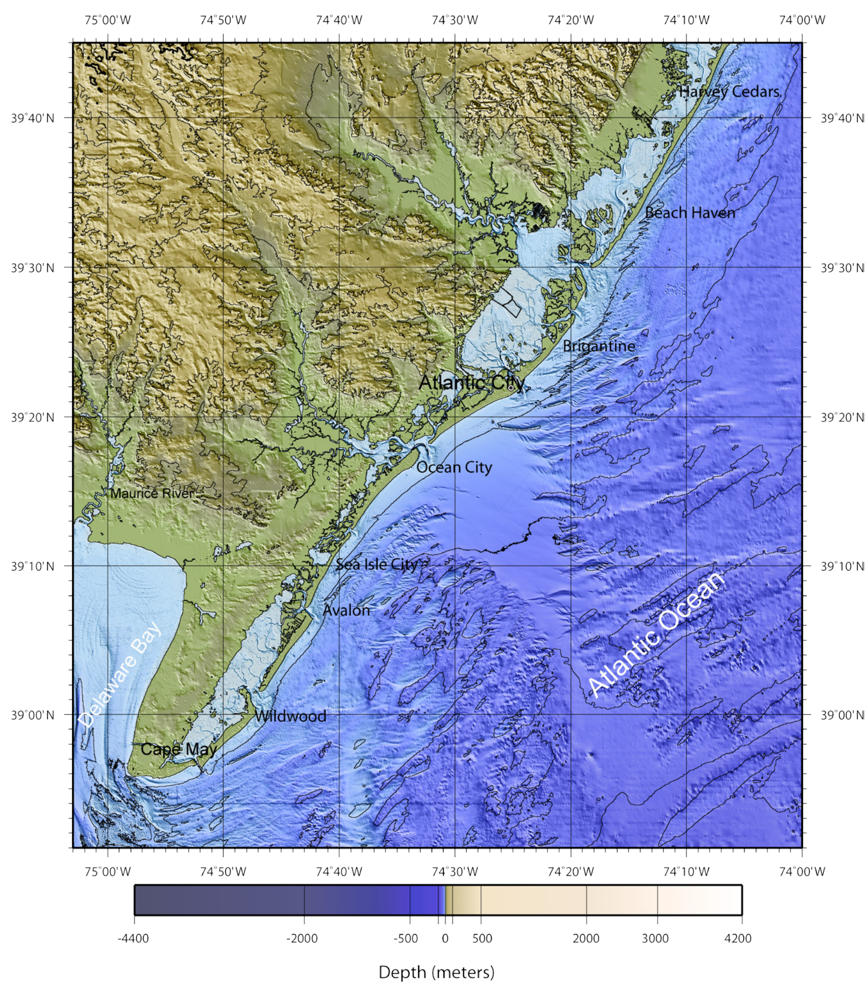

Figure 1. *Shaded-relief image of the Atlantic City, New Jersey DEM. Contour interval is 100 meters.*

1. The Atlantic City 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 Atlantic City, New Jersey (39°21.828′ N, 74°25.099′ W) 1/3 arc-second of latitude is equivalent to 10.28 meters; 1/3 arc-second of longitude equals 7.98 meters.

2. Study Area

The Atlantic City DEM covers the coastal region surrounding the town of Atlantic City, New Jersey from Cape May in the south to Barnegat Light in the north and includes the communities of Wildwood, Avalon, Sea Isle City, Ocean City, Brigantine, Beach Haven, and Harvey Cedars (Fig. 1).

Many of the rural communities surround Delaware Bay while the rapidly growing suburban and developing urban populations are along the Atlantic coast. New Jersey's coastal economy is based not only on tourism but also on commercial and recreational fishing. The Outer Coastal Plain supports the economy by providing habitat to wildlife, migratory birds, and marine life. The estuaries and salt marshes in this region were formed by the gradual infill of mud and sand from the rivers while the barrier islands to the east act to protect these wetlands. Coastal processes such as wave action and along shore currents continually shape and modify the New Jersey coastline.

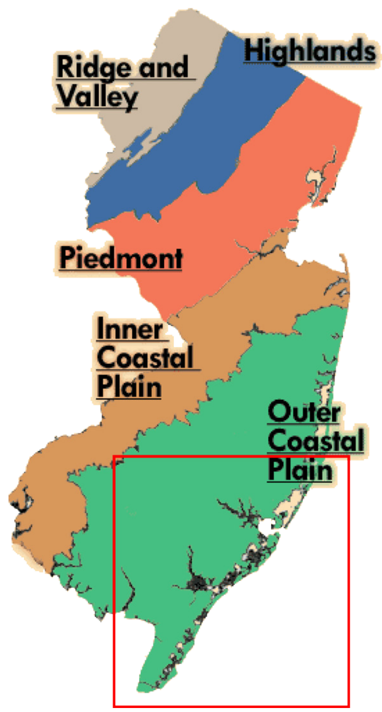

Figure 2. *Geologic regions of New Jersey. The Atlantic City DEM boundary is shown in red. (http://njaes.rutgers.edu/njriparianforestbuffers/nativeALL.htm).*

3. Methodology

The Atlantic City, New Jersey DEM was constructed to meet PMEL specifications (Table 1), based on input requirements for the development of Reference Inundation Models (RIMs) and Standby Inundation Models (SIMs) (V. Titov, pers. comm.) in support of NOAA's Tsunami Warning Centers use of SIFT to provide real-time tsunami forecasts in an operational environment. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: North America Datum 1983 (NAD 83) and Mean High Water (MHW), for modeling of maximum flooding, respectively[2]. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1: PMEL specifications for the Atlantic City, New Jersey DEM.

Grid Area	Atlantic City, New Jersey
Coverage Area	74.00º to 75.05º W; 38.85º to 39.75º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
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 bathymetric–topographic 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 Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX); 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 NAD 83 horizontal datum and to convert them into ESRI (http://www.esri.com/) ArcGIS shape files[3]. 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 data from the NOAA Atlantic City tide station and NOAA's Office of Coast Survey and National Geodetic Survey VDatum model software (http://www.nauticalcharts.noaa.gov/). Applied Imagery's Quick Terrain Modeler software (http://www.appliedimagery.com/) was used to edit and assess the quality of the LiDAR data as well as evaluate processing and gridding techniques.

2. The horizontal difference between the North American Datum of 1983 (NAD 83) and World Geodetic System of 1984 (WGS 84) geographic horizontal datums is approximately one meter across the contiguous U.S., which is significantly less than the cell size of the DEM. Most GIS applications treat the two datums as identical, so do not actually transform data between them, and the error introduced by not converting between the datums is insignificant for our purposes. NAD 83 is restricted to North America, while WGS 84 is a global datum. As tsunamis may originate most anywhere around the world, tsunami modelers require a global datum, such as WGS 84 geographic, for their DEMs so that they can model the wave's passage across ocean basins. This DEM is identified as having a WGS 84 geographic horizontal datum even though the underlying elevation data were typically transformed to NAD 83 geographic. At the scale of the DEM, WGS 84 and NAD 83 geographic are identical and may be used interchangeably.

3. FME uses the North American Datum Conversion Utility (NADCON; http://www.ngs.noaa.gov/TOOLS/Nadcon/Nadcon.html) developed by NOAA's National Geodetic Survey (NGS) to convert data from NAD 27 to NAD 83. NADCON is the U.S. Federal Standard for NAD 27 to NAD 83 datum transformations.

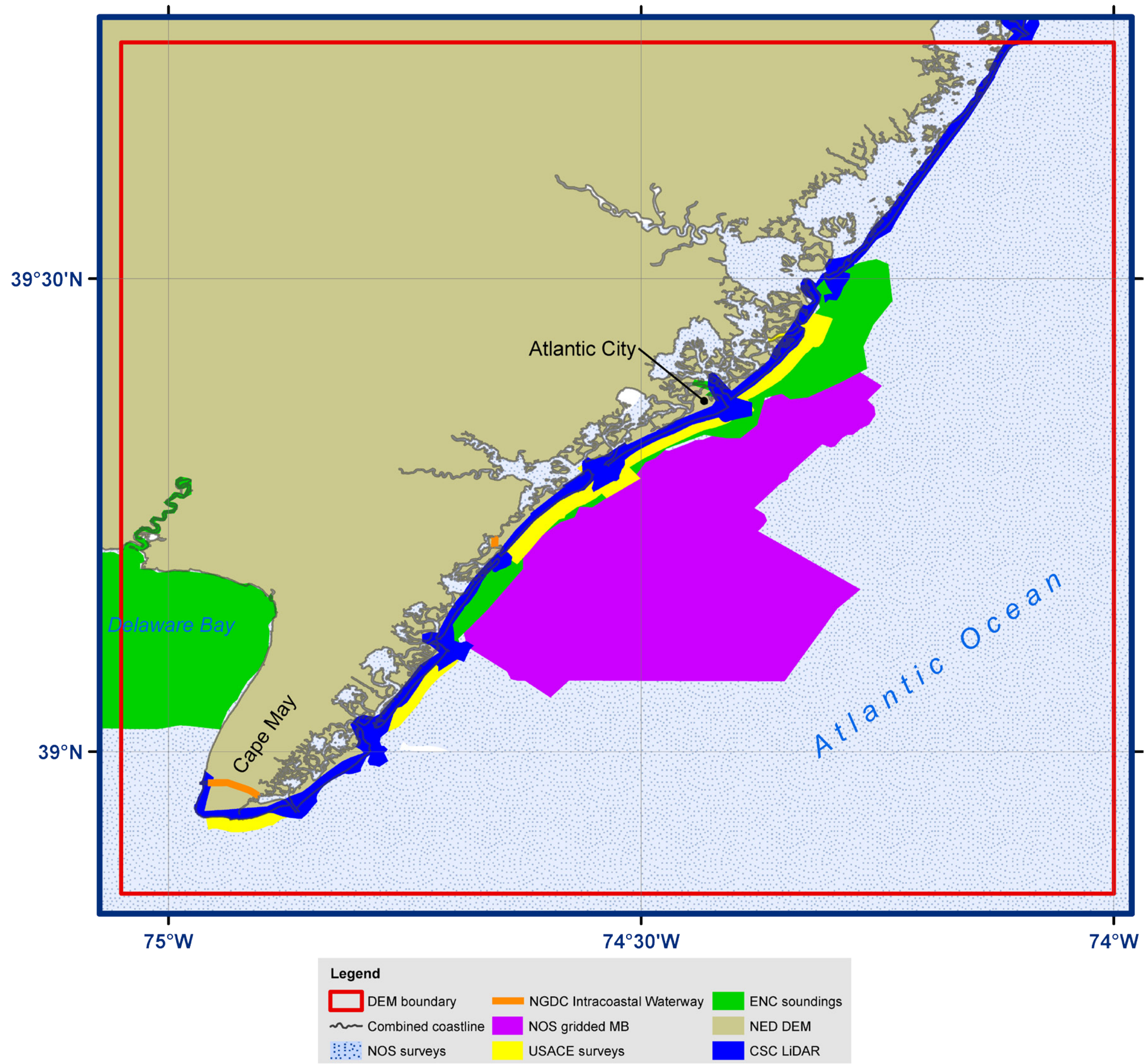

Figure 3. *Source and coverage of datasets used to compile the Atlantic City DEM.*

3.1.1 Shoreline

Coastline datasets of the Atlantic City region were obtained from NOAA's Office of Coast Survey, Coastal Services Center (CSC); the New Jersey Department of Environmental Protection (NJDEP); and Center for Remote Sensing and Spatial Analysis (CRSSA) at Rutgers University. Analysis of the NJDEP and Rutgers coastlines showed both to be less detailed than coastlines extracted from the ENCs and therefore were not used in building the Atlantic City DEM. NGDC created a partial shoreline from CSC coastal LiDAR data that was used in combination with the ENCs to build a 'combined coastline' for the Atlantic City region (Table 2; Fig. 4).

Table 2: Shoreline datasets used in the Atlantic City, DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
OCS ENCs	2006-2007	Coastline	1:80,000 to 1:400,000	WGS 84 geographic	Mean High Water	http://nauticalcharts.noaa.gov/mcd/enc/index.htm
NGDC/CSC LiDAR derived shoreline		Contour		WGS 84 geographic	Mean High Water	

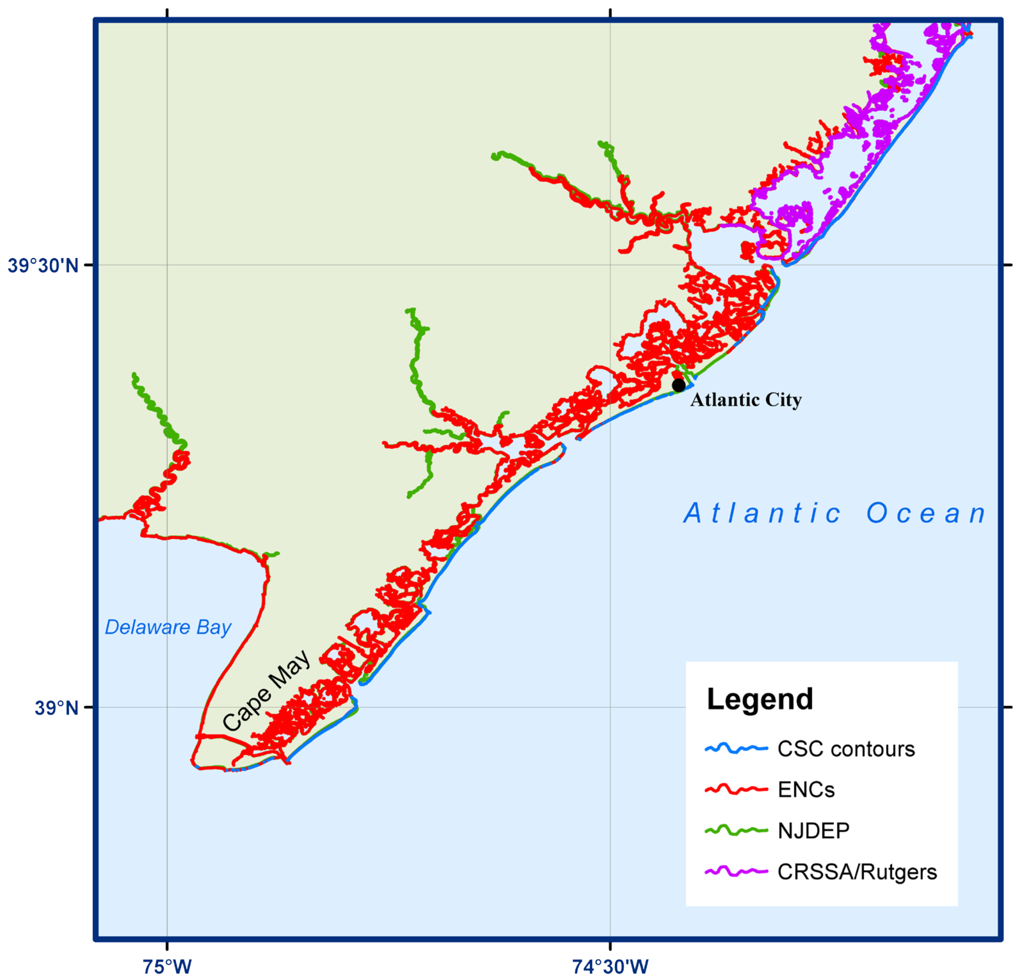

Figure 4. *Digital coastline datasets available in the Atlantic City region.*

1) **OCS electronic navigational chart**

Four electronic navigational charts (ENCs) were available for the Atlantic City area (Table 3) and 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 files referenced to Mean High Water. Other nautical charts were available as georeferenced raster nautical charts (RNCs; digital images of the charts) and were used to QC bathymetric, bathymetric–topographic, and topographic datasets.

2) **NGDC/Coastal Services Center LiDAR derived contour shoreline**

In order to define the current coastline, NGDC processed the most recent high-resolution coastal bathymetric–topographic LiDAR dataset available from CSC to create a zero-elevation coastline at Mean High Water vertical datum. The zero contour line incorporated some jetties and coastal land features not present in the ENC coastlines.

Table 3: Electronic navigational charts available in the Atlantic City, New Jersey region.

Chart	*Title*	*Edition*	*Year of Source data*	*Issue Date*	*Scale*
12300	Approaches to New York Nantucket Shoals to Five Fathom Bank	12	2003	2007-07-26	1:400,000
12214	Cape May to Fenwick Island	9	1999 to 2004	2007-06-25	1:80,000
12304	Delaware Bay	8	1999 to 2004	2007-08-01	1:80,000
12318	Little Egg Inlet to Hereford Inlet	1	2005	2007-07-26	1:80,000

The ENC coastlines were merged with the derived contour coastline to create a 'combined coastline' for the Atlantic City region. Channel inlets were included in the 'combined coastline' where digital bathymetric data were present. Modifications to the coastline include adjustments to fit the most recent bathymetric–topographic data. In addition, piers, docks, and bridges were removed (e.g., Fig. 5). All modifications were done using ArcMap editing tools.

Figure 5. *Aerial photo of Atlantic City at Absecon Inlet.*

3.1.2 Bathymetry

Bathymetric datasets used in the compilation of the Atlantic City DEM include 65 NOS hydrographic surveys, eight USACE surveys located within harbors and inlets, three NOS shallow-water multibeam sonar surveys that cover the near shore area, an NGDC digitized representation of the Intracoastal Waterway, and extracted ENC sounding data (Table 4; Fig. 6).

Table 4: Bathymetric datasets used in compiling the Atlantic City DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1935 to 2002	Hydrographic survey soundings	Ranges from 10 m to 1 km (varies with scale of survey, depth, traffic, and probability of obstructions)	NAD 27 or NAD 83 geographic	Mean Low Water or Mean Lower Low Water	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
USACE	2006 to 2007	Hydrographic survey profiles	Ranges from 150 to 1500 m line spacing 150 to 300 m apart with 2 to 5 m point spacing	NAD 83 New Jersey State Plane (feet)	NAVD88 (feet)	
NOS	2003	Shallow water multibeam sonar	10 meters	NAD 83 geographic	Mean Lower Low Water	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NGDC - ICW		digitized soundings	~ 10 meters	WGS 84 geographic	Mean High Water	
OCS ENC	2006 to 2007	Extracted soundings	1:80,000 to 1:400,000	WGS 84 geographic	Mean High Water	http://nauticalcharts.noaa.gov/mcd/enc/index.htm

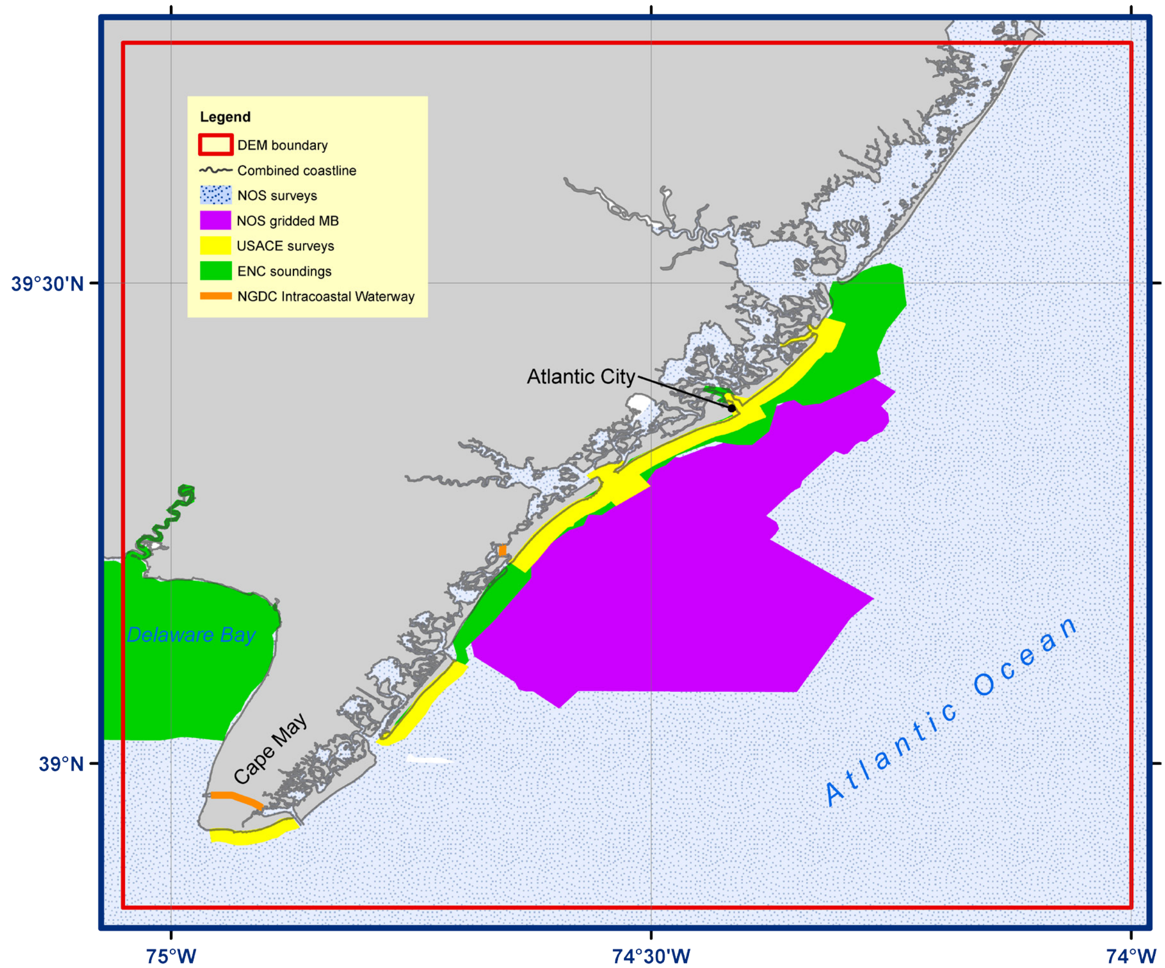

Figure 6. *Spatial coverage of bathymetric datasets used to compile the Atlantic City DEM.*

1) NOS hydrographic survey data

A total of 82 NOS hydrographic surveys conducted between 1935 and 2002 were available for use in developing the Atlantic City DEM (Table 5; Fig. 7). The hydrographic survey data were originally vertically referenced to Mean Lower Low Water (MLLW) or Mean Low Water (MLW) and horizontally referenced to either NAD 27 or NAD 83 datums. Only 65 of the 82 surveys were used in building the Atlantic City DEM, as some older surveys have been superseded.

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 NAD 83 and 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 Atlantic City DEM area to support data interpolation along grid edges.

After converting all NOS survey data to MHW using VDatum and tide station offset (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 bathymetric–topographic datasets, the combined coastline, and NOS raster nautical charts (RNCs). The surveys were clipped to remove soundings that overlap the more recent multibeam surveys, where the USACE surveys were located within the inlets and along the coastline and where soundings from older surveys have been superseded by more recent NOS surveys.

Table 5: Digital NOS hydrographic surveys used in compiling the Atlantic City DEM.

Survey ID	*Year*	*Scale*	*Original Vertical Datum*	*Original Horizontal Datum*	*Vertical Datum conversion used*
H05893	1935	10,000	mean low water	NAD 27	Offset and VDatum
H05894	1935	10,000	mean low water	NAD 27	Offset
H06141	1936	10,000	mean low water	NAD 27	Offset and VDatum
H06142	1936	10,000	mean low water	NAD 27	Offset
H06144	1936	10,000	mean low water	NAD 27	Offset and VDatum
H06188	1936	40,000	mean low water	NAD 27	Offset and VDatum
H06213	1936	10,000	mean low water	NAD 27	Offset
H06215	1936	10,000	mean low water	NAD 27	Offset
H06216	1936	10,000	mean low water	NAD 27	Offset and VDatum
H06214	1937	5,000	mean low water	NAD 27	Offset
H06218	1937	10,000	mean low water	NAD 27	Offset
H06224	1937	10,000	mean low water	NAD 27	Offset and VDatum
H06230	1937	10,000	mean low water	NAD 27	Offset and VDatum
H06231	1937	10,000	mean low water	NAD 27	Offset and VDatum
H06236	1937	10,000	mean low water	NAD 27	Offset and VDatum
H06254	1937	10,000	mean low water	NAD 27	Offset
H06262	1937	10,000	mean low water	NAD 27	Offset and VDatum

H06271	1937	40,000	mean low water	NAD 27	VDatum
H06345	1938	80,000	mean low water	NAD 27	Offset
H06225	1939	20,000	mean low water	NAD 27	Offset and VDatum
H06226	1940	20,000	mean low water	NAD 27	Offset and VDatum
H06227	1940	20,000	mean low water	NAD 27	Offset and VDatum
H08219	1954	10,000	mean low water	NAD 27	Offset and VDatum
H08220	1954	10,000	mean low water	NAD 27	Offset and VDatum
H08221	1954	10,000	mean low water	NAD 27	Offset and VDatum
H08222	1954	20,000	mean low water	NAD 27	VDatum
H08672	1962	10,000	mean low water	NAD 27	Offset and VDatum
H08674	1962	10,000	mean low water	NAD 27	Offset and VDatum
H08675	1962	10,000	mean low water	NAD 27	Offset and VDatum
H08676	1962	10,000	mean low water	NAD 27	Offset and VDatum
H09153	1970/71	20,000	mean low water	NAD 27	Offset and VDatum
H09154	1970	10,000	mean low water	NAD 27	Offset
H09203	1971	10,000	mean low water	NAD 27	Offset
H09204	1971	5,000	mean low water	NAD 27	Offset
H09241	1971	20,000	mean low water	NAD 27	Offset
H09310	1972	5,000	mean low water	NAD 27	Offset and VDatum
H09311	1972	10,000	mean low water	NAD 27	Offset and VDatum
H09312	1972	20,000	mean low water	NAD 27	Offset and VDatum
H09533	1975	20,000	mean low water	NAD 27	Offset
H09534	1975	40,000	mean low water	NAD 27	VDatum
H09542	1975	40,000	mean low water	NAD 27	VDatum
H09552	1975	40,000	mean low water	NAD 27	VDatum
H09573	1975	40,000	mean low water	NAD 27	VDatum
H09622	1976	40,000	mean low water	NAD 27	Offset and VDatum
H09699	1977	20,000	mean low water	NAD 27	Offset and VDatum
H09700	1977	20,000	mean low water	NAD 27	Offset

H09722	1977	5,000	mean low water	NAD 27	Offset
H09723	1977	20,000	mean low water	NAD 27	Offset
H10167	1984	20,000	mean lower low water	NAD 27	Offset
H10439	1992	20,000	mean lower low water	NAD 83	Offset
H10440	1992	20,000	mean lower low water	NAD 83	Offset
H10444	1992/93	20,000	mean lower low water	NAD 83	Offset
H10446	1992/93	20,000	mean lower low water	NAD 83	Offset
H10489	1993	20,000	mean lower low water	NAD 83	Offset
H10234	1994	10,000	mean lower low water	NAD 83	Offset
H10241	1994	10,000	mean lower low water	NAD 83	Offset
H10573	1994	10,000	mean lower low water	NAD 83	Offset
F00453	1999	10,000	mean lower low water	NAD 83	Offset
H10917	1999	10,000	mean lower low water	NAD 83	Offset
H10935	1999	20,000	mean lower low water	NAD 83	Offset and VDatum
H10936	1999	20,000	mean lower low water	NAD 83	Offset
H10926	1999/2000	10,000	mean lower low water	NAD 83	Offset
H11081	2001/02	20,000	mean lower low water	NAD 83	Offset
H11104	2002	20,000	mean lower low water	NAD 83	Offset and VDatum
H11241	2004	20,000	mean lower low water	NAD 83 UTM zone 18 North	VDatum

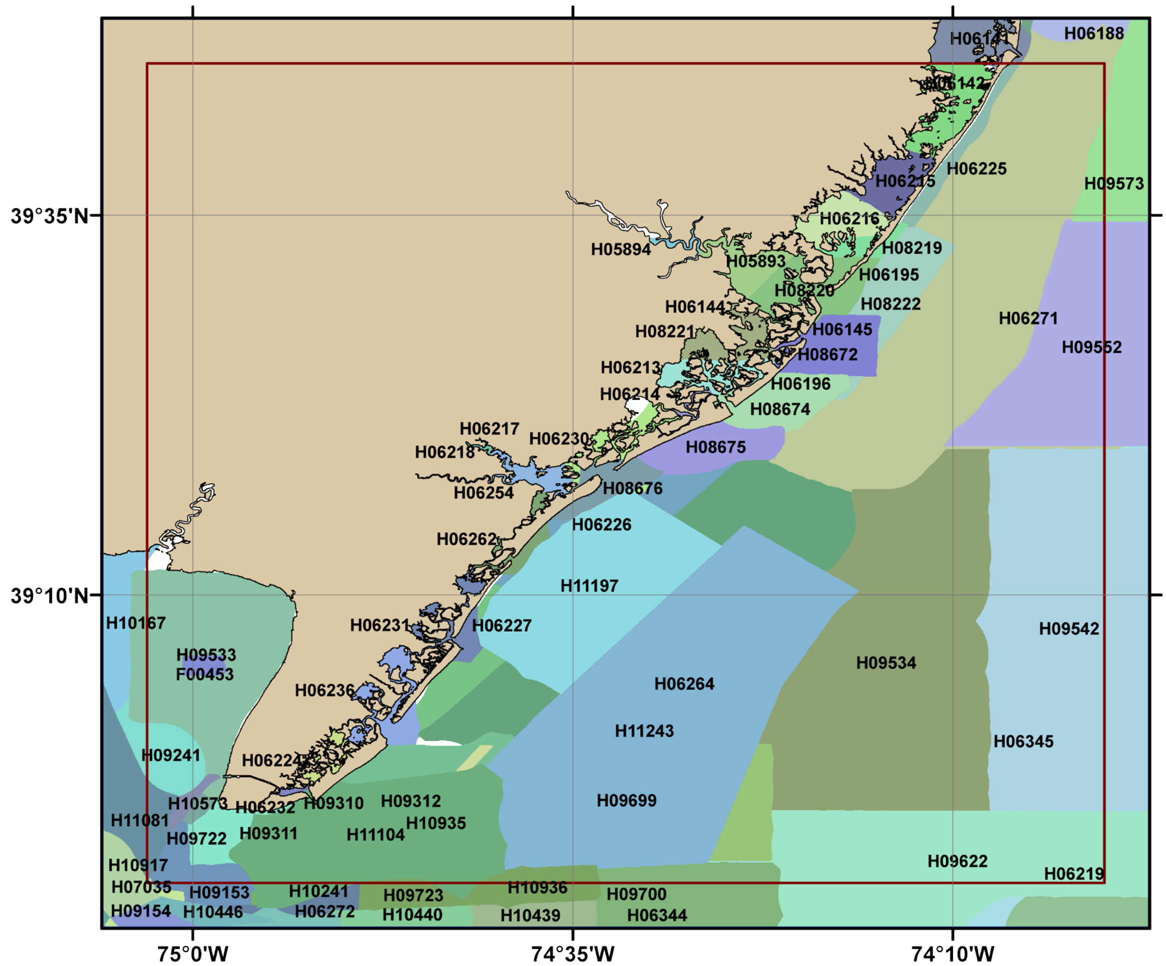

Figure 7. *Digital NOS hydrographic survey coverage in the Atlantic City region. Some older surveys were not used as they have been superseded by more recent surveys. DEM boundary in brown.*

2) U.S. Army Corps of Engineers hydrographic surveys

The USACE, Philadelphia District, provided NGDC with eight bathymetric surveys located along the New Jersey coastline and within inlets (Table 6, Fig. 8). The surveys were collected in 2006 and 2007, and referenced to NAD 83 New Jersey State Plane (feet) North and NAVD88 (feet) datums. The files were converted to NAD 83 and MHW using FME. Point spacing averages less than 2 meters along profiles 1500 to 1700 meters long and averaging 300 meters apart. Inlet surveys are several thousand meter square grids formed by intersecting survey lines with point spacing of less than 5 meters.

Beach profiles and inlet surveys were evaluated using Arc Map and surfaced with GMT (see section 3.3.2) to eliminate ridges and a "waffle" pattern.

Table 6: USACE surveys used in compiling the Atlantic City DEM.

Region	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum*
Absecon Inlet	2006	2600 x 3600 m grid with < 150 m line spacing and < 5 m point spacing	NAD 83 New Jersey State Plane (feet)	NAVD88 (feet)
Absecon Island profiles	2006	beach profiles ~1500 m wide, spaced ~300 m apart with < 2 m point spacing	NAD 83 New Jersey State Plane (feet)	NAVD88 (feet)
Cape May profiles	2007	beach profiles ~1500 m wide, spaced ~300 m apart with < 2 m point spacing	NAD 83 New Jersey State Plane (feet)	NAVD88 (feet)
Great Egg Harbor Inlet	2006	4400 x 3800 m grid with 150 m line spacing and < 5 m point spacing	NAD 83 New Jersey State Plane (feet)	NAVD88 (feet)
Avalon profiles	2007	beach profiles ~1500 m wide, spaced ~300 m apart with < 2 m point spacing	NAD 83 New Jersey State Plane (feet)	NAVD88 (feet)
Brigantine Inlet	2006	2500 x 3500 m grid with < 150 m line spacing and < 5 m point spacing	NAD 83 New Jersey State Plane (feet)	NAVD88 (feet)
Brigantine Island profiles	2006	beach profiles ~1500 m wide, spaced ~300 m apart with < 2 m point spacing	NAD 83 New Jersey State Plane (feet)	NAVD88 (feet)
Ocean City profiles	2006	beach profiles ~1700 m wide, spaced ~300 m apart with < 2 m point spacing	NAD 83 New Jersey State Plane (feet)	NAVD88 (feet)

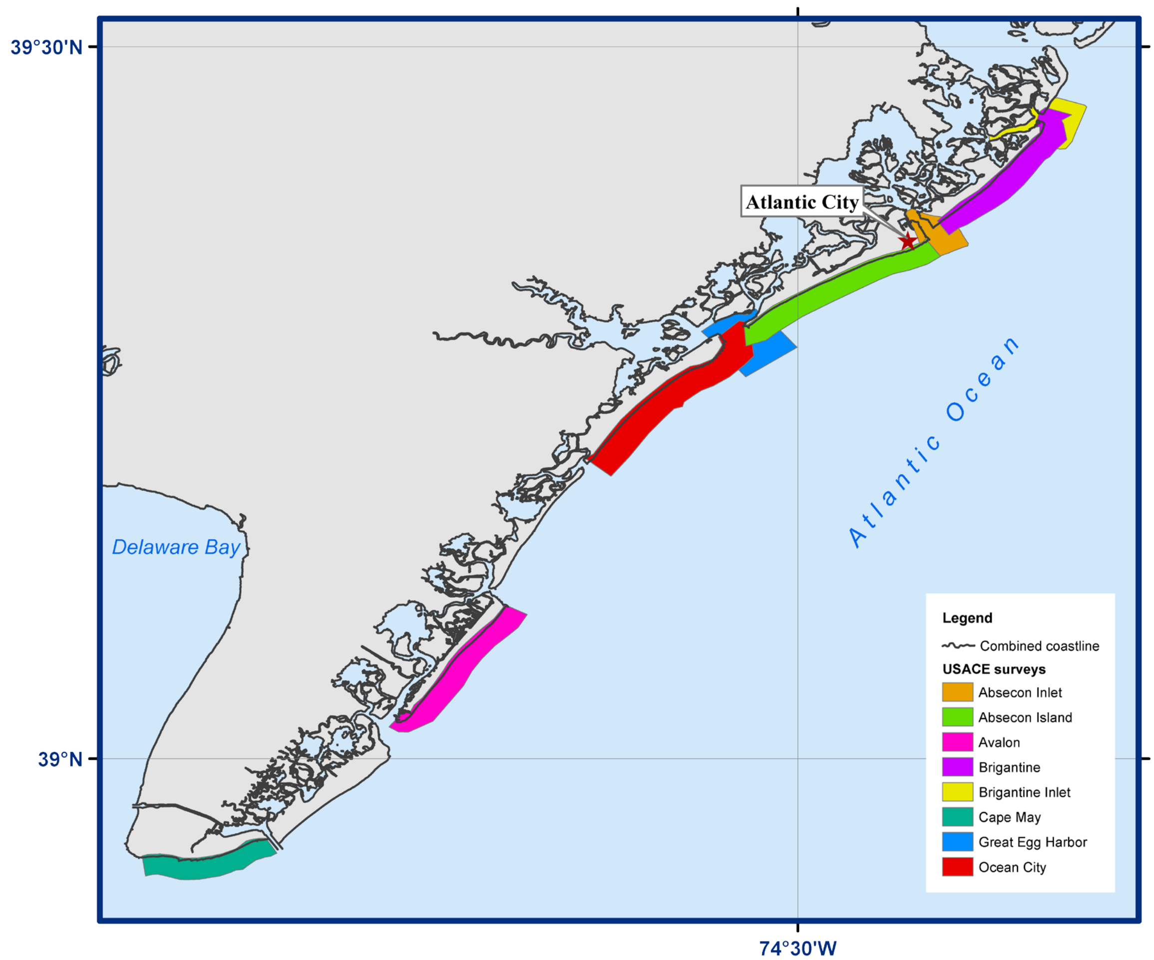

Figure 8. *Digital USACE hydrographic survey coverage in the Atlantic City region.*

3) NOS shallow water multibeam survey

NOAA's NOS conducted several shallow water multibeam sonar surveys along the New Jersey coast (Table 7, Fig. 9). Three surveys were downloaded from the NGDC hydrographic survey website (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) in ASCII xyz gridded format in NAD 83 geographic at 10-meter resolution and referenced to MLLW. This dataset provided dense bathymetric coverage for the area.

Table 7: Digital NOS shallow water multibeam surveys used in compiling the Atlantic City DEM.

NOS Survey ID	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum*
H11197	2003	20,000	mean lower low water	NAD 83 geographic
H11198	2003	20,000	mean lower low water	NAD 83 geographic
H11243	2004	40,000	mean lower low water	NAD 83 geographic

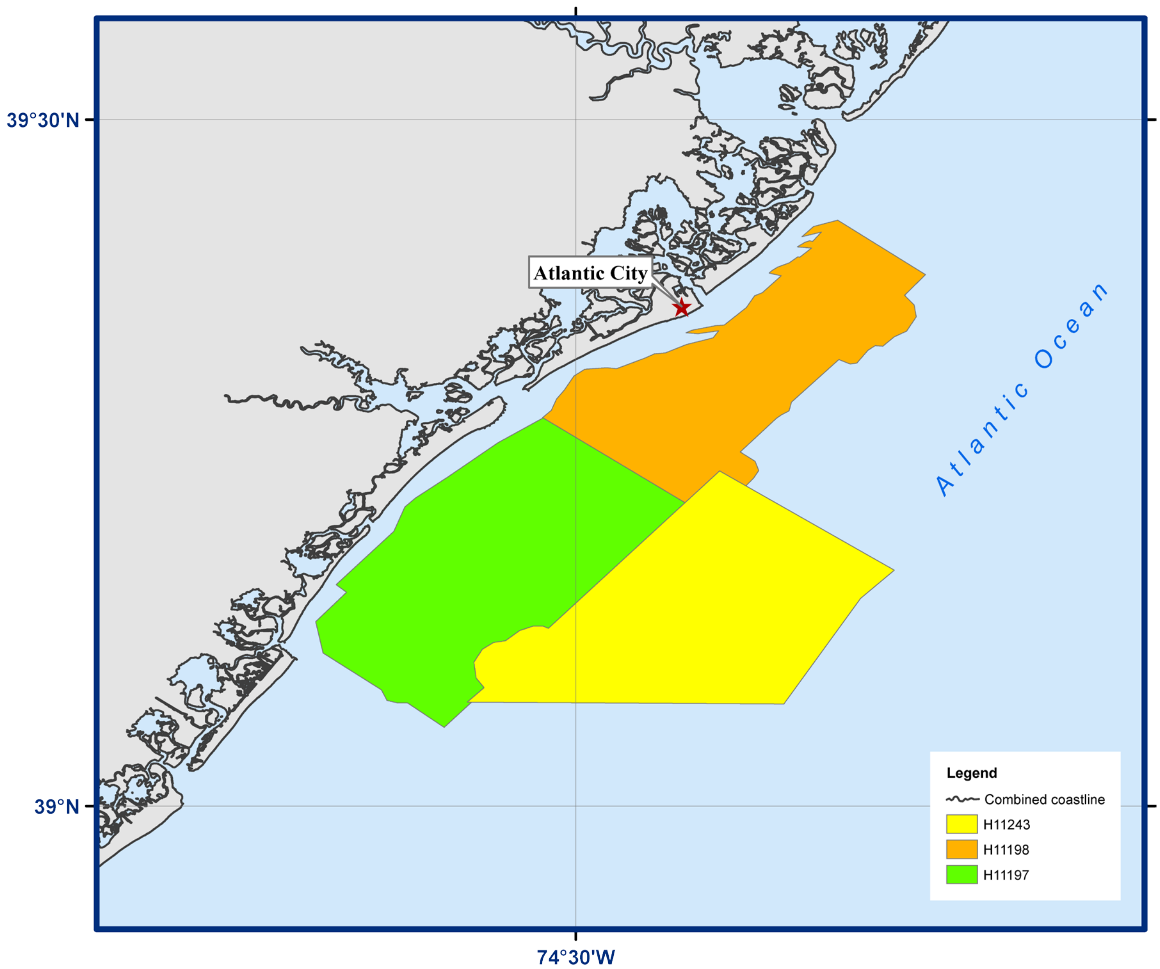

Figure 9. *Coverage of NOS shallow-water multibeam sonar surveys.*

4) Office of Coast Survey Electronic navigational chart extracted soundings

The OCS electronic navigational chart sounding data were extracted from charts #12318 and #12304 and converted to MHW using FME. NGDC digitized additional soundings from chart #12304 in the Maurice River channel at a depth of -1.82 meters based on Coast Pilot (Fig. 10). By increasing the density of soundings in the river channel, the appearance of 'pits' in the pre-surfaced bathymetric grid was reduced. Soundings from ENC #12318 were clipped to the shallow water multibeam surveys.

5) Digitized Intracoastal Waterway

NGDC digitized soundings with point spacing of less than one meter for the Intracoastal Waterway (ICW; Fig. 10) at a depth of -1.82 meters for the small inland channel north of Sea Isle City and -3.66 meters through the Cape May Channel. No other bathymetric data were available.

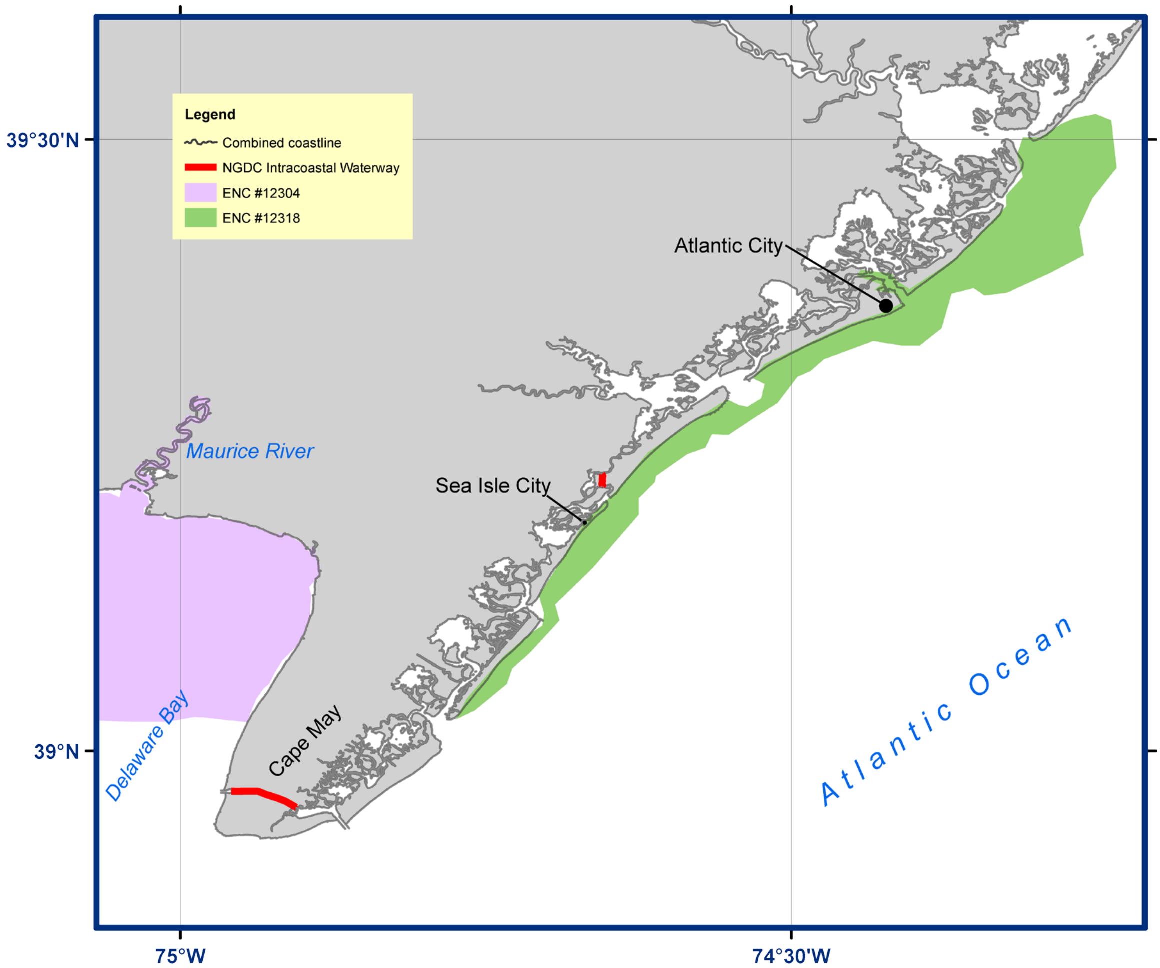

Figure 10. *Coverage of extracted ENC soundings and the Intracoastal Waterway segments digitized by NGDC.*

Some inconsistencies were identified while merging the bathymetric datasets due to the range in ages of the NOS hydrographic surveys. Coastal erosion and development have modified the coastline dramatically; the inlets surveyed in the early 40's and 50's have shifted hundreds of meters. In areas where more recent data were available, the older surveys were either edited or removed.

3.1.3 *Topography*

One topographic dataset in the Atlantic City region was obtained and used to build the Atlantic City DEM from the U.S. Geological Survey (USGS; Table 8; Fig. 11). NGDC evaluated but did not use the Shuttle Radar Topography Mission (SRTM) Elevation 1 arc-second DEM available from USGS.

Table 8: Topographic datasets used in compiling the Atlantic City DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
USGS	1999-2000	NED DEM	1/3 arc-second	NAD 83 geographic	NAVD88 (meters)	http://ned.usgs.gov/

1) USGS NED topographic DEM

The U.S. Geological Survey (USGS) National Elevation Dataset (NED; http://ned.usgs.gov/) provides complete 1/3 arc-second coverage of the Atlantic City region[4]. Data are in NAD 83 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 'combined coastline'.

In marshy areas, the NED topographic data had elevation values below zero. The Absecon Wilderness Management Area and the Edwin B. Forsythe National Wildlife Refuge consist of roughly 50,000 acres of salt marsh and wetlands. A management technique called "diking" is employed to create acres of impounded marsh habitat in the naturally occurring tidal salt marsh. Water levels are monitored and changed according to wildlife needs and seasons (http://www.fws.gov/northeast/forsythe/). The process could result in NED topographic data values of less than zero in areas represented as land on nautical charts and topographic maps.

The Grant F. Walton Center for Remote Sensing and Spatial Analysis (CRSSA) at Rutgers University also provides research data on the changes in coverage of submerged aquatic vegetation in the Barnegat Bay region (Fig. 11).

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 NAD 83, except for AK, which is NAD 27. 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]

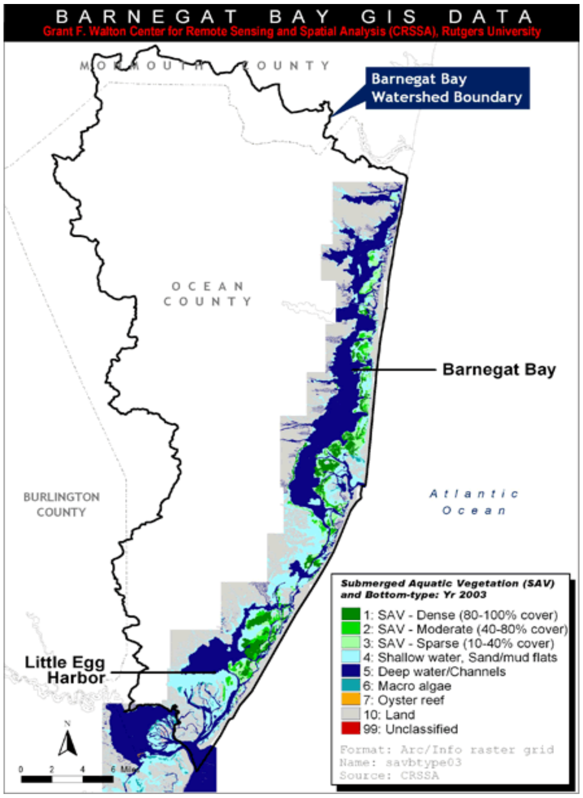

Figure 11. *Map of submerged aquatic vegetation in the Atlantic City region. Courtesy of Grant F. Walton Center for Remote Sensing and Spatial Analysis (CRSSA) at Rutgers University (http://crssa.rutgers.edu/projects/runj/bbdata/index.html).*

Two areas of the NED DEM dataset have an offset in elevation values of up to 1 meter. Both are located at the seams of the USGS quads, one just west of Townsend Inlet and the other in the Barnegat Bay area. Figure 12 illustrates the intersection of four quads and the corresponding area in the final 1/3 arc-second Atlantic City DEM. Other online topographic datasets at similar resolution also contained this offset as they use the NED data. The SRTM 1 arc-second DEM did not accurately reflect topography and was not used.

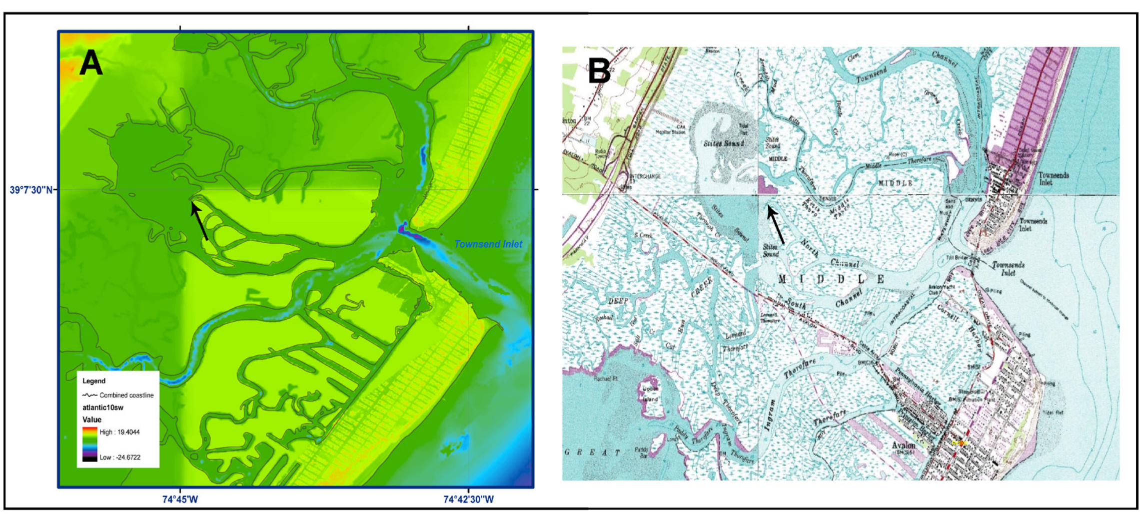

Figure 12. *1/3 arc-second Atlantic City DEM and quad sheets west of Townsend Inlet. A) The resulting elevation offsets shown as difference between light and dark green shades. B) Image of four USGS quad sheets. In both images, the black arrow points to the intersection of the quads.*

3.1.4 Bathymetry–Topography

Two bathymetric–topographic LiDAR datasets were available from NOAA's Coastal Services Center (CSC) Coastal Remote Sensing Program, covering the ocean coastal region of the Atlantic City DEM from Cape May to Barnegat Bay. The NOAA/USGS/NASA Airborne LiDAR Assessment of Coastal Erosion (ALACE) Project for the US Coastline dataset was conducted from 1996 to 2000 to study coastal changes along the New Jersey eastern seaboard. The CSC/JALBTCX 2005 dataset is part of the National Coastal Mapping Program to depict the elevations above and below water along the east coastal zone (Fig. 13, Table 9). As both datasets provide full coverage of the entire length of the Atlantic Ocean shoreline, only the more recent CSC/JALBTCX 2005 dataset was used in building the Atlantic City DEM. Neither dataset was processed to bare earth.

Table 9: Bathymetric–topographic dataset used in compiling the Atlantic City DEM.

Source	*Year*	*Data Tyle*	*Spacial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*
CSC/JALBTCX	2005	Coastal LiDAR	< 5 meters	NAD 83 geographic	NAVD88 (meters)

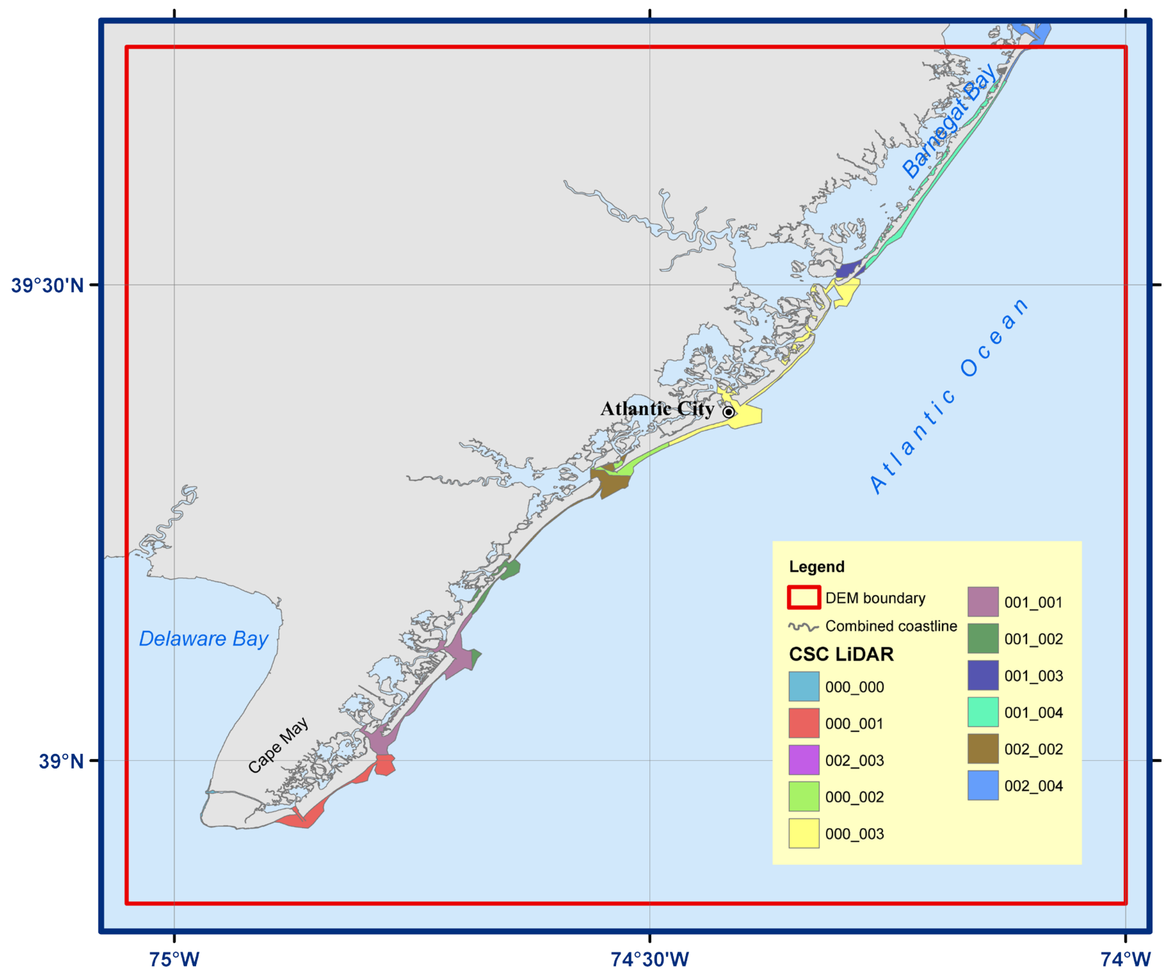

Figure 13. *Coverage of the CSC/JALBTCX 2005 LiDAR dataset used in building the Atlantic City DEM.*

1) **CSC/JALBTCX bathymetric–topographic LiDAR 2005**

The CSC/JALBTCX LiDAR dataset provided bathymetric–topographic coverage for the coastal and near shore regions of the New Jersey coast. These data were obtained in NAD 83 geographic horizontal datum and NAVD88. FME was used to re-project the xyz data to WGS 84 geographic and to MHW. Point spacing varied from less than 5 meters with full coverage at the shoreline to greater spacing farther from shore. These data were not processed to bare earth.

In order to simulate a bare earth surface, the LiDAR data were filtered using FME to remove all elevations on land over 5 meters. This elevation was used because the majority of the land surface located on the shoreline averaged less than 5 meters, referencing USGS quad sheets. Elevations over 5 meters in the NED topographic dataset that were also shown to be over 5 meters on the USGS quads sheets were retained for use in building the final DEM. While not a replacement for bare earth processing, the filtering removed the majority of buildings, elevated roadways, and large piers. Each data file was reviewed and edited using ArcMap tools to remove docks, bridges, and piers over water. Several anomalous returns were found during this QC process and were also removed.

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Atlantic City DEM were originally referenced to a number of vertical datums including Mean Lower Low Water (MLLW), Mean Low Water (MLW), and North American Vertical Datum of 1988 (NAVD88). All datasets were transformed to MHW to provide the maximum flooding for inundation modeling. Units were converted from feet to meters as appropriate.

1) **Bathymetric data**

   The NOS hydrographic surveys, the USACE surveys, and the NOS multibeam sonar survey were transformed from MLLW and MLW to MHW, using FME software, by adding a constant taken from the Atlantic City tide station #8534720 (Table 10) or by processing using the VDatum tool (http://www.nauticalcharts.noaa.gov/csdl/vdatum_enhancements.html) based on VDatum coverage (Fig. 14).

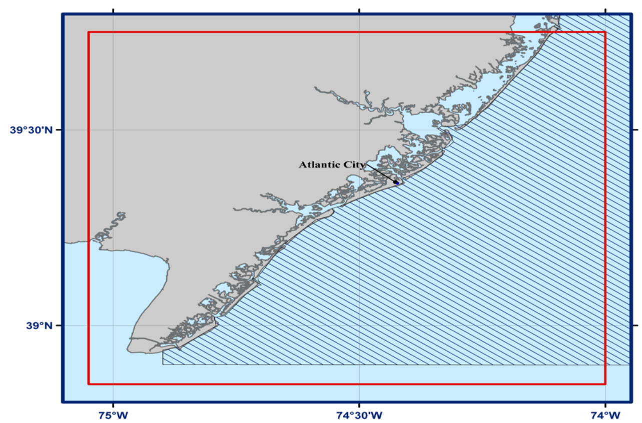

Figure 14. *Hachured area illustrates coverage of VDatum tool.*

2) **Topographic data**

   The USGS NED 1/3 arc-second DEMs were originally referenced to NAVD88. Conversion to MHW, using FME software, was accomplished by adding a constant offset of -0.479 meters (Table 10) as measured at the Atlantic City tide station.

3) **Bathymetric–topographic data**

   The CSC bathymetric–topographic LiDAR data were transformed from NAVD88 to MHW by adding a constant offset of -0.479 meters using FME.

Table 10. Relationship between Mean High Water and other vertical datums at the Atlantic City tide station #8534720.

Vertical datum	*Difference to MHW*
NAVD88	-0.479 meters
MLW	-1.225 meters
MLLW	-1.276 meters

3.2.2 Horizontal datum transformations

Datasets used to compile the Atlantic City DEM were originally referenced to WGS 84 geographic, NAD 83 UTM Zone 18 North, NAD 83 New Jersey State Plane, NAD 83 geographic, or NAD 27 geographic horizontal datums. The relationships and transformational equations between these horizontal datums are well established. All data were converted to a horizontal datum of NAD 83 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:

- Suspect elevations located on and within salt marshes and estuaries.
- Inconsistencies within the NED topographic data in two areas. These inconsistencies appear to result from merging of digitized USGS quad sheets.
- Data values over the ocean and rivers in the NED topographic data reflecting non-bare earth features. The dataset required automated clipping to the combined coastline.
- Bathymetric–topographic LiDAR dataset not processed to bare earth. The dataset required filtering of elevation values on land and manual editing of individual features.
- Digital, measured bathymetric values from NOS surveys date back over 70 years. More recent data, such as the USACE hydrographic surveys differed from older NOS data by as much as 10 meters vertically and over 100 meters horizontally. The older NOS survey data were excised where more recent bathymetric data exists.

3.3.2 Pre-surfacing of USACE bathymetric dataset

The USACE bathymetric surveys consist of widely spaced beach profiles and soundings with 'cross-hatched' patterns at inlets. This point distribution required pre-surfacing using GMT to minimize the artifacts. Original non-surfaced bathymetric datasets were not used in the final gridding process after test grids showed excessive "patchwork" artifacts where datasets merged or overlapped (Fig. 15).

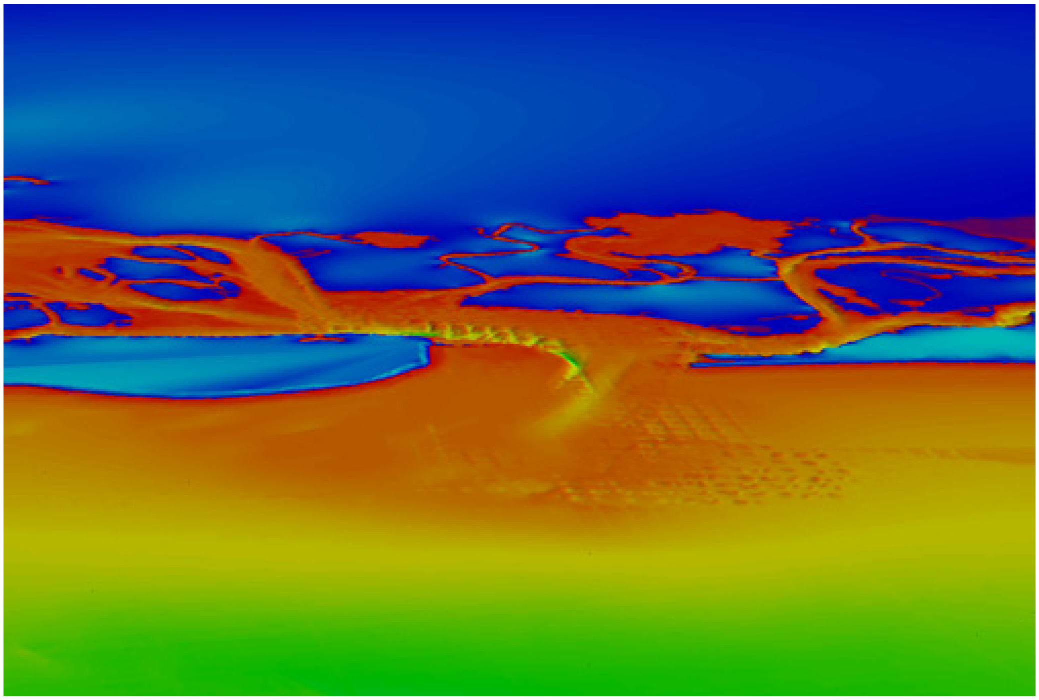

Figure 15. *Example of artifacts in test grid at Absecon Inlet. "Waffle" pattern resulted from incorporating non-surfaced USACE survey dataset in final gridding.*

3.3.3 *Smoothing of bathymetric data*

The NOS hydrographic survey data are generally sparse at the resolution of the 1/3 arc-second Atlantic City 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, a 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 clipped to remove overlap with the JALBTCX bathymetric–topographic LiDAR data, then combined with the surfaced and clipped USACE soundings, the NOS multibeam data, ENC sounding data, and the digitized ICW segments into a single file, along with points extracted from the combined coastline—to provide a buffer along the entire coastline. The coastline elevation value was set at -0.5 m to ensure a bathymetric surface below zero in areas where data is sparse or non-existent.

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 Atlantic City 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 combined coastline (to eliminate data interpolation into land areas). The resulting surface was compared with original soundings to ensure grid accuracy (e.g., Fig. 15), converted to a shape file, and then exported as an xyz file for use in the final gridding process (see Table 11).

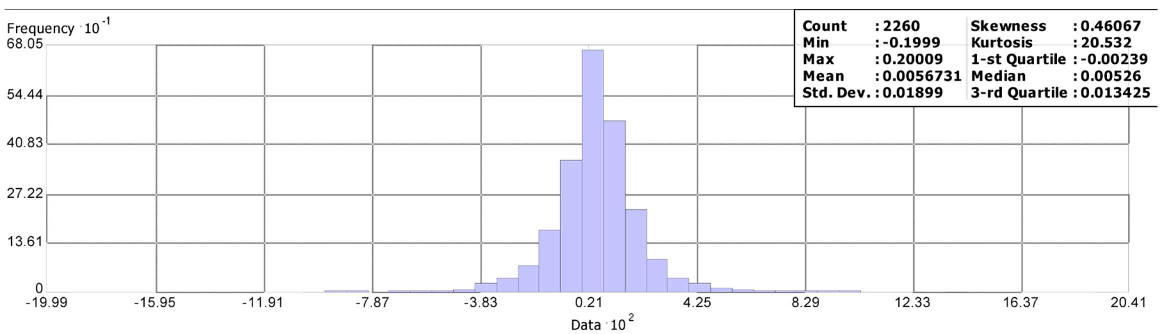

Figure 16. *Histogram of the differences between NOS hydrographic survey H09552 and the 1 arc-second pre-surfaced bathymetric grid.*

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 Atlantic City 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 CSC bare-earth LiDAR data. Least weight was given to the pre-surfaced 1 arc-second bathymetric grid. Gridding was performed in quads with the resulting Arc ASCII grids seamlessly merged in ArcCatalog to create the final 1/3 arc-second Atlantic City DEM.

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

Dataset	*Relative Gridding Weight*
CSC bathymetric–topographic coastal LiDAR	1,000,000
USGS NED topographic DEM	1000
Combined coastline	100
Pre-surfaced bathymetric grid	10

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Atlantic City 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 bathymetric–topographic LiDAR data have an accuracy of approximately 6 meters; 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 sub aerial 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 the morphologic change that occurs in this dynamic region.

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the Atlantic City 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 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 20th 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 Atlantic City DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 17). 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. 18). 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 Atlantic City DEM in its final version.

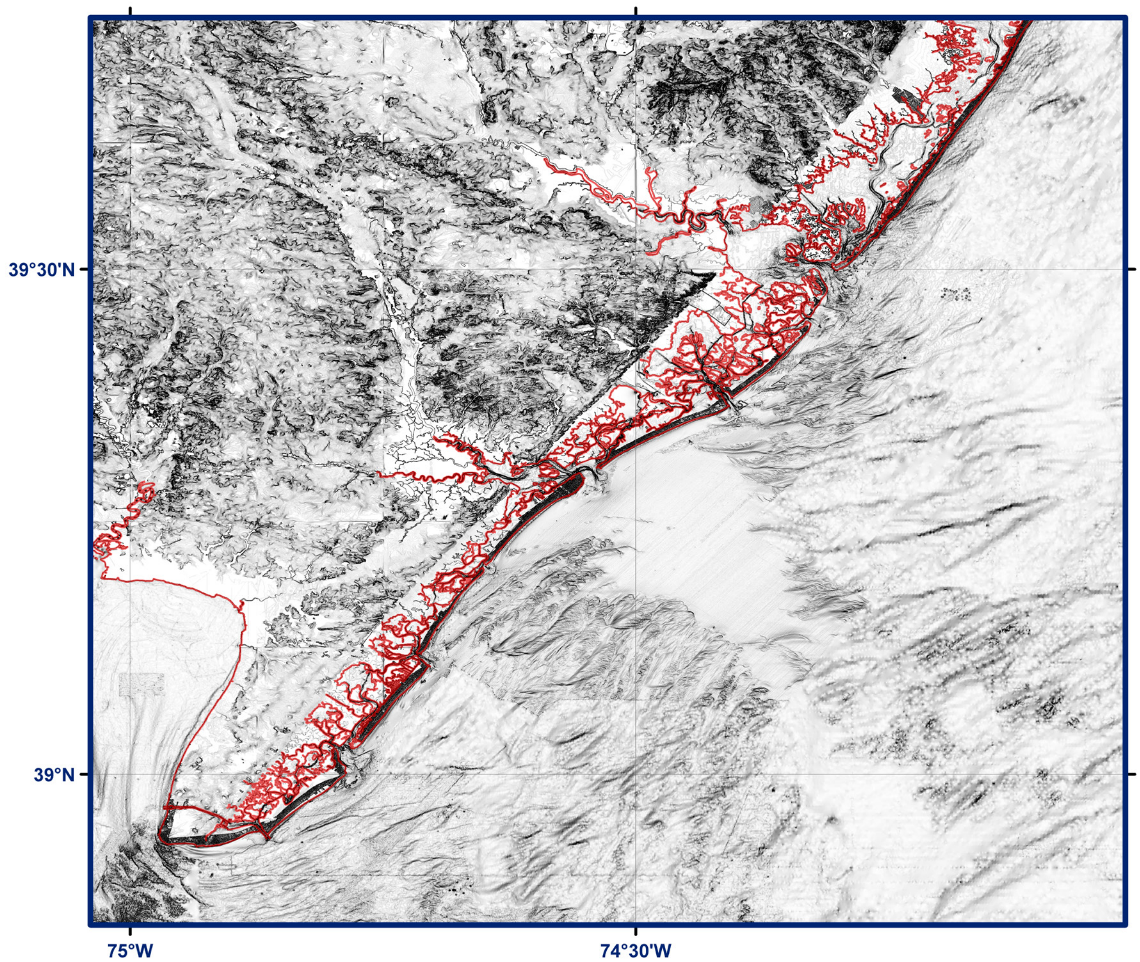

Figure 17. *Slope map of the Atlantic City DEM. Flat-lying slopes are white; dark shading denotes steep slopes; combined coastline in red.*

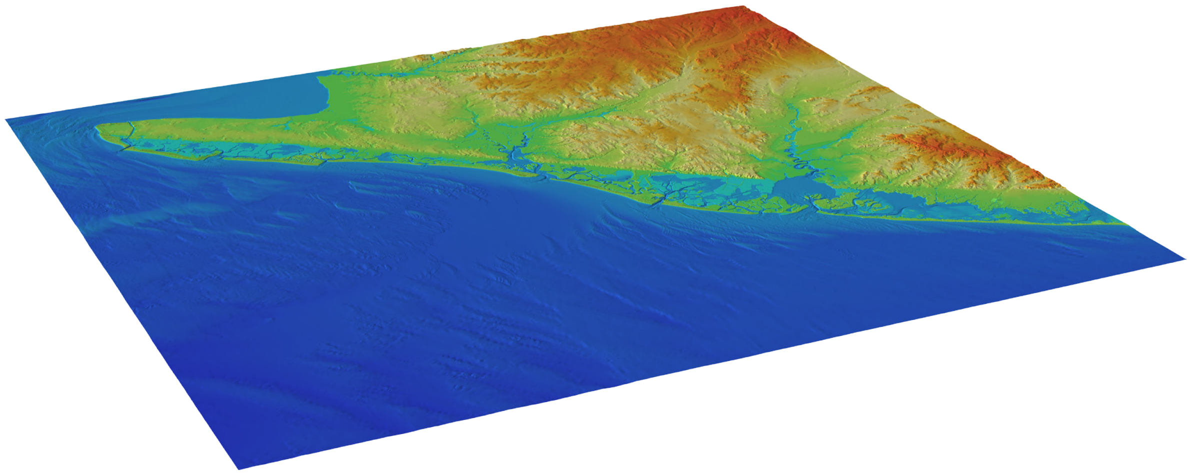

Figure 18. *Perspective view from the southeast of the Atlantic City DEM. Vertical exaggeration–times 50.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Atlantic City 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 a CSC topographic LiDAR survey file and the Atlantic City DEM is shown in Figure 19. Differences cluster around zero, with only a handful of soundings, in regions of steep topography, exceeding a 0.51-meter discrepancy from the DEM.

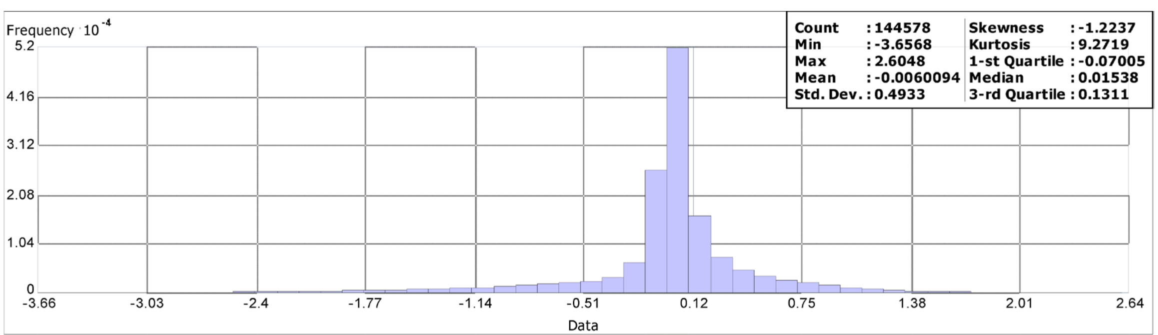

Figure 19. *Histogram of the differences between one CSC LiDAR survey and the Atlantic City DEM.*

3.4.5 *Comparison with NGS geodetic monuments*

The elevations of 1247 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 NAD 83 (typically sub-mm accuracy) and elevations in NAVD88 (in meters). Elevations were shifted to MHW vertical datum (see Table 10) for comparison with the Atlantic City DEM (see Fig. 21 for monument locations). Differences between the Atlantic City DEM and the NGS geodetic monument elevations range from -15 to 5 meters, with the majority of them being within +/-2 meters range. Negative values indicate that the monument elevation is less than the DEM (Fig. 20). Only 15 monuments out of 260 total showed significant deviations from the DEM. Such discrepancies are caused by the rough terrain in the Atlantic City area, where significant changes in local relief could occurhappen on the scale of less then 10 meters.

Many monuments are mounted on buildings and bridges and were therefore not included in assessment of the DEM.

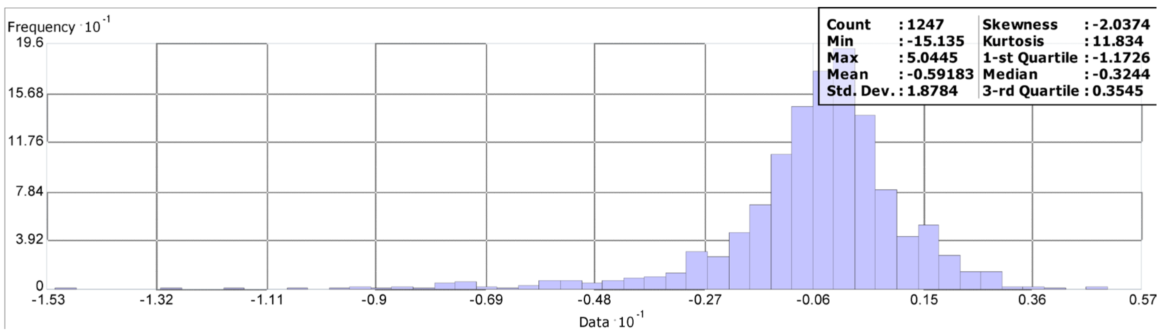

Figure 20. *Histogram of the differences between NGS geodetic monument elevations and the Atlantic City DEM.*

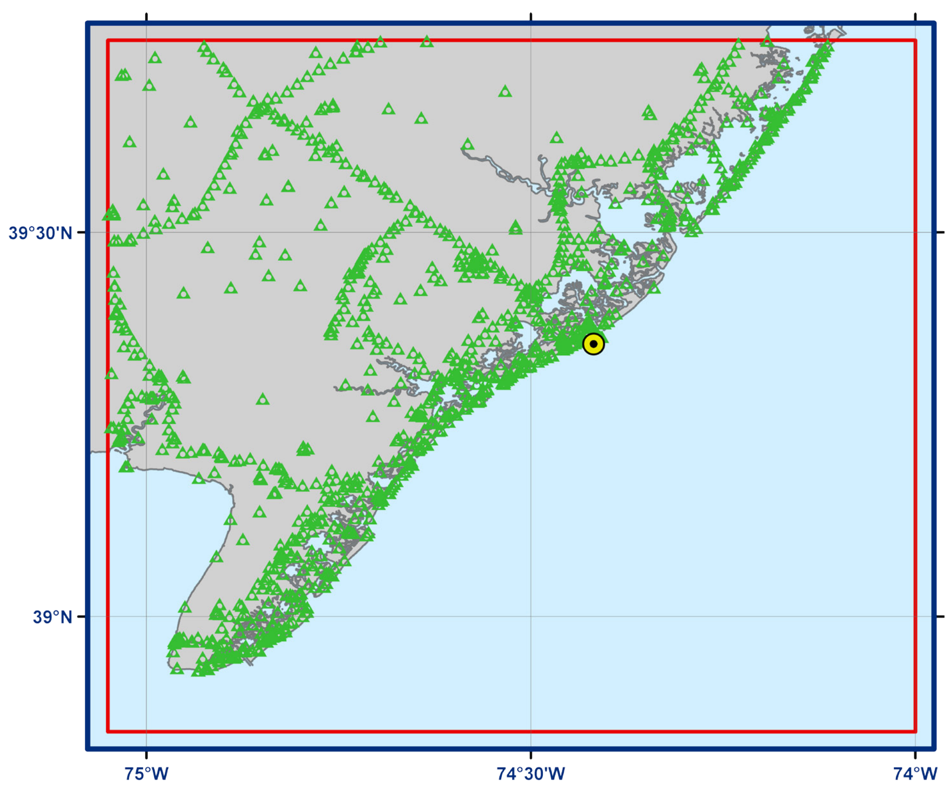

Figure 21. *Location of NGS geodetic monuments, shown as green triangles, and the NOAA Atlantic City tide station, yellow circle. NGS monument elevations were used to evaluate the DEM.*

4. Summary and Conclusions

A bathymetric–topographic digital elevation model of the Atlantic City, New Jersey 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, state and local 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, MB-System and Quick Terrain Modeler software.

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

- Conduct LiDAR surveys for near-shore areas especially in bays and estuaries.
- Complete topographic LiDAR surveying of entire region especially at coastal marshes.
- Process CSC bathymetric–topographic LiDAR data to bare earth.

5. Acknowledgments

The creation of the Atlantic City DEM was funded by the NOAA Pacific Marine Environmental Laboratory. The authors thank Chris Chamberlin, and Vasily Titov (PMEL); LTjg David Fischman, NOAA/NESDIS/NGDC/MGG; NOAA Atlantic Hydrographic Office staff; and Monica Chasten, Harry Friebel, and Joe Scolari, USACE Philadelphia District Office.

6. References

Nautical Chart #12214, 9th Edition, 2007. Cape May to Fenwick Island. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #12300, 12th Edition, 2007. Approaches to New York Nantucket Shoals to Five Fathom Bank. Scale 1:400,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #12304, 8th Edition, 2007. Delaware Bay. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #12318, 1st Edition, 2007. Little Egg Inlet to Hereford Inlet. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Lathrop, Richard G., Paul Montesano, Scott Haag, 2003, Submerged Aquatic Vegetation Mapping in the Barnegat Bay National Estuary Update to Year 2003, http://crssa.rutgers.edu/projects/runj/bbay.html

7. DATA PROCESSING SOFTWARE

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

FME 2007 GB – 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/

Quick Terrain Modeler v. 6.0.1, LiDAR processing software developed by John Hopkins University's Applied Physics Laboratory (APL) and maintained and licensed by Applied Imagery, http://www.appliedimagery.com/