NOAA Technical Memorandum NESDIS NGDC-37

DIGITAL ELEVATION MODEL OF OCEAN CITY, MARYLAND: PROCEDURES, DATA SOURCES AND ANALYSIS

P.R. Grothe
L.A. Taylor
B.W. Eakins
R.R. Warnken
K.S. Carignan
E. Lim
R.J. Caldwell
D.Z. Friday

National Geophysical Data Center
Marine Geology and Geophysics Division
Boulder, Colorado
July 2010

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / National Environmental Satellite, Data, and Information Service

NOAA Technical Memorandum NESDIS NGDC-37

DIGITAL ELEVATION MODEL OF OCEAN CITY, MARYLAND: PROCEDURES, DATA SOURCES AND ANALYSIS

Pamela R. Grothe[1]
Lisa A. Taylor[2]
Barry W. Eakins[1]
Robin R. Warnken[2]
Kelly S. Carignan[1]
Elliot Lim[1]
R. Jason Caldwell[1]
Dorothy Z. Friday[1]

[1]Cooperative Institute for Research in Environmental Sciences, University of Colorado at Boulder

[2]NOAA, National Geophysical Data Center, Boulder, Colorado

National Geophysical Data Center
Marine Geology and Geophysics Division
Boulder, Colorado
July 2010

UNITED STATES DEPARTMENT OF COMMERCE

Gary Locke
Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Dr. Jane Lubchenco
Under Secretary for Oceans and Atmosphere/Administrator

National Environmental Satellite, Data, and Information Service

Mary E. Kicza
Assistant Administrator

NOTICE

Mention of a commercial company or product does not constitute an endorsement by the NOAA National Environmental Satellite, Data, and Information Service. Use of information from this publication concerning proprietary products or the test of such products for publicity or advertising purposes is not authorized.

Corresponding project contact:
Lisa A. Taylor
NOAA National Geophysical Data Center
Marine Geology and Geophysics Division
325 Broadway, E/GC 3
Boulder, Colorado 80305
Phone: 303-497-6767
Fax: 303-497-6513
E-mail: Lisa.A.Taylor@noaa.gov
http://www.ngdc.noaa.gov/mgg/inundation/tsunami/inundation.html

---

Also available from the National Technical Information Service (NTIS)
(http://www.ntis.gov)

Contents

List of Figures

List of Tables

Digital Elevation Model of Ocean City, Maryland: Procedures, Data Sources and Analysis

1. Introduction

In October 2009, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed an integrated bathymetric–topographic digital elevation model (DEM) of Ocean City, Maryland (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 Short-term Inundation Forecasting for Tsunamis (SIFT) 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 Ocean City DEM.

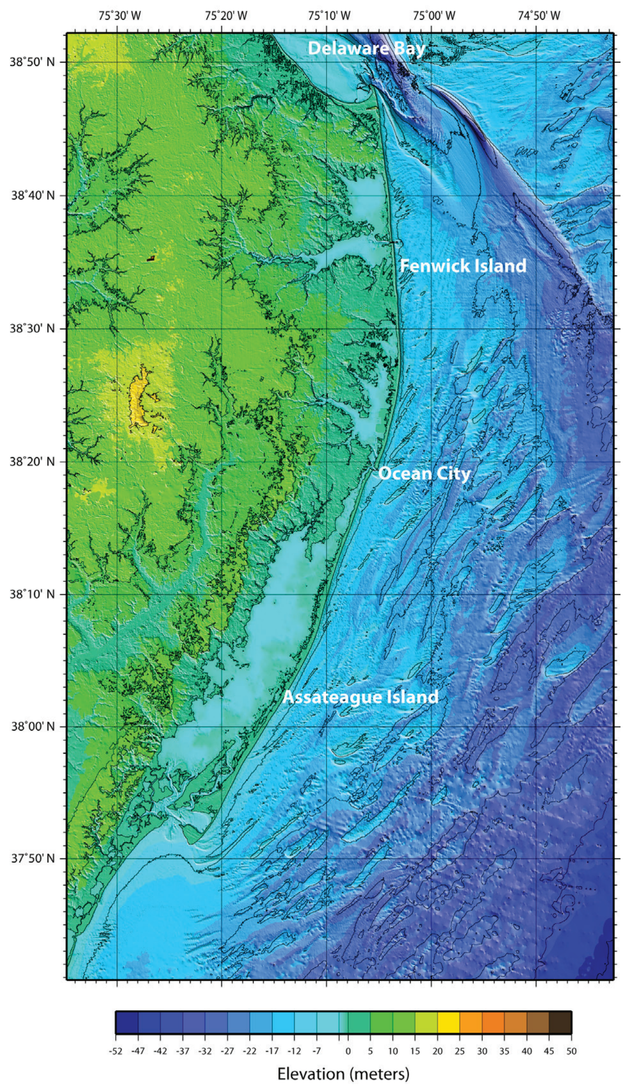

Figure 1. *Shaded-relief image of the Ocean City DEM. Contour interval is 10 meters.*

1. The Ocean 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 Ocean City, Maryland (38°19.4235′ N, 75°6.3111′ W) 1/3 arc-second of latitude is equivalent to 10.28 meters; 1/3 arc-second of longitude equals 8.10 meters.

2. Study Area

The Ocean City DEM includes the dynamic barrier islands, Fenwick and Assateague Islands (see Fig. 1), located off the Delaware, Maryland and Virginia coasts. Ocean City is a popular vacation destination located in an area with 30 million people. Approximately eight million people visit this area annually (http://www.mgs.md.gov/coastal/osr/ocsand1.html).

Barrier islands are unstable environments with constant erosion, deposition and migration of sediment from wave action. Ocean City's urbanization increases the instability of these islands, creating hazards to the economy and property. Along with general sediment transportation issues, rising sea level is another concern for coastal managers and property owners. To help stabilize the barrier islands, Ocean City uses beach nourishment and dune stabilization as the primary methods to protect their beaches and communities (http://www.mgs.md.gov/coastal/osr/ocsand1.html).

In 1933, a hurricane opened up the current Ocean City Inlet. The U.S. Army Corps of Engineers built two stone jetties to stabilize the inlet for it to remain open as a navigation channel (Fig. 2). The jetties maintain the opening of the inlet but have affected the longshore southerly drift of sand. This has trapped sand to the north at Ocean City Beach, but starved Assateague Island, south of the inlet, shifting the island more than 500 meters towards the shore (http://pubs.usgs.gov/circ/c1075/conflicts.html).

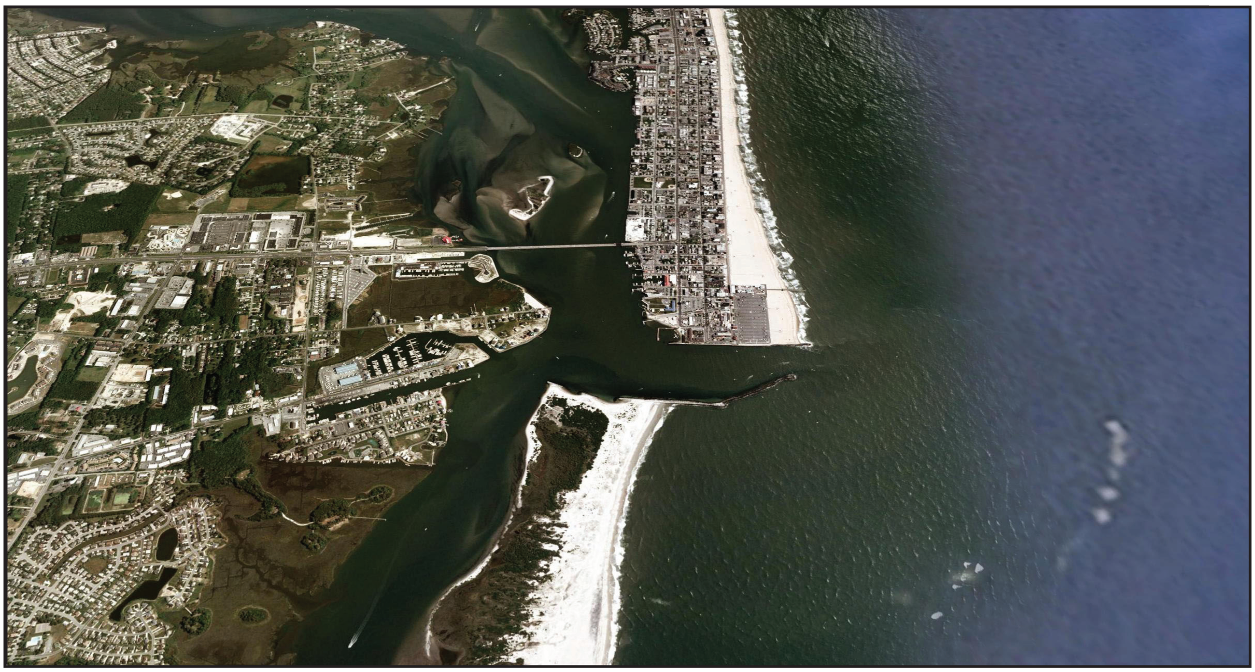

Figure 2. *Google Earth satellite image of the jetties at Ocean City Inlet. The jetties block the southward transport of sediment, causing Assateague Island to migrate westward.*

3. METHODOLOGY

The Ocean City 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 American Datum of 1983 (NAD 83)[2] geographic and mean high water (MHW), for modeling of maximum flooding, respectively. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1: PMEL specifications for the Ocean City DEM.

Grid Area	Ocean City, Maryland
Coverage Area	74.71º to 75.58º W; 37.68º to 38.87º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System of 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

Coastline, bathymetric, and topographic digital datasets (Fig. 3) were obtained from several U.S. federal agencies: NOAA's NGDC, 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 *FME* data translation tool package was used to shift datasets to NAD 83 geographic horizontal datum. The datasets were then displayed with ESRI's *ArcGIS*, ESRI Imagery *World 2D* Online World Imagery 2D, and Applied Imagery's *Quick Terrain Modeler* software (*QT Modeler*) to assess data quality and manually edit datasets. Vertical datum transformations to MHW were accomplished using NOAA National Geodetic Survey's *Vertical Datum* (*VDatum*) model software, and *FME* and *ArcGIS* 3D Analyst tool, based upon data from NOAA tide stations (see Sec. 3.2.1).

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 geographic is restricted to North America, while WGS 84 geographic 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 geographic and NAD 83 geographic are identical and may be used interchangeably.

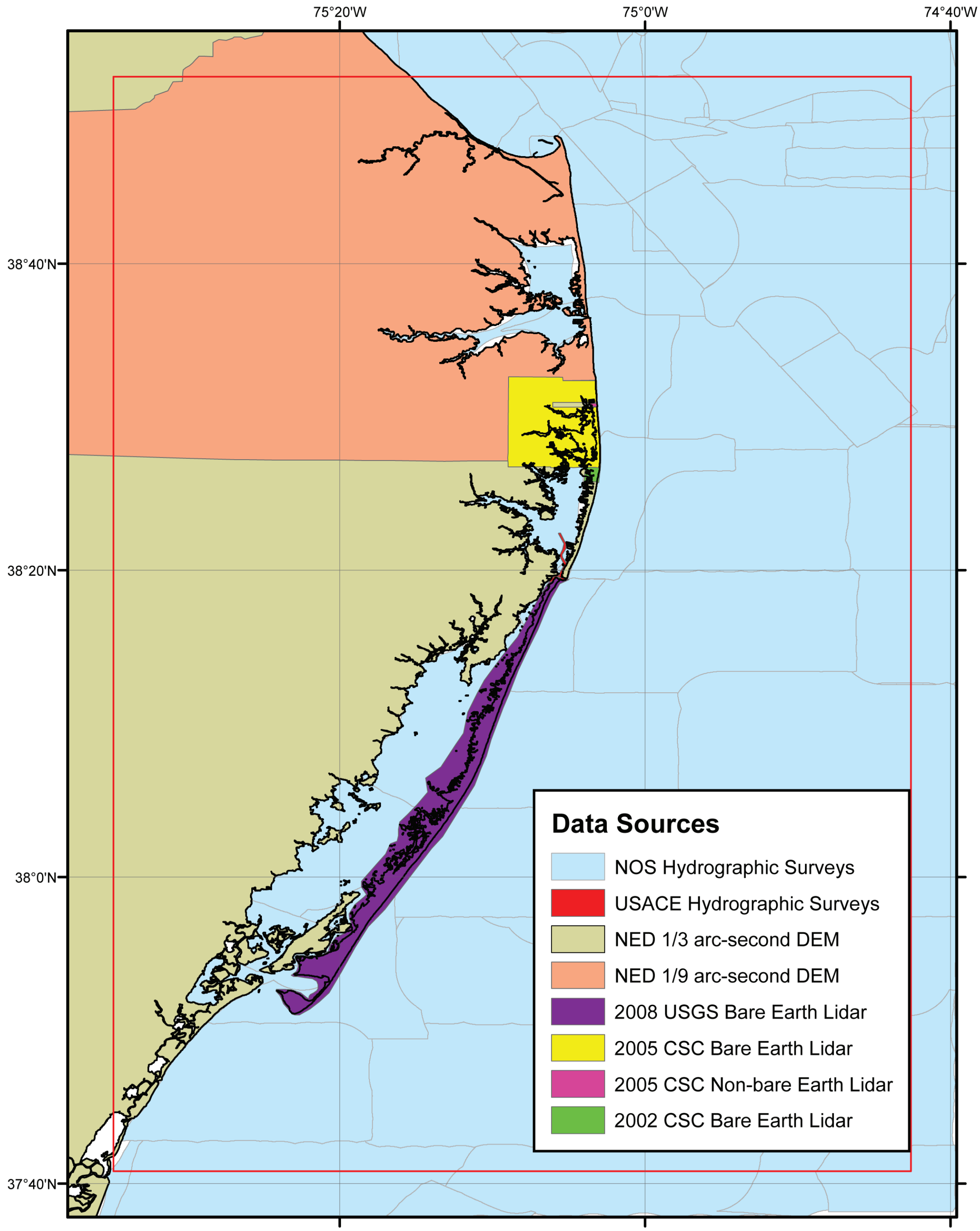

Figure 3. *Source and coverage of datasets used in building the Ocean City DEM. Red box denotes DEM extents.*

3.1.1 Coastline

Coastline datasets of the Ocean City region were obtained from NOAA's OCS, and USGS. (Table 2; Fig. 4).

Table 2: Coastline datasets used in building the Ocean City DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
OCS	2007-2008	ENC Coastline	1:20,000 to 1:80,000	WGS 84 geographic	MHW	http://nauticalcharts.noaa.gov/mcd/enc
USGS	2007	Jetty Outline	1 meter	NAD 83 UTM Zone 18N	Not defined	http://pubs.usgs.gov/of/2007/1388/data/Jetty

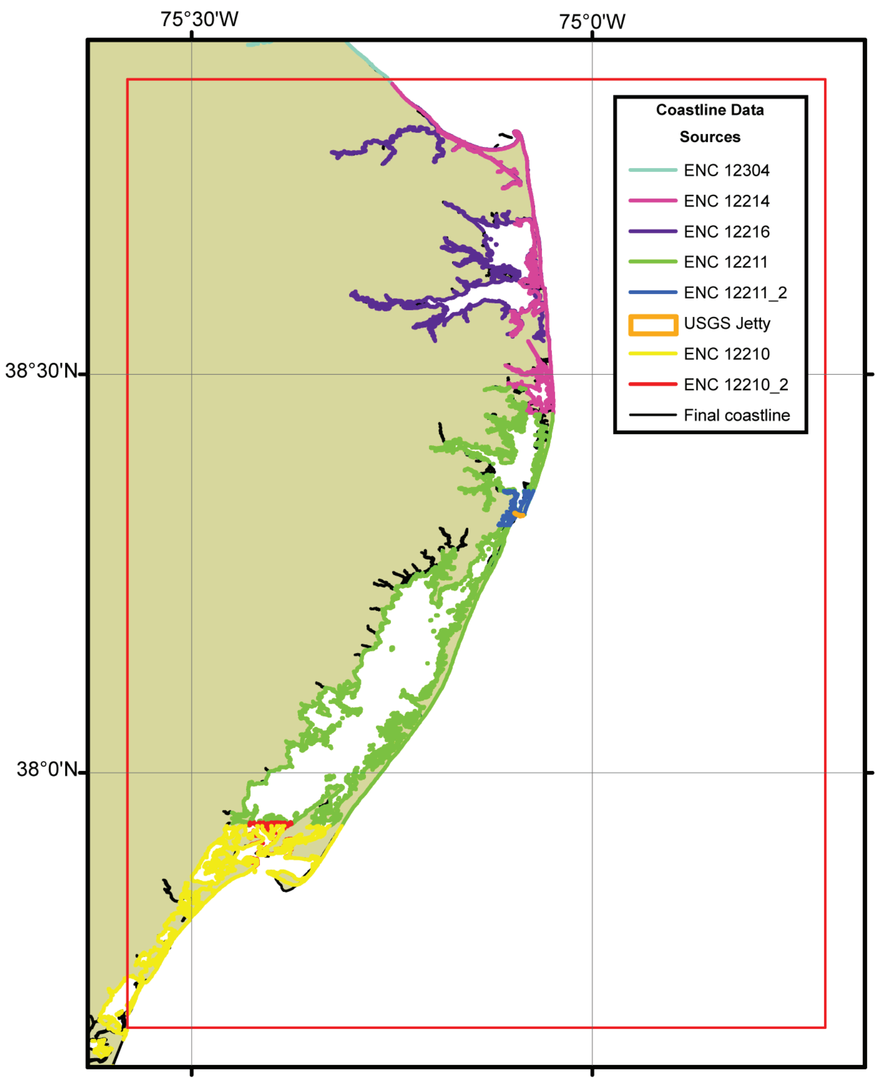

Figure 4. *Digital coastline datasets used in building the Ocean City DEM. ENCs with an "_2" refer to a higher resolution inset on the ENC.*

1) Office of Coast Survey ENCs

Five Electronic Navigational Charts (ENCs) are available for the Ocean City area (Table 3). They were downloaded from NOAA's OCS web site in S-57 format and include coastline data files referenced to MHW. The nautical charts are also available as georeferenced Raster Nautical Charts (RNCs; digital images of the charts) and were used in *ArcMap* to quality control (QC) bathymetric and topographic datasets, the bathymetric surface, and the final DEM.

Table 3: ENCs available in the Ocean City region.

Chart	*Title*	*Edition*	*Edition Date*	*Format*	*Scale*
12210	Chincoteague Inlet to Great Machipongo Inlet	38	5/1/2008	ENC/RNC	1:80,000 with 1:20,000 inset
12211	Fenwick Island to Chincoteague Inlet	43	10/1/2007	ENC/RNC	1:80,000 with 1:20,000 inset
12214	Cape May to Fenwick	48	10/1/2007	ENC/RNC	1:80,000
12216	Cape Henlopen to Indian River Inlet	28	4/1/2008	ENC/RNC	1:80,000
12304	Delaware Bay	45	2/1/2008	ENC/RNC	1:80,000

2) United States Geological Survey Ocean City Inlet Jetty

NGDC digitized the Ocean City Inlet jetty on Assateague Island using *ArcMap*, based on the USGS jetty shapefile, and included it the final coastline (Fig 5).

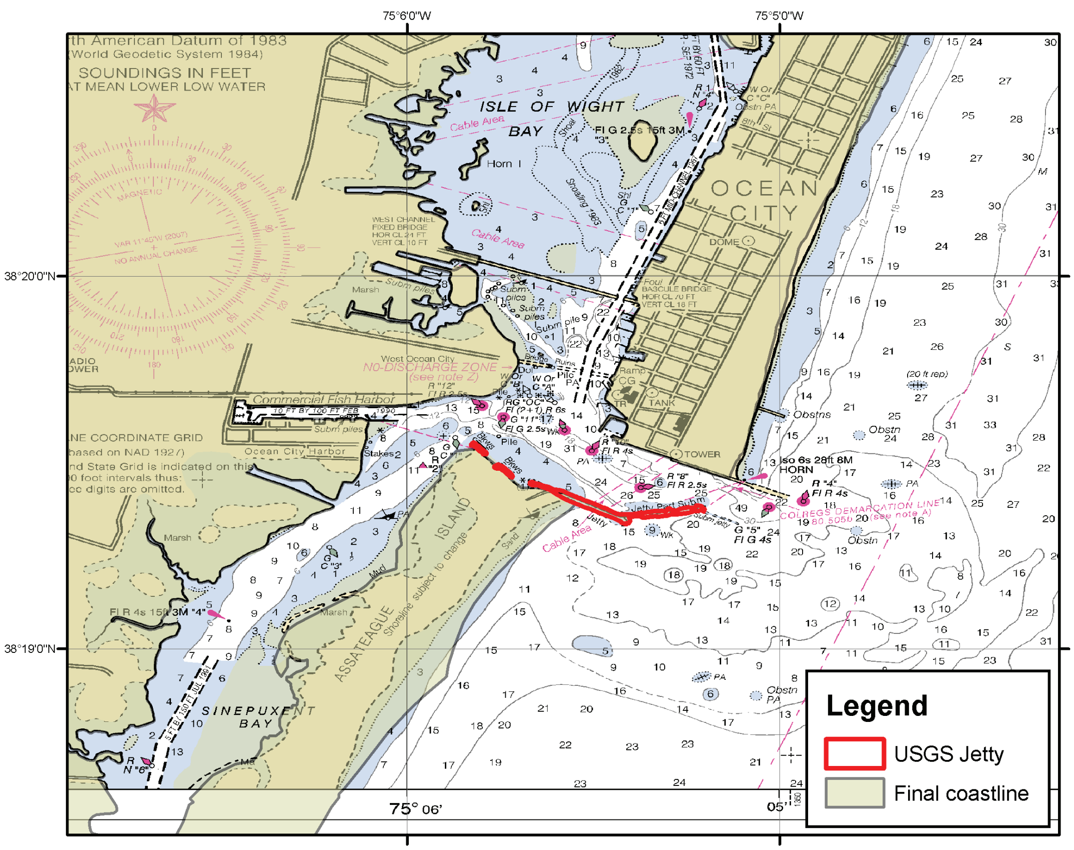

Figure 5. *USGS Ocean City Inlet jetty shapefile used as a trace for the final coastline. (RNC #12211 in background)*

The ENC coastlines and the USGS Ocean City Inlet jetty outline were merged in *ArcMap* to create a final coastline for the Ocean City region. NGDC edited the final coastline to include morphologic changes captured in the more recent lidar data (e.g., Fig 6). The final coastline was also draped over the world imagery layer in *ArcMap*, available from the *ArcGIS* Online Resource Center, and edited to include all tidal bays, channels, fingers, jetties, and breakwaters that were not included in some of the lower resolution ENC coastlines (e.g., Fig. 7). Piers and bridges were excluded from the final coastline.

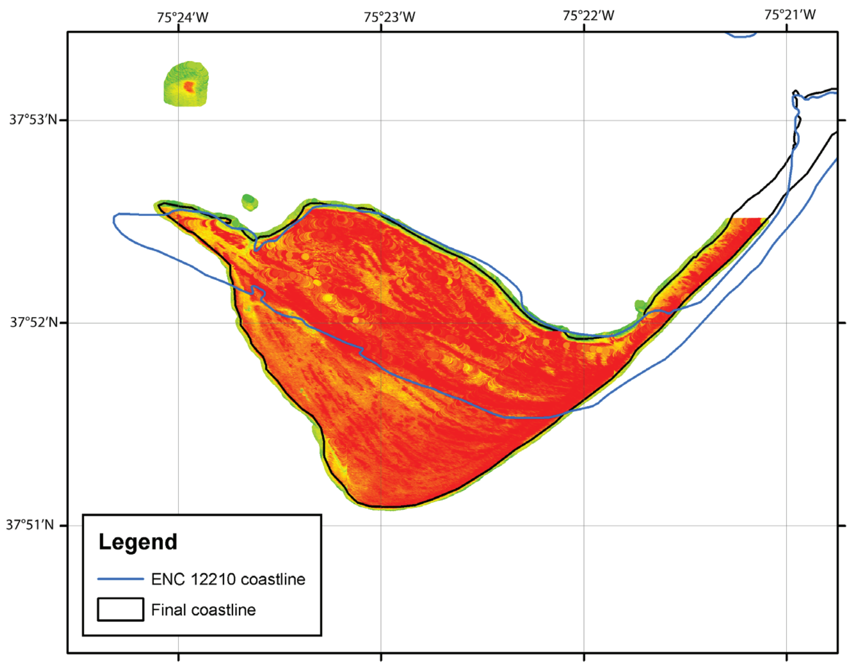

Figure 6. *Final coastline based on 2008 USGS topographic lidar survey.*

Figure 7. *The final coastline including fingers, inlets, and channels visible in satellite imagery but not represented in the ENC coastlines.*

3.1.2 Bathymetry

Bathymetric datasets available in the Ocean City region include 94 National Oceanographic Survey (NOS) hydrographic surveys, four USACE surveys located at the Ocean City Inlet, and one multibeam swath sonar survey from NGDC's multibeam bathymetry database (Table 4; Fig. 6). The multibeam swath sonar survey AT1L3 was evaluated but not used in gridding the DEM because the data coverage was insignificant, covering only 11 km by 0.1 km in a linear feature near the south-east corner of the DEM.

Table 4: Bathymetric datasets used in building the Ocean City DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Downloaded Horizontal Datum/ Coordinate System*	*Downloaded Vertical Datum*	*URL*
NGDC	1880 to 2004	NOS Hydrographic survey soundings	Ranges from 1:5,00 to 1:120,000 (varies with scale of survey, depth, traffic, and probability of obstructions)	NAD 83 geographic	Mean lower low water and mean low water	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
USACE	2006 to 2007	Hydrographic survey soundings	Line spacing ranging from 15 to 30 meters apart and point spacing 3 to 4 meters	NAD 83 Maryland State Plane (feet)	MLLW (feet)	http://www.nab.usace.army.mil/Navigation/DepthRpts.htm#052
NGDC	2009	Digitized surveys		WGS 84 geographic	MHW	

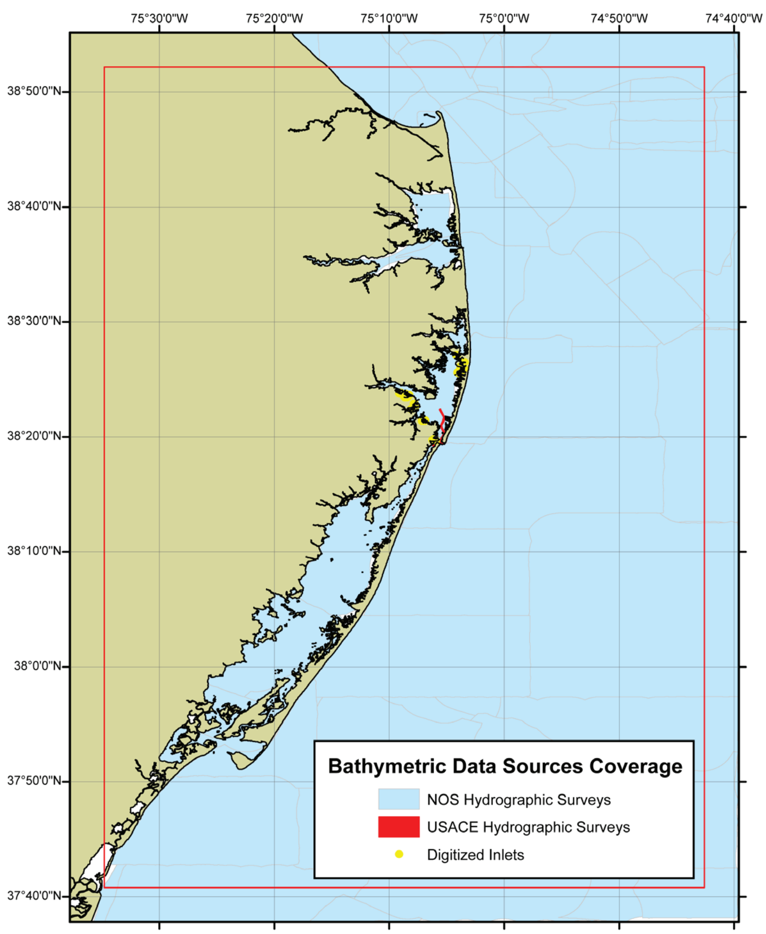

Figure 8. *Spatial coverage of bathymetric datasets used in building the Ocean City DEM. White areas denote no data and red box denotes DEM extent.*

1) NGDC hydrographic survey database

A total of 94 NOS hydrographic surveys conducted between 1880 and 2004 were available for use in developing the Ocean City DEM (Table 5; Fig. 9). The hydrographic survey data were downloaded from NGDC's online NOS hydrographic database using *GEODAS*[3]. The data are vertically referenced to mean lower low water (MLLW) or mean low water (MLW) and horizontally referenced to NAD 83 geographic. Survey data were downloaded in an area 0.05 degree (~5%) larger than the Ocean City DEM extent to support data interpolation across grid edges.

Only 76 of the 94 surveys were used in building the Ocean City DEM (Table 5), as some older surveys have been superseded by newer surveys. Data point spacing for the NOS surveys varies by collection date. In general, earlier surveys have greater point spacing than more recent surveys.

After converting all NOS survey data to MHW using either *VDatum* or a Tide station offset (see Sec. 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 and bathymetric, the final coastline, and RNCs. The surveys were clipped to remove soundings that overlap the more recent USACE surveys located within the Ocean City Inlet, along the coastline, and where soundings from older surveys have been superseded by more recent NOS surveys.

Table 5: Digital NOS hydrographic surveys available in the Ocean City region.

Survey ID	*Year*	*Scale*	*Original Vertical Datum*	*Downloaded Horizontal Datum*	*Vertical Datum Conversion Used*
D00023	1984	40,000	MLLW	NAD 83 geographic	Tide station offset
F00383	1993	20,000	MLLW	NAD 83 geographic	Tide station offset
F00437	1997	10,000	MLLW	NAD 83 geographic	Tide station offset
F00453	1999	10,000	MLLW	NAD 83 geographic	Tide station offset
H01455A	1880	20,000	MLW	NAD 83 geographic	*VDatum*
H01455B	1887	20,000	MLW	NAD 83 geographic	*VDatum*
H01816	1887	20,000	MLW	NAD 83 geographic	*VDatum*
H05230**	1932	5,000	MLW	NAD 83 geographic	Tide station offset
H05346*	1933	20,000	MLW	NAD 83 geographic	Tide station offset
H05347*	1934	20,000	MLW	NAD 83 geographic	Tide station offset
H05348*	1933	40,000	MLW	NAD 83 geographic	Tide station offset
H05349*	1933	20,000	MLW	NAD 83 geographic	Tide station offset
H05350*	1933	120,000	MLW	NAD 83 geographic	Tide station offset
H05351*	1933	40,000	MLW	NAD 83 geographic	Tide station offset
H05353	1934	40,000	MLW	NAD 83 geographic	Tide station offset
H05354*	1933	20,000	MLW	NAD 83 geographic	Tide station offset
H05355	1934	40,000	MLW	NAD 83 geographic	Tide station offset
H05356	1934	40,000	MLW	NAD 83 geographic	Tide station offset
H05357*	1933	20,000	MLW	NAD 83 geographic	Tide station offset
H05358*	1933	20,000	MLW	NAD 83 geographic	Tide station offset
H05673	1934	40,000	MLW	NAD 83 geographic	Tide station offset
H05675	1934	10,000	MLW	NAD 83 geographic	*VDatum*
H05770	1934	40,000	MLW	NAD 83 geographic	Tide station offset

3. *GEODAS* 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 NOS hydrographic survey data from NAD 27 geographic to NAD 83 geographic. NADCON is the U.S. Federal Standard for NAD 27 geographic to NAD 83 geographic datum transformations.

Survey ID	***Year***	***Scale***	***Original Vertical Datum***	***Downloaded Horizontal Datum***	***Vertical Datum conversion used***
H05771	1934	40,000	MLW	NAD 83 geographic	Tide station offset
H05702	1934	40,000	MLW	NAD 83 geographic	Tide station offset
H05703	1934	20,000	MLW	NAD 83 geographic	Tide station offset
H05713	1938	120,000	MLW	NAD 83 geographic	Tide station offset
H05714*	1934	20,000	MLW	NAD 83 geographic	Tide station offset
H05715	1934	40,000	MLW	NAD 83 geographic	Tide station offset
H05716	1934	10,000	MLW	NAD 83 geographic	*VDatum*
H05769	1934	10,000	MLW	NAD 83 geographic	*VDatum*l
H06232*	1937	10,000	MLW	NAD 83 geographic	Tide station offset
H06264*	1937	40,000	MLW	NAD 83 geographic	Tide station offset
H06272*	1937	40,000	MLW	NAD 83 geographic	Tide station offset
H06344*	1938	40,000	MLW	NAD 83 geographic	Tide station offset
H07034	1945	10,000	MLW	NAD 83 geographic	Tide station offset
H07035*	1945	10,000	MLW	NAD 83 geographic	Tide station offset
H07946**	1951	20,000	MLW	NAD 83 geographic	Tide station offset
H08710	1962	10,000	MLW	NAD 83 geographic	*VDatum*
H08711*	1962	10,000	MLW	NAD 83 geographic	Tide station offset
H08596*	1963	10,000	MLW	NAD 83 geographic	Tide station offset
H09136	1970	20,000	MLW	NAD 83 geographic	Tide station offset
H09153	1971	20,000	MLW	NAD 83 geographic	Tide station offset
H09154	1970	10,000	MLW	NAD 83 geographic	Tide station offset
H09175	1970	10,000	MLW	NAD 83 geographic	Tide station offset
H09176	1970	10,000	MLW	NAD 83 geographic	Tide station offset
H09202	1971	20,000	MLW	NAD 83 geographic	Tide station offset
H09203	1971	10,000	MLW	NAD 83 geographic	Tide station offset
H09204	1971	5,000	MLW	NAD 83 geographic	Tide station offset
H09311	1972	10,000	MLW	NAD 83 geographic	Tide station offset
H09312	1972	20,000	MLW	NAD 83 geographic	Tide station offset
H09578	1975	20,000	MLW	NAD 83 geographic	Tide station offset
H09579	1975	20,000	MLW	NAD 83 geographic	Tide station offset
H09629	1976	40,000	MLW	NAD 83 geographic	Tide station offset
H09639	1976	40,000	MLW	NAD 83 geographic	Tide station offset
H09640	1976	40,000	MLW	NAD 83 geographic	Tide station offset
H09663	1976	80,000	MLW	NAD 83 geographic	Tide station offset
H09699*	1977	20,000	MLW	NAD 83 geographic	Tide station offset
H09700*	1977	20,000	MLW	NAD 83 geographic	Tide station offset
H09714	1977	20,000	MLW	NAD 83 geographic	Tide station offset
H09715	1978	10,000	MLW	NAD 83 geographic	*VDatum*
H09722	1977	5,000	MLW	NAD 83 geographic	Tide station offset

Survey ID	*Year*	*Scale*	*Original Vertical Datum*	*Downloaded Horizontal Datum*	*Vertical Datum conversion used*
H09723*	1977	20,000	MLW	NAD 83 geographic	Tide station offset
H09727	1977	20,000	MLW	NAD 83 geographic	Tide station offset
H09759	1978	20,000	MLW	NAD 83 geographic	Tide station offset
H09764	1978	20,000	MLW	NAD 83 geographic	Tide station offset
H09780	1978	20,000	MLW	NAD 83 geographic	Tide station offset
H09788	1978	20,000	MLW	NAD 83 geographic	Tide station offset
H09796	1978	20,000	MLW	NAD 83 geographic	Tide station offset
H10044	1982	20,000	MLW	NAD 83 geographic	Tide station offset
H10045	1982	20,000	MLW	NAD 83 geographic	Tide station offset
H10046	1982	20,000	MLW	NAD 83 geographic	Tide station offset
H10234	1994	10,000	MLLW	NAD 83 geographic	Tide station offset
H10241	1994	10,000	MLLW	NAD 83 geographic	Tide station offset
H10439	1992	20,000	MLLW	NAD 83 geographic	Tide station offset
H10440	1992	20,000	MLLW	NAD 83 geographic	Tide station offset
H10444	1993	20,000	MLLW	NAD 83 geographic	Tide station offset
H10446	1993	20,000	MLLW	NAD 83 geographic	Tide station offset
H10464	1993	20,000	MLLW	NAD 83 geographic	Tide station offset
H10475	1993	20,000	MLLW	NAD 83 geographic	Tide station offset
H10476	1993	20,000	MLLW	NAD 83 geographic	Tide station offset
H10489	1993	20,000	MLLW	NAD 83 geographic	Tide station offset
H10533	1994	10,000	MLLW	NAD 83 geographic	Tide station offset
H10573	1994	10,000	MLLW	NAD 83 geographic	Tide station offset
H10854	1999	10,000	MLLW	NAD 83 geographic	Tide station offset
H10917	1999	10,000	MLLW	NAD 83 geographic	Tide station offset
H10926	2000	10,000	MLLW	NAD 83 geographic	Tide station offset
H10931	1999	10,000	MLLW	NAD 83 geographic	Tide station offset
H10935	1999	20,000	MLLW	NAD 83 geographic	Tide station offset
H10936	1999	20,000	MLLW	NAD 83 geographic	Tide station offset
H10989	2000	40,000	MLLW	NAD 83 geographic	Tide station offset
H11081	2002	20,000	MLLW	NAD 83 geographic	Tide station offset
H11104	2002	20,000	MLLW	NAD 83 geographic	Tide station offset
H11243	2004	20,000	MLLW	NAD 83 geographic	Tide station offset

*Surveys not used in the final DEM because they were superseded by newer surveys
**Surveys not used in the final DEM because they are located in interior creeks outside the western extent of the DEM

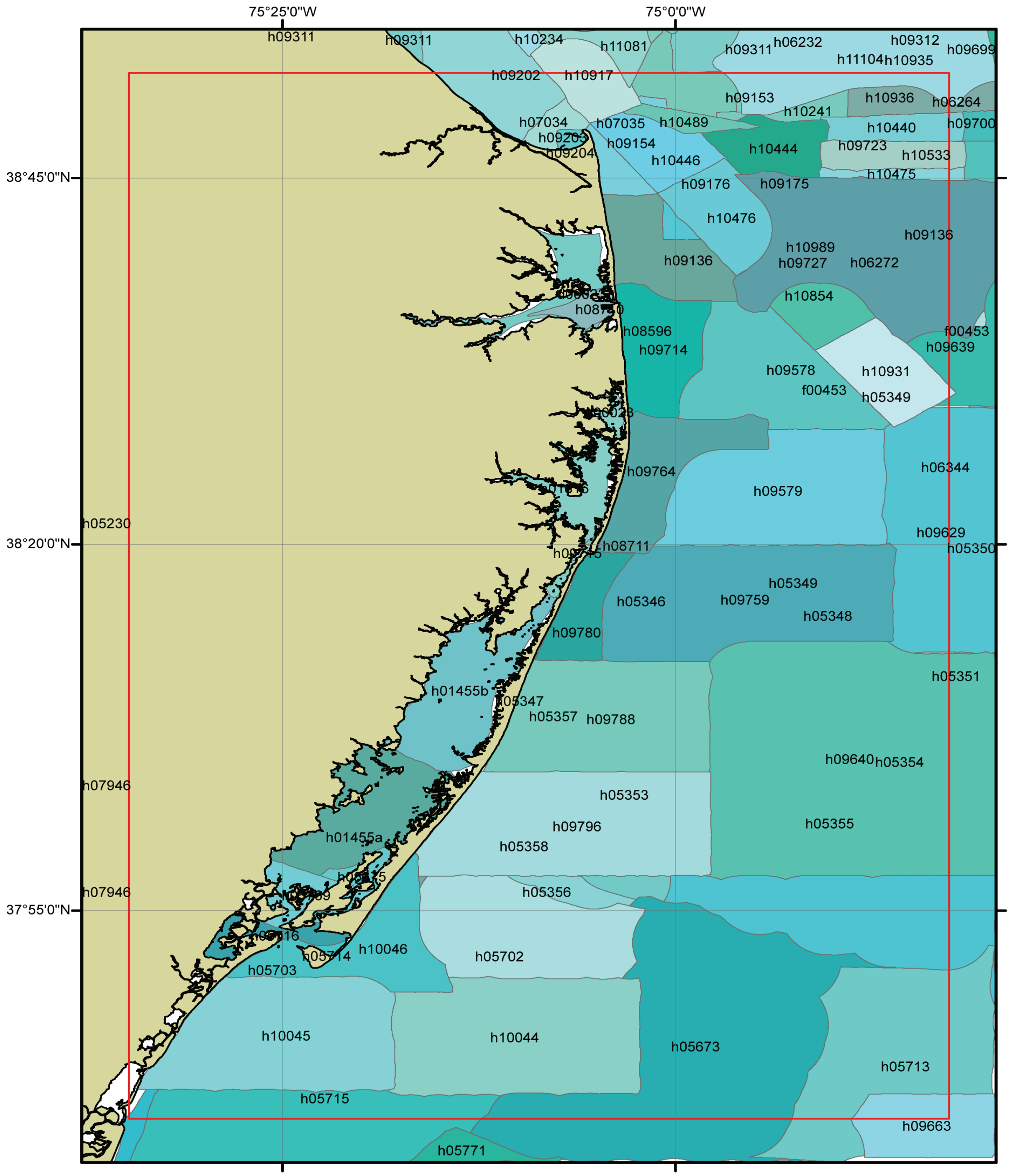

Figure 9. *Digital NOS hydrographic survey coverage in the Ocean City region. Some earlier surveys were not used as they have been superseded by more recent surveys. Three surveys outside the western extent of the DEM (H05230, H07947, and H07946) also were not used. DEM boundary in red.*

2) United States Army Corps of Engineers hydrographic surveys

Four hydrographic surveys are available from the USACE, Baltimore District (Table 6; Fig 10). Two surveys (s52waug08a, s052i026mar09a) were downloaded as xyz data and two surveys (s052i08may09, s052s37mar09a) were provided to NGDC by John Hill from the USACE Baltimore District. The surveys were collected in 2008 and 2009, and referenced to NAD 83 geographic Maryland State Plane (feet) and MLLW (feet) datums. The files were converted to NAD 83 geographic and MHW (meters) using *VDatum*. Point spacing averages 4 meters along profiles approximately 150 meters long and averaging 20 meters apart.

Table 6: USACE hydrographic surveys used in building the Ocean City DEM.

Survey File	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum*
s52waug08a	2008	5700 x 180 meter area with ~30 meter line spacing and ~3 meter point spacing	NAD 83 geographic Maryland State Plane (feet)	MLLW (feet)
s052i026mar09a	2009	920 x 140 meter area with ~30 meter line spacing and ~4 meter point spacing	NAD 83 geographic Maryland State Plane (feet)	MLLW (feet)
s052i08may09	2009	140 x 75 meter area with ~15 meter line spacing and ~3 meter point spacing	NAD 83 geographic Maryland State Plane (feet)	MLLW (feet)
s052s37mar09a	2009	1775 x 175 meter area with ~30 meter line spacing and ~3 meter point spacing	NAD 83 geographic Maryland State Plane (feet)	MLLW (feet)

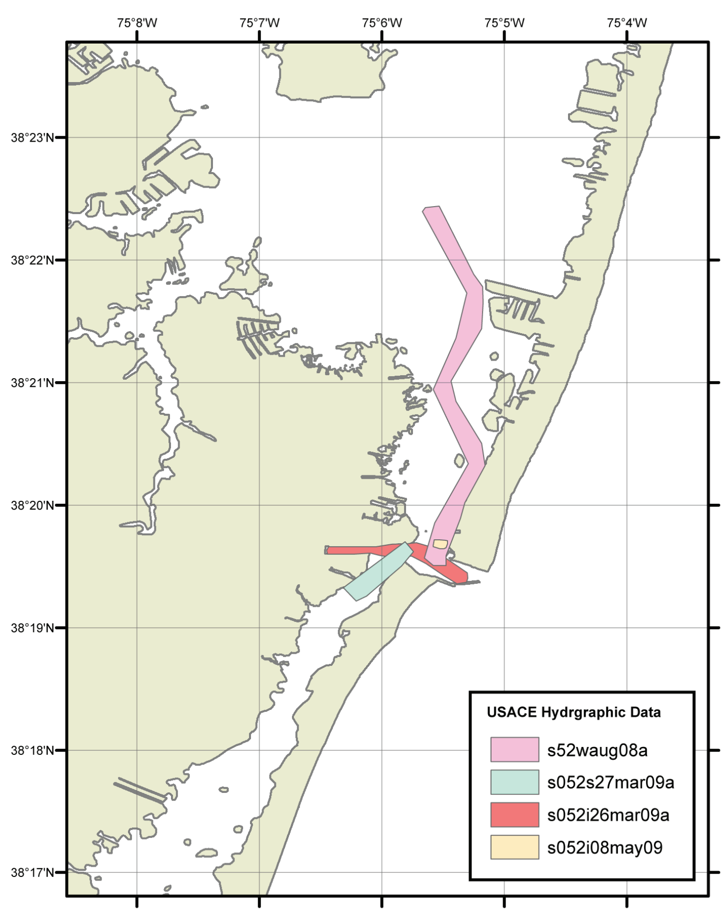

***Figure 10.** Digital USACE hydrographic survey coverage in the Ocean City region.*

2) Digitized Inlets and harbors

The Ocean City Harbor consists of many man-made inlets and harbors. Most of these inlets and harbors have not been surveyed by NOS or USACE. Therefore, the grid does not represent accurate depths for these areas. To maintain negative depths in these areas, a "pre-surface" bathymetric grid (see Sec. 3.3.2) was created with the coastline values at -1 meters. For most places, this maintained negative depths but in some of the narrow finger channels, gridding introduced artificial bridges in the waterways. NGDC digitized soundings with values of -2 meters to properly represent these inlets in the DEM. There is also one boat harbor right inside the Ocean City Inlet that does not exist in the data or on RNCs but is visible in satellite imagery. NGDC manually adjusted the coastline and digitized depths of -3 meters in the harbor (Fig. 11).

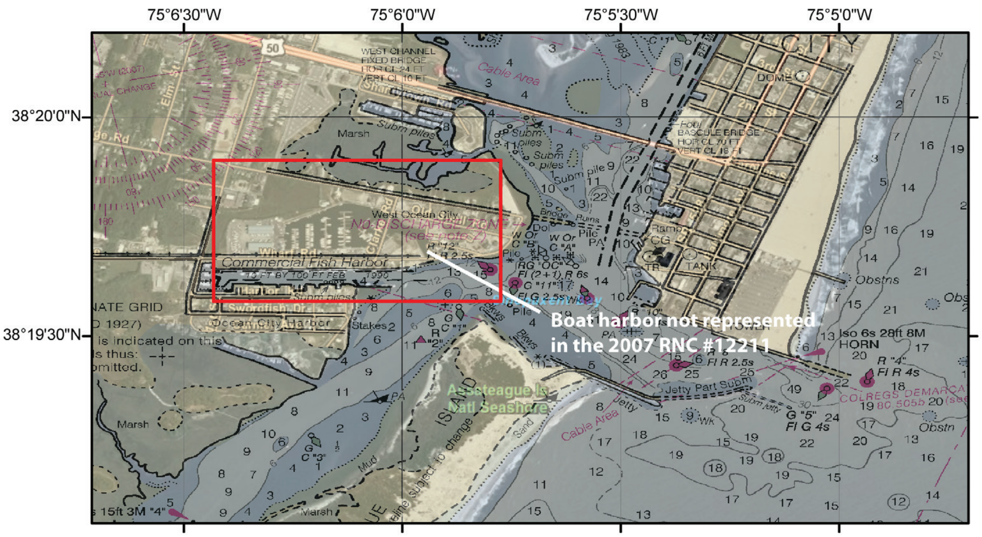

Figure 11. *New boat harbor shown in satellite imagery but not included on the 2007 RNC #12211 or other bathymetric data. NGDC adjusted the coastline using the satellite imagery and digitized -3 meters depth.*

3.1.3 Topography

The topographic datasets used to build the Ocean City DEM include: USGS NED 1/3 arc-second DEM, National Elevation Dataset (NED) 1/9 arc-second DEM, and 2008 bare-earth topographic lidar; 2002 bare-earth Worchester County lidar, 2005 bare-earth Sussex County lidar and 2005 USACE non-bare-earth lidar available from CSC's web site; and NGDC digitized hard structures (jetties and breakwaters; Table 7; Fig. 12). Many lidar surveys are available through the CSC web site for the Ocean City region dating back to 1996, but NGDC only downloaded and evaluated surveys post 2000. NGDC also evaluated but did not use the Shuttle Radar Topography Mission (SRTM) Elevation 1 arc-second DEM available from USGS.

Table 7: Topographic datasets used in building the Ocean City DEM.

Source	***Year***	***Data Type***	***Spatial Resolution***	***Original Horizontal Datum/Coordinate System***	***Original Vertical Datum***	***URL***
USGS	1999-2007	NED DEM	1/3 arc-second	NAD 83 geographic	NAVD 88 (meters)	http://ned.usgs.gov
USGS	2002-2007	NED DEM	1/9 arc-second	NAD 83 geographic	NAVD 88 (meters)	http://ned.usgs.gov
USGS	2008	Bare-earth lidar	2 meters	NAD 83 UTM meters Zone 18N	NAVD 88 (meters)	http://pubs.usgs.gov/ds/447
CSC	2005	Sussex County bare-earth lidar	3 meters	NAD 83 geographic	NAVD 88 (meters)	http://www.csc.noaa.gov
CSC	2005	Non-bare-earth lidar	2 meters	NAD 83 geographic	NAVD88 (meters)	http://www.csc.noaa.gov
CSC	2002	Worchester County bare-earth lidar	2 meters	NAD 83 geographic	NAVD 88 (meters)	http://www.csc.noaa.gov
NGDC	2009	Points		NAD 83 geographic	MHW	

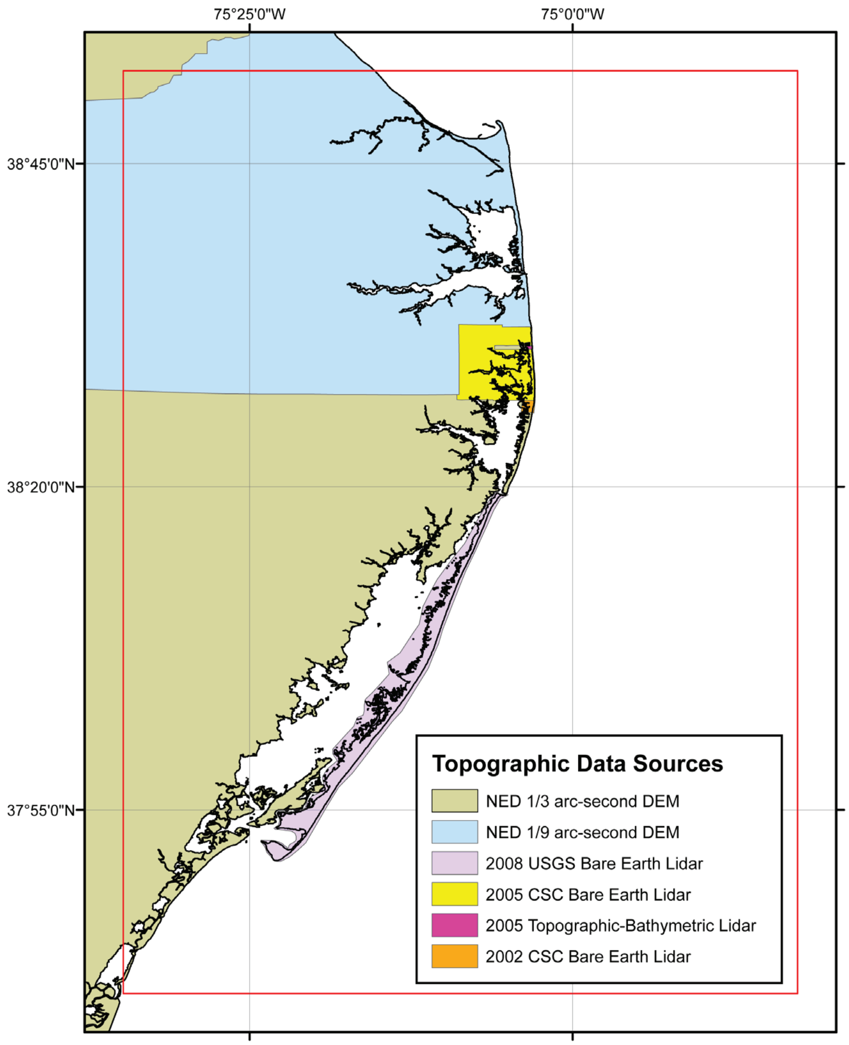

Figure 12. *Spatial coverage of topographic datasets used in building the Ocean City DEM.*

1) United States Geological Survey National Elevation Dataset 1/3 arc-second topographic DEM

The USGS National Elevation Dataset (NED) provides complete 1/3 arc-second coverage of the Ocean City DEM region[4]. Data are in NAD 83 geographic coordinates and NAVD 88 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, aerial photographs based on topographic surveys, and topographic lidar; it has been revised using data collected in 1999 to 2007. The NED DEM includes "zero" elevation values over the open ocean, which were removed from the dataset by clipping to the final coastline.

Regions of the NED 1/3 arc-second DEM were sub-sampled from the NED 1/9 arc-second DEM, which is derived from lidar data. NGDC used the NED 1/3 arc-second DEM in those regions since the higher resolution data were already incorporated (see Fig. 13). The NED 1/3 arc-second DEM was also used where no NED 1/9 arc-second data or lidar data existed.

2) United States Geological Survey National Elevation Dataset 1/9 arc-second topographic DEM

USGS provides limited high-resolution NED 1/9 arc-second DEMs, derived from 3 meter point-spacing lidar data. Data are in NAD 83 geographic coordinates and NAVD 88 vertical datum (meters), and are available for download as raster DEMs. The horizontal accuracy is 3 meters and the vertical accuracy, depending on input of source data, is less than 22 centimeters. The NED DEM included "zero" elevation values over the open ocean, which were removed from the dataset by clipping to the final coastline.

NGDC only used the NED 1/9 arc-second DEM where it was not incorporated in the NED 1/3 arc-second DEM (Fig. 13). The data were clipped to the coastline to remove values over the open water. Problems in the data included vertical stripes in the north of the DEM derived from the original lidar data (Fig. 14).

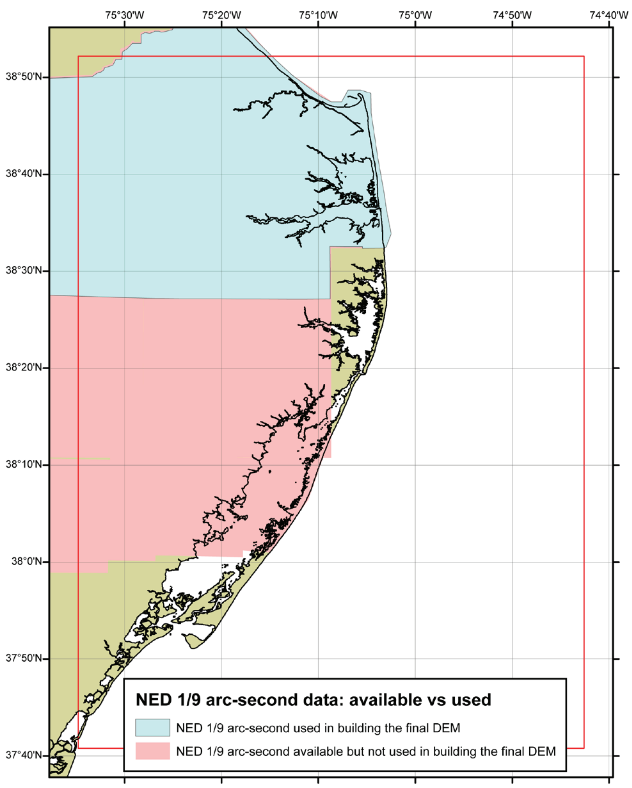

__Figure 13.__ Spatial coverage of the NED 1/9 arc-second DEM available versus used in the final Ocean City DEM. The data was not used because it was already incorporated in the NED 1/3 arc-second DEM, which is sufficient for the 1/3 arc-second DEM of Ocean City

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 geographic, except for AK, which is NAD 27 geographic. The vertical datum is NAVD 88, 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 meters) data covers the U.S., then this will also be a seamless dataset. [Extracted from USGS NED web site]

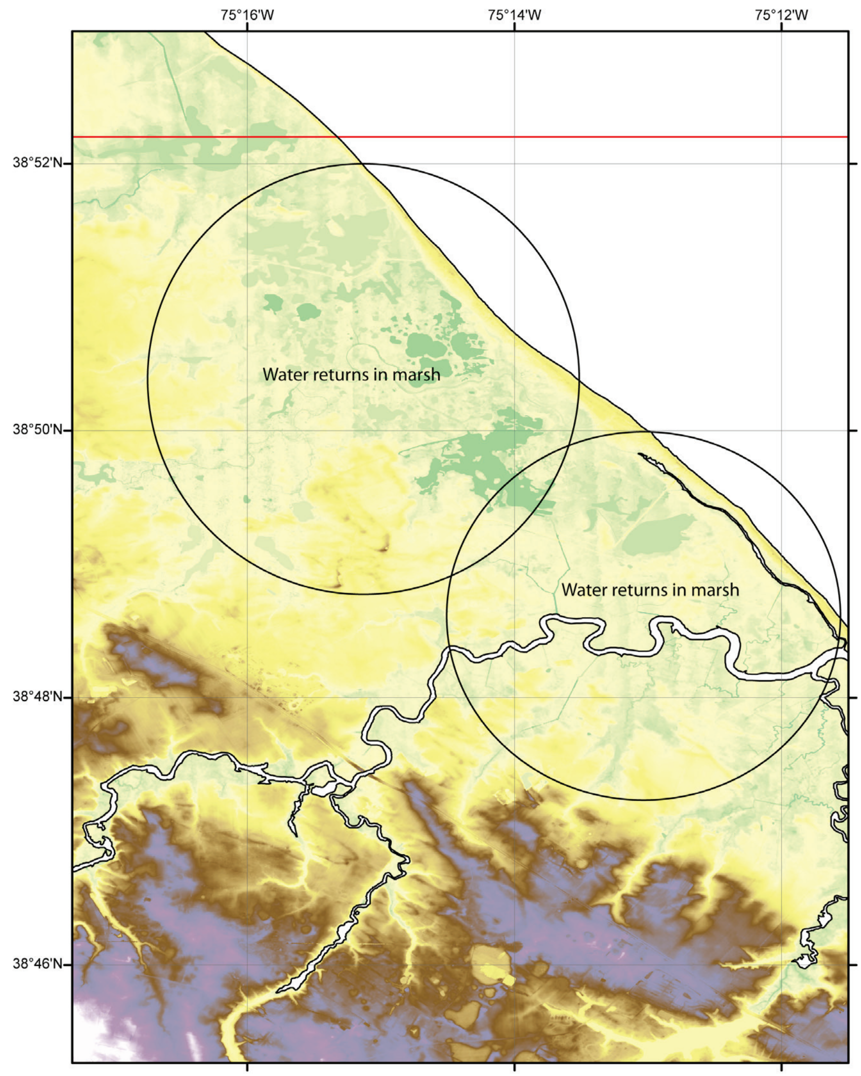

Figure 14. *Vertical stripes in marshy areas in the NED 1/9 arc-second DEM.*

3) United States Geological Survey 2008 bare-earth topographic lidar

USGS provided NGDC with 2008 bare-earth lidar of Assateague Island National Seashore (Fig. 15). The survey was divided into tiles 2 km by 2 km and is available for download or by DVD. Emily Klipp provided NGDC with a DVD of all tiles in las and xyz format. The horizontal accuracy of the survey is one meter and the vertical accuracy is +/- 15 centimeters.

The original horizontal and vertical datums are NAD 83 UTM Zone 18N and NAVD 88. NGDC used *FME* to transform the datums to NAD 83 geographic and MHW, and to convert the xyz files into shapefiles for editing in *ArcMap*. This survey supersedes all other topographic data and older data were clipped where they overlap this survey. Values over the open water were manually deleted before converting the data back into xyz for the final gridding process.

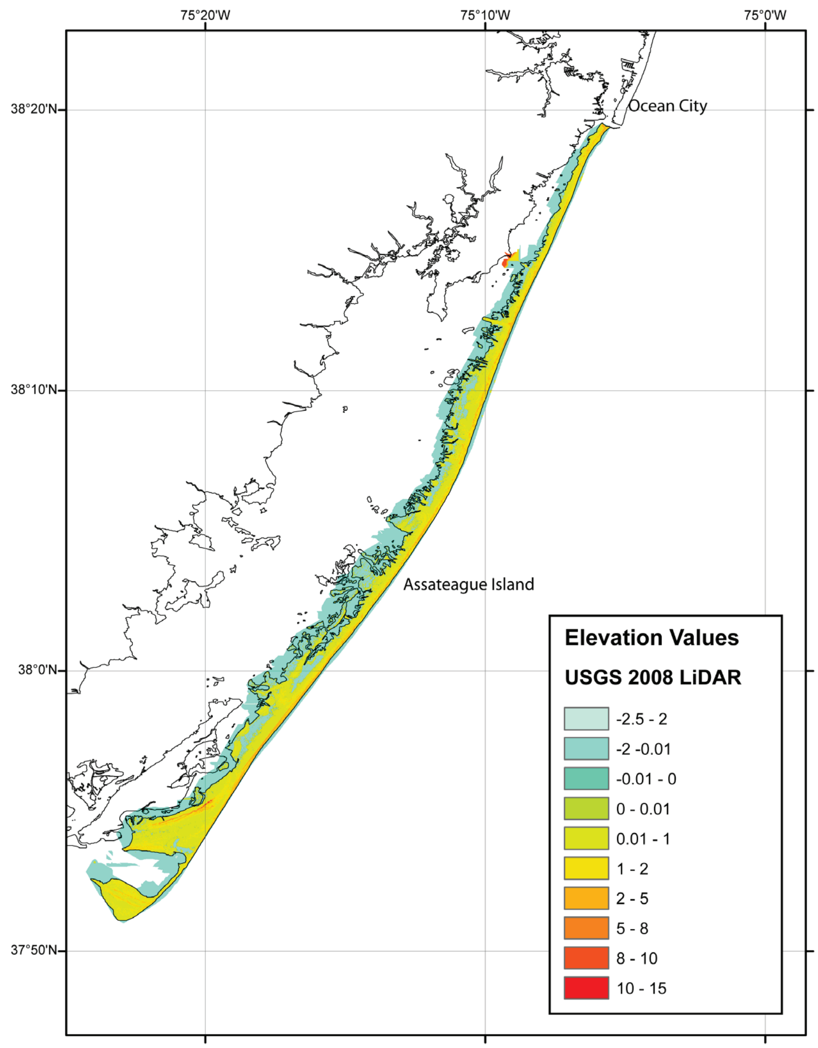

Figure 15. *USGS 2008 bare-earth lidar data on Assateague Island.*

4) Coastal Services Center 2005 bare-earth topographic lidar

A 2005 bare-earth topographic lidar survey was downloaded from the CSC web site. The topographic lidar, collected for the State of Delaware in March 2005, was provided to CSC by Delaware Natural Resources and Environmental Control, Delaware Coastal Programs. The survey's ground spacing is 3 meters, and has a vertical accuracy of 10.2 centimeters and a horizontal accuracy that has not been tested. The data were downloaded in NAD 83 geographic horizontal datum and NAVD 88 vertical datum. *FME* was used to transform the data to MHW and convert to shapefiles for editing in *ArcMap*.

NGDC only used the tiles from this dataset where there are no NED DEMs (1/3 arc-second or 1/9 arc-second) with lidar already incorporated into the data. Problems in the data include returns over the open water and a missing strip of data (Fig. 16). The values over the open water were manually deleted in *ArcMap*. The data were then converted back to xyz using *FME* for the final gridding process.

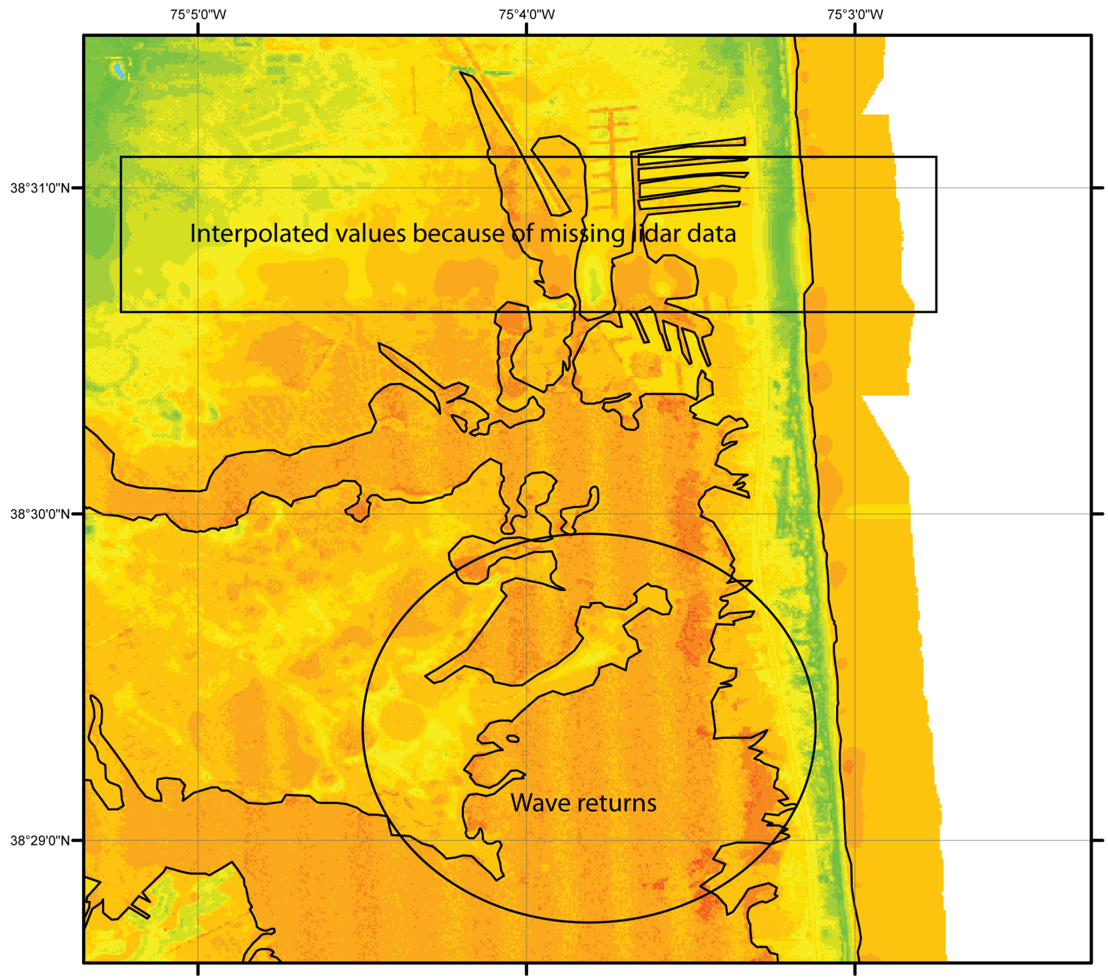

Figure 16. *Problems in the CSC 2005 bare-earth lidar illustrated in a gridded image. A strip of missing data caused a large gap. Water returns, seen as stripes, needed to be deleted before the final gridding process.*

5) 2005 Coastal Services Center non-bare-earth topographic lidar

A 2005 USACE topographic non-bare earth lidar survey was downloaded from the CSC web site. The data were collected by the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX). Metadata states this is a topographic-bathymetric survey, but there were no hydrographic data in the survey. The survey has a vertical accuracy of 0.2 meters and horizontal accuracy of 0.75 meters with 2-meter point spacing. The data were downloaded as xyz files in NAD 83 geographic horizontal datum and NAVD 88 vertical datum. The xyz files were transformed to MHW and converted to a shapefile using *FME*.

This survey covers the entire coastline in the Ocean City DEM, but because the data were not processed to bare earth, the survey was only used to fill in the missing strip of data in the CSC 2005 bare-earth lidar survey. NGDC manually removed rooftops of houses in *ArcMap* (Fig. 17).

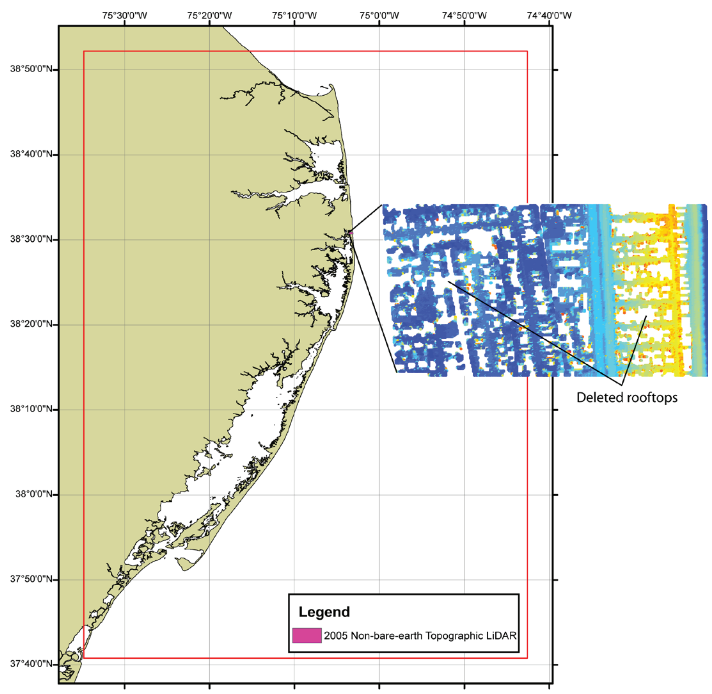

Figure 17. *Spatial coverage of the 2005 non-bare-earth topographic dataset used in building the Ocean City DEM with the resulting shapefile after rooftops were deleted to approximate bare earth.*

6) Coastal Services Center 2002 bare-earth topographic lidar

A 2002 bare-earth topographic lidar survey, contracted by the Maryland Department of Natural Resources, was downloaded from the CSC web site. The survey's ground spacing is 2 meters, and has a vertical accuracy of 21.3 centimeters and a horizontal accuracy appropriate for a 1:24,000 scale map. The data were download as xyz files in NAD 83 geographic and NAVD 88. They were transformed to MHW and converted to shapefiles for editing in *ArcMap* using *FME*. NGDC only used this data where there are no NED DEMs with lidar already incorporated into the data or newer topographic lidar data (see Fig. 12). Water returns were manually removed before converting the data back to xyz files for the final gridding process.

7) NGDC digitized structures

NGDC digitized positive elevations of breakwaters and jetties in the Ocean City DEM which were not represented in any topographic data (Fig. 18). Two breakwaters at the mouth of Delaware Bay were digitized at 5 meters elevation. Several jetties (Delaware Bay, Indian Rivet Inlet, and Ocean City Inlet) were digitized at 1 meter elevation.

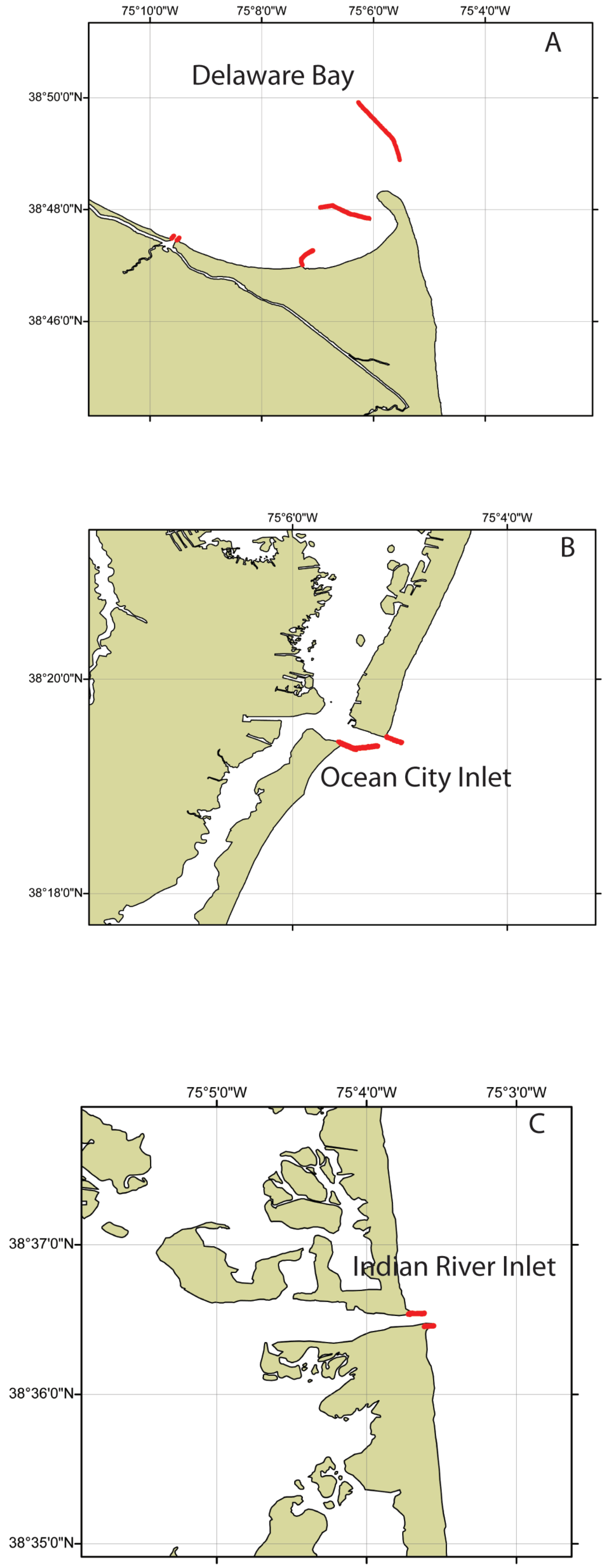

Figure 18. *NGDC-digitized breakwaters and jetties at A) Delaware Bay, B) Ocean City Inlet, and C) India River Inlet.*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Ocean City DEM were originally referenced to several vertical datums including MLLW, MLW, and NAVD 88. 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 and USACE hydrographic surveys were transformed from MLLW and MLW to MHW, using the *VDatum* transformation tool developed by OCS and NGS or *FME* software by adding a constant taken from the Ocean City, Fishing Pier tide station # 8570280 (see Fig. 20).

VDatum coverage was only available for the intertidal region of the Ocean City DEM (Fig. 19). NOS and USACE surveys that fell in this range were converted from MLLW or MLW to MHW using *VDatum*. In some cases, the surveys extended farther inshore than the *VDatum* coverage, in which case NGDC manually changed the vertical datum to MHW by comparing the conversion of nearby soundings.

No *VDatum* exists in the open ocean. NGDC used a constant offset of the differences from MLW (1.025 meters) and MLLW (1.073 meters) to MHW from the Ocean City, Fishing Pier tide station # 8570280.

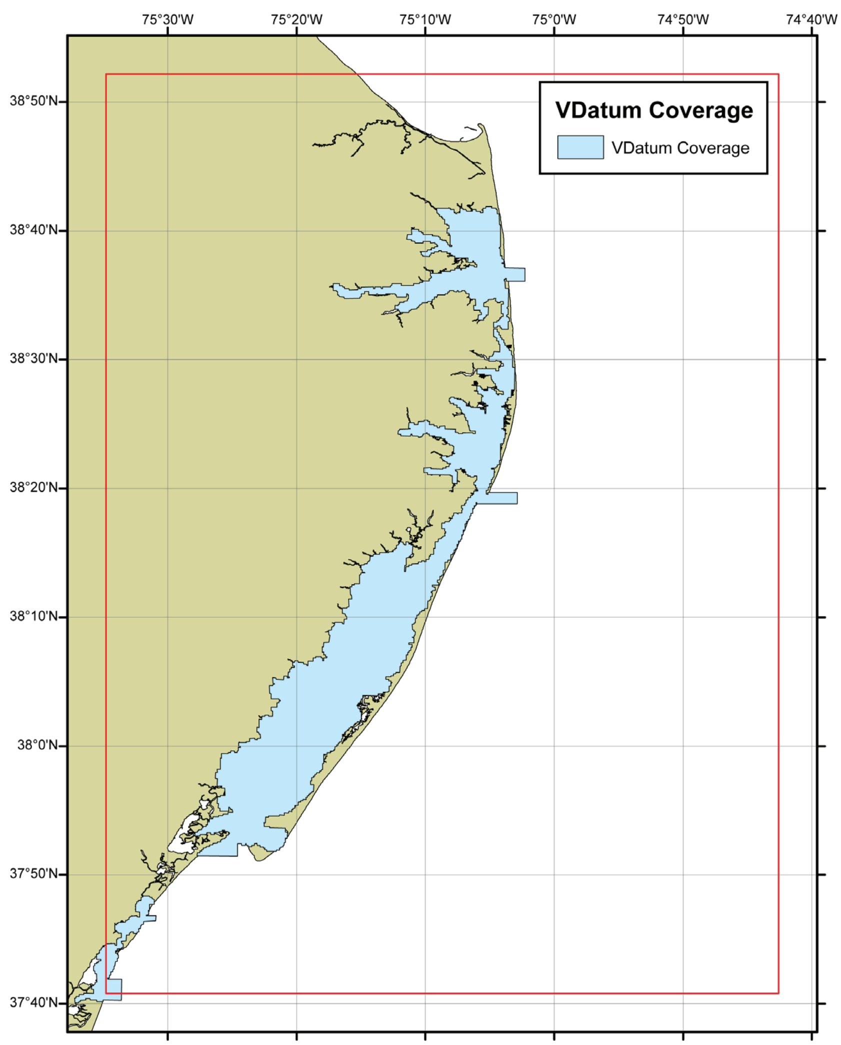

Figure 19. *Spatial coverage of the VDatum transformation tool.*

The USGS NED 1/3 arc-second DEM, NED 1/9 arc-second DEM, 2008 bare-earth topographic lidar data, and the CSC topographic lidar data were downloaded and referenced to NAVD 88 vertical datum. Transformations to MHW, using *FME* software or *ArcGIS*, was accomplished by adding an averaged constant offset of -0.19 meters (Table 8) as measured at various tide stations in the Ocean City region (Fig. 20).

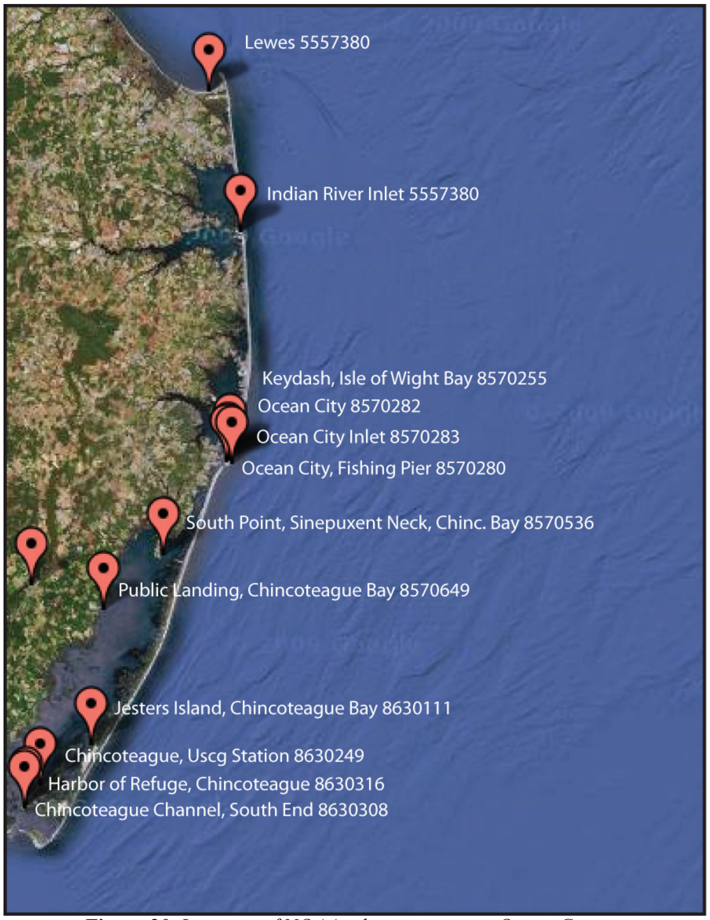

Figure 20. *Location of NOAA tide stations near Ocean City.*

Table 8. Relationship between MHW and NAVD 88 vertical datums at tide stations located within the Ocean City DEM extent.

Tide Station	*Station ID*	*Difference from NAVD 88 to MHW*
Keydash, Isle of Wight Bay	8570255	0.13
Ocean City	8570282	0.194
Ocean City Inlet	8570283	0.184
Lewes	8557380	0.488
Indian River Inlet	8558690	0.257
Chincoteague, USCG Station	8630249	0.189

3.2.2 Horizontal datum transformations

Datasets used to build the Ocean City DEM were downloaded and referenced to WGS 84 geographic, NAD 83 UTM Zone 18 North, NAD 83 Maryland State Plane, or NAD 83 geographic horizontal datums. The relationships and transformational equations between these horizontal datums are well established. Data were converted to a horizontal datum of NAD 83 geographic using *FME* software or *ArcGIS*.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

After horizontal and vertical transformations were applied, the resulting ESRI shapefiles 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 shapefiles were then converted to xyz files using *FME* in preparation for gridding. Problems included:

- Missing strip of data in the CSC 2005 bare-earth topographic lidar survey.
- Inconsistent elevation values in the NED 1/3 arc-second DEM and higher resolution lidar data.
- Topographic lidar dataset not processed to bare-earth. The dataset required manual editing of individual features.
- Bathymetric values in older NOS surveys dating back over 70 years are inconsistent with newer NOS and USACE surveys.
- Water returns in NED DEMs and topographic lidar data.

3.3.2 Smoothing of bathymetric data

The NOS hydrographic survey data are generally sparse at the resolution of the 1/3 arc-second Ocean City DEM (see Fig. 24): in deep water, the NOS survey data have point spacing up to 2000 meters apart, and some shallow water up to 1000 meters apart. In order to reduce the effect of artifacts in the form of lines or "pimples" in the DEM due to low resolution datasets, and to provide effective interpolation in the deep water and into the coastal zone, a 1 arc-second-spacing "pre-surface" bathymetric grid was generated using *GMT*[5], a NSF-funded shareware software application designed to manipulate data for mapping purposes.

The NOS hydrographic point data were clipped to remove overlap with USACE soundings, and older NOS surveys with newer NOS surveys. The coastline elevation value was set at -1 meters to ensure a bathymetric surface below zero in areas where data are 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 Ocean 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 final coastline (to eliminate data interpolation into land areas). The resulting surface was compared with original soundings to ensure grid accuracy (e.g., Figs. 21 and 22), and then exported as an xyz file for use in the final gridding process (see Table 9).

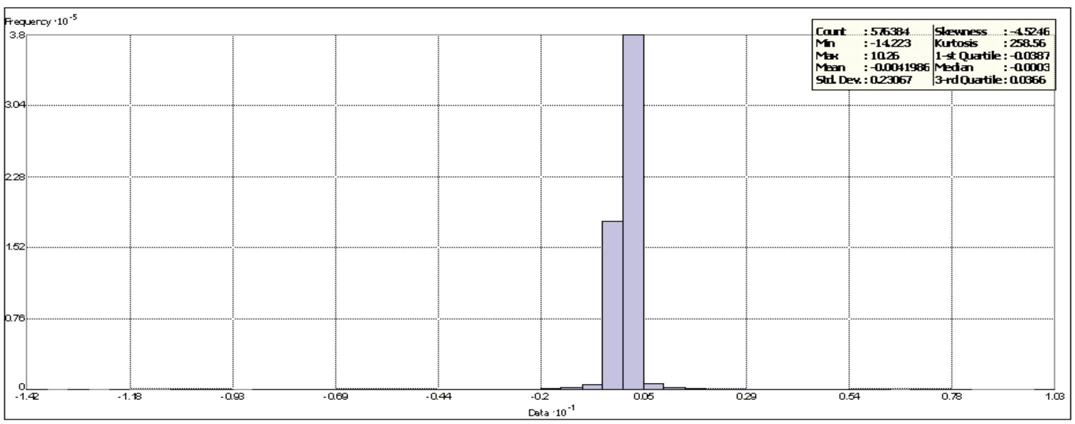

Figure 21. *Histogram of the differences between all NOS hydrographic surveys and the 1 arc-second pre-surface bathymetric grid.*

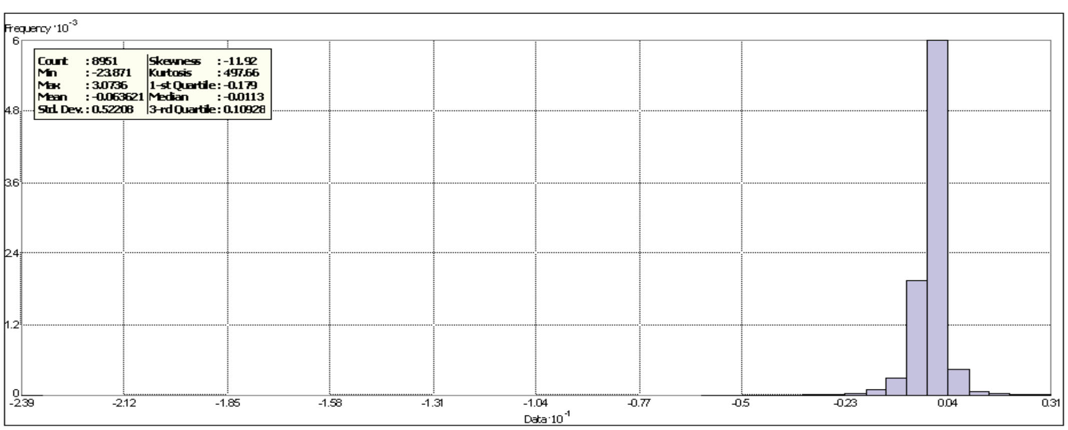

Figure 22. *Histogram of the differences between all USACE hydrographic surveys and the 1 arc-second pre-surfaced bathymetric grid.*

5. *GMT* is an open source collection of ~60 tools for manipulating geographic and Cartesian data sets (including filtering, trend fitting, gridding, projecting, etc.) and producing Encapsulated PostScript File (EPS) illustrations ranging from simple x-y plots via contour maps to artificially illuminated surfaces and 3-D perspective views. *GMT* supports ~30 map projections and transformations and comes with support data such as GSHHS coastlines, rivers, and political boundaries. *GMT* is developed and maintained by Paul Wessel and Walter H. F. Smith with help from a global set of volunteers, and is supported by the National Science Foundation. It is released under the GNU General Public License. URL: http://gmt.soest.hawaii.edu [Extracted from *GMT* web site.]

3.3.3 *Integrating topographic datasets*

Many different topographic surveys are available for the Ocean City region. To represent the most current morphology and integrate the data smoothly, NGDC used a 50 meter overlap between different high-resolution datasets to allow averaging of five cells, creating a seamless border. When integrating lower resolution datasets next to higher resolution datasets, NGDC used a 50 meter buffer to allow smoothing from interpolation. NGDC used the buffer to fill the CSC 2005 bare-earth topographic lidar survey data gap with the NED 1/3 arc-second DEM and the CSC 2005 non-bare-earth topographic lidar survey. Figure 23 illustrates there is still a noticeable difference between the three datasets, but no other higher resolution data were available of that area.

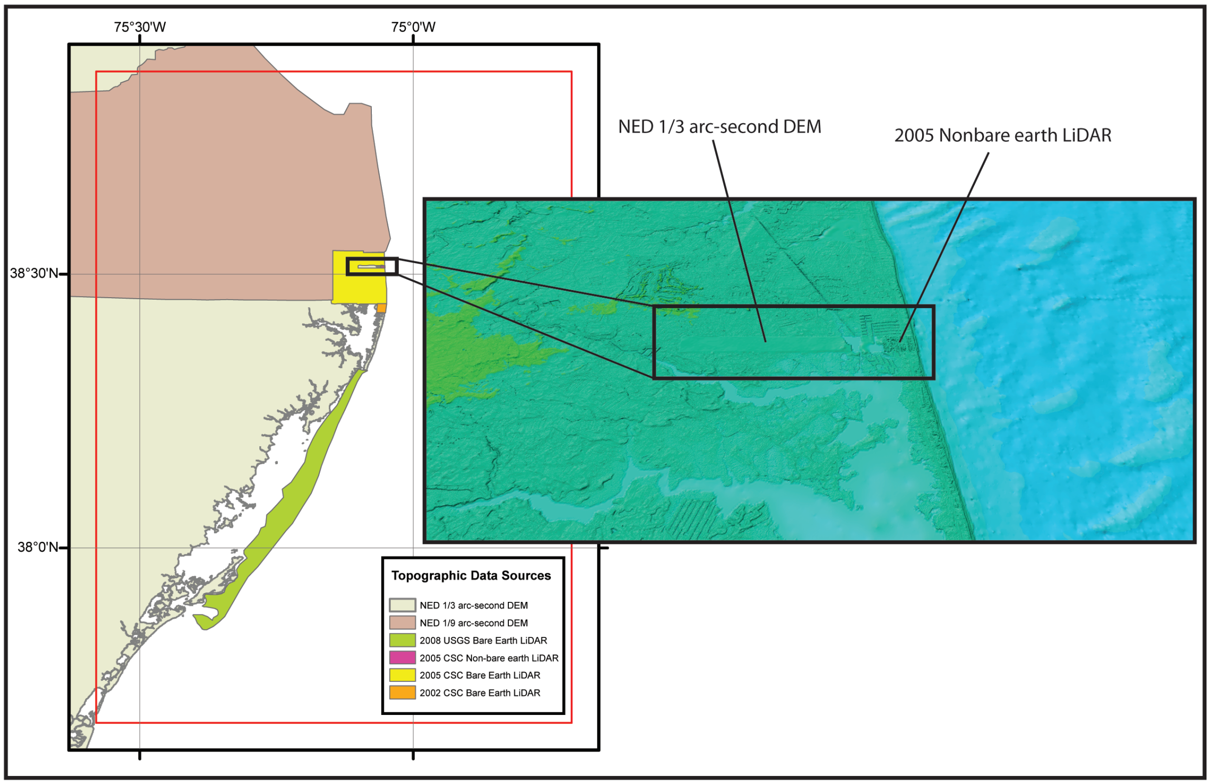

Figure 23. *Problems in the final grid due to a missing strip of lidar data filled in with the NED 1/3 arc-second DEM.*

3.3.4 *Gridding the data with MB-System*

MB-System[6] was used to create the 1/3 arc-second Ocean City DEM. *MB-System* is an NSF-funded shareware 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 9. Equal weight was given to all datasets except the NED 1/3 arc-second DEM and the “pre-surface” bathymetric grid. Gridding was performed in quadrants with the resulting Arc ASCII grids seamlessly merged in *ArcCatalog* to create the final 1/3 arc-second Ocean City DEM. Figure 24 illustrates cells in the DEM that have interpolated values (shown as white) versus data contributing to the cell value (shown in black).

Table 9. Data hierarchy used to assign gridding weight in *MB-System*.

Dataset	*Relative Gridding Weight*
NOS hydrographic surveys	100
USACE hydrographic surveys	100
Digitized features	100
CSC 2002 bare-earth lidar	100
CSC 2005 bare-earth lidar	100
CSC 2005 non-bare-earth lidar	100
USGS 2008 bare-earth lidar	100
USGS NED 1/9 arc-second topographic DEM	100
USGS NED 1/3 arc-second topographic DEM	10
Pre-surfaced bathymetric grid	0.01

Figure 24. *Ocean City DEM data distribution plot. White denotes no data contributed to the cell value; black denotes data contributed to the cell value. Final coastline in red.*

6. *MB-System* is an open source software package for the processing and display of bathymetry and backscatter imagery data derived from multibeam, interferometry, and sidescan sonars. The source code for *MB-System* is freely available (for free) by anonymous ftp (including “point and click” access through these web pages). A complete description is provided in web pages accessed through the web site. *MB-System* was originally developed at the Lamont-Doherty Earth Observatory of Columbia University (L-DEO) and is now a collaborative effort between the Monterey Bay Aquarium Research Institute (MBARI) and L-DEO. The National Science Foundation has provided the primary support for *MB-System* development since 1993. The Packard Foundation has provided significant support through MBARI since 1998. Additional support has derived from SeaBeam Instruments (1994-1997), NOAA (2002-2004), and others. URL: http://www.ldeo.columbia.edu/res/pi/MB-System[Extracted from *MB-System* web site.]

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Ocean City DEM is dependent upon the datasets used to determine corresponding DEM cell values and the cell size of the DEM. For topographic features, the horizontal accuracy is 10 meters (see Sec. 3.1.3 for individual topographic datasets horizontal accuracy). 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 the Ocean City DEM is also highly dependent upon the source datasets contributing to DEM cell values. Topographic areas have an estimated vertical accuracy between 15 to 21.3 centimeters for lidar derived data, and 7 to 15 meters for NED 1/3 arc-second 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.

3.4.3 Slope maps and 3-D perspectives

ESRI *ArcCatalog* was used to generate a slope grid from the Ocean City DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 23). The DEM was transformed to UTM Zone 18 North coordinates (horizontal units in meters) in *ArcCatalog* for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis (e.g., Fig. 25). Three-dimensional viewing of the UTM-transformed DEM was accomplished using ESRI *ArcScene*. Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEM. Figure 26 shows a perspective view image of the 1/3 arc-second Ocean City DEM in its final version.

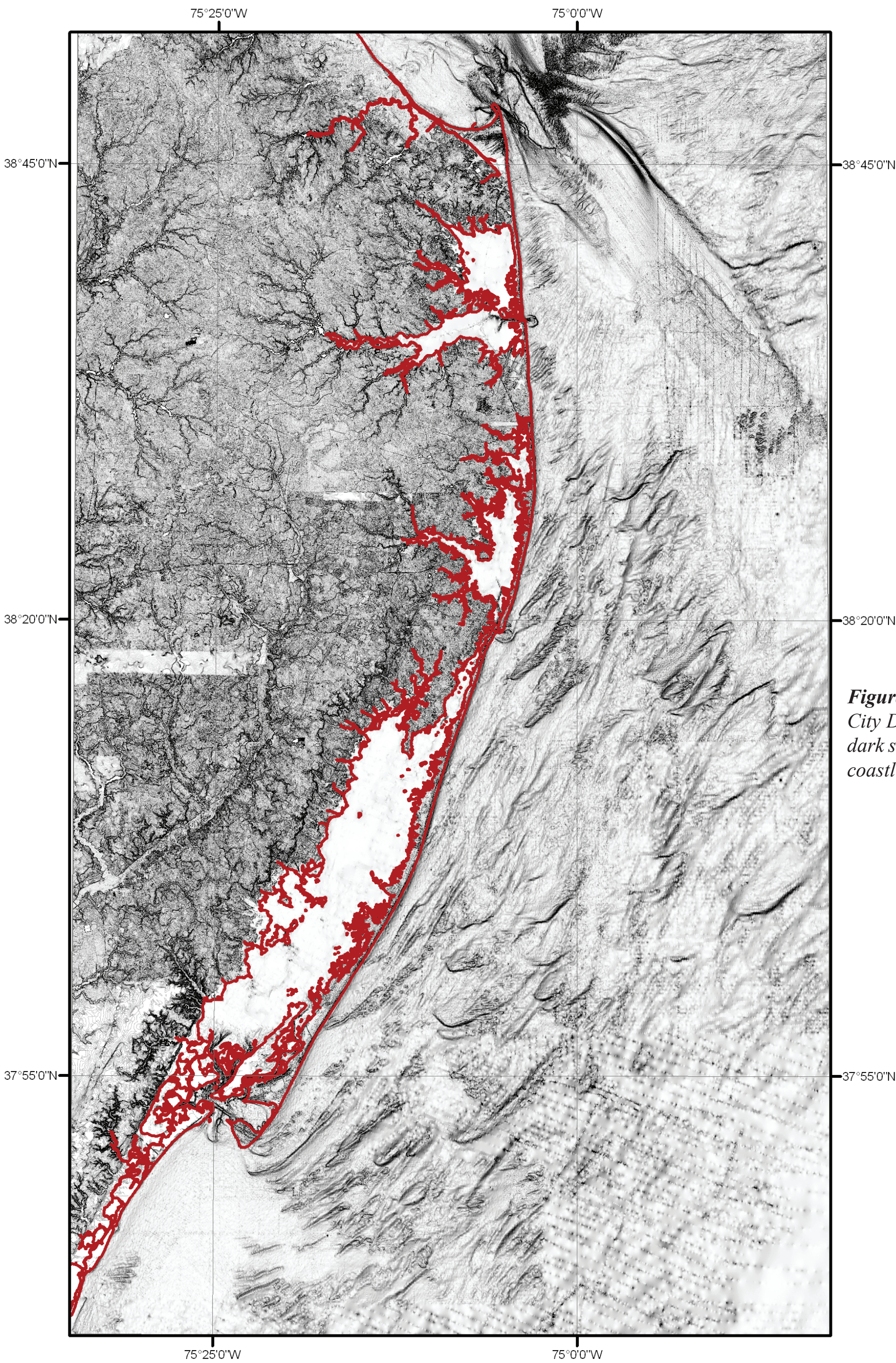

Figure 25. *Slope map of the Ocean City DEM. Flat-lying slopes are white; dark shading denotes steep slopes; final coastline in red.*

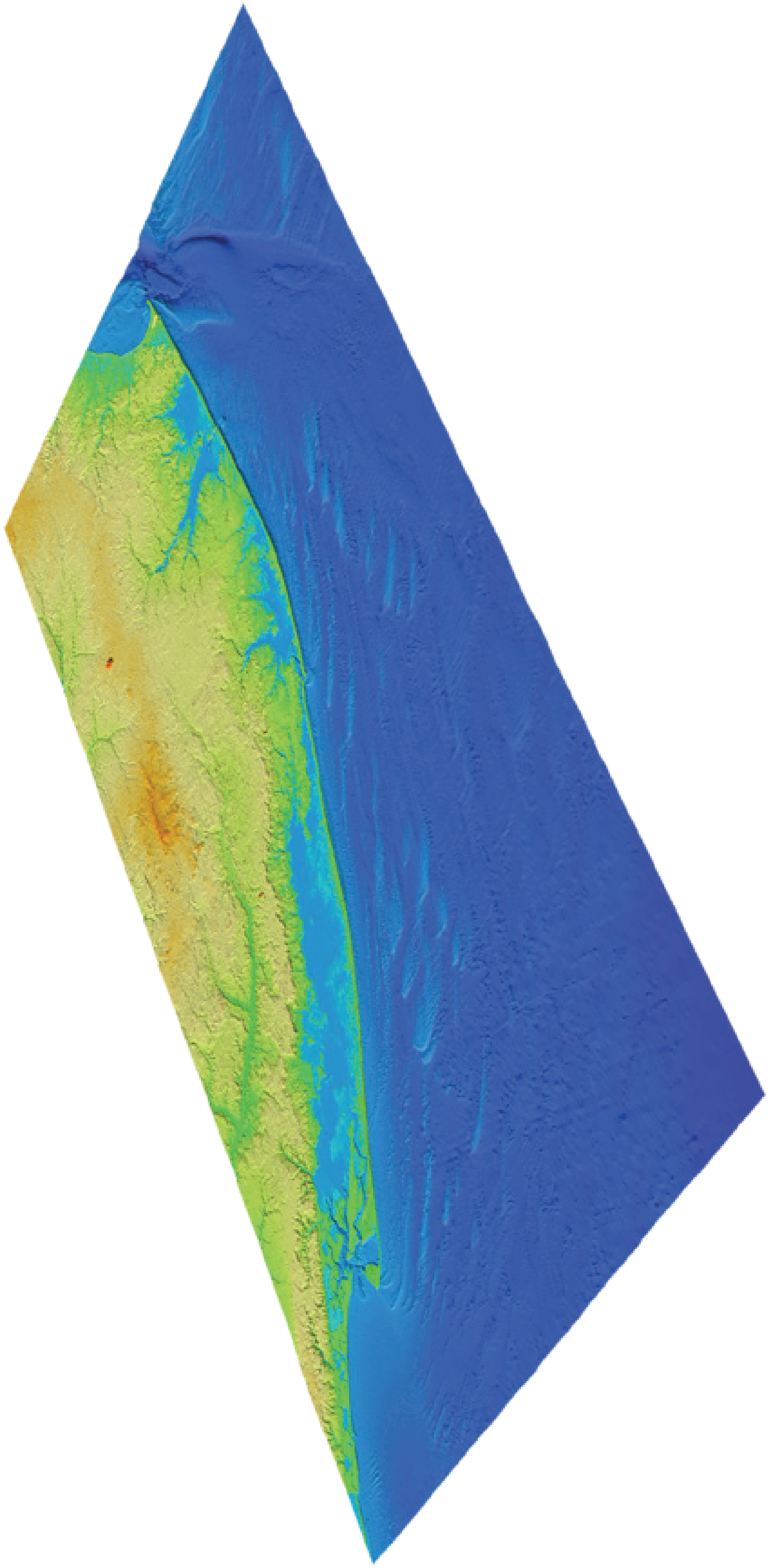

Figure 26. *Perspective view from the southeast of the Ocean City DEM. Vertical exaggeration–times 20.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Ocean City DEM was compared to source data files. All bathymetric data and select topographic data files from each dataset were chosen for comparison to the Ocean City DEM using *Fledermaus, FME* and *ArcMap.* A histogram of the differences between all NOS hydrographic surveys and the Ocean City DEM is shown in Figure 27 and all the USACE hydrographic surveys and the Ocean City DEM is shown in Figure 28. Differences cluster around zero. The major differences in elevations in NOS surveys with the grid (-16 meters and +10 meters) are from digitized breakwaters and jettys that were only represented in the final DEM. There is only one anomalous point (-23 meters) between the USACE hydrographic surveys and the grid, which is due to a bad sounding. NGDC manually deleted the sounding.

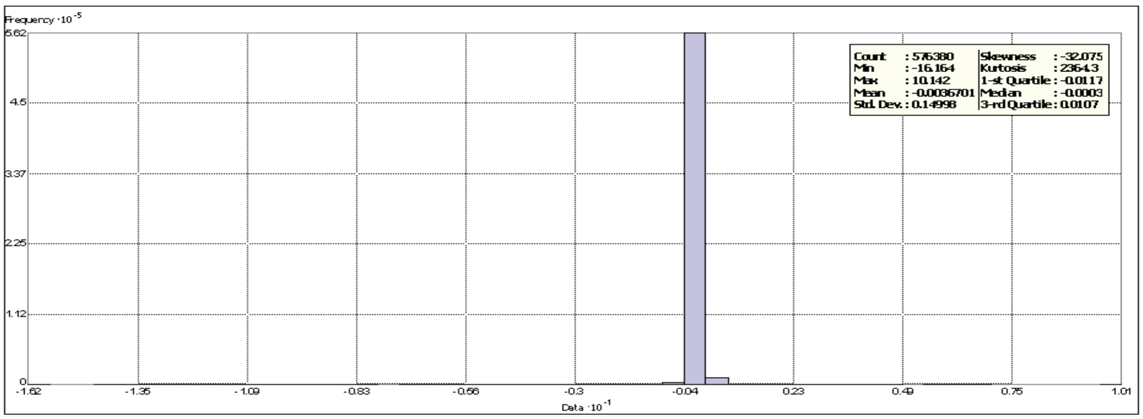

Figure 27. *Histogram of the differences between all the NOS surveys and the Ocean City DEM.*

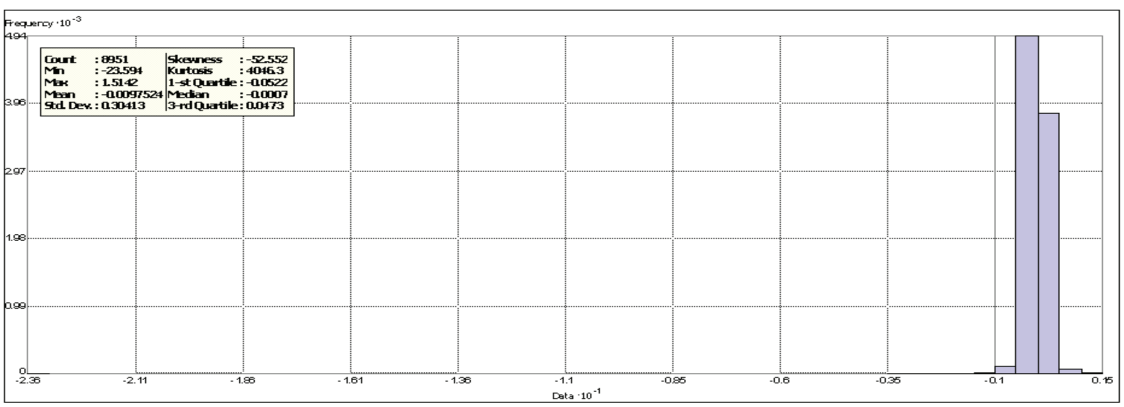

Figure 28. *Histogram of the differences between all the USACE surveys and the Ocean City DEM.*

Histograms to compare the differences between the topographic datasets and the Ocean City DEM were created for gridding evaluation (Figs. 29 - 34). All data points for the CSC 2002 bare-earth lidar survey and the CSC 2005 bare-earth lidar were used for comparison. Only select data points from the CSC 2005 bare-earth lidar survey, the 2008 USGS lidar survey, and the NED 1/3 and 1/9 arc-seconds DEM were used for comparison against the elevation of the grid because the data points were too dense to run a comparison on all data points in the DEM. Differences cluster around zero for all surveys, with the differences ranging from -2.25 meters to 3.7 meters. The CSC 2005 non-bare-earth survey was the only survey with a difference greater than 3 meters, and this is due to crude processing of the data to bare-earth.

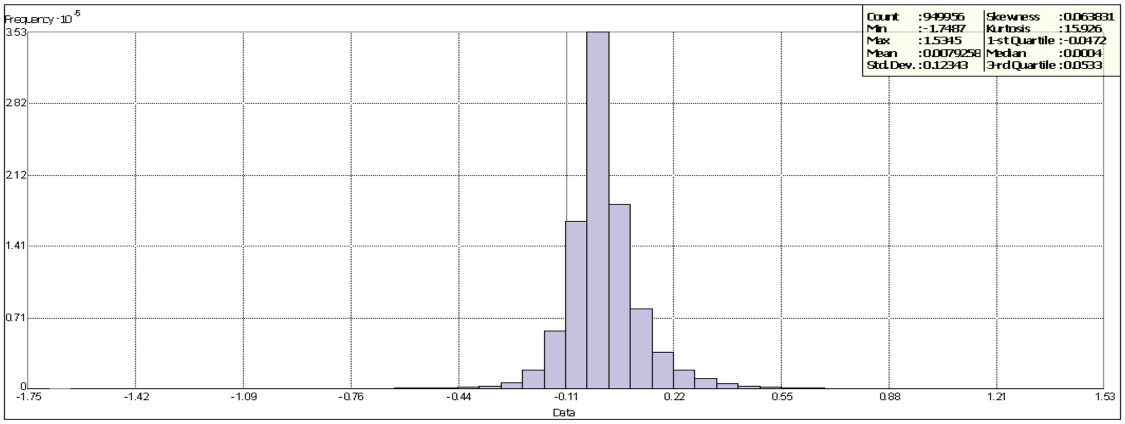

Figure 29. *Histogram of the differences between all the CSC 2002 bare-earth lidar data and the Ocean City DEM.*

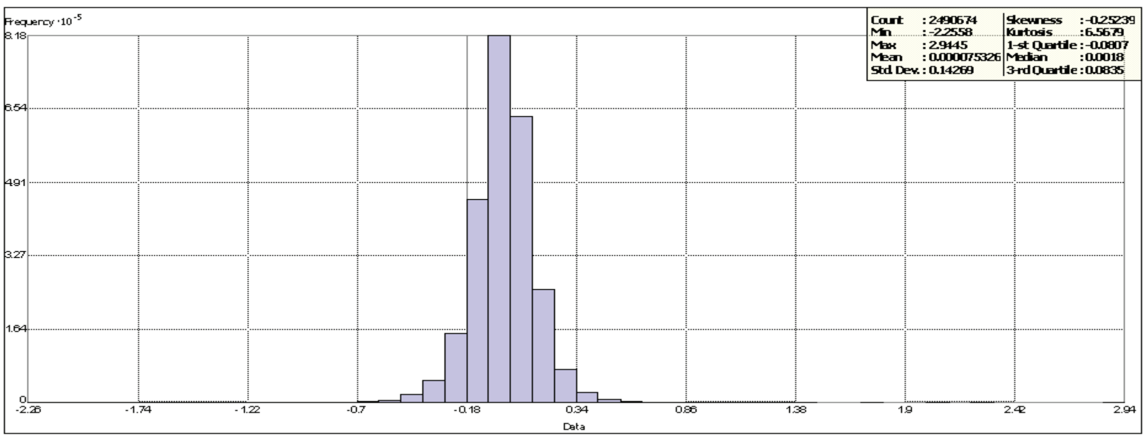

Figure 30. *Histogram of the differences between select CSC 2005 bare-earth lidar data and the Ocean City DEM.*

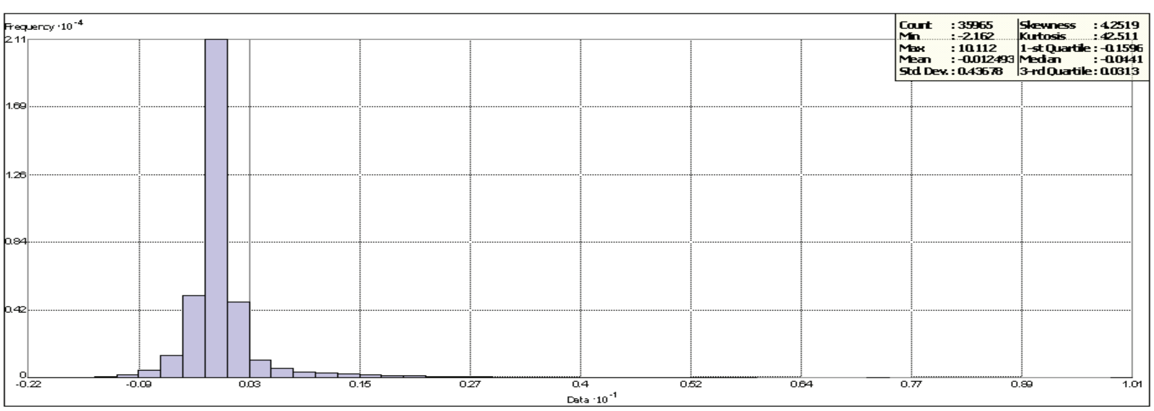

Figure 31. *Histogram of the differences between all CSC 2005 non-bare-earth topographic-bathymetric lidar data and the Ocean City DEM.*

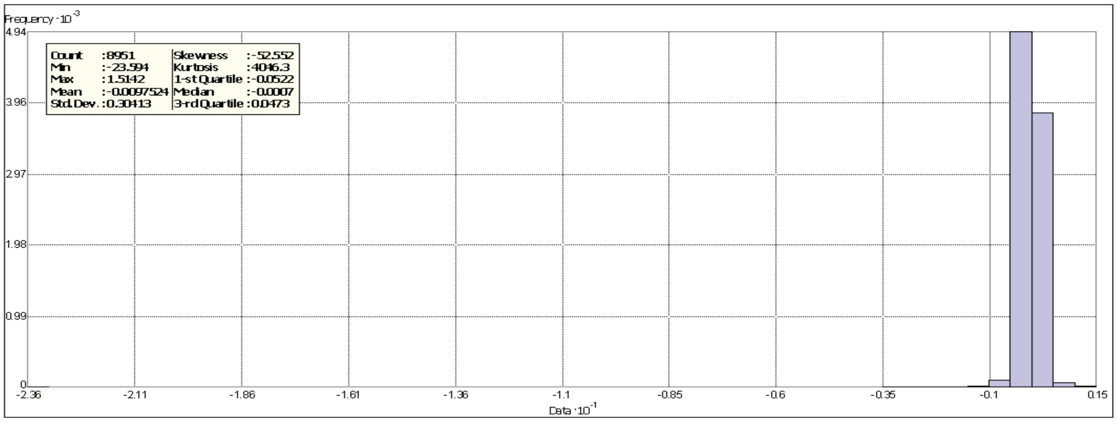

Figure 32. *Histogram of the differences between select USGS 2008 bare-earth lidar data and the Ocean City DEM.*

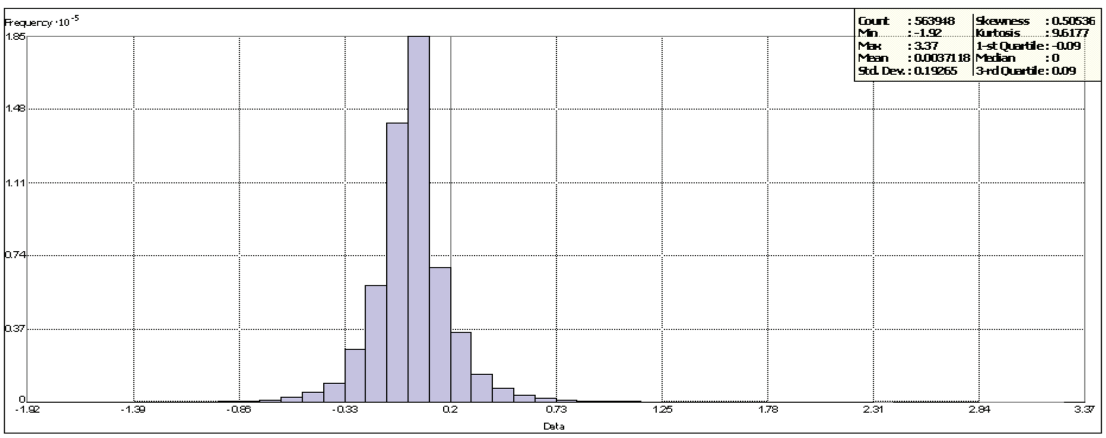

Figure 33. *Histogram of the differences between select NED 1/3 arc-second topographic DEM data points and the Ocean City DEM.*

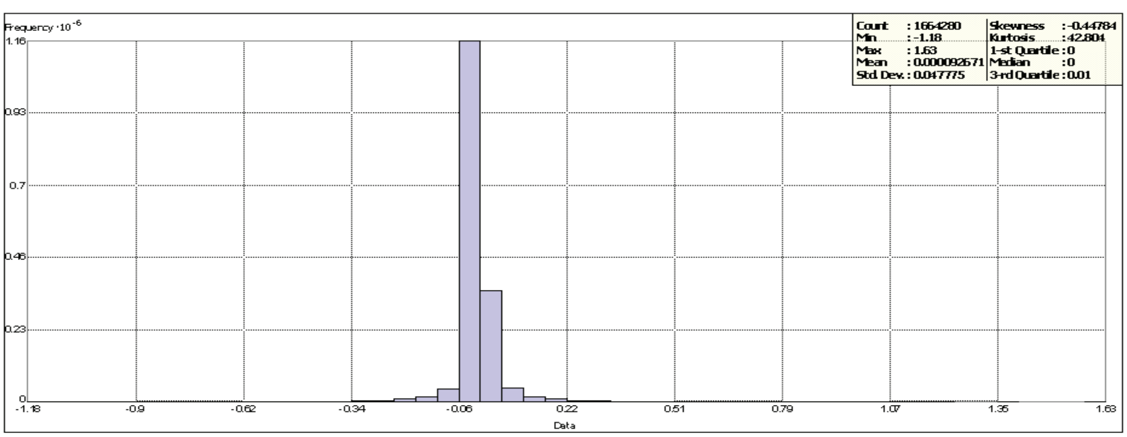

Figure 34. *Histogram of the differences between select NED 1/9 arc-second topographic DEM data points and the Ocean City DEM.*

3.4.5 Comparison with the National Geodetic Survey geodetic monuments

The elevations of 1,221 NOAA NGS geodetic monuments were extracted from online shapefiles of monument datasheets (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl), which give monument positions in NAD 83 geographic (typically sub-mm accuracy) and elevations in NAVD 88 (in meters). Elevations were shifted to MHW vertical datum for comparison with elevations of the Ocean City DEM (Fig. 35). Differences between the Ocean City DEM and the NGS geodetic monument elevations range from -10 to 25 meters, with the majority of them being within +/-1 meter (Fig. 36). Negative values indicate that the monument elevation is less than the DEM elevation. Only 16 monuments out of 1221 total showed deviations greater than 5 meters from the DEM. After examination, it was determined that those monuments do not represent ground surface as they are located on top of an observation tower, light house or at the apex of other structures.

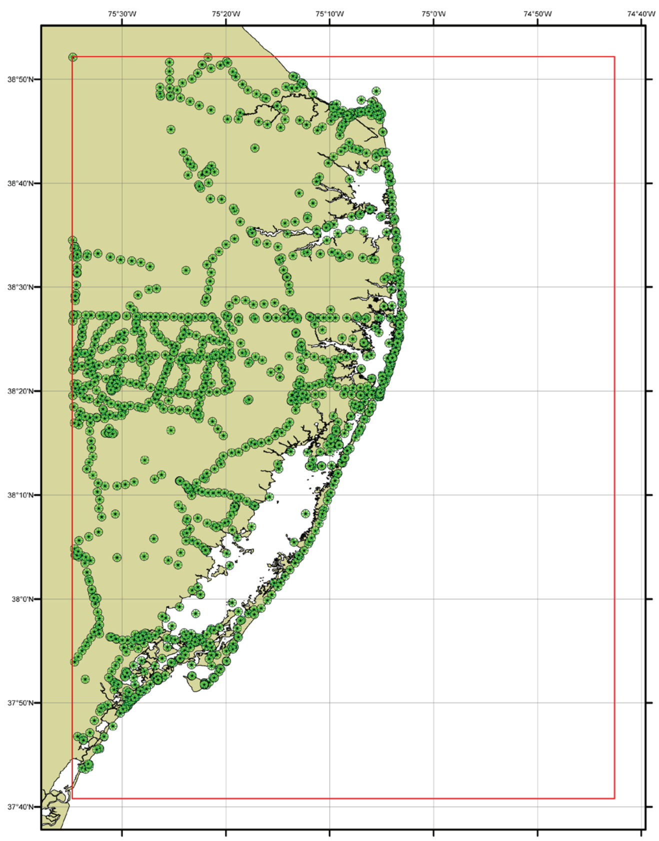

Figure 35. *Location of NGS geodetic monuments, shown as green circles. NGS monument elevations were used to evaluate the DEM.*

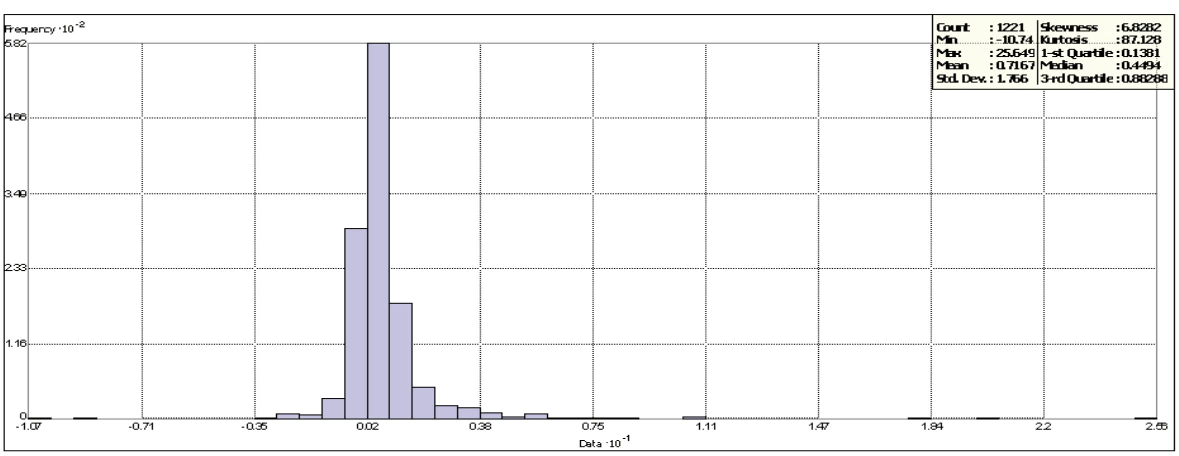

Figure 36. *Histogram of the differences between NGS geodetic monument elevations and the Ocean City DEM.*

4. Summary and Conclusions

A bathymetric–topographic digital elevation model of the Ocean City, Maryland 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*, *Quick Terrain Modeler*, and *Fledermaus* software.

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

- Conduct up-to-date topographic lidar surveys for all near-shore regions.
- Conduct NOS hydrographic surveys in hydrographic data gaps and the new harbor.
- Process CSC 2005 non-bare-earth topographic lidar data to bare-earth.
- Complete processing of the USACE hydrographic surveys in Sinepuxent Bay.

5. Acknowledgments

The creation of the Ocean City DEM was funded by the NOAA Pacific Marine Environmental Laboratory. The authors thank Nazila Merati,Chris Chamberlin, Marie Eble, and Vasily Titov (PMEL); Emily Klipp from the USGS for sending the 2008 bare-earth lidar on DVD; and John Hill from the USACE Philadelphia District office for providing USACE surveys that were not available on their web site.

6. References

Nautical Chart #12210, 38th Edition, 2008. Chincoteague Inlet to Great Machipongo Inlet. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #12211, 43rd Edition, 2007. Fenwick Island to Chincoteague Inlet. Scale 1:80,000 and 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #12214, 48th Edition, 2007. Cape May to Fenwick. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #12216, 28th Edition, 2008. Cape Henlopen to Indian River Inlet. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #12304, 45th Edition, 2008. Delaware Bay. Scale 1:40,000 and 1:10,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

7. Data Processing Software

ArcGIS v. 9.3, developed and licensed by ESRI, Redlands, California, http://www.esri.com

ESRI Imagery World 2D Online World Imagery 2D – ESRI ArcGIS Resource Centers, http://resources.esri.com/arcgisonlineservices

Fledermaus v. 7.0 – developed and licensed by Interactive Visualization Systems (IVS 3D), Fredericton, New Brunswick, Canada, http://www.ivs3d.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. 4.4.0 – 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. 5.1.1, 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. 6.0.6, Lidar processing software developed by John Hopkins University's Applied Physics Laboratory (APL) and maintained and licensed by Applied Imagery, http://www.appliedimagery.com

Datum Transformation Tool, Delaware, Maryland, Virginia Embayment V. 01 – developed and maintained by NOAA's National Geodetic Survey (NGS), Office of Coast Survey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS), http://vdatum.noaa.gov/welcome.html