Digital Elevation Model for Daytona Beach, Florida: Procedures, Data Sources and Analysis

Prepared for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research by the NOAA National Geophysical Data Center (NGDC)
October 31, 2007

Taylor, L.A., B.W. Eakins, K.S. Carignan, R.R. Warnken, T. Sazonova, and D.C. Schoolcraft
NOAA, National Geophysical Data Center, Boulder, Colorado

Corresponding author 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/

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Digital Elevation Model for Daytona Beach, Florida: Procedures, Data Sources and Analysis

1. INTRODUCTION

The National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), has developed a topographic–bathymetric digital elevation model (DEM) of Daytona Beach, Florida (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 Daytona Beach DEM.

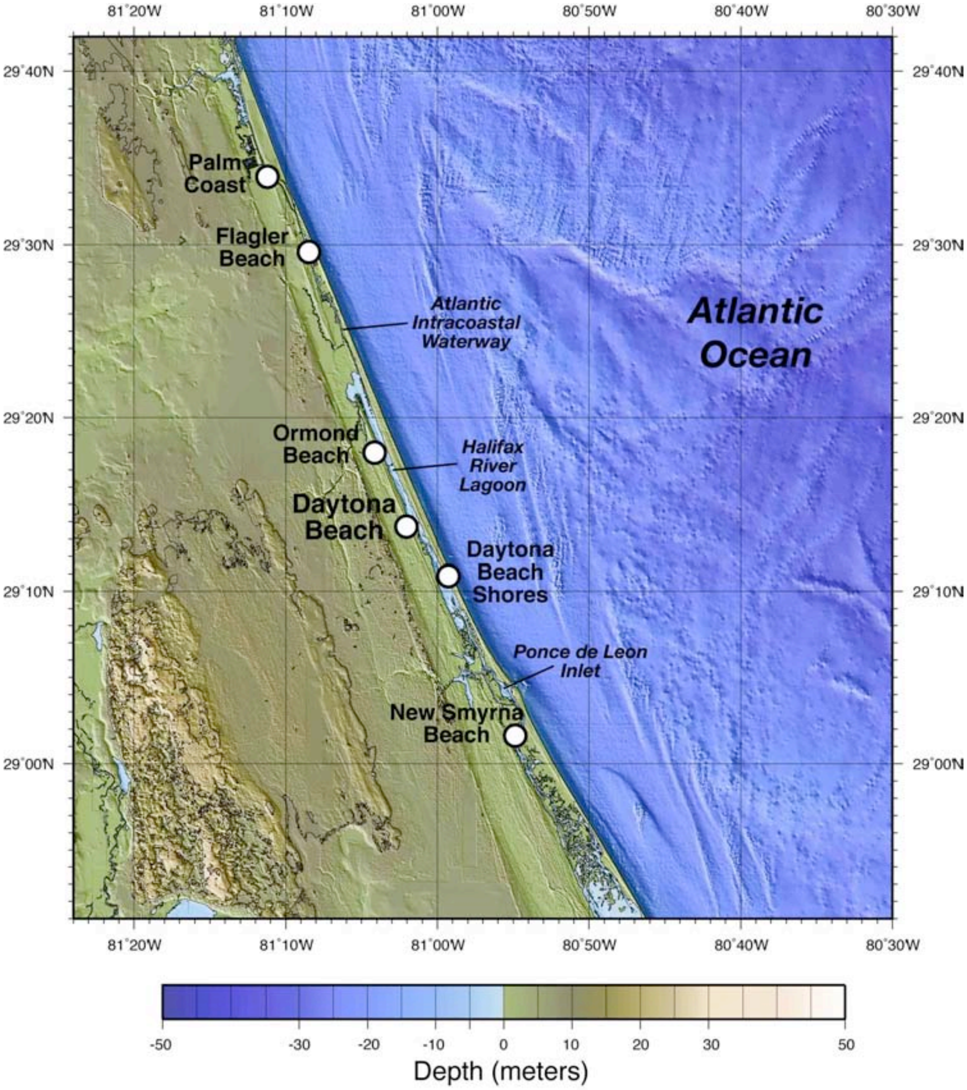

Figure 1. *Shaded-relief image of the Daytona Beach, Florida DEM.*

---

[1] The Daytona Beach 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 Daytona Beach, Florida (29°13′ N, 81°0′ W) 1/3 arc-second of latitude is equivalent to 10.263 meters; 1/3 arc-second of longitude equals 9.004 meters.

2. STUDY AREA

The Daytona Beach DEM covers the coastal region surrounding the town of Daytona Beach, Florida (Fig. 1), a popular tourist destination spot. Daytona Beach is bordered to the north by Palm Coast, Flagler Beach, and Ormond Beach and to the south by Daytona Beach Shores and New Smyrna Beach. The region has a long, heavily populated sandbar that is largely isolated from mainland Florida by the Halifax River lagoon. Entrance to the lagoon, whose banks provide anchorage for numerous ships and sailing vessels, is through the mouth of Ponce de Leon Inlet (Fig. 2). The Atlantic Intracoastal Waterway, which stretches from Miami to Maine, passes through the Halifax River lagoon, and is maintained by the U.S. Army Corps of Engineers.

The Atlantic shoreline near Daytona Beach is a dynamic system, though development has attempted to stabilize it. Sand is constantly being moved by wind and waves. Shorelines, islands, spits, bars, and dunes change shape, move, grow, or diminish in size or even disappear as part of the dynamic natural process.

Figure 2. *Ponce de Leon Inlet. A) Satellite image of the mouth of Ponce de Leon Inlet. B) Photo of Ponce de Leon Inlet looking south from the Ponce de Leon Lighthouse. (photo from http://ponceinletfirefighter.com/)*

3. METHODOLOGY

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

Table 1: PMEL specifications for the Daytona Beach, Florida DEM.

Grid Area	Daytona Beach, Florida
Coverage Area	81.40º to 80.50º W; 28.85º to 29.70º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Grid Spacing	1/3 arc-second
Grid Format	ESRI Arc ASCII grid

3.1 Data Sources and Processing

Shoreline, bathymetric, topographic, and topographic–bathymetric digital datasets (Fig. 3) were obtained from several U.S. federal, state and local agencies, and a private company, including: NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS) and Coastal Services Center (CSC); the U.S. Geological Survey (USGS); the U.S. Army Corps of Engineers (USACE); the Florida Fish and Wildlife Research Institute (FWRI); Lake, St. Johns, and Volusia Counties; and Jones Edmunds & Associates, Inc. Safe Software's (http://www.safe.com/) FME data translation tool package was used to shift datasets to WGS84 horizontal datum and to convert them into ESRI (http://www.esri.com/) ArcGIS shape files. The shape files were then displayed with ArcGIS to assess data quality and manually edit datasets. Vertical datum transformations to MHW were accomplished using FME, based upon the offset grids compiled by PMEL and the data from the NOAA tide stations. VDatum model software (http://nauticalcharts.noaa.gov/csdl/vdatum.htm) was not available for this area. Applied Imagery's Quick Terrain Modeler software (http://www.appliedimagery.com/) was used to edit and assess the quality of the LiDAR data. GEODAS (http://www.ngdc.noaa.gov/mgg/geodas/) was used to convert topographic contours into point data. GMT (http://gmt.soest.hawaii.edu/) and MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/) were used to grid the data and build the DEM.

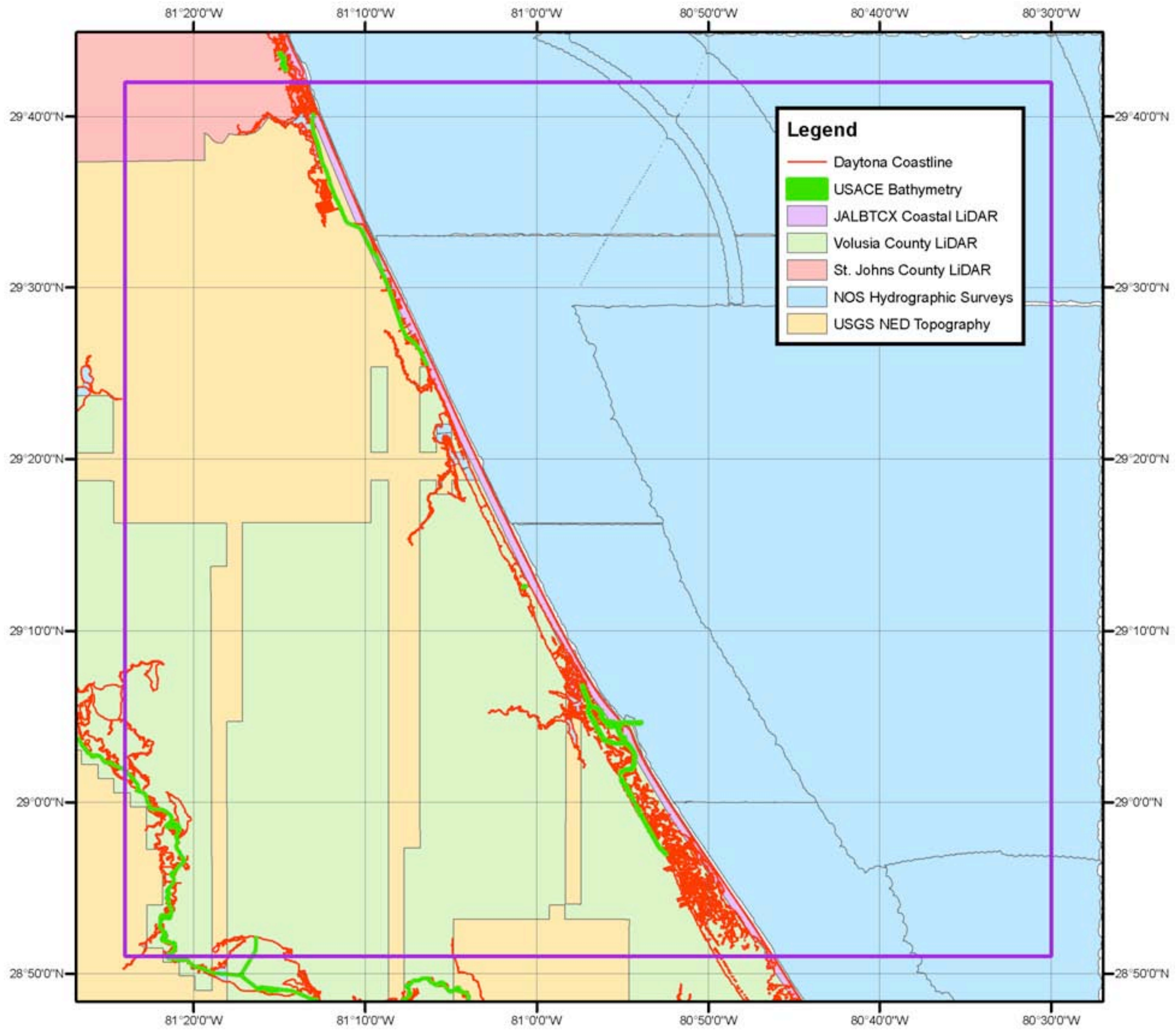

***Figure 3.** Source and coverage of datasets used to compile the Daytona Beach DEM. DEM boundary in purple.*

3.1.1 Shoreline

Coastline datasets of the Daytona Beach region were obtained from the Florida Fish and Wildlife Research Institute (FWRI), St. Johns County GIS Division, and NOAA's Office of Coast Survey (OCS; Table 2; Fig. 4).

Table 2: Shoreline datasets available in the Daytona Beach, Florida region.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
Florida Fish and Wildlife Research Institute	1995	Digitized coastline	1:40,000	NAD83 Albers Conical Equal Area (meters)	Inferred MHW	http://research.myfwc.com/
St. Johns County	2003–2004	LiDAR hydrography	1:24,000	NAD83 State Plane, Florida East (survey feet)	NAVD88	
OCS ENCs	2006–2007	Digitized Hydrography	1:80,000–1:449,659	WGS84 geographic	MHW	http://nauticalcharts.noaa.gov/mcd/enc/index.htm
NGDC	2006	Gridded coastal LiDAR		WGS84 geographic	MHW	

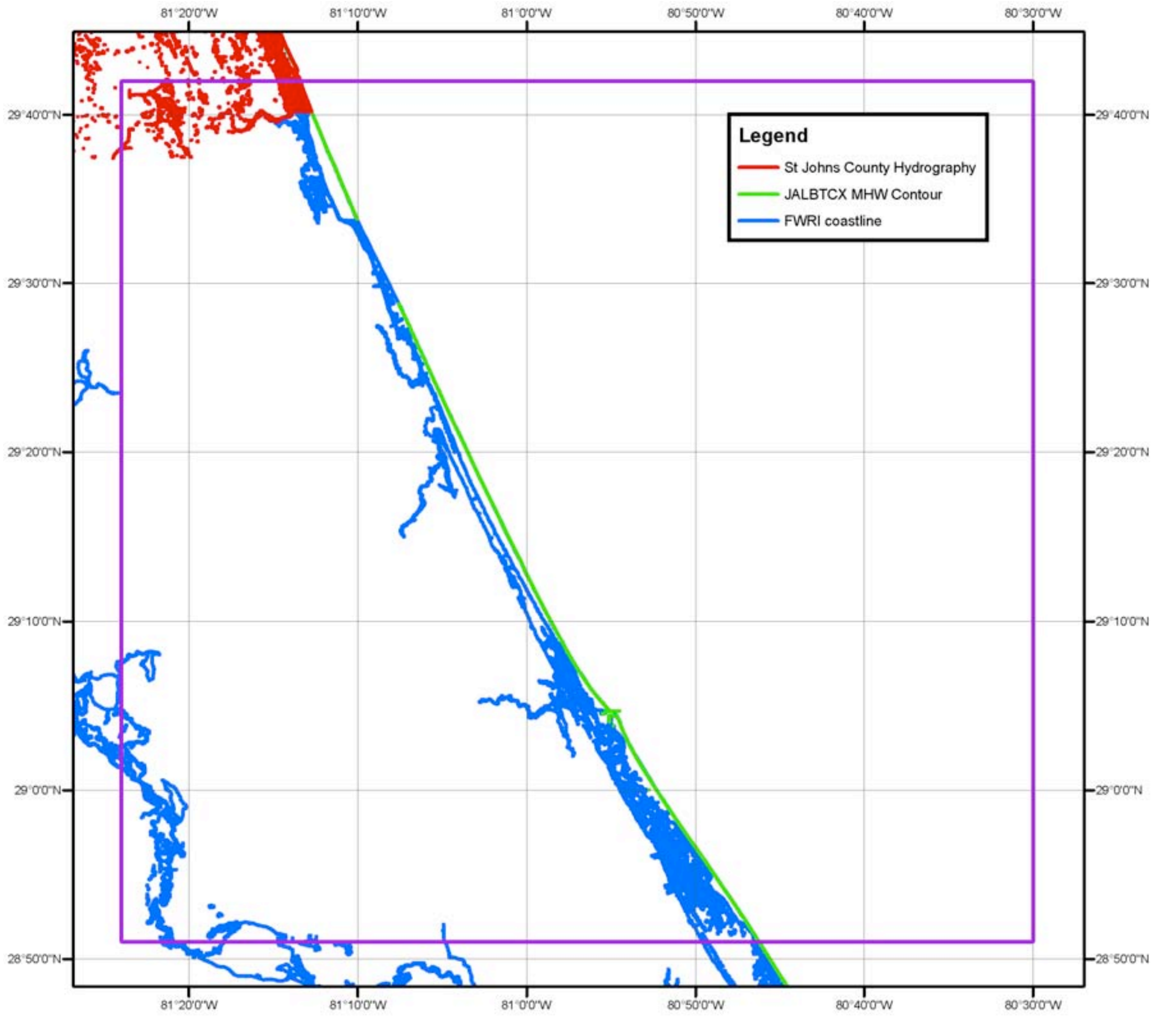

Figure 4. *Digital coastline datasets used in building a 'combined coastline' for the Daytona Beach region. DEM boundary in purple.*

1) **Florida Fish and Wildlife Research Institute Digitized Coastline**

   The Florida Fish and Wildlife Research Institute (FWRI; http://research.myfwc.com/) contracted the U.S. Fish and Wildlife Service to digitize the Florida coast in 1990. The data set was created from the most current National Oceanic and Atmospheric Administration (NOAA) Nautical Charts available at the time. The scale of the source charts varied from 1:10,000 in some harbors to 1:80,000 in the Big Bend area. However, most of the source scale is 1:40,000. The current, 2000, data set is the result of revisions to the 1990 version. Some areas, including inland areas where there is no chart coverage and areas that have needed more accuracy for individual projects, have been digitized from USGS 7.5-minute Quadrangles and Digital Orthophoto Quarter Quadrangles (DOQQs). This GIS data set represents the Florida shoreline as polygons and lines, in Albers Conical Equal Area projection. Vertical datum is undefined but is inferred to be MHW.

2) **St. Johns County LiDAR-derived Hydrography**

   The St. Johns County, Florida Board of County Commissioners contracted out for a high-resolution LiDAR survey of the entire county, which was performed in 2003 and 2004. The survey was designed to support the development of a digital terrain model sufficient to derive 1-foot contours. The work also included aerial photography, ground control survey points, and derivation of local hydrographic features for use as “breaklines” in modeling the terrain. Results of this work were provided to NGDC by Michael Campbell, St. Johns County GIS Division. Data were originally in NAD83 Florida East State Plane coordinates (survey feet) and NAVD88 vertical datum.

3) **OCS electronic navigational chart**

   Three electronic navigational charts (ENCs) were available for the Daytona Beach 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 (Table 4) are available as georeferenced raster nautical charts (RNCs; digital images of the charts) and were used to QC bathymetric, bathymetric–topographic, and topographic datasets.

Table 3: Electronic navigational charts available in the Daytona Beach, Florida region.

Chart	*Title*	*Edition*	*Issue Date*	*Scale*
11480	Charleston Light to Cape Canaveral	10	2007-03-22	1:449,659
11484	Ponce de Leon Inlet to Cape Canaveral	3	2007-07-10	1:80,000
11486	St. Augustine Light to Ponce to Leon Inlet	1	2006-10-23	1:80,000

Table 4. NOAA Raster Nautical Charts in the Daytona Beach, Florida region.

Nautical Chart #	*Region*	*Scale*	*Ed. Date*
11485	Intracoastal Waterway Tolmato River to Palm Shores	1:40,000	2007-08-01

4) **NGDC LiDAR-derived MHW contour**

   In order to define the current coastline, NGDC processed the most recent JALBTCX high-resolution bathymetric–topographic LiDAR dataset along the Atlantic coast, available from NOAA’s Coastal Services Center, to create a zero-elevation coastline at Mean High Water vertical datum.

The FWRI 1:40,000 scale coastline of Florida was merged with the St. Johns County hydrographic coastline and the MHW contour from the JALBTCX coastal LiDAR survey to create a ‘combined coastline’ of the Daytona Beach area; the ENC coastlines were not used due to their low resolution compared to the other datasets. River inlets were included in the ‘combined coastline’ where digital bathymetric data were present. Modifications to the combined coastline included adjustments to fit the most recent topographic LiDAR data. In addition, the jetty at the mouth of Ponce de Leon Inlet was added, as it was not well represented in the coastlines. All modifications were done using ArcMap editing tools.

3.1.2 Bathymetry

Bathymetric datasets used in the compilation of the Daytona Beach DEM include 41 NOS hydrographic surveys, and 6 USACE bathymetric surveys (Table 5; Fig. 5).

Table 5: Bathymetric datasets used in compiling the Daytona Beach DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1870 to 1983	Hydrographic survey soundings	Ranges from 10 m to 1 km (varies with scale of survey, depth, traffic, and probability of obstructions)	NAD27 geographic	Mean Low Water or Mean Lower Low Water (meters)	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
USACE	2006	Hydrographic survey profiles	Profiles 50 to 200 meters long, spaced 50 meters apart, with point spacing < 1 meter	NAD83 Florida State Plane East (survey feet)	Mean Lower Low Water (feet)	http://www.saj.usace.army.mil/hydroSurvey/hydro.htm

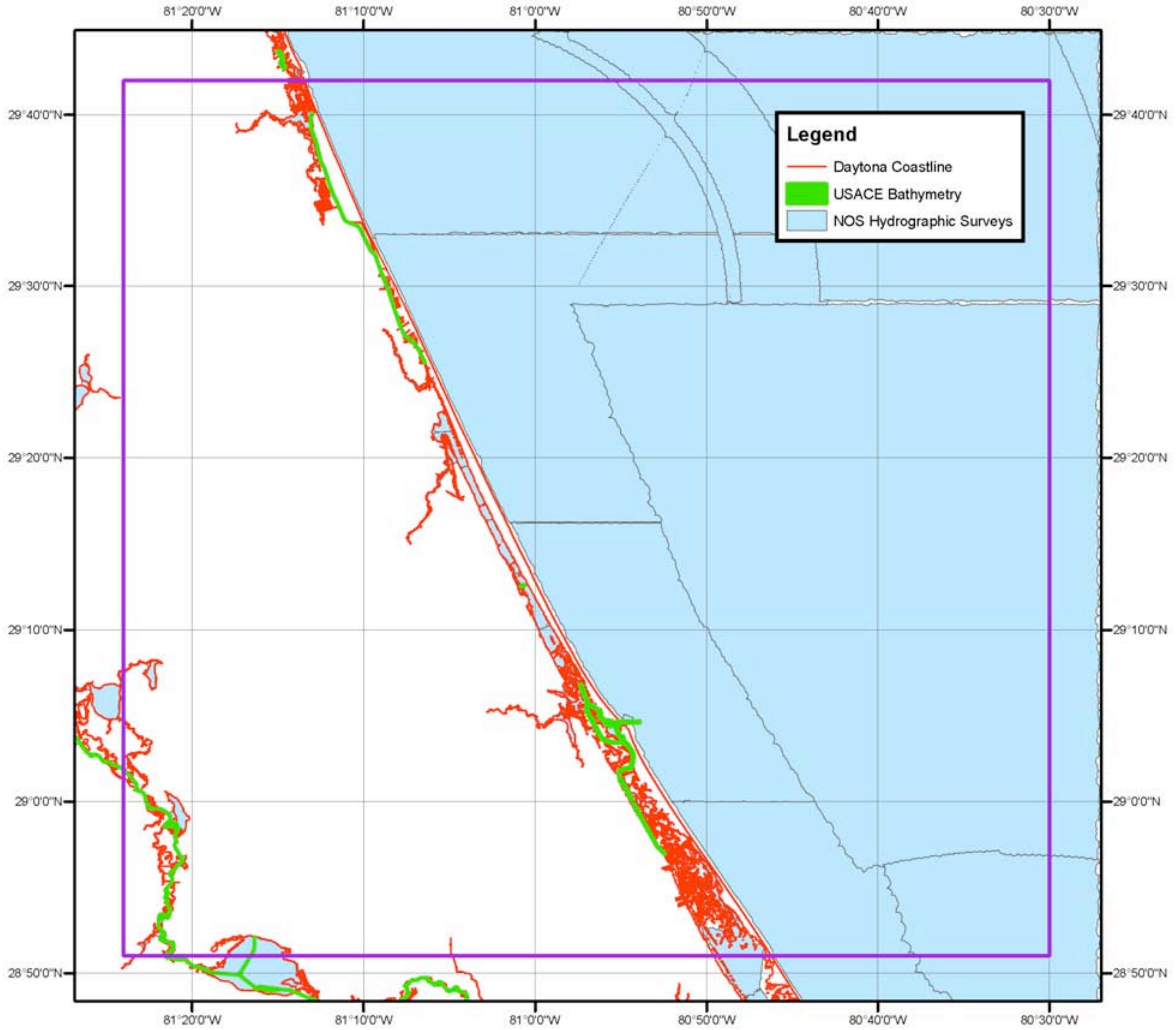

Figure 5. *Spatial coverage of bathymetric datasets used to compile the Daytona Beach DEM. DEM boundary in purple.*

1) NOS hydrographic survey data

A total of 41 NOS hydrographic surveys conducted between 1870 and 1983 were utilized in developing the Daytona Beach DEM (Table 6; Fig. 6). The hydrographic survey data were originally horizontally referenced to NAD27 or NAD83 geographic datum, and vertically referenced to Mean Lower Low Water (MLLW), Mean Low Water (MLW), "average water level during low river stages," or "local low water" datum. The last two vertical datums were inferred to be equivalent to MLW.

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

After converting all NOS survey data to MHW (see Section 3.2.1), the data were displayed in ESRI ArcMap and reviewed for digitizing errors against scanned original survey smooth sheets and edited as necessary. The surveys were also compared to the topographic, bathymetric, and topographic–bathymetric datasets, the combined coastline, and NOS raster nautical charts (RNCs). The surveys were clipped to remove soundings that overlap the more recent USACE bathymetric surveys.

Table 6: Digital NOS hydrographic surveys used in compiling the Daytona Beach DEM.

NOS Survey ID	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Horizontal Datum of digital records*
H01047	1870	10,000	mean low water	NAD27
H01148A	1872	5,000	mean low water	NAD27
H01148B	1872	5,000	mean low water	NAD27
H01232A	1874	5,000	mean low water	NAD27
H01232B	1874	5,000	mean low water	NAD27
H01232C	1874	5,000	mean low water	NAD27
H01233A	1874	5,000	mean low water	NAD27
H01233B	1874	5,000	mean low water	NAD27
H01234A	1874	5,000	mean low water	NAD27
H01234B	1874	5,000	mean low water	NAD27
H01289B	1874	5,000	mean low water	NAD27
H01289C	1874	5,000	mean low water	NAD27
H01290	1874/75	10,000	mean low water	NAD27
H01291	1875	20,000	mean low water	NAD27
H04478	1925	10,000	mean low water	NAD27
H06132	1935/37	10,000	mean lower low water	NAD27
H06263	1937	10,000	mean lower low water	NAD27
H06302	1938	10,000	mean lower low water	NAD27
H06306	1938	5,000	mean low water	NAD27
H06307	1938	10,000	mean low water	NAD27
H06308	1938	5,000	mean low water	NAD27
H06310	1938	5,000	avg water level during low river stages	NAD27
H06311	1938	5,000	mean low water	NAD27
H06312	1938	5,000	mean low water	NAD27
H06313	1938	5,000	avg water level during low river stages	NAD27
H06431	1939	5,000	mean low water	NAD27
H06432	1939	5,000	mean low water	NAD27
H06433	1939	5,000	mean low water	NAD27
H06434	1939	5,000	mean low water	NAD27

H06435	1939	10,000	mean low water	NAD27
H06676	1941	10,000	mean lower low water	NAD27
H08840	1965	80,000	mean low water	NAD27
H08879	1966	80,000	mean low water	NAD27
H08937	1966	80,000	mean low water	NAD27
H09344	1973	40,000	mean low water	NAD27
H09367	1973	80,000	mean low water	NAD27
H09358	1973/74	40,000	mean low water	NAD27
H09371	1974	40,000	mean low water	NAD27
H09455	1974	40,000	mean low water	NAD27
D00082	1983	25,000	local low water	NAD83
H10071	1983	10,000	local low water	NAD83

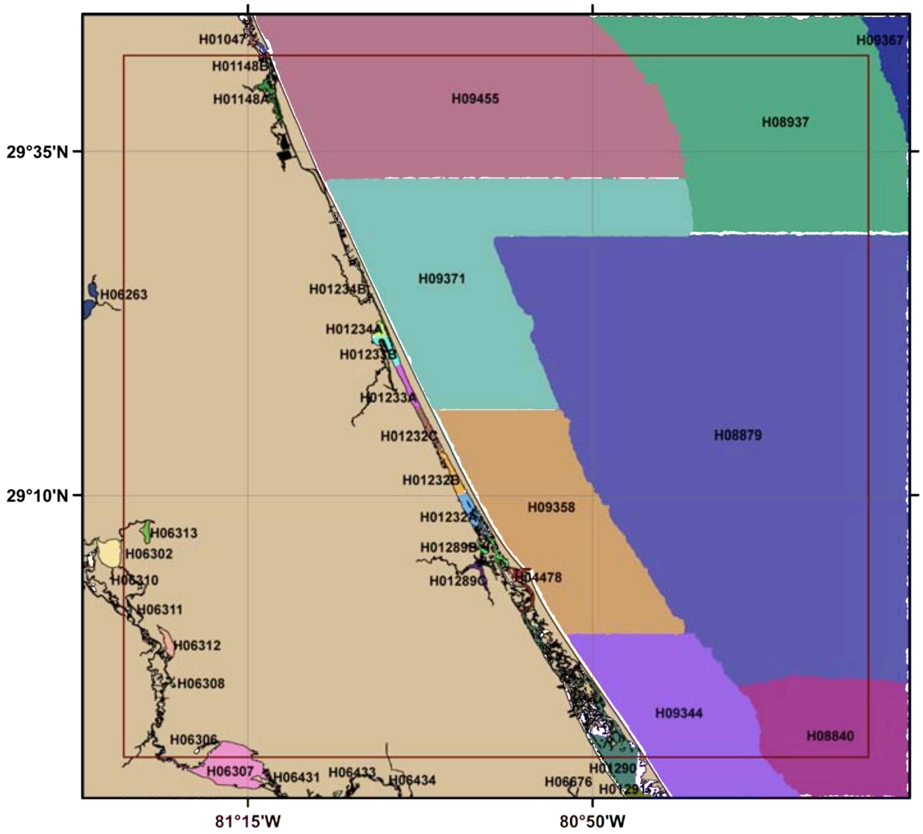

Figure 6. *Digital NOS hydrographic survey coverage in the Daytona Beach region. Some older surveys were not utilized as they have been superseded by more recent surveys. DEM boundary in red, land areas in brown.*

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

The USACE, Daytona Beach District provided NGDC with six recent bathymetric surveys located in Daytona Beach, Ponce Inlet, St. John River, and the Atlantic Intracoastal Waterway (Fig. 5). The surveys were collected in 2006, and referenced to NAD83 Florida State Plane East (survey feet) and MLLW (feet) datums. The files were converted to WGS84 and MHW using FME. The surveys consist of profiles 50 to 200 meters long, averaging 50 meters apart. Point spacing along the profiles is generally less than 1 meter.

3.1.3 Topography

Topographic datasets in the Daytona Beach region were obtained from Volusia County Special Projects, St. Johns County GIS Division, Lake County GIS Division, Jones Edmunds & Associates, Inc., and the U.S. Geological Survey (USGS; Table 7; Fig. 7). The Lake County data was outside the boundaries of the Daytona Beach DEM and not used. The LiDAR data from Jones Edmunds and Associates covered Flagler County, in the central part of the DEM region, however, the data were not processed to bare earth and vegetation and buildings were significantly represented in the data. NGDC therefore choose not to use the Flagler County LiDAR data.

Table 7: Topographic datasets used in compiling the Daytona Beach DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
Volusia County	2006	Topographic LiDAR	1 meter	NAD83 Florida East Sate Plane, (survey feet)	NAVD88 (feet)	
St Johns County	2003–2004	Topographic LiDAR	1 meter	NAD83 Florida East Sate Plane, (survey feet)	NAVD88 (feet)	
USGS	1999-2000	NED DEM	1/3 arc-second	NAD83 geographic	NAVD88 (meters)	http://ned.usgs.gov/

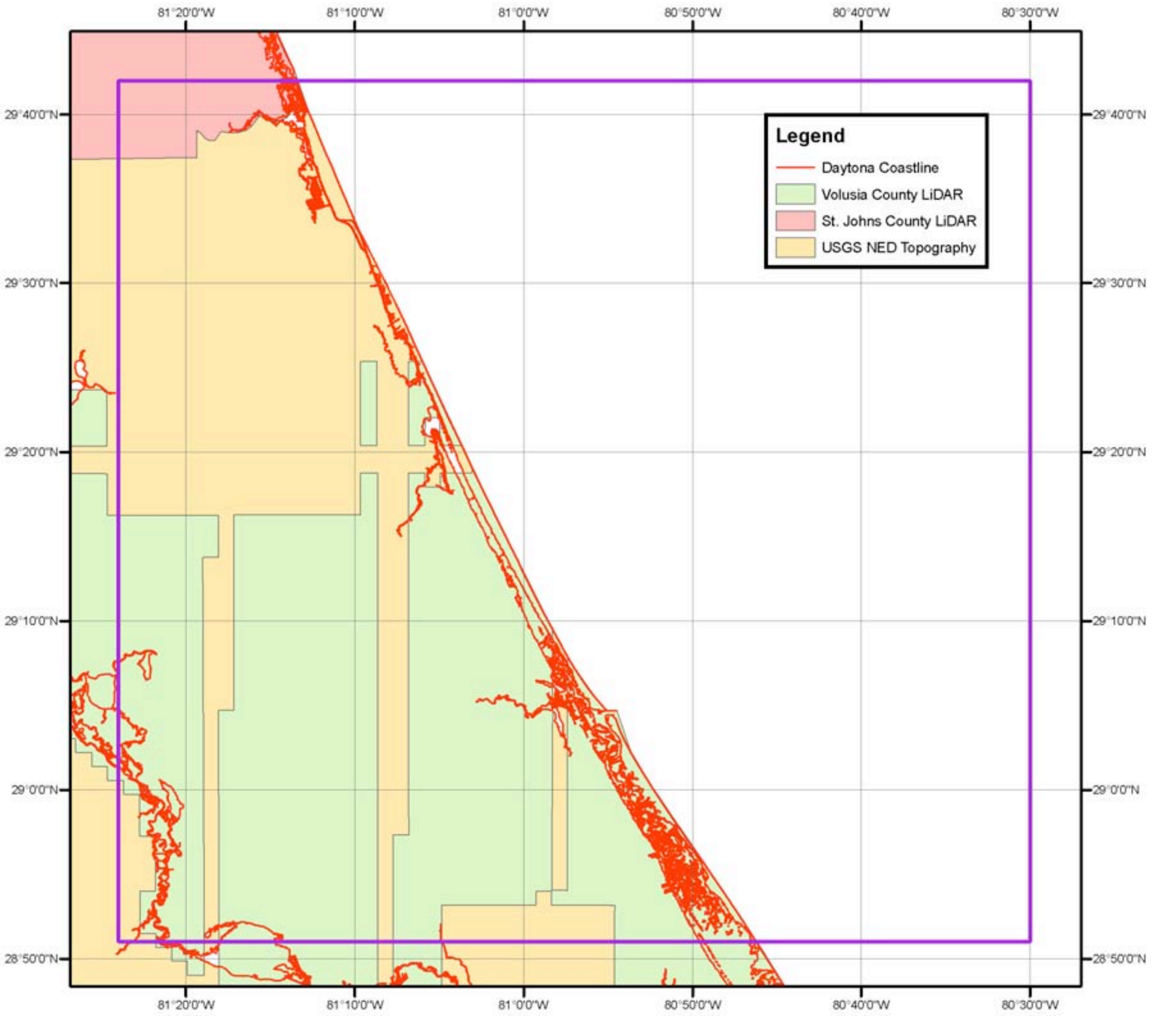

Figure 7. *Source and coverage of topographic datasets used to compile the Daytona Beach DEM. DEM boundary in purple.*

1) Volusia County topographic LiDAR

Volusia County Special Projects provided NGDC with topographic LiDAR data[2], in NAD83 Florida East State Plane (survey feet) datum and NAVD88 vertical datum, for Volusia County, Florida from a survey flight conducted in March 2006. These data have elevation points spaced approximately 1 meter apart covering the southern part of the Daytona Beach DEM region. NGDC processed the raw LAS files with Quick Terrain Modeler (http://www.appliedimagery.com/) to extract the second return, which roughly corresponds to bare earth. The data were transformed to WGS84 geographic coordinates and gridded with MB-system's (http://www.ldeo.columbia.edu/res/pi/MB-System/) 'mbgrid' tool to resample the dense bare-earth LiDAR data to 1/3 arc second cell size (see Section 3.3.2). The Volusia County LiDAR grid was brought into ArcMap (Fig. 8), where it was evaluated, clipped to the coastline to remove false returns from water bodies, and transformed to MHW. Gaps within the grid are the result of QT Modeler's inability to read some of the files provided to NGDC. The Volusia LiDAR data provided greater resolution of morphologic features compared with USGS NED topography, though on average the NED elevations were close to the Volusia County LiDAR elevations.

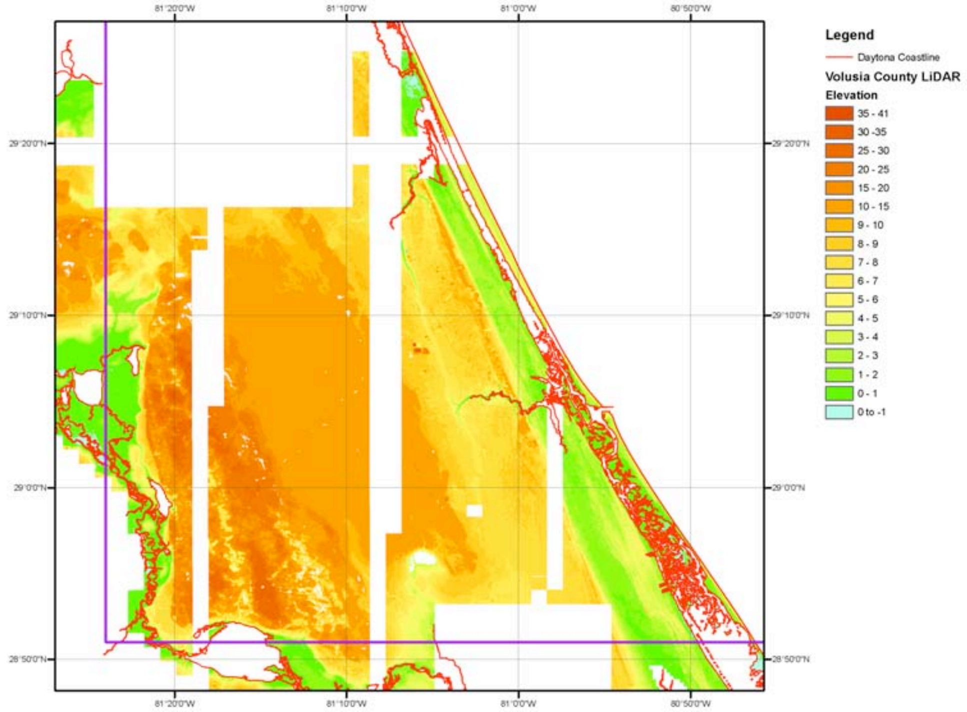

Figure 8. *Gridded relief image of the Volusia County topographic LiDAR data used in compiling the Daytona Beach DEM. DEM boundary in purple.*

---

[2] The LiDAR data was acquired using a Leica ALS50 from an altitude of 3,281' above ground level to provide a nominal ground sample distance of 3.3-feet. The scanner field of view was 42-degrees, and the scan rate was 33-hertz. First and last return data was collected along with the signal return intensity. A total of 141 flights of LiDAR data were acquired. Flight lines were flown with a 30% sidelap, providing a line-to-line swath width of 1,763-feet. Ten (10) airborne GPS base station locations were utilized across the county with as minimum of two redundant airborne GPS bases stations in operation during any data acquisition with maximum line-of-sight distance between the base station and aircraft of 30-km. The LiDAR data was reduced using Grafnav (Waypoint Consulting) for GPS post-processing, PosProc (Applanix Crop) for IMU processing, ALS50 Post Processor (LH Systems) to initial LiDAR processing, TerraScan (Terrasolid) for initial point classification, and proprietary Woolpert developed software for refining the point classification and QC. The LiDAR points within this file were derived from a full resolution LiDAR dataset using Keypoint identification. This results in a reduciton of the total number of points and retains only those points necessary to define the ground surface at the specified accuracies and tolerances. For a complete description of survey methods, processing methods, software, system parameters, and accuracy analysis, see the Florida MTS Report of Specific Purpose Survey, 2006/2007 Volusia County LiDAR DTM Project, dated June 2007. [Extracted form metadata.]

2) St. Johns County topographic LiDAR

The St. Johns County GIS Division provided NGDC with topographic datasets, in NAD83 Florida East State Plane (survey feet) datum and NAVD88 vertical datum, for St. Johns County, Florida (Fig. 7). The datasets included LiDAR-derived elevation points (processed to bare earth), 1-foot bare-earth topographic contours derived from the LiDAR data[3] using aerial photographs as an interpolation aid, and hydrographic lines, also derived from the LiDAR data and aerial photographs (e.g., Fig. 9). NGDC transformed the datasets to WGS84 geographic horizontal and MHW vertical datums using FME. The hydrographic lines near the Atlantic Coast were inferred to be at MHW and were used in building the combined coastline for Daytona Beach, however, interior lines defining rivers and lakes were clearly not at MHW and were not used in building the Daytona Beach DEM. NGDC extracted points sampled every 10 meters along the topographic contours, using GEODAS, which, along with the LiDAR elevations, were used in building the DEM.

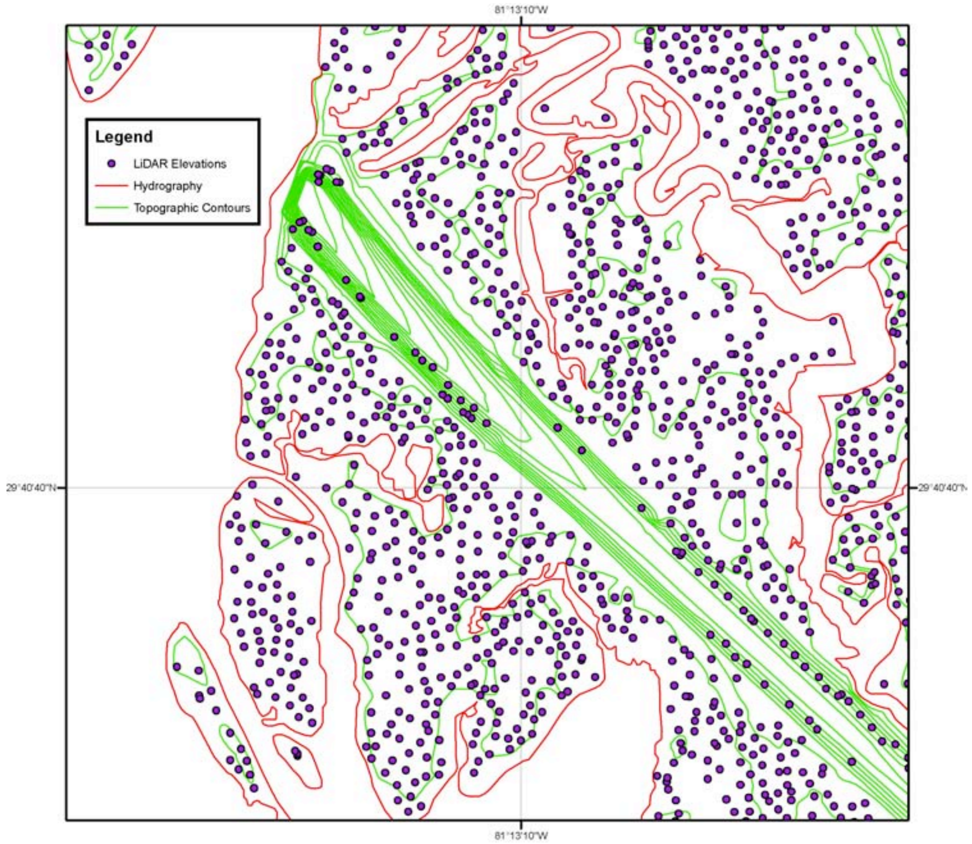

Figure 9. *Example of St. Johns County topographic data. Point elevations are from a 2003–2004 LiDAR survey. Hydrographic lines and topographic contours were derived from the LiDAR data and aerial photographs. Note the contours defining the ridge (highway), which were drawn using aerial photographs as a guide. No gridding algorithm is capable of properly representing such a linear morphologic feature from point elevation data alone. Contour interval: 1 foot.*

---

[3] The LiDAR data was acquired using a Leica ALS40. Ninety-three (93) flight lines of LiDAR data were acquired in 6 sessions across the County between January 17 and February 7, 2004. The average GSD of the raw LiDAR data was 3.3-feet. Three (3) concurrent airborne GPS base stations were used for each acquisition session. The ABGPS data was reduced using the GrafNav software package by Waypoint Consulting, Incorporated. The IMU data was reduced using the PosProc software package by Applanix Corporation. The initial LiDAR "point cloud" was derived through the ALS Post Processor software package by Leica Geosystems. The aircraft, LiDAR system, and associated computer hardware and software are owned and operated by Woolpert LLP. Once the initial LiDAR "point cloud" was derived, Woolpert performed QC to look for any systematic error within the LiDAR flights using proprietary software. After systematic error was identified and removed, the individual LiDAR flights were clipped to remove overlap between adjacent flight lines and provide a homogeneous coverage over the project extents. Using the homogeneous coverage, above ground features were classified and removed using proprietary software to produce the bare-earth coverage. [Extracted from survey report.]

3) 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 Daytona Beach region[4]. Data are in NAD83 geographic coordinates and NAVD88 vertical datum (meters), and are available for download as raster DEMs. The bare-earth elevations have a vertical accuracy of +/- 7 to 15 meters depending on source data resolution. See the USGS Seamless web site for specific source information (http://seamless.usgs.gov/). The dataset was derived from USGS quadrangle maps and aerial photographs based on topographic surveys; it has been revised using data collected in 1999 and 2000. The NED DEM included "zero" elevation values over the open ocean (Fig. 10), which were removed from the dataset by clipping to the combined coastline. The NED DEM was also clipped to the extents of the Volusia and St Johns county LiDAR datasets to prevent degradation of those two higher-resolution datasets in the Daytona Beach DEM.

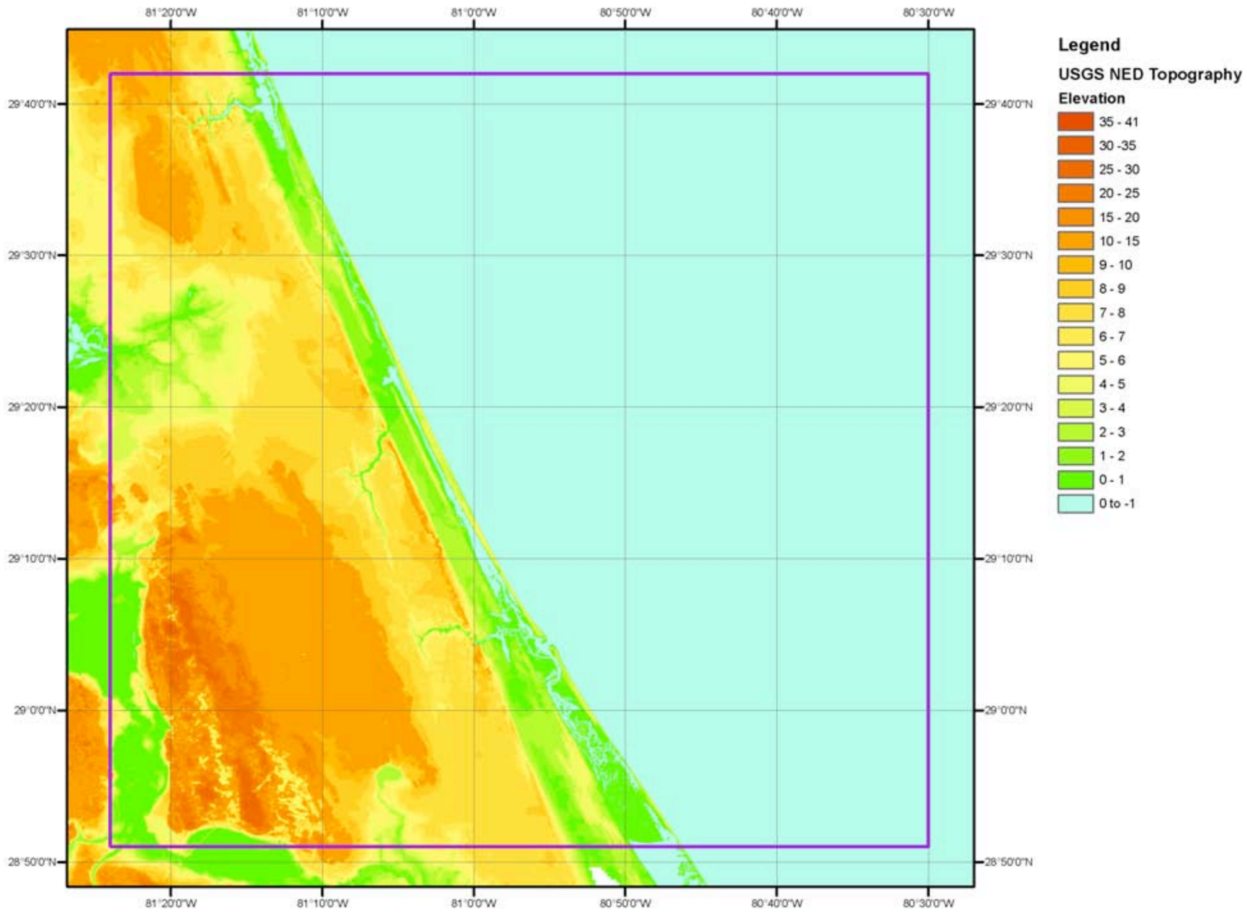

Figure 10. *Gridded relief image of USGS NED DEM. Blue is zero elevation over water, which had to be clipped from the NED DEM. DEM boundary in purple.*

---

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

3.1.4 Bathymetry–Topography

One bathymetric–topographic LiDAR dataset was available from NOAA’s Coastal Services Center (CSC) Coastal Remote Sensing Program, covering the Atlantic coastal region near Daytona Beach (Fig. 11, Table 8).

Table 8: Bathymetric–topographic dataset used in compiling the Daytona Beach DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*
JALBTCX/CSC	2006	Coastal LiDAR	< 5 meters	NAD83 geographic	NAVD88 (meters)

1) JALBTCX coastal LiDAR

The Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) conducted a bathymetric–topographic LiDAR survey of the Florida east coast in 2006 using the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system[5]. These data are published on the NOAA CSC web site (http://maps.csc.noaa.gov/TCM/) and were downloaded at 5-meter point spacing in NAD83 geographic and NAVD88 datums. Horizontal accuracy is 3 m, and vertical accuracy is estimated at 30 cm. These data have not been processed to bare earth, so buildings and trees are represented in the data. Because of this, the coastal LiDAR data was given lower weighting in the gridding process than the Volusia and St. Johns County topographic LiDAR data (see Section 3.3.4; Table 10).

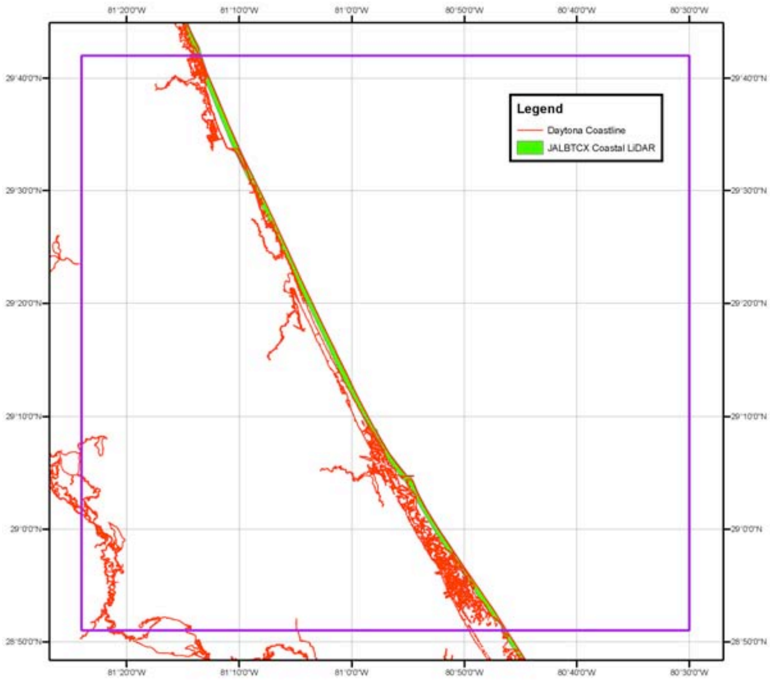

Figure 11. *Spatial coverage of JALBTCX coastal bathymetric–topographic LiDAR survey. Combined coastline in red; DEM boundary in purple..*

---

[5] These data were collected using a SHOALS-1000T system. It is owned and operated by Fugro Pelagos performing contract survey services for the US Army Corps of Engineers. The system collects topographic lidar data at 10kHz and hydrographic data at 1kHz. The system also collects RGB imagery at 1Hz. Aircraft position, velocity and acceleration information are collected through a combination of Novatel and POS A/V equipment. Raw data are collected and transferred to the office for downloading and processing in SHOALS GCS software. GPS data are processed using POSPac software and the results are combined with the lidar data to produce 3-D positions for each lidar shot. These data are edited using Fledermaus software where anomalous data are removed from the dataset. The edited data are unloaded from SHOALS GCS, converted from ellipsoid to orthometric heights, based on the GEOID03 model, and split into geographic tiles covering approximately 5km each. [Extracted from metadata.]

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Daytona Beach 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 worst-case scenario for inundation modeling. Units were first converted from feet to meters as appropriate. PMEL provided NGDC with conversion grids for MLLW to MHW, and NAVD88 to MHW for the Daytona Beach region. These grids were derived from vertical datum relationships measured at tide stations in the Daytona Beach region (http://tidesandcurrents.noaa.gov/).

1) **Bathymetric data**

   NOS hydrographic surveys in MLW were transformed to MLLW, using FME software, by adding a constant of 0.047, as measured at Daytona Beach Shores tide station, #8721120 (Table 9). Conversion of these soundings to MHW, along with NOS and USACE surveys in MLLW, was accomplished using the MLLW-to-MHW conversion grid.

2) **Topographic data**

   The USGS NED 1/3 arc-second DEM and the Volusia County and St Johns County LiDAR data were originally referenced to NAVD88. Conversion to MHW, using FME software, was accomplished by using the NAVD88-to-MHW grid provided by the PMEL.

Table 9. Relationship between Mean High Water and other vertical datums at the Daytona Beach Shores tide station, #8721120.

Vertical datum	*Difference to MHW*
NAVD88	-0.364 meters
MSL	-0.606 meters
MLW	-1.190 meters
MLLW	-1.237 meters

3.2.2 Horizontal datum transformations

Datasets used to compile the Daytona Beach DEM were originally referenced to NAD83 Florida East State Plane (survey feet), NAD83 geographic, NAD27 geographic, or WGS84 geographic horizontal datums. The relationships and transformational equations between these horizontal datums are well established. All data were converted to a horizontal datum of WGS84 geographic using FME and GMT 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:

- Data values were present over the Atlantic Ocean and rivers in the NED and Volusia County LiDAR topographic data. Each dataset required automated clipping to the combined coastline.
- Digital, measured bathymetric values from NOS surveys date back over 100 years. More recent data, such as the USACE hydrographic surveys differed from older NOS data by as much as 10 meters. The older NOS survey data were excised where more recent bathymetric data exists.
- The JALBTCX coastal bathymetric–topographic LiDAR dataset had not been processed to bare earth.

3.3.2 Gridding of Volusia County topographic LiDAR data

The high density and large volume of the Volusia County topographic LiDAR data necessitated gridding of this dataset for visualization and evaluation purposes. A 1/3 arc-second grid of the LiDAR data—0.05 degrees larger than the Daytona Beach DEM gridding region—was generated using MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/), 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 tool 'mbgrid' was used to create the grid, using low tension to ensure that the grid accurately represented the underlying data. This grid was evaluated in ArcMap, clipped to the extent of the LiDAR data—to limit interpolation into areas without data—then exported as an xyz file for use in the final gridding process (see Table 10).

3.3.3 Smoothing of bathymetric data

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

The point data were median-averaged using the GMT tool 'blockmedian' to create a 1 arc-second grid 0.05 degrees (~5%) larger than the Daytona Beach DEM gridding region. The GMT tool 'surface' was then used to fill in the data gaps. 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. 12), converted to a raster and used in the final gridding process (see Table 10).

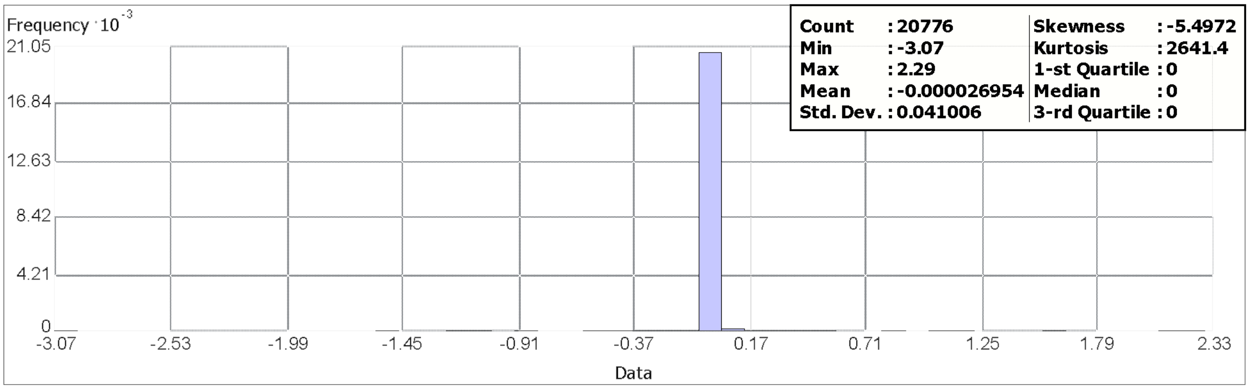

Figure 12. *Histogram of the differences between NOS hydrographic survey H09371 and the 1 arc-second pre-surfaced bathymetric grid.*

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 Daytona Beach DEM. 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 10. Greatest weight was given to the Volusia and St. Johns counties bare-earth LiDAR data. Least weight was given to the pre-surfaced 1 arc-second bathymetric grid. Gridding was performed in quadrants that were merged using GMT's 'grdblend' tool to create the final 1/3 arc-second Daytona Beach DEM.

Table 10. Data hierarchy used to assign gridding weight in MB-System.

Dataset	*Relative Gridding Weight*
Volusia County topographic LiDAR	1000
St. Johns County topographic LiDAR	1000
USACE bathymetric surveys	100
JALBTCX bathymetric–topographic LiDAR	100
USGS NED topographic DEM	10
NOS hydrographic surveys: bathymetric soundings	10
Combined coastline	10
Pre-surfaced bathymetric grid	1

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Daytona Beach DEM is dependent upon the datasets used to determine corresponding DEM cell values. Topographic features have an estimated accuracy of 1 to 10 meters: Volusia County and St. Johns County topographic LiDAR data and JALBTCX coastal LiDAR data have accuracies between 1 and 3 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 subaerial topographic features. Positional accuracy is limited by: the sparseness of deep-water soundings; potentially large positional uncertainty of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys; and by the morphologic change that occurs in this dynamic region.

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the Daytona Beach 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 Volusia County and St. Johns County topographic LiDAR data and JALBTCX coastal LiDAR data, and up to 7 meters for NED topography. Bathymetric areas have an estimated accuracy of between 0.1 meters and a few meters. Those values were derived from the wide range of input data sounding measurements from the early 20th century to recent, GPS-navigated USACE bathymetric 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 Daytona Beach DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 13). The DEM was transformed to UTM Zone 9 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. 14). 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 Daytona Beach DEM in its final version.

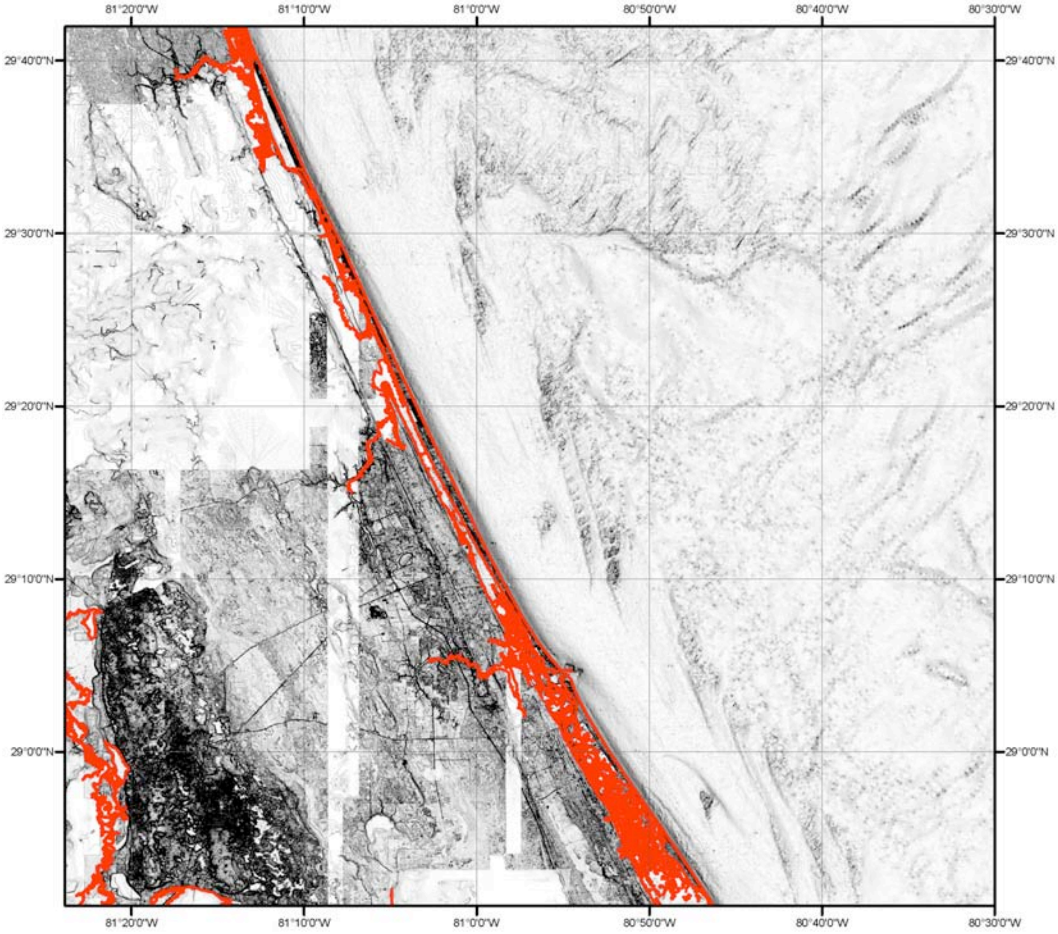

Figure 13. *Slope map of the Daytona Beach DEM. Flat-lying slopes are white; dark shading denotes steep slopes; combined coastline in red.*

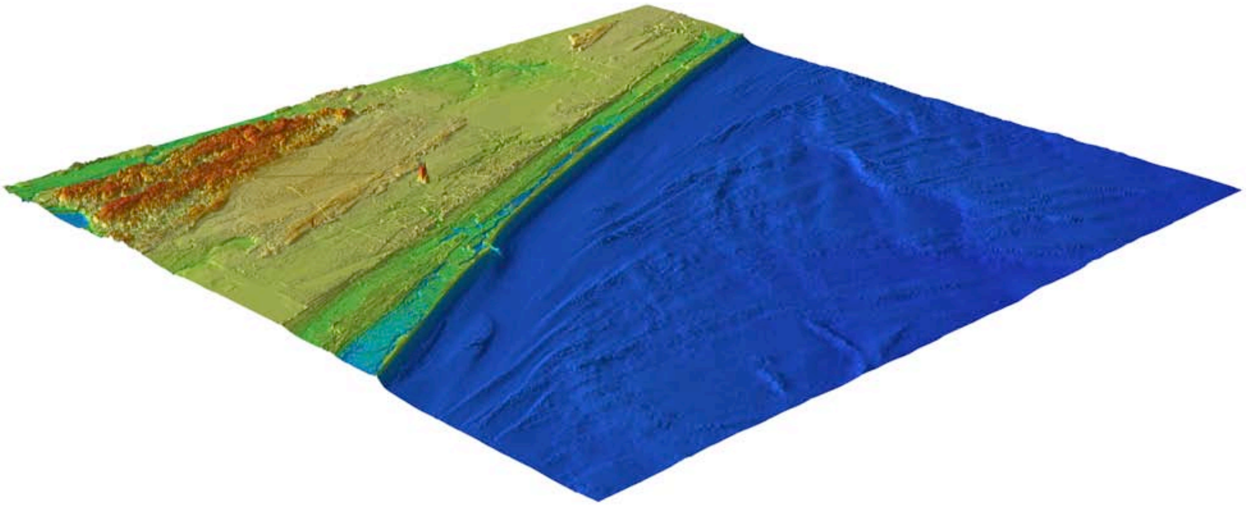

Figure 14. *Perspective view from the southeast of the Daytona Beach DEM. The red isolated peak to the east of Ponce de Leon Inlet is the Tomoka landfill. Vertical exaggeration–times 50.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Daytona Beach 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). Histogram of the differences between one St. Johns County topographic LiDAR file, and one JALBTCX coastal LiDAR file with the Daytona Beach DEM are shown in Figures 15 and 16. Differences cluster around zero, with only a handful of soundings exceeding 0.5-meter discrepancy from the DEM.

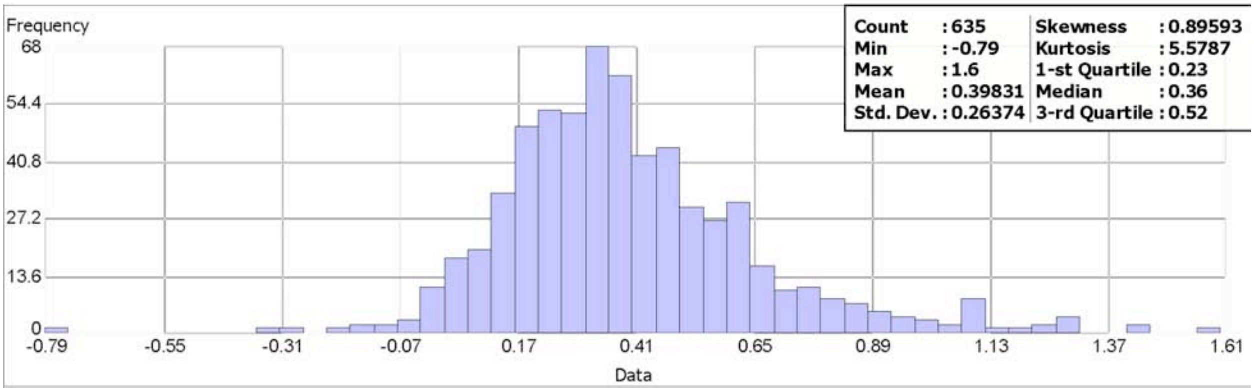

Figure 15. *Histogram of the differences between one St Johns County LiDAR file and the Daytona Beach DEM.*

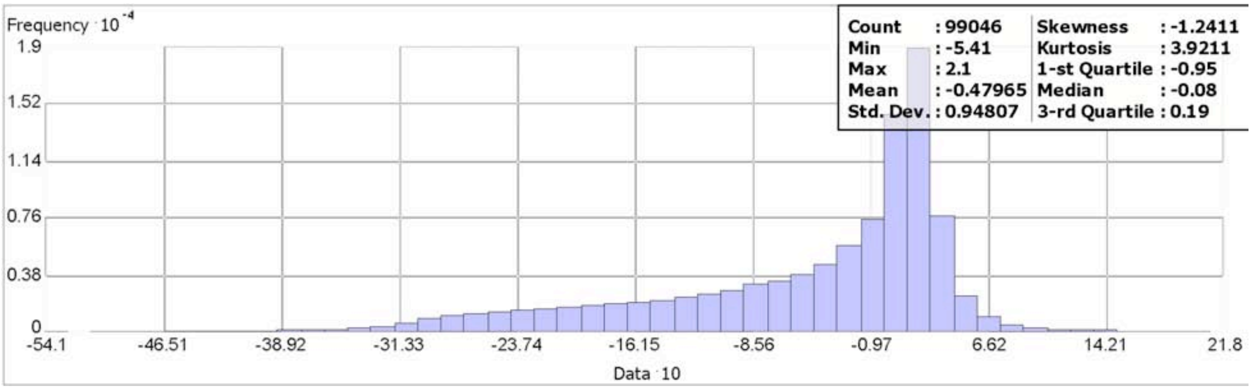

Figure 16. *Histogram of the differences between one JALBTCX LiDAR file and the Daytona Beach DEM.*

3.4.5 Comparison with NGS geodetic monuments

The elevations of 1637 NOAA NGS geodetic monuments were extracted from online shape files of monument datasheets (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl), which give monument positions in NAD83 (typically sub-mm accuracy) and elevations in NAVD88 (in meters). Elevations were shifted to MHW vertical datum for comparison with the Daytona Beach DEM (see Fig. 18 for monument locations). Differences between the Daytona Beach DEM and the NGS geodetic monument elevations range from -11 to 14 meters, with the majority of them being within ± 2 meters. Positive values indicate that the DEM is greater than the monument elevation (Fig. 17). The largest discrepancies with the DEM were generally caused by monuments being mounted on bridges and other man-made structures or by monument locations that are only known to within 6 arc-seconds (~180 meters). At least one monument has been lost and presumed destroyed.

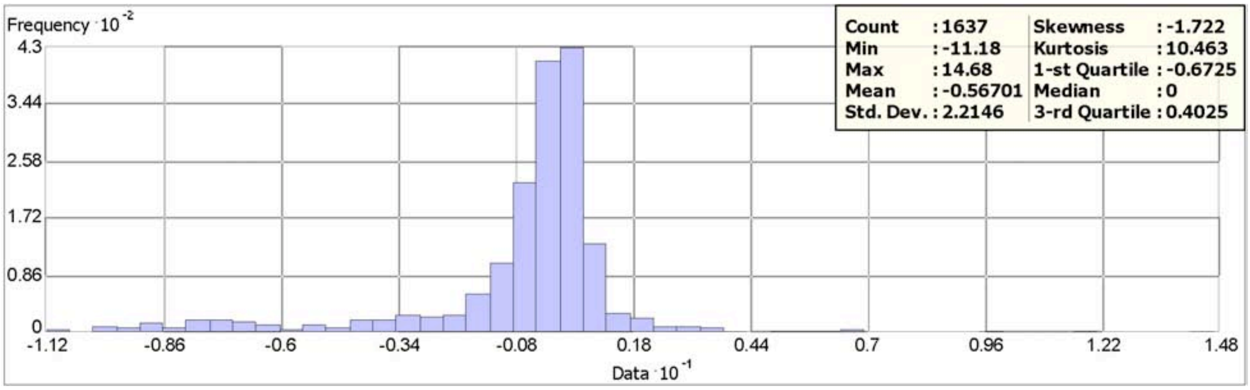

Figure 17. *Histogram of the differences between NGS geodetic monument elevations and the Daytona Beach DEM.*

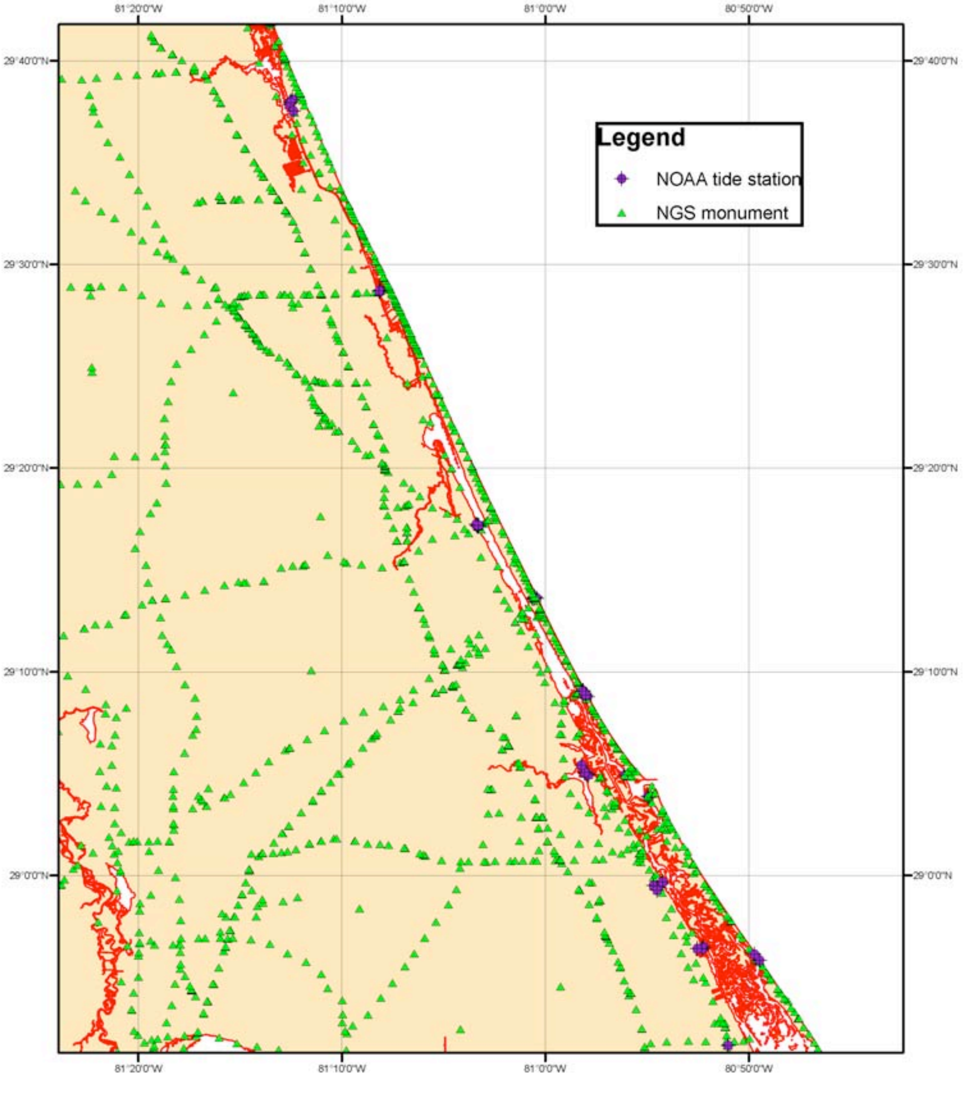

Figure 18. *Location of NGS geodetic monuments and NOAA tide stations.*
NGS monument elevations were used to evaluate the DEM. Combined coastline in red.

4. SUMMARY AND CONCLUSIONS

A topographic–bathymetric digital elevation model of the Daytona Beach, Florida 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, GEODAS, and Quick Terrain Modeler software.

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

- Jones Edmunds & Associates, Inc. graciously provided NGDC with topographic LiDAR data for all of Flagler County, which had not been processed to bare earth. The significant amount of vegetation and buildings represented in the data precluded their use in the Daytona Beach DEM. Processing of these data to bare earth would result in nearly complete topographic lidar coverage for the region.
- Process JALBTCX coastal LiDAR data to bare earth.

5. ACKNOWLEDGMENTS

The creation of the Daytona Beach DEM was funded by the NOAA Pacific Marine Environmental Laboratory. The authors thank Chris Chamberlin and Vasily Titov (PMEL), Lisa Holland (USACE, Jacksonville District), Kitty Cooper (Lake County GIS Division), Arden Fontaine (Volusia County Special Projects), Mark Nelson and Bill Millinor (Jones Edmunds & Associates, Inc), and Michael Campbell (St. Johns County GIS Division).

6. REFERENCES

Nautical Chart #11480, 40th Edition, 2007. Charleston Light to Cape Canaveral. Scale 1:449,659. U.S. Department of Commerce, NOAA, National Ocean Service, Office of Coast Survey.

Nautical Chart #11484, 23rd Edition, 2007. Ponce de Leon Inlet to Cape Canaveral. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Office of Coast Survey.

Nautical Chart #11485, 35th Edition, 2007. Intracoastal Waterway Tolmato River to Palm Shores. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Office of Coast Survey.

Nautical Chart #11486, 15th Edition, 2007. St. Augustine Light to Ponce de Leon Inlet. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Office of Coast Survey.

7. DATA PROCESSING SOFTWARE

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

FME 2007 – 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/