NOAA Technical Memorandum NESDIS NGDC-1

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National Geophysical Data Center
Marine Geology and Geophysics Division
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Digital Elevation Models of Myrtle Beach, South Carolina: Procedures, Data Sources and Analysis

1. Introduction

In May 2006, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed two spatially coincident bathymetric/topographic digital elevation models (DEMs) of Myrtle Beach, South Carolina for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). A 1/3 arc-second (~10 meter) elevation grid was generated from numerous, diverse digital datasets in the region (grid boundary shown in Figs. 1 and 2). This grid was then resampled to generate a 1 arc-second (~30 meter) grid. The grids will be used as input for the Method of Splitting Tsunami (MOST) Model (http://www.pmel.noaa.gov/pubs/PDF/tito1927/tito1927.pdf) developed by PMEL to simulate tsunami generation, propagation and inundation. An intermediate 9 arc-second bathymetric grid of the East Coast previously developed by NGDC, will also be used as input to the MOST Model. This report provides a summary of the data sources and methodology used in developing the grids for Myrtle Beach, South Carolina.

2. Study Area

The study area covers the coastal community of Myrtle Beach, South Carolina in an area known as the Grand Strand. It is situated within Long Bay between the Atlantic Intracoastal Waterway to the west and the Atlantic Ocean to the East (Fig. 1). According to the 2000 Census, the city of Myrtle Beach is at the heart of the 13th fastest growing metropolitan area in the U.S. with a population of 22,759. Known for its wide sandy beaches and numerous golf courses, the Myrtle Beach area is one of the major coastal resorts and tourist destinations along the South Atlantic seaboard, attracting over 14 million visitors a year (http://www.cityofmyrtlebeach.com/).

About half of South Carolina is part of the South Atlantic Coastal Plain which is fringed by the Sea Islands and separated from the mainland by salt marshes, lagoons, and sounds. The Coastal Plain surface is almost level, rising gradually inland. The gently, curving, elliptical shoreline follows a northeast to southwest direction. Swamps and marshes are widespread and are made up of characteristic dark peat and muck, while other soils are generally sandy and light. Below the surface are unconsolidated sedimentary beds of sand and clay.

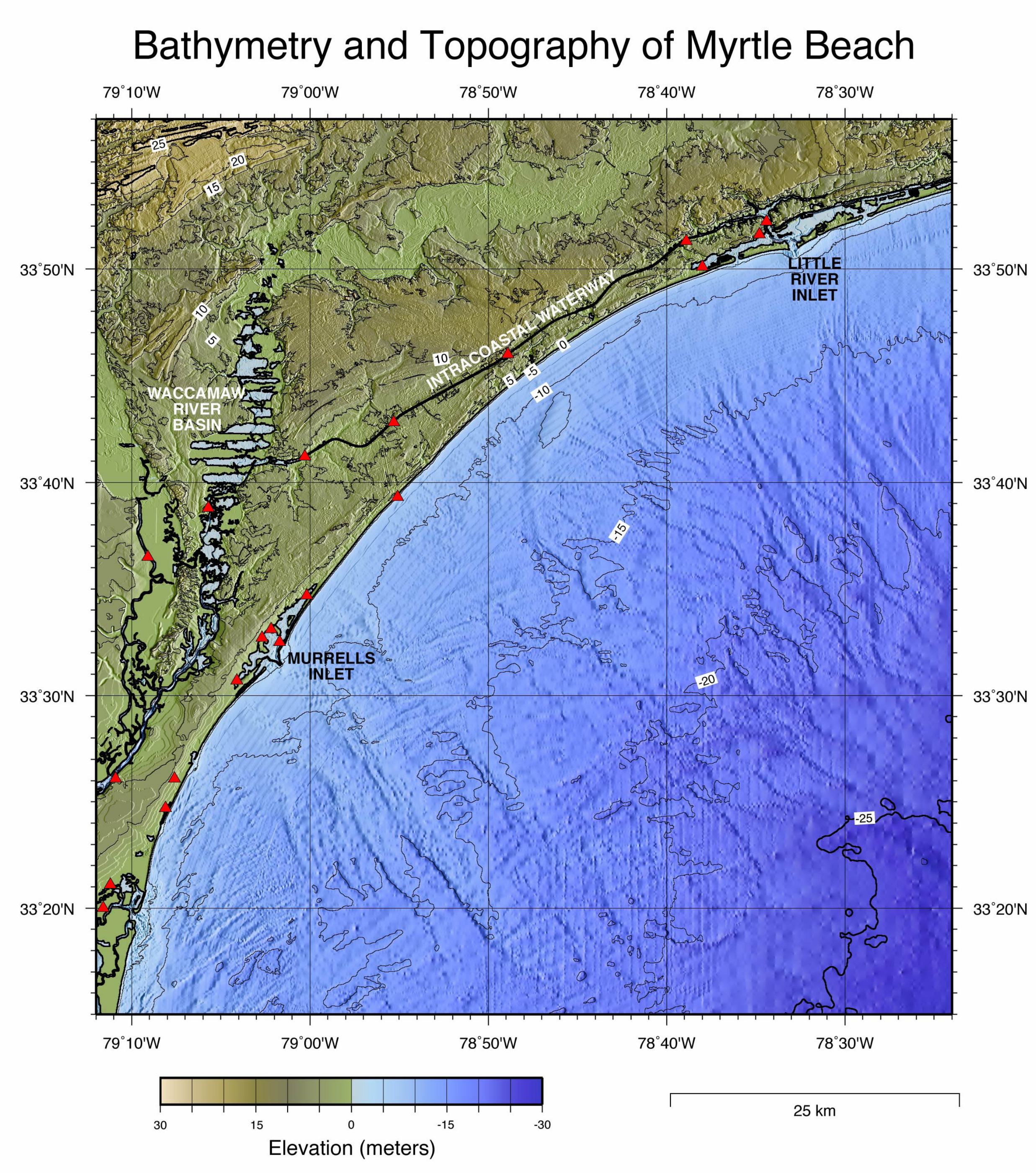

Figure 1. Shaded-relief image, derived from the 1 arc-second grid, of the Myrtle Beach, South Carolina area. Red triangles locate tidal bench marks listed in Table 7. Contour interval: 5 meters, referenced to MHW.

3. METHODOLOGY

The digital elevation grids were developed to meet PMEL required specifications (Table 1), based on input requirements for the MOST inundation model. The best available data were obtained by NGDC and used to produce the grids. Data processing, grid assembly, and quality assessment are described in the following subsections.

Table 1: PMEL specifications for the Myrtle Beach, South Carolina grids.

Grid Area	Myrtle Beach, South Carolina
Coverage Area	78.4º W to 79.2º; 33.25º N to 33.95º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System (WGS84)
Vertical Datum	Mean High Water
Vertical Units	Meters
Grid Spacings	1 arc-second and 1/3 arc-seconds
Grid Format	ASCII raster grid

3.1 Data Sources and Processing

Shoreline, bathymetric, topographic, and shoreline-crossing data (Fig. 2) were obtained from numerous federal and state government agencies, universities and private companies, including the U.S. Geological Survey (USGS), the NOAA National Ocean Service (NOS), the U.S. Army Corps of Engineers (USACE), Coastal Carolina University (CCU), Coastal Science and Engineering, Inc. (CSE), and Horry County, South Carolina. Datasets were converted into ESRI shape files and transformed to Mean High Water (MHW) and WGS84 geographic coordinates. As no V-Datum (http://vdatum.noaa.gov) model was available for the gridding area, vertical datum transformations were applied based on tidal model information supplied by PMEL.

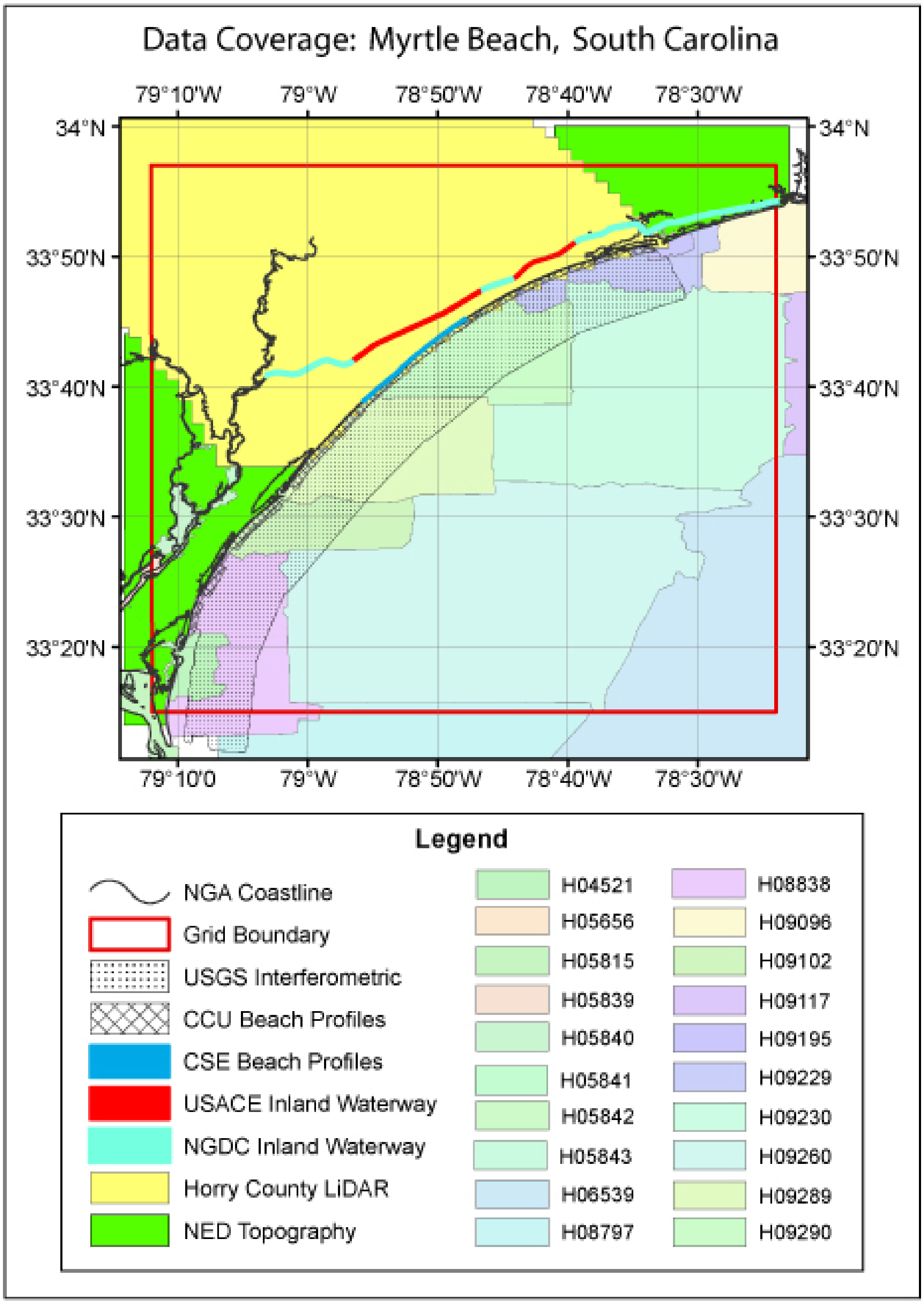

Figure 2. *Coverage of data sources used to compile the 1 arc-second and 1/3 arc-second Myrtle Beach, South Carolina grids.*

3.1.1 Shoreline

Digital shorelines were obtained from the USGS and the National Geospatial-Intelligence Agency (NGA). The NGA Global Imagery-Derived Shoreline corresponds closely with Horry County topographic LiDAR along the open ocean-land boundary and with satellite imagery viewable with Google Earth (e.g., Fig. 3). The USGS National Hydrography Dataset (NHD) shoreline provides a more accurate representation of inland water bodies (rivers, inlets and the Intracoastal Waterway). As the open ocean beach face is clearly resolvable in the LiDAR data, and shoreline-crossing beach profiles exist for much of the coastline, neither digital shoreline was used in the gridding process.

1) **National Hydrography Dataset**

The USGS collaborated with the U.S. Environmental Protection Agency (EPA) to produce the National Hydrography Dataset (http://nhd.usgs.gov/). The NHD is a comprehensive set of seamless digital spatial data based upon the content of USGS Digital Line Graph (DLG) 1:100,000 scale hydrography data integrated with reach-related information from the EPA Reach File Version 3 (RF3). It contains information about surface water features such as lakes, ponds, streams, rivers, springs and wells.

2) NGA Global Imagery-Derived Shoreline

The NGA Global Imagery-Derived Shoreline is an unclassified vector dataset generated by Earth Satellite Corporation (EarthSat) of Rockville, Maryland for NGA, under contract to Boeing in 2004. The shoreline is referenced to MHW and constructed from consistently orthorectified Landsat TM satellite imagery (GeoCover Ortho), acquired between 1998-2002 for NASA under the Global Land Mapping Program (GLMP). NDVI and SWIR models were used to define the landward extent of inundation (i.e., MHW). Independently verified positional accuracy for the source product (GeoCover Ortho) is consistently better than 50m root mean square (RMS) error.

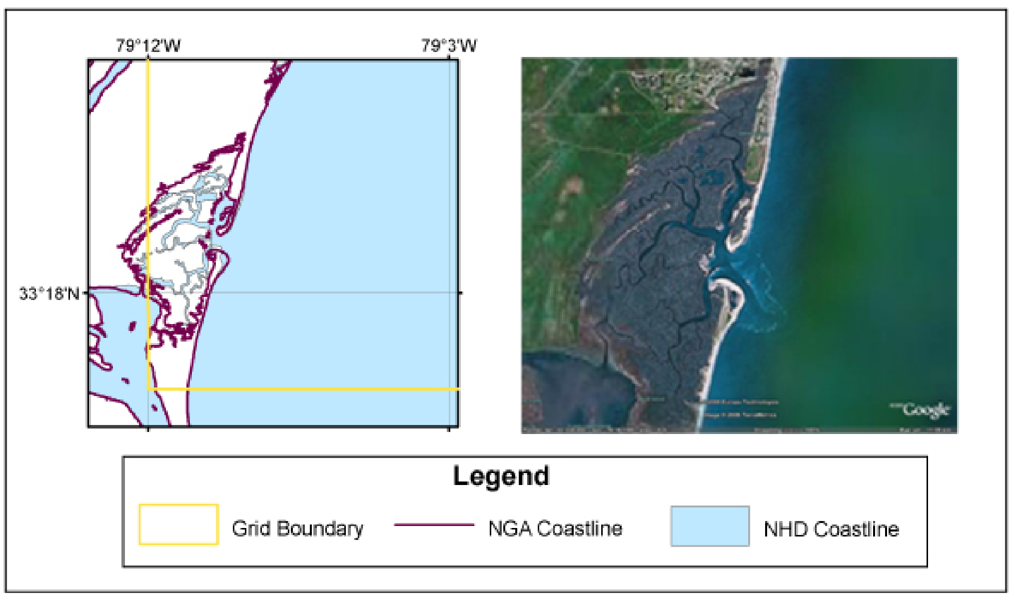

Figure 3. *NGA and NHD coastlines in the area of North Inlet (left) and a Google Earth view of same area (right). The NHD coastline defines inland waterways, while the NGA coastline defines the MHW mark along the open ocean-land boundary.*

3.1.2 Bathymetry

Bathymetric datasets used in the compilation of the grids included 20 NOS hydrographic surveys, USGS gridded interferometric sonar data, USACE Atlantic Intracoastal Waterway surveys, and digitized depths taken from NOS Coast Pilot, Volume 4 and NOAA Nautical Chart #11534.

Table 2. Bathymetric data sources used in gridding.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1925 to 1972	Hydrographic survey soundings	Ranges from 10 meters to 1 kilometer (varies with scale of survey, depth, traffic and probability of obstructions)	NAD27 (undocumented for H04521)	MLW	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
USGS	1999 to 2002	Interferometric sonar grid	100 meters grid spacing	WGS84, UTM Zone 17	MLLW	http://pubs.usgs.gov/of/2004/1013/index.html
USACE	2005 to 2006	Hydrographic surveys within the Intracoastal Waterway	Two parallel survey lines ~ 20 meters apart with ~ 0.4 meter point spacing	NAD83, South Carolina State Planes, US foot	MLW	http://www.sac.usace.army.mil/

1) **NOS hydrographic survey data**

A total of 20 NOS hydrographic surveys conducted between 1925 and 1972 were included in the grid compilation (Fig. 4). The survey data were originally vertically referenced to Mean Low Water (MLW) and horizontally referenced to NAD27, with one survey referenced to an undocumented original horizontal datum (Table 3). Three surveys conducted in 1924 (H04450, H04450I2, and H04450I3) were not included in the compilation, as more recent survey data covered the same areas. Data point spacing for the surveys ranged from about 10 meters in shallow water to 1 kilometer in deep water. All surveys were extracted from NGDC's online database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) in NAD83 and MLW datums.

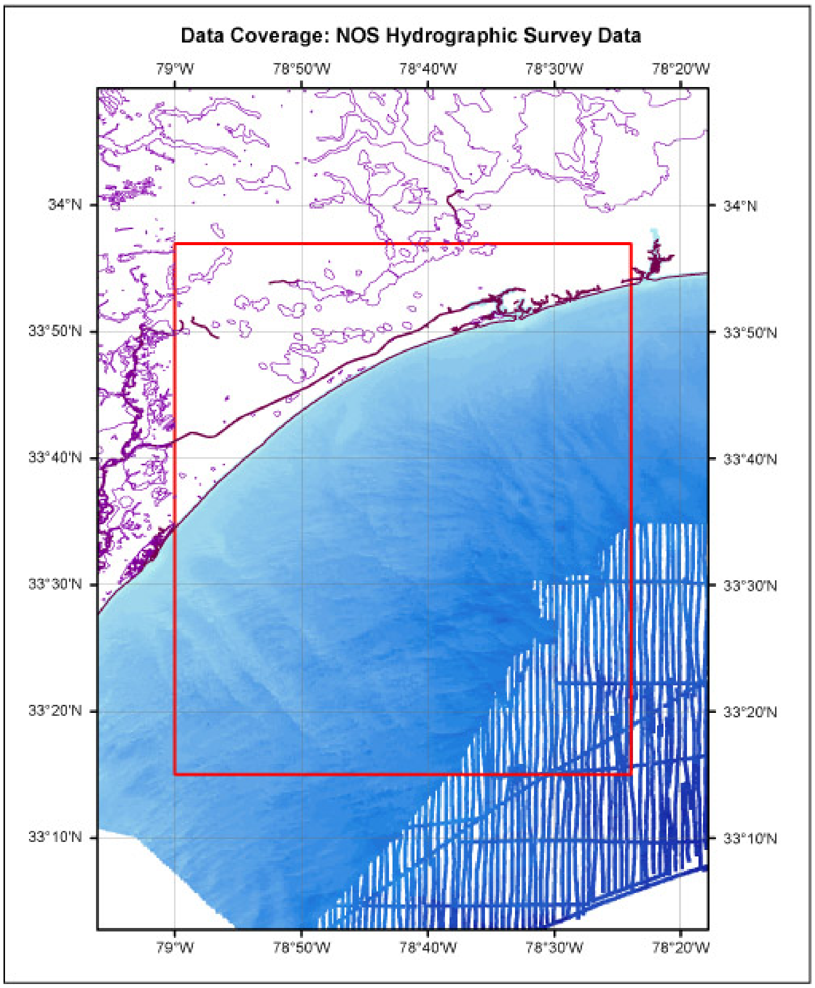

Figure 4. *NOS hydrographic survey data coverage in gridding area, which provides complete coverage of marine areas, though sparse in deep water.*

Table 3. NOS hydrographic surveys included in the compilation of the Myrtle Beach, South Carolina grids.

Survey ID	Year	Region	Survey Scale	Vertical Datum	Horizontal Datum
H04521	1925	Open Ocean	20,000	MLW	UNDOCUMENTED
H05656	1934	Inland Waterway	10,000	MLW	NAD27
H05815	1935	Inland Waterway	10,000	MLW	NAD27
H05839	1935	Inland Waterway	10,000	MLW	NAD27
H05840	1935	Inland Waterway	10,000	MLW	NAD27
H05841	1935	Inland Waterway	10,000	MLW	NAD27
H05842	1935	Inland Waterway	10,000	MLW	NAD27
H05843	1935	Inland Waterway	10,000	MLW	NAD27
H06539	1940	Open Ocean	80,000	MLW	NAD27
H08797	1964	Open Ocean	40,000	MLW	NAD27
H08838	1964/65	Open Ocean	20,000	MLW	NAD27
H09096	1970	Open Ocean	20,000	MLW	NAD27
H09102	1965	Open Ocean	20,000	MLW	NAD27
H09117	1970	Open Ocean	40,000	MLW	NAD27
H09195	1971	Open Ocean	10,000	MLW	NAD27
H09229	1971/72	Open Ocean	20,000	MLW	NAD27
H09230	1971/72	Open Ocean	40,000	MLW	NAD27
H09260	1971/72	Open Ocean	40,000	MLW	NAD27
H09289	1972	Open Ocean	20,000	MLW	NAD27
H09290	1972	Open Ocean	20,000	MLW	NAD27

Due to geomorphologic and anthropogenic changes since the NOS hydrographic surveys were conducted, and resulting inconsistencies between bathymetric and recent topographic elevation values, some editing of the NOS data was necessary. Original NOS hydrographic smooth sheets, NOAA navigation charts (11532, 11534, and 11535) and Google Earth satellite imagery were referenced before making changes to the data, which are documented below.

- **North Inlet: Hydrographic Surveys H04521 and H08838.** Soundings from these surveys, conducted in 1925 and 1964/65 respectively, were edited to represent the presence of a single major entry into the North Inlet (79.16° W, 33.33° N). Soundings that defined multiple entries into the inlet were deleted using NOAA navigation charts and images from Google Earth as references.

- **Winyah Bay: Hydrographic Survey H05815.** Soundings from this survey, conducted in 1935 were deleted along the northeast portion of Winyah Bay and the connecting waterway to North Inlet to represent current shorelines. NOAA navigation charts and Google Earth satellite imagery were used for reference.

- **Pawleys Inlet: Hydrographic Survey H08838.** Twelve soundings from this 1964/65 survey of Pawleys Inlet (79.14° W, 33.39° N) were deleted because they did not match USGS NED topographic data values.

- **Pee Dee and Waccamaw Rivers: Hydrographic Surveys H05841, H05842, and H05843.** These surveys, all conducted in 1935, cover the Pee Dee River and Waccamaw River north of Winyah Bay. NOAA navigation charts and Google Earth satellite imagery were used to identify changes in meandering rivers, sizes and shapes of islands and silt deposits since the surveys were conducted. Horry County topographic LiDAR and USGS NED data were deleted in rivers and tributaries where NOS soundings from these surveys exist.

- **Murrells Inlet: Hydrographic Surveys H09102 and H09289.** NOS hydrographic soundings in the area of Murrells Inlet (79.03° W, 33.53° N) were collected in 1965 and 1972 before construction of the Murrells Inlet jetty between 1977 and 1980. The only topography data available for this area was USGS NED data, which did not include the jetty; Google Earth satellite imagery clearly shows the jetty (Fig. 5). NGDC digitized the jetty with ESRI ArcMap, assigning a 1-meter elevation above MHW, and using Google Earth and NOAA Nautical Chart #11534 for reference.

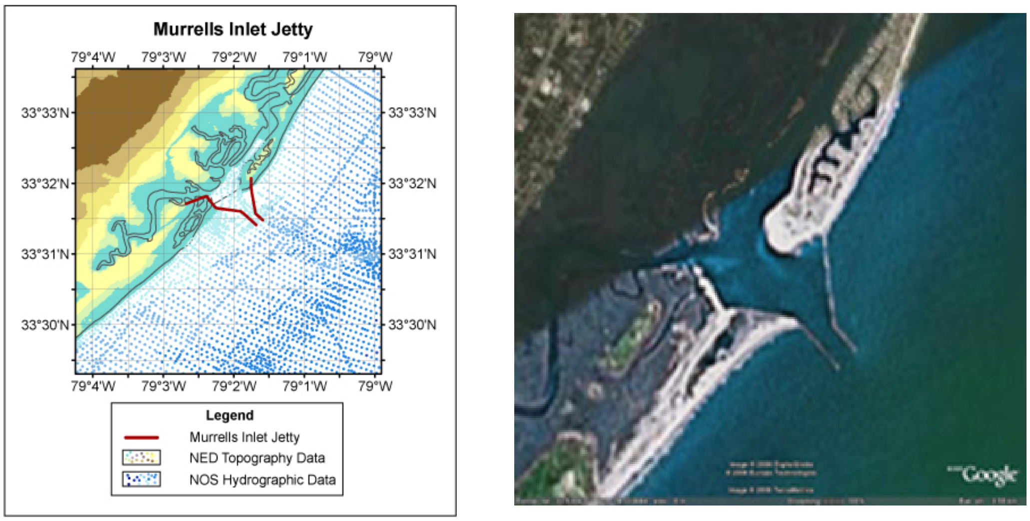

Figure 5. *Murrells Inlet jetty. The digitized jetty is shown on the left with surrounding NOS soundings and NED topographic data; neither dataset includes the jetty. The Google Earth satellite image on the right, in conjunction with NOAA Nautical Chart #11534, was used to digitize the jetty as a 1-meter elevation feature for gridding.*

- **Little River Inlet: Hydrographic Surveys H09195 and H09229.** NOS soundings from these two surveys, conducted in 1971 and 1972, were clipped to more recent NED topographic data north of the Little River Inlet (78.52° W, 33.86° N), as neither survey reflects the current coastline configuration.

- **Hydrographic Survey H09096.** Sixteen soundings were deleted by clipping to NED topographic data at the open-ocean shoreline.

- **Horse Ford, Little River Inlet: Hydrographic Survey H05656.** Eleven soundings from the 1934 H05656 NOS survey (Fig. 6) were shifted horizontally up to 15 meters to accommodate geomorphologic changes in the Horse Ford Channel in the Little River Inlet (78.56° W, 33.86° N). Forty two soundings from Little River were also removed to reflect changes in the same channel (78.6° W, 33.86° N). Horry County topographic LiDAR tiles #735745 and #730745 and GoogleEarth satellite imagery were referenced to locate the modern river channel. In addition, soundings that lay within the Intracoastal Waterway were excised to reflect modern dredging of the channel (see Intracoastal Waterway discussion in Section 3.1.1.3 below).

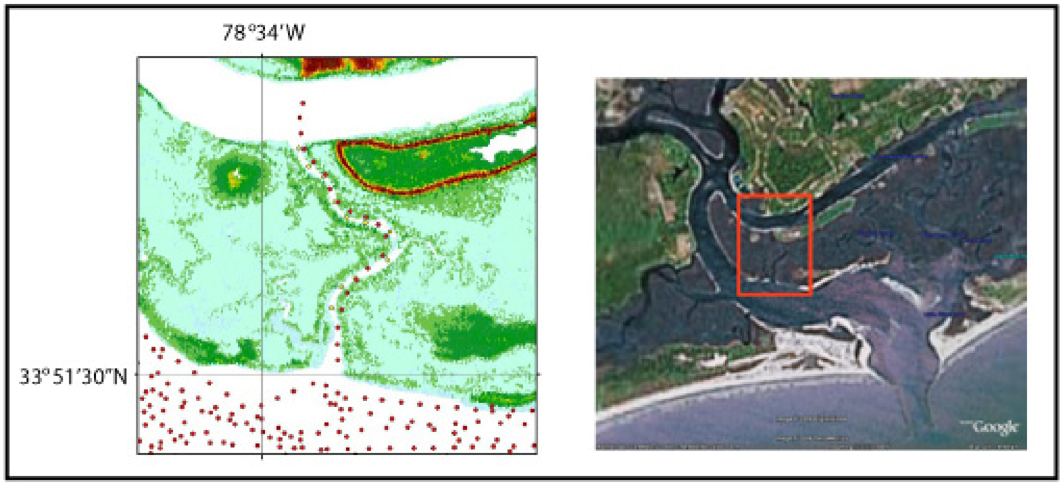

Figure 6. *Horse Ford Channel in the Little River Inlet. Figure on left shows original sounding locations in red and modified sounding locations in yellow. The same area is depicted on the right (red box) in a Google Earth satellite image.*

2) USGS Interferometric Sonar Bathymetry Data

The USGS interferometric sonar data used in the gridding compilation were collected between 1999 and 2003 on multiple USGS cruises. The data extends from the Little River to Winyah Bay and from about 200 meters to 10 km offshore (Fig. 7). Depths were originally referenced to Mean Lower Low Water (MLLW) and UTM Zone 17, in meters. Swath width averaged 70 meters with trackline spacing of 300 meters. The data were collected using a SEA Ltd. Submetrix 2000 Series interferometric sonar system (234 kHz), mounted below a Seatronics TSS DMS2-05 motion reference unit (MRU). Data were acquired at a 0.133 second ping rate and logged at a 2K sample rate using the SEA Ltd. RTS2000 acquisition software. Bathymetric swath width varied as a function of depth, but averaged roughly 10 times water depth within the depth range between 6 to 14 meters (Baldwin, et al., 2004). The USGS used a GRASS interpolation routine (spline with tension) to generate a continuous surface with a grid cell size of 100 meters, which was provided to NGDC. This grid was subsequently resurfaced by NGDC to generate depth points every 10 meters, which were then used in the gridding process.

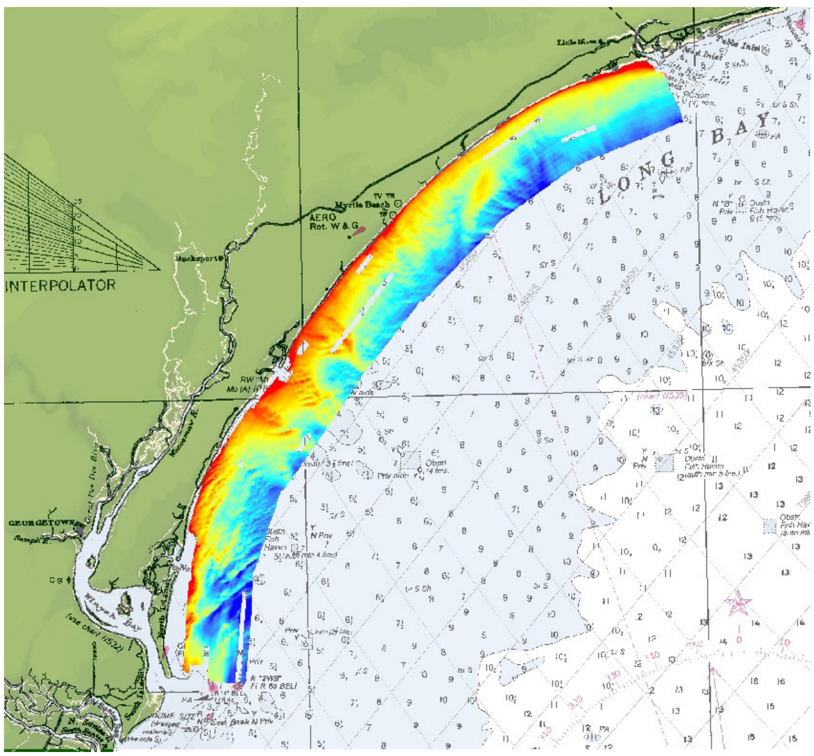

Figure 7. *Spatial coverage and shaded relief image of USGS interferometric sonar bathymetry data.*

3) USACE surveys in the Intracoastal Waterway

The Navigation Section of the Charleston District, USACE provided four hydrographic surveys covering much of the Atlantic Intracoastal Waterway in Horry County, South Carolina. The data were collected between December 2005 and January 2006 and cover most of the area from just northeast of the Highway 17 bridge to Highway 501. Surveys consist of two parallel track lines spaced ~20 meters apart, with soundings every 0.4 meters. As coverage of the waterway was incomplete, NGDC digitized the remaining channel segments in ESRI ArcMap using soundings of 12 feet below MLW (the minimum dredged depth in the waterway). Figure 8 shows the segments of the waterway surveyed by the USACE and the segments digitized by NGDC at dredge depth (see NOAA Nautical Chart #11534 data and Coast Pilot, Volume 4 for more information on the waterway).

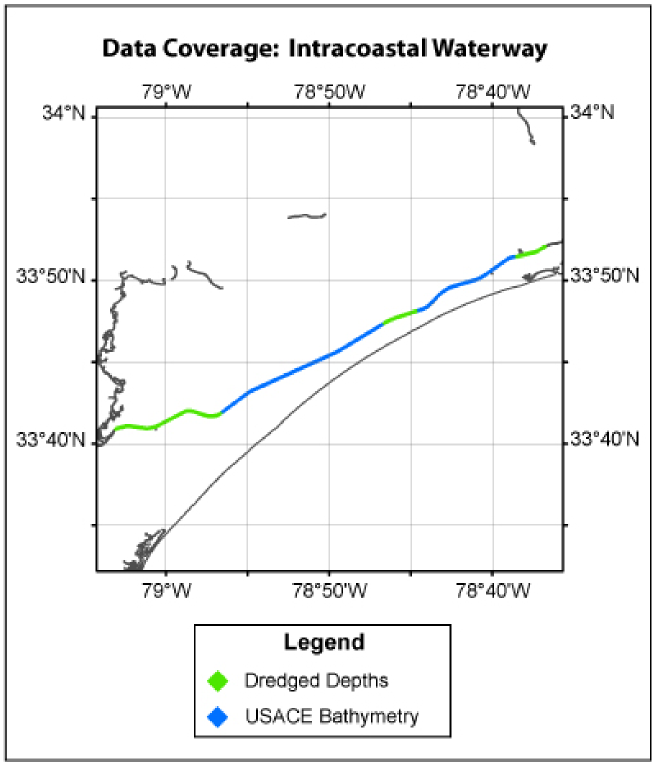

Figure 8. Atlantic Intracoastal Waterway data coverage. Blue indicates segments of the channel surveyed by the USACE, green those segments digitized by NGDC and assigned a depth of 12 feet below MLW.

3.1.3 Topography

Topographic datasets used in the compilation of the grids include high-resolution topographic LiDAR data collected and processed by Sanborn Inc. for Horry County, South Carolina, and the USGS National Elevation Dataset 1 arc-second gridded data for the northeast and southwest corners of the gridding area.

Table 4. Topographic data sources used in gridding.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
Horry County - Sanborn	2005	LiDAR	1 to 7 meters	NAD83	NAVD88	http://www.horrycounty.org/; http://www.sanborn.com/
USGS	various	National Elevation Data Set (NED)	1 arc-second	WGS84	NAVD88 (MSL)	http://seamless.usgs.gov/

1) Horry County, South Carolina topographic LiDAR data

Topographic LiDAR data collected and processed by Sanborn, Inc. was obtained from Horry County, South Carolina. The data were collected between February 17 and 27, 2005 at a ground spacing of 1.2 meters referenced to NAVD88 and NAD83, South Carolina State Planes. This dataset is proprietary and was released for compilation of these grids only: it cannot not be made available to the general public at the time of this writing.

One new NGS station was set and two existing NGS stations were used as Airborne GPS base stations for this project. A ground control network was surveyed using GPS to tie the newly set station to existing NGS control monuments. The data were collected at an altitude of 1,200 meters above ground level, with an airspeed of 140 knots, a scan frequency of 32 Hertz, a scan width half angle of 20 degrees, and pulse rate of 50 kHz. Data were processed to produce a bare-earth filtered data set with variable spacing between points of 1 to 7 meters. The maximum RMS value is 0.139 meters and the maximum standard deviation is 0.103 meters. The average RMS is 0.097 meters. A total of 744 LiDAR files, “tiles”, were used in the gridding process, each covering a roughly 1500-meter square area (see Fig. 1 for spatial coverage of entire dataset).

The LiDAR dataset includes elevations over water bodies, reflecting the surface of those bodies. ESRI ArcMap was used to interactively clip elevation values less than zero that are seaward of the coastline. Elevation values were also deleted along the Intracoastal Waterway, and where NOS hydrographic data was available north of Winyah Bay in the Pee Dee and Waccamaw rivers and adjoining tributaries, and in the Little River Inlet.

2) USGS National Elevation Dataset

USGS National Elevation Dataset (NED) 1 arc-second DEM data was used for small areas in the northeast and southwest corners of the gridding area (Fig. 1). The bare-earth elevations were originally referenced to NAD83 and NAVD88 and 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 quad maps and aerial photos based on surveys conducted in the 1970s and 1980s. This dataset was also interactively clipped where NOS survey data exists, along the Atlantic Intracoastal Waterway, and along the coastline.

3.1.4 Topography/Bathymetry

High-resolution "beach-profiles", elevation measurements that cross the subaerial-submarine coastal transition zone, were collected by two groups: Coastal Carolina University and Coastal Science and Engineering, Inc. These measurements provide excellent control on the open-ocean coastal relief boundary, though the transect lines are widely spaced, and were not conducted at river inlets.

Table 5. Beach profile data sources included in grid compilation.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
Coastal Carolina University	2006	Beach profile	Profile spacing ranges from 200 to 1000 meters; point spacing along profile~ 0.3 meters	NAD83, South Carolina State Plane-3900	NAVD88	http://www.coastal.edu/
Coastal Science & Engineering, Inc	2005	Beach profile	Profile spacing ranges from 80 to 780 meters; point spacing along profile 1 to 32 meters	NAD83, South Carolina State Plane-3900	NGVD29	http://www.coastalscience.com/

1) **Beach profiles, Coastal Carolina University**

Beach profiles were obtained from Dr. Scott Harris of the Coastal Carolina University (CCU). CCU, with funding from the South Carolina Office of Ocean and Coastal Resource Management (SC OCRM), USGS, and the South Carolina Sea Grant Consortium, collects beach profiles of the South Carolina coast every year using the same benchmarks (see Fig. 1 for spatial coverage). The data were originally referenced to NAVD88 and South Carolina State Plane, with elevation units of feet. Elevations were taken ~0.3 meters along each profile, though profiles are spaced between 200 and 1000 meters apart. Profiles are generally between 1000 and 1300 meters in length, and span roughly the 5 to -8 meter elevation range.

2) **Beach profiles, Coastal Science and Engineering, Inc.**

Beach profiles surveyed in May of 2005 were obtained from Coastal Science and Engineering, Inc. (CSE). The data were originally referenced to NGVD29 and South Carolina State Plane. Subaerial portions of the profiles were measured using RTK-GPS with a Trimble 5700. Hydrographic portions of the profiles were obtained via a shallow-draft survey boat equipped with RTK-GPS linked to a Sonar Lite (Ohmex Ltd.) precision echo sounder sampling at 1 to 10 Hz. After removing spikes from the hydrographic data, it was reduced using a 7-point running average filter. The hydrographic data were then coupled with the onshore data to create individual profiles. Elevation points vary between 1 and 32 meters apart along individual profiles, with the profiles themselves spaced 80 to 780 meters apart. Profiles are generally 100 to 125 meters long, covering an elevation range from approximately 2 to -2 meters. The area covered by the CSE beach profiles is completely overlapped by CCU beach profiles, though the CSE profiles are more closely spaced within this area (see Fig. 1). This dataset is proprietary and was released for compilation of these grids only: it cannot not be made available to the general public at the time of this writing.

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation of the grids were originally referenced to a number of vertical datums including Mean Low Water (MLW), Mean Lower Low Water (MLLW), North American Vertical Datum of 1988 (NAVD88), and National Geodetic Vertical Datum of 1929 (NGVD29). All datasets were transformed to a Mean High Water (MHW) datum to provide the worst case scenario for inundation modeling.

1) **Bathymetric data**

As no VDatum (http://vdatum.noaa.gov) model was available for the gridding area, transformation of bathymetric data to MHW was achieved by using data and information supplied by PMEL. Three ASCII grids, with values representing the differences between MHW and depths referenced to MSL, NAVD88 and MLLW, were generated by PMEL by dividing coastline polygons from the USGS/EPA National Hydrographic Dataset (http://nhd.usgs.gov) into zones, and linearly interpolating between nearby tide gauge station values. The difference between adjacent zones was constrained to less than 0.1 meter. The polygons were then converted to a 3-arc second resolution grid and filtered slightly to reduce stair-stepping effects between zones. The entire open ocean area was represented by one zone, the value for which was computed using the mean values of the coastal tide gauge stations. These interpolated surfaces were applied to the bathymetric datasets using FME software to convert data points to MHW; FME is an integrated collection of spatial extract, transform, and load tools for data transformation and data translation (http://www.safe.com). Soundings referenced to MLW were adjusted to MLLW by adding 0.047 meters—derived by computing the average difference between MLW and MLLW over the gridding area—prior to transformation to MHW.

2) **Topographic data**

LiDAR and NED topographic data were converted to MHW using FME software by adding a constant value of 0.546 meters, which was derived by computing the average difference between NAVD88 and MHW over the gridding area.

3.2.2 Horizontal datum transformations

Datasets used to compile the grids were originally horizontally referenced to NAD83, NAD27, South Carolina State Plane and WGS84. NOS hydrographic survey data were converted to WGS84 using GEODAS (NADCON); the relationships and transformational equations between these horizontal datums are well established. All other data, except that referenced to NAD83 (the difference between NAD83 and WGS84 is negligible; Wilson, 1995) were converted to a horizontal datum of WGS84 using FME software.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

After horizontal and vertical transformations were applied, ESRI shape files were generated for each data file, and value consistency between datasets was checked in ESRI ArcMap. Problems and errors were identified and resolved before proceeding with subsequent gridding steps; the quality-assessed ESRI shape files were subsequently converted to xyz files in preparation for gridding. Problems included:

- The LiDAR topographic data had numerous “wells”, anomalous elevations that were 5 to 25 meters deeper than surrounding points. Typically, these points were surrounded by open spaces without elevation points, so were readily identifiable as erroneous elevations: they were deleted from the shape files prior to creation of the xyz files.
- The LiDAR data within the Waccamaw River basin exhibits unusual, and artificial, east-west lineaments (prominent in Fig. 1, where blue bands of east-west “below MHW” areas are visible). This problem appears to have occurred during data collection or initial processing and could not be rectified by NGDC.
- The southwest NED dataset contains artificial plateaus resulting from meter-high steps in the dataset from one elevation to the next (see Fig. 9). This problem could not be corrected.

- The sparseness of the NED data (30-meter spacing) and the fact that each point reflects an average of a 30-by-30 meter area on the ground, resulted in significant offset with other datasets, especially the CCU beach profiles. One feature that could not be avoided was a step-down on the back side of the beach profile data, as that dataset's landward-most elevations are on the order of 2 meters, while the NED data in the same area was approximately 1 meter. The beach profile data was considered to be more accurate than the NED data and was preferentially utilized in grid development (see Table 6).

3.3.2 Smoothing of sparse datasets

Several datasets are sparse at the resolution of the 1/3 arc-second (10 meter) grid. Three of these (USGS interferometric sonar bathymetry, and the CCU and CSE beach profiles) are recent and considered to be of high quality. Nevertheless, the distance between beach profiles (80 to 1000 meters) and the distance between USGS interferometric sonar depths is significantly larger than the required 10-meter spacing of the 1/3 arc-second grid. As a result, each of these datasets was separately pre-surfaced to 10-meter spacing to fill in gaps between the beach profiles, and within the interferometric sonar data. The beach profiles were pre-surfaced using a Delauney triangulation method in GMT (http://gmt.soest.hawaii.edu/), while the interferometric sonar data was pre-surfaced using a tight spline interpolation method, also in GMT. Each of the resulting surfaces was closely cropped to the spatial coverage of the original data to ensure that extrapolation outside the coverage window was minimized.

In deep water, the NOS survey data had point spacings up to 1 kilometer apart. In order to reduce the effect of artifacts in the form of lines of "pimples" in the grid due to this low resolution dataset, a 1 arc-second-spacing surface was generated from the 13 "open-ocean surveys" using ESRI ArcCatalog (Table 3). This surface was closely clipped to the spatial extent of these 13 surveys, and then exported as an xyz file. The original soundings were checked against the processed values to ensure grid value accuracy. The 7 NOS inland-waterway surveys (H05656, H0518, H-5839, H05840, H05841, H05842 and H05843; Table 3) had soundings tens of meters apart, which also necessitated pre-surfacing to ensure that grid cells within the inland waterways had values representative of the river systems, and not that of the surrounding topographic data. These surfaces were created using the ESRI ArcCatalog "IDW" tool, which interpolates grid cells within 3 to 5 cells of existing data. The resulting grid for each inland waterway survey was exported as xyz point data for input to the 1/3 arc-second Myrtle Beach grid.

3.3.3 Gridding the data with MB-System

All processed xyz files were gridded using MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/). MB-System is an NSF-funded share-ware software application specifically designed to manipulate submarine multibeam sonar data, though it can utilize a wide variety of data types, including generic xyz data. The MB-System tool 'mbgrid' was used to create the 1/3 arc-second Myrtle Beach grid—a modeled surface draping the point data—of weighted sounding and topographic point data, using a tight spline tension to interpolate cells without data values. The data hierarchy used in the 'mbgrid' gridding algorithm as relative gridding weights is listed in Table 6. Greatest weight was given to the pre-surfaced beach profile grids, which define the subaerial to submarine transition, and to the Intracoastal Waterway to ensure its representation in the grids. Least weight was given to the pre-surfaced, deep-water NOS grid. The 1/3 arc-second grid was resampled using the ESRI ArcCatalog 'Raster Resample' tool to create the 1 arc-second grid.

Table 6. Data hierarchy used to assign gridding weight in MB-System.

Dataset	*Relative Gridding Weight*
USACE Intracoastal Waterway surveys	100
NGDC-digitized Intracoastal Waterway dredged depths	100
Beach profiles, Coastal Science and Engineering, Inc.	100
Beach profiles, Coastal Carolina University	50
Horry County Topographic LiDAR	50
USGS NED topography	10
USGS interferometric sonar bathymetry data: pre-surfaced	5
NOS hydrographic surveys: gridded inland waterways	1
NOS hydrographic surveys: gridded open ocean	0.1

3.4 Quality Assessment of the Grids

3.4.1. Horizontal accuracy

The digital elevation grids have an estimated horizontal accuracy of no better than 10 meters for topographic features; the LiDAR data has an accuracy of ~2 meters for individual postings, while the NED data is accurate to within about 15 meters. Bathymetric features are resolved only to within a few hundred meters in deep water areas; shallow, near-coastal regions have an accuracy approaching the subaerial topographic features. Positional accuracy is limited by: transformation of multiple datasets from various datums; sparseness of deep-water and inland-waterway soundings; potentially large positional accuracy of pre-satellite navigated (GPS) hydrographic surveys; and natural and artificial morphologic change that has occurred since the hydrographic surveys were conducted.

3.4.2 Vertical accuracy

The grids have an estimated vertical accuracy of 0.1 to 1 meters for topographic areas and 0.1 meters to 5% of water depth for bathymetric areas (~1.5 meters in the southeast corner of the grids). Topographic values are largely derived from Horry County LiDAR surveys, which have an estimated vertical accuracy of 0.1 to 0.15 meters. The 1 arc-second NED data have a vertical accuracy of ~1 meter. Bathymetric values were derived from the wide range of input data sounding measurements from the early 20th century to recent, GPS-navigated interferometric sonar surveys and beach profiles. Gridding interpolation to determine values between sparse, poorly-located NOS soundings degrades the vertical accuracy of elevations in deep-water. Also suspect are the accuracy of values within inland-waterways, as substantial morphologic change has occurred in some areas since the NOS hydrographic surveys of the 1930s to 1970s (e.g., dredging and jetty building).

3.4.3 Comparison with South Carolina tidal bench marks

Twenty tidal bench marks lying within the Myrtle Beach study area were compared with values taken at the same locales from the 1 arc-second (~30 meter) grid (see Fig. 1 and Table 7 for station locations). Each bench mark has a geographic position recorded to within 1 arc-second, with an accuracy of +/-6 arc-seconds (http://tidesandcurrents.noaa.gov/). Most bench marks are level with the ground surface; the rest are within a few centimeters. The National Geodetic Survey (NGS) data sheets for the tidal stations also document bench mark elevation above MHW, in meters, allowing for direct comparison with grid values at those locations. Most grid values compare favorably with the known bench mark elevations. Bench marks with three of the largest discrepancies (stations 8661299, 8661582, and 8661991) fall within the coverage of the NED topographic dataset in the southwest corner of the grid. This particular dataset has known deficiencies, as documented above. Three others are in the vicinity of the Little River Inlet: two (8660166 and 8660265) are located on the boundaries between datasets and likely result from gridding interpolation between the datasets; the other (8660098) is embedded within high-resolution topographic LiDAR data—its discrepancy is of unknown origin.

Table 7. Comparison of tidal bench mark elevations, in meters, with the 1 arc-second Myrtle Beach grid.

Number	*Year*	*Longitude*	*Latitude*	*Bench Mark*	*Grid Value*	*Difference*
8660098	1975	078° 34’45”W	33° 52’07”N	5.025	6.62464	1.59964
8660147	1975	078° 34’41”W	33° 51’39”N	7.416	6.82289	-0.59310
8660166	1986	078° 39’00”W	33° 51’23”N	2.362	-1.38160	-3.74360
8660265	1976	078° 37’49”W	33° 49’59”N	1.531	-0.96400	-2.49500
8660642	1982	078° 48’40”W	33° 45’51”N	10.849	10.54685	-0.30214
8660854	1982	078° 55’06”W	33° 42’40”N	5.864	5.26787	-0.59612
8660983	1982	079° 00’24”W	33° 41’21”N	5.095	5.40844	0.31344
8661070	1979	078° 55’15”W	33° 39’23”N	3.876	2.88868	-0.98731
8661139	1982	079° 05’47”W	33° 39’02”N	3.703	3.15566	-0.54733
8661299	1981	079° 09’11”W	33° 36’28”N	3.473	0.67200	-2.80099
8661419	1975	079° 00’32”W	33° 35’01”N	3.837	4.17221	0.33521
8661529	1982	079° 01’50”W	33° 33’35”N	1.519	0.72462	-0.79437
8661559	1975	079° 02’30”W	33° 33’04”N	1.980	0.91384	-1.06615
8661582	1982	079° 01’22”W	33° 32’40”N	1.465	-0.44029	-1.90529
8661684	1986	079° 04’09”W	33° 30’35”N	1.176	0.23777	-0.93822
8661989	1982	079° 07’30”W	33° 26’13”N	1.693	2.00841	0.31541

8661991	1975	079° 10’45”W	33° 26’16”N	3.767	1.18093	-2.58606
8662071	1975	079° 07’56”W	33° 24’44”N	1.735	1.14338	-0.59161
8662245	1982	079° 11’43”W	33° 21’02”N	0.811	0.12637	-0.68462
8662299	1976	079° 11’40”W	33° 20’06”N	0.842	0.14878	-0.69321
					Standard Deviation:	*1.25010*

3.4.4 Slope map and 3-D perspectives

ESRI ArcCatalog was used to generate a slope map from the 1/3 arc-second grid to allow for visual inspection of the grid, and identification of artificial slopes along boundaries between datasets (Fig. 9); the grid was transformed to UTM Zone 17 coordinates (horizontal units in meters) in ArcCatalog for derivation of the slope grid. Analysis of preliminary slope maps revealed suspect data points, which were corrected before regridding the data. Known limitations in the grids are also apparent from the slope map, specifically, small steps at the edges of the surfaced USGS interferometric sonar data, where that recent survey abuts the older NOS hydrographic survey data, and along the landward side of the pre-surfaced beach profile data, where it misfits the NED topographic data. Also, artificial steps, appearing as contour lines in the southwest corner of Figure 9, result from the low quality of the NED topographic data in that region. Of particular interest is the presence of numerous man-made features visible in the region of the grid covered by the high-resolution topographic LiDAR data. Three-dimensional viewing of the UTM-transformed grid was accomplished using ESRI ArcScene. This interactive, rotational viewing tool was especially valuable for locating LiDAR “wells” present within the grid, which were subsequently deleted from the original data prior to regridding.

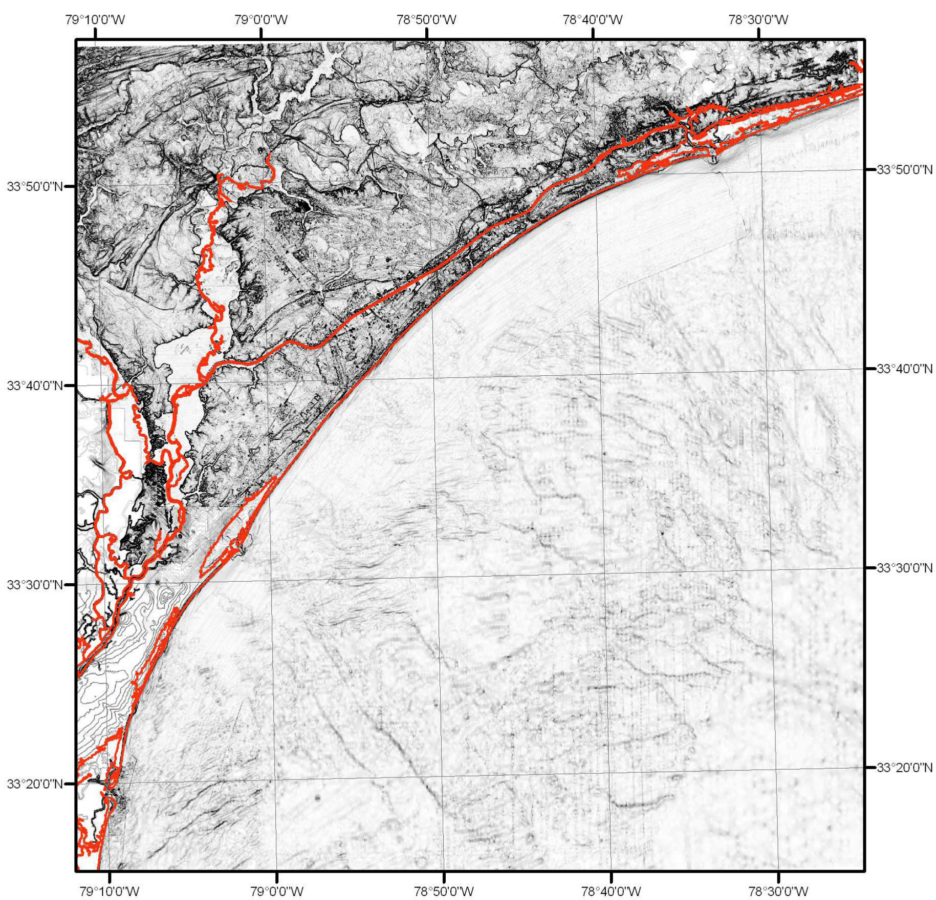

Figure 9. *Slope map of the 1/3 arc-second grid with NGA coastline in red. Flat-lying slopes are white; dark shading denotes steep slopes. Note the artificial “contour lines” present in the southwest corner of the image, resulting from the NED topographic data in this region.*

4. Summary and Conclusions

Two topographic/bathymetric digital elevation models of the Myrtle Beach, South Carolina area were developed for the Pacific Marine Environmental Laboratory (PMEL), NOAA Center for Tsunami Inundation Mapping Efforts (TIME). The two grids cover the same geographic area and have cell spacings of 1 arc-second and 1/3 arc-second. The best available data from U.S. federal and state agencies, universities and private companies were obtained for grid compilation. The data were quality checked, processed and gridded using ESRI ArcGIS, FME, GMT and MB-System software.

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

- Incorporate coastal bathymetric/topographic LiDAR data when available.
- Improvement of topography in the regions currently covered by NED 1 arc-second data (in the northeast and southwest parts of the grids).
- NOS mapping of inland waterways where significant morphologic change has occurred since the original surveys utilized in this study were conducted, especially in Little River Inlet and Murrells Inlet.
- Investigation into suspected data-collection or initial-processing problems with the topographic LiDAR data. The east-west lineaments apparent in Fig. 1 (Waccamaw River basin) are artificial in origin.

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