Digital Elevation Model for Panama City, 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)
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1. INTRODUCTION

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

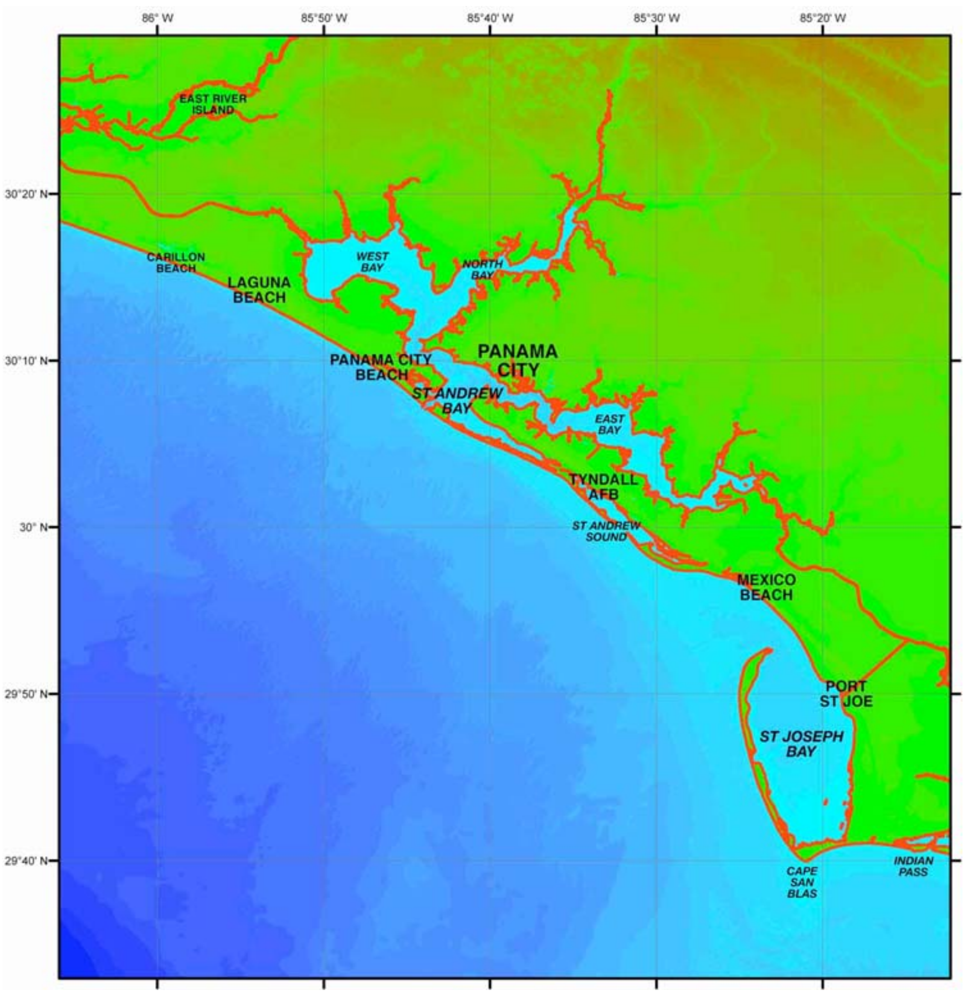

Figure 1. *Color image of the Panama City, Florida region. Coastline in red.*

1. The Panama 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 Panama City, Florida (30°10′ N, 85°40′ W) 1/3 arc-second of latitude is equivalent to 10.26 meters; 1/3 arc-second of longitude equals 8.92 meters.

2. Study Area

The Panama City DEM covers the coastal region centered on Panama City, Florida including the communities of Laguna Beach, Panama City Beach, Tyndall Air Force Base, Mexico Beach, and Port St. Joe (Fig. 1). Geologically, the region is located where the Gulf Coastal Plain meets the Florida Platform. Siliclastic sediments overlay the carbonate sediments that dominate the Florida peninsula. These are, in turn, covered by young, unconsolidated sand deposits that form barrier islands (http://pubs.usgs.gov/of/2004/1044/setting.html).

The beaches and barrier islands in the region are severely impacted by seasonal storms and coastal erosion processes. Recent hurricane seasons have had a dramatic effect on the shape and geomorphology of the coastline. Beach restoration projects are part of the continuing effort to maintain the tourist-based economy by mitigating the kind of hurricane damage caused during the 2005 hurricane season. The Florida Department of Environmental Protection (FDEP), Division of Water Resource Management, Bureau of Beaches and Coastal System has published a comprehensive report on the impacts of the 2005 hurricane season on Northwest Florida (http://bcs.dep.state.fl.us/reports/2005/2005hur1.pdf).

According to the FDEP Bureau of Coastal Studies: "At Stump Hole, between Cape San Blas and St. Joseph Peninsula, storm tide flooding occurred during both Tropical Storm Arlene and Hurricane Dennis. Waves from both storms battered the revetment causing rock displacement and damage. Storm tides from both storms flooded the road and additional road damage was caused by Dennis. Cape San Blas erodes at about 40 feet per year. With every passing storm severe erosion is experienced. On June 11, Tropical Storm Arlene inflicted another approximately 25 feet of bluff recession at the Cape San Blas Lighthouse. With Hurricane Dennis, another 100 feet or so of erosion was sustained. This area is the most severely eroding area in Florida." (http://bcs.dep.state.fl.us/reports/dennis.pdf)

Figure 2. *An example of coastal erosion at Carillon Beach post-Hurricane Dennis (http://bcs.dep.state.fl.us/reports/2005/2005hur1.pdf).*

3. Methodology

The Panama City 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 Panama City, Florida DEM.

Grid Area	Panama City, Florida
Coverage Area	85.2º to 86.1º W; 29.55º to 30.5º 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 ASCII raster grid

3.1 Data Sources and Processing

Shoreline, bathymetric, topographic and combined topographic–bathymetric digital datasets (Fig. 3) were obtained from several U.S. federal, state and local agencies, including: NOAA's National Ocean Service (NOS) and Coastal Services Center (CSC); the U.S. Geological Survey (USGS); the U.S Army Corps of Engineers (USACE); the Florida Department of Environmental Protection (FDEP); and the Bay County, Florida GIS Office. Safe Software's (http://www.safe.com/) FME data translation tool package was used to shift datasets to WGS84 horizontal datum and to convert 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; NGDC's GEODAS software (http://www.ngdc.noaa.gov/mgg/geodas/) was used to manually edit large xyz datasets. Vertical datum transformations to MHW were also accomplished using FME, based upon data from local NOAA Panama City tidal stations, as no VDatum model software (http://nauticalcharts.noaa.gov/csdl/vdatum.htm) was available for this area.

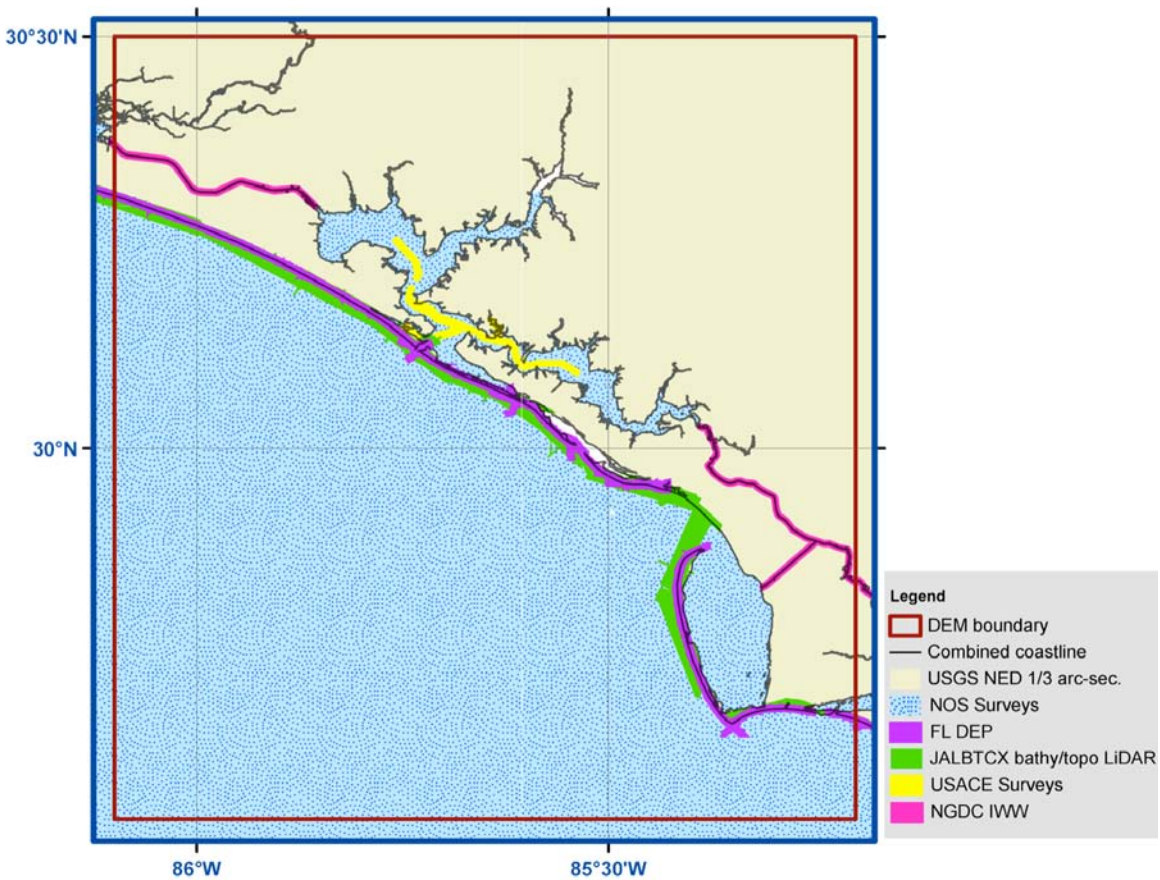

Figure 3. *Source and coverage of datasets used to compile the Panama City DEM.*

3.1.1 Shoreline

Three digital coastline datasets of the Panama City region were analyzed for inclusion in the Panama City DEM: OCS Electronic Navigational Charts, FDEP digital shoreline, and the USGS High Resolution National Hydrography Dataset shoreline (Table 2).

Table 2: Shoreline datasets used in compiling the Panama City DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
OCS Electronic Navigational Charts	2001 to 2004	MHW coastline	Digitized from 1:40,000 to 1:456,394 scale charts	WGS84 geographic	MHW	http://chartmaker.ncd.noaa.gov/
Florida Department of Environmental Protection (FDEP) BIS/GIS Section	1999	MHW coastline	1:40,000	NAD83 geographic	MHW	http://www.dep.state.fl.us/gis/datadir.htm
USGS High Resolution National Hydrography Dataset	2002 to 2004	shoreline	1:100,000	NAD83 geographic	NGVD29	http://nhd.usgs.gov/index.html

1) OCS electronic navigational charts

Eleven NOAA nautical charts were available for the Panama City region (Table 3) and were downloaded from NOAA's Office of Coast Survey (OCS) website (http://chartmaker.ncd.noaa.gov/). All of the nautical charts are available in raster nautical chart (RNC) format—georeferenced map imagery, which are frequently updated—with some also available as Electronic Navigational Charts (ENCs)—digital GIS chart components (Fig. 4). The NOAA Coastal Services Center's 'Electronic Navigational Chart Data Handler for ArcView' extension (http://www.csc.noaa.gov/products/enc/) was used to import the ENCs into ArcGIS. The ENCs include coastline data files (MHW), which were compared with the other coastline datasets, high-resolution coastal LiDAR data, topographic data, and NOS hydrographic soundings. The ENCs also include soundings (extracted from NOS hydrographic surveys) and land elevations.

Five of the ENCs (#11360, #11385, #11388, #11393, and #11400) were used in conjunction with other coastline datasets to build a 'combined coastline' (Fig. 9). The coastline files extracted from ENCs #11400 and #11360 were at a lower resolution and were used only where no other higher resolution coastline data was available. ENCs #11385, #11388, and #11393 were at a higher resolution, but provided only limited coverage in the gridding area. Editing all of the ENC coastline data was necessary to provide more detail in areas where recent bathymetric survey data existed. Those nautical charts that exist only as RNCs were used to evaluate other coastline, bathymetric and topographic datasets and for digitization of coastal features not represented in any digital coastline dataset (e.g., Fig 5).

Table 3: NOAA nautical charts in the Panama City, Florida region.

Chart Number	*Title*	*Edition*	*Date*	*Scale*	*Available Format*	*Used in Combined Coastline*
11360	Cape St. George to Mississippi Passes	7	06/2006	1:456,394	ENC	yes
11385	West Bay to Santa Rosa Sound	7	11/2006	1:40,000	ENC	yes
11388	Choctawhatchee Bay	2	12/2006	1:80,000	ENC	yes
11389	St. Joseph and St. Andrews Bay	3	05/2006	1:80,000	ENC	no
11390	East Bay to West Bay Florida Side A	23	02/2004	1:40,000	RNC	no
11391	St. Andrew Bay	24	12/2005	1:25,000	RNC	no
11392	St. Andrew Bay – Bear Point to Sulpher Point	7	05/2006	1:5,000	ENC	no
11393	Lake Wimico to East Bay Side A & B	7	11/2006	1:40,000	ENC	yes
11400	Tampa Bay to Cape San Blas	5	09/2006	1:456,394	ENC	yes
11401	Apalachicola Bay to Cape San Blas	4	11/2006	1:80,000	ENC	no
11402	Apalachicola Bay to Lake Wimico	6	07/2006	1:40,000	ENC	no

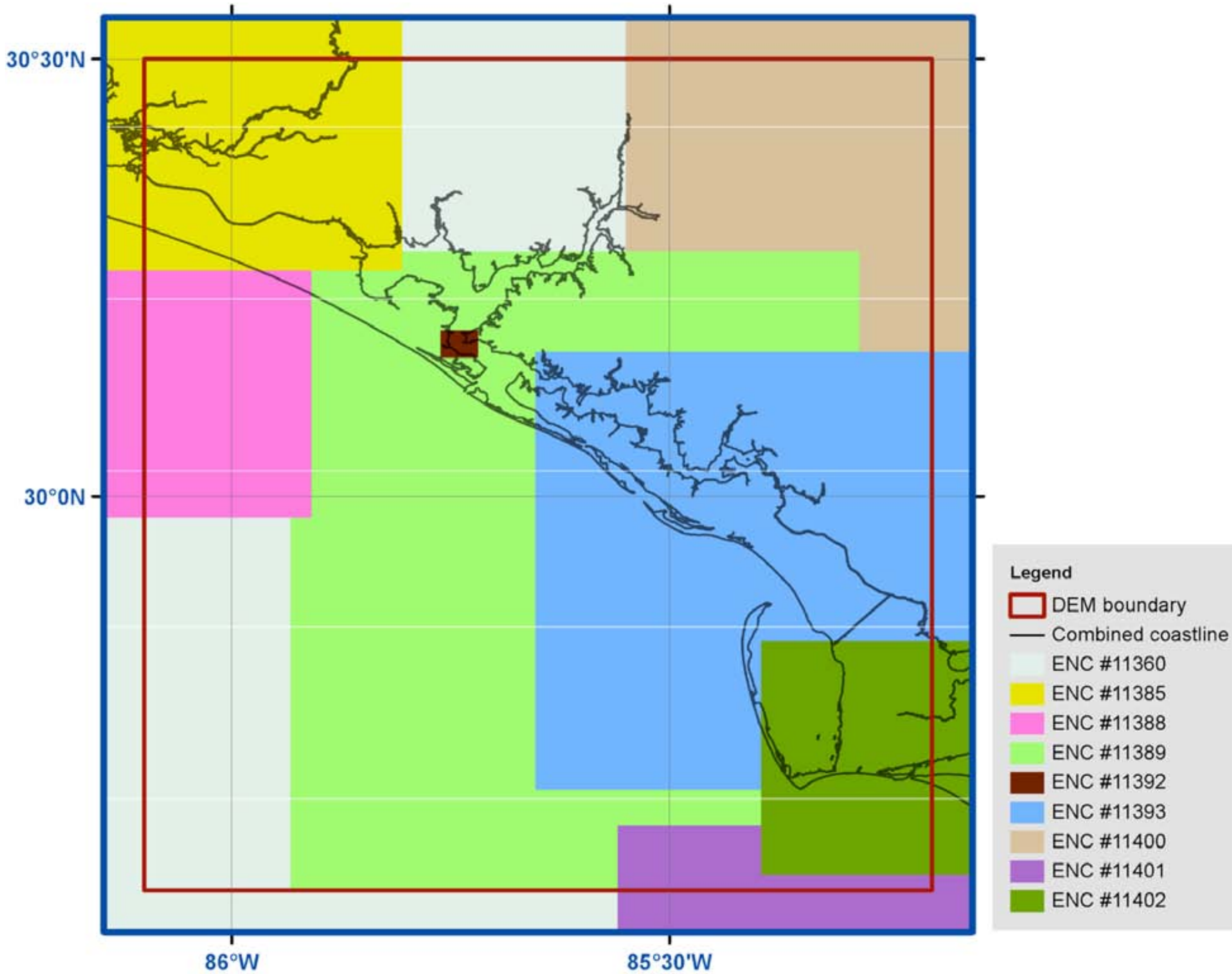

Figure 4. *NOAA Electronic Navigational Charts available in the Panama City region.*

2) Florida Department of Environmental Protection

The Florida Department of Environmental Protection (FDEP) has developed a dataset merging extracted Florida county lines from USGS DLG boundary layers with the FLSHORE/FMRI Florida 1:40,000 shoreline (http://www.dep.state.fl.us/gis/datadir.htm). This shoreline coverage was originally digitized from 1:40,000 NOAA nautical charts and edited to the coverage by FDEP using 1:24,000 USGS quadrangles.

In order to match the FDEP shoreline to recent NOS bathymetric surveys, NGDC manually edited the dataset using ArcMap to fit the coastline to RNCs. Figure 5 illustrates the lack of detail in available digital coastline datasets for Upper Goose Bayou, along the North Bay of St Andrew. Both the 1:456,394-scale ENC #11360 and the FDEP coastline in the area fail to capture the intricate details of the bayou (Fig 5A). The larger scale RNC #11390 (1:40,000; Fig. 5B) provided enough detail to enable NGDC to digitize the bayou's coastline, specifically to enclose soundings from NOS survey H10236. *Google Earth* satellite imagery was used to check shoreline accuracy throughout the coastline editing process (Fig. 5B).

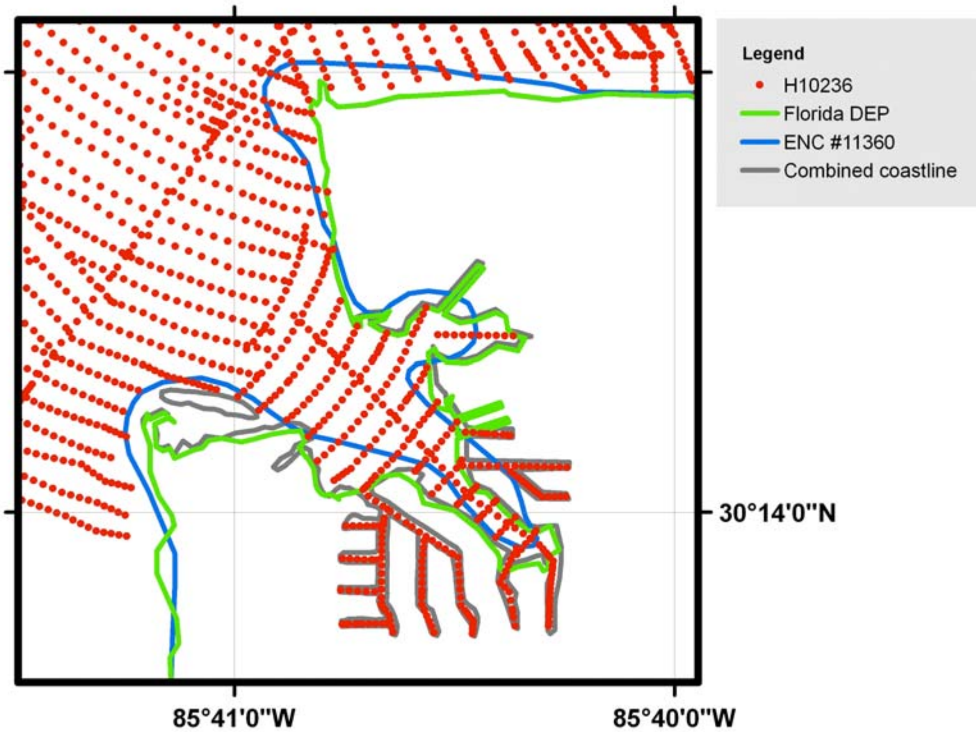

Figure 5A. Detail of coastline datasets for Upper Goose Bayou. 1987 NOS survey H10236, in red, extended into upper reaches of the bayou. Neither the FDEP coastline (green) nor coastline from ENC #11360 (blue, scale 1:456,394) captured the intricate details of the bayou. The combined coastline (gray) was built by digitizing the coastline from RNC #11390 (scale 1:40,000; see Fig 5B).

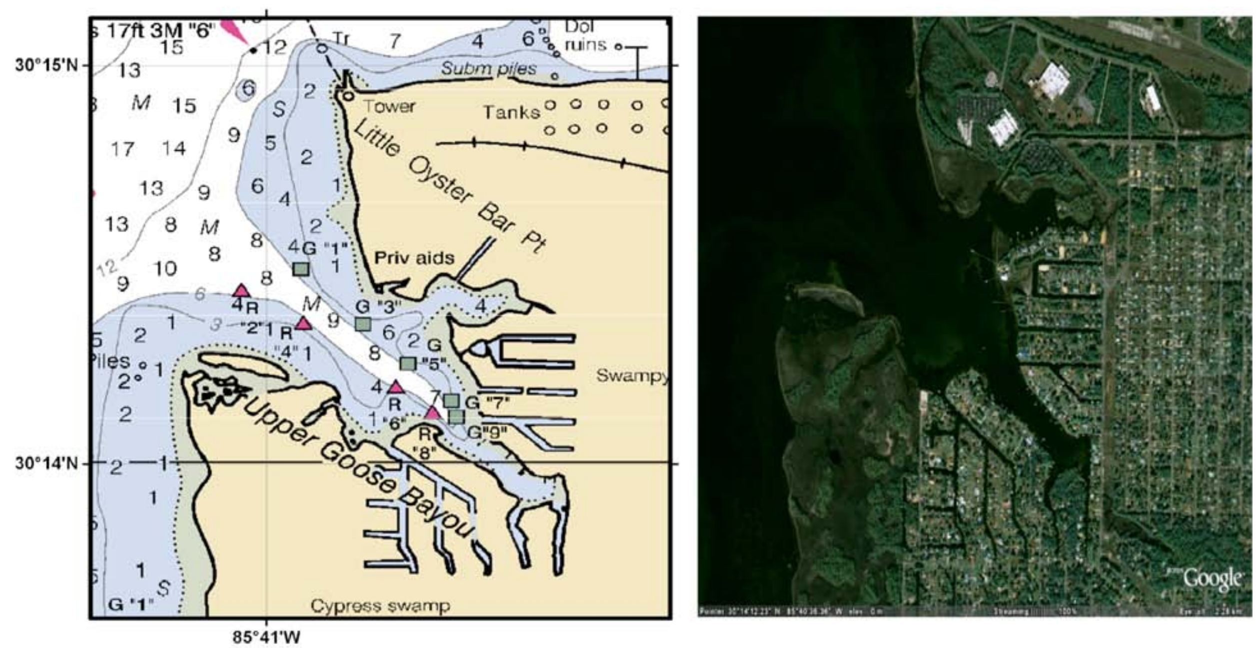

Figure 5B. *Image of RNC #11390, on left, showing Upper Goose Bayou. Google Earth satellite image of same area on right.*

3) USGS National Hydrography Dataset

The USGS National Hydrography Dataset (NHD) provides information on both naturally occurring and developed bodies of water, rivers, streams, and water related features (http://nhd.usgs.gov/index.html). The shoreline for this dataset was extracted from 1:100,000 USGS quads in DLG format. NGDC downloaded, re-projected, and clipped the data for the north-western corner of the DEM, to improve the accuracy of the East River Island area (Fig. 1). This dataset was subsequently edited in the southern part of East River Island to be consistent with NOS hydrographic soundings from survey H06452.

To obtain the best digital MHW coastline, NGDC combined the ENC, FDEP, and NHD coastlines into a 'combined coastline' (Fig. 6). Where overlap occurred between coastline datasets, the one with the most detail and consistency with topographic, bathymetric, and topographic–bathymetric datasets was used. This combined coastline was also manually adjusted along the Gulf coast, in ESRI ArcMAP, to match the JALBTCX high-resolution coastal LiDAR data, particularly the late 2005 post-Hurricane Katrina survey. Piers, docks, and other manmade structures were also deleted. The combined coastline was converted to point data for use as a coastal buffer for the bathymetric pre-surfacing algorithm (see Section 3.3.2) to ensure that interpolated bathymetric values reached "zero" at the coast. It was also used to clip USGS NED topographic DEMs, which contain elevation values, typically zero, over the open ocean (Section 3.1.3).

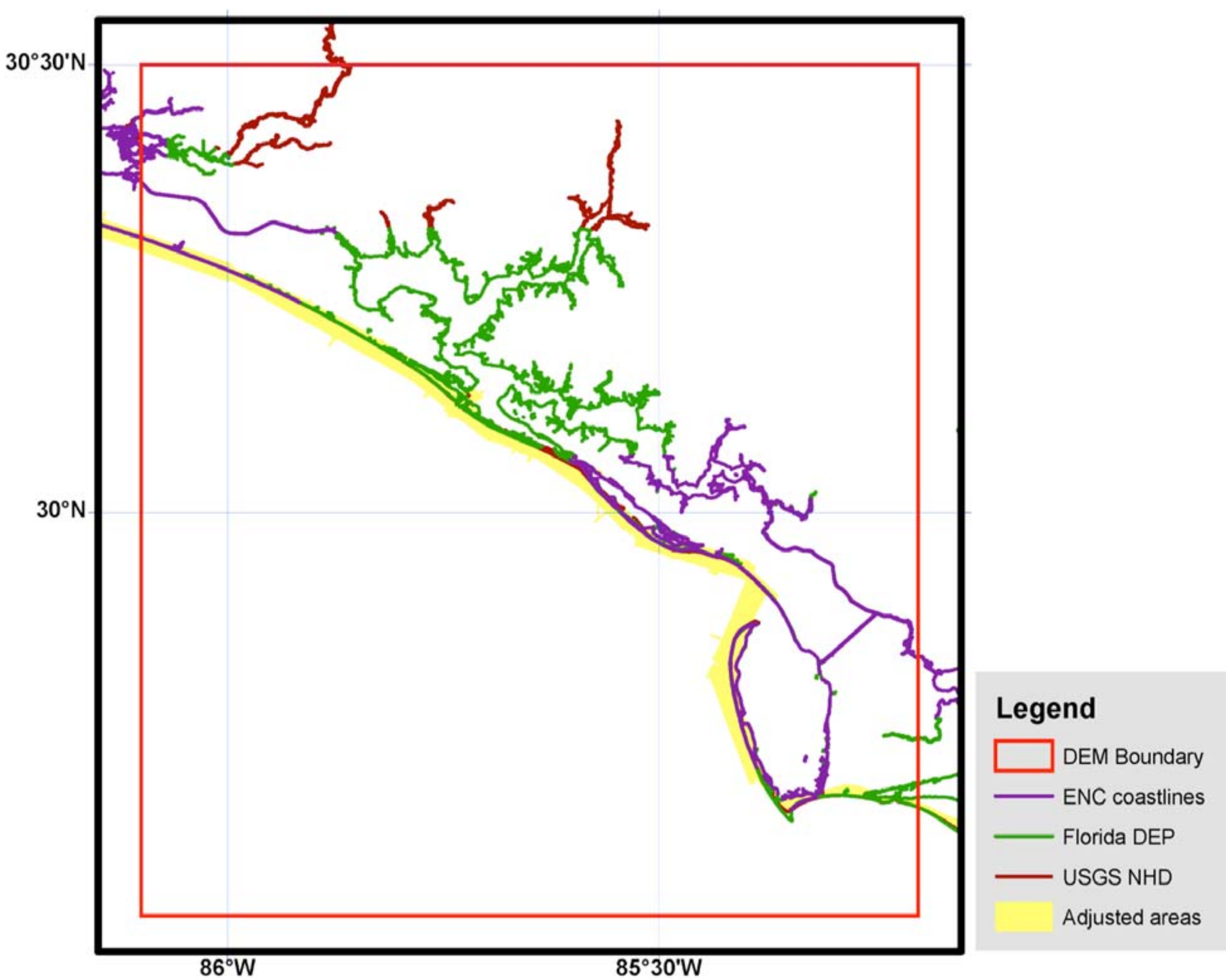

Figure 6. *Digital coastline segments used to create a 'combined coastline' for the Panama City region. Areas in yellow highlight coastline segments that were manually adjusted to match recent bathymetric–topographic LiDAR surveys.*

The Gulf coast in the Panama City region is subject to rapid morphologic change, particularly by hurricanes. The 2005 hurricane season had a dramatic impact along the coastline here, as exemplified by Figure 7—Indian Pass, in the southeast corner of the DEM—with Hurricanes Dennis and Katrina significantly modifying the coastline.

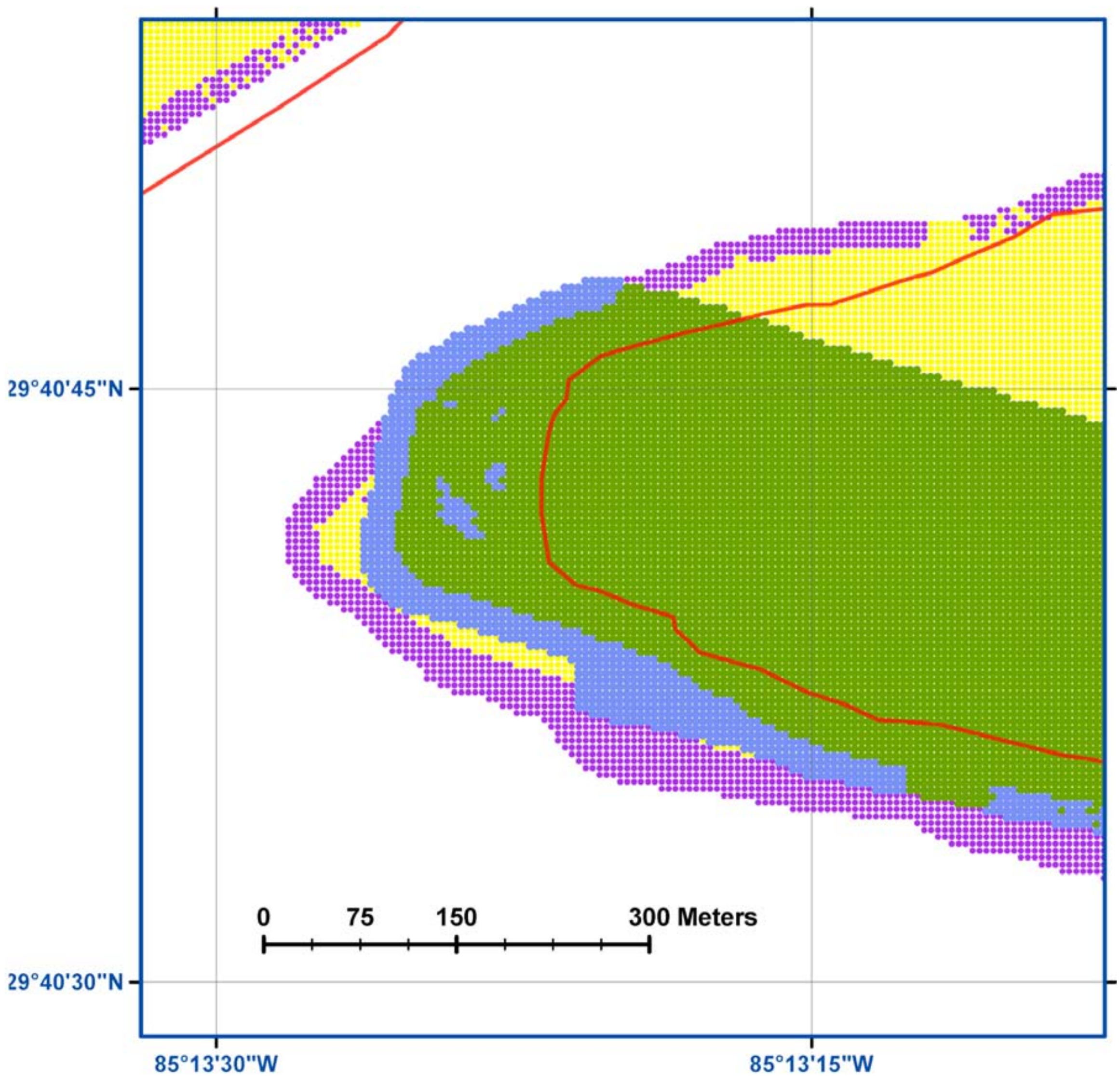

Figure 7. *Example of the difference in coastal morphology around Indian Pass between 2004 and 2005 LiDAR surveys. Green–blue transition represents the MHW coastline in the 2004 JALBTCX LiDAR survey. Yellow–purple transition represents the MHS coastline in the 2005 post-Dennis JALBTCX LiDAR survey. The FDEP shoreline is shown in red.*

3.1.2 Bathymetry

Bathymetric datasets used in the compilation of the Panama City DEM include 50 NOS hydrographic surveys, 25 USACE surveys of dredged shipping channels, and NGDC-digitized soundings within the Intracoastal Waterway (Table 4).

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

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
USACE	2005 to 2006	Bathymetric surveys	Profiles 60 to 500 m long, 60 to 150 m apart with .5 to 20 m point spacing	NAD83 State Plane Florida North (feet)	MLLW (meters)	
NOS	1930 to 1993	Hydrographic survey soundings	Ranges from 10 m to 1 km (varies with scale of survey, depth, traffic, and probability of obstructions)	NAD27, NAD83 geographic	MLLW, MLW, and Gulf Coast Low Water (meters)	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NGDC	2006	Digitized Intracoastal Waterway soundings	2 parallel tracks 10 to 20 m apart with <10 m point spacing	WGS84 geographic	MHW (feet)	

1) **NOS hydrographic survey data**

A total of 50 NOS hydrographic surveys conducted between 1930 and 1993 were utilized in developing the Panama City DEM (Table 5; Fig. 8). The hydrographic survey data were originally vertically referenced to Mean Lower Low Water (MLLW), Mean Low Water (MLW), or Gulf Coast Low Water (GCLW) and horizontally referenced to either NAD27 or NAD83 geographic datums. Gulf Coast Low Water datum is equivalent to MLLW (National Tidal Datum Convention of 1980, http://tidesandcurrents.noaa.gov/publications/glossary2.pdf).

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) in their original, digitized datums (Table 5). 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 degrees (~5%) larger than the Panama City 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 compared to the USACE bathymetric surveys and coastal LiDAR data, NED topographic data, the combined coastline, RNCs, and *Google Earth* satellite imagery.

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

NOS Survey ID	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum*
H05024	1930	10,000	mean low water	NAD27
H05780	1935	10,000	mean low water	NAD27
H05781	1935	10,000	mean low water	NAD27
H05782	1935	10,000	mean low water	NAD27
H05783	1935	10,000	mean low water	NAD27
H05791	1935	10,000	mean low water	NAD27
H05793	1935	10,000	mean low water	NAD27
H05796	1935	10,000	mean low water	NAD27
H05812	1935	20,000	mean low water	NAD27

H06449	1939	10,000	mean low water	NAD27
H06450	1939	10,000	mean low water	NAD27
H06451	1939	10,000	mean lower low water	NAD27
H06452	1939	10,000	mean low water	NAD27
H06689	1941	40,000	mean low water	NAD27
H06691	1941	80,000	mean low water	NAD27
H06694	1941/47	20,000	mean low water	NAD27
H06784	1942/43	40,000	mean low water	NAD27
H06785	1942/43	40,000	mean low water	NAD27
H06786	1942/43	20,000	mean low water	NAD27
H6787	1942/43	20,000	mean low water	NAD27
H07173	1947	10,000	mean lower low water	NAD27
H07603	1947/48	200,000	mean low water	NAD27
H07631	1947	40,000	mean low water	NAD27
H07632	1947	40,000	mean low water	NAD27
H07633	1947	40,000	mean low water	NAD27
H07723	1948/50	100,000	mean low water	NAD27
H09734	1977/78	20,000	mean low water	NAD27
H09735	1977/78	20,000	Gulf Coast low water	NAD27
H09755	1978	20,000	Gulf Coast low water	NAD27
H09761	1978	20,000	mean low water	NAD27
H09786	1978	40,000	mean low water	NAD27
H09846	1979/80	40,000	mean lower low water	NAD27
H09883	1980	40,000	Gulf Coast low water	NAD27
H09915	1980	20,000	Gulf Coast low water	NAD27
H09924	1980/81	10,000	mean lower low water	NAD27
H09925	1980/81	10,000	mean lower low water	NAD27
H09989	1981/82	10,000	mean low water	NAD27
H09996	1982	10,000	mean low water	NAD27
H10069	1982/83	10,000	mean lower low water	NAD27
H10122	1983/84	10,000	mean low water	NAD27
H10166	1984/85	10,000	mean lower low water	NAD27
H10170	1985	10,000	mean low water	NAD27
H10235	1986/88	10,000	mean lower low water	NAD27
H10236	1987	10,000	mean lower low water	NAD27
H10237	1986/87	10,000	mean lower low water	NAD27
H10259	1987/89	10,000	mean lower low water	NAD27
H10260	1987/88	10,000	mean lower low water	NAD27
H10266	1988/89	10,000	mean lower low water	NAD27
H10267	1988	10,000	mean lower low water	NAD27
H10452	1993	10,000	mean lower low water	NAD83

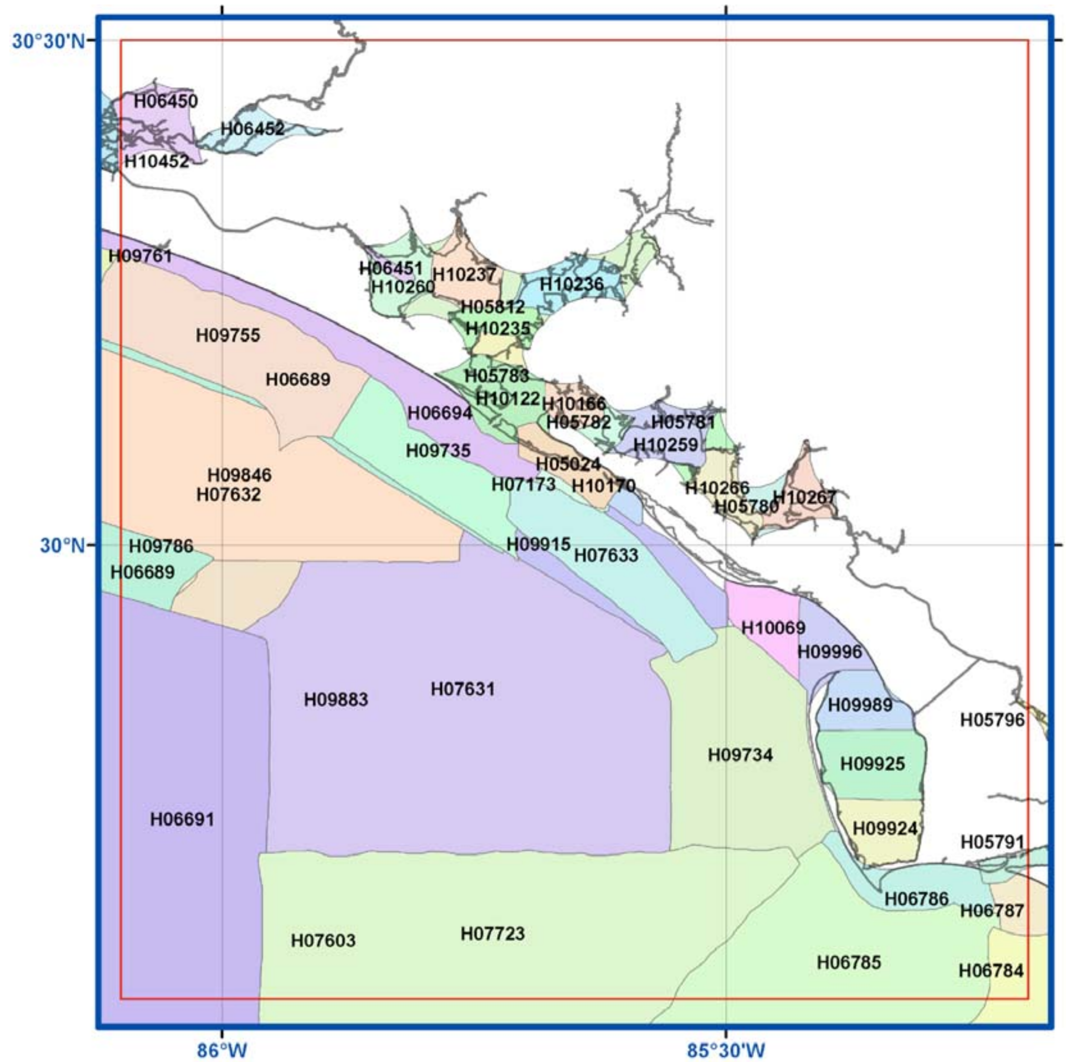

Figure 8. *Digital NOS hydrographic survey coverage in the Panama City region. DEM boundary in red, combined coastline in gray.*

2) USACE surveys of dredged shipping channels

USACE bathymetric surveys of dredged shipping channels in St. Andrew Bay, East Bay, and West Bay (Fig. 9) were provided to NGDC by Victoria Ann Anderson, USACE Mobile Dist., Panama City Site Office. All data were originally in NAD83 Florida State Plane North coordinates, and MLLW vertical datum (Table 6). Surveys consist of numerous, parallel, across-channel profiles, spaced 60 to 150 meters apart, with point soundings 0.5–20 meters apart.

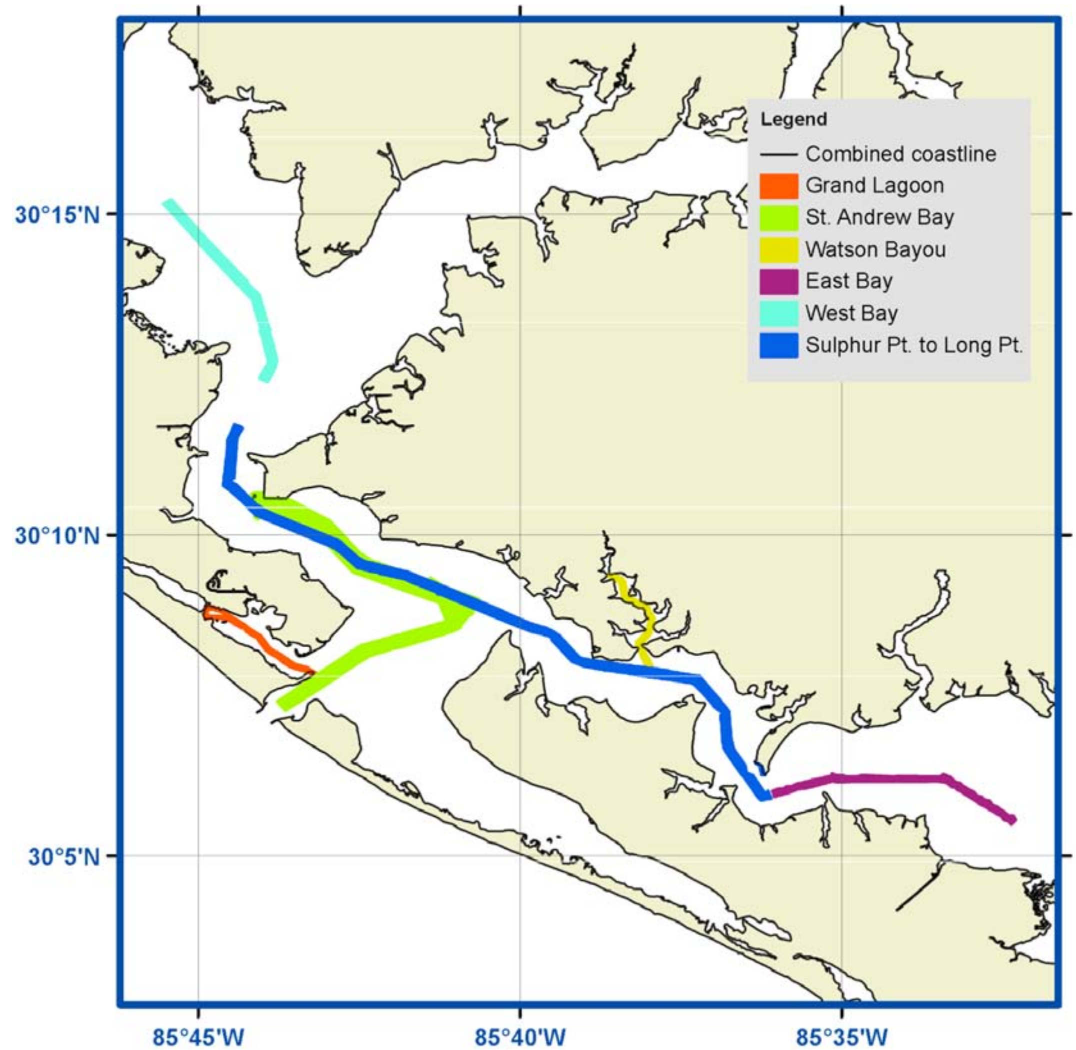

Figure 9. *Location of USACE survey data within dredged shipping channels in the Panama City region.*

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

Region	*Original horizontal datum*	*Original vertical datum*	*Spatial Resolution*
Grand Lagoon	NAD83 State Plane Florida North (feet)	MLLW	Profiles ~125 m long, spaced 60 m apart, with <10 m point spacing
Watson Bayou	NAD83 State Plane Florida North (feet)	MLLW	Profiles ~150 m long, spaced 60 m apart, with <0.5 m point spacing
St. Andrew Bay	NAD83 State Plane Florida North (feet)	MLLW	Profiles ~350 to 500 m long, spaced 60 m apart, with <20 m point spacing
East Bay	NAD83 State Plane Florida North (feet)	MLLW	Profiles ~250 m long, spaced 100 m apart, with <10 m point spacing
St. Andrew Bay to West Bay	NAD83 State Plane Florida North (feet)	MLLW	Profiles ~250 m long, spaced 100 to 150 m apart, with ~1 m point spacing
St. Andrew Bay – Sulpher Pt. to Long Pt.	NAD83 State Plane Florida North (feet)	MLLW	Profiles ~250 m long, ~spaced 100 to 150 m apart, with ~1 m point spacing

3) NGDC Digitized Intracoastal Waterway

The Intracoastal Waterway (ICW) in the Panama City region was digitized by NGDC, as no digital bathymetric survey data were available (Fig. 10). Digitization was performed in ArcMAP, referencing RNCs #11385 and #11393, and Coast Pilot 5. Two parallel lines along the ICW, 25 meters apart, were created, with points spaced every 10 meters along each line. An elevation value of -4.05 meters at MHW was assigned to the points, derived from the project depth of 12 feet at MLLW, as listed in Coast Pilot 5 and the NOAA nautical charts.

Figure 10. *NGDC's digitized representation of the Intracoastal Waterway (green). DEM boundary in red.*

3.1.3 Topography

Topographic datasets in the Panama City region were obtained from the Florida Department of Environmental Protection and the U.S. Geological Survey (Table 7; Fig. 11). NASA 1 arc-second SRTM data, Bay County Florida data and a NOAA CSC LiDAR survey from 1998 were not utilized in developing the Panama City DEM as they were superceded by higher-resolution, or more recent, datasets.

Table 7: Topographic datasets used in compiling the Panama City DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
Florida Dept. of Environmental Protection	2004	LiDAR	~1 m	NAD83 State Plane Florida North	NAVD88 (feet)	http://www.dep.state.fl.us/
USGS	1999 to 2004	NED 1/3 arc-second	~10 m	NAD83 geographic	NAVD88 (meters)	http://ned.usgs.gov/

Figure 11. *Source and coverage of topographic datasets used in building the Panama City DEM.*

1) Florida Department of Environmental Protection

The Florida Department of Environmental Protection (FDEP) provided NGDC with 68 files of high resolution topographic LiDAR data averaging 1500 meters in length and 500 meters wide, generally covering beach topography up to 300 meters inland. Coverage extends the length of the Gulf coast within the Panama City region, except for the entrance to St. Joseph Bay. The data were originally in Florida State Plane North coordinates and in NAVD88 vertical datum. They were converted to WGS84 and MHW using FME software, then visually displayed and edited using ArcGIS to eliminate elevation values below zero and those points located over water, by clipping to the combined coastline.

As the LiDAR data had not been processed to bare earth, NGDC simulated bare-earth by eliminating elevation values greater than 8 meters above MHW. This "clipping" elevation value of 8 meters was selected to remove any elevations associated with man-made structures such as buildings, while retaining most of the natural topographic variability along the coast. Numerous piers and other coastal structures were also excised from the dataset using ArcMap. Figure 12 illustrates the results of NGDC's processing efforts on one data file.

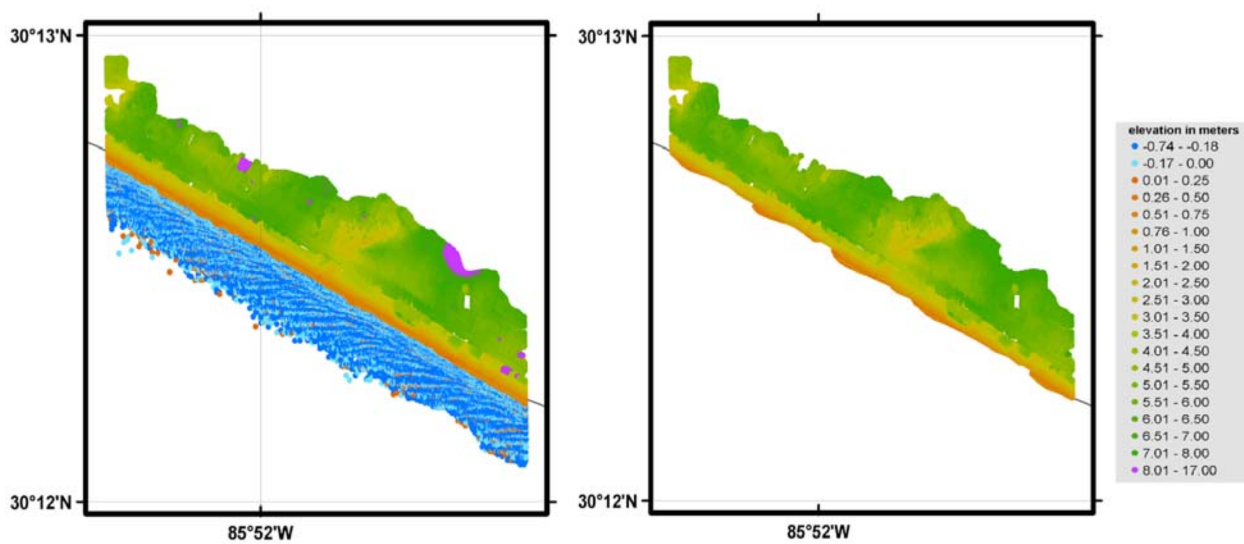

Figure 12. *FDEP topographic LiDAR data before (left) and after (right) NGDC processing.*

2) USGS NED topography

The U.S. Geological Survey (USGS) National Elevation Dataset (NED; http://ned.usgs.gov/) provided complete 1/3 arc-second coverage of the Panama City region[2]. Data are in NAD83 geographic coordinates and NGVD88 vertical datum (meters), and are available for download as raster DEMs. The extracted 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 2004.

The NED data included "zero" elevation values over the open ocean (Fig. 13), which were removed from the dataset before gridding. Some anomalous values still remained over the open ocean, which were visually inspected and compared with NOAA nautical charts, the combined coastline, and *Google Earth* satellite imagery. ESRI Arc Catalog was used to clip the data to the combined coastline.

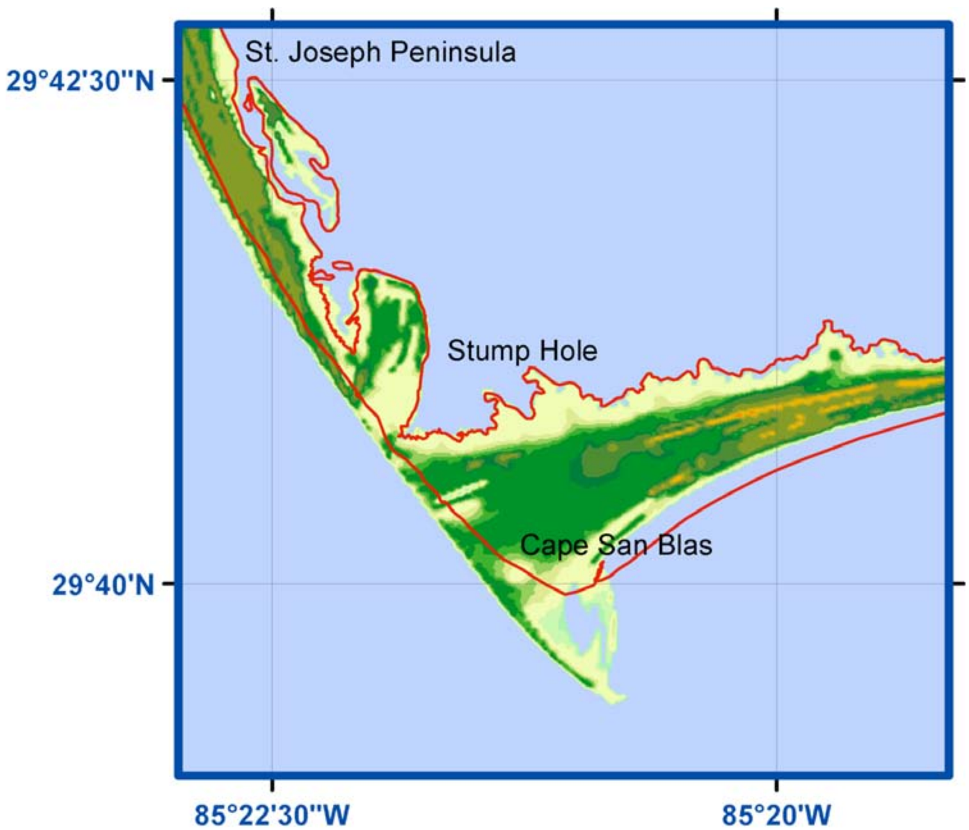

Figure 13. *Color image of the NED DEM in the vicinity of Cape San Blas. Blue represents "zero" values in NED DEM over the open ocean. Combined coastline, derived from post-Dennis LiDAR survey, in red illustrates the magnitude of coastal change that has occurred in this area.*

2. 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 Topography–Bathymetry

Combined topographic–bathymetric surveys of coastal Florida (Fig. 14) were performed in 2004 and 2005—post-Hurricanes Dennis and Katrina—by the Joint Airborne LiDAR Bathymetry Technical Center of Expertise (JALBTCX; Table 8; Fig. 14). The data were collected using the CHARTS (Compact Hydrographic Airborne Rapid Total Survey) system to depict elevations above and below water along the immediate coastal zone[3]. The surveys generally extend 750 meters inland and up to 1500 meters over the water. Data points are spaced approximately every 5 meters, and have an accuracy better than 3.0 meters horizontally and 0.3 meters vertically. These data were not processed to bare earth, therefore NGDC deleted all values greater than 8 meters above MHW to remove the effect of buildings in the datasets.

Table 8. Combined topographic–bathymetric datasets used in compiling the Panama City DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*
JALBTCX 2004	2004	LiDAR	5 m	NAD83 geographic	NAVD88 (meters)
JALBTCX post-Dennis	2005	LiDAR	5 m	NAD83 geographic	NAVD88 (meters)
JALBTCX post-Katrina	2005	LiDAR	5 m	NAD83 geographic	NAVD88 (meters)

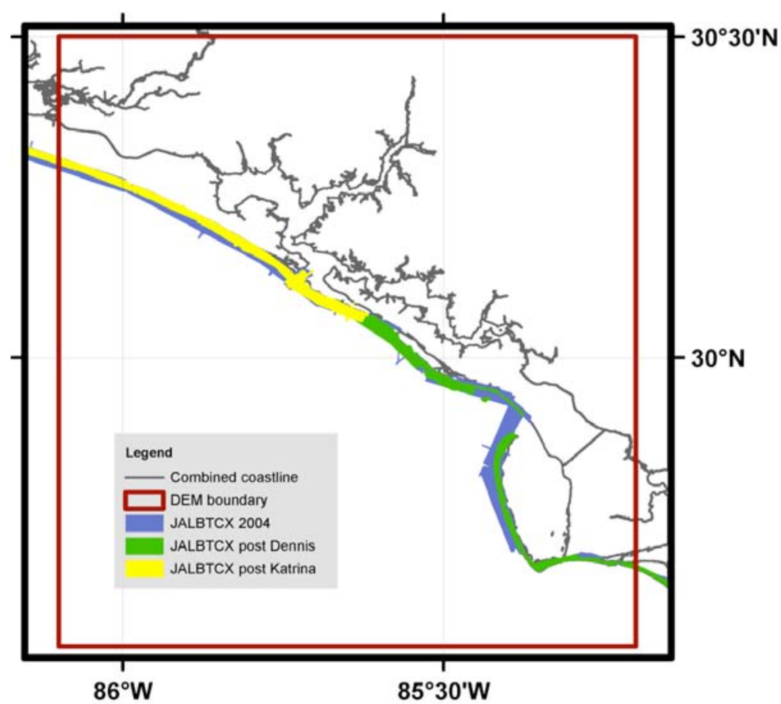

Figure 14. *Spatial coverage of JALBTCX high-resolution (5-meter point spacing) coastal bathymetric–topographic LiDAR surveys utilized in DEM development.*

3. 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 to remove anomalous data 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]

1) Post-Hurricane Katrina 2005 JALBTCX LiDAR survey

This dataset consists of a bathymetric–topographic coastal LiDAR survey covering 60 kilometers of the coastal region from Greyton Beach to St. Andrew Sound. Post-Hurricane Katrina elevations were collected above and below water along the immediate coastal zone.

The survey has a spatial resolution of 5 meters and straddles the shoreline from 1,000 to 1,500 meters in width. NGDC removed elevations greater than 8 meters using FME, roughly approximating 'bare earth' by removing buildings, tall structures and trees. Other features such as piers, docks, and anomalous returns were also edited out using ArcMap (e.g., Fig. 15).

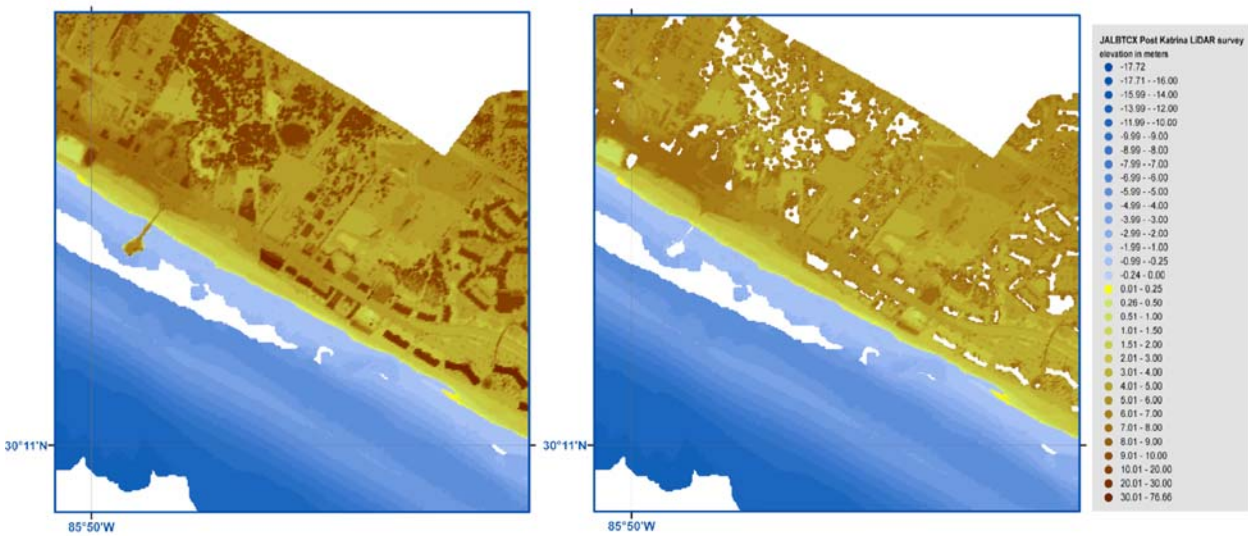

Figure 15. *Post-Hurricane Katrina JALBTCX data before (left) and after (right) NGDC processing to simulate bare earth. Note pier and beach-front structures present before processing.*

2) Post-Hurricane Dennis 2005 JALBTCX LiDAR survey

This dataset consists of a bathymetric–topographic coastal LiDAR survey covering the entire Gulf Coast shoreline within the DEM area, with the exception of St. Joseph Bay. The survey has a spatial resolution of 5 meters and straddles the shoreline from 500 to 2200 meters. The "zero" elevation line representing MHW is less sharply defined in this dataset than in the post-Katrina dataset (e.g., Fig. 16). NGDC removed elevations greater than 8 meters using FME software, roughly approximating 'bare earth' by removing buildings, tall structures and trees. Other features such as piers, docks, and anomalous returns were also edited out using ArcMap. The coastal area of the St. Joseph Peninsula was particularly impacted by Hurricane Dennis in 2005, making this data set critical in defining the current shoreline.

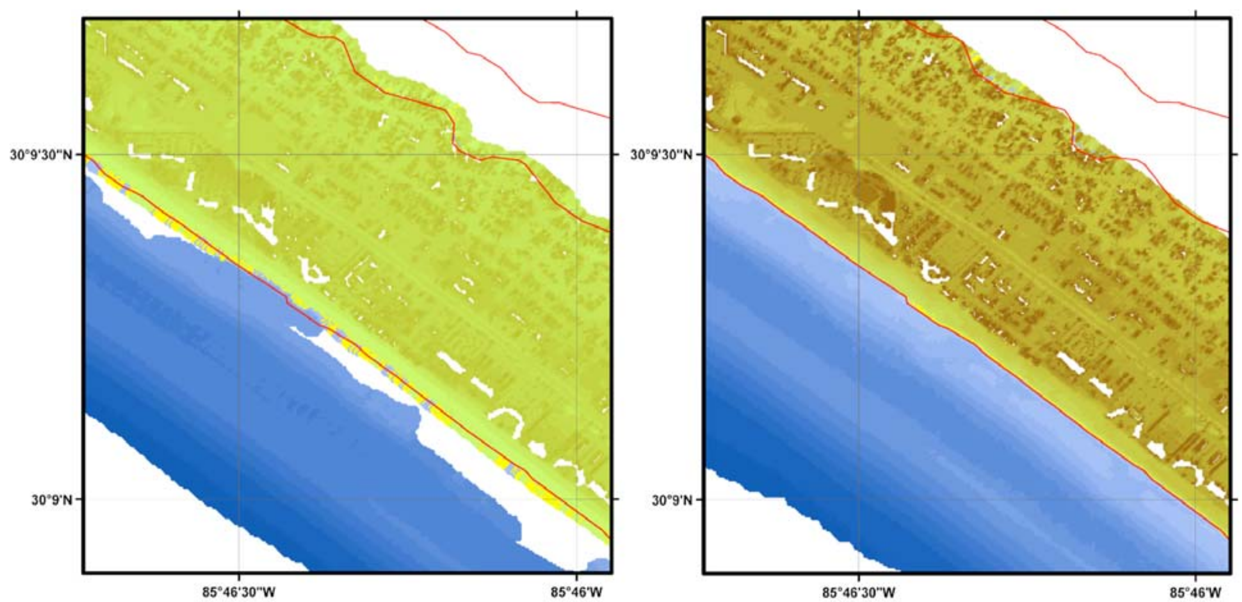

Figure 16. *Indistinct MHW coastline in post-Hurricane Dennis JALBTCX survey (left). Clearly defined MHW coastline in post-Hurricane Katrina JALBTCX survey (right).*

3) 2004 JALBTCX LiDAR survey

This dataset consists of a bathymetric–topographic coastal LiDAR survey covering the entire Gulf Coast shoreline within the DEM area, with the exception of St. Joseph Bay. The survey has a spatial resolution of 5 meters and straddles the coastline from 1500 to 2200 meters. NGDC used this dataset for the coastal areas not covered by either the post-Hurricane Katrina or post-Hurricane Dennis datasets, specifically the offshore area on and to the north of St. Joseph Peninsula. NGDC removed elevations greater than 8 meters using FME, roughly approximating 'bare-earth' by removing buildings, tall structures and trees. Other features such as piers, docks, and anomalous returns were also edited out using ArcMap. This dataset was used to modify the St. Andrew Bay East Pass Inlet coastline to reflect inlet closure information provided by Terry Jangula at the USACE Panama City Field office.

Analysis of the data revealed anomalous elevations near shore not present in the post-Dennis and post-Katrina datasets (Fig. 17). Jeff Lillycrop, USACE, confirmed that these features are dredged areas used for local beach restoration projects.

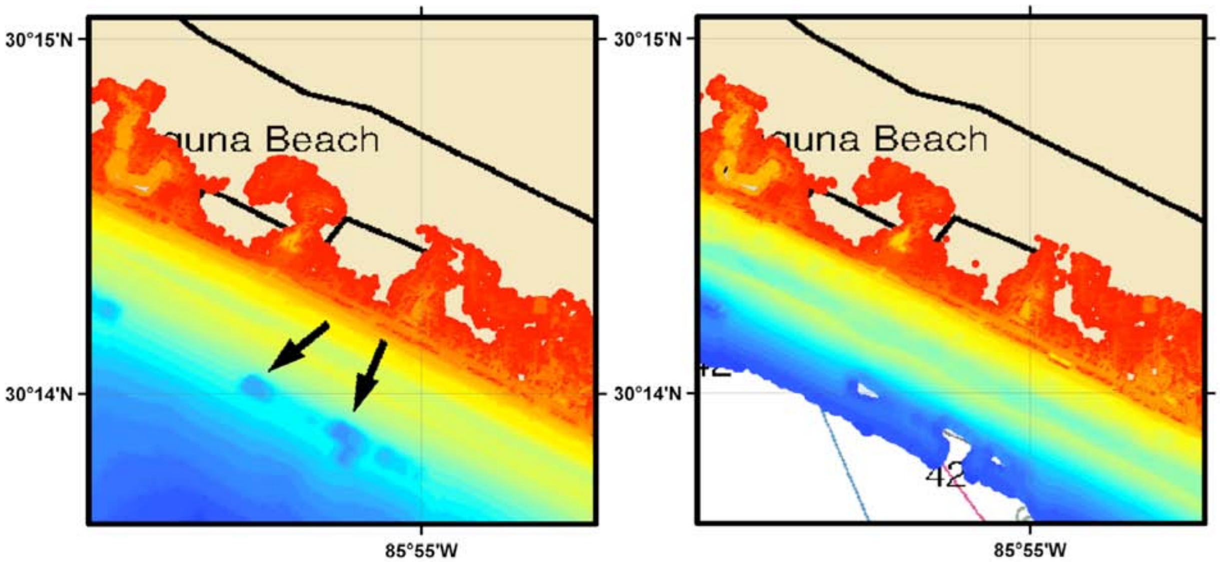

Figure 17. *Beach replenishment areas offshore Laguna Beach. JALBTCX 2004 survey data, on left, reveals numerous geometric shapes of deeper than expected elevations (arrows), which are dredged source areas for beach restoration and replenishment projects in the Panama City region. Right panel shows the 2005 post-Hurricane Katrina dataset in the same area, which also reveals these pits.*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Panama City DEM were originally referenced to a number of vertical datums including Mean Lower Low Water (MLLW), Gulf Coast Low Water (GCLW), 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 converted from feet to meters as appropriate.

1) **Bathymetric data**

   The NOS hydrographic surveys and the USACE surveys were transformed from MLLW, MLW, and GCLW to MHW, using FME software, by adding a constant offset determined by averaging two Panama City NOAA tidal stations (Table 9; Fig. 23).

2) **Topographic data**

   The USGS NED 1/3 arc-second DEM and the Florida Department of Environmental Protection LiDAR data were originally referenced to NAVD88. Conversion to MHW, using FME software, was accomplished by adding tide-station derived constant offsets (Table 9).

3) **Topographic–bathymetric data**

   Combined topographic–bathymetric coastal LiDAR survey data were transformed from NAVD88 to MHW using FME software (Table 9).

Table 9. Relationship between Mean High Water and other vertical datums in the Panama City region.*

Vertical datum	*Difference to MHW*
NAVD88	-0.224
MLW	-0.337
Gulf Coast Low Water[+]	-0.394
MLLW	-0.394

* Datum relationships determined by averaging values from tide stations #8729108, Panama City/St. Andrew Bay and #8729210, Panama City Beach.

+ Equivalent to MLLW.

3.2.2 Horizontal datum transformations

Datasets used to compile the Panama City DEM were originally referenced to State Plane Florida North, NAD27, NAD83 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 using FME software.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

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

- Presence of man-made structures and river banks in most coastline datasets, which had to be removed.
- Inconsistencies between various coastline datasets and bathymetric, topographic and bathymetric–topographic datasets. These inconsistencies are partly the result of differing resolution between datasets and of morphologic change in the highly dynamic coastal zone.
- Data values over the open ocean and rivers in the NED DEMs and FDEP LiDAR data. Each dataset required automated clipping to the combined coastline.
- Presence of buildings and other man-made structures, as well as trees, in the coastal bathymetric–topographic LiDAR datasets from JALBTCX. As these datasets were not bare-earth, NGDC eliminated elevations greater than 8 meters above MHW to crudely remove such features while retaining coastal morphology.
- Digital, measured bathymetric values from NOS surveys date back over 70 years. More recent data, such as USACE surveys in dredged shipping channels, differed from older, pre-dredging NOS data by as much as 10 meters. The older NOS survey data were excised where more recent bathymetric data exists.

3.3.2 Smoothing of bathymetric data

The NOS hydrographic surveys are generally sparse at the resolution of the 1/3 arc-second Panama City DEM: in deep water, the NOS survey data have point spacings up to 2 km 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' or grid was generated using GMT, an NSF-funded share-ware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

The NOS hydrographic point data, in xyz format, were combined with the USACE and ICW soundings, and JALBTCX bathymetric–topographic survey data into a single file, along with points extracted from the combined coastline—to provide a "zero" buffer along the entire coastline. These point data were then median-averaged using the GMT tool 'blockmedian' to create a 1 arc-second grid 0.05 degrees (~5%) larger than the Panama City DEM gridding region. The GMT tool 'surface' then applied a tight spline tension to interpolate cells without data values. The GMT grid created by 'surface' was converted into an ESRI Arc ASCII grid file, and clipped to the combined coastline (to eliminate data interpolation into land areas). The resulting surface was compared with the original soundings to ensure grid accuracy (e.g., Fig. 18), converted to a shape file, and then exported as an xyz file for use in the final gridding process (see Table 10).

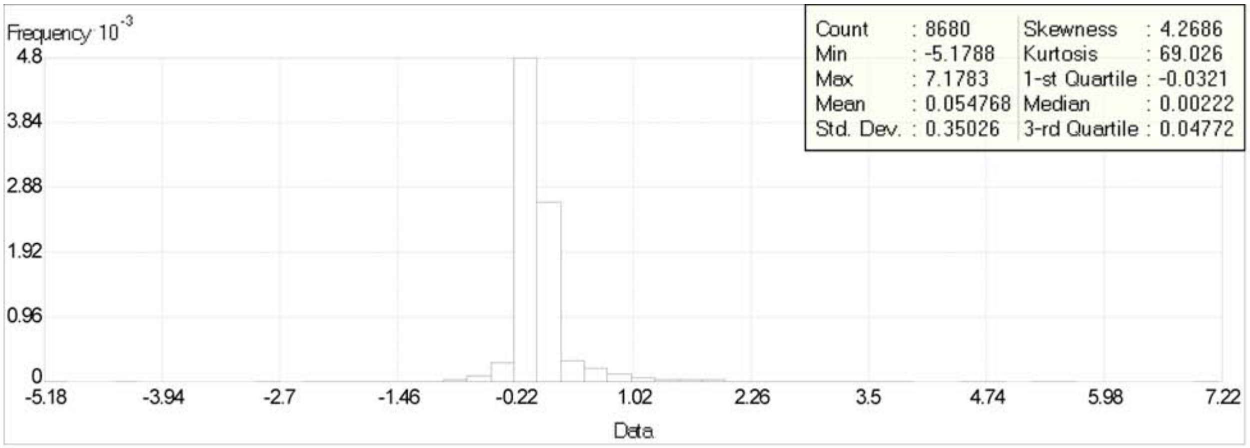

Figure 18. *Histogram of the difference between NOS hydrographic survey H10236 (relatively dense survey in North Bay) and the 1 arc-second pre-surfaced bathymetric grid. Discrepencies between survey soundings and the pre-surface grid result from the averaging of several closely spaced soundings.*

3.3.3 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 Panama City DEM. MB-System is an NSF-funded share-ware software application specifically designed to manipulate submarine multibeam sonar data, though it can utilize a wide variety of data types, including generic xyz data. The MB-System tool 'mbgrid' applied a tight spline tension to the xyz data, and interpolated 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 high-resolution post-Katrina coastal LiDAR survey. Least weight was given to the pre-surfaced 1 arc-second bathymetric grid. Gridding was performed in quadrants, each with a 5% data overlap buffer. The resulting Arc ASCII grids were seamlessly merged in ArcCatalog to create the final 1/3 arc-second Panama City DEM.

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

Dataset	*Relative Gridding Weight*
JALBTCX coastal lidar bathymetry–topography: post-Katrina	10000
JALBTCX coastal lidar bathymetry–topography: post-Dennis	1000
JALBTCX coastal lidar bathymetry–topography: 2004	100
USACE bathymetry	100
NGDC-digitized Intracoastal Waterway	100
FDEP coastal lidar topography	10
USGS NED topographic DEM	1
NOS hydrographic surveys: bathymetric soundings	1
Pre-surfaced bathymetric grid	0.01

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Panama City DEM is dependent upon the datasets used to determine corresponding DEM cell values. Topographic features have an estimated accuracy of 1 to 15 meters: JALBTCX and FDEP coastal LiDAR data have an accuracy of between 1 and 3 meters, NED topography is accurate to within about 15 meters. Bathymetric features are resolved only to within a few hundred meters in deep-water areas (i.e., the southwest corner of the DEM). Shallow, near-coastal regions, rivers, and dredged shipping channels 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 rapid morphologic change that occurs in this dynamic region.

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the Panama City DEM is also highly dependent upon the source datasets contributing to DEM cell values. Topographic areas have an estimated vertical accuracy between 0.15 (for JALBTCX and FDEP coastal LiDAR data) and up to 7 meters (for NED topography). Bathymetric areas have an estimated accuracy of between 0.1 meters and 5% of water depth (~4 meters in the southwest corner of the DEM). Those values were derived from the wide range of input data sounding measurements from the early 20th century to recent, GPS-navigated sonar surveys. Gridding interpolation to determine values between sparse, poorly-located NOS soundings degrades the vertical accuracy of elevations in deep water.

3.4.3 Slope maps and 3-D perspectives

ESRI ArcCatalog was used to generate a slope grid from the Panama City DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 19). The DEM was transformed to UTM Zone 16 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 (e.g., Fig. 20) was accomplished using ESRI ArcScene. 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 Panama City DEM in its final version

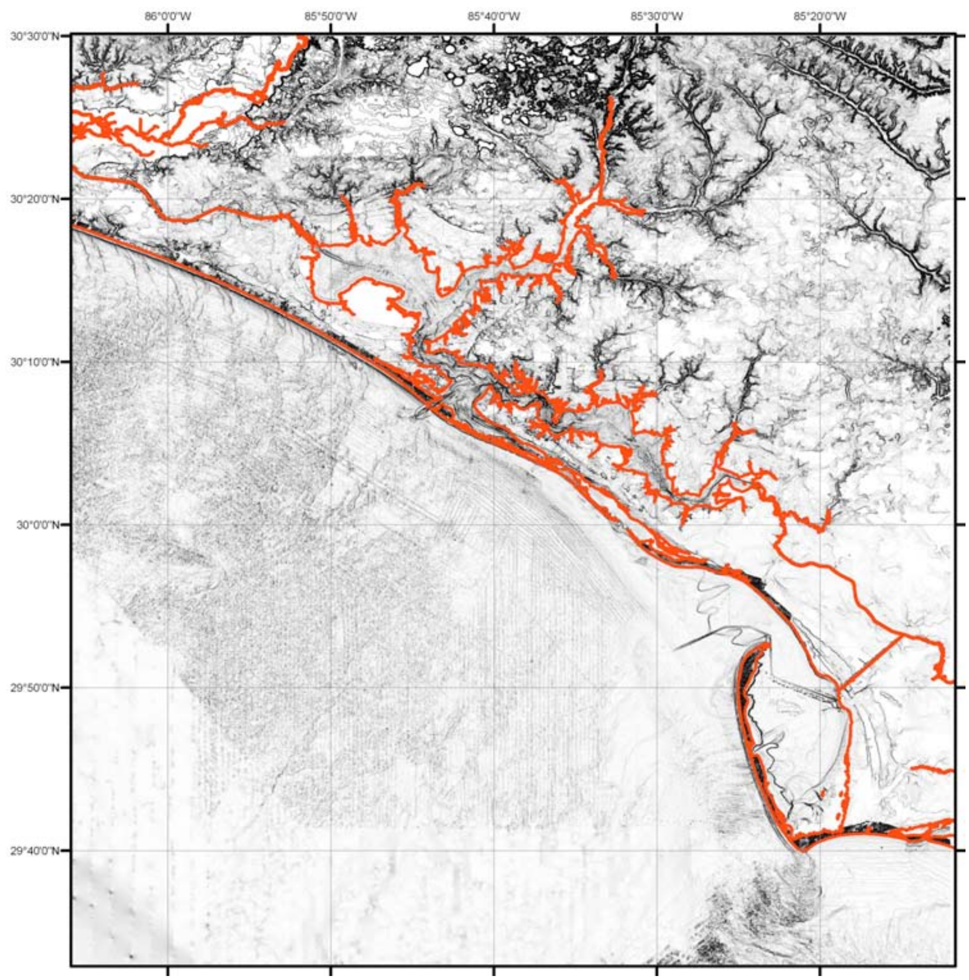

Figure 19. *Slope map of the Panama City DEM. Flat-lying slopes are white; dark shading denotes steep slopes; combined coastline in red.*

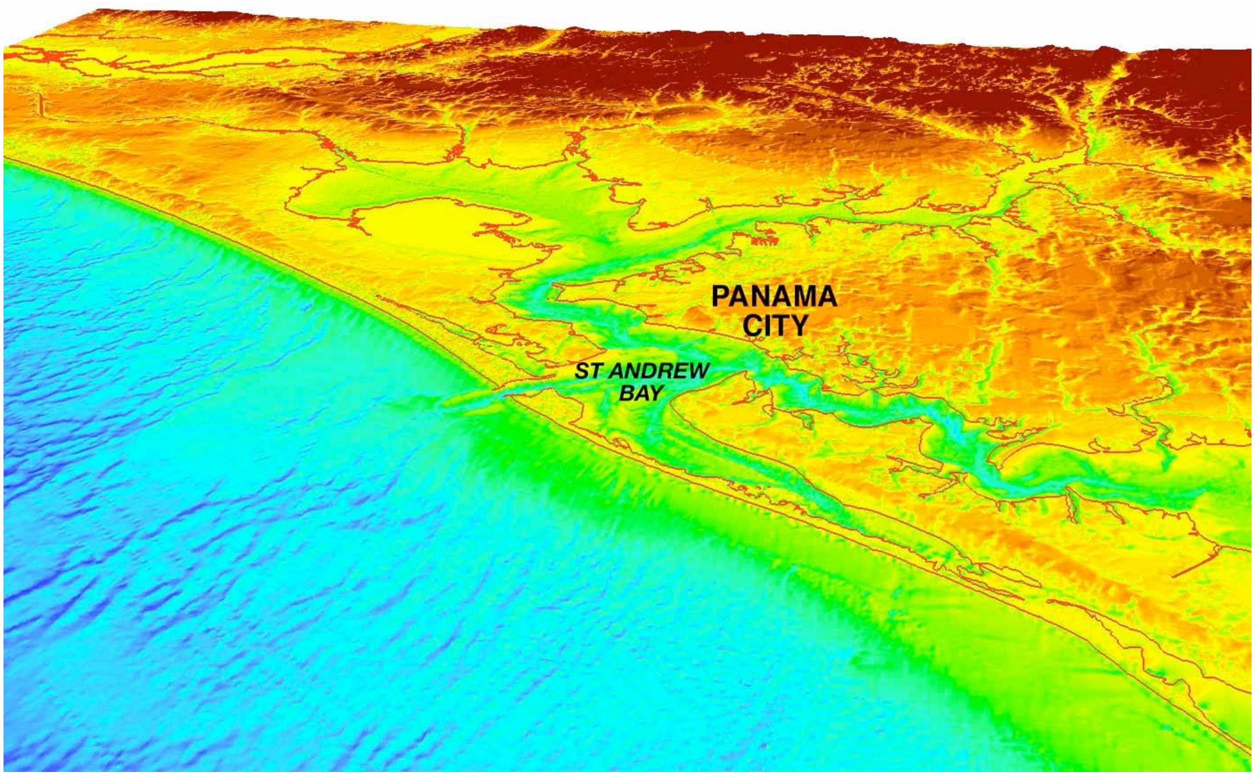

Figure 20. *Perspective view from the south of the Panama City DEM. Combined coastline in red; vertical exaggeration–times 10.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Panama City DEM was compared to select source data files. Files were chosen on the basis of their contribution to the grid-cell values in their coverage areas (i.e., had the greatest weight and did not significantly overlap other data files with comparable weight). A histogram of the difference between a post-Hurricane Katrina JALBTCX coastal bathymetric–topographic LiDAR survey file and the Panama City DEM is shown in Figure 21.

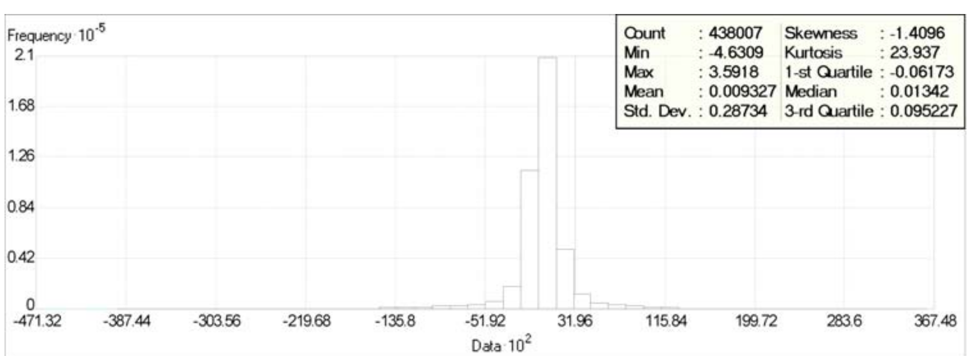

Figure 21. *Histogram of the difference between one file of the post-Katrina JALBTCX coastal bathymetric–topographic LiDAR survey (438,007 points) and the Panama City DEM.*

3.4.5 Comparison with NGS geodetic monuments

The elevations of 101 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 (sub-mm accuracy) and elevations in NAVD88 (in meters). Elevations were shifted to MHW vertical datum (see Table 9) for comparison with the Panama City DEM (see Fig. 23 for monument locations). Differences between the Panama City DEM and the NGS geodetic monument elevations range from -2.3 to 5.2 meters, with a negative value indicating that the monument elevation is less than the DEM (Fig. 22). Examination of the monuments with the largest positive offsets from the DEM revealed that they lie within the East River Island region, alongside a highway, or atop a small hill that is poorly resolved within the NED topographic DEM.

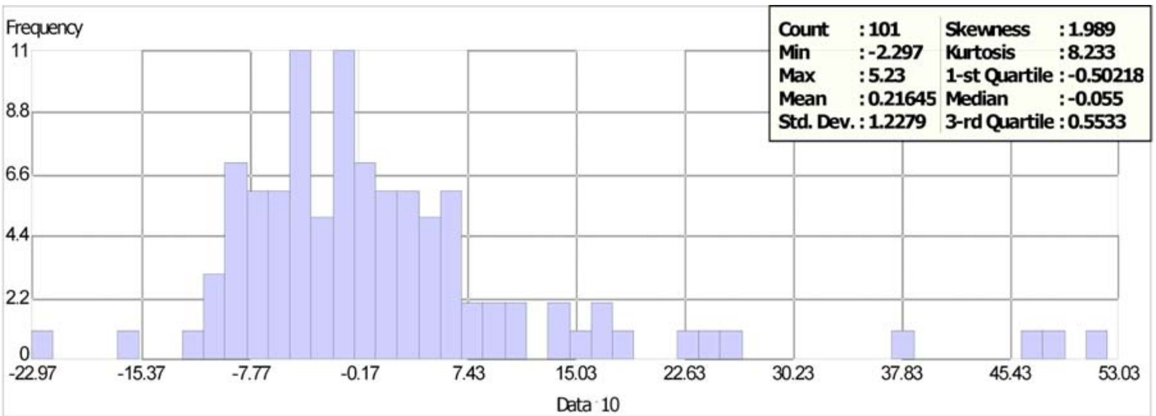

Figure 22. *Histogram of the differences between NGS geodetic monument elevations and the Panama City DEM.*

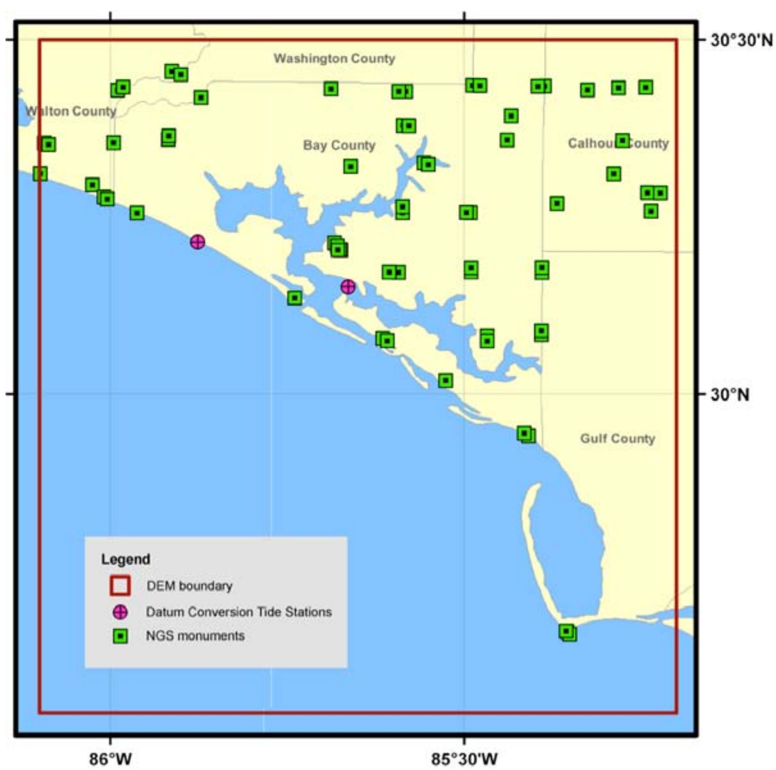

Figure 23. *Location of NGS monuments and NOAA tide stations in the Panama City region. Tide stations used to convert between vertical datums; NGS monument elevations used to evaluate the DEM.*

4. SUMMARY AND CONCLUSIONS

A topographic–bathymetric digital elevation model of the Panama City, 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 agencies were obtained by NGDC, shifted to common horizontal and vertical datums, and evaluated and edited before DEM generation. The data were quality checked, processed and gridded using ESRI ArcGIS, FME, GMT, and MB-System software.

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

- Process coastal LiDAR data to bare earth.
- Obtain digital versions of several NOAA nautical charts (#11390 and 11391) that have not yet been digitized.
- NGDC digitized the Intracoastal Waterway in the vicinity of Panama City, based upon minimum depths reported in Coast Pilot 5, as no digital data existed for these channels. The channels are frequently deeper along much of their lengths than their representation in the DEM, which could be remedied with new survey work.

5. ACKNOWLEDGMENTS

The creation of the Panama City DEM was funded by the NOAA, Pacific Marine Environmental Laboratory. The authors thank Chris Chamberlin and Vasily Titov (PMEL), Jeff Lillycrop (USACE), Terry Jangula and Victoria Ann Anderson (USACE Panama City Field Office), Janet Bogere (Bay County GIS Office), and Gary Cook, (Florida Department of Environmental Protection).

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Nautical Chart #11385, 7th Edition, 2006. West Bay to Santa Rosa Sound. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11388, 2nd Edition, 2006. Choctawhatchee Bay. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11389, 3rd Edition, 2006. St. Joseph and St. Andrews Bay. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11390, 23rd Edition, 2004. East Bay to West Bay Florida Side A. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11391, 24th Edition, 2005. St. Andrew Bay. Scale 1:25,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11392, 7th Edition, 2006. St. Andrew Bay – Bear Point to Sulphur Point. Scale 1:5,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11393, 7th Edition, 2006. Lake Wimico to East Bay Side A & B. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11400, 5th Edition, 2006. Tampa Bay to Cape San Blas. Scale 1:456,394. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11401, 4th Edition, 2006. Apalachicola Bay to Cape San Blas. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11402, 6th Edition, 2006. Apalachicola Bay to Lake Wimico. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

7. DATA PROCESSING SOFTWARE

ArcGIS v. 9.1, developed and licensed by ESRI, Redlands, California, http://www.esri.com/

Electronic Navigational Chart Data Handler for ArcView, developed by NOAA Coastal Services Center, http://www.csc.noaa.gov/products/enc/

FME 2006 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

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

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

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