NOAA Technical Memorandum NESDIS NGDC-50

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http://www.ngdc.noaa.gov/mgg/inundation/vdatum/vdatum.html

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Digital Elevation Models of Panama City, Florida: Procedures, Data Sources and Analysis

1. Introduction

In May of 2010, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed two bathymetric–topographic digital elevation models (DEMs) of Panama City, Florida (Fig. 1). The DEMs were developed for NOAA Coast Survey Development Laboratory (CSDL) through the American Recovery and Reinvestment Act (ARRA) of 2009[1] to evaluate the utility of the *Vertical Datum Transformation* tool (*VDatum*), developed jointly by NOAA's Office of Coast Survey (OCS), National Geodetic Survey (NGS), and Center for Operational Oceanographic Products and Services (CO-OPS) (http://vdatum.noaa.gov/). A 1/3 arc-second[2] DEM referenced to North American Vertical Datum of 1988 (NAVD 88) was carefully developed and evaluated. A conversion grid derived from *VDatum* project areas was then created to model the relationship between NAVD 88 and mean high water (MHW) in the Panama City region. NGDC combined the NAVD 88 DEM and the conversion grid to develop a 1/3 arc-second MHW DEM. The NAVD 88 DEM was generated from diverse digital datasets in the region (grid boundary and sources shown in Fig. 4) and the DEMs will be used for storm-surge inundation and sea-level-rise modeling. This report provides a summary of the data sources and methodology used in developing the Panama City DEMs.

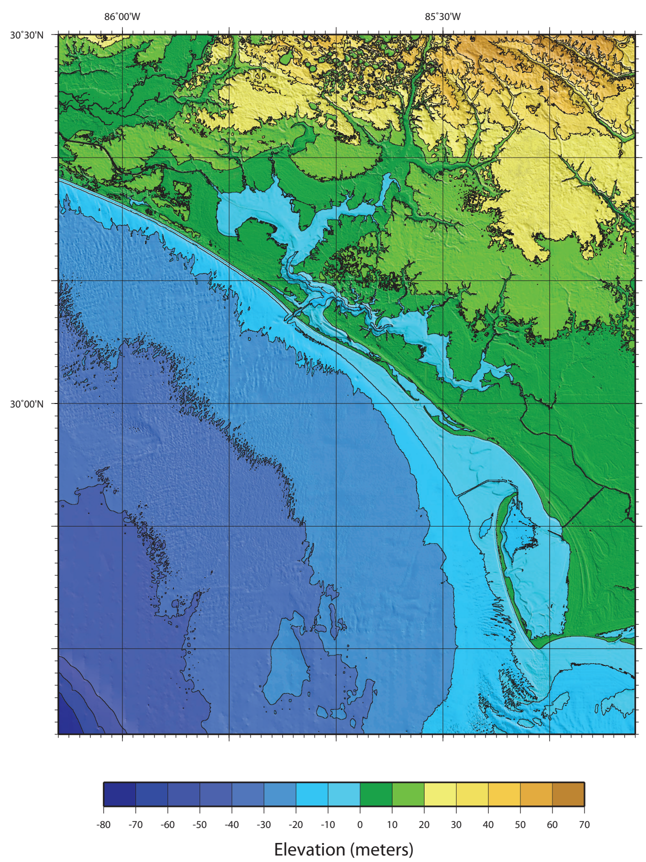

Figure 1. *Shaded-relief image of the Panama City NAVD 88 DEM. Contour interval is 10 meters.*

1. On Feb. 13, 2009, Congress passed the American Recovery and Reinvestment Act of 2009 at the urging of President Obama, who signed it into law four days later. A direct response to the economic crisis, the Recovery Act's three goals are to create new jobs as well as save existing ones, spur economic activity and invest in long-term economic growth and foster unprecedented levels of accountability and transparency in government spending (http://www.recovery.gov/Pages/home.aspx).

2. 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, FL (30°1′30″N 85°39′0″W) 1/3 arc-second of latitude is equivalent to 10.2642 meters; 1/3 arc-second of longitude equals 8.9317 meters.

2. Study Area

The Panama City DEMs cover the area surrounding the City of Panama City, Florida, including portions of Bay County, Gulf County, Calhoun County, Washington County, and Walton County (Fig. 2). As of the 2000 census, there were 36,417 permanent residents of Panama City. In addition, Panama City Beach is a popular vacation destination. The Panama City region is located on the north western coast of Florida. 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 (Morton, 2004).

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 (Fig. 3). Beach restoration projects are part of the continuing effort to maintain the tourist-based economy by mitigating the type 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 Systems has published a comprehensive report on the impacts of the 2005 hurricane season on Northwest Florida (Bureau of Beaches and Coastal Systems, 2006).

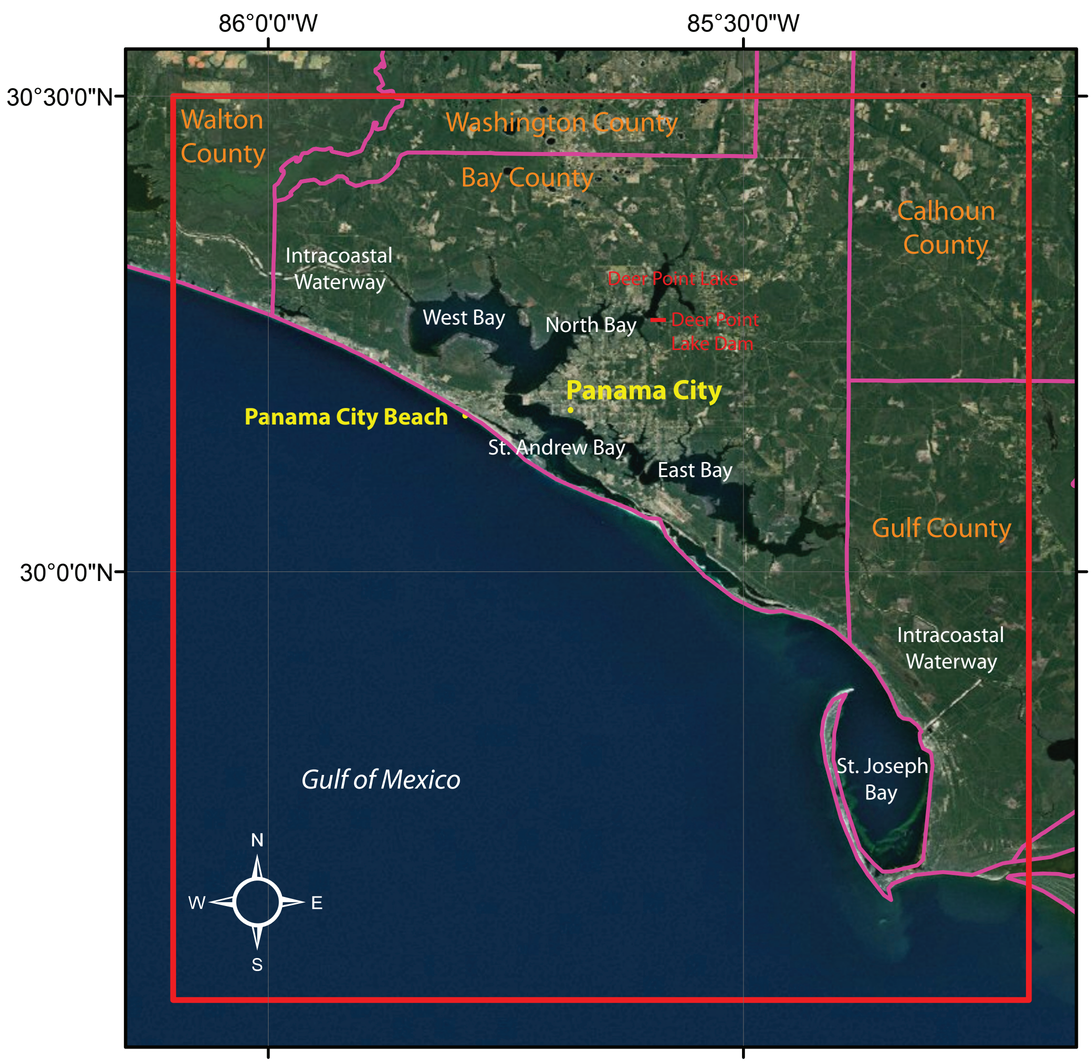

Figure 2. *ESRI World 2D imagery of the Panama City region.*

Figure 3. *An example of coastal erosion at Carillon Beach, post-Hurricane Dennis.*

3. Methodology

The Panama City DEMs were constructed to meet CSDL specifications, based on storm-surge and sea-level-rise modeling requirements (Tables 1 and 2). The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: North American Datum of 1983 (NAD 83) and North American Vertical Datum of 1988 (NAVD 88). NGDC developed a conversion grid derived from *VDatum* project areas to transform the Panama City DEM in its entirety from NAVD 88 to MHW, for modeling of maximum flooding (Section 3.3.4). Data were gathered in an area slightly larger (~5%) than the DEM extents. This data "buffer" ensures that gridding occurs across rather than along the DEM boundaries to prevent edge effects. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1. Specifications for the Panama City NAVD 88 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	North American Datum of 1983 (NAD 83)
Vertical Datum	North American Vertical Datum of 1988 (NAVD 88)
Vertical Units	Meters
Grid Spacing	1/3 arc-second
Grid Format	ESRI Arc ASCII grid

Table 2. Specifications for the Panama City MHW 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	North American Datum of 1983 (NAD 83)
Vertical Datum	Mean high water (MHW)
Vertical Units	Meters
Grid Spacing	1/3 arc-second
Grid Format	ESRI Arc ASCII grid

3.1 Data Sources and Processing

Coastline, bathymetric, topographic and combined bathymetric-topographic digital datasets (Fig. 4) were obtained from NOAA's Coastal Services Center (CSC) and NGDC, U.S. Army Corps of Engineers (USACE), Florida Division of Emergency Management (FDEM), Northwest Florida Water Management District (NWFWMD), United States Geological Survey (USGS), and the University of Florida. Safe Software's *Feature Manipulation Engine* (*FME)* data translation tool package was used to shift datasets to NAD 83 horizontal datum. Vertical datum transformations to NAVD 88 were accomplished using NOAA's jointly developed *VDatum* software and *ArcGIS* based upon *VDatum* coverage (Section 3.2.1). The datasets were then displayed with ESRI's *ArcGIS,* ESRI's online *World 2D* imagery and Applied Imagery's *Quick Terrain Modeler* (*QT Modeler*) software to assess data quality and manually edit datasets.

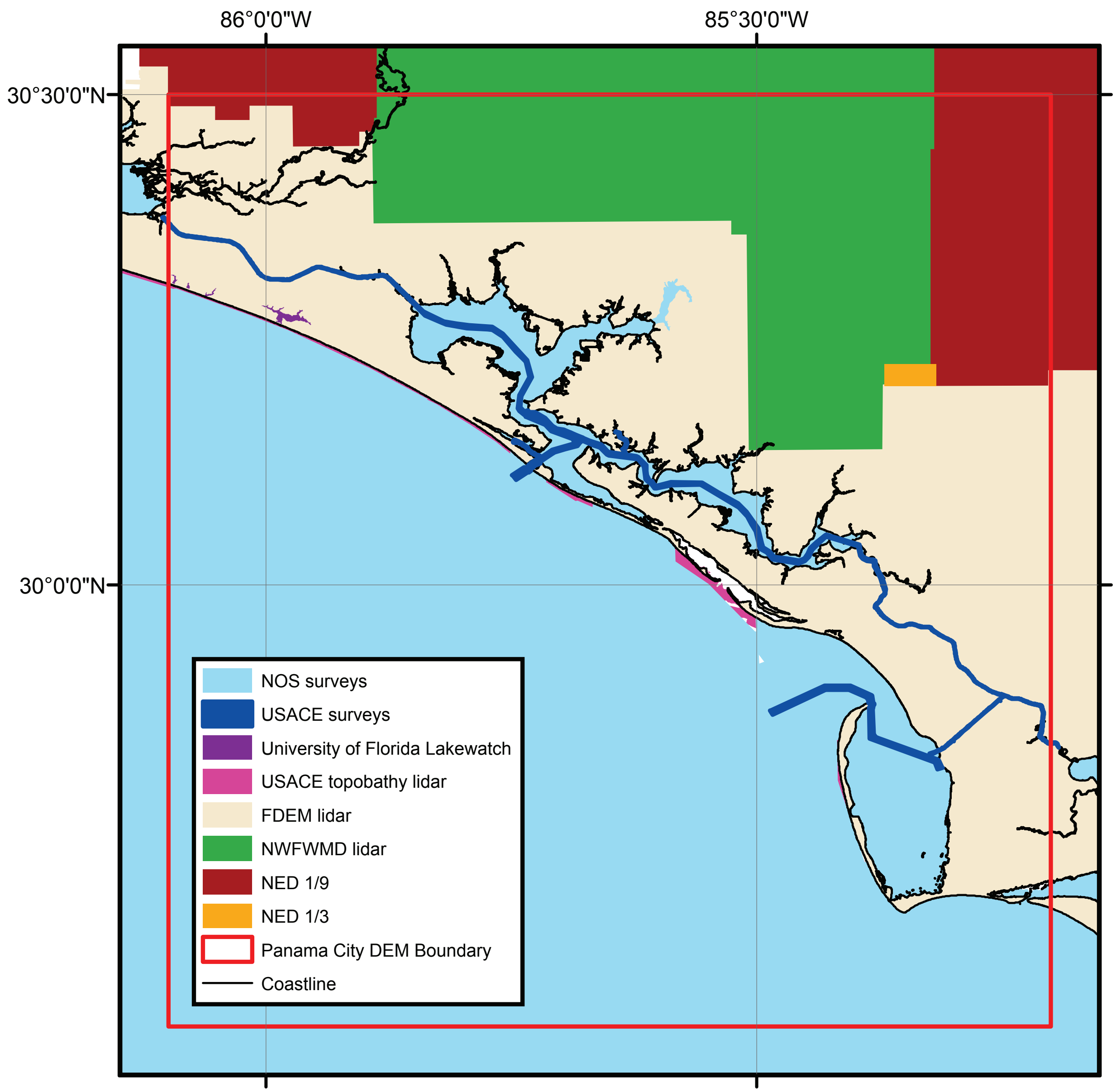

Figure 4. *Source and coverage of datasets used in building the Panama City NAVD 88 DEM.*

3.1.1 Coastline

The Panama City region coastline was obtained from a previous DEM of Panama City developed by NGDC in 2007 (Taylor et al., 2008). The coastline, originally referenced to MHW and World Geodetic System of 1984 (WGS 84)[3], was transformed to NAVD 88 by manually editing the coastline to align with the zero line of topographic lidar referenced to NAVD 88 and the coastline depicted in ESRI's online *World 2D* imagery (Fig. 5). The original NGDC coastline was derived from numerous sources including NOAA OCS Electronic Navigational Charts (ENCs), Florida Department of Environmental Protection (FDEP) BIS/GIS Section, and USGS High Resolution National Hydrography Dataset. A detailed description of data sources used to build the coastline of the 2007 DEM can be found in the NOAA Technical Memorandum NESDIS NGDC-8 (Taylor et al., 2008).

Table 3. Coastline datasets used in building the Panama City NAVD 88 DEM

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum*	*Original Vertical Datum*	*URL*
NGDC	2007	Composite vectorized coastline	1/3 arc-second	WGS 84 geographic	MHW	http://www.ngdc.noaa.gov/mgg/inundation/tigp/ngdc/data/panama_city_fl/panama_city_fl.pdf

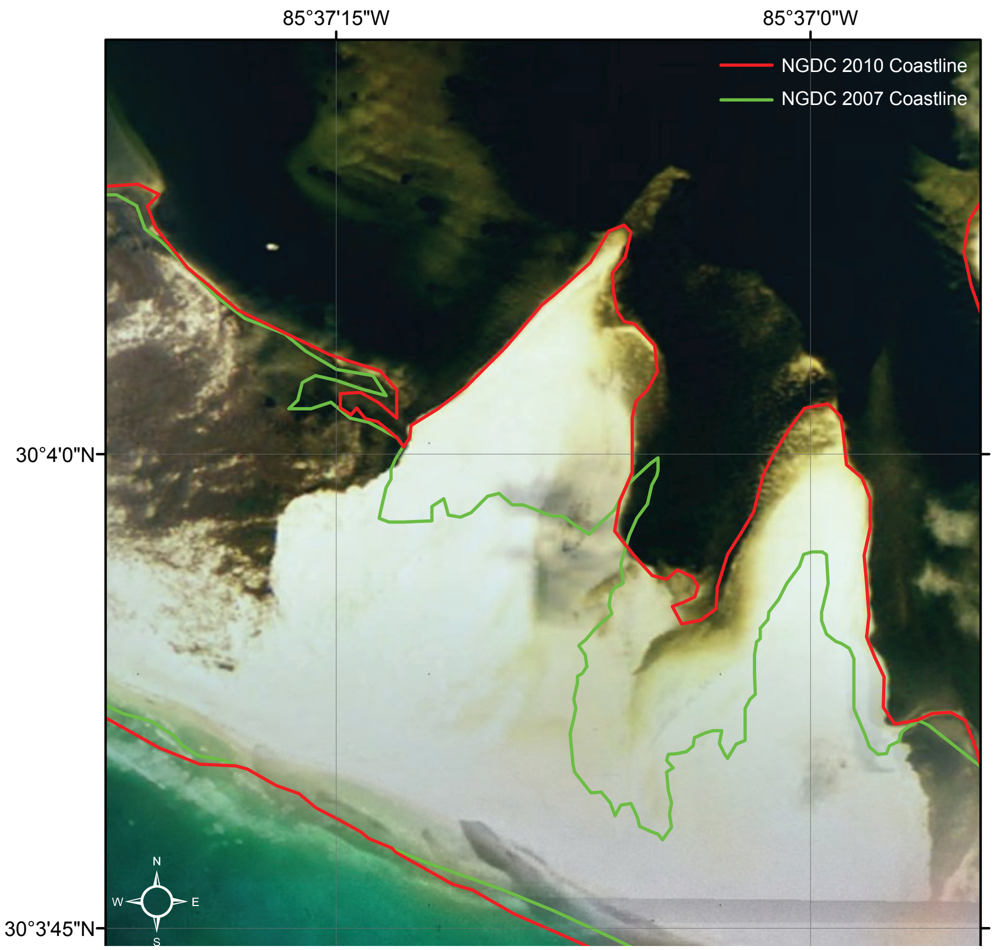

Figure 5. *Differences between the NGDC 2007 (green) and 2010 (red) coastlines (ESRI online World 2D imagery in background). Coastal morphologic change has greatly altered the land-water interface.*

3. The horizontal difference between the North American Datum of 1983 (NAD 83) and World Geodetic System of 1984 (WGS 84) geographic horizontal datums is approximately one meter across the contiguous U.S., which is significantly less than the cell size of the DEMs. At the scale of the DEMs, WGS 84 and NAD 83 geographic are identical and may be used interchangeably.

3.1.2 *Bathymetry*

Bathymetric datasets available in the Panama City region included 50 NOS hydrographic surveys, 5 USACE hydrographic surveys of dredged channels, and University of Florida hydrographic surveys of coastal fresh-water lakes. (Table 4; Fig. 6).

Table 4. Bathymetric datasets used in building the Panama City NAVD 88 DEM

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum*	*Original Vertical Datum*	*URL*
NGDC	1935 to 1993	NOS hydrographic survey soundings	Ranges from 1:5,000 to 1:80,000 (varies with scale of survey, depth, traffic, and probability of obstructions)	NAD 27 geographic and NAD 83 geographic	MLLW, MLW, and Gulf Coast Low Water (meters)	http://www.ngdc.noaa.gov/ngdc.html
USACE Mobile District	2008 to 2010	Hydrographic survey soundings	Line spacing ranges from 30 to 120 m apart and point spacing 0.2 to 10 m	NAD 83 Florida State Plane North (feet)	MLLW (feet)	http://www.usace.army.mil/Pages/default.aspx
University of Florida	2000 to 2007	Hydrographic survey soundings	Point spacing ranges from 2 to 20 m	UTM Zone 16 N (feet)	Undefined	http://lakewatch.ifas.ufl.edu/index.htm
NGDC	2009	Digitized soundings	N/A	NAD 83 geographic	NAVD 88	

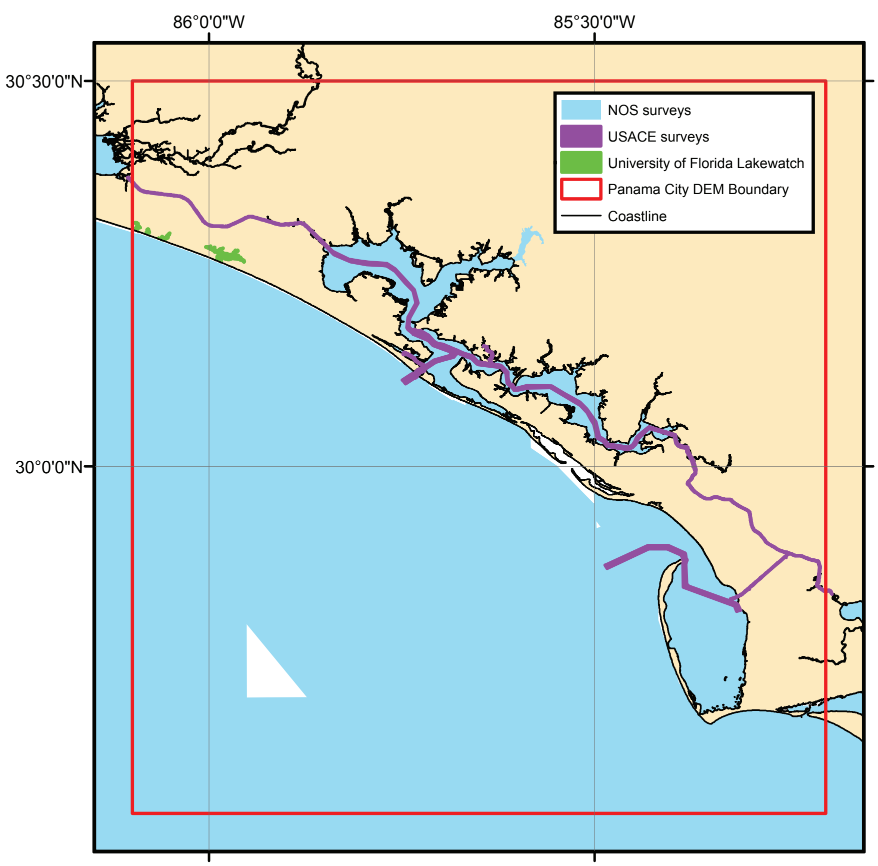

Figure 6. *Source and coverage of bathymetric datasets used in building the Panama City NAVD 88 DEM.*

1) NOS hydrographic surveys

A total of 39 NOS hydrographic surveys conducted between 1935 and 1993 were utilized in developing the Panama City DEM (Table 5; Fig. 7). Eleven surveys were not used, as they were superseded by more recent surveys. 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 NAD 27 or NAD 83 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 vertical datums and referenced to the NAD 83 horizontal datum[4] (Table 5). 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 NAVD 88 (Section 3.2.1), the data were displayed in ESRI *ArcMap* and reviewed for digitizing errors against scanned original survey smooth sheets. The data were also compared to the USACE bathymetric surveys, coastal lidar data, the coastline, NOAA Raster Nautical Charts (RNCs; http://www.nauticalcharts.noaa.gov/mcd/Raster/), and ESRI's online *World 2D* imagery. The NOS surveys were clipped to the bathymetric-topographic lidar (Section 3.1.4) coverage polygon as the coastal lidar data were more recent and at a higher resolution.

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

Survey ID	*Year*	*Scale*	*Original Vertical Datum*	*Original Horizontal Datum*
*H05024	1930	10,000	MLW	NAD 27
H05780	1935	10,000	MLW	NAD 27
*H05781	1935	10,000	MLW	NAD 27
*H05782	1935	10,000	MLW	NAD 27
*H05783	1935	10,000	MLW	NAD 27
H05791	1935	10,000	MLW	NAD 27
H06793	1935	10,000	MLW	NAD 27
H05796	1935	10,000	MLW	NAD 27
*H05812	1935	20,000	MLW	NAD 27
H06449	1939	10,000	MLW	NAD 27
H06450	1939	10,000	MLW	NAD 27
H06451	1939	10,000	MLLW	NAD 27
H06452	1941	10,000	MLW	NAD 27
*H06689	1941	40,000	MLW	NAD 27
H06691	1941	80,000	MLW	NAD 27
*H06694	1941/47	20,000	MLW	NAD 27
H06784	1942/43	40,000	MLW	NAD 27
H06785	1942/43	40,000	MLW	NAD 27
H06786	1942/43	20,000	MLW	NAD 27
H06787	1942/43	20,000	MLW	NAD 27
*H07173	1947	10,000	MLLW	NAD 27

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

Survey ID	***Year***	***Scale***	***Original Vertical Datum***	***Original Horizontal Datum***
H07603	1947/48	200,000	MLW	NAD 27
*H07631	1947	40,000	MLW	NAD 27
*H07632	1947	40,000	MLW	NAD 27
*H07633	1947	40,000	MLW	NAD 27
H07723	1948/50	100,000	MLW	NAD 27
H09734	1977/78	20,000	MLW	NAD 27
H09735	1977/78	20,000	GCLW	NAD 27
H09755	1978	20,000	GCLW	NAD 27
H09761	1978	20,000	MLW	NAD 27
H09786	1978	40,000	MLW	NAD 27
H09846	1979/80	40,000	MLLW	NAD 27
H09883	1980	40,000	GCLW	NAD 27
H09915	1980	20,000	GCLW	NAD 27
H09924	1980/81	10,000	MLLW	NAD 27
H09925	1980/81	10,000	MLLW	NAD 27
H09989	1981/82	10,000	MLW	NAD 27
H09996	1982	10,000	MLW	NAD 27
H10069	1982/83	10,000	MLLW	NAD 27
H10122	1983/84	10,000	MLW	NAD 27
H10166	1984/85	10,000	MLLW	NAD 27
H10170	1985	10,000	MLW	NAD 27
H10235	1986/88	10,000	MLLW	NAD 27
H10236	1987	10,000	MLLW	NAD 27
H10237	1986/87	10,000	MLLW	NAD 27
H10259	1987/89	10,000	MLLW	NAD 27
H10260	1987/88	10,000	MLLW	NAD 27
H10266	1988/89	10,000	MLLW	NAD 27
H10267	1988	10,000	MLLW	NAD 27
H10452	1993	10,000	MLLW	NAD 83

*Superseded survey not used in building the Panama City NAVD 88 DEM.

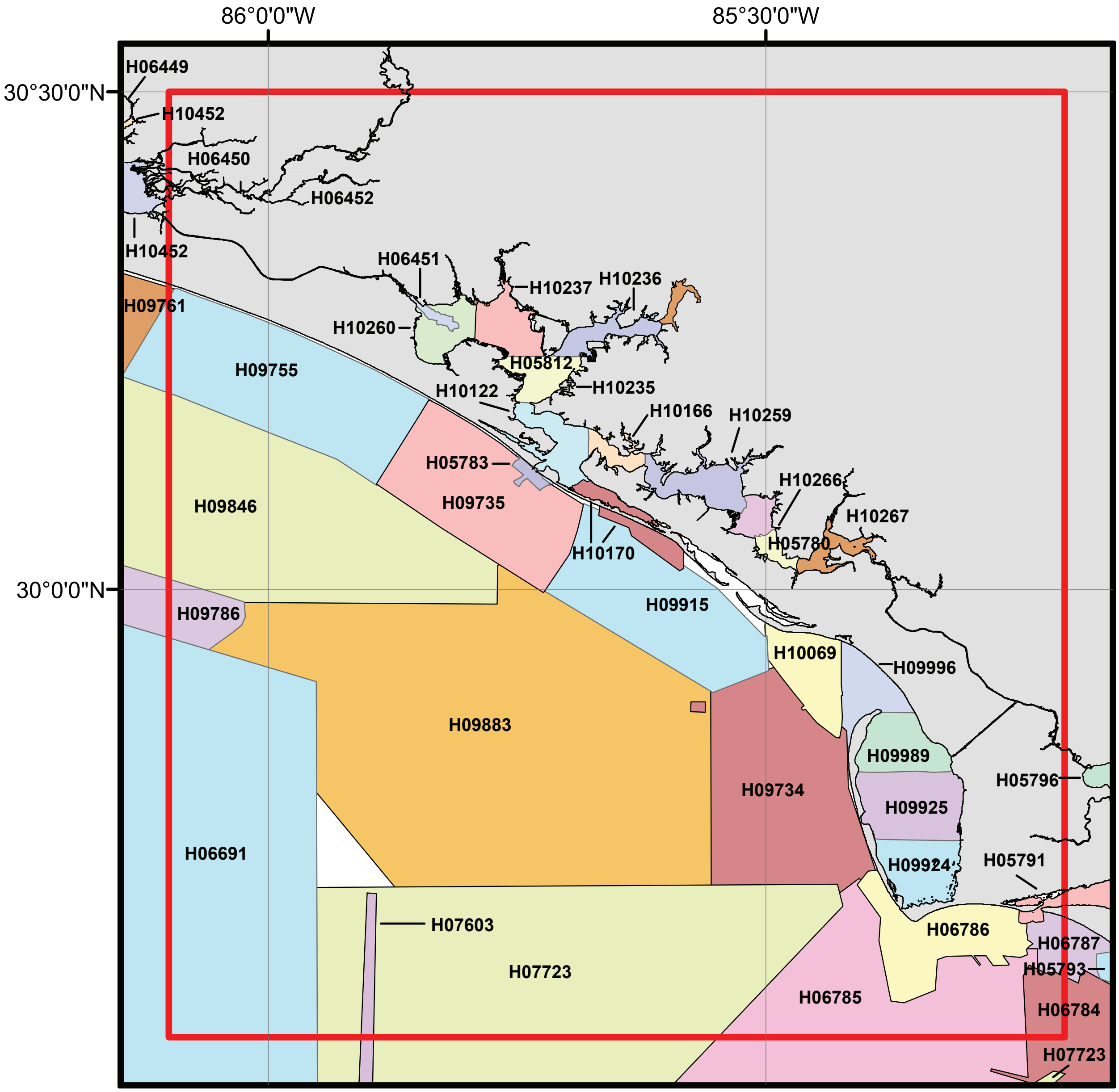

Figure 7. *Spatial coverage of NOS hydrographic surveys used in building the Panama City NAVD 88 DEM. Eleven surveys were not used, as they have been superseded by more recent surveys. DEM boundary in red.*

2) USACE hydrographic surveys

Six USACE bathymetric survey projects located within the Panama City DEM boundaries were provided by Mark White of the USACE Mobile District in xyz format (Table 6; Fig. 8). NGDC digitized sections of the dredged channels to ensure their representation in the DEMs (Figs. 11 and 12). The surveys were collected between 2008 and 2010, and referenced to NAD 83 Florida State Plane West (feet) and MLLW (feet) datums. The files were converted to NAD 83 geographic and NAVD 88 (meters) using *FME* and *VDatum*, respectively. Surveys consist of numerous, parallel, across-channel profiles, spaced 30 to 120 meters apart, with point soundings 0.2 to 10 meters apart.

Table 6. USACE hydrographic surveys used in building the Panama City NAVD 88 DEM

Region	*Year of Survey*	*Spatial Resolution*	*Original Vertical Datum*	*Original Horizontal Datum*
Gulf County Channel	2010	~ 30 - 60 m profile spacing ~ 5 - 10 m point spacing	MLLW (feet)	NAD 83 Florida State Plane West (feet)
GIWW	2008 - 2010	~ 60 m profile spacing ~ 0.2 - 10 m point spacing	MLLW (feet)	NAD 83 Florida State Plane West (feet)
Grand Lagoon	2010	~ 60 m profile spacing ~ 5 - 10 m point spacing	MLLW (feet)	NAD 83 Florida State Plane West (feet)
Panama City Harbor	2010	~ 60 m profile spacing ~ 0.2 - 10 m point spacing	MLLW (feet)	NAD 83 Florida State Plane West (feet)
St. Joe's	2009	~ 120 m profile spacing ~ 0.2 - 10 m point spacing	MLLW (feet)	NAD 83 Florida State Plane West (feet)
Watson Bayou	2009	~ 30 m profile spacing ~ 5 - 10 m point spacing	MLLW (feet)	NAD 83 Florida State Plane West (feet)

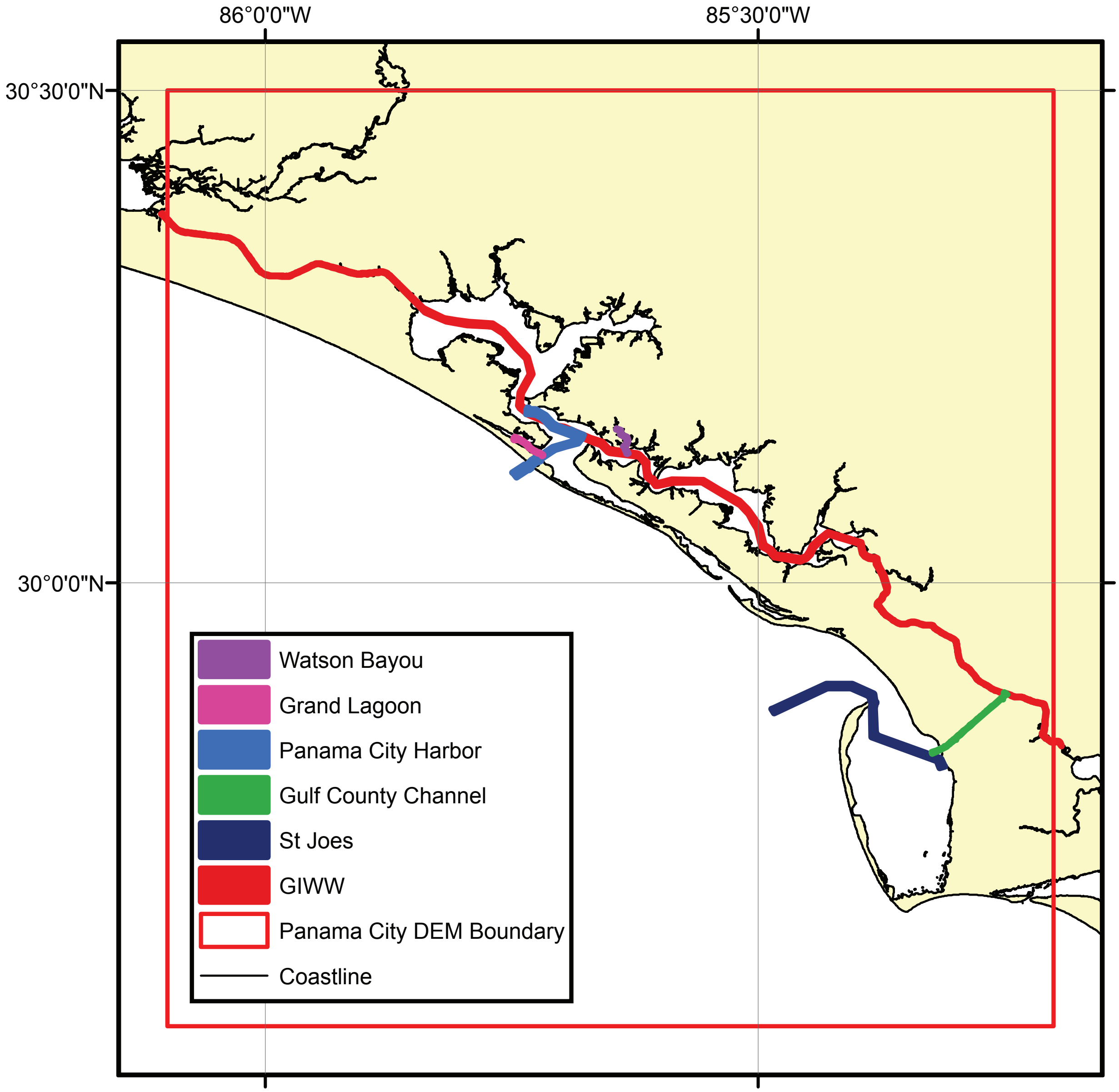

Figure 8. *Spatial coverage of USACE hydrographic surveys used in building the Panama City NAVD 88 DEM.*

3) University of Florida Lakewatch hydrographic surveys

University of Florida Lakewatch hydrographic surveys of coastal fresh-water lakes were provided to NGDC by the Florida Lakewatch Regional Coordinator, David Watson. The surveys were provided in xyz format, horizontally referenced to UTM Zone 16 N and an undefined vertical datum, assumed to be local lake level. The data were transformed from feet to meters and to NAD 83 geographic using *FME.*

The soundings ranged from 2 to 20 meter point spacing. To more accurately characterize the lake depths, NGDC applied a tight spline tension at 1 arc-second to the xyz data using *Generic Mapping Tools*[5] (*GMT)* 'surface' command to interpolate elevations for cells without data values. The resulting surface was clipped to the lake extents using a polygon created from the soundings and satellite imagery and then exported to xyz format for gridding. The xyz data were transformed to NAVD 88 using a constant offset based on the elevation difference between the local lake level zero elevation and the FDEM lidar (Section 3.1.3).

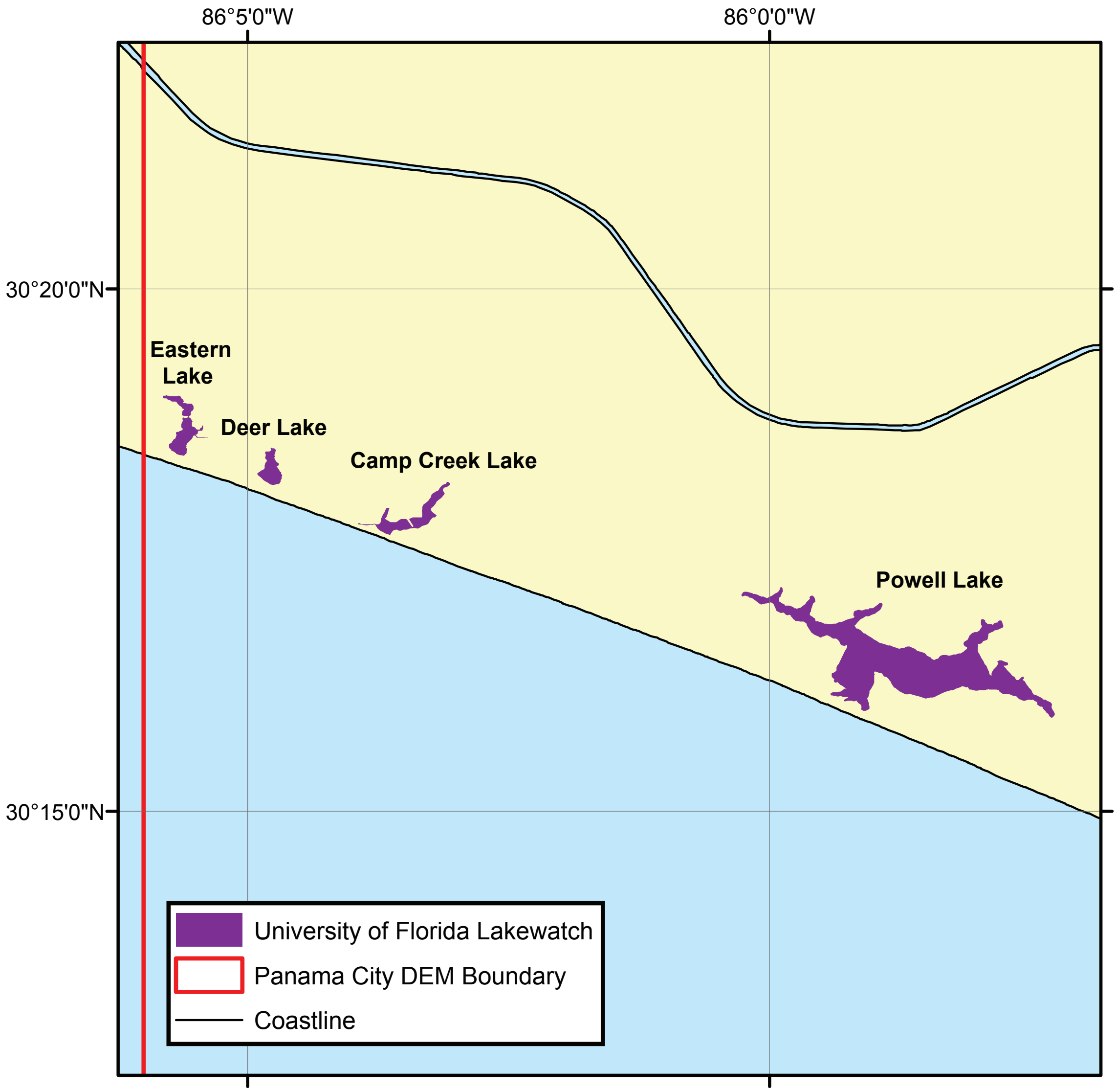

Figure 9. *Spatial coverage of University of Florida Lakewatch hydrographic surveys used in building the Panama City NAVD 88 DEM.*

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

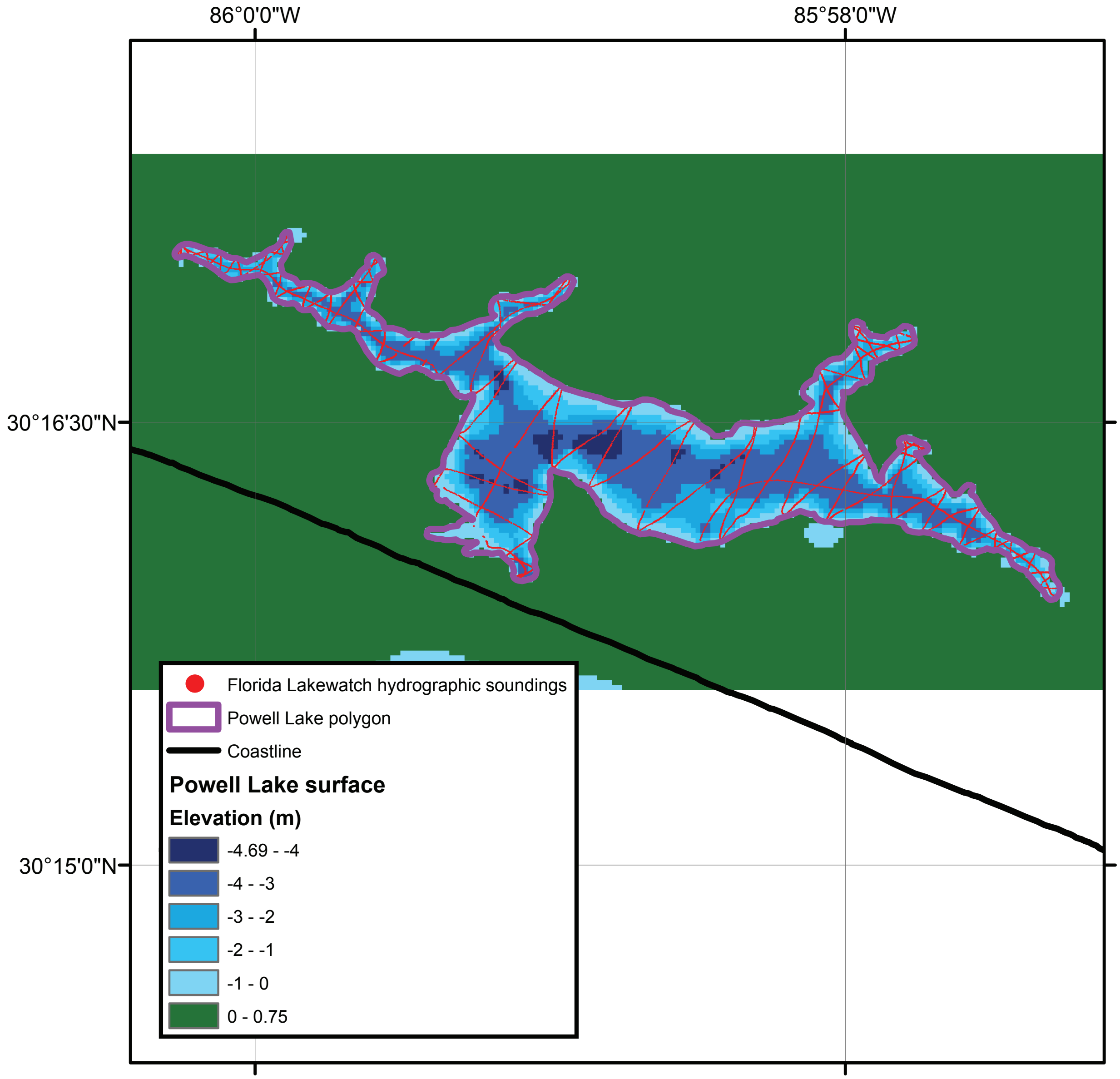

Figure 10. *One arc-second surface of the University of Florida Lakewatch data. The surface was clipped to each lake's respective polygon and converted to xyz points for gridding.*

4) NGDC-digitized bathymetric soundings

NGDC used GEODAS *Hydro-Plot*[6] to digitize bathymetric soundings in estuary rivers and dredged channels. NGDC interpolated bathymetric soundings at 5 meter spacing based on available USACE and NOS bathymetric soundings. Interpolated soundings were created in estuary rivers and dredged channels to more accurately model the channels' morphology where USACE survey profile spacing or NOS soundings' point spacing was significantly greater than 10 meters (Figs. 11 and 12).

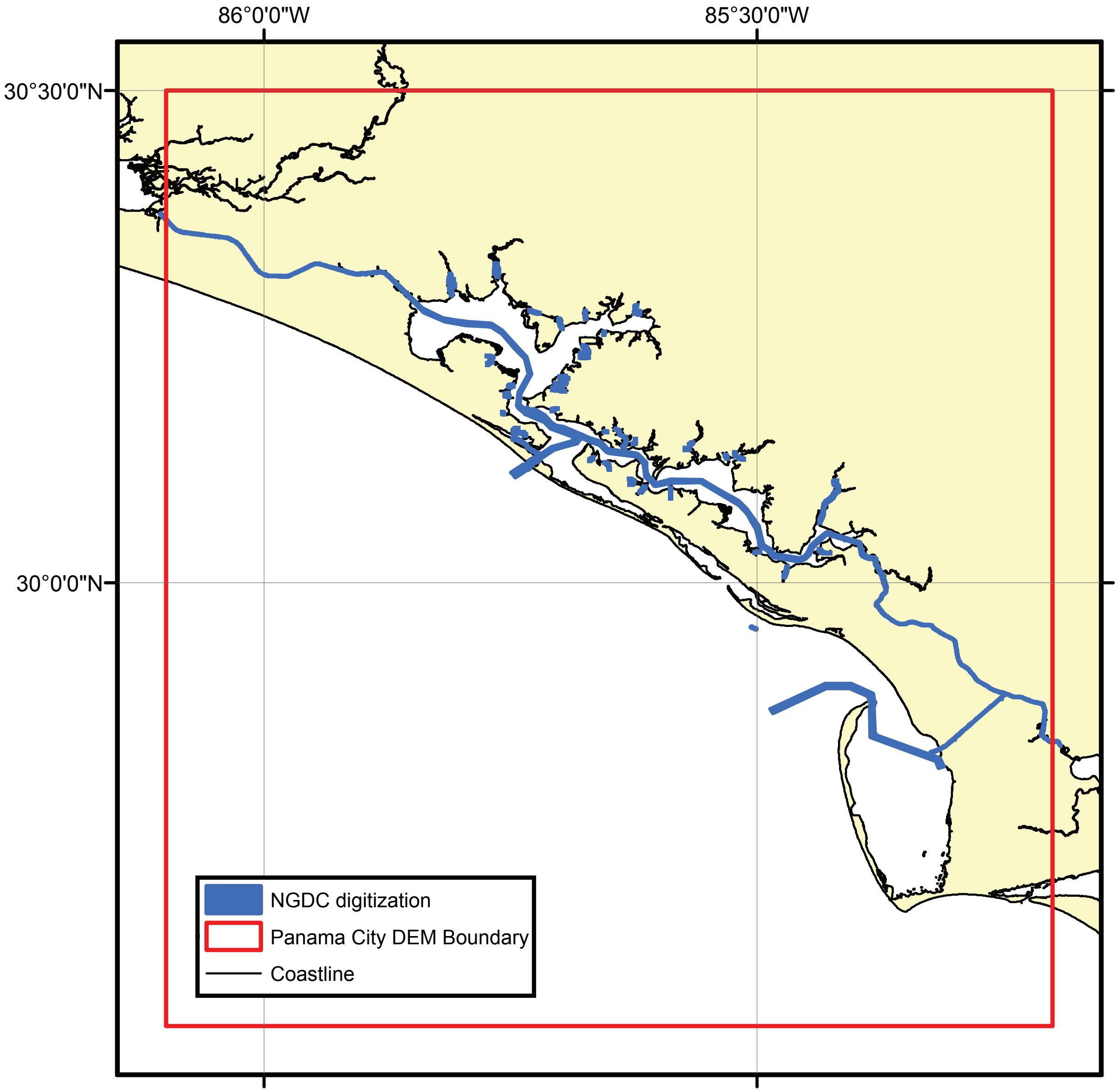

Figure 11. *Spatial coverage of NGDC-digitized bathymetric soundings used in building the Panama City NAVD 88 DEM.*

6. *Hydro-Plot* is a MS Windows and Linux-x86 GEODAS application developed by NGDC to display geographical plots of data from the *GEODAS* DVD sets, including NOS Hydrographic Surveys, Marine Trackline Geophysics and *GEODAS* Gridded Databases, as well as XYZ-type data files, Arc-type grids and ESRI shapefiles for data, contours and coastlines. Hydro-Plot displays maps of data directly on the screen, coloring the data according to their value. *Hydro-Plot* can also be used for viewing histograms and profiles of the data, and for editing data, including deleting records, changing record fields, and creating new records, as well as for automated quality control of data files [Extracted from *GEODAS Hydro-Plot* help section].

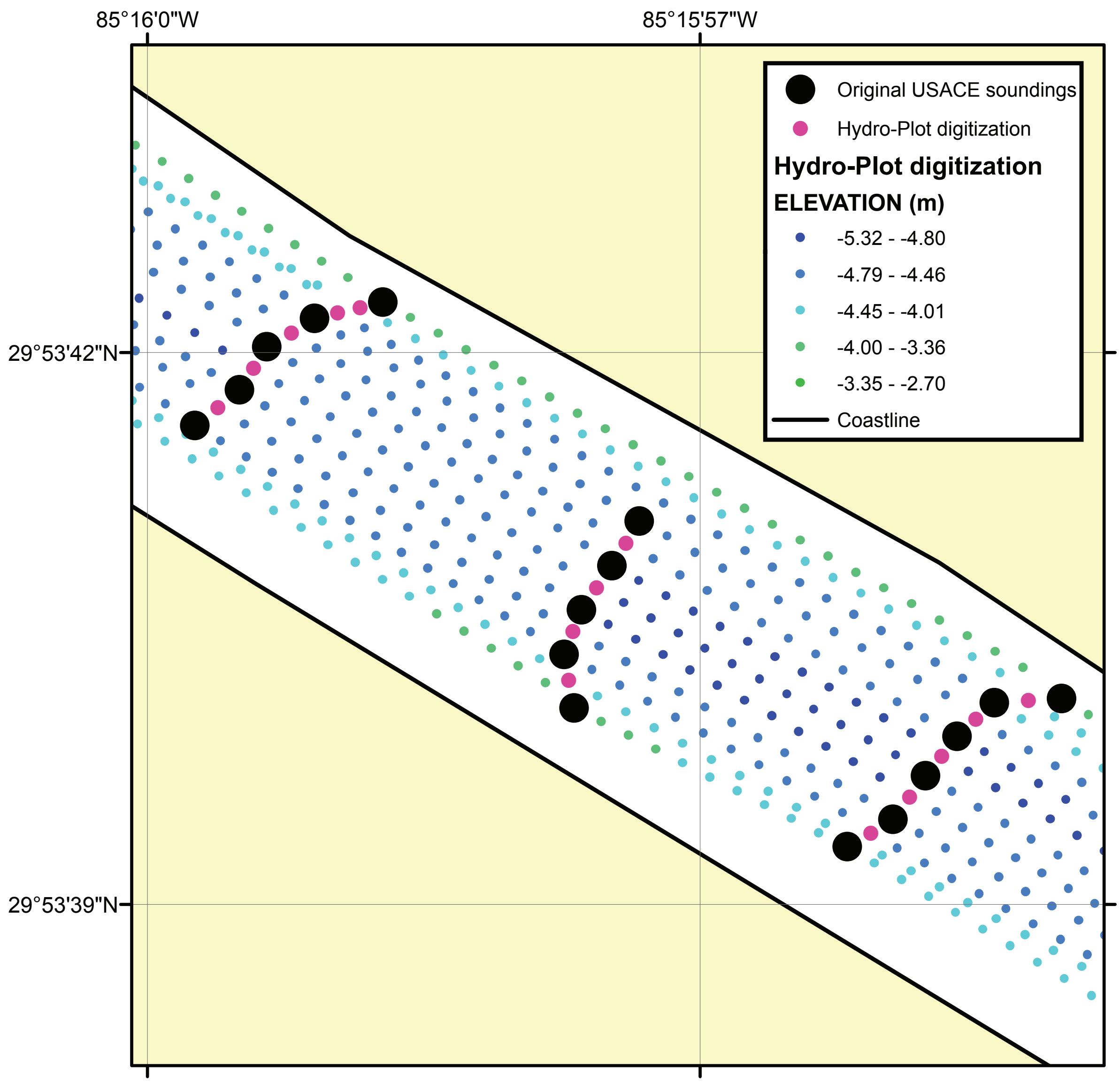

Figure 12. *Example of Hydro-Plot digitization in the Gulf Intracoastal Waterway. NGDC digitized soundings between original USACE soundings and between profiles.*

3.1.3 Topography

The topographic datasets used to build the Panama City NAVD 88 DEM include: FDEM lidar, NWFWMD lidar, and USGS National Elevation Dataset (NED) 1/9 and 1/3 arc-second DEMs (Table 7; Fig. 13).

Table 7. Topographic datasets used in building the Panama City NAVD 88 DEM

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
FDEM	2007	Bare-earth lidar	2.0 meters	NAD 83 Florida State Plane West (feet) / NAD 83 geographic (meters)	NAVD 88	http://www.floridadisaster.org/gis/lidar/ http://mapping.ihrc.fiu.edu/fldemlidar20100504/Default.aspx
NWFWMD	2007	Bare-earth lidar	1.0 meter	NAD 83 geographic	NAVD 88	http://csc-s-maps-q.csc.noaa.gov/dataviewer/viewer.html
USGS	1999 - 2009	NED 1/9 bare-earth DEM and NED 1/3 bare-earth DEM	1/9 arc-second to 1/3 arc-second	NAD 83 geographic	NAVD 88	http://seamless.usgs.gov/
NGDC	2005	Digitized elevations	N/A	NAD 83 geographic	NAVD 88	

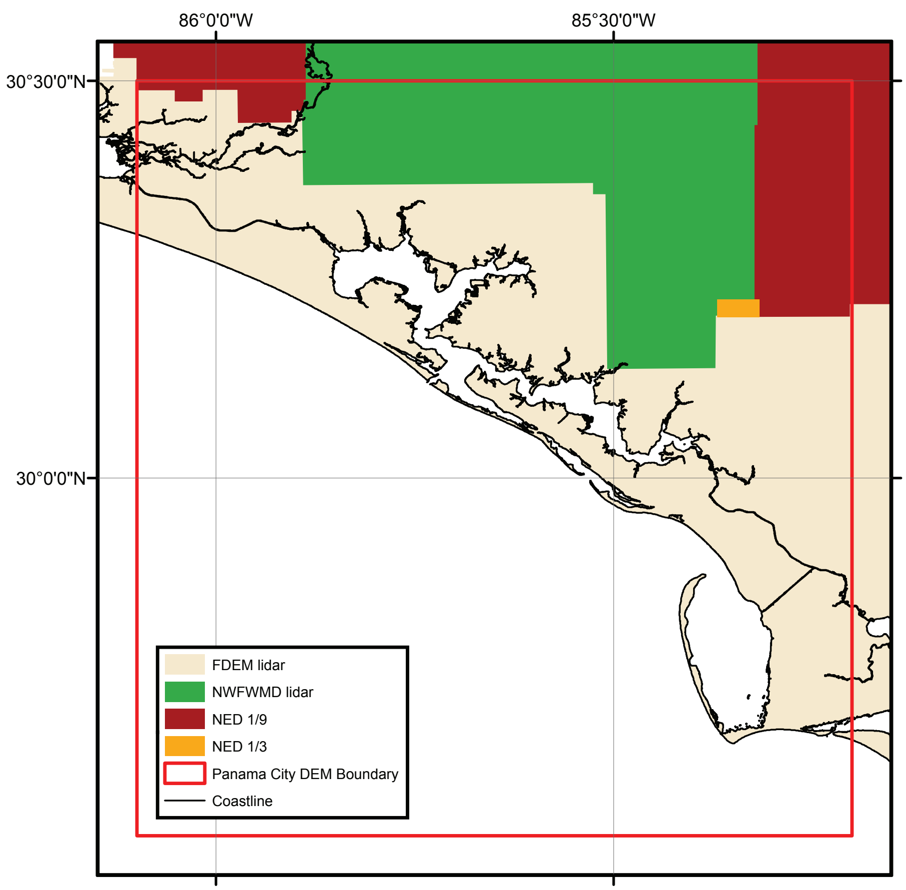

Figure 13. *Source and coverage of topographic datasets used in building the Panama City NAVD 88 DEM.*

1) **Florida Division of Emergency Management lidar**

Topographic lidar was collected by Sandborn in 2007 for a coalition of GIS practitioners, including the FDEM, Florida Water Management Districts, Florida Fish and Wildlife Conservation Commission, Florida Department of Environmental Protection, USACE Jacksonville District, and other state and federal agencies. The goal for this project is to use the lidar data as new elevation inputs for updated SLOSH data grids resulting in the update of the Regional Hurricane Evacuation Studies (RHES; http://www.saw.usace.army.mil/floodplain/Hurricane%20Evacuation.htm) for the state. This is a classified lidar dataset; bare-earth points (class 2), water returns (class 9), and unclassified data (class 1). The lidar data were collected at a density sufficient to support a maximum final post spacing of 4 feet for unobscured areas (extracted from metadata).

FDEM lidar for Bay County were provided to NGDC as classified LAS files from the FDEM GIS Administrator, Richard Butgereit. The data were horizontally referenced to NAD 83 Florida State Plane West (feet) and vertically referenced to NAVD 88. The data were transformed from feet to meters and to NAD 83 geographic using *FME*. FDEM classified LAS files for Gulf and Walton counties were downloaded from the FDEM web site (http://mapping.ihrc.fiu.edu/fldemlidar20100504/Default.aspx), referenced to NAD 83 geographic (meters) and NAVD 88 (Fig. 14). The data have a vertical accuracy of 9.14 cm root mean square error (RMSE) and meet the 1 meter horizontal accuracy standard at the 95% confidence level. Only data classified as "bare-earth" were used in building the Panama City NAVD 88 DEM. NGDC used bathymetric-topographic lidar in two small areas along the coast that did not have FDEM bare-earth data coverage (Section 3.1.4).

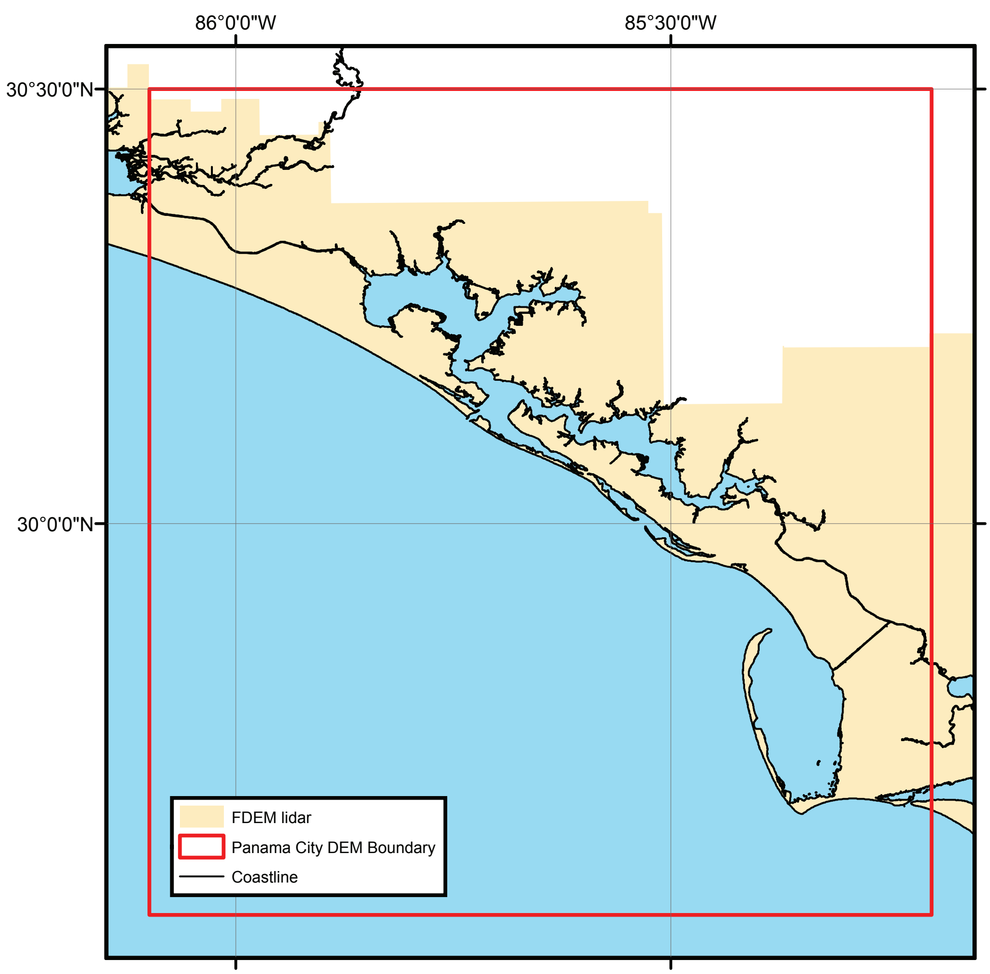

Figure 14. *Spatial coverage of FDEM lidar used in building the Panama City NAVD 88 DEM.*

2) Northwest Florida Water Management District lidar

Topographic lidar was collected by Sandborn in 2007 to support regulatory, land management and acquisition, planning, engineering, and habitat restoration projects; the creation of the Federal Emergency Management Agency Flood Insurance Rate Maps (FEMA FIRM); and the development of an integrated ground surface model for portions of Bay, Calhoun, Jackson, and Washington counties. The data were downloaded in bare-earth xyz format from NOAA's Digital Coast web site (http://csc-s-maps-q.csc.noaa.gov/dataviewer/viewer.html), horizontally referenced to NAD 83 geographic, and vertically referenced to NAVD 88 (meters; Fig. 15). The data have a vertical accuracy of 11.12 cm RMSE and meet the 1 meter horizontal accuracy standard at the 95% confidence level.

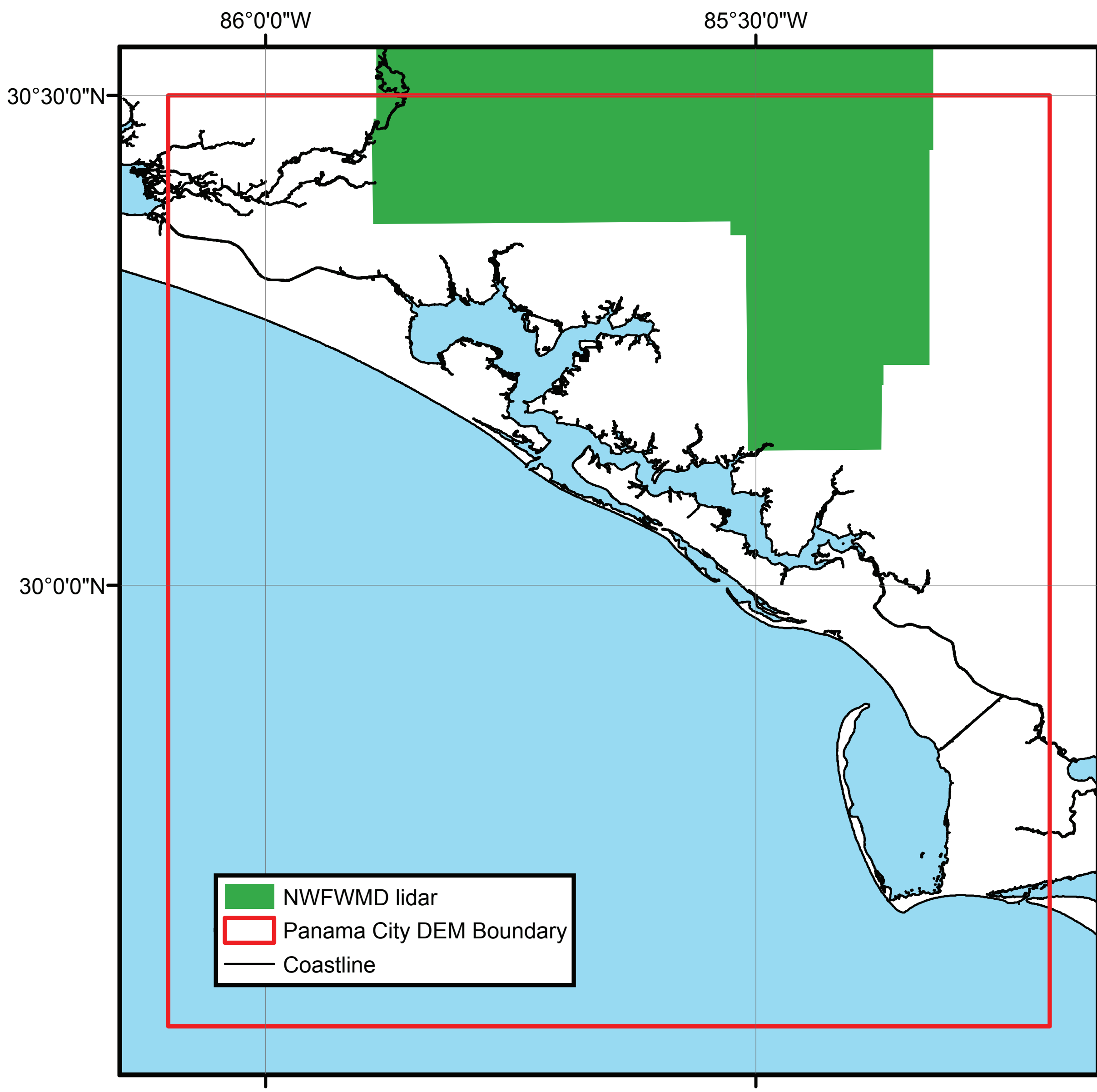

Figure 15. *Spatial coverage of NWFWMD lidar used in building the Panama City NAVD 88 DEM.*

3) USGS NED

The USGS NED provided complete 1/3 arc-second bare-earth DEM (NED 1/3 DEM) coverage and partial 1/9 arc-second DEM (NED 1/9 DEM) coverage of the Panama City region[7] (Fig. 16). The NED 1/9 DEM was utilized in gridding the Panama City DEM where there was no available FDEM or NWFWMD lidar coverage. The NED 1/3 DEM was utilized for gridding where there was no available FDEM, NWFWMD, or NED 1/9 DEM data coverage. In 2009, lidar data from the NWFWMD were incorporated into the NED 1/9 DEM. The vertical and horizontal accuracy of the NED 1/9 DEM were not assessed. The extracted bare-earth elevations from the NED 1/3 DEM have a reported vertical accuracy of +/- 7 to 15 meters depending on source data resolution. The NED 1/3 DEM was derived from USGS quadrangle maps and aerial photographs based on topographic surveys, and has been revised using data from 1999 to 2009. The NED DEMs were converted to xyz for gridding using *FME*.

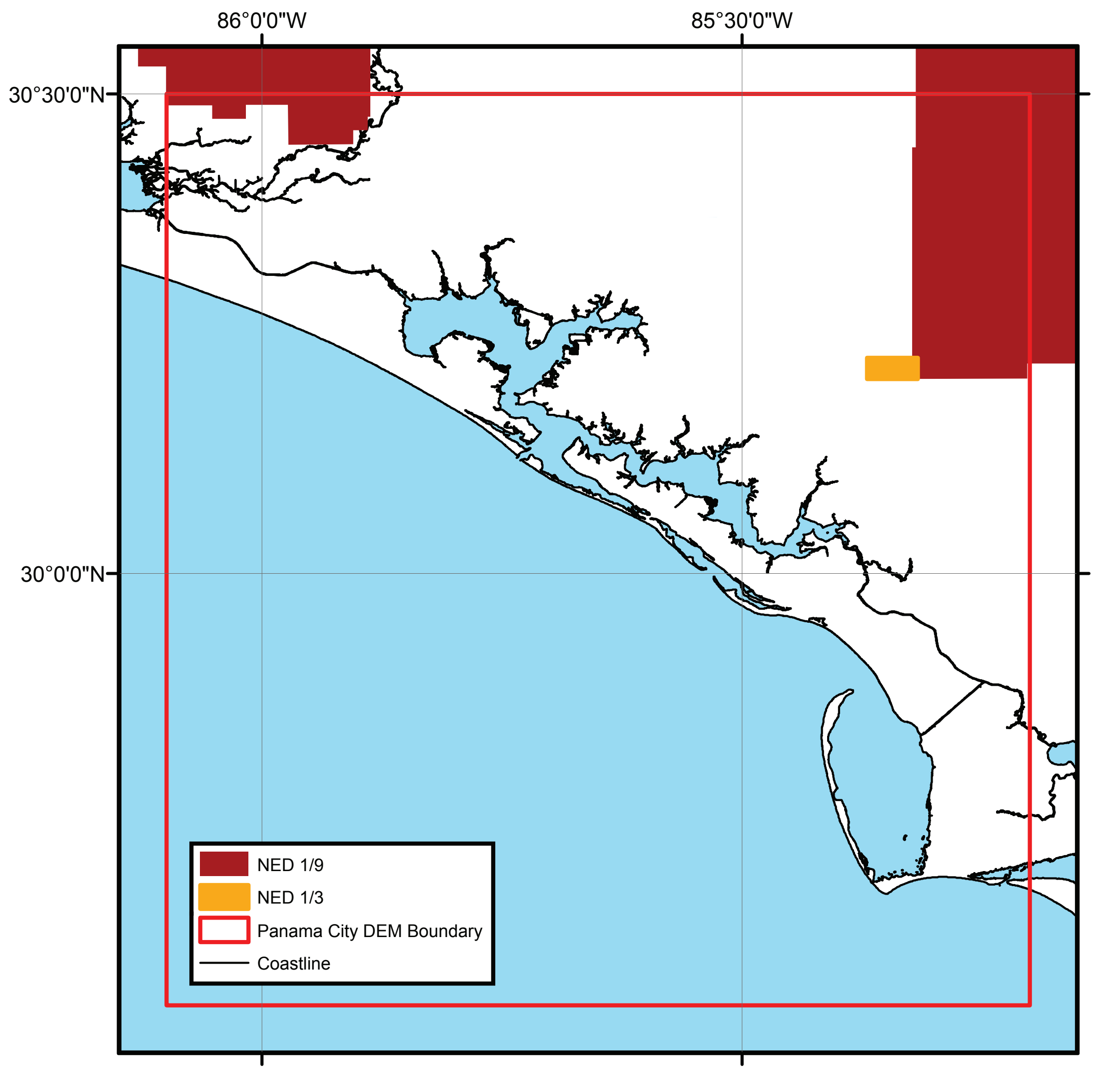

Figure 16. *Spatial coverage of USGS NED used in building the Panama City NAVD 88 DEM.*

7. The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the maturation of the USGS effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous U.S. and 1:63,360-scale DEM data for Georgia. The dataset provides seamless coverage of the United States, HI, AK, and the island territories. NED has a consistent projection (Geographic), resolution (1 arc second), and elevation units (meters). The horizontal datum is NAD 83, except for AK, which is NAD 27. The vertical datum is NAVD 88, except for AK, which is NGVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc second (10 m) data covers the U.S., then this will also be a seamless dataset. [Extracted from USGS NED web site]

4) NGDC-digitized elevations

NGDC digitized topographic elevations in areas with no topographic data (Fig. 17). The most significant area that lacked topographic data was the Deer Point Lake Dam. NGDC digitized 1.5 m elevations to represent the dam at an elevation equivalent to the edge of FDEM lidar coverage of the dam (Fig. 18). NGDC also digitized elevations to control data interpolation of inland bodies of water where the topographic lidar data were classified as water return and not used in gridding (Fig. 19).

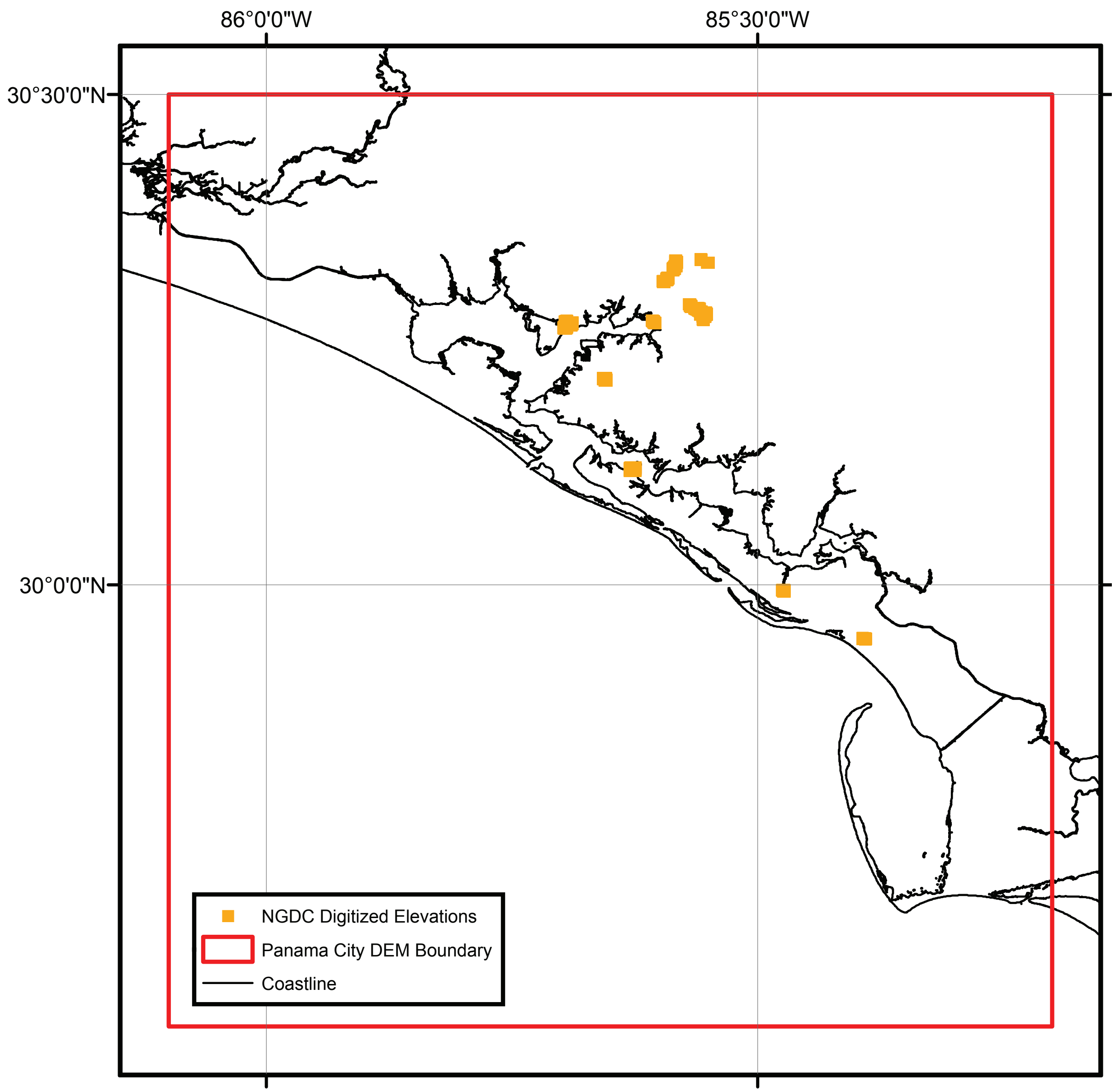

Figure 17. *Spatial coverage of NGDC-digitized topographic elevations used in building the Panama City NAVD 88 DEM.*

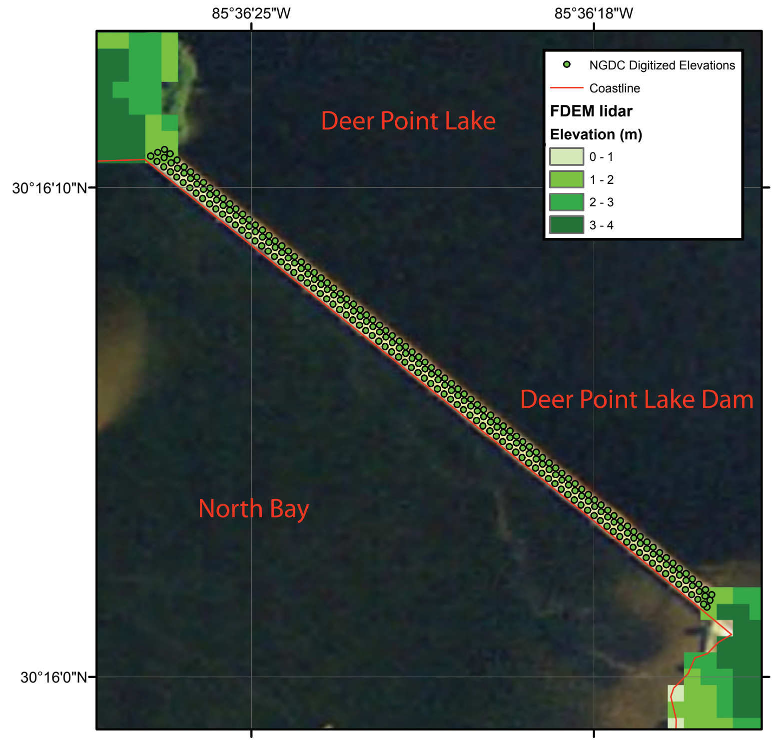

Figure 18. *NGDC-digitized 1.5 m elevations representing the Deer Point Lake Dam (ESRI World 2D Imagery in background).*

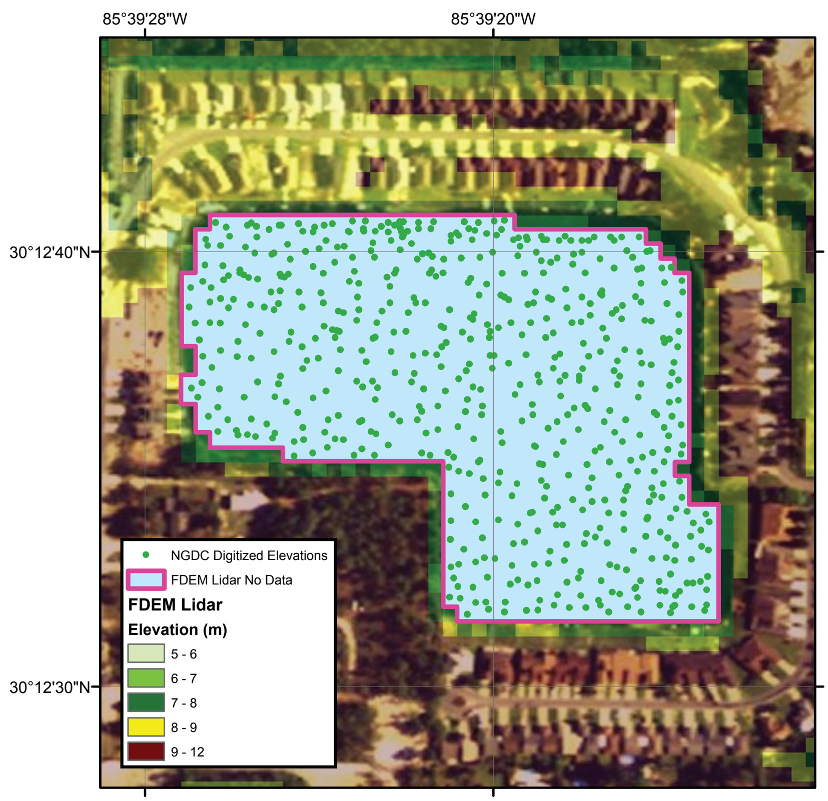

Figure 19. *NGDC-digitized elevations used to control elevations of inland bodies of water.*

3.1.4 Bathymetry-Topography

Three USACE bathymetric-topographic lidar datasets used to build the Panama City NAVD 88 DEM were downloaded from the NOAA CSC Coastal Lidar web site (Fig. 20; Table 8)[8]. The bathymetric-topographic lidar-derived data were collected by the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) using the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) system. The data were collected to depict the elevations above and below water along the immediate coastal zone. The survey generally extends 750 meters inland and up to 1500 meters over the water (depending on water depth and clarity).

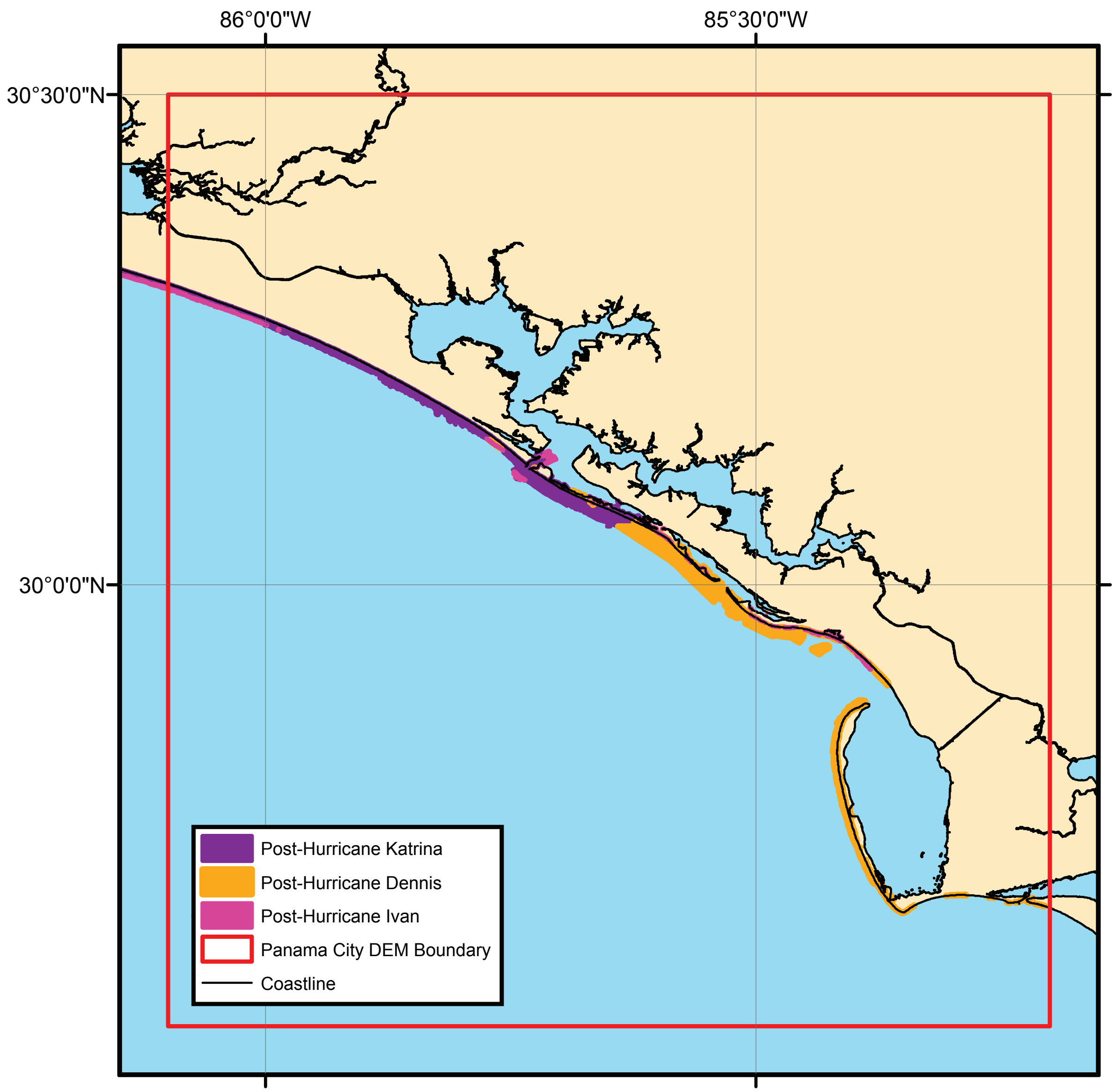

Figure 20. *Source and coverage of bathymetric-topographic lidar datasets used in building the Panama City NAVD 88 DEM.*

8. The goal of the USACE Topo/Bathy Lidar Project is to collect data covering the shoreline of the conterminous United States where feasible. The project is led by USACE. [Extracted from CSC Coastal Lidar web site].

Table 8. **Bathymetric-topographic datasets used in building the Panama City NAVD 88 DEM.**

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
CSC	2004	USACE non bare-earth lidar	3.0 meters	NAD 83 geographic	NAVD 88	http://csc-s-maps-q.csc.noaa.gov/dataviewer/viewer.html
CSC	2005	USACE non bare-earth lidar	2.0 meters	NAD 83 geographic	NAVD 88	http://csc-s-maps-q.csc.noaa.gov/dataviewer/viewer.html
CSC	2005	USACE non bare-earth lidar	2.0 meters	NAD 83 geographic	NAVD 88	http://csc-s-maps-q.csc.noaa.gov/dataviewer/viewer.html

1) USACE 2004 Post-Hurricane Ivan Topo/Bathy Lidar Project

The bathymetric and topographic data were collected in 2004 (Post-Hurricane Ivan) along the Alabama and Florida coastline by JALBTCX using the CHARTS system (Fig. 21). The vertical accuracy is 15 cm RMSE and the horizontal accuracy is 80 cm RMSE. The dataset was clipped to the other two more recent bathymetric-topographic datasets. NGDC excluded topographic data from the dataset using *FME* because it was not processed to bare-earth, with the exception of a small area of missing FDEM topographic lidar data along the coast (Fig. 23).

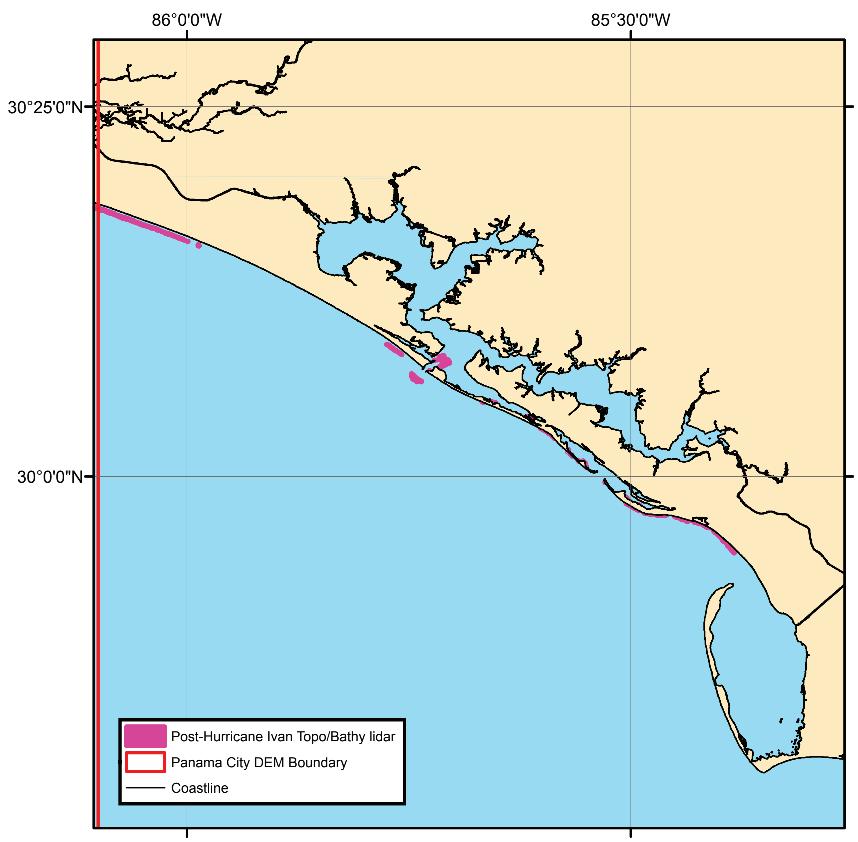

Figure 21. *Spatial coverage of the USACE Post-Hurricane Ivan bathymetric-topographic lidar survey used in building the Panama City NAVD 88 DEM.*

2) USACE 2005 Post-Hurricane Dennis Topo/Bathy Lidar Project

The bathymetric and topographic data were collected in 2005 (Post-Hurricane Dennis) along the Alabama and Florida coastline by JALBTCX using the CHARTS system (Fig. 22). The vertical accuracy is 0.20 meters at 1 sigma and the horizontal accuracy is 0.75 meters at 1 sigma. NGDC excluded topographic data from the dataset using *FME* because it was not processed to bare-earth, with the exception of a small area of missing FDEM topographic lidar data along the coast (Fig. 23). NGDC created a polygon of the missing FDEM topographic lidar data extents and used *FME* to extract only data inside the polygon from the Post-Hurricane Ivan and Post-Hurricane Dennis datasets (there were no available Post-Hurricane Katrina data located inside the polygon).

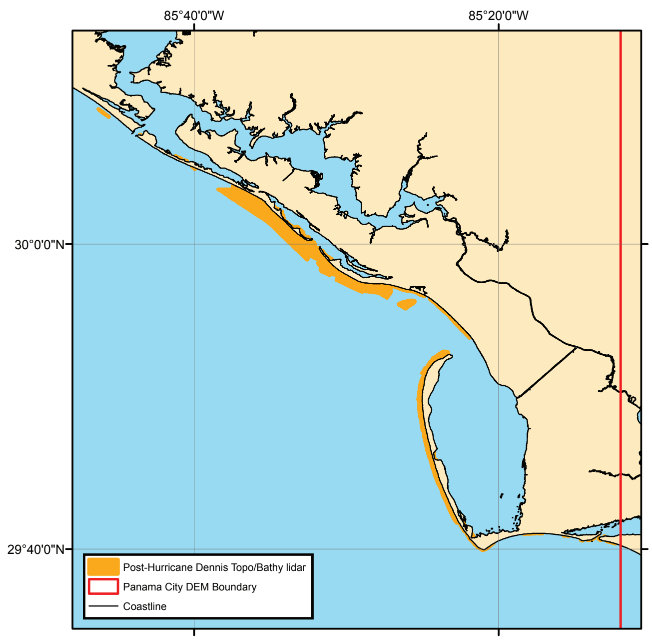

Figure 22. *Spatial coverage of the USACE Post-Hurricane Dennis bathymetric-topographic lidar survey used in building the Panama City NAVD 88 DEM.*

Figure 23. *Spatial coverage of topographic data from the USACE Post-Hurricane Ivan and Post-Hurricane Dennis datasets used in areas of missing FDEM topographic lidar.*

3) USACE 2005 Post-Hurricane Katrina Topo/Bathy Project

The bathymetric and topographic data were collected in 2005 (Post-Hurricane Katrina) along the Louisiana, Mississippi, Alabama, and Florida coastline by JALBTCX using the CHARTS system (Fig. 24). The vertical accuracy is 0.20 meters at 1 sigma and the horizontal accuracy is 0.75 meters at 1 sigma. NGDC excluded topographic data from the dataset using *FME* because it was not processed to bare-earth.

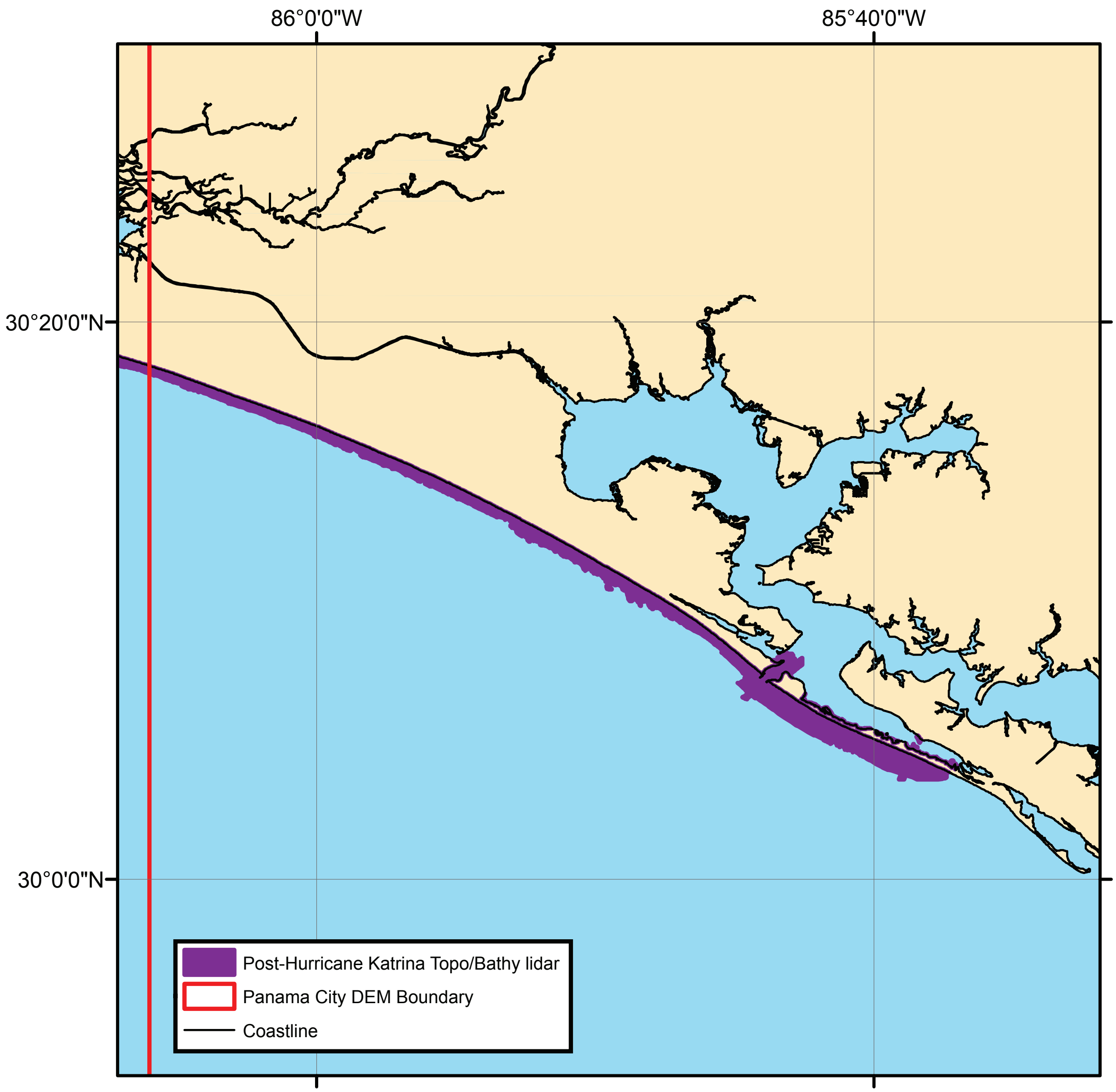

Figure 24. *Spatial coverage of the USACE Post-Hurricane Katrina bathymetric-topographic lidar survey used in building the Panama City NAVD 88 DEM.*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Panama City NAVD 88 DEM were originally referenced to several vertical datums including MLLW, MLW, GCLW and NAVD 88. All datasets were transformed to NAVD 88 using *VDatum*.

1) **Bathymetric data**
   All hydrographic surveys were transformed from GCLW, MLLW or MLW to NAVD 88, using *VDatum*. A few surveys were located outside of VDatum coverage, in which case NGDC manually transformed the surveys to NAVD 88 by comparing the conversion of nearby soundings at the edge of *VDatum* coverage and using an equivalent constant offset.

2) **Topographic data**
   All topographic datasets used in the compilation of the Panama City NAVD 88 DEM originated in NAVD 88 vertical datum. No further vertical transformations were required for these datasets.

3.2.2 Horizontal datum transformations

Datasets used to build the Panama City NAVD 88 DEM were downloaded or received referenced to NAD 83 geographic, NAD 83 Florida State Plane West (feet) and NAD 83 UTM Zone 16 North (feet) horizontal datums. The relationships and transformational equations between these horizontal datums are well established. Data were converted to a horizontal datum of NAD 83 geographic using *FME*.

3.2.3 VDatum assessment

VDatum is a free software tool developed jointly by NOAA's OCS, NGS and CO-OPS. *VDatum* is designed to transform geospatial data among a variety of tidal, orthometric and ellipsoidal vertical datums - allowing users to convert their data from different vertical references into a common system and enabling the fusion of diverse geospatial data in desired reference levels (http://vdatum.noaa.gov/). Five *VDatum* project areas were utilized in the development of the Panama City DEMs (Fig. 25).

VDatum proved useful in the transformations of a diverse range of datasets, all originating in various vertical datums to a vertical reference system. The accuracy and reliability of an integrated bathymetric-topographic DEM depends upon the processes used to transform the various source datasets into common reference systems. *VDatum* provides a clear and reliable method of achieving datum parity between datasets.

VDatum also proved useful in the development of various 'conversion grids' used in creating the derivative Panama City MHW DEM (Section 3.3.4), negating the need to apply constant offsets to achieve the same result at a lesser degree of accuracy. This methodology allows for the development of one NAVD 88 DEM, which can then be used to generate various DEMs in any of the supported *VDatum* vertical datums, allowing for any source data updates to be performed solely on the NAVD 88 DEM.

Possible improvements to *VDatum* include: support for State Plane horizontal datums and support for the input and output of American Society of Photogrammetry and Remote Sensing (ASPRS) formatted LAS lidar files. These two improvements would lessen the need for pre-processing of data prior to use in *VDatum* and improve the overall workflow involved in transforming a variety of datasets to common vertical datums.

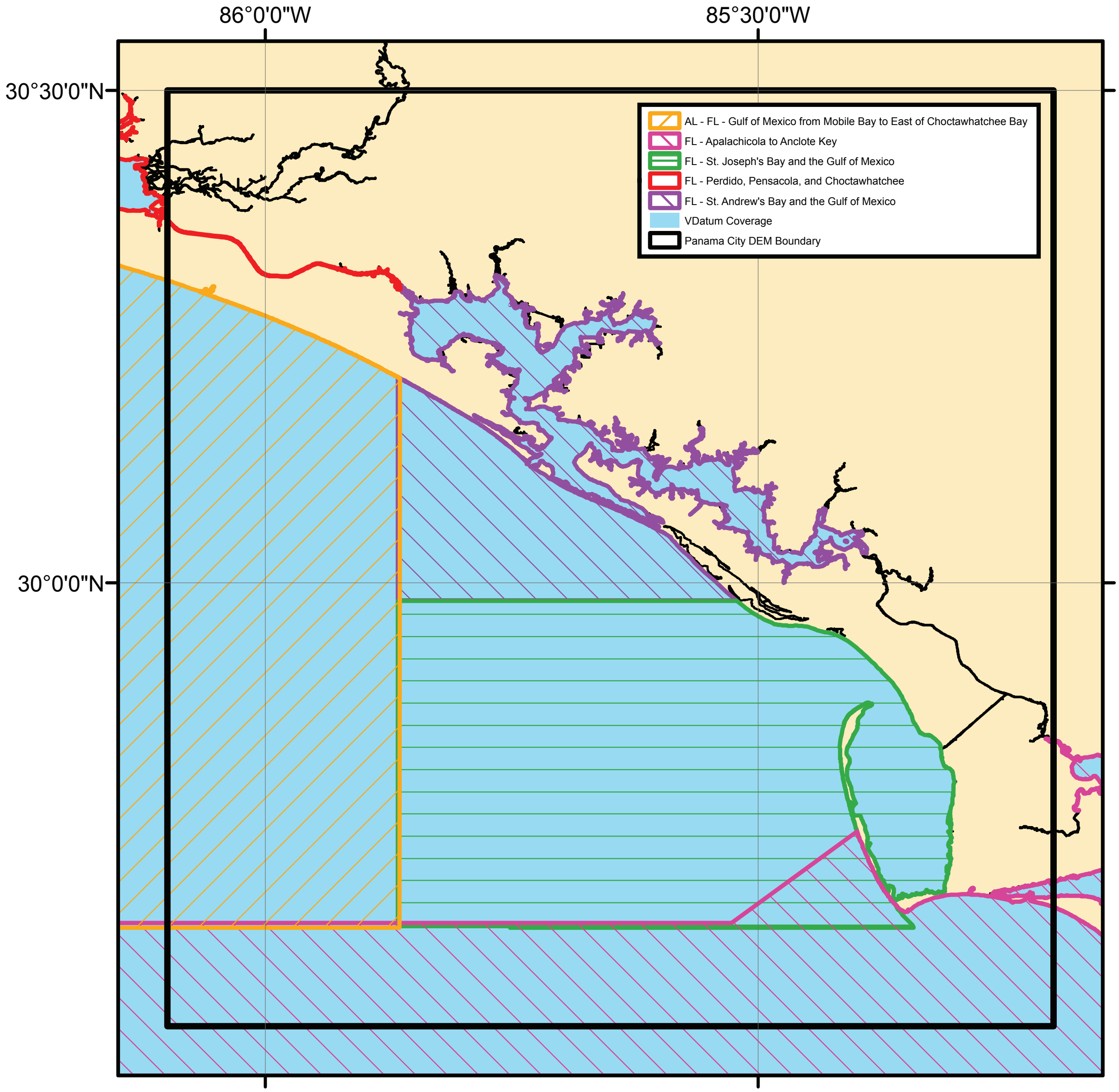

Figure 25. *Spatial coverage of the VDatum projects in the Panama City region.*

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

After horizontal and vertical transformations were applied, the xyz files were converted to ESRI shapefiles for review. The resulting ESRI shapefiles were checked for consistency between datasets. Problems and errors were identified and resolved before proceeding with subsequent gridding steps. The evaluated and edited ESRI shapefiles were then converted to xyz files using *FME* in preparation for gridding.

3.3.2 Smoothing of bathymetric data

The NOS hydrographic survey data are generally sparse relative to the resolution of the 1/3 arc-second Panama City NAVD 88 DEM. This is especially true for deeper-water surveys in the Gulf of Mexico where data have point spacing up to 350 meters apart. In order to reduce the effect of artifacts created in the DEM by the low-resolution NOS datasets, and to provide effective interpolation in the deep water and into the coastal zone, a 1 arc-second 'pre-surface' bathymetric grid was generated using *GMT*. The coastline elevation value was set at -1 meter to ensure a bathymetric surface below zero in areas where data are sparse or non-existent.

The point data were median-averaged using the *GMT* tool 'blockmedian' to create a 1 arc-second grid 0.05 degrees (~5%) larger than the Panama City NAVD 88 DEM gridding region. The *GMT* tool 'surface' was then used to apply a tight spline tension to interpolate elevations for cells without data values. The netcdf grid created by 'surface' was converted into an ESRI Arc ASCII grid file, and clipped to the final coastline (to eliminate data interpolation into land areas). The resulting surface was compared with original NOS soundings to ensure grid accuracy and the difference xyz file was used to generate a histogram using *Gnuplot*[9] (Fig. 26). The surface was exported as an xyz file for use in the final gridding process (Table 9).

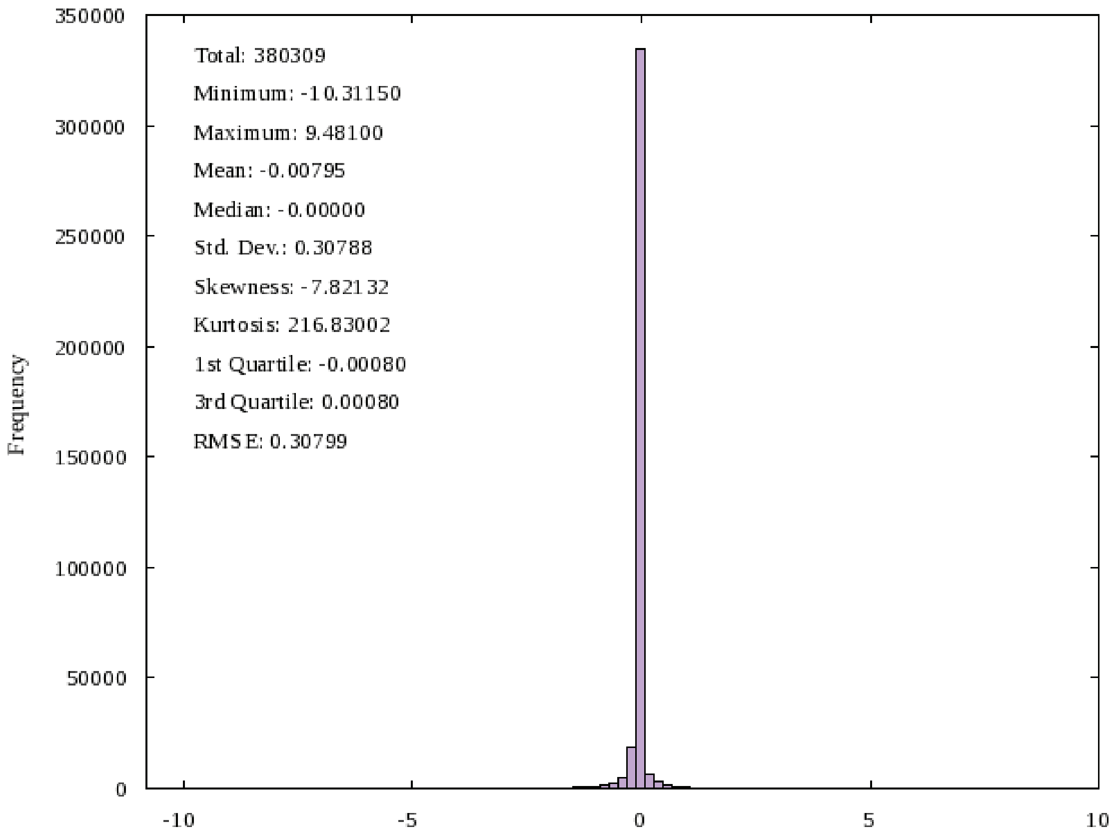

Figure 26. *Histogram of the differences between the NOS hydrographic soundings and the Panama City bathymetric surface.*

9. *Gnuplot* is an open-source command-driven interactive function plotting program. It can be used to plot functions and data points in both two- and three-dimensional plots in many different formats. It is designed primarily for the visual display of scientific data.

3.3.3 Building the NAVD 88 DEM

MB-System[10] was used to create the 1/3 arc-second Panama City NAVD 88 DEM. *MB-System* is an NSF-funded open source software application specifically designed to manipulate submarine multibeam sonar data, though it can utilize a wide variety of data types, including generic xyz data. The *MB-System* tool 'mbgrid' was used to apply a tight spline tension to the xyz data, and interpolate values for cells without data. The data hierarchy used in the 'mbgrid' gridding algorithm, as relative gridding weights, is listed in Table 9. The resulting binary grid was converted to an Arc ASCII grid using the *MB-System* tool 'mbm_grd2arc' to create the final 1/3 arc-second Panama City NAVD 88 DEM. Figure 27 illustrates cells in the DEM that have interpolated values (shown as white) versus data contributing to the cell value (shown as black).

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

Dataset	Relative Gridding Weight
FDEM topographic lidar	10
NWFWMD topographic lidar	10
Post-Hurricane Katrina bathymetric-topographic lidar	10
Post-Hurricane Dennis bathymetric-topographic lidar	10
Post-Hurricane Ivan bathymetric-topographic lidar	10
NGDC-digitized features	10
USGS NED 1/9 DEM	1
USGS NED 1/3 DEM	1
NOS hydrographic surveys	1
USACE hydrographic surveys	1
Pre-surfaced bathymetric grid	1
Coastline	1
Florida Lakewatch hydrographic surveys	0.1

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

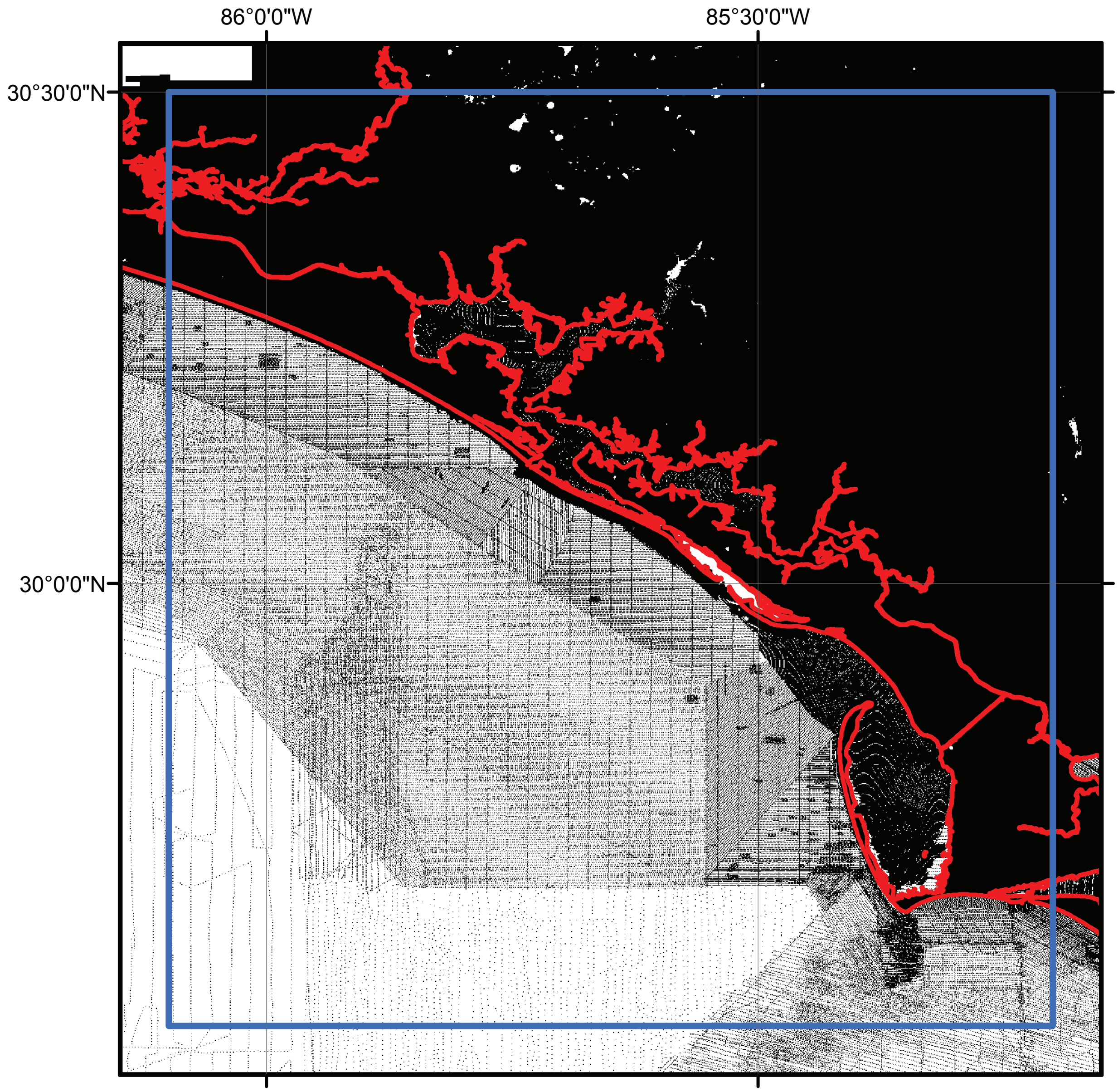

Figure 27. *Data distribution plot of the Panama City DEMs. Areas where source data were available are depicted in black; areas where grid interpolation was necessary are depicted in white. Panama City DEM boundary in blue, coastline in red.*

3.3.4 Developing the MHW DEM

The MHW DEM was created by adding a 'NAVD 88 to MHW' conversion grid to the NAVD 88 DEM.

1) Developing the conversion grid

Using extents slightly larger (~5%) than the NAVD 88 DEM, an initial xyz file was created that contained the coordinates of the four bounding vertices and midpoint of the larger extents. The elevation value at each of the points was set to zero. The *GMT* tool 'surface' applied a tension spline to interpolate cell values making a zero-value 3 arc-second grid. This zero-grid was then converted to an intermediate xyz file using the *GMT* tool 'grd2xyz.' Conversion values from NAVD 88 to MHW at each xyz point were generated using *VDatum* and the null values were removed. NGDC used the GMT tool 'blockmedian' to median-average multiple elevation values where *VDatum* project areas overlapped.

The median-averaged xyz file was then interpolated with the GMT tool 'surface' to create the 1/3 arc-second 'NAVD 88 to MHW' conversion grid with the extents of the NAVD 88 DEM. The *GMT* tool 'surface' interpolated values inland to represent the differences between the two datums onshore (Fig. 28).

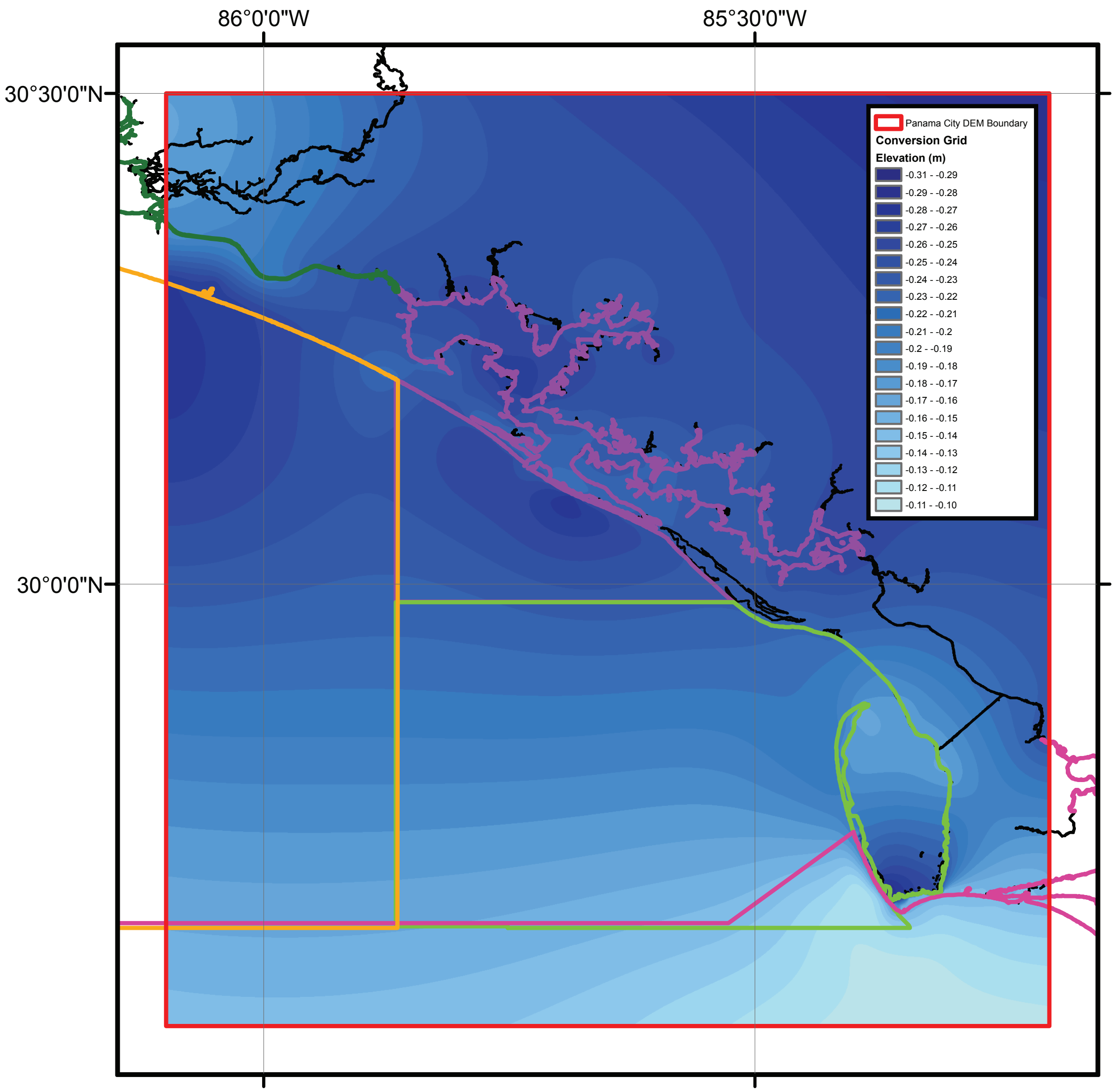

Figure 28. *Elevation values of the 'NAVD 88 to MHW' conversion grid derived from VDatum. Values equal the difference between NAVD 88 and MHW; colored lines represent the VDatum project areas.*

2) Assessing accuracy of conversion grid

The 'NAVD 88 to MHW' conversion grid was assessed using the NOS survey data. To test this methodology, the NOS hydrographic survey data were transformed from MLW and MLLW to NAVD 88 using *VDatum*. The resultant xyz files were filtered to remove any null values and then were merged together to form a single xyz file of the NOS hydrographic survey data with a vertical datum of NAVD 88. A second xyz file of NOS data was created with a vertical datum of MHW using the same method. Elevation differences between the MHW and NAVD 88 xyz files were computed.

To verify the conversion grid methodology, the difference xyz file was used to generate a histogram using *Gnuplot* to evaluate the performance of the 1/3 arc-second conversion grid by comparing the 'NAVD 88 to MHW' grid to the combined difference xyz files from the *VDatum* project areas (Fig. 29). Errors in the vertical datum conversion method will reside for the most part in the 'NAVD 88 to MHW' conversion grid, as the topographic data are already referenced to NAVD 88. Errors in the source datasets will require rebuilding just the NAVD 88 DEM.

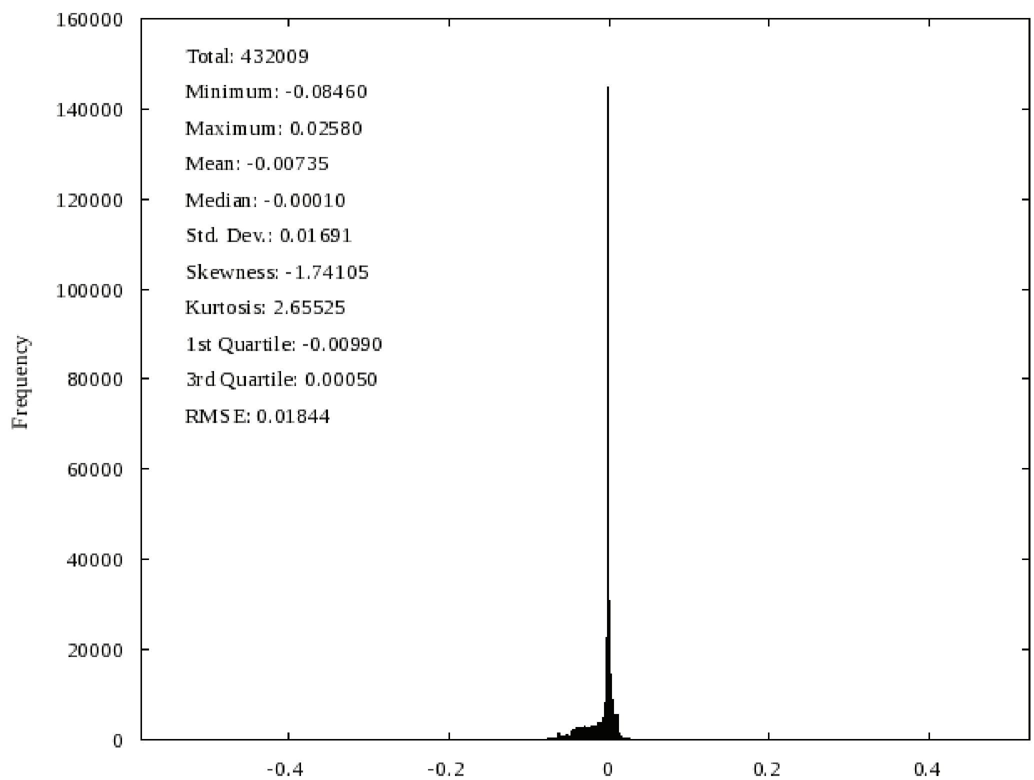

Figure 29. *Histogram of the differences between the conversion grid and xyz difference files using NOS hydrographic survey data.*

3) Creating the MHW DEM

Once the NAVD 88 DEM was completed and assessed for errors, the conversion grid was added to the NAVD 88 DEM using *ArcCatalog*. The resulting MHW DEM was reviewed and assessed using RNCs, USGS topographic maps, and ESRI *World 2D* imagery.

3.4 Quality Assessment of the DEMs

3.4.1 Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Panama City DEMs is dependent upon the datasets used to determine corresponding DEM cell values and the cell size of the DEM. The horizontal accuracy is ~10 meters where lidar datasets contribute to the DEM cell value. Bathymetric features are resolved only to within a few tens of meters in deep-water areas. Shallow, near-coastal regions, rivers, and harbor surveys have an accuracy approaching that of sub-aerial topographic features. Positional accuracy is limited by: the sparseness of deep-water soundings; potentially large positional uncertainty of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys; and by morphologic change that occurs in this dynamic region.

3.4.2 Vertical accuracy

Vertical accuracy of the Panama City DEMs is also highly dependent upon the source datasets contributing to DEM cell values. Topographic lidar has an estimated RMSE of 9.14 to 11.12 cm. Bathymetric-topographic lidar-derived data have a vertical accuracy of 0.20 meters at 1 sigma. Bathymetric areas have an estimated accuracy of between 0.1 meters and 5% of water depth. Those values were derived from the wide range of input data sounding measurements from the early 20th century to recent, GPS-navigated sonar surveys. Gridding interpolation to determine values between sparse, poorly-located NOS soundings degrades the vertical accuracy of deepwater elevations.

3.4.3 Slope maps and 3D perspectives

ESRI *ArcCatalog* was used to generate a slope grid from the Panama City NAVD 88 DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (Fig. 30). The DEM was transformed to UTM Zone 16 North coordinates (horizontal units in meters) in *ArcCatalog* for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Three-dimensional viewing of the UTM-transformed DEM was accomplished using ESRI *ArcScene*. Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEM. Figure 31 shows a perspective view image of the 1/3 arc-second Panama City NAVD 88 DEM in its final version.

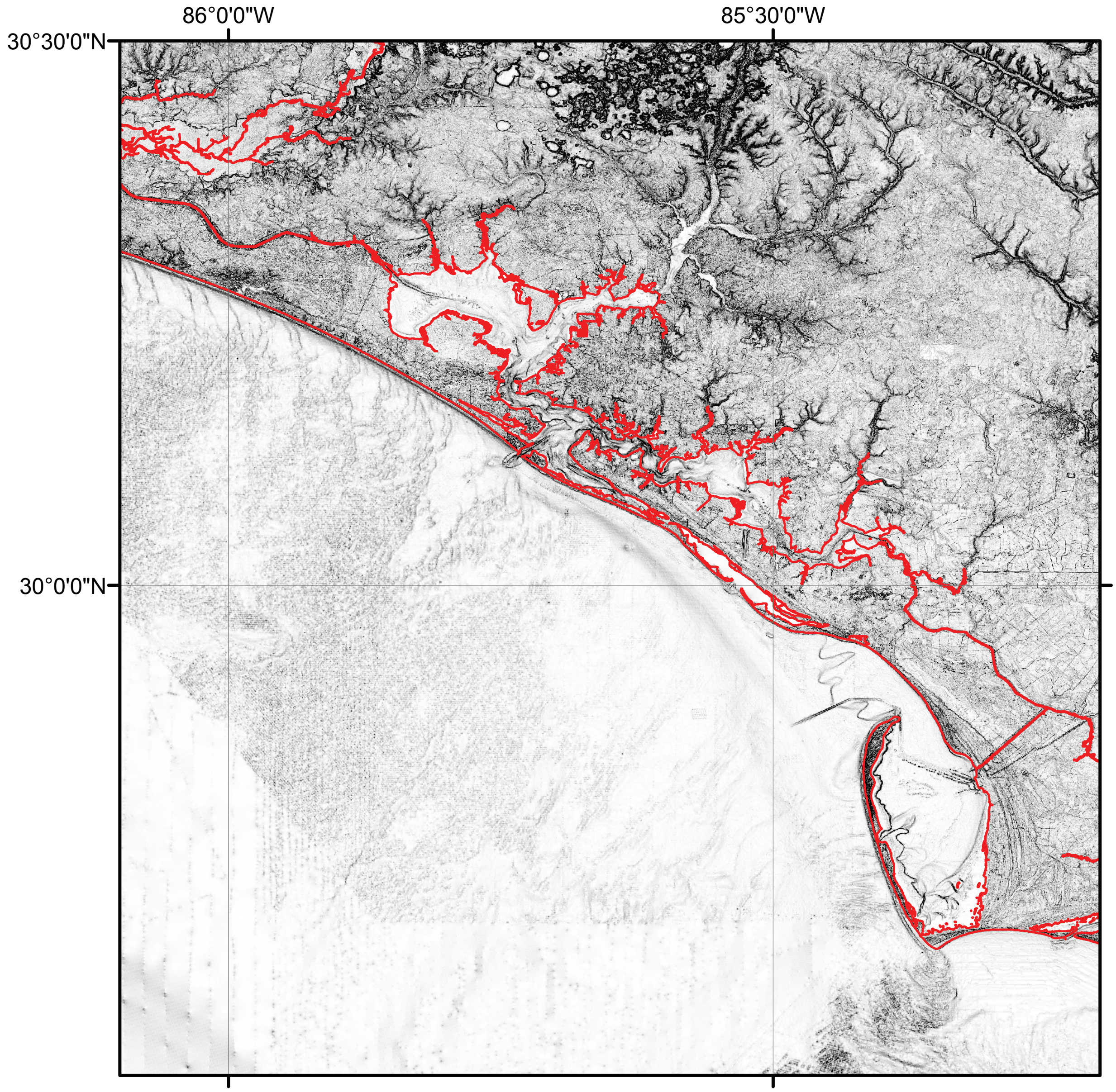

Figure 30. *Slope map of the Panama City NAVD 88 DEM. Flat-lying slopes are white; dark shading denotes steep slopes; Panama City coastline in red.*

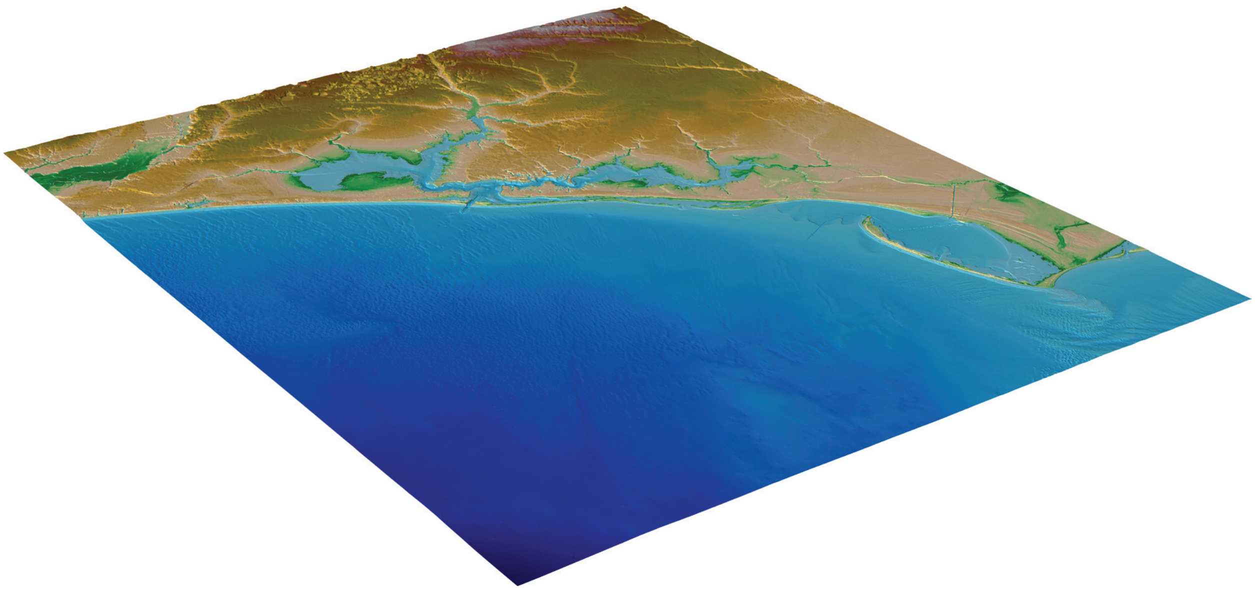

Figure 31. *Perspective view from the southwest of the Panama City NAVD 88 DEM. Ten times vertical exaggeration.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Panama City NAVD 88 DEM was compared to source data files. All bathymetric and topographic source data were compared to the Panama City NAVD 88 DEM using *Python, GDAL* and *Gnuplot.* Histograms of the differences between individual datasets and the Panama City NAVD 88 DEM are shown in Figures 32 through 43. Largest differences between source datasets and the DEM resulted from the averaging of multiple topographic source datasets where data coverage overlapped, particularly in regions of steep slopes.

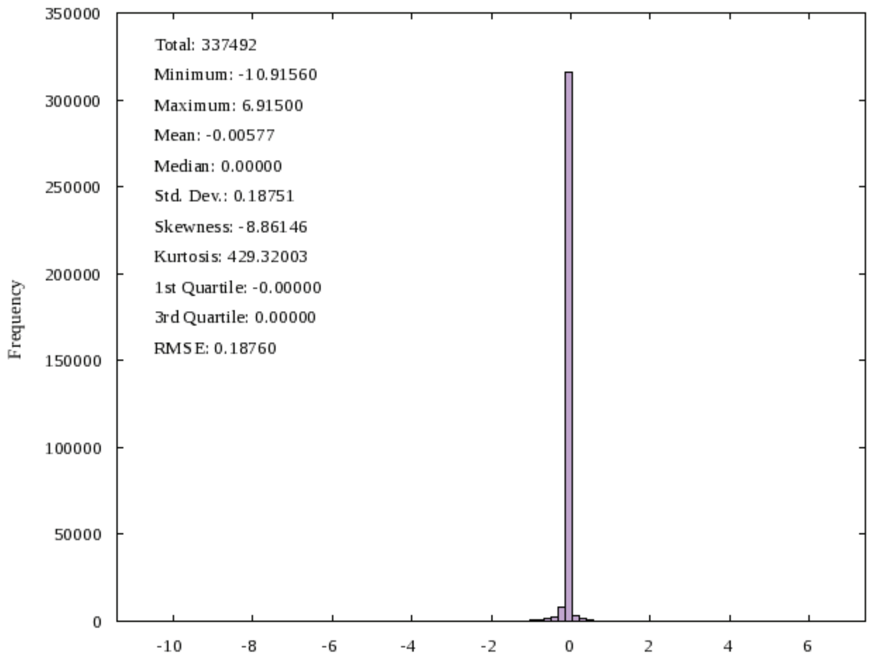

Figure 32. *Histogram of the differences between the NOS hydrographic survey dataset and the Panama City NAVD 88 DEM.*

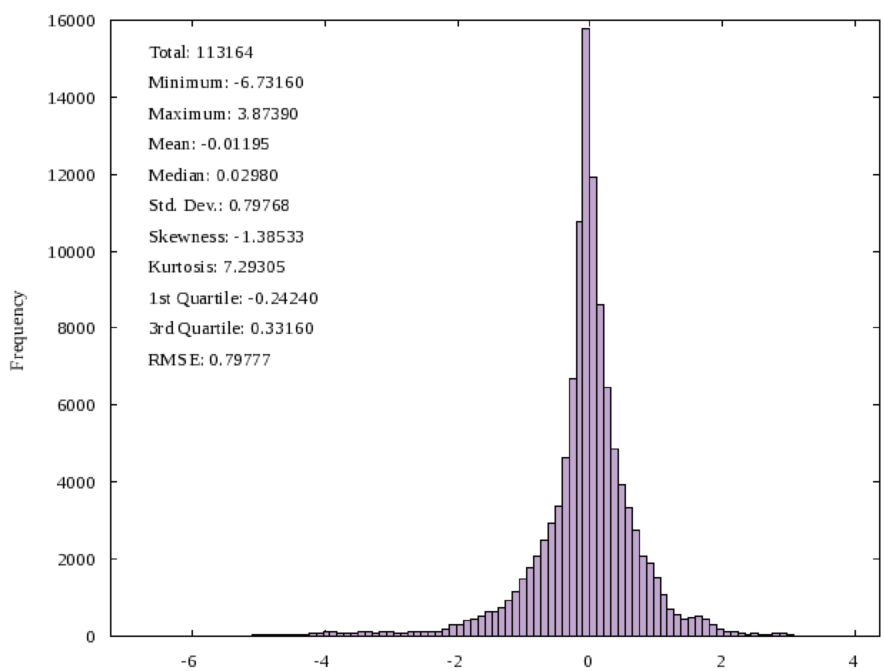

Figure 33. *Histogram of the differences between the USACE hydrographic survey dataset and the Panama City NAVD 88 DEM.*

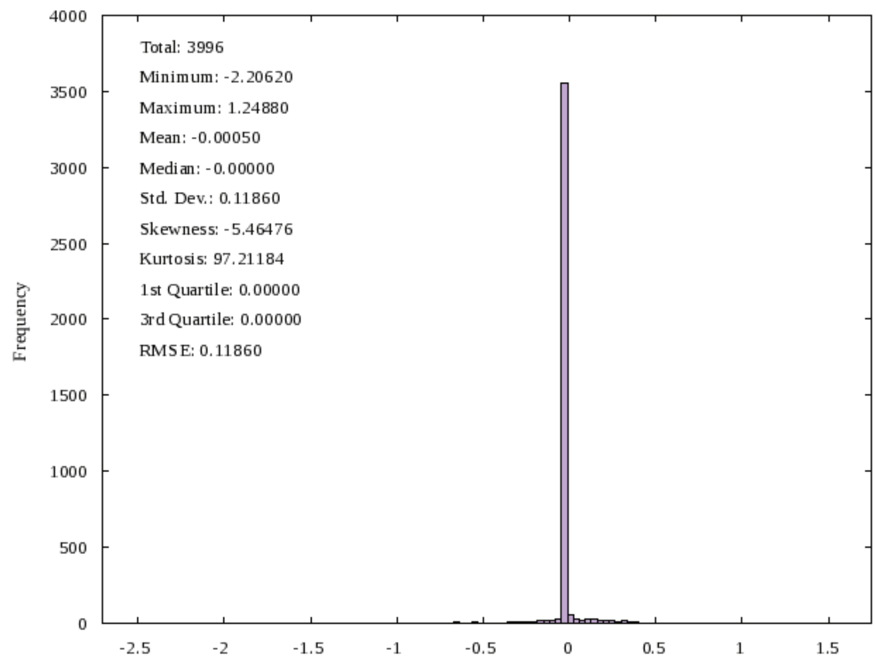

Figure 34. *Histogram of the differences between the Florida Lakewatch hydrographic survey dataset and the Panama City NAVD 88 DEM.*

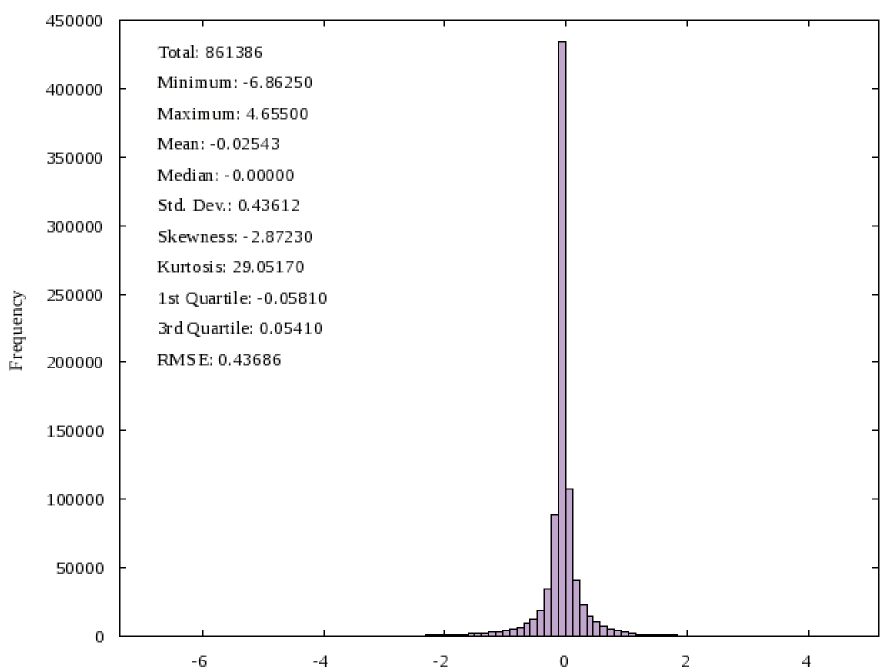

Figure 35. *Histogram of the differences between the NGDC-digitized bathymetric soundings dataset and the Panama City NAVD 88 DEM.*

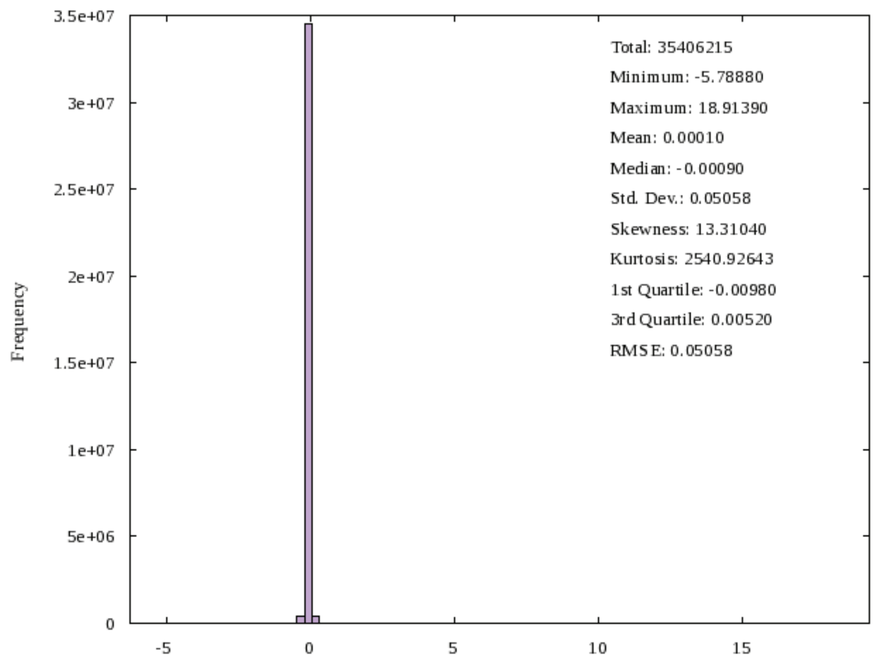

Figure 36. *Histogram of the differences between the FDEM lidar dataset and the Panama City NAVD 88 DEM.*

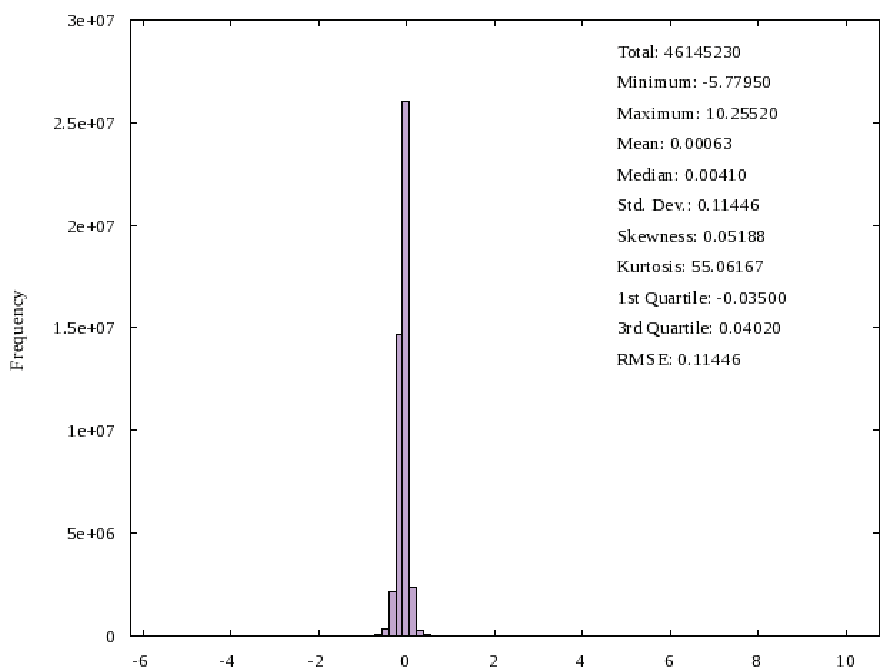

Figure 37. *Histogram of the differences between the NWFWMD lidar dataset and the Panama City NAVD 88 DEM.*

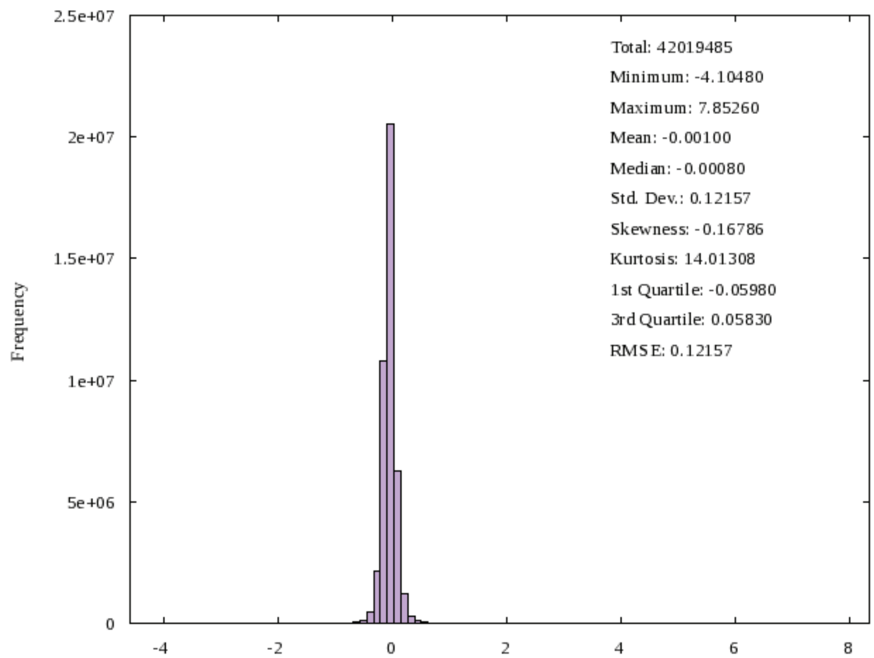

Figure 38. *Histogram of the differences between the NED 1/9 dataset and the Panama City NAVD 88 DEM.*

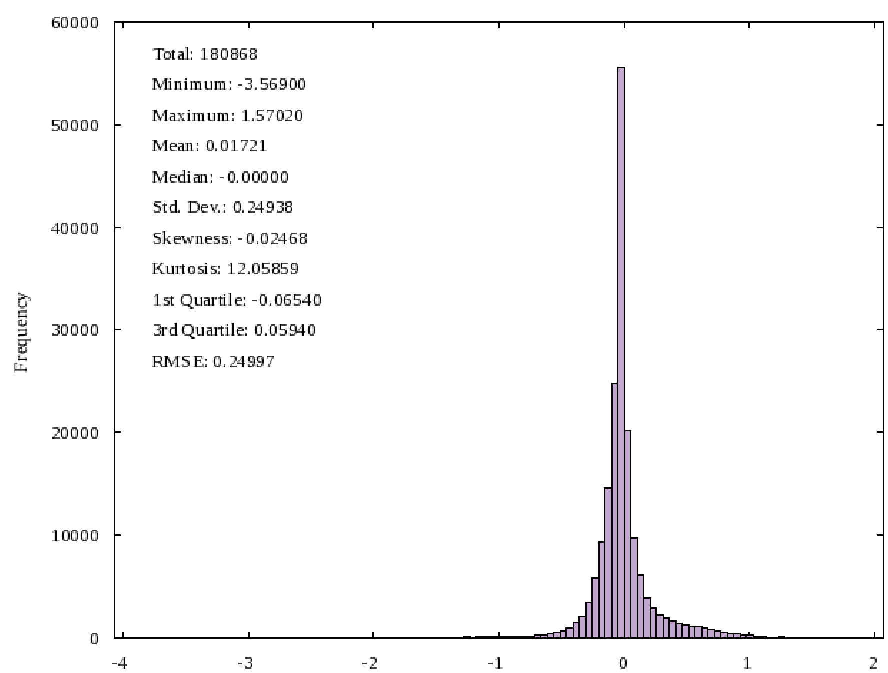

Figure 39. *Histogram of the differences between the NED 1/3 dataset and the Panama City NAVD 88 DEM.*

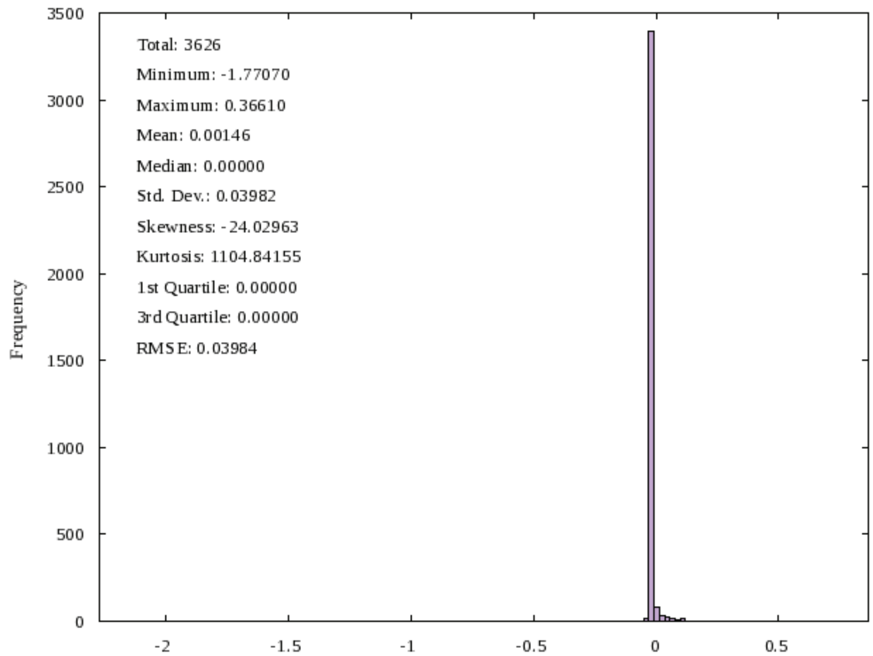

Figure 40. *Histogram of the differences between the NGDC-digitized topographic elevations dataset and the Panama City NAVD 88 DEM.*

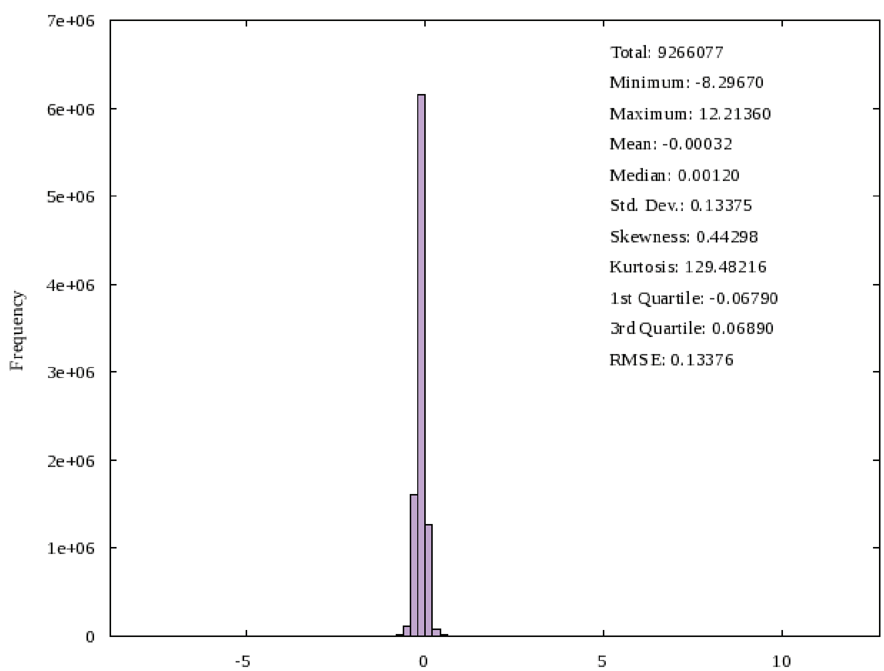

Figure 41. *Histogram of the differences between the Post-Hurricane Katrina dataset and the Panama City NAVD 88 DEM.*

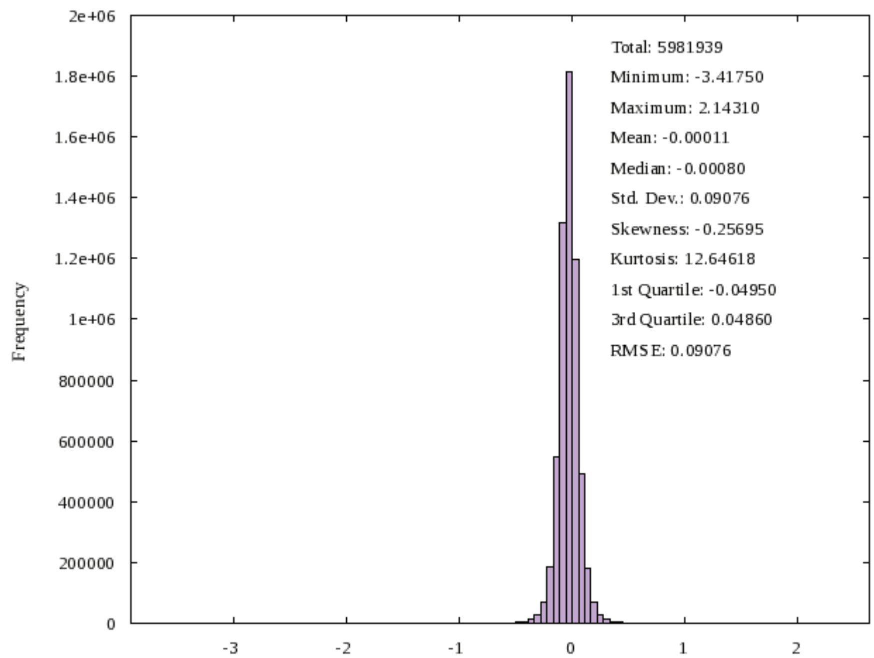

Figure 42. *Histogram of the differences between the Post-Hurricane Dennis dataset and the Panama City NAVD 88 DEM.*

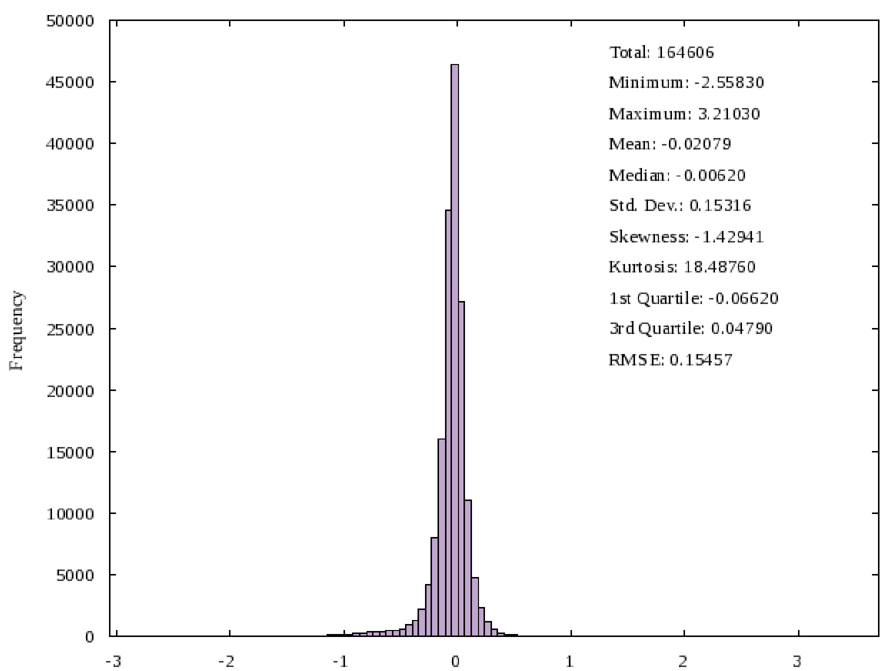

Figure 43. *Histogram of the differences between the Post-Hurricane Ivan dataset and the Panama City NAVD 88 DEM.*

3.4.5 Comparison with National Geodetic Survey geodetic monuments

The elevations of 1,155 NOAA NGS geodetic monuments (Fig. 44) were extracted from online shapefiles of NGS geodetic monument datasheets (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl), which give monument positions in NAD 83 (typically sub-mm accuracy) and elevations in NAVD 88 (in meters). Monument elevations were compared with elevations of the Panama City NAVD 88 DEM. Differences between the Panama City NAVD 88 DEM and the NGS geodetic monument elevations range from -10.24 to 77.48 meters, with the majority of them being within +/-1 meter (Fig. 45). Negative values indicate that the monument elevation is less than the DEM elevation. After examination, it was determined that those monuments with the largest deviations do not represent ground surface as they are located on top of an observation tower, light house or at the apex of other structures.

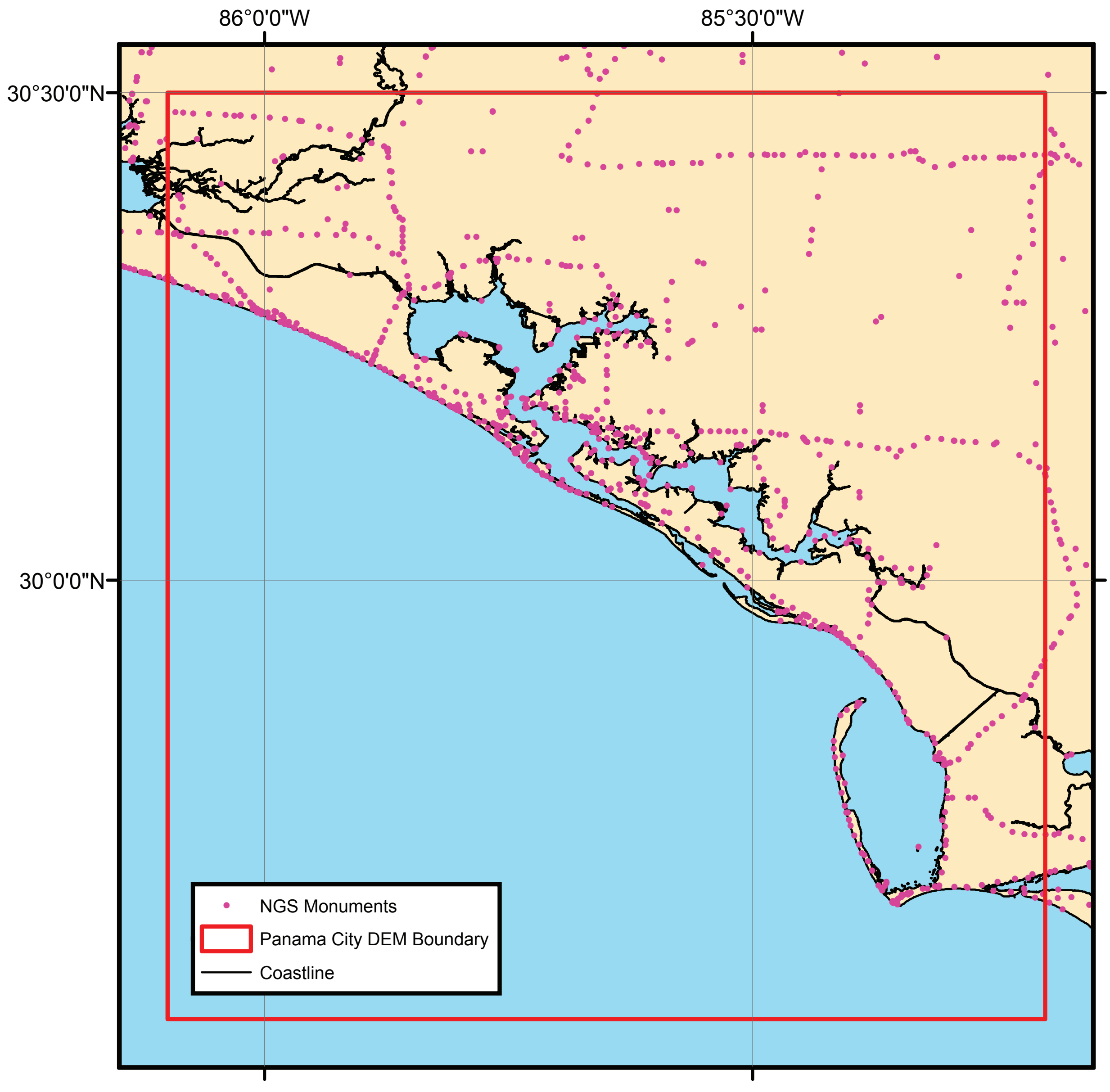

Figure 44. *Locations of NGS monuments used in evaluation of the Panama City NAVD 88 DEM.*

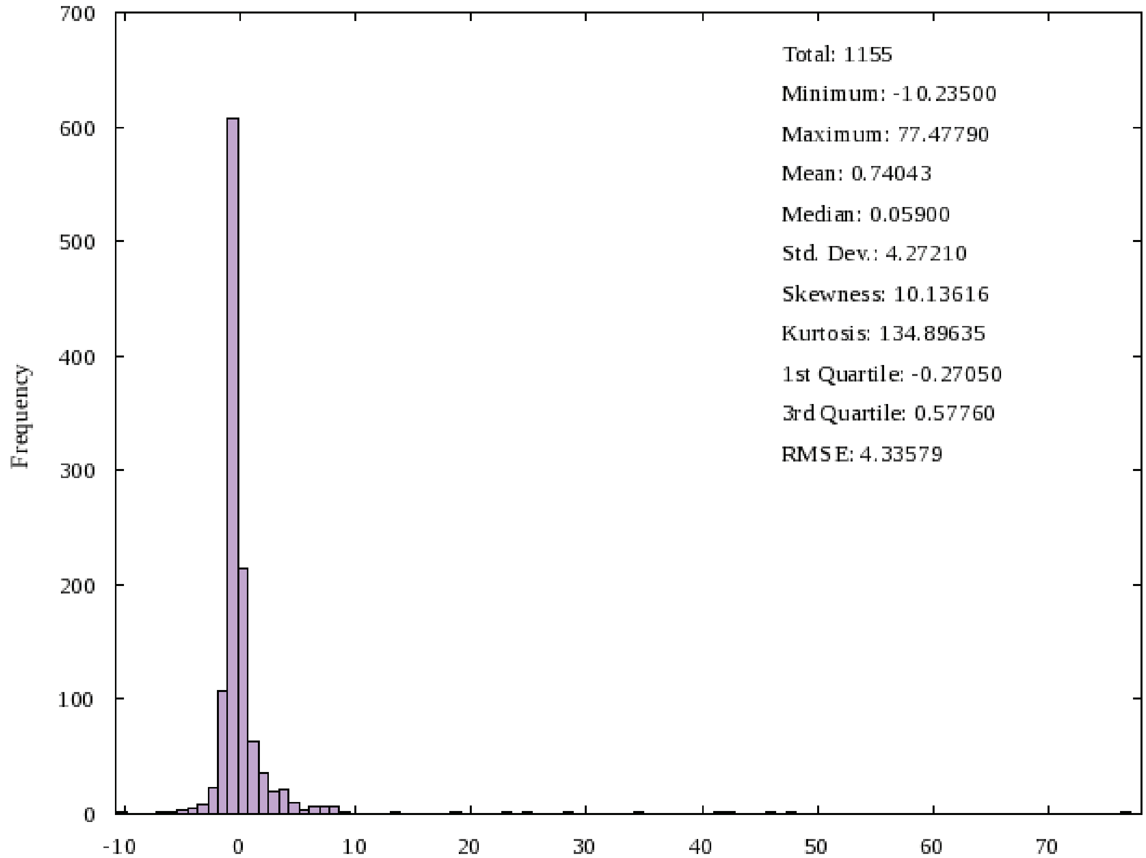

Figure 45. *Histogram of the differences between the NGS monument elevation values and the Panama City NAVD 88 DEM.*

4. Summary And Conclusions

Two bathymetric–topographic digital elevation models of the Panama City, Florida region, with cell spacing of 1/3 arc-second, and vertical datums of NAVD 88 and MHW were developed for CSDL through the American Recovery and Reinvestment Act (ARRA) of 2009. The DEMs were developed to validate the utility of *VDatum*, NOAA's OCS, NGS, and CO-OPS jointly developed datum transformation software tool. The DEMs will be used for storm-surge inundation and sea-level-rise modeling. 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 *VDatum*, ESRI *ArcGIS*, *FME*, *GMT*, *MB-System*, *Quick Terrain Modeler*, *GDAL*, *Gnuplot*, *Python*, and *Fledermaus* software. *VDatum* was utilized throughout the development of the Panama City DEMs to transform data to a common vertical datum. NGDC also developed a conversion grid using *VDatum* to transform the Panama City NAVD 88 DEM to MHW.

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

- Process USACE Post-Hurricane Katrina, Post-Hurricane Dennis, and Post-Hurricane Ivan bathymetric-topographic lidar to bare-earth.
- Conduct bathymetric surveys for St. Andrew Sound.

Recommendations to improve *VDatum*, based on NGDC's research and analysis, are listed below:

- Develop support for State Plane Coordinate Systems.
- Develop support for additional input and output file formats, such as ASPRS LAS files.

5. Acknowledgments

The creation of the Panama City DEMs was funded by the American Recovery and Reinvestment Act (ARRA) of 2009. The authors thank the GIS Administrator of FDEM, Richard Butgereit, for providing topographic lidar data, Florida Lakewatch Regional Coordinator, David Watson, for providing bathymetric data for coastal fresh-water lakes, and Mark White of the USACE Mobile District for providing bathymetric surveys of dredged channels.

6. References

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Morton, R.A., 2004. Eastern Panhandle of Florida Coastal Classification Maps - Lighthouse Point to St. Andrew Bay Entrance Channel. USGS Open File Report 2004-1044. http://pubs.usgs.gov/of/2004/1044/setting.html

Nautical Chart #11385 (RNC) 27th Edition, 2007. Intracoastal Waterway West Bay to Santa Rosa Sound. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11389 (RNC) 33rd Edition, 2005. St. Joseph and St. Andrew Bays. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11390 (RNC) 24th Edition, 2007. Intracoastal Waterway East Bay to West Bay. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

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

Nautical Chart #11393 (RNC) 21st Edition, 2005. Intracoastal Waterway Lake Wimico to East Bay. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11401 (RNC) 30th Edition, 2004. Apalachicola Bay to Cape San Blas. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11402 (RNC) 21st Edition, 2003. Intracoastal Waterway Apalachicola Bay to Lake Wimico. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

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7. Data Processing Software

ArcGIS v. 9.3.1, developed and licensed by ESRI, Redlands, California, http://www.esri.com/

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

Fledermaus v. 7.0 – developed and licensed by Interactive Visualization Systems (IVS 3D), Fredericton, New Brunswick, Canada, http://www.ivs3d.com/

FME 2009 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

GDAL v. 1.7.1 – Geographic Data Abstraction Library is a translator library maintained by Frank Warmerdam, http://www.gdal.org/

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. 4.2.1 – Generic Mapping Tools, free software developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/

Gnuplot v. 4.2, free software developed and maintained by Thomas Williams, Colin Kelley, Russell Lang, Dave Kotz, John Campbell, Gershon Elber, Alexander Woo http://www.gnuplot.info/

MB-System v. 5.1.0, free software 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/

Python v. 2.4, free software developed and maintained by Guido van Rossum, http://www.python.org/

Quick Terrain Modeler v. 6.0.6, Lidar processing software developed by John Hopkins University's Applied Physics Laboratory (APL) and maintained and licensed by Applied Imagery, http://www.appliedimagery.com/

VDatum Transformation Tool, Alabama, Florida, Louisiana, Mississippi, Alabama - Florida - Gulf of Mexico to East of Choctawhatchee Bay V. 01, Florida - Perdido, Pensacola and Choctawhatchee V. 01, Florida - St. Andrew's bay and the Gulf of Mexico V. 01, Florida - St. Joseph's Bay and the Gulf of Mexico V. 01, Florida - Apalachicola to Anclote Key V.01 - developed and maintained by NOAA's National Geodetic Survey (NGS), Office of Coast Survey (OCS), and Center for Operational Oceanographic Products and Services (CO-OPS), http://vdatum.noaa.gov/