Digital Elevation Model for Biloxi, Mississippi: 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) centered on Biloxi, Mississippi (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 Biloxi DEM.

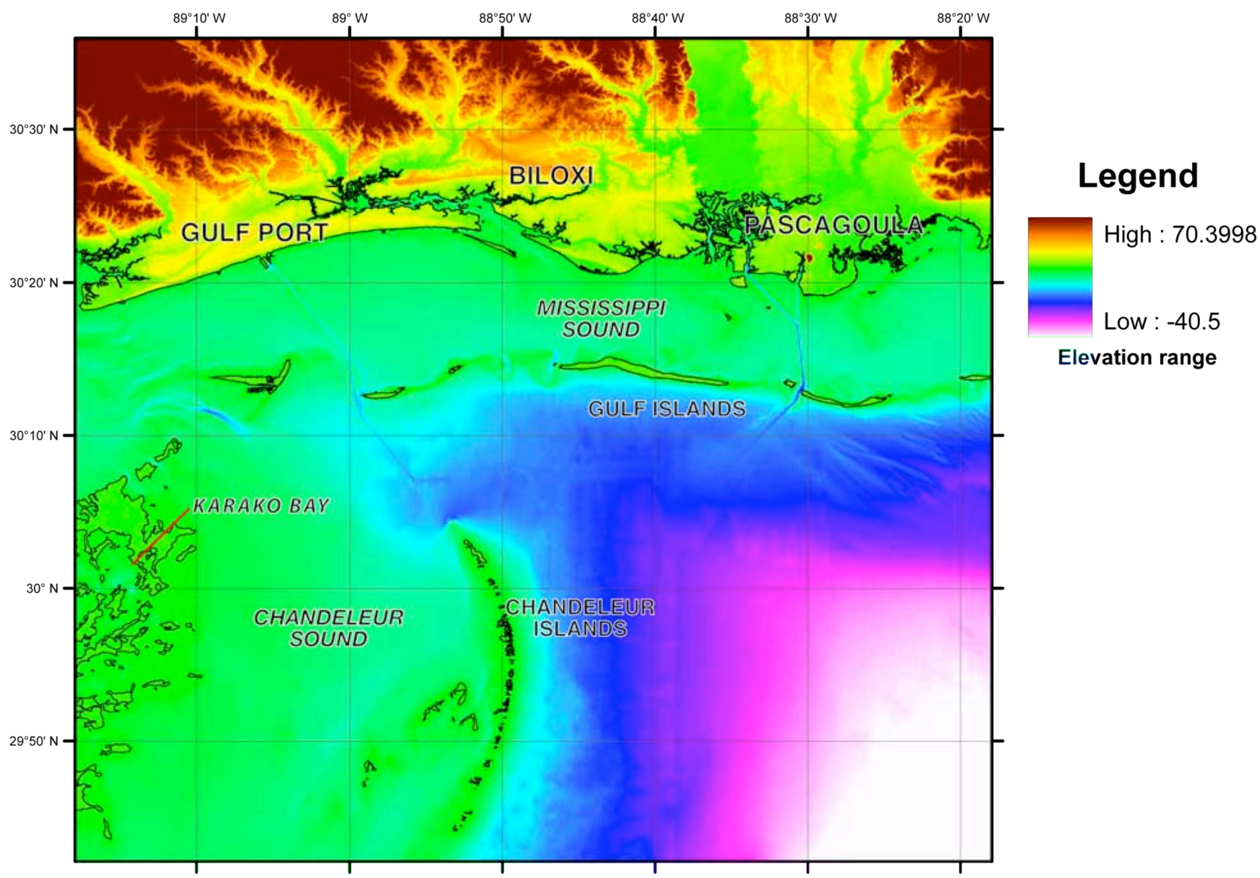

Figure 1. *Color image of the Biloxi, Mississippi DEM.*

1. The Biloxi 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 Biloxi, Mississippi (30°24′ N, 88°53.3′ W) 1/3 arc-second of latitude is equivalent to 10.26 meters; 1/3 arc-second of longitude equals 8.90 meters.

2. STUDY AREA

The Biloxi DEM covers the coastal region surrounding Biloxi, Mississippi, including the communities of Gulfport and Pascagoula (Fig. 1), as well as the offshore areas of the Mississippi Sound, Chandeleur Sound, and the Gulf Islands. The Chandeleur Islands (e.g., Fig 2) have undergone coastal erosion and changes in sediment deposition that have modified the shoreline in the geologically short time span of 150 years.

More recently, the 2005 hurricane season severely impacted the landscape and economy of the Mississippi Gulf Coast region. Hurricanes Arlene, Cindy, Dennis, and Katrina made landfall in the area between June and August 2005, dramatically changing the shape of the coastline.

Figure 2. *Barrier Islands in Mississippi Sound (http://pubs.usgs.gov/of/2005/1151/images/fig1LG.jpg).*

3. METHODOLOGY

The Biloxi 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 Biloxi, Mississippi DEM.

Grid Area	Biloxi, Mississippi
Coverage Area	88.3º to 89.3º W; 29.7º to 30.6º 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 and state 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 Mississippi Office of Geology (MOG), Coastal Geology and Energy Division; and the Mississippi Automated Resource Information System (MARIS). Safe Software's (http://www.safe.com/) FME data translation tool package was used to shift datasets to WGS84 horizontal datum and to convert them into ESRI (http://www.esri.com/) ArcGIS shape files. The shape files were then displayed with ArcGIS to assess data quality and manually edit datasets; 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 Biloxi tidal stations. VDatum model software (http://nauticalcharts.noaa.gov/csdl/vdatum.htm) was not available for this area.

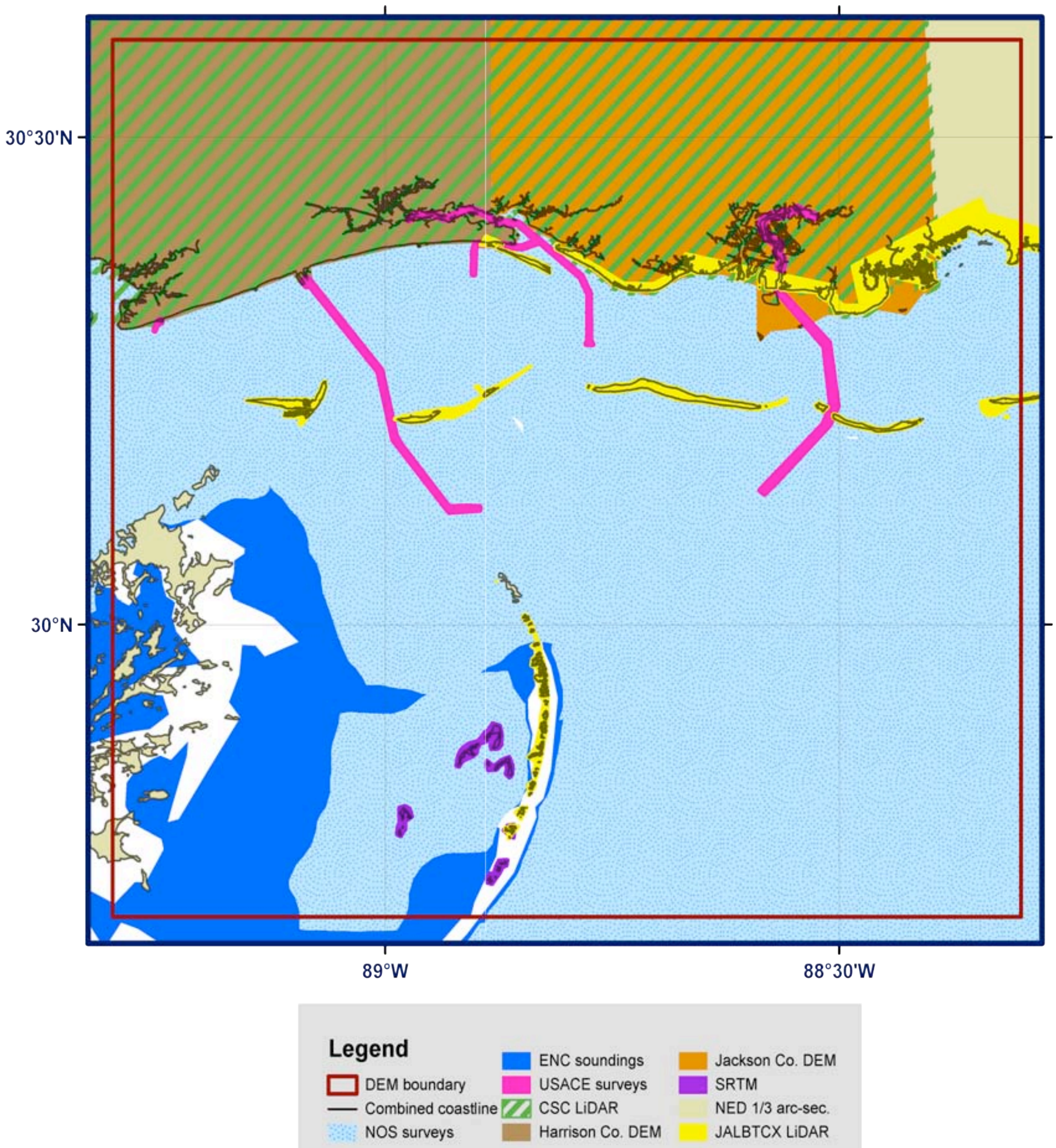

Figure 3. *Source and coverage of datasets used to compile the Biloxi DEM.*

3.1.1 Shoreline

Two digital coastline datasets of the Biloxi region were analyzed for inclusion in the Biloxi DEM: OCS Electronic Navigational Charts and the Mississippi Office of Geology (MOG), Coastal Geology and Energy Division High Water shoreline (Table 2).

Table 2: Shoreline datasets used in compiling the Biloxi DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
OCS Electronic Navigation Charts (ENC)	2002 to 2004	extracted coastline	Digitized from 1:250,000 to 1:456,394 scale charts	WGS84	MHW	http://chartmaker.ncd.noaa.gov/
Mississippi Office of Geology (MOG), Coastal Geology and Energy Division	1986 to 2002	MS High water shoreline	~ 5 meters	WGS84	"High water shoreline"	http://geology.deq.state.ms.us/coastal/Shorelines-GPS.htm

1) NOAA Office of Coast Survey electronic navigational charts

Thirteen NOAA nautical charts within the Biloxi DEM region were downloaded from the NOAA 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 eight also available as Electronic Navigational Charts (ENCs)—digital GIS chart components (Table 3 and 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.

Two of the ENCs (#11360 and #11366) were used in conjunction with the MOG coastline dataset to build a 'combined coastline' (Fig. 6). Coastline files extracted from lower resolution ENCs #11360 and #11366 were used instead of the higher resolution ENC #11363 and #11371 through #11375, as the data more closely matched recent LiDAR data in areas with high rates of coastal change. Editing all of the ENC coastline data was necessary to capture detail in areas where recent bathymetric survey data existed. Nautical charts in RNC format were used to evaluate other coastline, bathymetric and topographic datasets and for digitization of coastal features not represented in any digital coastline dataset.

Table 3: NOAA Electronic navigational charts in the Biloxi, Mississippi region.

Chart Number	*Title*	*Edition*	*Date*	*Scale*	*Available Format*	*Used in Combined Coastline*
11360	Cape St. George to Mississippi Passes	7th	2006	1:456,394	ENC	yes
11363	Chandeleur and Breton Sounds	40th	2005	1:80,000	ENC	
11366	Approaches to Mississippi River	7th	2007	1:250,000	ENC	yes
11371	Lake Borgne and Approaches Cat Island to Point Aux Herbes	2nd	2007	1:80,000	ENC	
11372	Dog Keys Pass to Waveland	21st	2006	1:40,000	ENC	
11373	Mississippi Sound and Approaches Dauphin Island to Cat Island	8th	2007	1:80,000	ENC	
11374	Dauphin Island Alabama to Horn Island Mississippi	12th	2006	1:40,000	ENC	
11375	Pascagoula Harbor Mississippi	10th	2007	1:20,000	ENC	

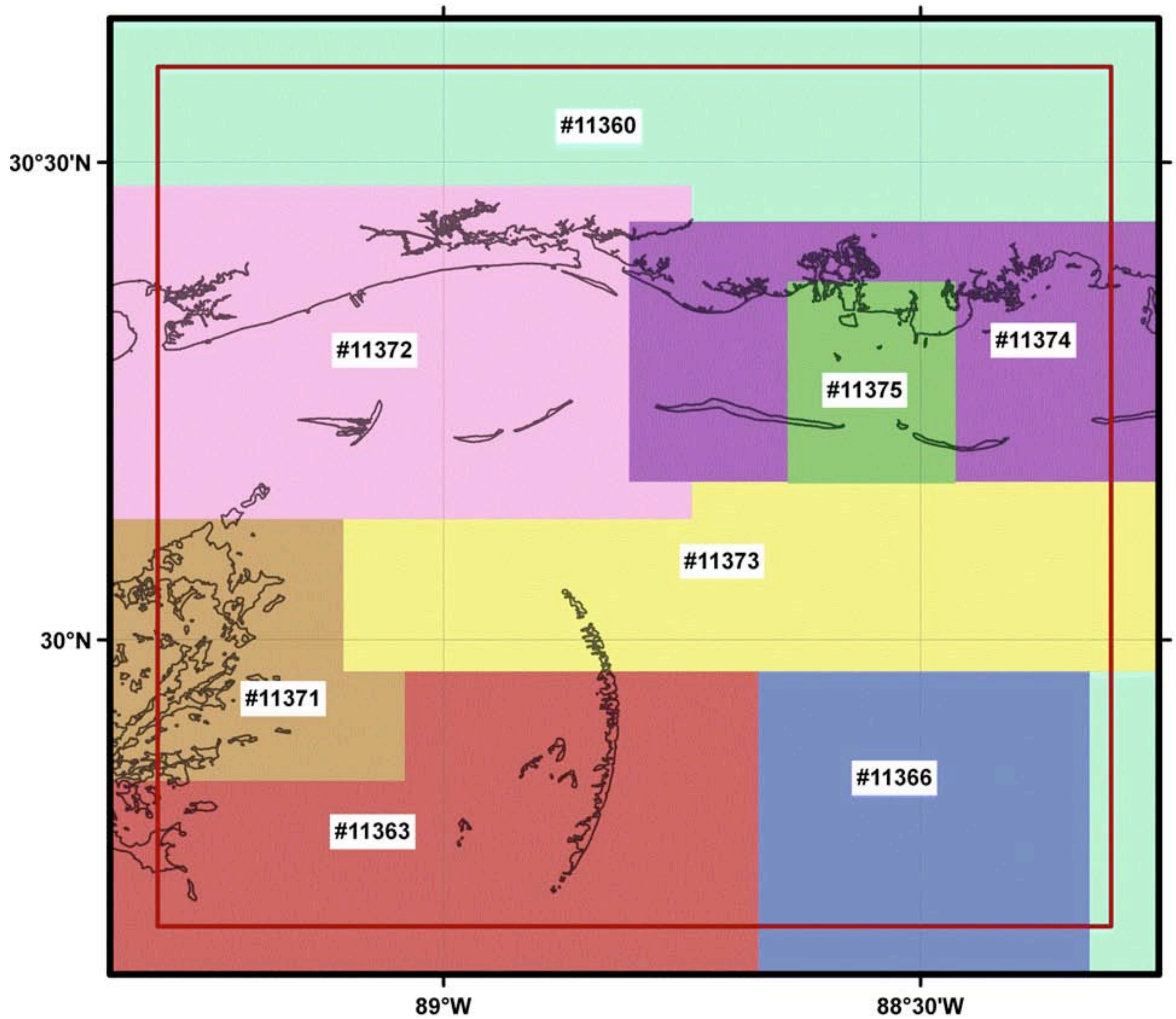

Figure 4. *NOAA Electronic Navigational Charts available in the Biloxi region. ENCs #11360 and #11366 provide coverage for the majority of the DEM area.*

2) Mississippi Office of Geology, Mississippi High Water Shoreline

The Mississippi Office of Geology (MOG), Coastal Geology and Energy Division has developed a High Water shoreline for use in coastal morphology studies and to provide a baseline dataset for monitoring yearly shoreline changes. The primary data were collected in the field using backpack GPS receivers while walking the high tide line. Orthophotos were also digitized and combined with the GPS data to form complete coastal coverage[2].

The MOG shoreline was manually edited using ESRI ArcMap to eliminate features such as piers and docks. A comparison of the MOG shoreline with other coastline datasets available for the Mississippi mainland is illustrated in Figure 5. The NGA and NGS datasets show bridge features, which were not present in the MOG shoreline.

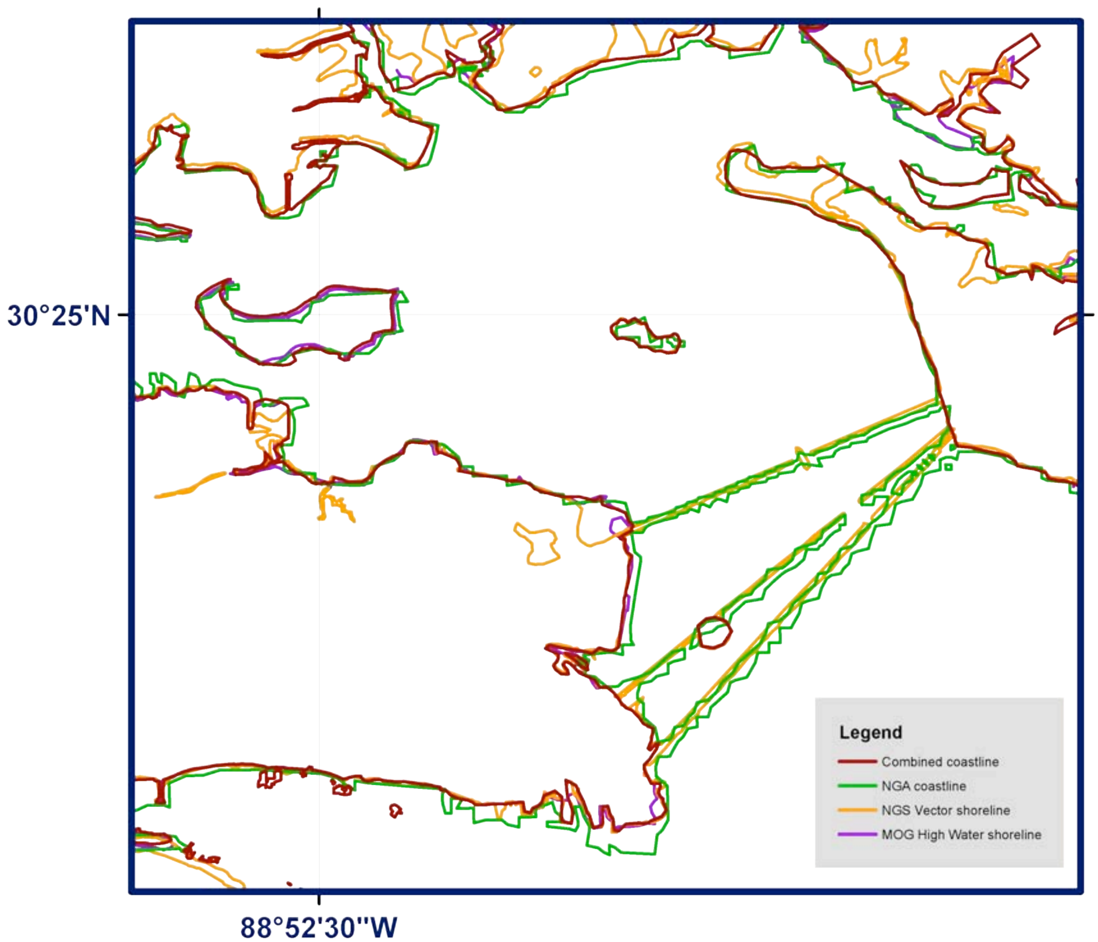

Figure 5. *Detail of coastline datasets available for Biloxi Bay.*

2 GPS Data were collected in the field with backpack GPS receivers while walking the high tide line. GPS data post processed using base station data from MOG base stations in Biloxi and Jackson. Shoreline vectors were cleaned to remove hanging nodes and manually corrected to remove clusters and errant data points. Shoreline loops were also removed. Areas where survey parties met were joined by removing redundant sections or nodes. Jagged shorelines sections, a result of data errors, were simplified where possible. OrthoImagery was used to supplement the GPS data and complete the shoreline. This data is not as accurate as the GPS data. Ortho Image Data: shoreline digitized from aerial photo using ArcGIS. All data cleaned to insure topological correctness. Polylines were split in segments less than 100 m in length for attributing. Dangles and overshoots removed in process of line splitting. Shoreline is not continuous in all locations. Attribute data were conflated from previous sources and from data created by the Mississippi Office of Geology. Previous source data were used as is. Created data were visually checked using map analysis and orthoimagery. [Extracted from metadata]

To obtain the best digital MHW coastline, NGDC combined the MOG High Waterline and ENC coastlines into a ‘combined coastline’ (Fig. 6). Where overlap occurred between coastline datasets, the dataset with the most detail and consistency with topographic, bathymetric and topographic–bathymetric datasets was used. This combined coastline was manually adjusted along the Gulf coast, using ESRI ArcMap to match the JALBTCX high-resolution coastal LiDAR data, particularly the late 2005 post-Hurricane Katrina survey. For areas where coastline data were unavailable or grossly inaccurate in the Katrina-impacted Chandeleur Island region (e.g., Fig 7), NGDC manually digitized a MHW coastline based on zero elevation data from both CSC topographic and JALBTCX bathymetric/topographic datasets.

The combined coastline was converted to point data for use as a coastal buffer in 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).

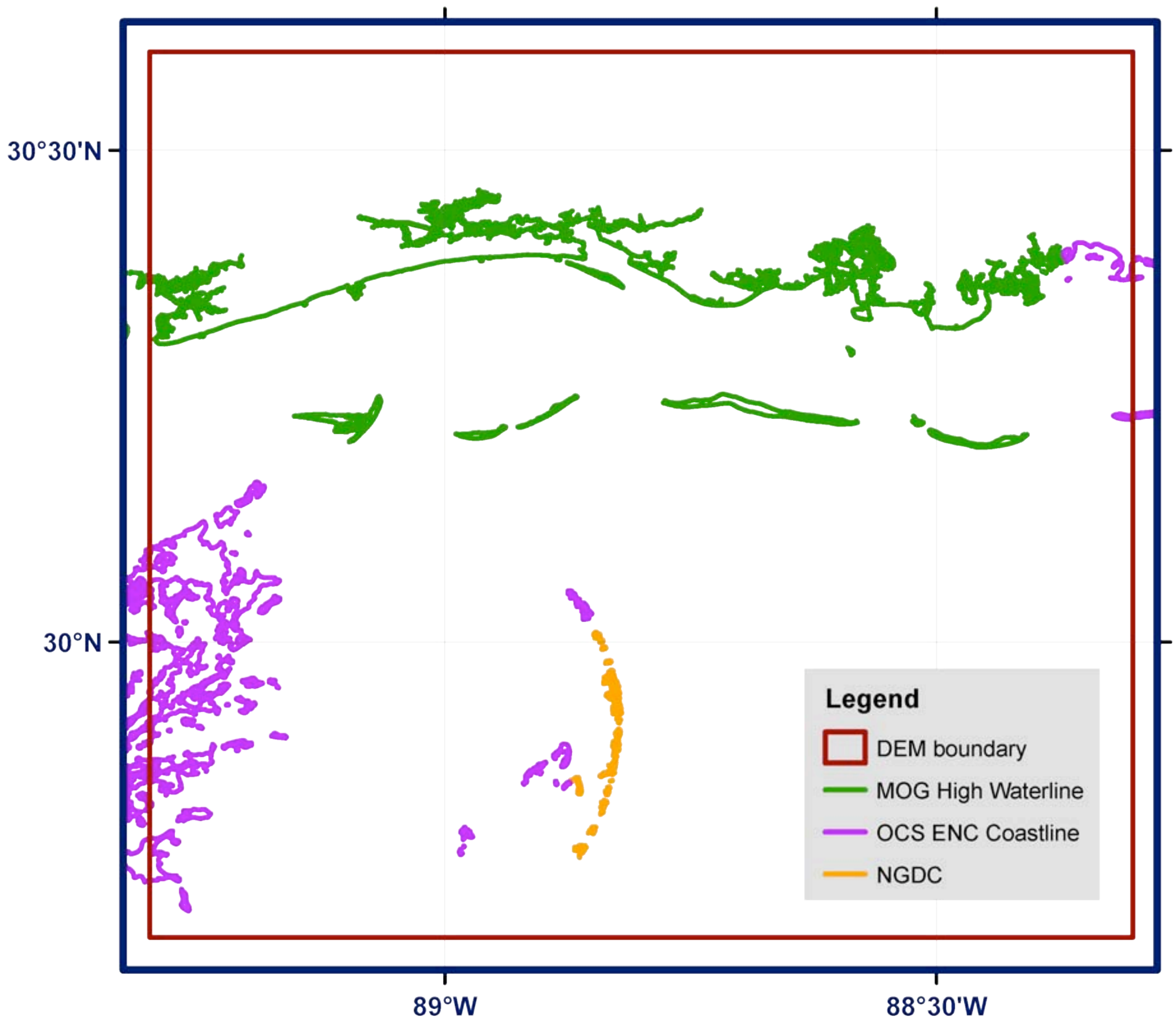

Figure 6. *Digital coastline segments used to create a ‘combined coastline’ for the Biloxi region.*

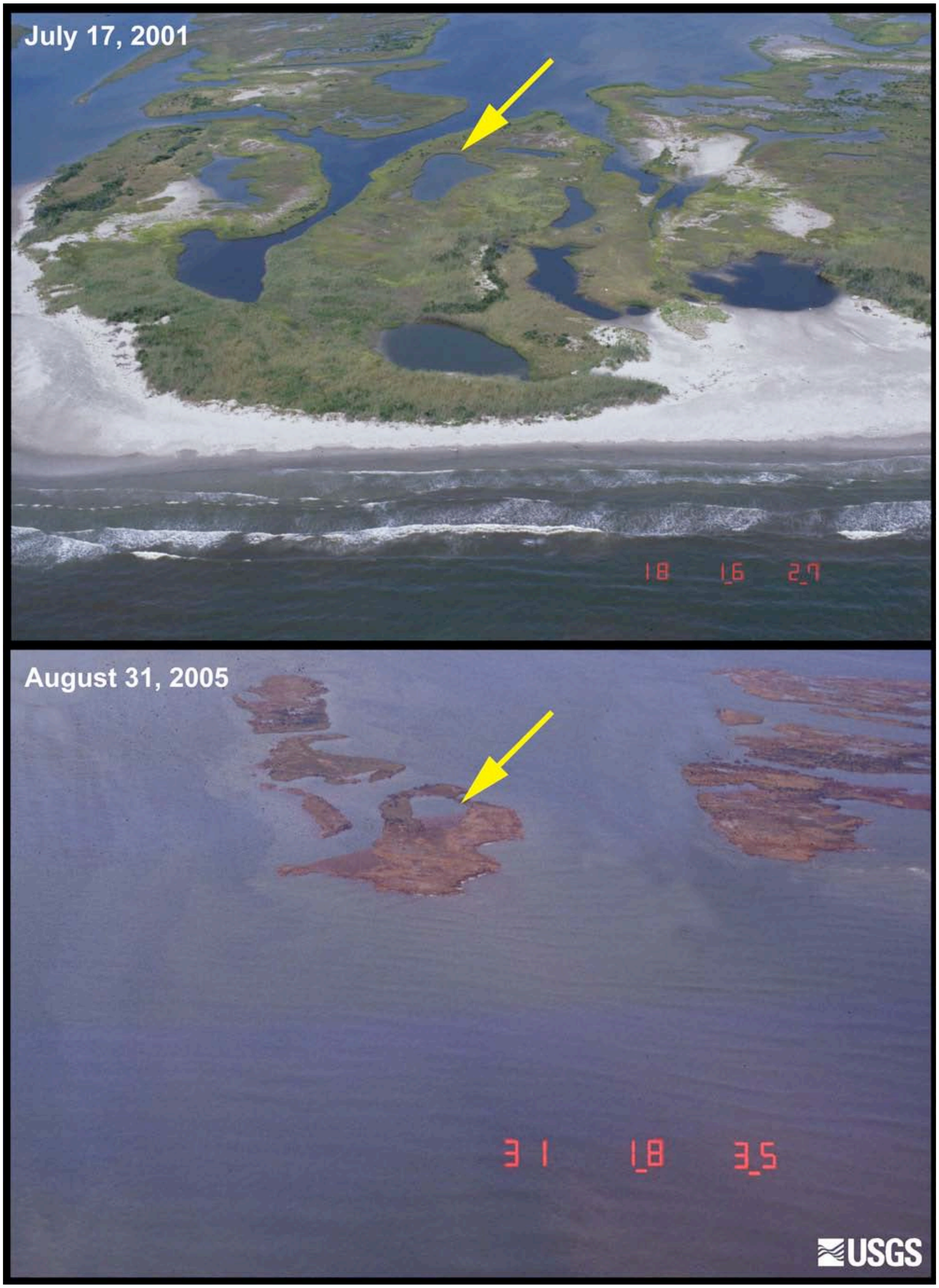

Figure 7. *Changes in coastal morphology of the Chandeleur Island Chain pre- and post-Katrina (http://coastal.er.usgs.gov/hurricanes/katrina/photo-comparisons/chandeleur.html#set5).*

3.1.2 Bathymetry

Bathymetric datasets used in the compilation of the Biloxi DEM include 48 NOS hydrographic surveys, 25 USACE surveys of dredged shipping channels, and OCS ENC extracted soundings in the Chandeleur Sound region (Table 4).

Table 4: Bathymetric datasets used in compiling the Biloxi DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
USACE	2005 to 2007	Bathymetric surveys	Profiles 75 to 300 m long, 5 to 150 m apart with < 1 m point spacing	NAD83 State Plane Mississippi East (feet)	MLLW (meters)	
NOS	1917 to 1989	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 or MLW (meters)	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
OCS	2006	extracted ENC soundings	200 to 2500 m point spacing	WGS84 geographic	MLLW (meters)	

1) NOS hydrographic survey data

A total of 48 NOS hydrographic surveys conducted between 1917 and 1989 were utilized in developing the Biloxi DEM (Table 5; Fig. 8). The hydrographic survey data were originally vertically referenced to Mean Lower Low Water (MLLW) or Mean Low Water (MLW) and horizontally referenced to either NAD27 or NAD83 geographic datums.

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 degree (~5%) larger than the Biloxi 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 multibeam and coastal LiDAR data, NED topographic data, the combined coastline, RNCs, and *Google Earth* satellite imagery. Data point spacing for the NOS surveys varied by collection date. In general, earlier surveys had greater point spacing than more recent surveys.

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

Survey ID	*Year*	*Scale*	*Original vertical datum*	*Original horizontal datum*
D00077	1988	20,000	Mean Lower Low water	NAD83
D00078	1984/87	40,000	Mean Lower Low water	NAD27
D00079	1988	20,000	Mean Lower Low water	NAD83
F00077	1948/88	40,000	Mean Low Water	NAD27
F00314	1988	20,000	Mean Lower Low water	NAD83
F00315	1988	20,000	Mean Lower Low water	NAD83
F00324	1989	20,000	Mean Lower Low water	NAD83
F00329	1989	20,000	Mean Lower Low water	NAD83
F00335	1989	20,000	Mean Lower Low water	NAD83

H04000	1917	40,000	Mean Low Water	undetermined
H04021	1917	40,000	Mean Low Water	undetermined
H04171	1920	80,000	Mean Low Water	undetermined
H04212	1921/22	80,000	Mean Low Water	undetermined
H04219	1922	80,000	Mean Low Water	undetermined
H04223	1922	80,000	Mean Low Water	undetermined
H06550	1940	80,000	Mean Low Water	NAD27
H06552	1940	40,000	Mean Low Water	NAD27
H06688	1941	40,000	Mean Low Water	NAD27
H08643	1961/62	10,000	Mean Low Water	NAD27
H08644	1961/64	10,000	Mean Low Water	NAD27
H08645	1961/62	10,000	Mean Low Water	NAD27
H08646	1961/62	10,000	Mean Low Water	NAD27
H08647	1961/62	20,000	Mean Low Water	NAD27
H08648	1961/62	20,000	Mean Low Water	NAD27
H08649	1962	10,000	Mean Low Water	NAD27
H08650	1962	10,000	Mean Low Water	NAD27
H08651	1962	10,000	Mean Low Water	NAD27
H08652	1962	10,000	Mean Low Water	NAD27
H08922	1966/68	10,000	Mean Low Water	NAD27
H08923	1966/68	10,000	Mean Low Water	NAD27
H08924	1967/68	20,000	Mean Low Water	NAD27
H08925	1967/68	10,000	Mean Low Water	NAD27
H08970	1968	10,000	Mean Low Water	NAD27
H08971	1968	20,000	Mean Low Water	NAD27
H09004	1968/69	20,000	Mean Low Water	NAD27
H09028	1970/71	20,000	Mean Low Water	NAD27
H09103A	1970	20,000	Mean Low Water	undetermined
H09103B	1970	20,000	Mean Low Water	undetermined
H09118	1970/75	20,000	Mean Low Water	NAD27
H09156	1970/71	10,000	Mean Low Water	NAD27
H09177	1970/71	10,000	Mean Low Water	NAD27
H09200	1971	20,000	Mean Low Water	NAD27
H10113	1983	40,000	Mean Lower Low water	NAD27
H10206	1985	40,000	Mean Lower Low water	NAD27
H10208	1985	20,000	Mean Lower Low water	NAD27
H10247	1987	20,000	Mean Lower Low water	NAD83
H10261	1987	20,000	Mean Lower Low water	NAD27

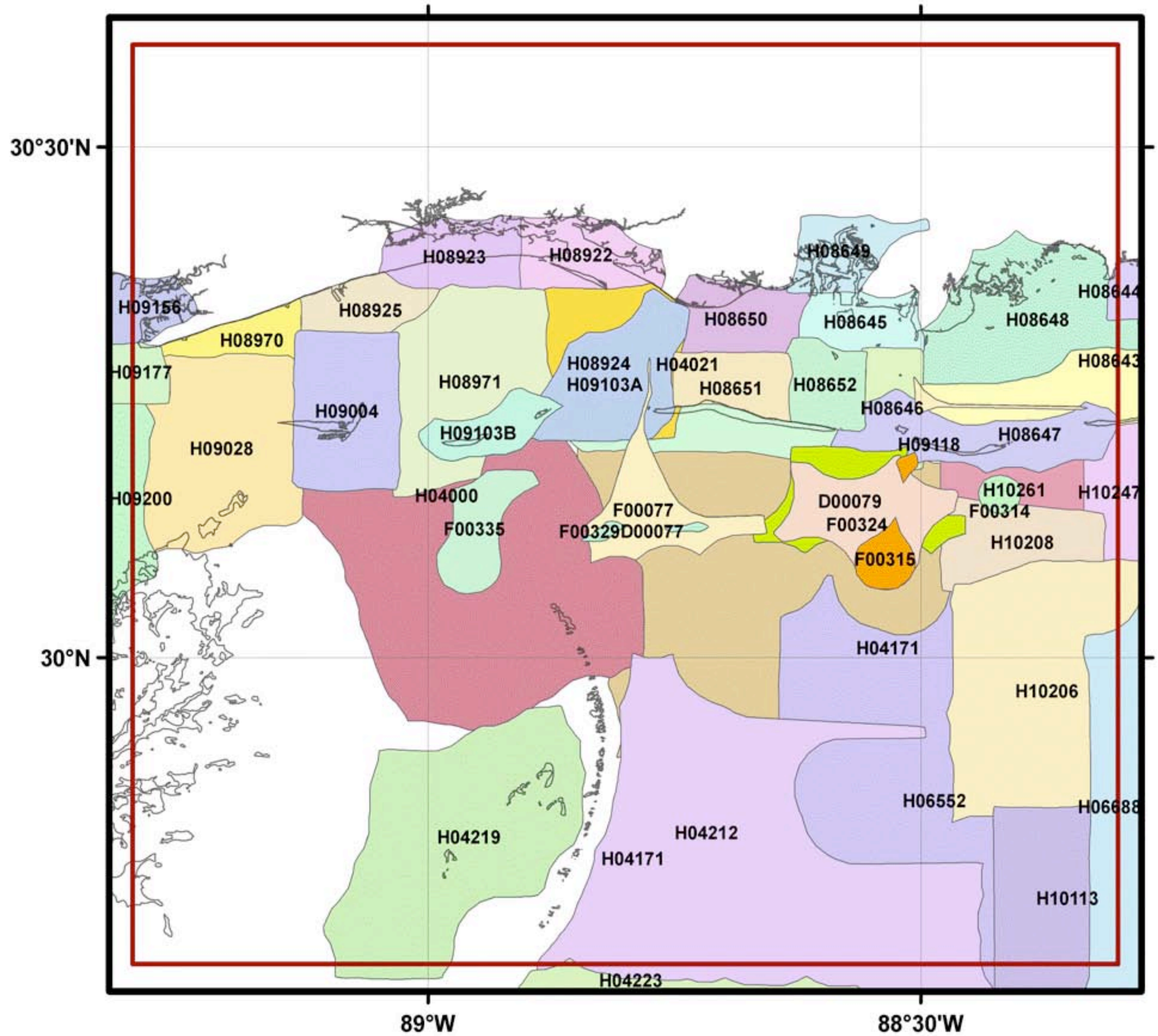

Figure 8. *Digital NOS hydrographic survey coverage in the Biloxi region. DEM boundary shown in red, combined coastline shown in gray.*

2) USACE surveys of dredged shipping channels

Twenty five USACE bathymetric surveys of dredged shipping channels in the Mississippi Sound (Fig. 9) were provided to NGDC by Matt Tate, USACE Mobile District, Irvington Site Office. All data were originally in NAD83 Mississippi State Plane East coordinates, and MLLW vertical datum (Table 6). Surveys consist of parallel, across-channel profiles, spaced 5 to 125 meters apart, with point soundings less than 1 meter apart. Two surveys (GA121306HIGH and GA121306LOW) were edited in ArcMap to remove soundings inconsistent with neighboring soundings and nautical chart data. NGDC created soundings along the axis of the Gulf Port shipping channel to insure its representation in the DEM.

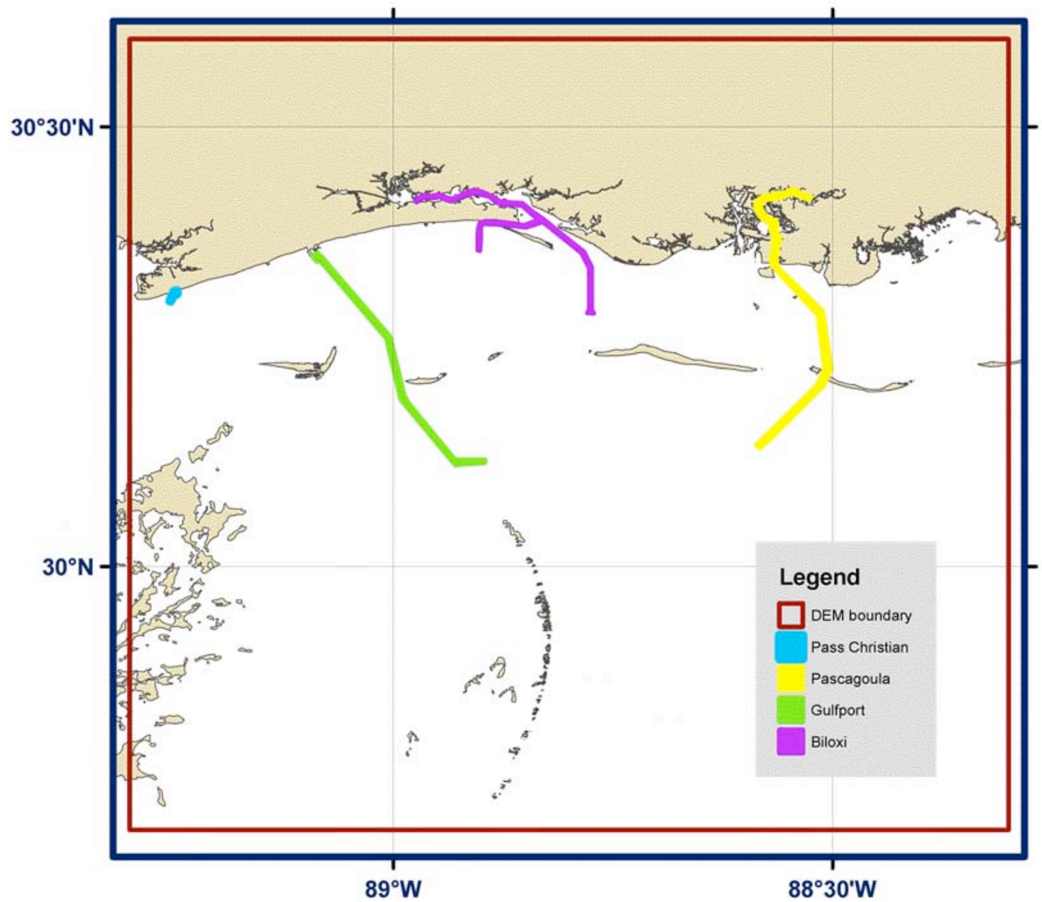

Figure 9. *Location of USACE survey data within dredged shipping channels in the Biloxi region.*

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

Region	*Original horizontal datum*	*Original vertical datum*	*Spatial Resolution*
Biloxi	NAD83 State Plane Mississippi East (feet)	MLLW	Profiles ~100 m long, spaced 125 m apart, with <1 m point spacing
Gulfport	NAD83 State Plane Mississippi East (feet)	MLLW	Profiles ~200 m long, spaced 150 m apart, with <1 m point spacing
Pascagoula	NAD83 State Plane Mississippi East (feet)	MLLW	Profiles ~125 to 250 m long, spaced 25 to 125 m apart, with <1 m point spacing
Pass Christian	NAD83 State Plane Mississippi East (feet)	MLLW	Profiles ~75 to 300 m long, spaced 5 to 25 m apart, with <1 m point spacing

3) Office of Coast Survey Electronic Nautical Chart extracted soundings

Two of the available ENCs for the Biloxi DEM were used to provide bathymetric sounding coverage in the Chandeleur Sound region where NOS surveys were either non existent or provided sparse data coverage (Fig. 10). ENCs #11363 and #11371 were downloaded from the OCS website (http://chartmaker.ncd.noaa.gov/MCD/enc/index.htm) in S-57 format and imported to a coverage using ArcCatalog. Elevations were converted from MLLW to MHW, and values greater than zero were deleted. The data were then clipped using ArcCatalog to remove points more than 2.5 minutes outside the DEM boundary. Figure 11 illustrates the unusual morphology of pitting on the seabed identified in ENC#11371.

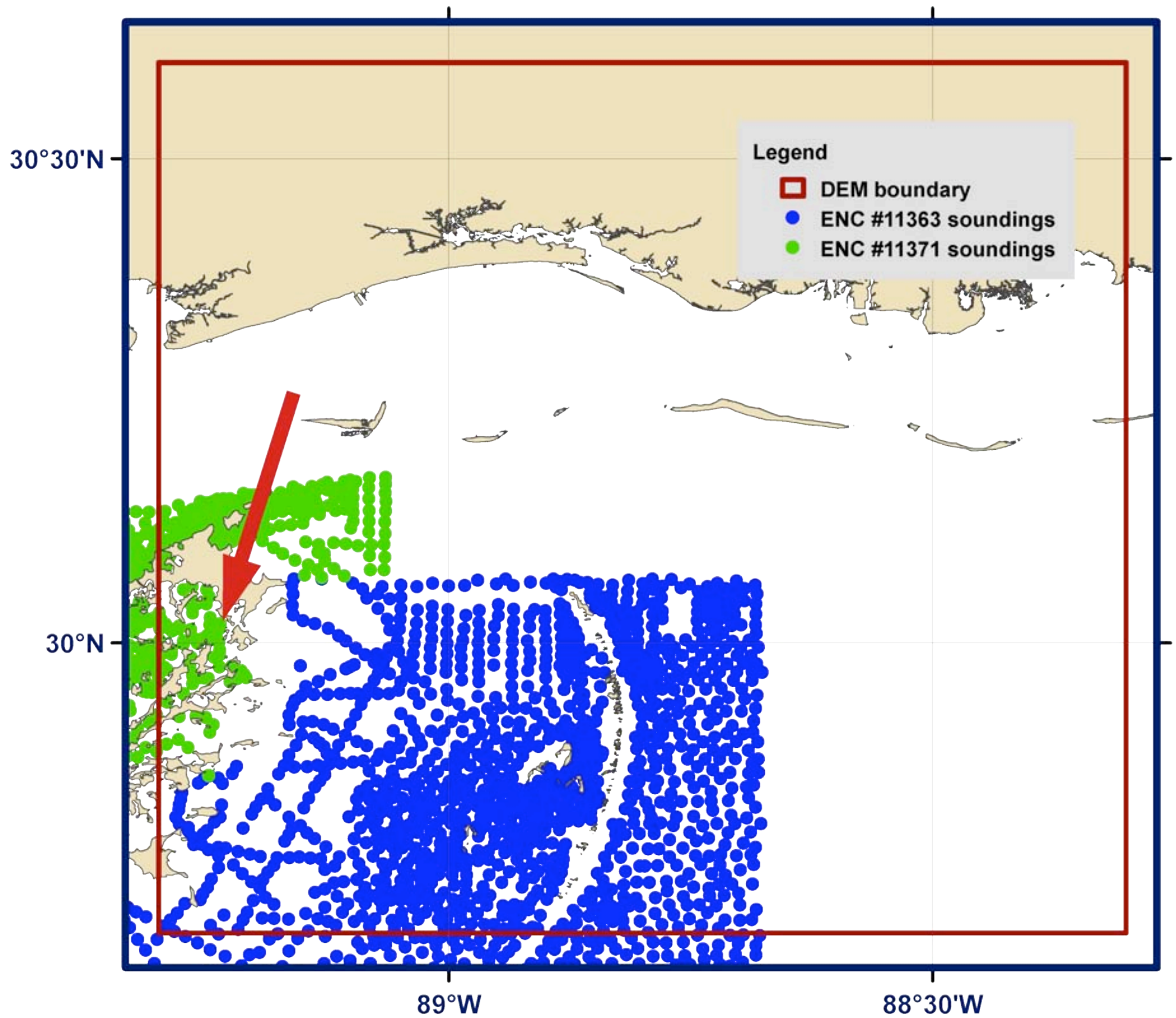

Figure 10. *Soundings taken from ENCs #11363 and #11371shown in green and blue, respectively. Biloxi DEM boundary shown in red, combined coastline shown in black. Arrow indicates Karako Bay shown in Figure 11.*

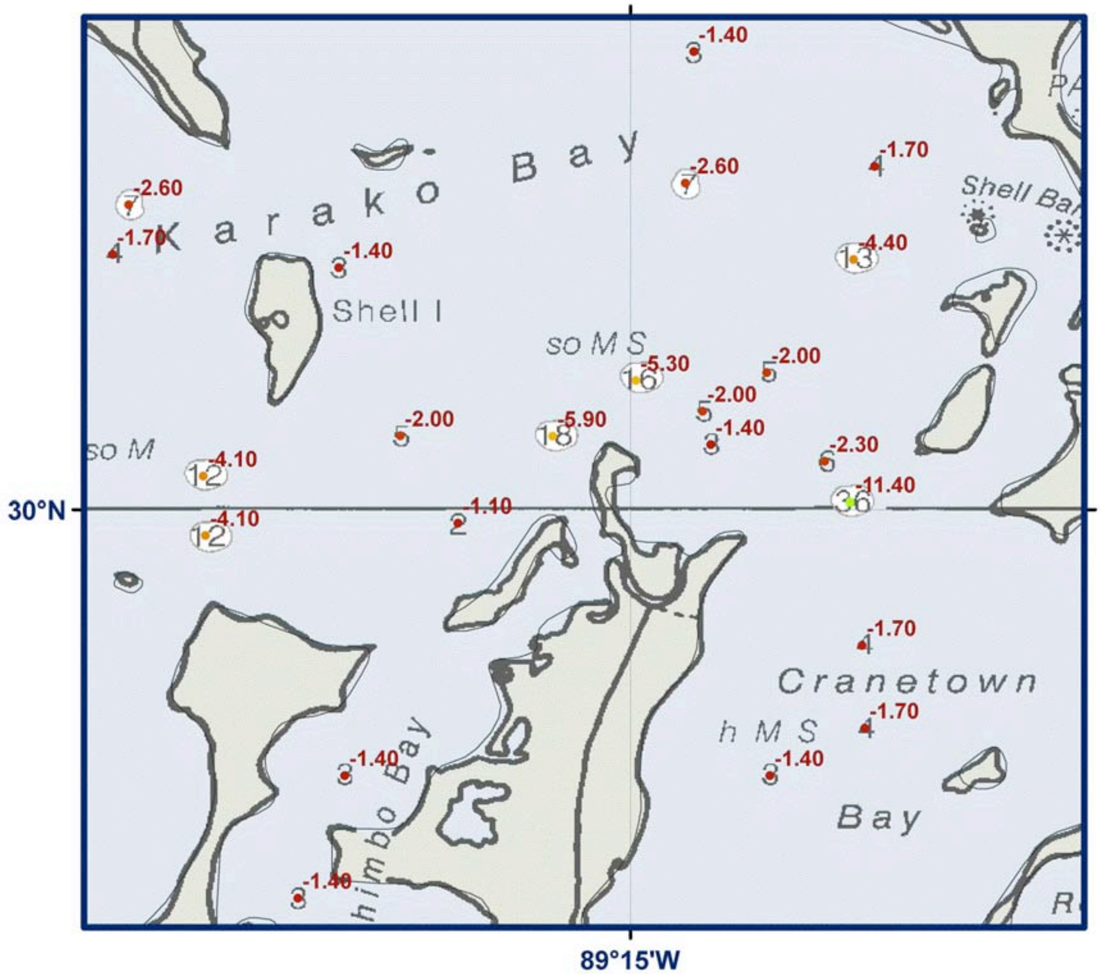

Figure 11. Small depressions on the sea bed of Karako Bay identified in ENC#1137. Numbers in red are elevation values transformed to MHW in meters.

3.1.3 Topography

Topographic datasets in the Biloxi region were obtained from the U.S. Geological Survey, Mississippi Automated Resource Information System (MARIS), and NOAA Coastal Services Center (CSC) (Fig.12). The U.S. Army Corps of Engineers provided NGDC with a coastal Mississippi DEM that was not processed to bare earth; it was not used in building the Biloxi DEM.

Table 7: Topographic datasets used in compiling the Biloxi DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
USGS/NED	1998 to 2000	DEM	1/3 arc second	NAD83	NAVD88 (meters)	http://seamless.usgs.gov/
USGS/SRTM	2004	DEM	~ 30 meters	WGS84	assumed Mean Sea Level	http://seamless.usgs.gov/
Mississippi Automated Resource Information System (MARIS)	1964 to 1996	county DEM	10 meters	NAD83	NGVD29 (feet)	http://www.maris.state.ms.us/Htm/DownloadData/DEM.html
CSC/Mississippi LiDAR for Harrison County	2004	coastal LiDAR	5 meters	NAD83	NAVD88 (meters)	http://www.csc.noaa.gov/lidar
CSC/Mississippi LiDAR post-Katrina merged flood	2005	bare earth coastal LiDAR	5 meters	NAD83	NAVD88 (meters)	http://www.csc.noaa.gov/lidar
CSC/Mississippi LiDAR for Jackson and Hancock Counties	2005	coastal LiDAR	5 meters	NAD83	NAVD88 (meters)	http://www.csc.noaa.gov/lidar

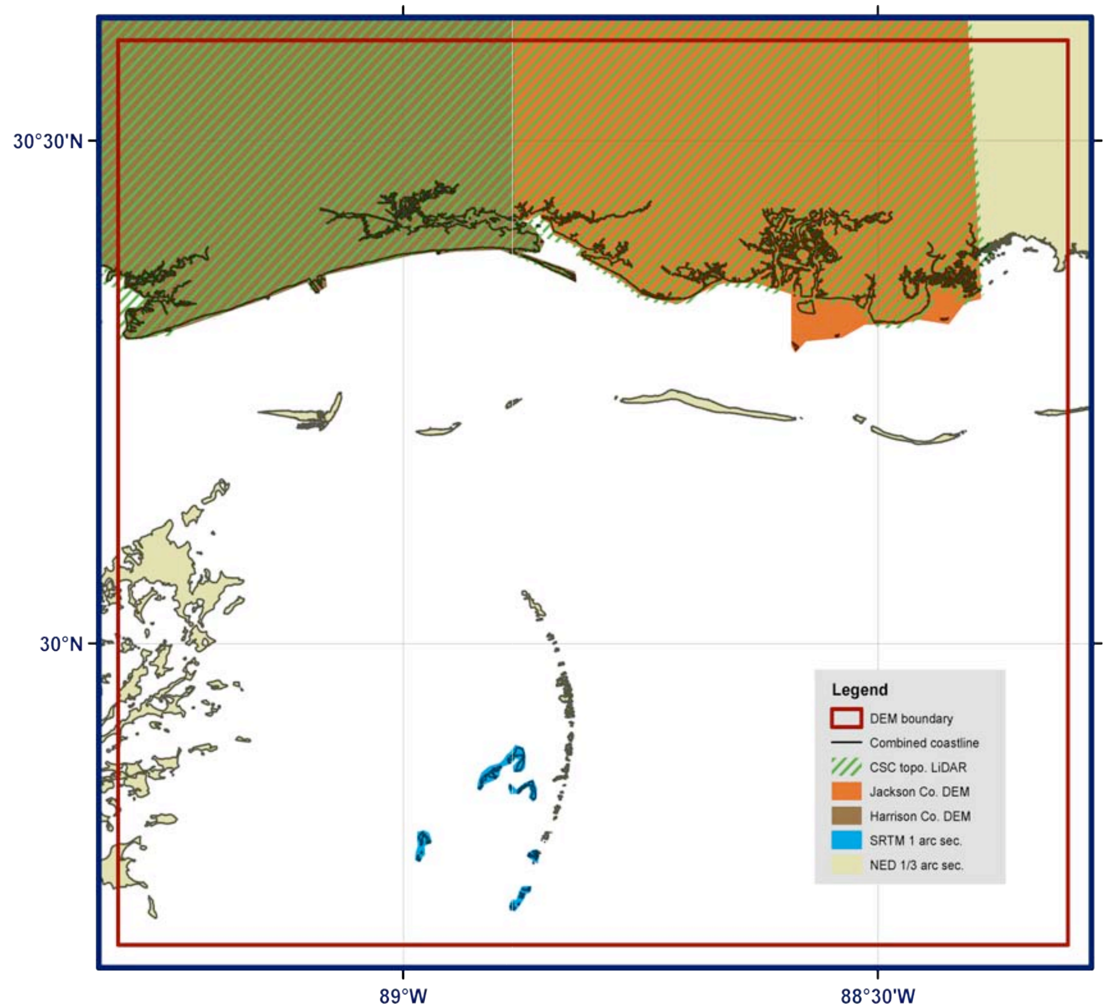

Figure 12. *Source and coverage of topographic datasets used in building the Biloxi DEM.*

1) 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 Biloxi region[3]. 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 1998 and 2000. The DEMs include zero values over the ocean, which were clipped to the combined coastline.

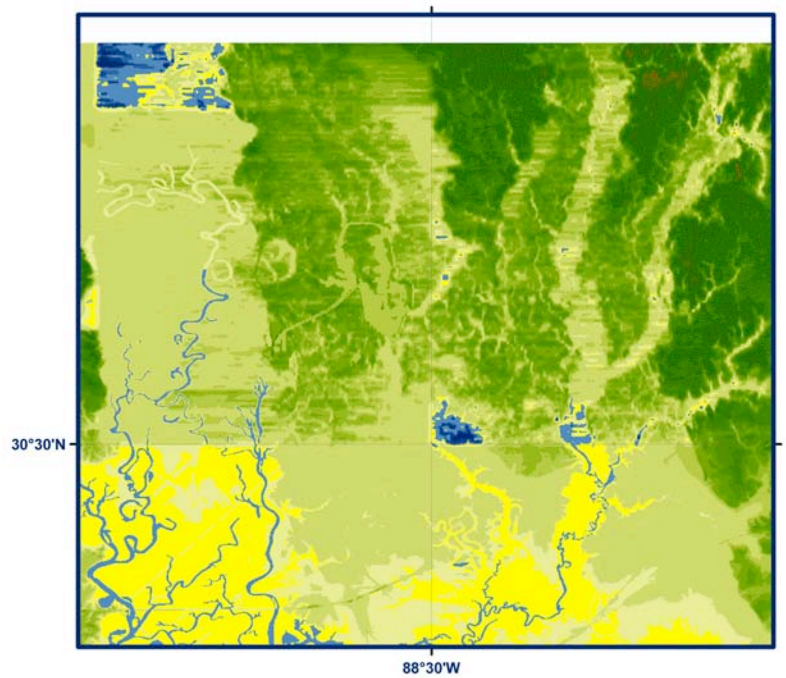

Figure 13. *NED topographic data for the northeastern section of the DEM showing lineations in data. The lineated section was clipped from the final DEM.*

The NED data for the northeastern section of the Biloxi DEM includes anomalous lineations that were clipped from the dataset using ArcCatalog. The NED data were used exclusively in the eastern section of the DEM located in Alabama and for the western Chandeleur Sound region as no LiDAR data were available in those regions.

3. 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]

2) Mississippi Automated Resource Information System DEMs

The MARIS data consist of two 10-meter resolution DEMs within Harrison and Jackson counties. These DEMs were generated from 1:24,000 USGS topographic maps and are available on the MARIS website (http://www.maris.state.ms.us/Htm/DownloadData/DEM.html).

NGDC clipped the MARIS DEMs to the combined coastline and converted the resulting DEM to points, using ArcCatalog tools. Elevation values in the area of the barrier islands were anomalous; they were removed using ArcMap (Fig. 14). The remaining data were included in the final DEM where NED data were eliminated and where LiDAR data were unavailable.

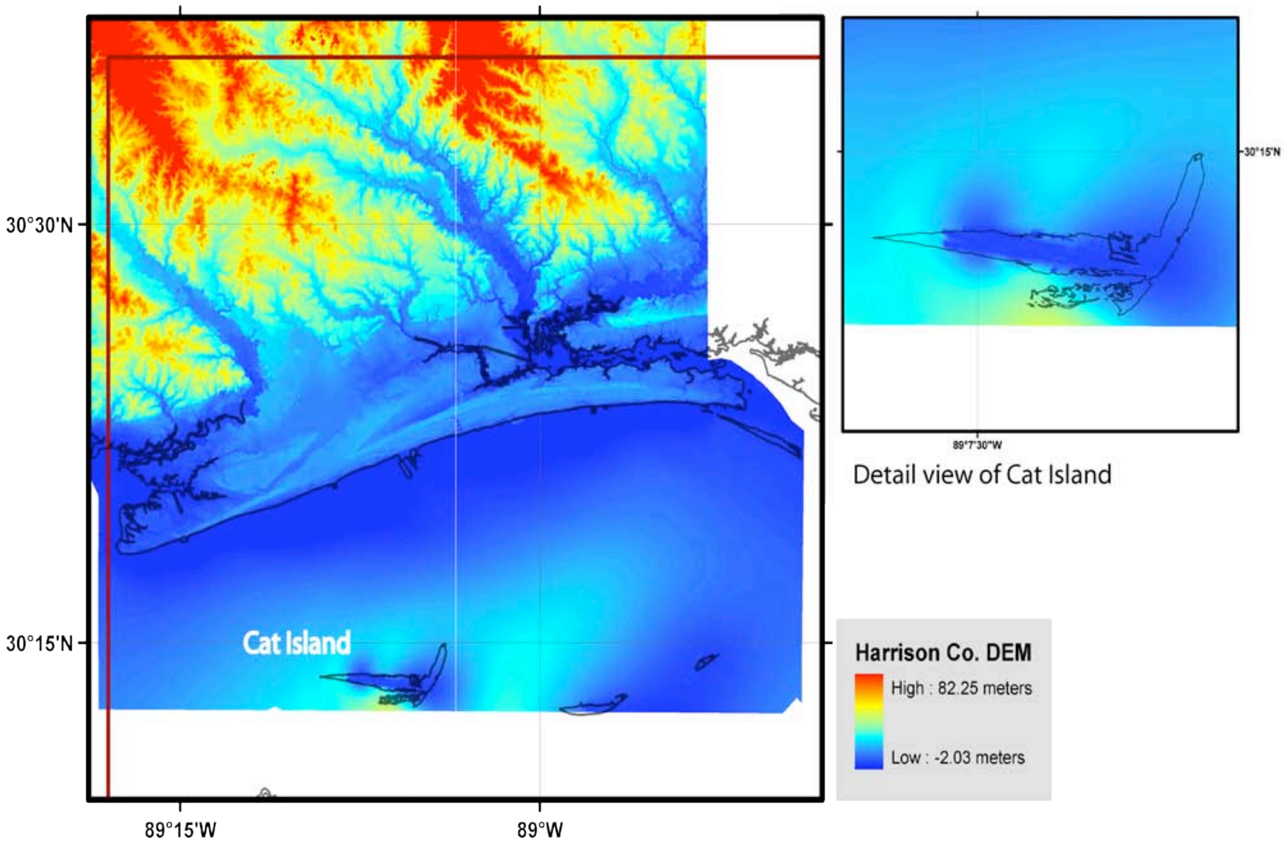

Figure 14. *Color image of the MARIS Harrison County DEM in the north eastern part of the Biloxi region. Note the detail view of Cat Island showing an example of the poor data quality around the barrier islands.*

3) CSC Coastal LiDAR

NOAA's Coastal Services Center provided coastal LiDAR datasets that were 95% processed to bare-earth for Harrison, and Jackson and Hancock counties, as well as a post-Katrina Merged Flood[4] dataset that covered all three counties. Anomalous elevations below zero, located on land, were eliminated by filtering the data using FME.

The post-Katrina Merged Flood dataset is processed to bare-earth; however Figures 16, 17, and 18 illustrate discrepancies between the LiDAR data and other topographic datasets that could not be rectified by NGDC.

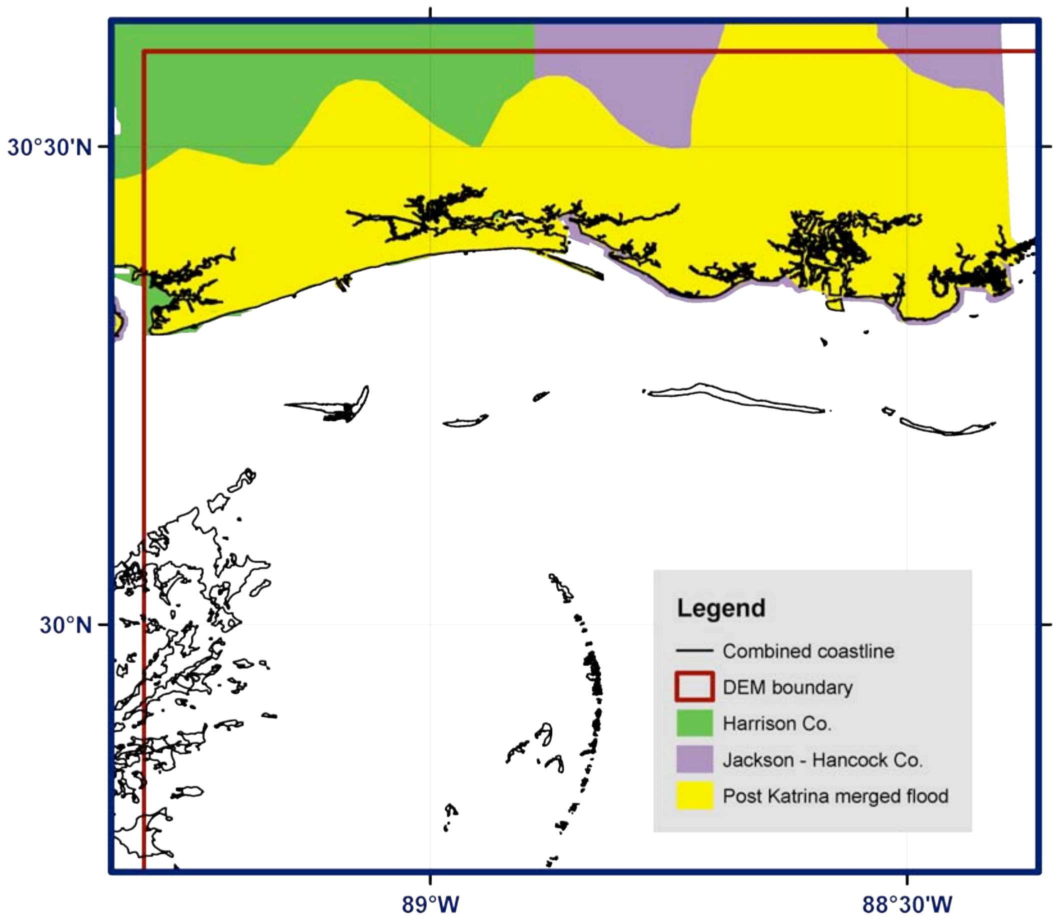

Figure 15. Spatial coverage of the CSC topographic LiDAR datasets for the Biloxi DEM.

4 Pre- and post-hurricane Katrina LiDAR datasets of Hancock, Harrison, and Jackson Counties, MS, were merged into a seamless coverage by URS. The pre-Katrina LiDAR data was collected by EarthData International at a 5-meter posting density during the period of February 25 to March 30, 2005. Woolpert and USACE collected the post-Katina LiDAR data. Woolpert acquired 1-meter posting density data of Coastal Mississippi between the dates of September 19 and October 9, 2005. USACE collected 1-meter posting density LiDAR of the Mississippi barrier islands over the same time period. Each dataset was clipped at the approximate location of the debris line. Data south of the debris line was removed from the Mississippi LiDAR dataset. Data north of the debris line was removed from the post-Katrina LiDAR dataset. The post-Katrina LiDAR dataset was then imported into the seamless Mississippi LiDAR dataset creating a merged seamless coverage. [Extracted form metadata.]

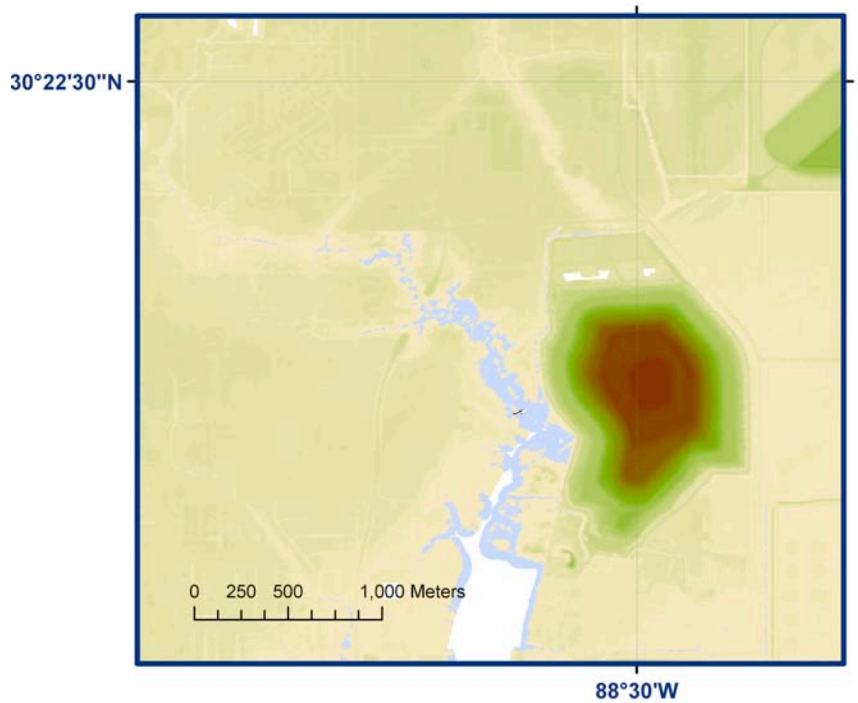

Figure 16. *CSC LiDAR merged post-Katrina dataset showing a ~40 meter "hill" at Bayou Casotte. It is an actual feature that was retained in the Biloxi DEM..*

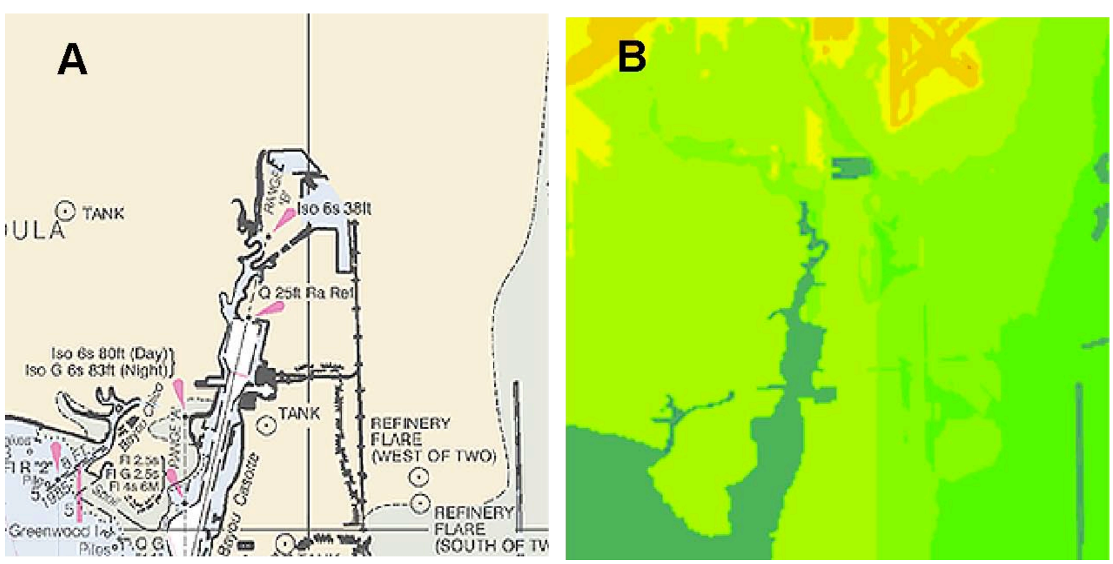

Figure 17. ***A.*** *Image of RNC #11373 at Bayou Casotte.*
B. *Image of NED data at Bayou Casotte, showing no expression of large hill in LiDAR data.*

Figure 18. *Chevron Refinery at Bayou Casotte. Image from USGS (http://coastal.er.usgs.gov/hurricanes/katrina/quickphotos/pascagoula/).*

3) NASA Shuttle Radar Topography Mission

The NASA Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth[5]. The SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. Data from this mission have been processed into 1 degree × 1 degree tiles that have been edited to define the coastline, and are available from the USGS *Seamless* web site (http://seamless.usgs.gov/) as raster DEMs. The data have not been processed to bare earth, but meet absolute horizontal and vertical accuracies of 20 and 16 meters, respectively.

The SRTM data were used for a small area in the southern most section of the Chandeleur Island chain (Fig 3). No other topographic data were available for this area.

5. The SRTM data sets result from a collaborative effort by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA – previously known as the National Imagery and Mapping Agency, or NIMA), as well as the participation of the German and Italian space agencies, to generate a near-global digital elevation model (DEM) of the Earth using radar interferometry. The SRTM instrument consisted of the Spaceborne Imaging Radar-C (SIR-C) hardware set modified with a Space Station-derived mast and additional antennae to form an interferometer with a 60 meter long baseline. A description of the SRTM mission can be found in Farr and Kobrick (2000). Synthetic aperture radars are side-looking instruments and acquire data along continuous swaths. The SRTM swaths extended from about 30 degrees off-nadir to about 58 degrees off-nadir from an altitude of 233 km, and thus were about 225 km wide. During the data flight the instrument was operated at all times the orbiter was over land and about 1000 individual swaths were acquired over the ten days of mapping operations. Length of the acquired swaths range from a few hundred to several thousand km. Each individual data acquisition is referred to as a "data take." SRTM was the primary (and pretty much only) payload on the STS-99 mission of the Space Shuttle Endeavour, which launched February 11, 2000 and flew for 11 days. Following several hours for instrument deployment, activation and checkout, systematic interferometric data were collected for 222.4 consecutive hours. The instrument operated almost flawlessly and imaged 99.96% of the targeted landmass at least one time, 94.59% at least twice and about 50% at least three or more times. The goal was to image each terrain segment at least twice from different angles (on ascending, or north-going, and descending orbit passes) to fill in areas shadowed from the radar beam by terrain. This 'targeted landmass' consisted of all land between 56 degrees south and 60 degrees north latitude, which comprises almost exactly 80% of Earth's total landmass. [Extracted from SRTM online documentation]

3.1.4 Topography–Bathymetry

Combined topographic–bathymetric surveys of coastal Mississippi 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. 19). 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[6]. The surveys generally extend from 200 to 2500 meters inland and up to 150 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. The dataset covers much of the barrier island chain with the exception of the islands to the west of Chandeleur Sound; it covers the mainland excluding Harrison County.

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

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

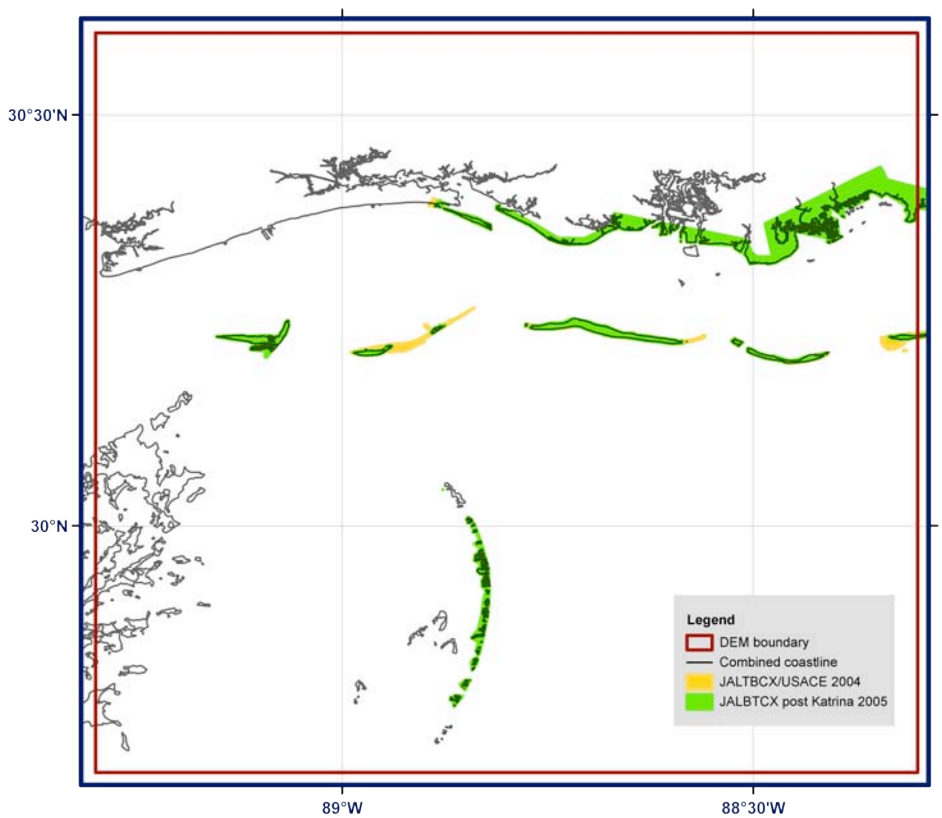

Figure 19. *Spatial coverage of topographic- bathymetric datasets utilized in Biloxi DEM development.*

6. 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 10 kHz and hydrographic data at 1 kHz. 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-Katrina 2005 JALBTCX LiDAR survey

This dataset consists of a bathymetric–topographic LiDAR survey covering 70 kilometers of the coastal region from the eastern DEM boundary at San Souci Beach, Alabama to Deer Island at Biloxi, Mississippi; the Gulf Islands National Seashore's barrier islands; and the central section of the Chandeleur Island chain. 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 covers the shoreline with an approximate width of 2,000 meters. Very little bathymetric information exists in the data, and the shoreline can not be easily extracted from this dataset due to the near shore noise.

2) 2004 JALBTCX LiDAR survey

This dataset consists of a bathymetric–topographic coastal LiDAR survey covering Ship Island, Horn Island, Petit Bois Island, Dauphin Island, and Deer Island. The survey has a spatial resolution of 5 meters and consists primarily of topographic data. NGDC used this dataset for the areas not covered by the post-Hurricane Katrina dataset.

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Biloxi DEM were originally referenced to a number of vertical datums including Mean Lower Low Water (MLLW), Mean Low Water (MLW), Mean Sea Level, National Geodetic Vertical Datum of 1929 (NGVD29), 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.

1) Bathymetric data

The NOS hydrographic surveys, the extracted ENC soundings, and the USACE surveys were transformed from MLLW or MLW to MHW, using FME software, by adding a constant offset determined by averaging two Biloxi NOAA tidal stations (Table 9; Fig. 26).

2) Topographic data

The USGS NED 1/3 arc-second DEM and the CSC LiDAR data were originally referenced to NAVD88. The SRTM data were assumed to be referenced to MSL. The DEMs provided by MARIS were referenced to NGVD29. 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 Biloxi region.*

Vertical datum	*Difference to MHW*
NAVD88	-0.380
NGVD29	-0.4175
MSL	-0.230
MLW	-0.470
MLLW	-0.502

* Datum relationships determined by averaging values from tide stations #8743735, Biloxi Bay and #8775557, Gulfport.

3.2.2 Horizontal datum transformations

Datasets used to compile the Biloxi DEM were originally referenced to State Plane Mississippi 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 such as the barrier islands area.
- Data values over the open ocean and rivers in the NED DEMs and LiDAR data. Each dataset required automated clipping to the combined coastline.
- 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 Biloxi 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 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 Biloxi 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, converted to a shape file, and then exported as a xyz file for use in the final gridding process.

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 Biloxi 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 NOS multibeam and coastal LiDAR survey data. Least weight was given to the pre-surfaced 1 arc-second NOS 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 Biloxi DEM.

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

Dataset	*Relative Gridding Weight*
JALBTCX coastal lidar bathymetry–topography: post-Katrina	1
JALBTCX coastal lidar topography: merged flood	1000
Maris DEMs	1000
SRTM	1000
ENC soundings	100
USGS NED topographic DEM	10000
NOS hydrographic surveys: bathymetric soundings	100
Pre-surfaced bathymetric grid	10

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Biloxi 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 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 southeast 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 Biloxi 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 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 (~1-2 meters in the southeast corner of the DEM). These 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 map from the Biloxi DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 20). 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 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 final version of the 1/3 arc-second Biloxi DEM.

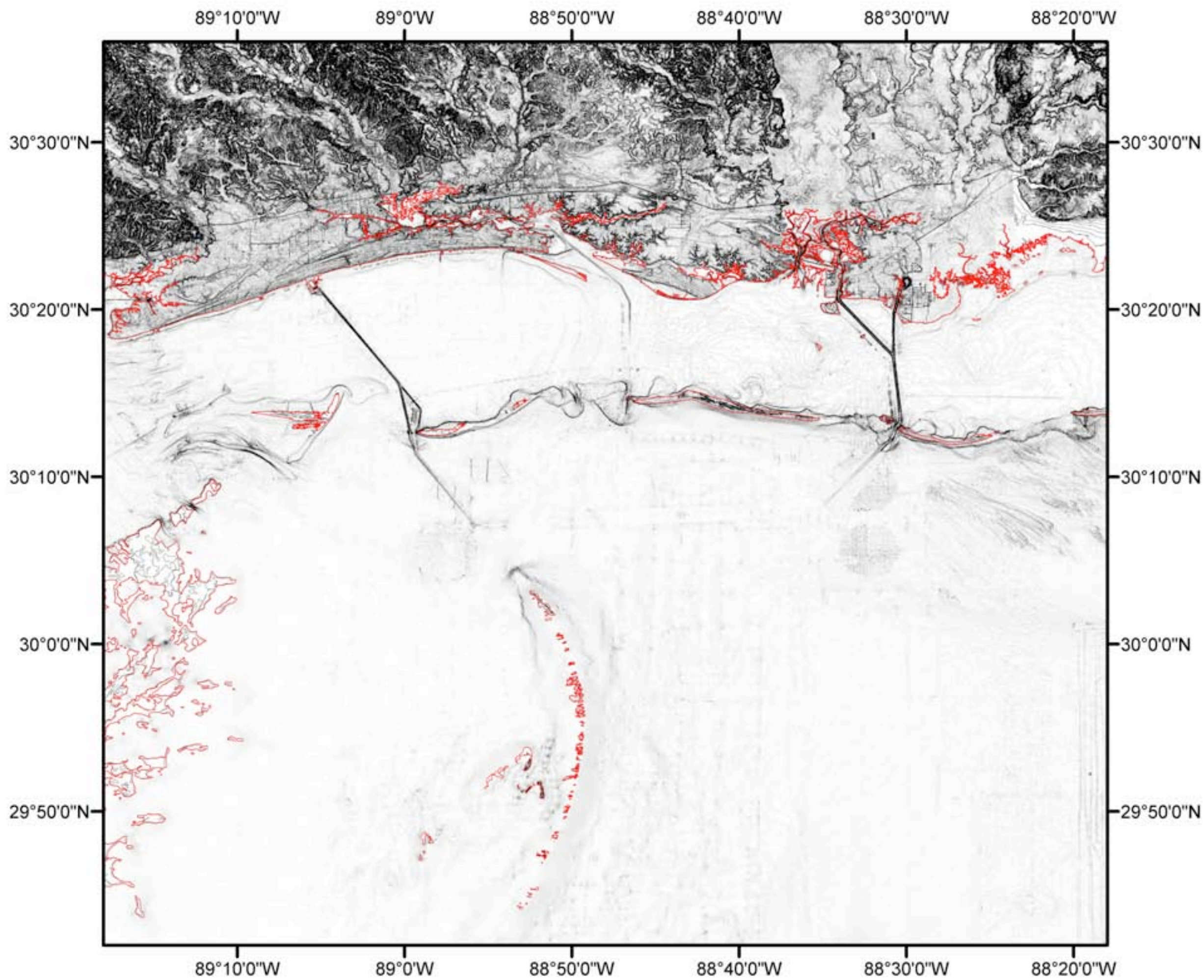

Figure 20. *Slope map of the Biloxi DEM. Flat-lying slopes are white. Dark shading denotes steep slopes; combined coastline in red.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Biloxi 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 Biloxi DEM is shown in Figure 21. A histogram of the difference between a NOS hydrographic survey file and the Biloxi DEM is shown in Figure 22.

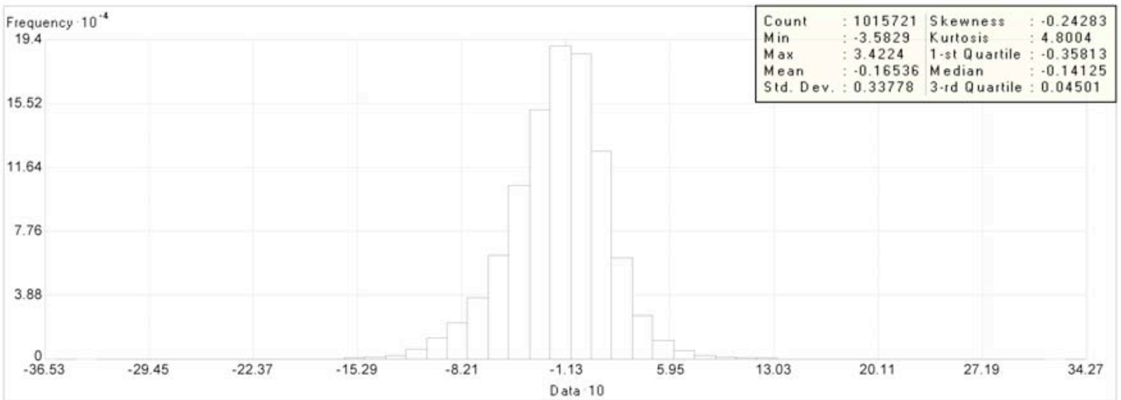

Figure 21. *Histogram of the difference between one post-Katrina JALBTCX coastal bathymetric–topographic LiDAR survey (438,007 points) and the Biloxi DEM.*

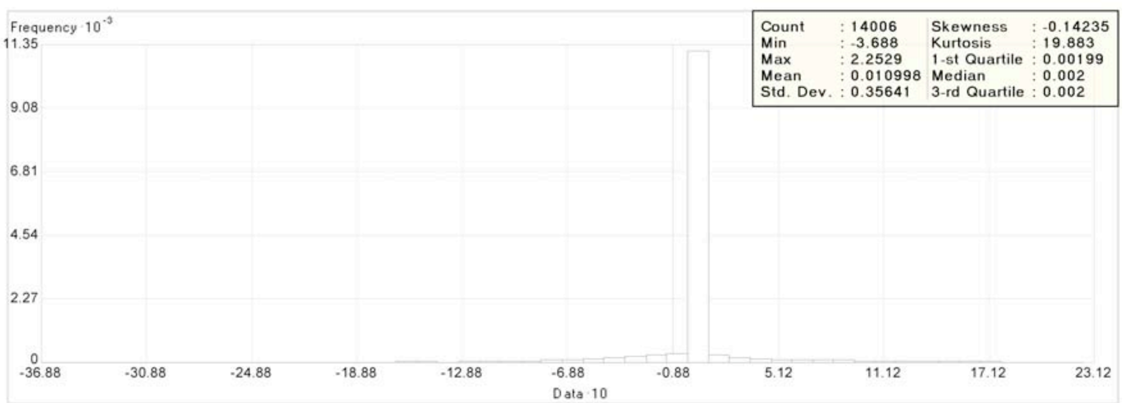

Figure 22. *Histogram of the difference between NOS hydrographic survey H010206 and the Biloxi DEM.*

3.4.5 Comparison with NGS geodetic monuments

The elevations of 63 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 Biloxi DEM (see Fig. 24 for monument locations). Differences between the Biloxi DEM and the NGS geodetic monument elevations range from -12.3 to 27.9 meters, with a negative value indicating that the monument elevation is less than the DEM (Fig. 23). 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.

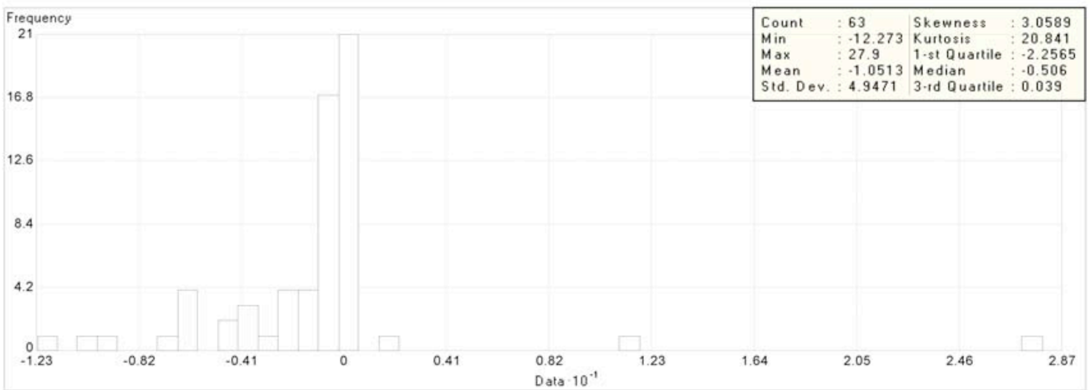

Figure 23. *Histogram of the differences between NGS geodetic monument elevations and the Biloxi DEM.*

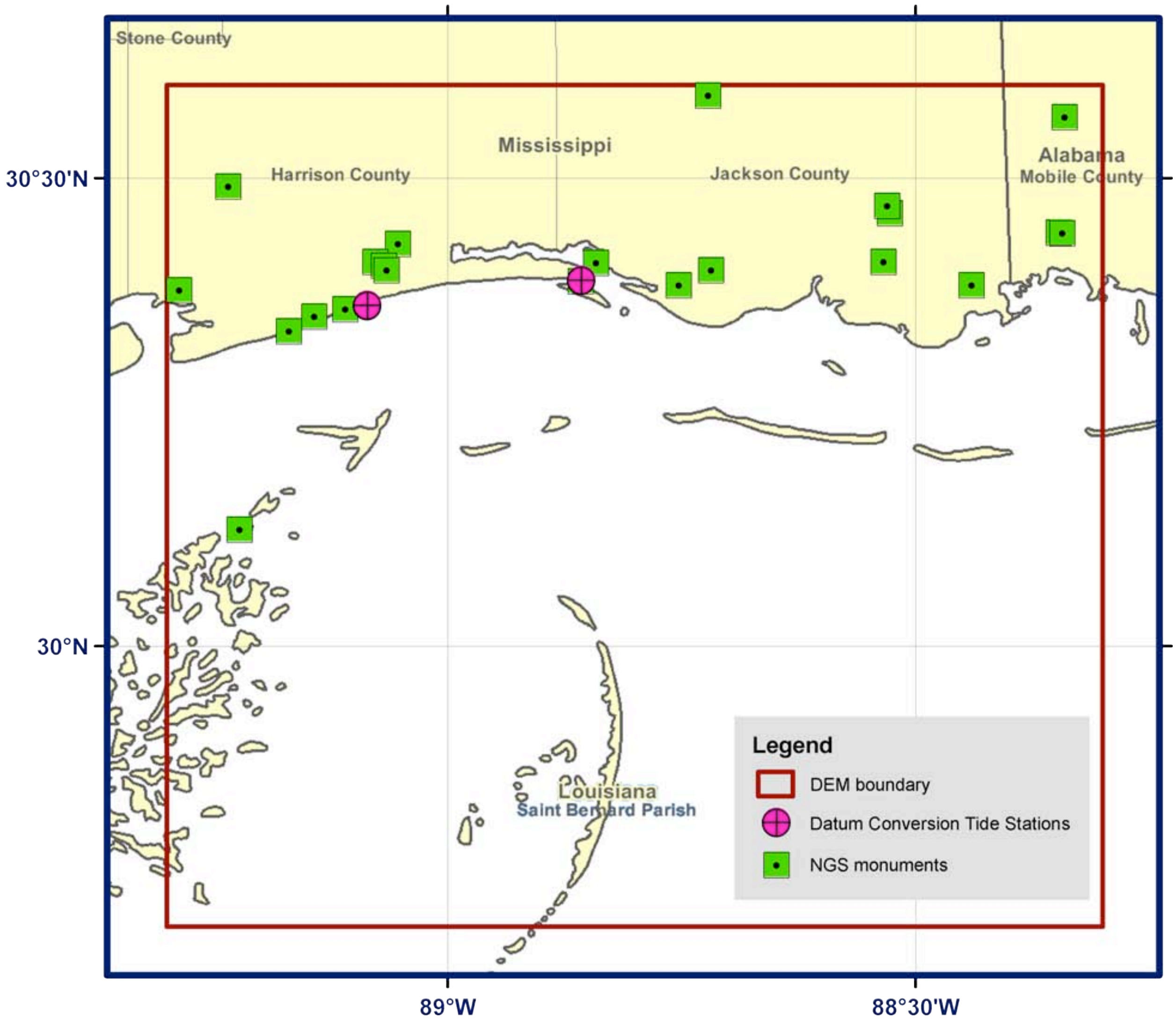

Figure 24. *Location of NGS monuments and NOAA tide stations in the Biloxi region. Tide stations used to convert between vertical datums; NGS monument elevations used to evaluate the DEM.*

4. Summary and Conclusions

A topographic–bathymetric digital elevation model of the Biloxi, Mississippi 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 and state 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 Biloxi 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 that have not yet been digitized.
- Resurvey coastal areas impacted by Hurricane Katrina.

5. Acknowledgments

The creation of the Biloxi DEM was funded by the NOAA, Pacific Marine Environmental Laboratory. The authors thank Chris Chamberlin and Vasily Titov (PMEL), Jeff Lillycrop (USACE), Matt Tate (USACE Irvington Site Office), and Cheryl Bosley (USACE Mobile District Office).

6. References

Nautical Chart #11360, 7th Edition, 2006. Cape St. George to Mississippi Passes. Scale 1:456,394. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11363, 40th Edition, 2005.Chandeleur and Breton Sounds. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11366, 7th Edition, 2007. Approaches to Mississippi River. Scale 1:250,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11371, 2nd Edition, 2006. Lake Borgne and Approaches Cat Island to Point Aux Herbes. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11372, 21st Edition, 2006. Dog Keys Pass to Waveland. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11373, 8th Edition, 2007.Mississippi Sound and Approaches Dauphin Island to Cat Island. Scale 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11374, 12th Edition, 2006. Dauphin Island Ala. To Horn Island Miss.. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #11375, 10th Edition, 2007. Pascagoua Harbor Mississippi. Scale 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

7. Data Processing Software

ArcGIS v. 9.2, 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/