NOAA Technical Memorandum NOS CS 19

VDATUM FOR EASTERN LOUISIANA AND MISSISSIPPI COASTAL WATERS: TIDAL DATUMS, MARINE GRIDS, AND SEA SURFACE TOPOGRAPHY

Silver Spring, Maryland
September 2010

noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Coast Survey Development Laboratory

Office of Coast Survey
National Ocean Service
National Oceanic and Atmospheric Administration
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ABSTRACT

A vertical datum transformation software tool, VDatum, is developed for an area covering the coastal waters of Mississippi and the eastern half of Louisiana. The area encompasses major embayments (Atchafalya, Terrebonne, and Barataria Bays, LA), the Mississippi River Delta, and sounds (Breton, Chandeleur, and Mississippi Sounds, MS). VDatum provides spatially-varying conversions between tidal, orthometric, and ellipsoid-based 3D reference frames.

The tidal datums fields were derived from tidal simulations using ADCIRC, a finite element hydrodynamic model which uses unstructured triangular grids. A grid consisting of 167,646 nodes and 306,749 cells was created for this project. The model was forced with nine tidal constituents (M_2, S_2, N_2, K_2, K_1, P_1, O_1, Q_1, and M_4) and integrated for 65 days. Various tidal datum fields, including mean lower low water (MLLW), mean low water (MLW), mean high water (MHW), and mean higher high water (MHHW), were derived using the water level time series from the final 55 days of the simulation. Model results were validated by comparing with observations at 70 water level stations maintained by the NOAA's Center for Operational Oceanographic Products and Services (CO-OPS). Discrepancies between model results and observational datums were attributed to model errors and interpolated over the whole model domain using TCARI (Tidal constituent And Residual Interpolation), a spatial interpolation tool based on solution of Laplace's equation. The error fields were applied to the direct model results to derive corrected tidal datums on the model grid. These final tidal datum fields were interpolated onto a regularly structured marine grid to be used by the VDatum software.

The Topography of Sea Surface (TSS), defined as the elevation of NAVD88 relative to local mean sea level (LMSL), was developed based on interpolation of bench mark data maintained by CO-OPS and the National Geodetic Survey (NGS). The NAVD88-to-LMSL values were derived either by fitting tidal model results to tidal bench marks leveled in NAVD88 or by calculating orthometric-to-tidal datum relationships at NOAA tidal gauges. Results by both methodologies were coupled to create the final TSS grids using spatial interpolation.

Operationally, this particular VDatum grid will have to be updated at least every 5-years in order to account for rapid elevation changes in tidal datums and NAVD88 due to land subsidence in the region. CO-OPS has formal Modified 5-Year Tidal Epoch procedures for updating tidal datums and NGS is developing a Vertical Time Dependent NAVD system for Louisiana.

Key Words: tides, tidal datums, Louisiana and Mississippi coast waters, ADCIRC, mean sea level, bathymetry, coastline, spatial interpolation, marine grid, North American Vertical Datum of 1998

1. INTRODUCTION

NOAA's NOS has developed software tool called VDatum to transform elevation data among approximately 30 vertical datums (Gill and Schultz, 2001; Hess et al., 2003; Milbert, 2002; Parker, 2002; Myers et al., 2005; Spargo, et al., 2006). Once VDatum has been established for a region, data sets referenced to different vertical datums can be integrated through transformations to a common vertical datum (Parker et al., 2003). VDatum allows all bathymetric and topographic data to be integrated in this manner through its inherent geoidal, ellipsoidal, and tidal datum relationships.

To be applicable over coastal waters, VDatum requires spatially varying fields of the tidal datums and the Topography of Sea Surface (TSS). The former involves datums such as MHHW, MHW, MLW, MLLW, Mean Tide Level (MTL), and Diurnal Tide Level (DTL) defined relative to local mean sea level (LMSL). The latter refers to the elevation of the North American Vertical Datum of 1988 (NAVD88) relative to LMSL.

The VDatum tool software is currently available for Tampa Bay (Hess, 2001), Long Island Sound and New York Bight and Harbor (Yang et al., 2008(2)), Delaware and Chesapeake Bays (Yang et al., 2008(1)), central California (Myers and Hess, 2006), southern California (Yang et al., unpublished manuscript), central/northern North Carolina (Hess et al., 2005), Lake Calcasieu and Charles River (Spargo and Woolard, 2005), Port Fourchon, Puget Sound (Hess and Gill, 2003; Hess and White, 2004), and the Strait of Juan de Fuca (Spargo et al., 2006(1)).

This report describes the development of VDatum for an area covering the coastal waters of the eastern half of Louisiana and of Mississippi (Figure 1). It encompasses all major embayments (Atchafalya, Terrebonne, and Barataria Bays, LA), sounds (Breton, Chandeleur, and Mississippi Sounds, MS), and lakes (Lake Maurepas and Pontchartrain) in the area, as well as the Mississippi River Delta waters. In Figure 1, black lines represent the MHW coastline and the green line denotes the 25-nm offshore demarcation. Tidal datums for VDatum are generally developed for water areas between the coastline and the 25-nm offshore limit.

Development of VDatum begins with tidal simulations using a hydrodynamic model. Various tidal datum fields (MHHW, MHW, MLW, and MLLW) were derived using the simulated water level time series. The tidal datums were verified by comparing with observational data, and error corrections were made based on these comparisons. Regularly structured VDatum marine grids were created and populated with corrected tidal datums. Finally, for the same marine grid, the NAVD88-to-LMSL field was derived by either fitting tidal model results to tidal bench marks leveled in NAVD88 or calculating orthometric-to-tidal datum relationships at NOAA tidal gauges.

This technical report is organized as follows: After an introduction in Section 1, Section 2 discusses data input needed to set up the hydrodynamic model run and the validation of the model results.Such data inputs include digital coastline, bathymetry, and tidal datums derived from observational data. Section 3 details tidal datum simulation procedures, including an introduction of the tidal hydrodynamic model, its setup, validation of results, and error corrections. Section 4 discusses creation of the regularly structured marine grid required for the VDatum software tool and its population with error-corrected model datums. In Section 5, creation of TSS for the area is described. Finally, a summary is given in Section 6.

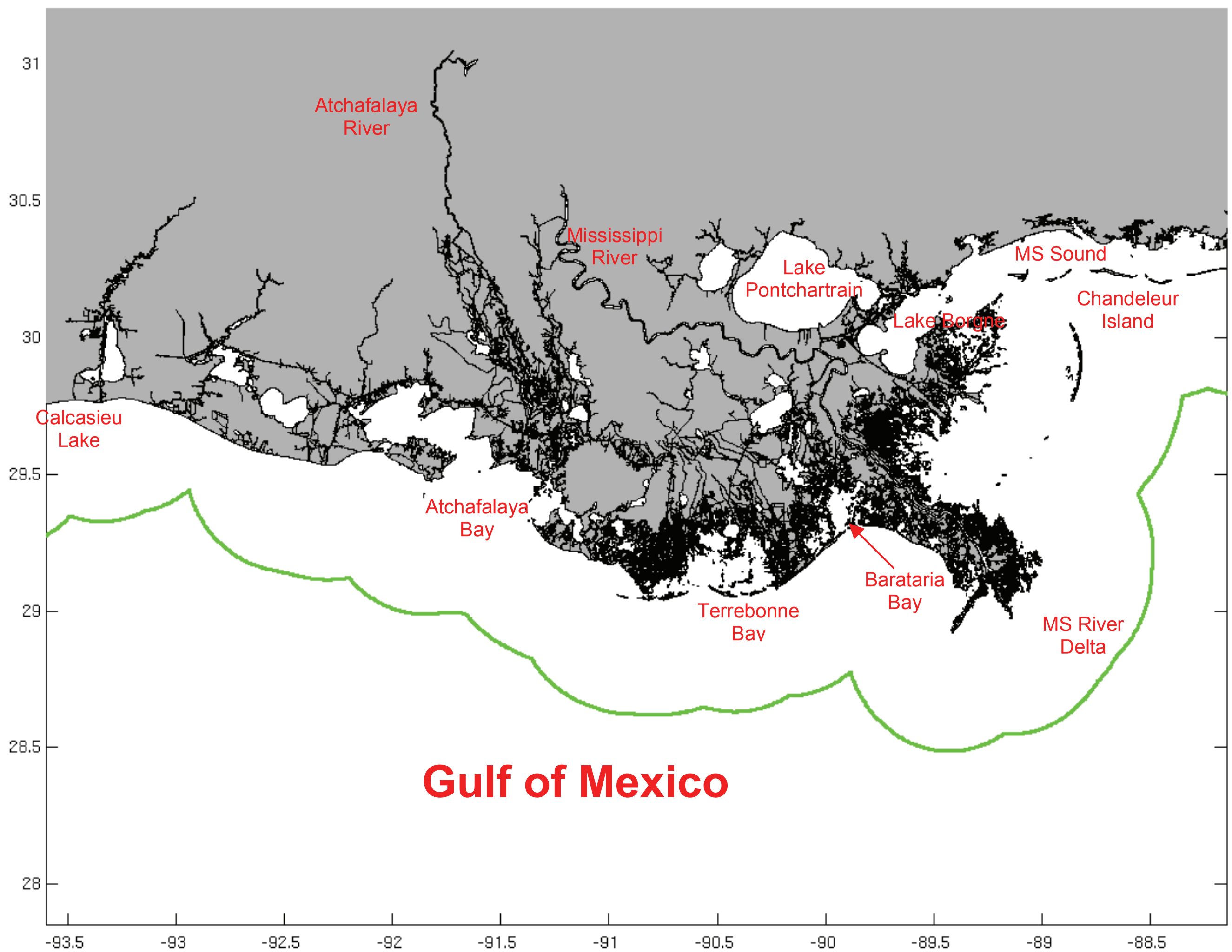


Figure 1. Map of the coastal areas of LA and MS. Red lines illustrate the MHW shoreline. The green line denotes a distance 25-nautical miles offshore.

2. COASTLINE, BATHYMETRIC, AND WATER LEVEL DATA

VDatum requires an accurate representation of spatially varying tidal datum fields (Milbert and Hess, 2001). To achieve this, VDatum applications are developed using a combination of observational data, hydrodynamic models, and spatial interpolation techniques (Spargo et al., 2006(2); Yang et al., 2006, Spargo and Woolard, 2005). For this VDatum application for Mississippi and eastern Louisiana, a tide model was first set up to compute spatially varying tidal datums. The modeled tidal datums were next compared with those derived from CO-OPS observational data. Finally, spatial interpolation techniques were used to create a correction field to be applied to the model results to derive a corrected field of tidal datums that are consistent with the observations.

For the tidal simulations, coastline data are required for delineating land-water boundaries so as to define hydrodynamic model domains. In addition, bathymetric data are needed to provide the model grid bathymetry. Numerical model results may not exactly match CO-OPS observations, and therefore observational data are needed to validate and correct the model results.

2.1. Digital Coastline

For VDatum the mean high water shoreline is used as the coastline to delineate the land-water boundaries (Parker, 2002). The shoreline data used in the present study were mainly based on the Electronic Navigational Chart (ENC) Shoreline from the NOS Office of Coast Survey (OCS). However, in certain areas the ENC shoreline appears to be incomplete/inaccurate in terms of the existence of dangling shoreline segments or confusing outlines of artificial constructs with true shorelines. The erroneous MHW depictions were corrected using computer-aided techniques to match the MHW coastlines illustrated on raster nautical charts (RNCs). This was implemented via a commercial software package called Surface-Water Modeling System (SMS). Using SMS, geo-referenced RNCs and the ENC shoreline data were overlaid and contrasted visually. Wherever the two do not match, the latter was judged to be inaccurate and replaced by the corresponding chart coastline. In Figure 1, the red line illustrates the final corrected coastline.

2.2. Bathymetric Data

Bathymetric data used in this study were from two sources: NOS soundings and the NOAA Electronic Navigational Charts (ENCs) bathymetry. The former were from the NOS/OCS hydrographic database maintained at the National Geophysical Data Center (NGDC), and the latter were based on the NOAA ENCs. Figures 2 and 3 illustrate the spatial coverage of the soundings and ENC data, respectively.

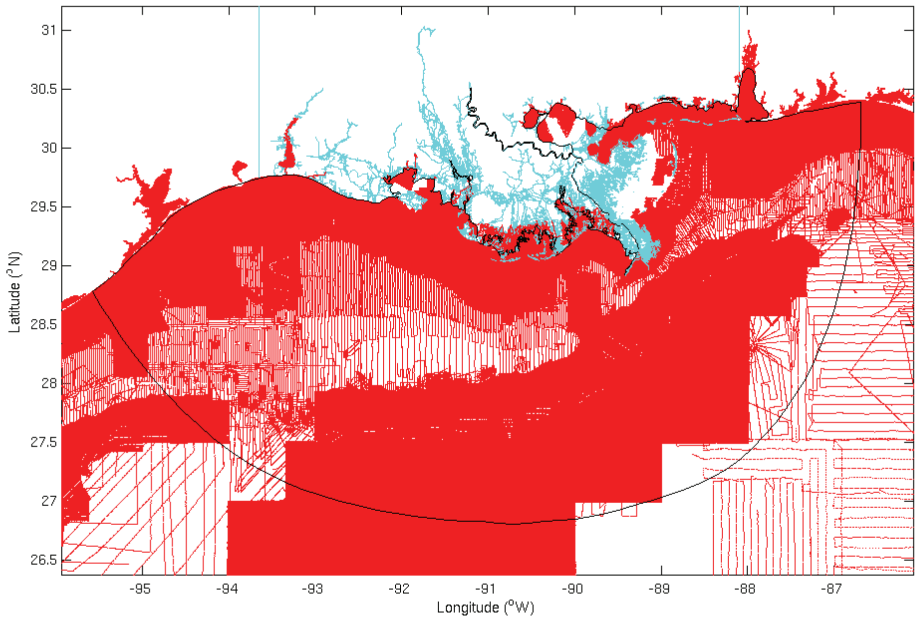


Figure 2. Locations of NOS sounding survey data.

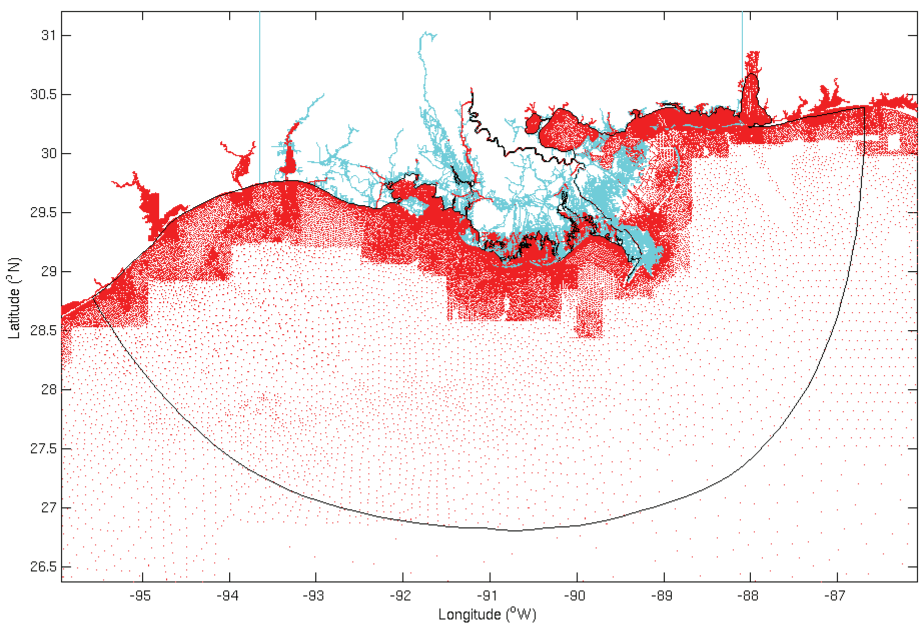


Figure 3. Locations of ENC bathymetric data

The NOS sounding data include surveys conducted between 1885 and 2000. In the areas where data from multiple years were available, those from more recent years were used. The datums were referenced to either MLW or MLLW, depending on the years of data collection. The ENC data were referenced to MLLW. The horizontal and vertical accuracy standards for NOAA surveys are listed in Table A.1 of Appendix A .

The NOS soundings possess a higher spatial distribution density than the ENC data. However, neither of them provides complete coverage for the whole study area. Hence, they were blended for a better regional coverage.

2.3. Tidal Datum Elevations

Tidal datums from CO-OPS water level stations were used for validating model results. These observational data are available online (Hess and Spargo, 2005) and correspond to the 1983-2001 National Tidal Datum Epoch (NTDE). Many of the tide stations in Louisiana are now part of a Modified 5-year Tidal Epoch process in which tidal datums are frequently updated using the most recent 5-years of monthly mean sea level (still using a Diurnal Range based on the 1983-2002 NTDE). These stations are asterisked in the Appendix B.

Many stations are located within either embayments or near obstructions not mapped by the present model grid (Section 3.2), or at upper-reaches of riverine areas where datums exhibit strong seasonal variability. These observations were determined to be unsuitable for validating model results and were therefore discarded. Data from 70 stations were selected for use in the model validations. This area is subject to rapid rates of land subsidence, and listings of stations will frequently change as new tidal and geodetic observations are made. Tables B.1 and B.2 in Appendix B list the station and tidal datum information used for this particular model.

3. TIDAL DATUM SIMULATION

3.1. Hydrodynamic Model

The ADvanced CIRCulation (ADCIRC) model (Westerink, et al., 1993) was used to simulate water level time histories. The ADCIRC model is an unstructured grid hydrodynamic circulation model. It solves the shallow water equations and has been used in modeling tides in various ocean, coastal and estuarine environments (Luettich et al., 1999; Mukai et al., 2002). The ADCIRC model provides a variety of options for users to specify input parameters and execution modes. For instance, the model may be run in either 2- or 3-dimensonal modes, serial or parallel execution, linear or quadratic bottom friction formulation with constant or variable friction coefficients, etc. More details on the model setup such as model grid generation, bathymetry definitions, and parameter specifications are addressed in following sections.

3.2. Model Grid

The model domain for this VDatum application is shown in Figure 4. A high-resolution, unstructured grid of 167,646 nodes and 306,562 triangular elements was created to map the domain up to the MHW shoreline. The spacing between grid nodes ranges from around 17 m to 5.5 km. In general, finer elements were created for nearshore areas compared to those in deep waters, so as to accurately resolve fine coastline features and the bathymetric-dependent variability of the tidal wavelengths.

Figures 5(a) and (c) show close-up views of three sections (from west to east) of the model grid. They correspond to the water areas of the mid- to eastern Louisiana coast (Figure 5(a)), Mississippi River Delta (Figure 5(b), and Mississippi coast (Figure 5(c)).

Note that the present model domain goes far beyond the area in which the present VDatum development is concerned. This is for the sake of ensuring model computational stability and pursuing accurate tidal simulations. In areas far away from the shoreline, tidal currents are relatively weak and tidal fields exhibit rather gradual variability. The former helps maintain model computational stability, while the latter helps choose accurate tidal harmonic constants used as the model forcing on its open boundary.

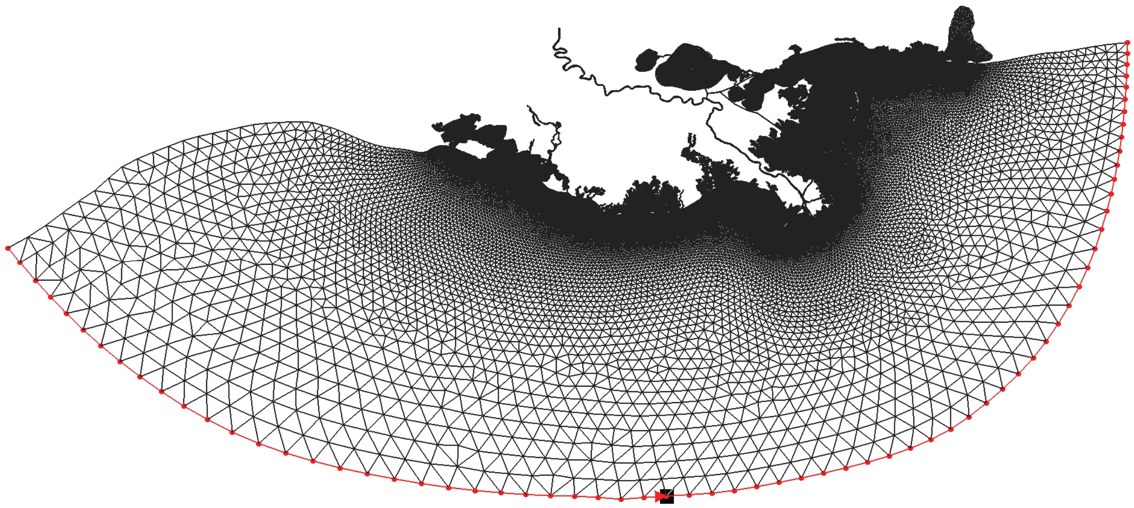


Figure 4. Finite element grid for the entire model domain. Red dots denote the model open ocean boundary nodes.

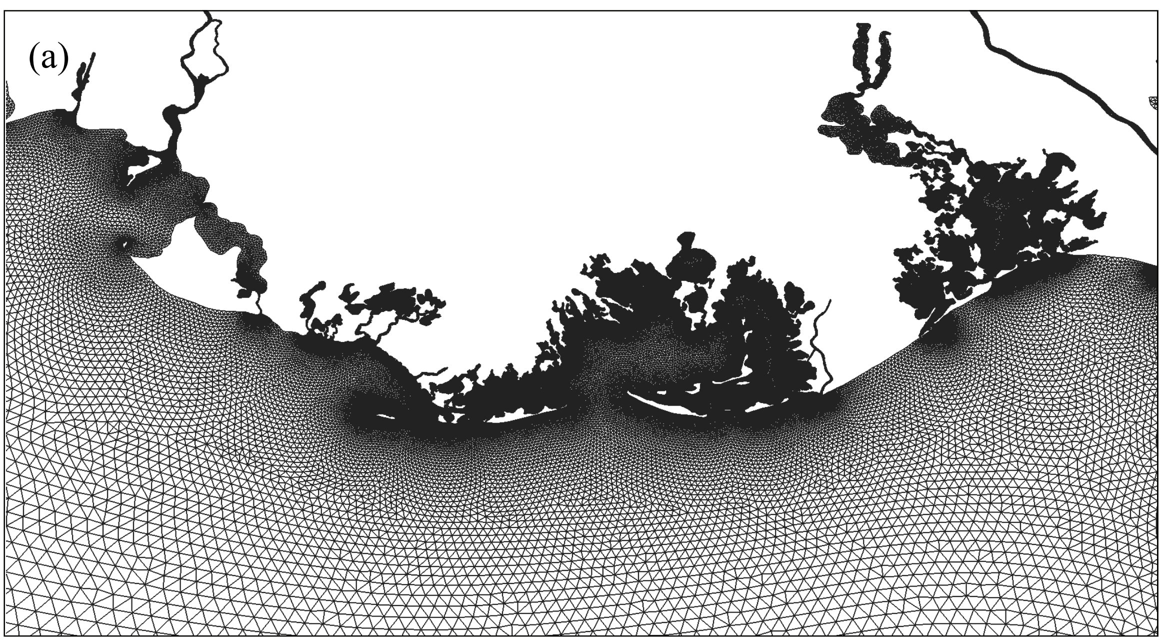
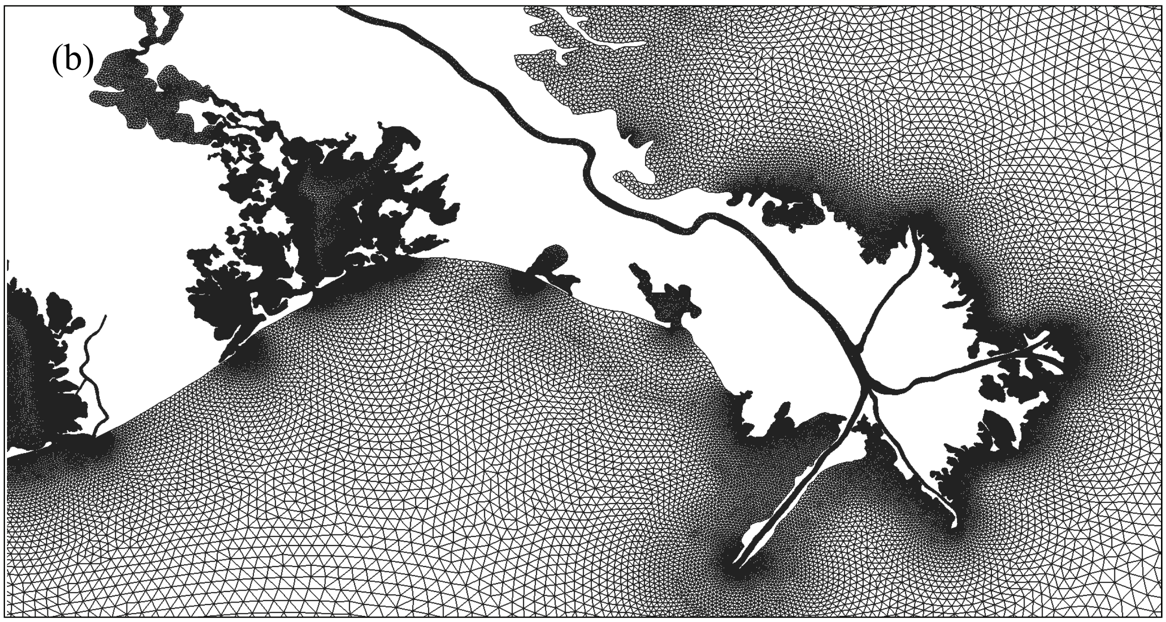


Figure 5. Close-up views of the model grid, (a) mid- to eastern Louisiana coast, (b) Mississippi River Delta, and (c) Mississippi coast.



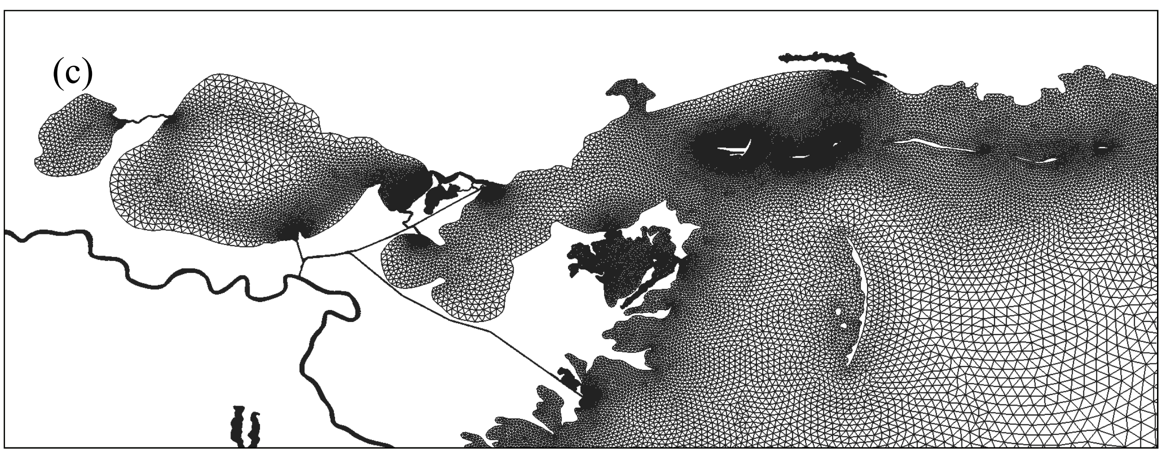


Figure 5. (Continued)

3.3. Bathymetry of Model Grid

The bathymetry datasets described in Section 2.2 were used to specify the model grid bathymetry. Note that NOS soundings and ENC data were of different spatial resolution and coverage. As for the soundings alone, bathymetry may be referenced to either MLW or MLLW. Hence, they were categorized into two groups and applied to the grid separately. In short, the bathymetry data were classified into three groups: (1) MLLW NOS soundings (2) MLW NOS soundings, and (3) MLLW ENC data. The three groups were interpolated onto the model grid separately, resulting in three meshes corresponding to the three bathymetric datasets.

The algorithm used for interpolating bathymetry onto the three meshes was the same. Bathymetry at each model node represents an average of data points within the node's surrounding elements. Since element size changes throughout the model domain, the searching range for bathymetric data points varies from node to node. As the element size is smaller in coastal waters, bathymetry for nodes near the coastline were from more locally distributed data points compared to those in deep waters.

As none of the three data sets provided complete coverage of the model domain, each of the three meshes left numerous unpopulated nodes. Hence, the three meshes were combined to obtain a more complete coverage. At nodes where bathymetric data were available in more than one mesh, an arithmetic average was taken; otherwise, the value from the solely available mesh was taken. After merging the three meshes, there still remained some nodes without valid bathymetry. These nodes were populated by averaging bathymetry from adjacent nodes.

It is worthwhile to note that the bathymetry of the three meshes had two different reference datums: MLW and MLLW. Setup of the tidal model requires the grid bathymetry to be referenced to the model zero (MZ), a geopotential surface. It is therefore necessary to adjust the reference datum from MLLW/MLW to MZ prior to any data blending. However, the *(MZ – MLLW/MLW)* values are unknown prior to the model runs. The adjustment was accomplished by iteratively updating the $\Delta_{MLLW} = (MZ\text{-}MLLW)$ and $\Delta_{MLW} = (MZ\text{-}MLW)$ fields based on model results from a series of simulations: initial constant values of $\Delta_{MLLW} = 0.3\ m$ and $\Delta_{MLW} = 0.2\ m$ were assumed for the whole grid. Following each model run, new sets of tidal datum fields were derived and were used to update the Δ_{MLLW} and Δ_{MLW} fields. Multiple runs were conducted until invariant Δ_{MLLW} and Δ_{MLW} values were achieved. Multiple iterations were made to meet a convergence criteria of both $|\Delta_{MLLW}|$ and $|\Delta_{MLW}|$ less than 5×10^{-3} m. Figure 6 shows the bathymetry used in the final model run.

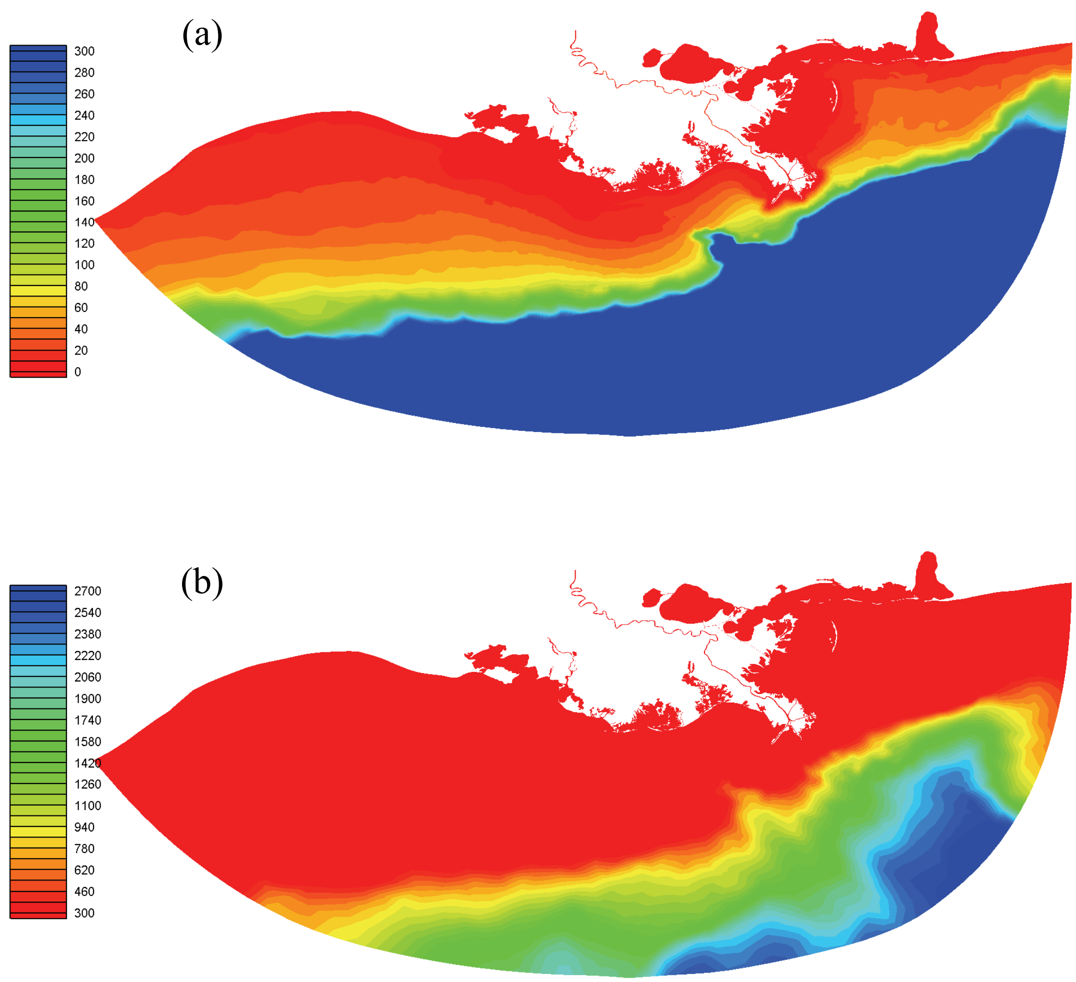


Figure 6. Model grid bathymetry relative to MZ. Color bars are meters. (a) bathymetry between [0, 300] m; those beyond 300 m are shown with the same color as the 300-m bathymetry; (b) bathymetry between [300, 2700] m; values less than 300 m are shown in the same color as the 300-m bathymetry.

3.4. Model Parameters Setup

In the present study, model parameters were set up to solve the shallow water equations in Two-Dimensional Depth-Integrated (2DDI) mode with finite amplitude and convection terms and the wetting and drying option activated. Lateral viscosity was set as a constant, 5.0 m s^{-2}, throughout the model domain. A quadratic friction scheme with a spatially-varying coefficient (C_f) was specified to calculate bottom friction. Multiple runs were conducted to test various C_f values in an attempt to mitigate model-data discrepancy in terms of tidal datums. Figure 7 shows the C_f values derived for the final tidal simulations.

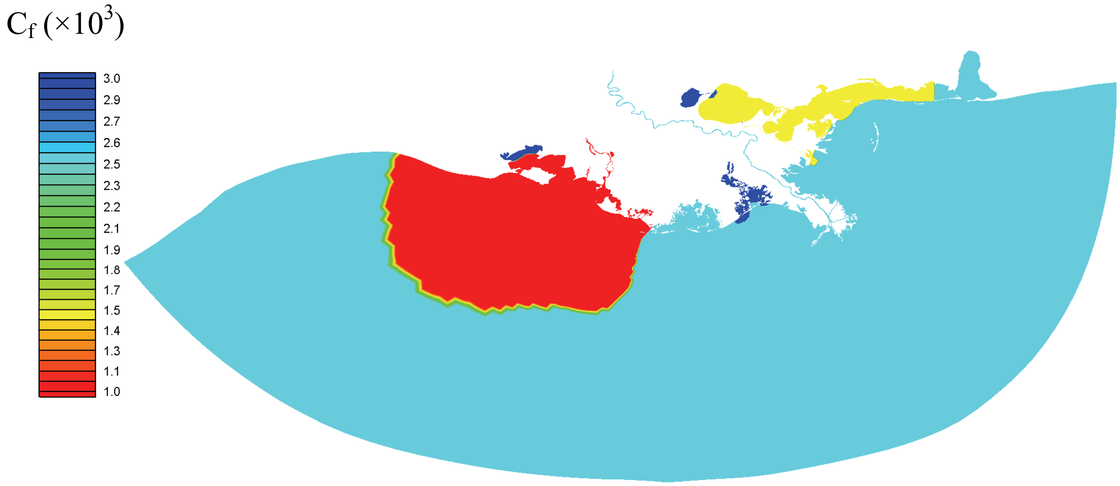


Figure 7. Spatially-varied bottom friction coefficient (C_f).

Nine astronomical tidal constituents (M_2, S_2, N_2, K_2, K_1, P_1, O_1, Q_1, and M_4) were input as tidal forcings along the model's open boundary. Corresponding harmonic constants were interpolated based on a tidal database derived from the West North Atlantic Ocean Tidal Model (Myers, unpublished manuscript). A time step equal to 3 seconds was used to ensure computational stability. The simulation covered a period of over 65 days. First, the model was ramped up for 5 days with a hyperbolic tangent function. It was then integrated for another 5 days to allow for the tidal field to reach an equilibrium state. Afterwards, 6-minute interval water level time series were recorded for 55 days to derive the tidal datums. It is noted that water level records of various lengths were tested to gain insight into the sensitivity of record lengths to the stability of the resultant tidal datum values. The test proved that a 55-day period is an appropriate choice to obtain statistically stable results.

The present setup did not apply the Mississippi River inflow at the River's upstream end. However, it is noted that some pre-final model testing runs were conducted with monthly mean river inflows. The results did indicate significant improvement on the tidal datum results compared with the case without the river forcing.

The parallel version of ADCIRC model was adopted and the model run was conducted on 50-processors on the JET computer at NOAA's Earth System Research Laboratory. It took approximately 7.5 hours to complete the 65-day simulation.

3.5. Tidal Datum Computation and Results

From the modeled water time series, tidal datums including MSL, MHHW, MHW, MLW, and MLLW at each model node were derived by selecting the tides over a 19-year time period on a predicted tide curve derived from the modeled-output harmonic constants, averaging them over the period and then referencing each to the modeled MSL. Henceforth, references to each of the tidal datums shall imply this adjusted value relative to MSL. Note that MTL is defined as the algebraic average of MHW and MLW, and DTL is the algebraic average of MHHW and MLLW. The two fields were not computed until error-corrected MHHW, MHW, MLW, and MLLW fields were obtained (Section 4.2).

Figures 8(a)-(d) display the model derived tidal datum fields for MHHW, MHW, MLW, and MLLW, respectively. As expected, the four fields exhibit a similar spatial pattern. In general the LA coast demonstrates a higher tidal range (around 0.6 m) than that around the Mississippi River Delta (about 0.3 m) or Mississippi Sound (about 0.4 m). The tidal range in Lake Pontchartrain appears to be ~0.12 m.

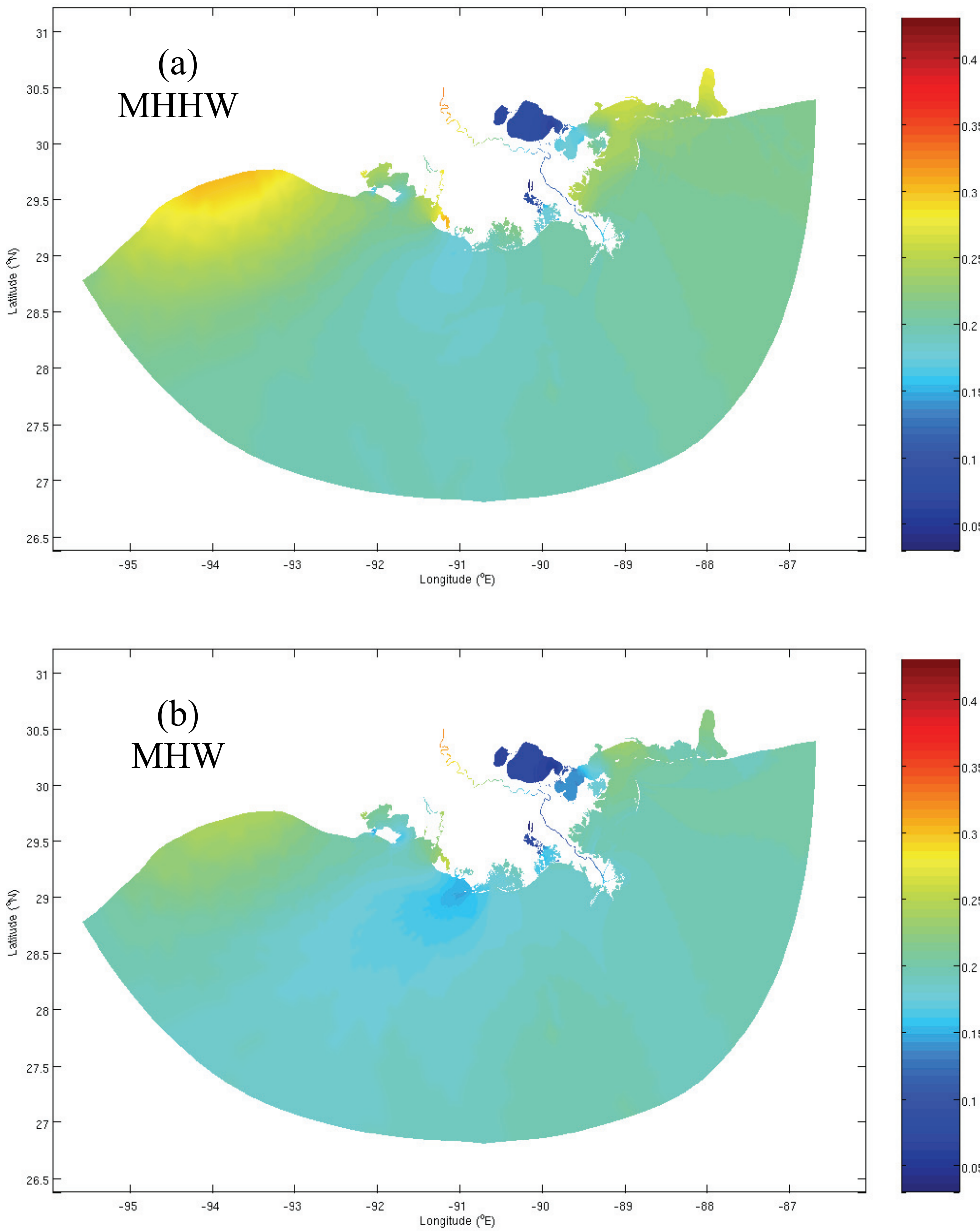


Figure 8. Model-derived tidal datum fields, (a) MHHW, (b) MHW, (c) MLW, and (d) MLLW. Color bars are in meters.

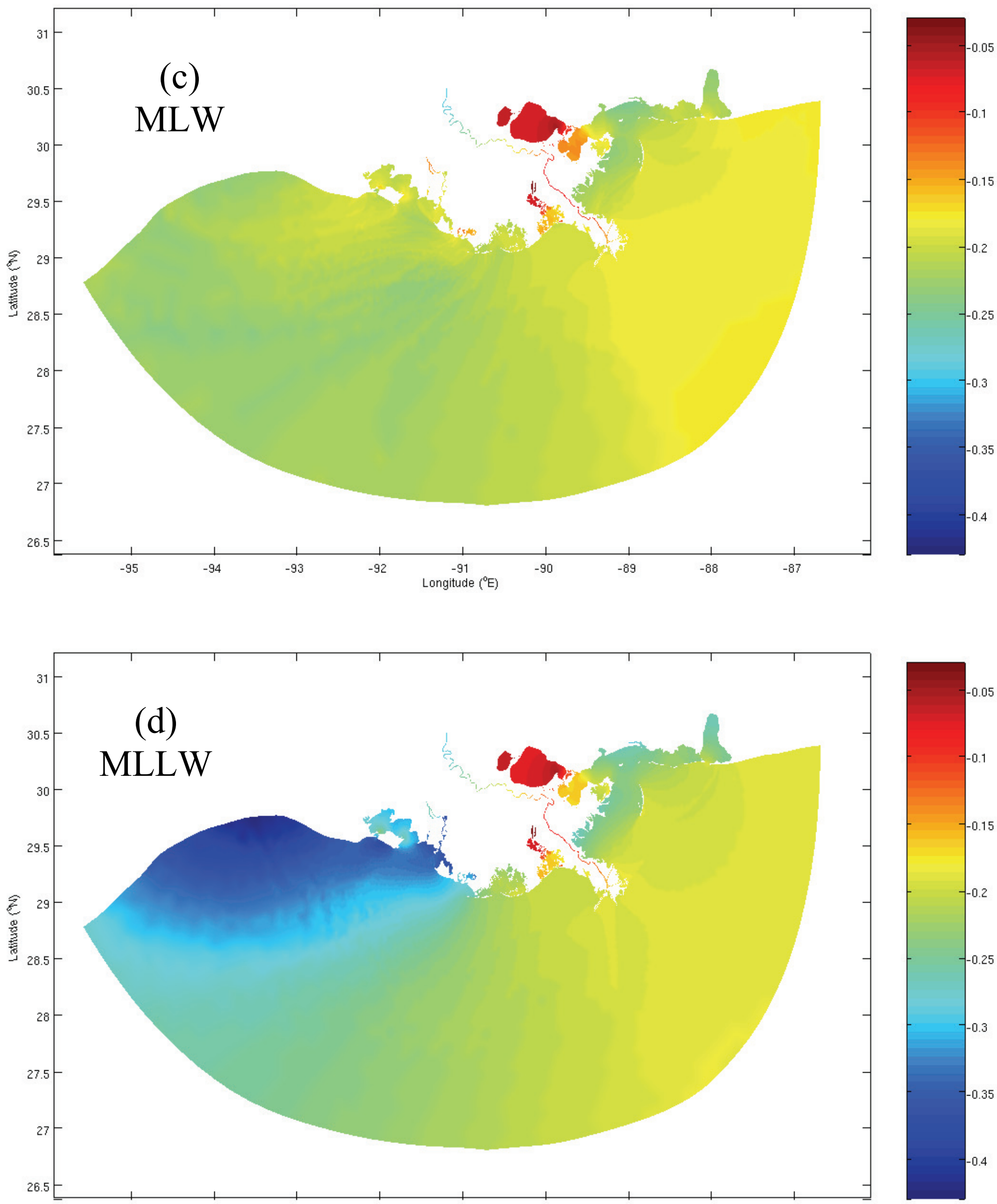


Figure 8. (Continued)

3.6. Validation and Error Corrections

3.6.1. Comparisons with Observations

To validate model results, modeled tidal datums were compared with those from 70 CO-OPS water level gauges in the region (Appendix B). Figures 9(a)-(d) display model-data contrasts for MHHW, MHW, MLW, and MLLW, respectively. In general, there exhibits good model-data agreement. Over the 70 stations, magnitudes of the model-data differences are averaged to be 1.8 cm, 2.0 cm, 1.6 cm, and 1.8 cm for MHHW, MHW, MLW, and MLLW, respectively. The model-data correlation coefficients are between 0.98-0.99 for all four tidal datums.

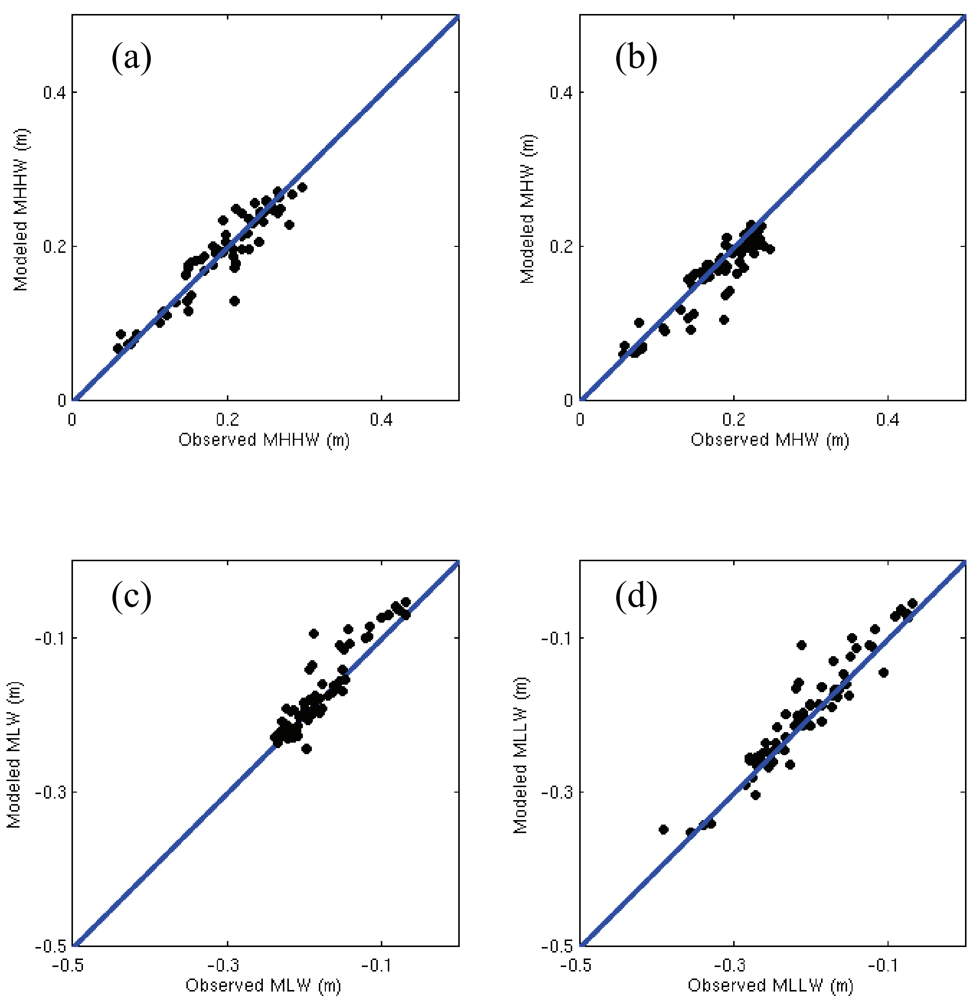


Figure 9. Comparisons of the modeled (a) MHHW, (b) MHW, (c) MLW, and (d) MLLW datums against observations.

For each individual station, averaged magnitudes (|Avg|) of model-data differences over the four datums are examined. Figure 10 illustrates |Avg|'s scaled in color-coded symbols. Table 1 lists the mean and standard deviation (std) of the |Avg|'s for MHHW, MHW, MLW, and MLLW over the 70 stations.

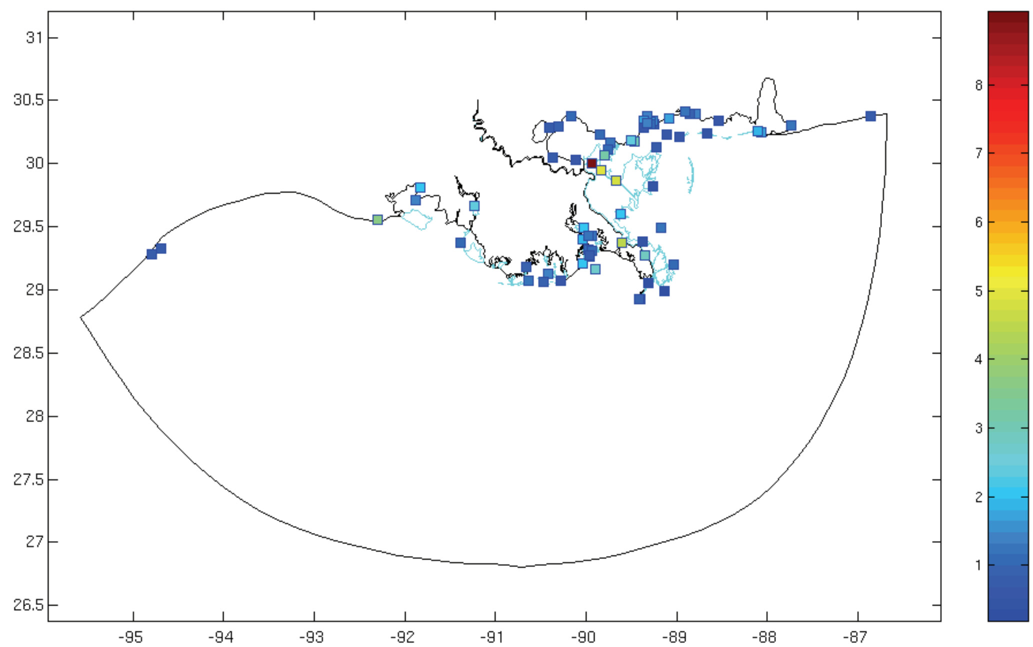


Figure 10. Color-scaled average model-data errors (|Avg|). Color bar is in cm.

Table 1. Statistics of model-data errors

	MHHW (cm)	*MHW (cm)*	*MLW (cm)*	*MLLW (cm)*
mean(|Avg|)	1.8	2.0	1.6	1.8
std(|Avg|))	1.6	1.7	1.7	1.8

3.6.2. Match with Tidal Datums in Adjacent areas

The present model domain overlaps with the Gulf of Mexico and Alabama Bays VDatum applications (Spargo et al., 2008) (Figure 12). In reality, tidal datum fields should be matched seamlessly across domain boundaries. However, this is not necessarily engendered when the two tidal datum fields datasets were developed separately with slightly different model setups in terms of tidal boundary forcings, magnitudes of the bottom friction coefficients, etc. It is therefore worthwhile to examine discrepancies and work out ways to reach seamless matches if needed.

Comparisons between the present model results and those of the Gulf of Mexico and Alabama Bays VDatum applications were made along transect AA', shown in Figure 11. The two exhibit similar magnitude of the differences and hence were combined to examine the statistics. Table 2 lists the statistics of the tidal datum differences.

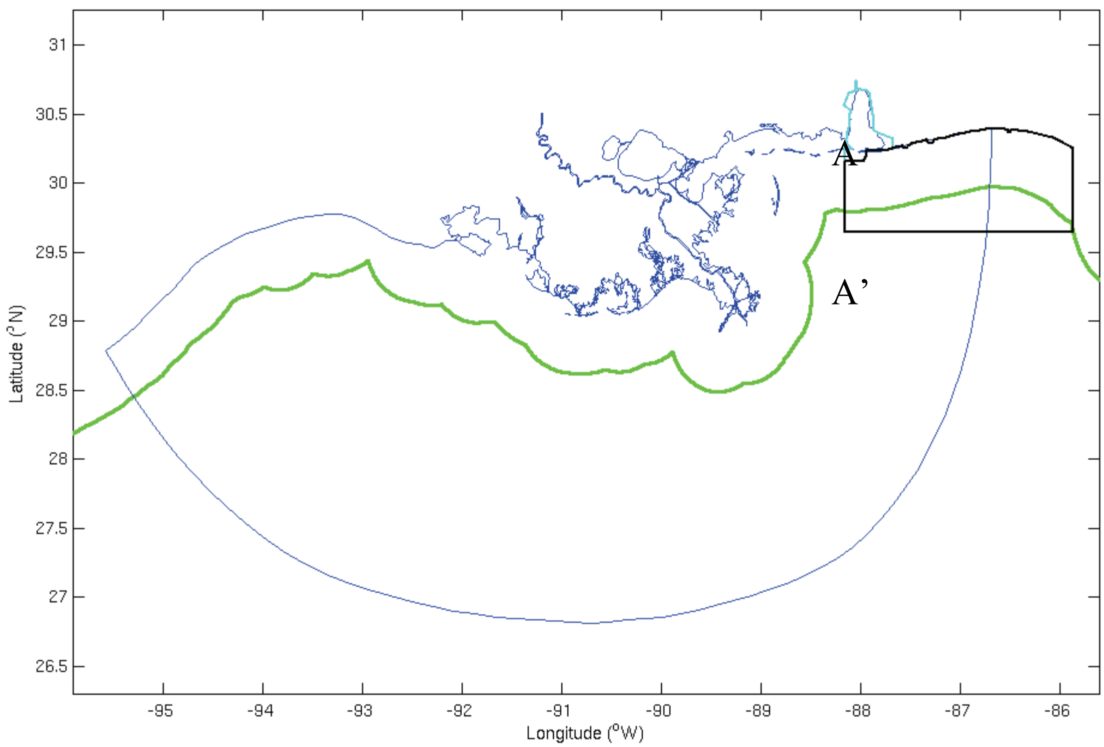


Figure 11. Outlines of the present hydrodynamic model domain (blue lines) and bounding polygons (cyan and black lines) of two neighboring VDatum areas. The cyan and black lines illustrate bounding polygons of the Alabama Bays and Gulf of Mexico VDatum areas, respectively. Transect AA' indicates the locations where tidal datum discrepancies between adjacent areas were examined. The green line illustrates locations 25-nm offshore.

Table 2. Statistics of tidal datum differences (Δ) between the present model results and those for the Alabama Bays and Gulf of Mexico along transect AA' (Figure 11).

	MHHW (cm)	*MHW (cm)*	*MLW (cm)*	*MLLW (cm)*
mean(|Δ|)	2.6	0.7	0.7	1.5
Standard deviation (Δ)	1.2	0.3	0.6	1.2

The mean |Δ| for MHHW and MLLW are greater than 1.5 cm. The standard deviation of the differences ranges from 0.3 to 1.2 cm. It was therefore necessary to make adjustments to the present model results so as to reach a seamless match of tidal datums between different adjacent regions. This was accomplished by using TCARI, the details of which are described in the next section.

3.6.3. Corrections

Tidal datum corrections were developed to eliminate model-data differences at observational stations (Section 3.6.1) as well as to minimize datum discrepancies across boundaries of different VDatum domains (Section 3.6.2). This was achieved using the TCARI (Tidal Constituent And Residual Interpolation spatial interpolation tool (Hess, 2002; Hess, 2003). TCARI was used to spatially interpolate the error fields defined at a number of individual control stations onto the whole domain by solving Laplace's equation. TCARI has been developed for use with both structured and unstructured model grids, and a version of the latter was employed in this study.

To run TCARI, both the observational stations and the domain boundary stations were treated as control stations. For each tidal datum, both model-data differences (at 70 tidal stations) and across-boundary discrepancies were computed and merged into one dataset for input to TCARI.

After applying TCARI, error fields for MHHW, MHW, MLW, and MLLW were derived that matched the tidal datum differences at the 70 control stations. The initial model results (Section 3.5) were then corrected by subtracting the error fields over the entire model grid. Figures 12(a)-(d) display the final corrected tidal datum fields.

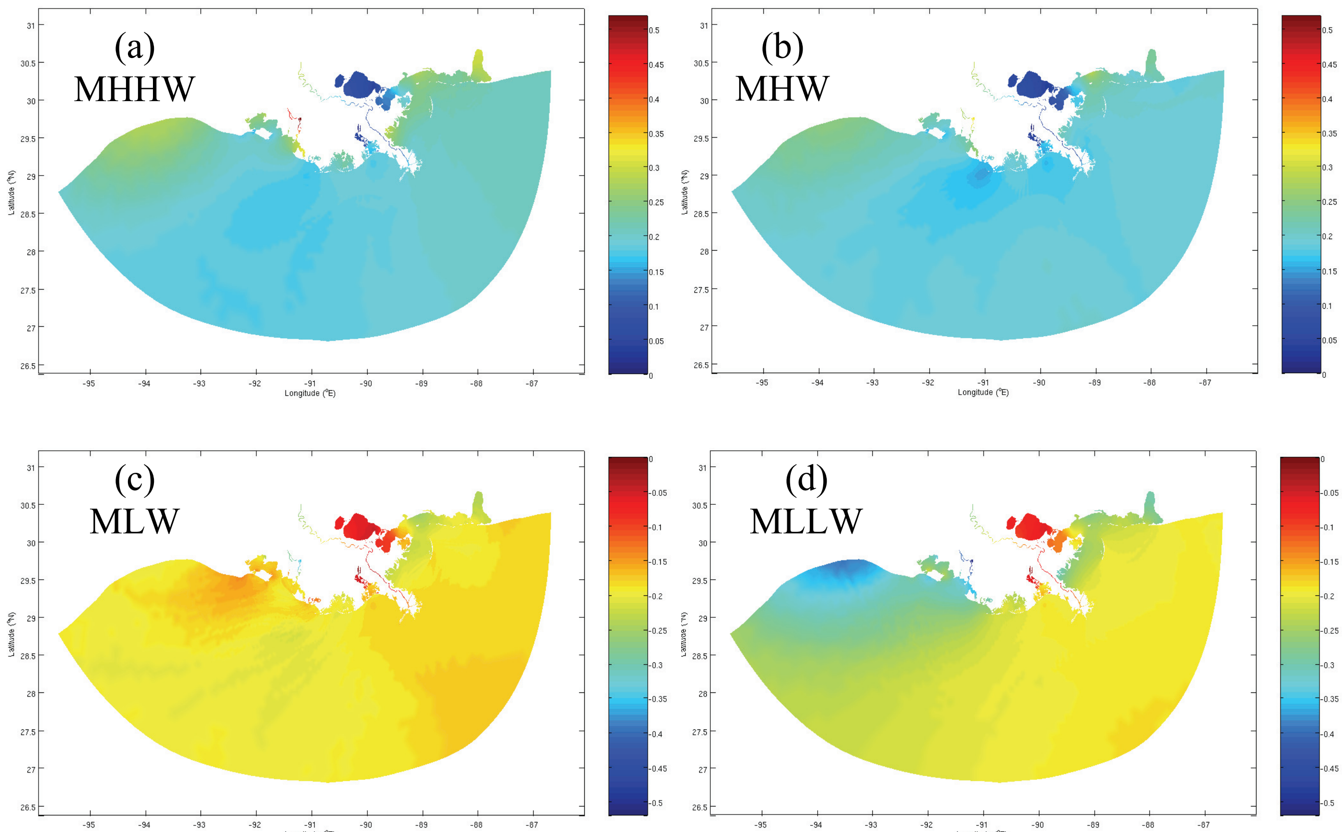


Figure 12. Error-corrected tidal datum fields over the whole model domain, (a) MHHW, (b) MHW, (c) MLW, and (d) MLLW. Color bars are in meters.

4. CREATION AND POPULATION OF THE MARINE GRID

4.1. Creation of VDatum Marine Grid

Tidal datums in the VDatum software are defined on a regularly structured grid, referred to as the marine grid (Hess and White, 2004). Hence, it is necessary to convert the tidal datum fields from the unstructured grid onto the equally-spaced raster VDatum marine grid.

Nodes in the marine grid were specified as either water points or land points. The water nodes are to be populated with valid tidal datum values and the land nodes are assigned with null values. To create the marine grid, the high-resolution MHW coastline (Section 2.1) and a bounding polygon (Figure 13) were used. The bounding polygon was set up to guide the delineation of water/land nodes. Only nodes within the bounding polygons or within up to one half of a cell size outside the coastline are delineated as water nodes; those outside of the bounding polygons or those more than one half of a cell size away from the coastline are marked as land nodes.

Marine grid points are equally spaced. For a point at the *i*-th row and *j*-th column relative to the point $(longitude_0, latitude_0)$ at the region's southwest corner, its location *(longitude_i, latitude_j)* is defined as,

$$\text{Longitude\_i} = \text{longitude}_0 + (i-1)\times \text{del\_lon},\ \ i=1, \ldots, \text{N\_lon},$$
$$\text{Latitude\_j} = \text{latitude}_0 + (j-1)\times \text{del\_lat},\ j=1, \ldots, \text{N\_lat},$$

where *del_lon*, and *del_lat* denote separation between neighboring points along the meridional and zonal directions, respectively; *N_lon* and *N_lat* represent, respectively, the longitude and latitude dimensions of the raster data set. It is noted that the *del_lon* and *del_lat* are prescribed parameters representing the expected grid resolutions, while *N_lon* and *N_lat* are derived parameters according to

$$\text{N\_lon} = 1 + (\text{longitude}_1 - \text{longitude}_0)/\text{del\_lon}$$
$$\text{N\_lat} = 1 + (\text{latitude}_1 - \text{latitude}_0)/\text{del\_lat}$$

where $(longitude_1, latitude_1)$ are the coordinate at the raster region's northeast corner. Table 3 lists parameters used to define the marine grid.

Table 3. Marine grid parameters

	Region Name	*Longitude$_0$ (degree)*	*Latitude$_0$ (degree)*	*del_lon (degree)*	*del_lat (degree)*	*N_lon*	*N_lat*
RA	Eastern LA and MS	-93.0	28.0	0.001	0.001	5001	2501

The water-land node specifications in the grid were then further quality controlled by comparing with coastline imagery acquired by NGS. Compared with the aforementioned MHW coastline (Section 2.1), the imagery coastline is more recently updated and gives a more realistic coastline representation. By comparing with the NGS coastline, the nearshore water-land node specifications in the original marine grid were adjusted, while the definition of the marine grid parameters (Table 3) was retained. This NGS marine grid was then used to populate the tidal datums.

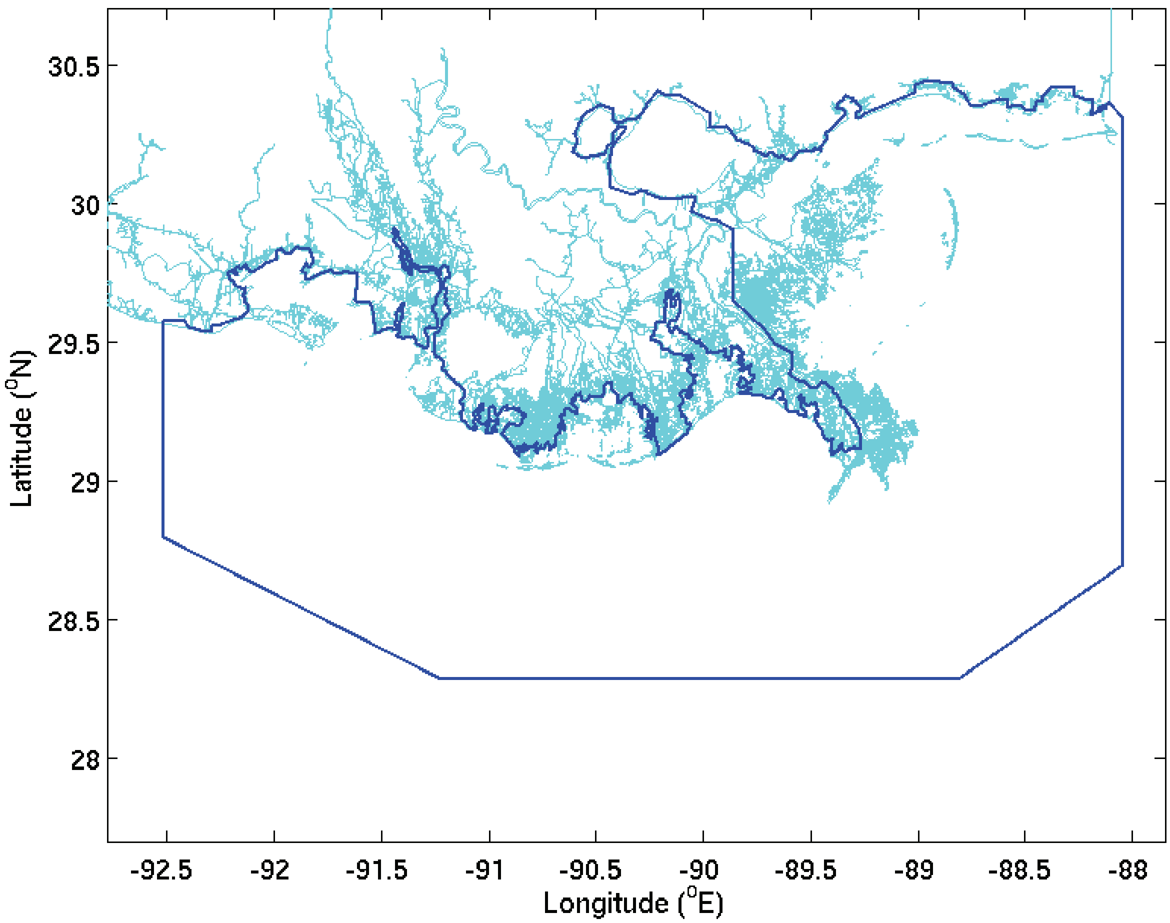


Figure 13. Definition of VDatum marine grid bounding polygon: MHW coastline (cyan line), bonding polygon (blue line).

4.2. Population of VDatum Grid with Tidal Datums

Tidal datums on the VDatum marine grid were populated by interpolating the TCARI-corrected tidal datums (Section 3.6) following the algorithm of Hess and White (2004). Datums at each grid point were computed by averaging or linearly interpolating those values within a user-specified searching radius or the closest user-specified number of points. Marine points were populated differently depending on whether a point was inside/outside of the ADCIRC model grid elements. If it was inside an element, datums were calculated using an interpolation of the 3 nodes of the element; otherwise, datums were computed using the inverse distance weighting of the closest two node values. Figures C.1(a)-(e) in Appendix C display the populated tidal datums, MHHW, MHW, MLW, MLLW, MTL, and DTL, respectively.

As a quality control procedure, the tidal datum fields were further verified against those from the water level stations (Section 3.6.1). The test gave a maximum absolute model-data error less than 0.2 cm and an rms error less than 0.1 cm for all four datums (MHHW, MHW, MLW, and MLLW).

In addition, the datum consistency along a border transect (AA' in Figure 11) between the present VDatum domain and those of the Gulf of Mexico and Alabama Bays VDatum applications (Section 3.6.2) were tested. A good agreement was achieved: For each of MHHW, MHW, MLW, and MLLW, the maximum absolute differences were less than 0.1 cm.

5. GENERATION OF THE SEA SURFACE

The TSS is defined as the elevation of NAVD 88 relative to local MSL. It is created by combining observed datums at NGS bench marks and CO-OPS water level stations with the tidal model results. Figure 14 illustrates the station locations used in this application (see details of the station information in Table D.1 of Appendix D). To create the TSS over the VDatum domain, the TSS values at the observation stations were first derived. These values were then interpolated over the whole domain. Afterwards, a quality control procedure was followed and appropriate changes were made to meet certain criteria. The NAVD 88 heights are realized utilizing either GEOID99 or GEOID03. Hence two sets of NAVD88 data were created. It is noted that the generation of both data sets shared the same algorithms and procedures.

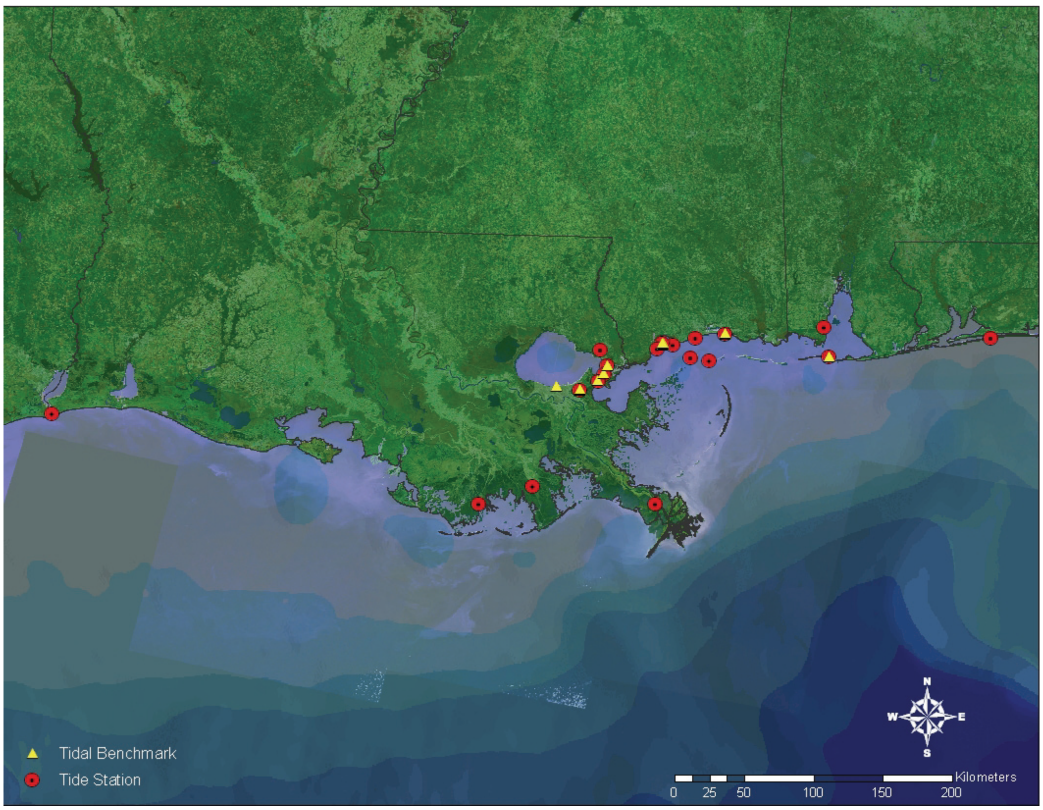


Figure 14. Locations of tidal bench marks and tide stations used to compute the New Orleans VDatum TSS grids.

5.1. Derivation of TSS

Two methodologies were used to compute the TSS at the observational stations: an indirect method using data from the NGS database (see Appendix E) and a direct method using data from the CO-OPS database (see Appendix F). To derive the TSS at the NGS stations using the indirect method, residuals (R_{datum}) at every NGS bench mark location were computed as:

$$R_{datum} = TBM_{navd88} - TBM_{datum} + VD_{datum}$$

where TBM_{navd88} and TBM_{datum} are the observed (NAVD88–MLLW) and (Datum-MLLW) differences, respectively, and VD_{datum} denotes modeled (Datum–MSL) differences. The residual, R_{datum}, represents an estimation of the (MSL-NAVD88) difference.

There are four sets of R_{datum}, corresponding to MHHW, MHW, MLW, and MLLW. Each represents an independent estimation of the quantity MSL–NAVD88 associated with a tidal datum. Tables E.1 lists R_{datum}'s at stations located within the present VDatum bounding polygons (Figure 13). At each station, the four R_{datum}'s were then averaged to produce a mean residual ($\overline{R}_{datum}$). $\overline{R}_{datum}$ represents an overall estimation of MSL–NAVD88 and is used for further development of the TSS grid.

The TSS values at CO-OPS stations were simply derived by calculating orthometric-to-tidal datum relationships. Table F.1 shows the station location inventories and observations of elevation information.

Next, the $\overline{R}_{datum}$ values are merged with TSS values from CO-OPS stations to form a data set for creating a TSS mesh using the gridding software, Surfer©. A grid covering the entire area of bench marks and water level stations with a spatial resolution similar to that of the VDatum marine grid was created. Breaklines were inserted to represent the influence of land. The Surfer© software's minimum curvature algorithm was employed to create a primary TSS field (TSS_{grid}) that honors the data as closely as possible. The maximum allowed departure value used was 0.0001 meters. To control the amount of bowing on the interior and at the edges of the grid, an internal and boundary tension of 0.3 was utilized. Once the gridded topography field had been generated, null values were obtained from the marine tidal grids and are inserted to denote the presence of land.

It is noted that the TSS_{grid} represents an estimation of the quantity MSL- NAVD88 and still requires further quality control and correction procedures (Section 5.2). Figures 15 and 16 show the final TSS fields based on NAVD88 realized through GEOID99 and GEOID03, respectively. In each figure, a positive value specifies that the NAVD 88 reference value is further from the center of the Earth than the MSL surface. Data derived from both the indirect and direct methodology are initially relative to NAVD88 realized through GEOID03. This data derived for both methods is transformed back through GEOID03 to an ellipsoidal reference and then transformed back utilizing GEOID99. Therefore, we now have two datasets for both methods, one relative to GEOID03 and the other relative to GEOID99. This particular area is lacking in sufficient observation points for tidal datums, NAVD88 elevations, and GPS ellipsoidal connections. NOAA is actively working to fill these observational gaps. Full evaluation and calibration of the transformations awaits more observational points.

5.2. Quality Control

Quality control is necessary for obtaining a final TSS field. This is facilitated through examining the differences ($\Delta_{R\text{-}TSS}$) between R_{datum} and TSS_{grid} observational stations:

$$\Delta_{R\text{-}TSS} = -(R_{datum} - TSS_{grid})$$

The $\Delta_{R\text{-}TSS}$ approximately represents the difference between the observed tidal datum and the datum as computed by the gridded fields. The average $\Delta_{R\text{-}TSS}$ at each bench mark should be less than 0.01 m. If it is not, the input data and grids are checked, appropriate changes are made, and the values are recomputed until the criterion is met. This results in a final TSS field. Tables F.1 and F.2 in Appendix F list the average $\Delta_{R\text{-}TSS}$ at observational stations for the GEOID 99 and GEOID 03 grids, respectively. They are consistent and small. This provides confidence that grids are in agreement. Finally, a land mask is applied to denote the presence of land.

In response to the limited amount of data available, the data used to compile the TSS_{grid} for both methods described in Section 5.1 were utilized in comparing against the TSS_{grid} to generalize internal consistency. Tables G.1 and G.2 in Appendix G tabulate the model-data differences for the TSS realized through GEOID99 and GEOID03, respectively. For the GEOID99 case, the mean and standard deviation were 2.3×10^{-4} meters and 2.7×10^{-3} meters, respectively. In the GEOID03 case, they were 1.2×10^{-4} meters and 2.6×10^{-3} meters, respectively. Note that this qulaity control is performed using available observation points. These points are not uniformly distributed over the model domain, this adding some uncertainty to the process. The rapid rate of subsidence adds complexity to understanding and deriving the TSS grids (Shinkle and Dokka, 2004).

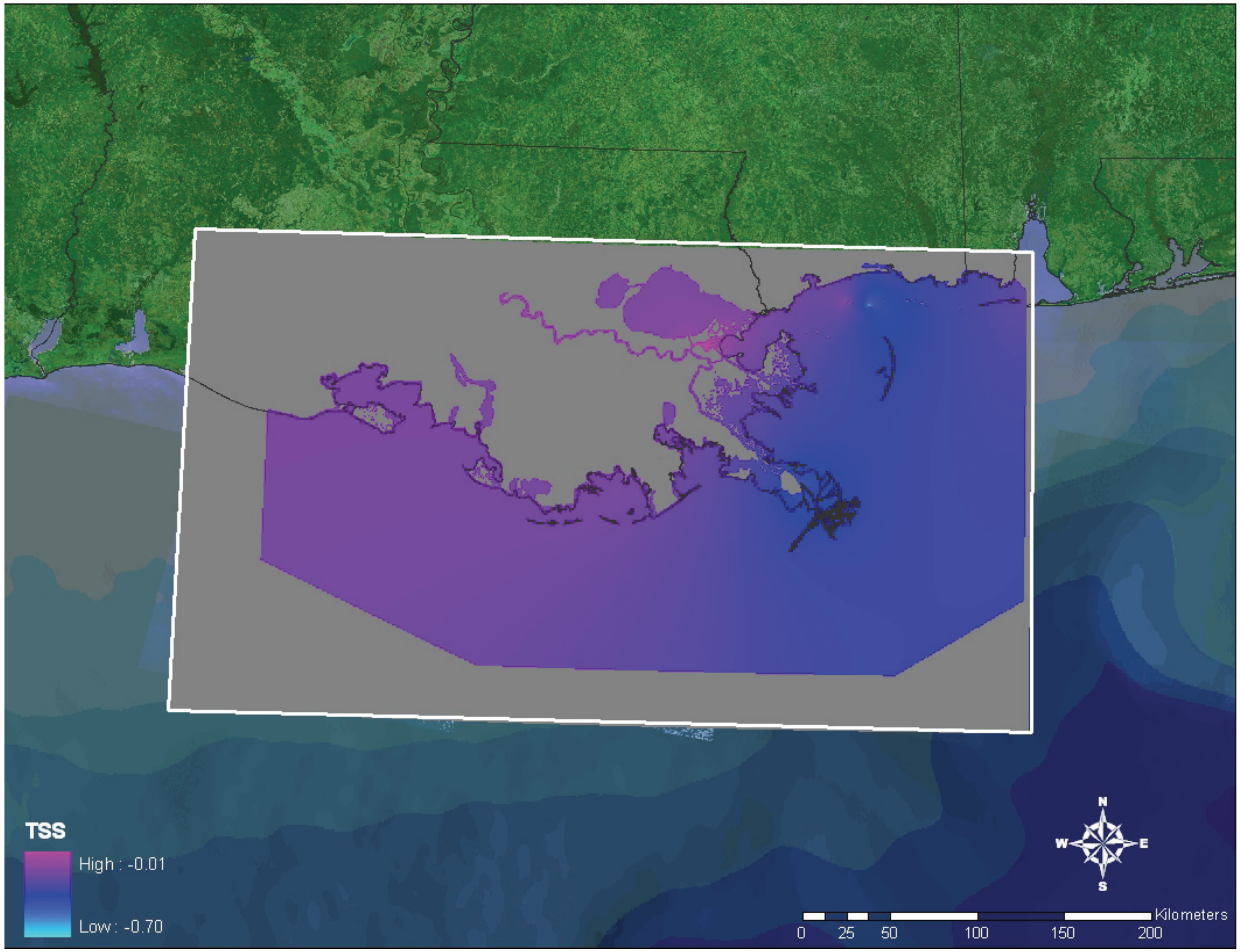


Figure 15. The New Orleans TSS field based on NAVD88 realized through GEOID99.

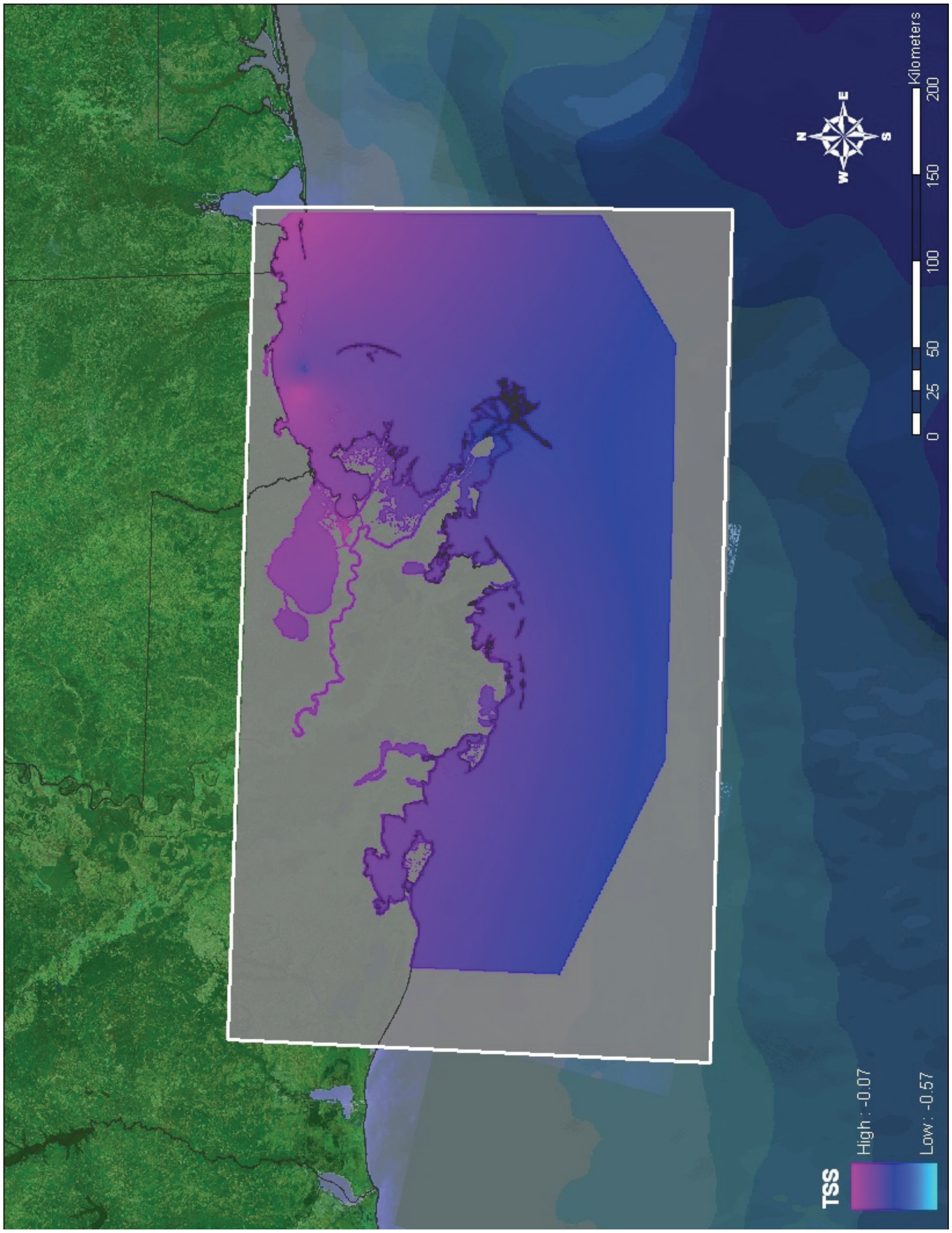


Figure 16. The New Orleans TSS field based on NAVD88 realized through GEOID03.

6. SUMMARY

VDatum tidal datum and TSS fields for the coastal waters of eastern Louisiana and Mississippi were developed in this study. Creation of VDatum begins with creating tidal datums with numerical tidal simulations using the ADCIRC model. A triangular finite-element grid consisting of 167,646 nodes and 306,749 cells was created. The model was forced with nine tidal constituents (M_2, S_2, N_2, K_2, K_1, P_1, O_1, Q_1, and M_4) and run for 65 days. Various tidal datum fields, including mean lower low water (MLLW), mean low water (MLW), mean high water (MHW), and mean higher high water (MHHW), were derived using the modeled water level time series from the final 55 days of the simulation. Model results were validated by comparing with observations at 70 water level stations maintained by NOAA's Center for Operational Oceanographic Products and Services (CO-OPS). Discrepancies between model results and observational datums were attributed to model errors and interpolated over the whole model domain using the tidal constituent and residual interpolation (TCARI) technique. The error fields were applied to the direct model results to achieve error-corrected tidal datums on the model grid. Finally, tidal datum fields were interpolated onto a regular VDatum marine grid.

A regular VDatum marine grid was created to be used as input to the VDatum software tool. Tidal datums defined on the unstructured grid were interpolated onto the regular grid to form the final datums as input to the VDatum tool.

The TSS fields were derived using two methodologies: by fitting tidal model results to tidal bench marks leveled in NAVD88 or by calculating orthometric-to-tidal datum relationships at NOAA tidal gauges. Results from the two methods were coupled to create the final TSS grids and incorporated into the VDatum tool.

The Louisiana portion of the VDatum grid has significantly more uncertainty due to the lack of observational tidal data and geodetic data. In addition, the significant vertical land subsidence in the region created the need for frequent tidal datum updates and updated in geodetic datum elevations. This will require frequent updates to the operational VDatum products for this particular model domain.

ACKNOWLEDEGEMENTS

Digital coastline and bathymetric data sets were provided by Julia Skory and Cuong Hoang, respectively. Dr. Kurt Hess developed the software for the VDatum grid generation, tidal datum population, and final product quality control tests. Drs. Richard A. Schmalz, Jr. at CSDL and Stephen Gill at CO-OPS reviewed the entire manuscript. The authors would like to express genuine gratitude for their time and effort.

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APPENDIX A. HORIZONTAL AND VERTICAL ACCURACY STANDARDS FOR NOAA BATHYMETRY SURVEY

Table A.1. The required horizontal and vertical accuracy standards for NOAA surveys. Accuracy requirements before 1957 were prescribed for survey projects.

Survey Year*	Horizontal Accuracy	Vertical Accuracy	Standard
1998 – present	**Order 1** 1 – 100 m depth: 5.0 m + 5% of depth **Order 2** 100 – 200 m depth: 20 m + 5% of depth **Order 3** 100 – 200 m depth: 150 m + 5% of depth	**Order 1** 1 – 100 m depth: 0.5 – 1.4 m **Order 2** 100 – 200 m depth: 2.5 – 4.7 m **Order 3** > 100 m depth: same as Order 2	IHO S-44 [1] and NOAA [2]
1988 – 1998	95% probability that the true position lies within a circle of radius 1.5 mm, at the scale of the survey	0 – 30 m depth: 0.3 m > 30 m depth: 1% of depth	IHO S-44 [1] and NOAA [2]
1982 – 1988	probable error shall seldom exceed twice the plottable error (1.0 mm) at the scale of the survey	0 – 20 m depth: 0.3 m 20 – 100 m depth: 1.0 m > 100 m depth: 1% of depth	IHO S-44 [1] and NOAA [2]
1957 – 1982	maximum error of plotted positions shall seldom exceed 1.5 mm at the scale of the survey	0 – 20 m depth: 0.3 m 20 – 100 m depth: 1.0 m > 100 m depth: 1% of depth	IHC [3] NOAA [2] and IHO S-44 [1]
before 1957	undetermined	undetermined	undocumented

* end of field collection

[1] International Hydrographic Organization (IHO) Standards for Hydrographic Surveys, Special Publication 44, (First Edition, 1968; Second Edition, 1982; Third Edition, 1987; Fourth Edition, 1998).

[2] U.S. Department of Commerce Coast and Geodetic Survey Hydrographic Manual (1931, 1942, 1960, 1976) NOAA NOS Office of Coast Survey Specifications and Deliverables, 1999 – 2006. NOAA was established in 1970.

[3] International Hydrographic Conference, 1957.

APPENDIX B. WATER LEVEL STATION DATA

Table B.1. NOS Water Level Station Names

1	8729678	NAVARRE BEACH
2	8731952	BON SECOUR
3	8735180	DAUPHIN ISLAND, MOBILE BA
4	8735587	NORTH POINT DAUPHIN ISLAN
5	8741196	PASCAGOULA POINT, MISS. S
6	8742221	HORN ISLAND, MISSISSIPPI
7	8743281	OCEAN SPRINGS
8	8743735	BILOXI (CADET POINT), BIL
9	8744117	BILOXI, BAY OF BILOXI
10	8744756	SHIP ISLAND, MISSISSIPPI
11	8745557	GULFPORT HARBOR, MISSISSI
12	8745799	CAT ISLAND, MISSISSIPPI S
13	8746819	PASS CHRISTIAN YACHT CLUB
14	8746943	HENDERSON AVENUE BRIDGE
15	8747131	MALLINI BAYOU NORTH
16	8747145	MALLINI BAYOU SOUTH
17	8747398	NORTH SHORE, BAY OF ST. L
18	8747437	BAY WAVELAND YC BAY ST.
19	8747739	JOURDAN RIVER ENTRANCE
20	8747766	WAVELAND, MISSISSIPPI SOU
21	8748525	LOWER POINT CLEAR MISS SO
22	8748842	WESTERN CAMPBELL OUTSIDE
23	8760412	NORTH PASS
24	8760551	SOUTH PASS
25	8760595	BRETON ISLAND
26	8760668	GRAND PASS
27	8760742	COMFORT ISLAND
28	8760781	SHELL OIL, EAST BAY
29	8760849	VENICE, GRAND PASS
30	8760889	OLGA COMPRESSOR STATION,
31	8760922	PILOTS STATION EAST, SOUT
32	8760943	PILOT STATION, SW PASS
33	8761108	BAY GARDENE
34	8761207	EMPIRE DOULLUT CANAL LA
35	8761305	SHELL BEACH, LAKE BORGNE
36	8761402	U.S. HIGHWAY 90, THE RIGO
37	8761426	GREENS DITCH, LAKE ST. CA
38	8761487	CHEF MENTEUR, CHEF MENTEU
39	8761529	MARTELLO CASTLE, LAKE BOR
40	8761534	BIG POINT, LAKE PONTCHART
41	8761623	HUMBLE OIL PLATFORM GRAND
42	8761677	INDEPENDENCE IS BARATARIA
43	8761678	MICHOUD SUBSTATION, ICWW
44	8761679	ST. MARYS POINT, BARATARI
45	8761722	GRAND ISLE EAST POINT LA

46	8761724	GRAND ISLE, EAST POINT
47	8761732	MANILLA VILLAGE BARATARIA
48	8761742	MENDICANT ISLAND, BARATAR
49	8761799	M.V. PETROLEUM DOCK, BAYO
50	8761819	TEXACO DOCK, HACKBERRY BA
51	8761826	CHENIERE CAMINADA, CAMINA
52	8761927	USCG NEW CANAL STA., LAKE
53	8761993	TCHEFUNCTA RIVER, LAKE PO
54	8762223	EAST TIMBALIER ISLAND, TI
55	8762273	EAST END, PASS MANCHAC
56	8762372	EAST BANK 1, NORCO, BAYOU
57	8762419	U.S. HIGHWAY 51 PASS MAN
58	8762481	PELICAN ISLAND TIMBALIER
59	8762582	TIMBALIER ISLAND TIMBALIE
60	8762888	E ISLE DERNIERES LAKE PEL
61	8762938	TEXACO TB#3 BAYOU PETIT C
62	8764025	STOUTS PASS AT SIX MILE L
63	8764044	TESORO MARINE TERM, ATCH
64	8764227	LAWMA, AMERADA PASS
65	8764311	EUGENE ISLAND
66	8765148	WEEKS BAY
67	8765251	CYPREMORT POINT
68	8766072	FRESHWATER CANAL LOCKS
69	8771416	GALVESTON BAY ENTRANCE, S
70	8771510	GALVESTON LEASURE PIER

Table B.2. Tidal datums (meters) relative to mean seal level. The 'N/A's in the table denote missing values.

1	8729678	-86.865	30.37667	0.22	0.2	-0.185	-0.201	NAVARRE_BEACH	1983-2002
2	8731952	-87.735	30.30333	0.236	0.225	-0.221	-0.234	BON_SECOUR	1983-2002
3	8735180	-88.075	30.25	0.195	0.189	-0.169	-0.172	DAUPHIN_ISLAND,_MOBILE_BA	1983-2002
4	8735587	-88.1133	30.25833	0.247	0.226	-0.229	-0.259	NORTH_POINT_DAUPHIN_ISLAN_	1960-1979
5	8741196	-88.5333	30.34	0.234	0.209	-0.207	-0.233	PASCAGOULA_POINT,_MISS._S_	1983-2001
6	8742221	-88.6667	30.23833	0.243	0.211	-0.208	-0.245	HORN_ISLAND,_MISSISSIPPI__	1983-2001
7	8743281	-88.7983	30.39167	0.262	0.237	-0.22	-0.264	OCEAN_SPRINGS____________	1983-2001
8	8743735	-88.8567	30.39	0.267	0.235	-0.237	-0.27	BILOXI_(CADET_POINT),_BIL_	1983-2001
9	8744117	-88.9033	30.41167	0.266	0.24	-0.231	-0.276	BILOXI,_BAY_OF_BILOXI_____	1983-2001
10	8744756	-88.9717	30.21333	0.256	0.219	-0.222	-0.257	SHIP_ISLAND,_MISSISSIPPI__	1983-2001
11	8745557	-89.0817	30.36	0.25	0.223	-0.197	-0.25	GULFPORT_HARBOR,_MISSISSI_	1983-2001
12	8745799	-89.1167	30.23167	0.243	0.214	-0.208	-0.236	CAT_ISLAND,_MISSISSIPPI_S_	1983-2001
13	8746819	-89.245	30.31	0.259	0.232	-0.234	-0.267	PASS_CHRISTIAN_YACHT_CLUB_	1983-2001
14	8746943	-89.265	30.34167	0.268	0.22	-0.23	-0.278	HENDERSON_AVENUE_BRIDGE	1983-2001
15	8747131	-89.2883	30.32667	0.265	0.234	-0.228	-0.271	MALLINI_BAYOU_NORTH_______	1983-2001
16	8747145	-89.2867	30.31167	0.261	0.227	-0.222	-0.262	MALLINI_BAYOU_SOUTH_______	1983-2001
17	8747398	-89.3217	30.37333	0.268	0.22	-0.226	-0.274	NORTH_SHORE,_BAY_OF_ST._L_	1983-2001
18	8747437	-89.325	30.325	0.262	0.231	-0.233	-0.265	BAY_WAVELAND_YC__BAY_ST.__	1983-2001
19	8747739	-89.3667	30.33667	0.27	0.222	-0.23	-0.278	JOURDAN_RIVER_ENTRANCE____	1983-2001
20	8747766	-89.3667	30.28167	0.244	0.221	-0.217	-0.244	WAVELAND,_MISSISSIPPI_SOU_	1983-2001
21	8748525	-89.4633	30.17333	0.241	0.213	-0.214	-0.244	LOWER_POINT_CLEAR_MISS_SO_	1960-1979
22	8748842	-89.5067	30.18667	0.229	0.205	-0.201	-0.21	WESTERN_CAMPBELL_OUTSIDE__	1960-1979
23	8760412	-89.0367	29.205	0.17	0.165	-0.163	-0.166	NORTH_PASS_______________	1983-2001
24	8760551	-89.14	28.99	0.187	0.181	-0.18	-0.185	SOUTH_PASS_______________	1983-2001*
25	8760595	-89.1733	29.49333	0.199	0.199	-0.217	-0.218	BRETON_ISLAND____________	1983-2001*
26	8760668	-89.2217	30.12667	0.226	0.209	-0.204	-0.221	GRAND_PASS_______________	1983-2001*
27	8760742	-89.27	29.82333	0.229	0.216	-0.227	-0.249	COMFORT_ISLAND___________	1983-2001*
28	8760781	-89.305	29.0533	0.202	0.197	-0.192	-0.199	SHELL_OIL,_EAST_BAY	1983-2001*
29	8760849	-89.3517	29.27333	0.149	0.149	-0.149	-0.149	VENICE,_GRAND_PASS________	1983-2001*
30	8760889	-89.38	29.385	0.198	0.183	-0.198	-0.211	OLGA_COMPRESSOR_STATION,__	1983-2001*
31	8760922	-89.4067	28.93167	0.185	0.183	-0.185	-0.189	PILOTS_STATION_EAST,_SOUT_	1983-2001*
32	8760943	-89.4183	28.925	0.189	0.184	-0.187	-0.194	PILOT_STATION,_SW_PASS____	1983-2001*
33	8761108	-89.6183	29.59833	0.212	0.197	-0.21	-0.227	BAY_GARDENE______________	1983-2001*
34	8761207	-89.6017	29.375	0.15	0.144	-0.143	-0.146	EMPIRE_DOULLUT_CANAL_LA___	1960-1979
35	8761305	-89.6733	29.86833	0.239	0.226	-0.194	-0.225	SHELL_BEACH,_LAKE_BORGNE__	1983-2001
36	8761402	-89.7367	30.16667	0.116	0.11	-0.121	-0.125	U.S._HIGHWAY_90,_THE_RIGO_	1983-2001
37	8761426	-89.76	30.11167	0.118	0.11	-0.117	-0.121	GREENS_DITCH,_LAKE_ST._CA_	1983-2001
38	8761487	-89.8	30.065	0.153	0.141	-0.154	-0.17	CHEF_MENTEUR,_CHEF_MENTEU_	1983-2001

39	8761529	-89.835	29.945	0.212	0.175	-0.192	-0.207	MARTELLO_CASTLE,_LAKE_BOR_	1983-2001
40	8761534	-89.8533	30.22833	0.072	0.07	-0.082	-0.083	BIG_POINT,_LAKE_PONTCHART_	1983-2001
41	8761623	-89.9	29.16667	0.219	0.208	-0.223	-0.232	HUMBLE_OIL_PLATFORM_GRAND_	N/A
42	8761677	-89.9383	29.31	0.181	0.169	-0.176	-0.185	INDEPENDENCE_IS_BARATARIA_	N/A
43	8761678	-89.9367	30.00667	0.21	0.188	-0.188	-0.212	MICHOUD_SUBSTATION,_ICWW__	1983-2001
44	8761679	-89.9383	29.43167	0.147	0.145	-0.149	-0.157	ST._MARYS_POINT,_BARATARI_	1983-2001
45	8761722	-89.9583	29.275	0.167	0.161	-0.162	-0.171	GRAND_ISLE_EAST_POINT_LA__	1960-1979
46	8761724	-89.9567	29.26333	0.159	0.157	-0.16	-0.163	GRAND_ISLE,_EAST_POINT____	1983-2001*
47	8761732	-89.9767	29.42667	0.151	0.141	-0.146	-0.154	MANILLA_VILLAGE_BARATARIA_	N/A
48	8761742	-89.98	29.31833	0.15	0.146	-0.152	-0.155	MENDICANT_ISLAND,_BARATAR_	1983-2001*
49	8761799	-90.025	29.49667	0.112	0.111	-0.115	-0.116	M.V._PETROLEUM_DOCK,_BAYO_	1983-2001*
50	8761819	-90.0383	29.40167	0.134	0.131	-0.139	-0.141	TEXACO_DOCK,_HACKBERRY_BA_	1983-2001*
51	8761826	-90.04	29.21	0.152	0.15	-0.149	-0.15	CHENIERE_CAMINADA,_CAMINA_	1983-2001*
52	8761927	-90.1133	30.02667	0.08	0.081	-0.075	-0.076	USCG_NEW_CANAL_STA.,_LAKE_	1983-2001
53	8761993	-90.16	30.37833	0.083	0.082	-0.091	-0.091	TCHEFUNCTA_RIVER,_LAKE_PO_	1983-2001
54	8762223	-90.285	29.07667	0.193	0.182	-0.198	-0.209	EAST_TIMBALIER_ISLAND,_TI_	1983-2001*
55	8762273	-90.3117	30.29667	0.075	0.074	-0.079	-0.079	EAST_END,_PASS_MANCHAC____	1983-2001
56	8762372	-90.3683	30.05	0.063	0.059	-0.069	-0.073	EAST_BANK_1,_NORCO,_BAYOU_	1983-2001
57	8762419	-90.4017	30.285	0.058	0.057	-0.068	-0.068	U.S._HIGHWAY_51__PASS_MAN_	1983-2001*
58	8762481	-90.4233	29.12833	0.181	0.169	-0.176	-0.185	PELICAN_ISLAND_TIMBALIER__	N/A
59	8762582	-90.4767	29.06667	0.208	0.192	-0.195	-0.216	TIMBALIER_ISLAND_TIMBALIE_	1960-1979
60	8762888	-90.6417	29.07167	0.208	0.189	-0.192	-0.21	E_ISLE_DERNIERES_LAKE_PEL_	1960-1979
61	8762938	-90.6667	29.18667	0.192	0.18	-0.18	-0.201	TEXACO_TB#3_BAYOU_PETIT_C_	1960-1979
62	8764025	-91.23	29.7433	0.145	0.121	-0.105	-0.126	STOUTS_PASS_AT_SIX_MILE_L	1983-2001*
63	8764044	-91.2367	29.66667	0.097	0.086	-0.078	-0.099	TESORO_MARINE_TERM,_ATCH__	1983-2001*
64	8764227	-91.34	29.45	0.246	0.202	-0.172	-0.279	LAWMA,_AMERADA_PASS	1983-2001*
65	8764311	-91.385	29.37167	0.265	0.225	-0.195	-0.33	EUGENE_ISLAND____________	1983-2001*
66	8765148	-91.8267	29.81167	0.219	0.192	-0.195	-0.271	WEEKS_BAY________________	1983-2001*
67	8765251	-91.88	29.71333	0.253	0.221	-0.204	-0.272	CYPREMORT_POINT__________	1983-2001*
68	8766072	-92.305	29.555	0.275	0.234	-0.216	-0.363	FRESHWATER_CANAL_LOCKS___ _	1983-2001*
69	8771416	-94.6933	29.32667	0.297	0.236	-0.23	-0.356	GALVESTON_BAY_ENTRANCE,_S	1983-2001*
70	8771510	-94.7894	29.2853	0.284	0.225	-0.219	-0.338	GALVESTON_LEASURE_PIER	1983-2001*

Note : stations with * means the control station used for datum determination used an accepted datum based on the 5-year Modified Tidal Epoch procedure in order to take into account rapid vertical land movement.

APPENDIX C. TIDAL DATUM FIELDS DEFINED ON VDATUM MARINE GRID

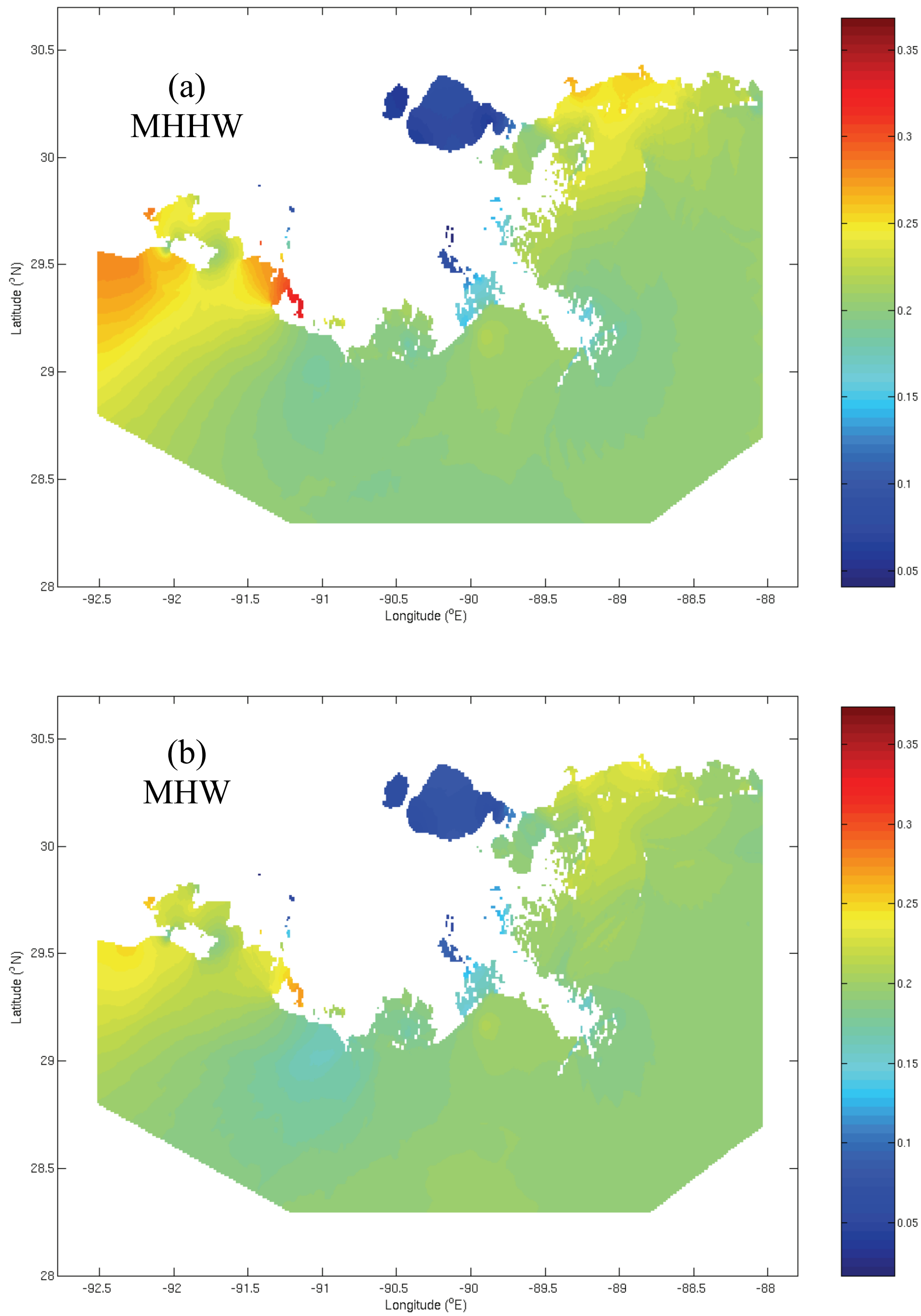
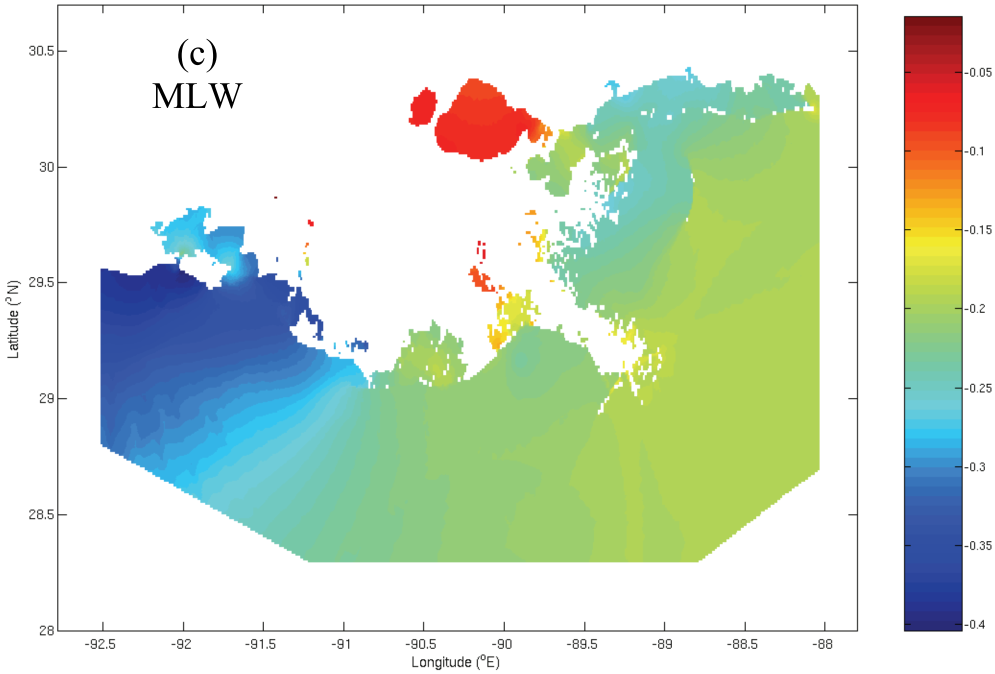


Figure C.1. Tidal Datums defined on VDatum marine grid, (a) MHHW, (b) MHW, (c), MLW, (d) MLLW, (e) MTL, and (f) DTL.



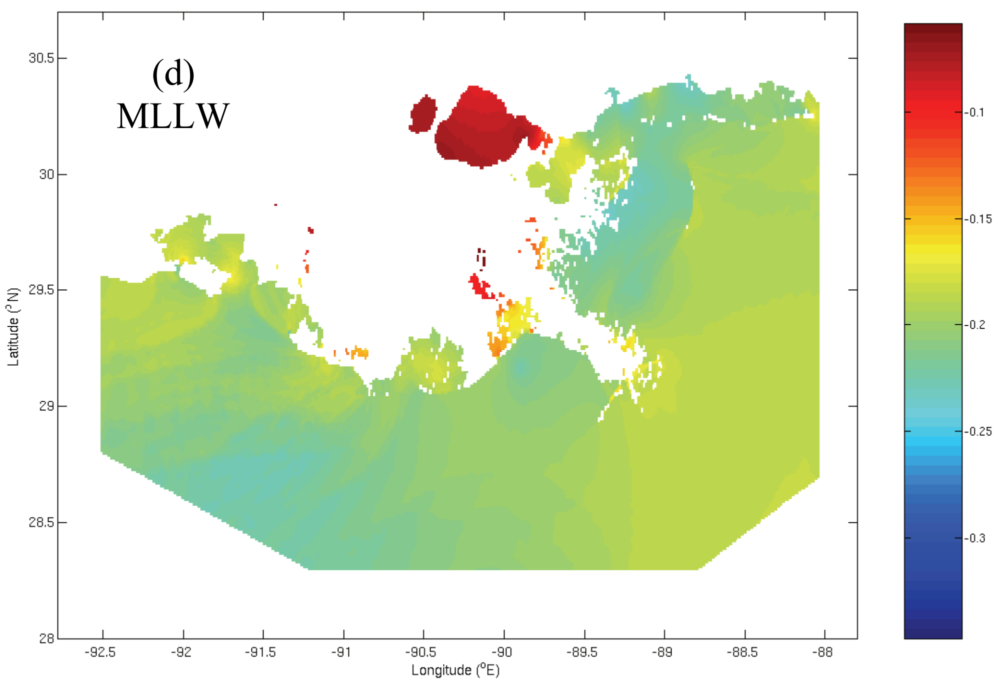
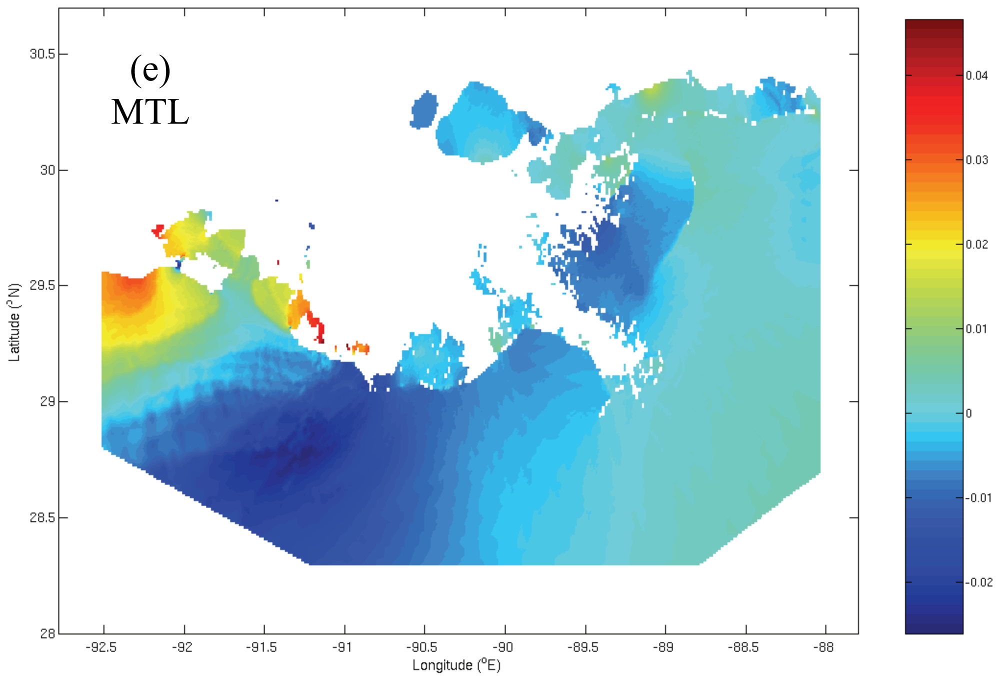


Figure C.1. (Continued)



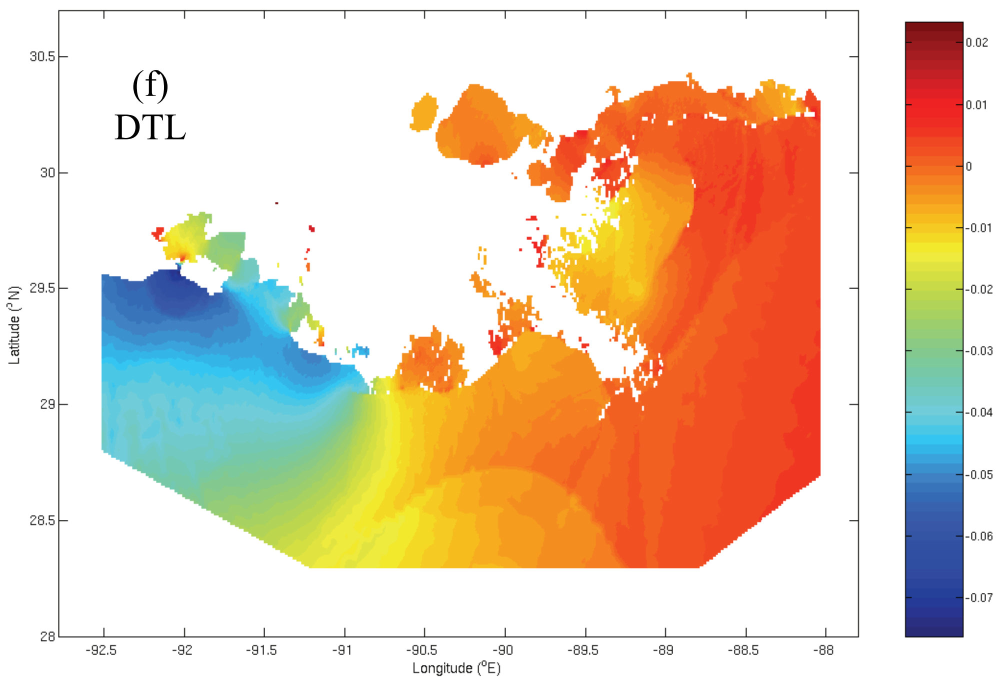


Figure C.1. (Continued)

APPENDIX D. Tidal gauge and bench marks data used to create the TSS

Table D.1. Location and elevation information for NOAA water level gauges used to create the New Orleans TSS grid. Tidal datums are relative to MLLW. MSL data are from CO-OPS, and NAVD88 heights were calculated by NGS.

Station ID	Latitude (deg)	Longitude (deg)	MSL (m)	NAVD88 [GEOID03] (m)	NAVD88 [GEOID99] (m)	TSS [GEOID03] (m)	TSS [GEOID99] (m)
8729678	30.37670	-86.86500	8.057	8.000	7.807	-0.057	-0.250
8735180	30.25000	-88.07500	1.049	0.947	0.822	-0.102	-0.227
8735523	30.44330	-88.11330	1.074	0.941	0.822	-0.133	-0.252
8743735	30.39000	-88.85670	1.097	0.942	0.792	-0.155	-0.305
8744756	30.21330	-88.97170	1.326	0.759	0.629	-0.567	-0.697
8745557	30.36000	-89.08170	0.996	0.823	0.723	-0.173	-0.273
8745799	30.23170	-89.11670	1.239	1.168	1.085	-0.071	-0.154
8746819	30.31000	-89.24500	0.854	0.700	0.643	-0.154	-0.211
8747437	30.32500	-89.32500	0.990	0.825	0.782	-0.165	-0.208
8747766	30.28170	-89.36670	8.696	8.518	8.492	-0.178	-0.204
8760849	29.27330	-89.35170	0.844	0.414	0.406	-0.430	-0.439
8761402	30.16670	-89.73670	1.052	0.842	0.902	-0.210	-0.150
8761426	30.11170	-89.76000	0.905	0.685	0.766	-0.220	-0.139
8761473	30.27170	-89.79330	0.920	0.688	0.711	-0.232	-0.209
8761487	30.06500	-89.80000	1.041	0.829	0.925	-0.212	-0.116
8761678	30.00670	-89.93670	1.110	0.992	1.095	-0.118	-0.015
8762184	29.37330	-90.26500	1.001	0.694	0.842	-0.307	-0.159
8762928	29.24500	-90.66170	1.082	0.821	0.915	-0.261	-0.167
8770590	29.70500	-93.85330	1.810	1.379	1.302	-0.431	-0.509

APPENDIX E. DERIVED NAVD 88-TO-MSL VALUES

Table E.1. Derived NAVD 88-to-MSL values for each tidal datum at NGS bench marks from the New Orleans Vicinity Tidal Grid. NAVD88 values were realized through GEOID99.

Bench-mark	Latitude	Longitude	From MLLW (m)	From MLW (m)	From MHW (m)	From MHHW (m)	Average (m)	Std. Dev. (m)
BH3007	30.00666	-89.93861	-0.008	-0.008	-0.007	-0.007	-0.007	0.001
BH1083	30.01138	-89.93916	-0.022	-0.022	-0.022	-0.021	-0.022	0.000
BJ3686	30.02611	-90.11250	-0.139	-0.138	-0.140	-0.141	-0.140	0.001
BJ1342	30.02638	-90.11250	-0.136	-0.135	-0.137	-0.138	-0.137	0.001
BJ1344	30.02666	-90.11277	-0.130	-0.129	-0.131	-0.132	-0.131	0.001
BH1133	30.06805	-89.80361	-0.116	-0.117	-0.118	-0.118	-0.117	0.001
BH1145	30.11333	-89.76138	-0.142	-0.141	-0.143	-0.141	-0.142	0.001
BH1147	30.11888	-89.76277	-0.140	-0.139	-0.143	-0.141	-0.141	0.002
BH1539	30.16500	-89.73833	-0.148	-0.147	-0.150	-0.150	-0.149	0.002
BH1160	30.16611	-89.73750	-0.146	-0.145	-0.146	-0.146	-0.146	0.001
BH1164	30.16611	-89.73722	-0.135	-0.134	-0.135	-0.135	-0.134	0.001
BH1163	30.16638	-89.73750	-0.150	-0.149	-0.150	-0.150	-0.149	0.001
BH1537	30.16666	-89.73694	-0.150	-0.149	-0.150	-0.150	-0.149	0.001
BH1538	30.16666	-89.73777	-0.150	-0.149	-0.150	-0.150	-0.149	0.001
BH1754	30.24888	-88.07666	-0.227	-0.227	-0.238	-0.238	-0.233	0.006
BH1752	30.24916	-88.07666	-0.227	-0.227	-0.238	-0.238	-0.233	0.006
BH1755	30.24916	-88.07583	-0.230	-0.230	-0.241	-0.241	-0.236	0.006
BH1756	30.24944	-88.07555	-0.227	-0.227	-0.238	-0.238	-0.233	0.006
BH0946	30.30861	-89.32666	-0.234	-0.228	-0.211	-0.200	-0.218	0.016
BH0945	30.30888	-89.32555	-0.238	-0.232	-0.214	-0.202	-0.221	0.016
BH0934	30.31888	-89.32083	-0.207	-0.205	-0.208	-0.207	-0.207	0.001
BH0935	30.31972	-89.32361	-0.206	-0.204	-0.207	-0.206	-0.206	0.001
BH0936	30.32305	-89.32638	-0.210	-0.208	-0.211	-0.210	-0.209	0.001
BH0937	30.32361	-89.32722	-0.210	-0.208	-0.211	-0.210	-0.209	0.001
BH0392	30.39000	-88.85666	-0.304	-0.305	-0.305	-0.303	-0.305	0.001
BH0390	30.39277	-88.85777	-0.307	-0.308	-0.308	-0.306	-0.307	0.001

Table E.2. Derived NAVD 88-to-LMSL values for each tidal datum at NGS bench marks from the New Orleans Vicinity Tidal Grid. NAVD88 values realized through GEOID03.

Bench-mark	Latitude	Longitude	From MLLW (m)	From MLW (m)	From MHW (m)	From MHHW (m)	Average (m)	Std. Dev. (m)
BH3007	30.00666	-89.93861	-0.111	-0.111	-0.110	-0.110	-0.110	0.001
BH1083	30.01138	-89.93916	-0.124	-0.124	-0.123	-0.123	-0.123	0.000
BJ3686	30.02611	-90.11250	-0.216	-0.215	-0.217	-0.218	-0.217	0.001
BJ1342	30.02638	-90.11250	-0.213	-0.212	-0.214	-0.215	-0.214	0.001
BJ1344	30.02666	-90.11277	-0.207	-0.206	-0.208	-0.209	-0.208	0.001
BH1133	30.06805	-89.80361	-0.211	-0.212	-0.213	-0.213	-0.212	0.001
BH1145	30.11333	-89.76138	-0.222	-0.221	-0.223	-0.221	-0.222	0.001
BH1147	30.11888	-89.76277	-0.218	-0.217	-0.221	-0.219	-0.219	0.002
BH1539	30.16500	-89.73833	-0.209	-0.208	-0.211	-0.211	-0.210	0.002
BH1160	30.16611	-89.73750	-0.207	-0.206	-0.207	-0.207	-0.207	0.001
BH1164	30.16611	-89.73722	-0.195	-0.194	-0.195	-0.195	-0.195	0.001
BH1163	30.16638	-89.73750	-0.210	-0.209	-0.210	-0.210	-0.210	0.001
BH1537	30.16666	-89.73694	-0.210	-0.209	-0.210	-0.210	-0.210	0.001
BH1538	30.16666	-89.73777	-0.210	-0.209	-0.210	-0.210	-0.210	0.001
BH1754	30.24888	-88.07666	-0.102	-0.102	-0.113	-0.113	-0.108	0.006
BH1752	30.24916	-88.07666	-0.102	-0.102	-0.113	-0.113	-0.108	0.006
BH1755	30.24916	-88.07583	-0.105	-0.105	-0.116	-0.116	-0.111	0.006
BH1756	30.24944	-88.07555	-0.102	-0.102	-0.113	-0.113	-0.108	0.006
BH0946	30.30861	-89.32666	-0.194	-0.189	-0.171	-0.160	-0.179	0.016
BH0945	30.30888	-89.32555	-0.198	-0.192	-0.174	-0.163	-0.182	0.016
BH0934	30.31888	-89.32083	-0.164	-0.162	-0.165	-0.164	-0.164	0.001
BH0935	30.31972	-89.32361	-0.164	-0.162	-0.165	-0.164	-0.164	0.001
BH0936	30.32305	-89.32638	-0.167	-0.165	-0.168	-0.167	-0.167	0.001
BH0937	30.32361	-89.32722	-0.167	-0.165	-0.168	-0.167	-0.167	0.001
BH0392	30.39000	-88.85666	-0.154	-0.155	-0.155	-0.153	-0.154	0.001
BH0390	30.39277	-88.85777	-0.157	-0.158	-0.158	-0.156	-0.157	0.001

APPENDIX F. QC Deltas at Stations for TSS Grids

Table F.1. QC Deltas from the New Orleans TSS Grid, based on NAVD88 heights realized through GEOID 99.

PID	Latitude (deg)	Longitude (deg)	MHHW Deltas (m)	MHW Deltas (m)	MLW Deltas (m)	MLLW Deltas (m)	Avg. (m)	Std. Dev. (m)
BH3007	30.00666	-89.93861	0.001	0.001	0.002	0.002	0.002	0.001
BH1083	30.01138	-89.93916	0.000	0.000	0.000	0.001	0.000	0.000
BJ3686	30.02611	-90.11250	-0.003	-0.002	-0.004	-0.005	-0.004	0.001
BJ1342	30.02638	-90.11250	-0.001	0.000	-0.002	-0.003	-0.002	0.001
BJ1344	30.02666	-90.11277	0.003	0.004	0.002	0.001	0.002	0.001
BH1133	30.06805	-89.80361	0.001	0.000	-0.001	-0.001	0.000	0.001
BH1145	30.11333	-89.76138	0.000	0.001	-0.001	0.001	0.001	0.001
BH1147	30.11888	-89.76277	0.001	0.002	-0.002	0.000	0.000	0.002
BH1539	30.16500	-89.73833	0.001	0.002	-0.001	-0.001	0.000	0.002
BH1160	30.16611	-89.73750	-0.001	0.000	-0.001	-0.001	-0.001	0.001
BH1164	30.16611	-89.73722	0.010	0.011	0.010	0.010	0.010	0.001
BH1163	30.16638	-89.73750	-0.003	-0.002	-0.003	-0.003	-0.003	0.001
BH1537	30.16666	-89.73694	-0.002	-0.001	-0.002	-0.002	-0.002	0.001
BH1538	30.16666	-89.73777	-0.002	-0.001	-0.002	-0.002	-0.001	0.001
BH1754	30.24888	-88.07666	0.007	0.007	-0.005	-0.005	0.001	0.006
BH1752	30.24916	-88.07666	0.006	0.006	-0.005	-0.005	0.001	0.006
BH1755	30.24916	-88.07583	0.003	0.003	-0.008	-0.008	-0.002	0.006
BH1756	30.24944	-88.07555	0.004	0.004	-0.007	-0.007	-0.001	0.006
BH0946	30.30861	-89.32666	-0.015	-0.009	0.008	0.020	0.001	0.016
BH0945	30.30888	-89.32555	-0.017	-0.011	0.007	0.018	-0.001	0.016
BH0934	30.31888	-89.32083	0.001	0.003	-0.001	0.001	0.001	0.001
BH0935	30.31972	-89.32361	0.000	0.002	-0.001	0.000	0.000	0.001
BH0936	30.32305	-89.32638	0.000	0.002	-0.001	0.000	0.000	0.001
BH0937	30.32361	-89.32722	0.000	0.002	-0.001	0.000	0.000	0.001
BH0392	30.39000	-88.85666	0.001	0.000	0.000	0.002	0.001	0.001
BH0390	30.39277	-88.85777	0.000	-0.001	-0.001	0.001	0.000	0.001

Table F.2. QC Deltas from the New Orleans TSS Grid, based on NAVD88 heights realized through GEOID 03.

PID	Latitude (deg)	Longitude (deg)	MHHW Deltas (m)	MHW Deltas (m)	MLW Deltas (m)	MLLW Deltas (m)	Avg. (m)	Std. Dev. (m)
BH3007	30.00666	-89.93861	0.001	0.001	0.002	0.002	0.001	0.001
BH1083	30.01138	-89.93916	-0.001	-0.001	0.000	0.000	-0.001	0.000
BJ3686	30.02611	-90.11250	-0.003	-0.002	-0.004	-0.005	-0.003	0.001
BJ1342	30.02638	-90.11250	-0.001	0.000	-0.002	-0.003	-0.001	0.001
BJ1344	30.02666	-90.11277	0.003	0.004	0.002	0.001	0.003	0.001
BH1133	30.06805	-89.80361	0.001	0.000	-0.001	-0.001	0.000	0.001
BH1145	30.11333	-89.76138	0.000	0.001	-0.001	0.001	0.000	0.001
BH1147	30.11888	-89.76277	0.001	0.002	-0.002	0.000	0.000	0.002
BH1539	30.16500	-89.73833	0.001	0.002	-0.001	-0.001	0.000	0.002
BH1160	30.16611	-89.73750	-0.001	0.000	-0.001	-0.001	0.000	0.001
BH1164	30.16611	-89.73722	0.010	0.011	0.010	0.010	0.011	0.001
BH1163	30.16638	-89.73750	-0.003	-0.002	-0.003	-0.003	-0.002	0.001
BH1537	30.16666	-89.73694	-0.002	-0.001	-0.002	-0.002	-0.002	0.001
BH1538	30.16666	-89.73777	-0.001	0.000	-0.001	-0.001	-0.001	0.001
BH1754	30.24888	-88.07666	0.007	0.007	-0.004	-0.004	0.001	0.006
BH1752	30.24916	-88.07666	0.006	0.006	-0.005	-0.005	0.001	0.006
BH1755	30.24916	-88.07583	0.003	0.003	-0.008	-0.008	-0.002	0.006
BH1756	30.24944	-88.07555	0.004	0.004	-0.007	-0.007	-0.001	0.006
BH0946	30.30861	-89.32666	-0.014	-0.008	0.009	0.020	0.002	0.016
BH0945	30.30888	-89.32555	-0.016	-0.010	0.008	0.019	0.000	0.016
BH0934	30.31888	-89.32083	0.000	0.002	-0.001	0.000	0.001	0.001
BH0935	30.31972	-89.32361	0.000	0.002	-0.001	0.000	0.000	0.001
BH0936	30.32305	-89.32638	0.000	0.002	-0.001	0.000	0.000	0.001
BH0937	30.32361	-89.32722	0.000	0.002	-0.001	0.000	0.001	0.001
BH0392	30.39000	-88.85666	0.001	0.000	0.000	0.002	0.001	0.001
BH0390	30.39277	-88.85777	0.000	-0.001	-0.001	0.001	-0.001	0.001

APPENDIX G. COMPARISONS of DERIVED TSS WITH OBSERVATIONS AT TIDAL GAUGE AND TIDAL BENCH MARKS

Table G.1. New Orleans TSS (NAVD88 realized through GEOID99) Comparison to Tide Gauges and Tidal Bench marks.

ID	Latitude (deg)	Longitude (deg)	NAVD 88 to MSL (m)	TSS Derived Value (m)	Delta (m)
8735180	30.25000	-88.07500	-0.227	-0.227	0.000
8735523	30.39000	-88.85670	-0.305	-0.305	0.000
8743735	30.21330	-88.97170	-0.697	-0.686	0.011
8744756	30.36000	-89.08170	-0.273	-0.273	0.000
8745557	30.23170	-89.11670	-0.154	-0.156	-0.002
8745799	30.31000	-89.24500	-0.211	-0.211	0.000
8746819	30.32500	-89.32500	-0.208	-0.208	0.000
8747437	30.28170	-89.36670	-0.204	-0.204	0.000
8747766	29.27330	-89.35170	-0.439	-0.438	0.001
8760849	30.16670	-89.73670	-0.150	-0.148	0.003
8761402	30.11170	-89.76000	-0.139	-0.139	0.000
8761426	30.06500	-89.80000	-0.116	-0.116	0.000
8761473	30.00670	-89.93670	-0.015	-0.016	-0.001
8761487	29.24500	-90.66170	-0.167	-0.167	0.000
BH3007	30.00666	-89.93861	-0.007	-0.009	-0.002
BH1083	30.01138	-89.93916	-0.022	-0.022	0.000
BJ3686	30.02611	-90.11250	-0.140	-0.136	0.004
BJ1342	30.02638	-90.11250	-0.137	-0.135	0.002
BJ1344	30.02666	-90.11277	-0.131	-0.133	-0.002
BH1133	30.06805	-89.80361	-0.117	-0.117	0.000
BH1145	30.11333	-89.76138	-0.142	-0.142	-0.001
BH1147	30.11888	-89.76277	-0.141	-0.141	0.000
BH1539	30.16500	-89.73833	-0.149	-0.149	0.000
BH1160	30.16611	-89.73750	-0.146	-0.145	0.001
BH1164	30.16611	-89.73722	-0.134	-0.145	-0.010
BH1163	30.16638	-89.73750	-0.149	-0.147	0.003
BH1537	30.16666	-89.73694	-0.149	-0.147	0.002
BH1538	30.16666	-89.73777	-0.149	-0.148	0.001
BH1754	30.24888	-88.07666	-0.233	-0.234	-0.001
BH1752	30.24916	-88.07666	-0.233	-0.233	-0.001
BH1755	30.24916	-88.07583	-0.236	-0.233	0.002
BH1756	30.24944	-88.07555	-0.233	-0.231	0.001
BH0946	30.30861	-89.32666	-0.218	-0.219	-0.001
BH0945	30.30888	-89.32555	-0.221	-0.221	0.001
BH0934	30.31888	-89.32083	-0.207	-0.207	-0.001
BH0935	30.31972	-89.32361	-0.206	-0.206	0.000
BH0936	30.32305	-89.32638	-0.209	-0.209	0.000
BH0937	30.32361	-89.32722	-0.209	-0.209	0.000
BH0392	30.39000	-88.85666	-0.305	-0.305	-0.001
BH0390	30.39277	-88.85777	-0.307	-0.307	0.000

Table G.2. New Orleans TSS (NAVD88 realized through GEOID03) Comparison to Tide Gauges and Tidal Bench marks.

ID	Latitude (deg)	Longitude (deg)	NAVD 88 to MSL (m)	TSS Derived Value (m)	Delta (m)
8735180	30.25000	-88.07500	-0.102	-0.102	0.000
8735523	30.39000	-88.85670	-0.155	-0.155	0.000
8743735	30.21330	-88.97170	-0.567	-0.557	0.011
8744756	30.36000	-89.08170	-0.173	-0.173	0.000
8745557	30.23170	-89.11670	-0.071	-0.073	-0.002
8745799	30.31000	-89.24500	-0.154	-0.154	0.000
8746819	30.32500	-89.32500	-0.165	-0.165	0.000
8747437	30.28170	-89.36670	-0.178	-0.178	0.000
8747766	29.27330	-89.35170	-0.430	-0.430	0.000
8760849	30.16670	-89.73670	-0.210	-0.208	0.002
8761402	30.11170	-89.76000	-0.220	-0.220	0.000
8761426	30.06500	-89.80000	-0.212	-0.212	0.000
8761473	30.00670	-89.93670	-0.118	-0.119	-0.001
8761487	29.24500	-90.66170	-0.261	-0.261	0.000
BH3007	30.00666	-89.93861	-0.110	-0.112	-0.001
BH1083	30.01138	-89.93916	-0.123	-0.123	0.001
BJ3686	30.02611	-90.11250	-0.217	-0.213	0.003
BJ1342	30.02638	-90.11250	-0.214	-0.212	0.001
BJ1344	30.02666	-90.11277	-0.208	-0.210	-0.003
BH1133	30.06805	-89.80361	-0.212	-0.212	0.000
BH1145	30.11333	-89.76138	-0.222	-0.222	0.000
BH1147	30.11888	-89.76277	-0.219	-0.219	0.000
BH1539	30.16500	-89.73833	-0.210	-0.210	0.000
BH1160	30.16611	-89.73750	-0.207	-0.206	0.000
BH1164	30.16611	-89.73722	-0.195	-0.205	-0.011
BH1163	30.16638	-89.73750	-0.210	-0.208	0.002
BH1537	30.16666	-89.73694	-0.210	-0.208	0.002
BH1538	30.16666	-89.73777	-0.210	-0.209	0.001
BH1754	30.24888	-88.07666	-0.108	-0.109	-0.001
BH1752	30.24916	-88.07666	-0.108	-0.108	-0.001
BH1755	30.24916	-88.07583	-0.111	-0.108	0.002
BH1756	30.24944	-88.07555	-0.108	-0.106	0.001
BH0946	30.30861	-89.32666	-0.179	-0.180	-0.002
BH0945	30.30888	-89.32555	-0.182	-0.182	0.000
BH0934	30.31888	-89.32083	-0.164	-0.164	0.000
BH0935	30.31972	-89.32361	-0.164	-0.164	0.000
BH0936	30.32305	-89.32638	-0.167	-0.167	0.000
BH0937	30.32361	-89.32722	-0.167	-0.167	0.000
BH0392	30.39000	-88.85666	-0.154	-0.155	-0.001
BH0390	30.39277	-88.85777	-0.157	-0.157	0.001