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NOAA Technical Memorandum NOS CS 37

UPDATE TO THE TIDAL DATA IN VDATUM FOR EASTERN FLORIDA, GEORGIA, AND SOUTH CAROLINA

Silver Spring, Maryland
July 2016

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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July 2016

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ABSTRACT

The tidal component of VDatum for east Florida, Georgia, and South Carolina has been updated to include tidal datum values derived from the most recent water level observations. Also, additional coastline detail has been introduced to allow the incorporation of all tide stations in the region, including many in the uppermost portions of rivers and streams that were not previously in VDatum. Other improvements include modified non-tidal areas and the use of the EEZ for the outer boundary of the region. This third revision of the area features higher resolution of the marine grid (spacing of 0.001 deg in both directions), covers the shelf out to 75 nm (up from the previous 25 nm), and an altered boundary near the North Carolina VDatum region (which was also revised). Multiple unstructured grids were added to the original hydrodynamic model grid mesh to cover the rivers, but no additional model runs were carried out. Instead, datum fields were extrapolated over the new grid cells, and later corrected using the TCARI method. Revised uncertainty values were calculated using both the direct comparison between observed values and hydrodynamic–modeled values, and in the case of additional grids, a jackknifing procedure.

Key words: Florida, Georgia, South Carolina, tides, tidal datums, VDatum, coastline, hydrodynamic model, ADCIRC, unstructured grids, fused grids, TCARI

1. INTRODUCTION

VDatum, the NOAA vertical datum transformation application, was initially developed for eastern Florida, Georgia, and South Carolina (Yang et al., 2012) and included five regional data sets. These data sets include the datum transformation grids and a bounding polygon. This VDatum application became operational in 2010.

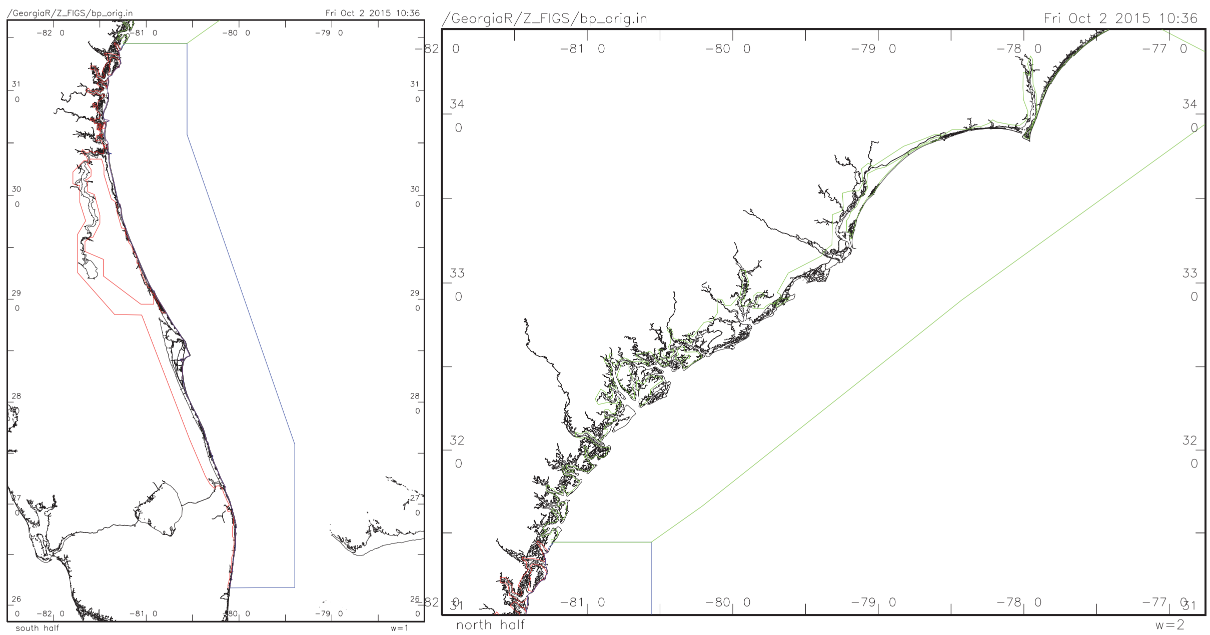
After certain problems were identified by the U.S. Army Corps of Engineers, a revised version was developed (Hess et al., 2013) and consisted of two regions instead of the original single region. The new regions were the Georgia-Florida coastal waterways region and the Georgia-Florida continental shelf region. This version became operational in April 2012.

Since the 2012 update, several new developments have occurred. Water level observations at several new tide stations have been added to the data base, and new datums, based on more recent observations, have been computed for many existing stations. Revised digital coastline information for the region has become available, and a digitized file of the U.S.'s Exclusive Economic Zone (EEZ) is available. For these reason, it was decided to update the tidal portion of the VDatum application data sets for the following three regions: (a) the Florida-Georgia waterways, the (b) Florida-Georgia continental shelf, and (c) the Georgia-South Carolina region. Updates to the Topography of the Sea Surface are covered elsewhere (White et al., in review). At the same time, VDatum for North Carolina is also being revised; details are available elsewhere (Wang and Myers, in preparation). These three regions and the original bounding polygons are shown in Figure 1.

For the purpose of making the text more compact, the following names for the regions shall be used in place of the full VDatum website names (Table 1).

Table 1. Names for the three regions on the VDatum website and as used in this report.

VDatum Website Name	Name in This Report
Georgia/South Carolina – Sapelo Island GA to the SC/NC border	S.C. Coast
Florida/Georgia – Shelf, Fort Lauderdale FL to Sapelo Island GA	Fla. Shelf
Florida/Georgia – Inland Waterways, Ft Lauderdale to Sapelo Is	Fla. Waterways



(a) (b)

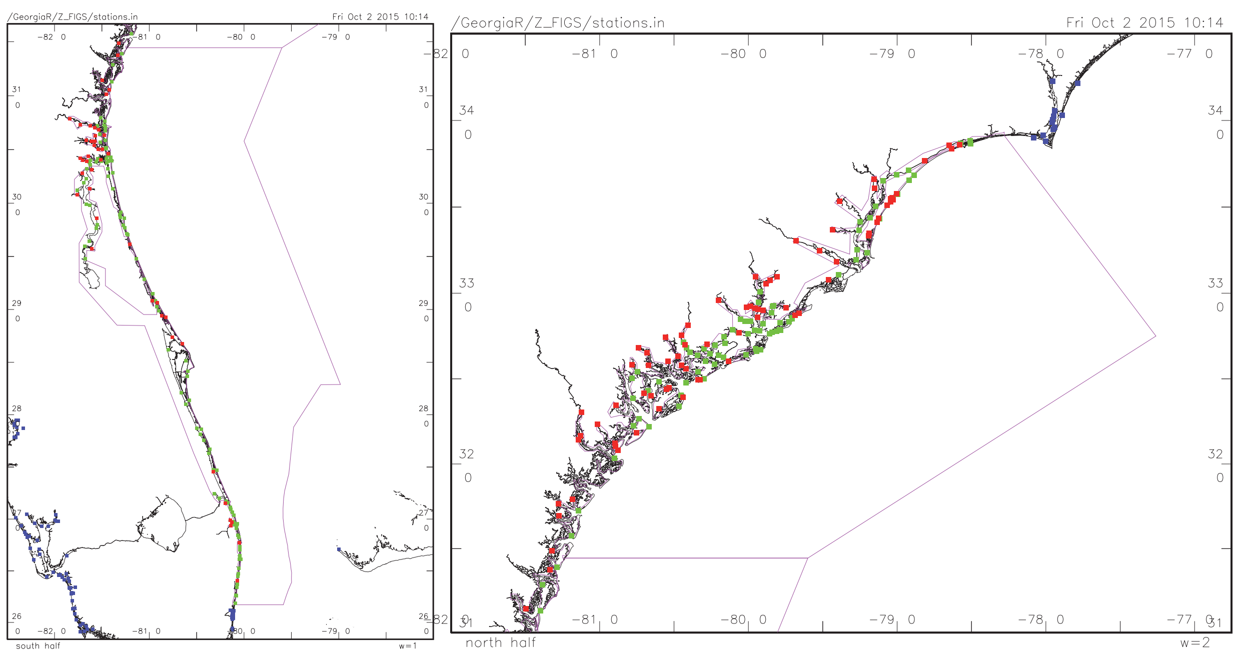
Figure 1. Regions covered by VDatum that were updated. Shown are the bounding polygons for (a) Fla. Waterways (red), Fla. Shelf (blue), and (b) S.C. Coast (green).

2. TIDE AND COASTLINE DATA

A tide survey of the Georgia coast was recently completed by NOAA's Center for Operational Oceanographic Products and Services (CO-OPS, 2011), and has resulted in updated tidal datum values at the region's tide stations. In this VDatum revision, it was also decided to include tide stations located significantly upstream from coastal water that were not included in the previous two VDatum file set generation. Many of these stations were not within the area covered by the existing Coast Survey Development Laboratory (CSDL) digital shoreline, so an enhanced shoreline was developed.

2.1. Tide Data

Tide station locations within the three VDatum regions are shown in Figure 2. All stations (file `merged_20150413.dat`) were used in updating VDatum. Stations and their positions and datum values are listed in Appendix A.



(a) (b)

Figure 2. Location of tide stations in the (a) Fla. Waterways VDatum and Fla. Shelf VDatum, and (b) S.C. Coast VDatum. Shown are tide stations inside the original Florida-South Atlantic Bight grid but outside the area of the present update (blue), inside the three bounding polygons (green), and inside the new, add-on grid areas (red).

2.2. Coastline Data

Additional coastline data was provided by National Geodetic Survey (NGS) as part of the Continually Updated Shoreline Project (CUSP). This high-resolution digital data was manually integrated into the existing digital shoreline to create a new product that included areas far up many of the rivers. The additional shoreline is shown in Figure 3.

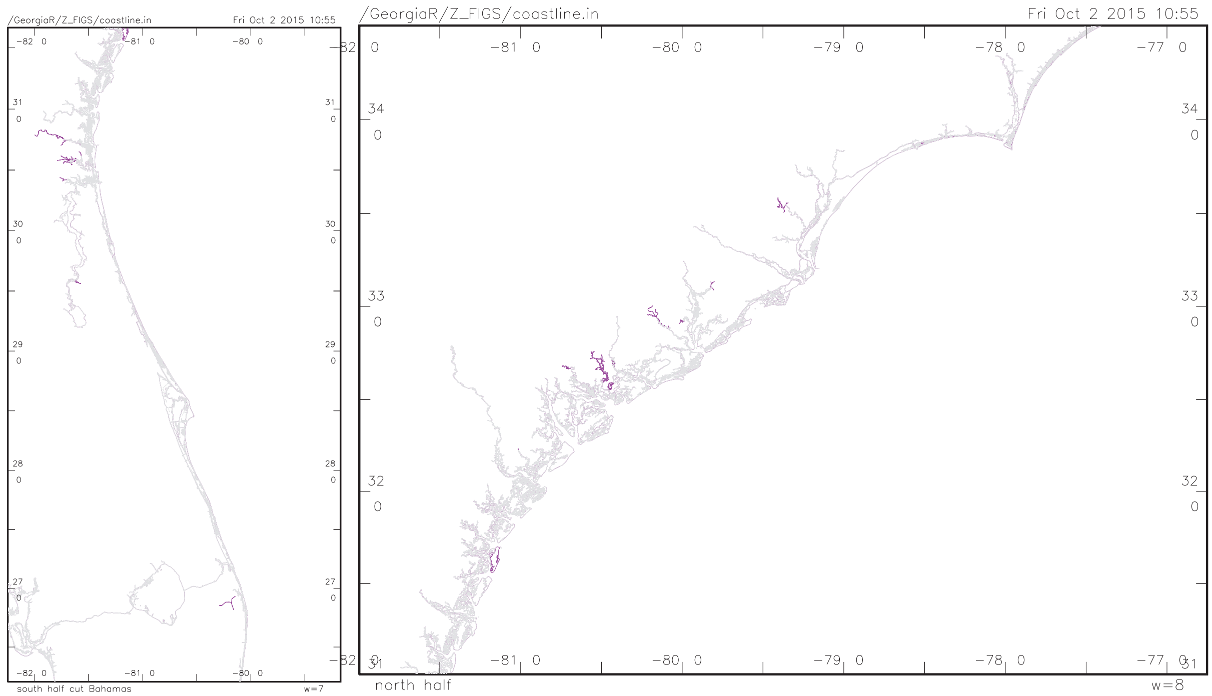


Figure 3. Revisions to shoreline, showing the original (grey) and added (purple) data.

3. UNSTRUCTURED HYDRODYNAMIC MODEL GRIDS

The inclusion of new tide stations required that some additional geographic areas be incorporated into the unstructured hydrodynamic model grid. These new areas included portions of rivers that were not previously covered. Another change to the grid was a shift in the nodes in the vicinity of the border with the North Carolina VDatum to more accurately represent the location of the Intra-Coastal Waterway. These modifications are discussed below.

3.1. Addition of Grid Cells

Several previously-unused tide stations were incorporated into the revised model grid. One such area is the upper reaches of the Nassau River, Florida, and is shown in Figure 4. In this area, there are several tide stations that lie outside the existing bounding polygon, and at least one station not within any river delineated by the existing digitized shoreline. Therefore, to include these stations, we revised the digitized shoreline data (Section 2), extended the bounding polygon (Section 4), and generated some additional grids.

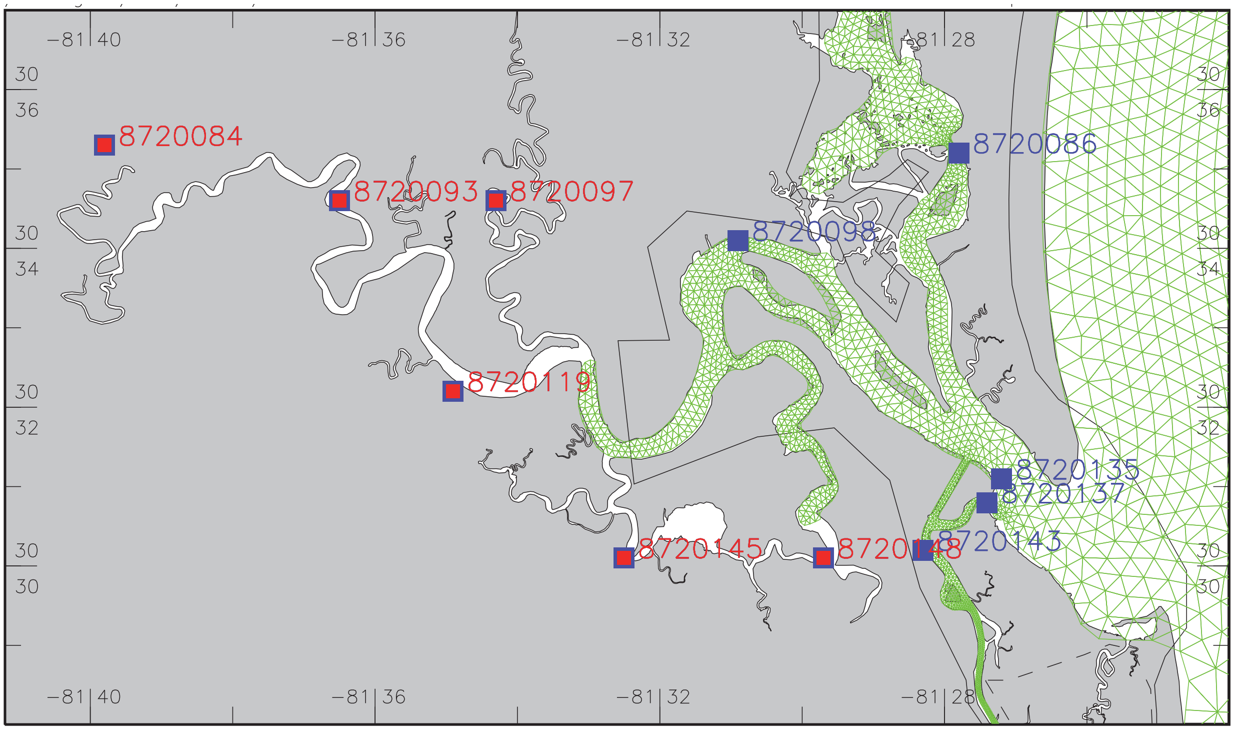


Figure 4. Tide stations around the Nassau River, Fla., showing the existing unstructured grid (green), tide stations within the existing grid (blue) and stations outside the exiting grid (red centers). The bounding polygon is shown as black lines.

To cover the new areas, additional grids were created using the Surface-water Modeling System (SMS) software. These grids conformed to the Advanced Circulation model (ADCIRC) input grid (fort.14) format, but had a depth value of zero. Using the revised shoreline, the new water regions were manually outlined, and the software created the unstructured triangular grids and saved them in ADCIRC-compatible format. For the example shown for the Nassau River (Figure 4), there were two separate, isolated grids generated to cover the area (Figure 5).

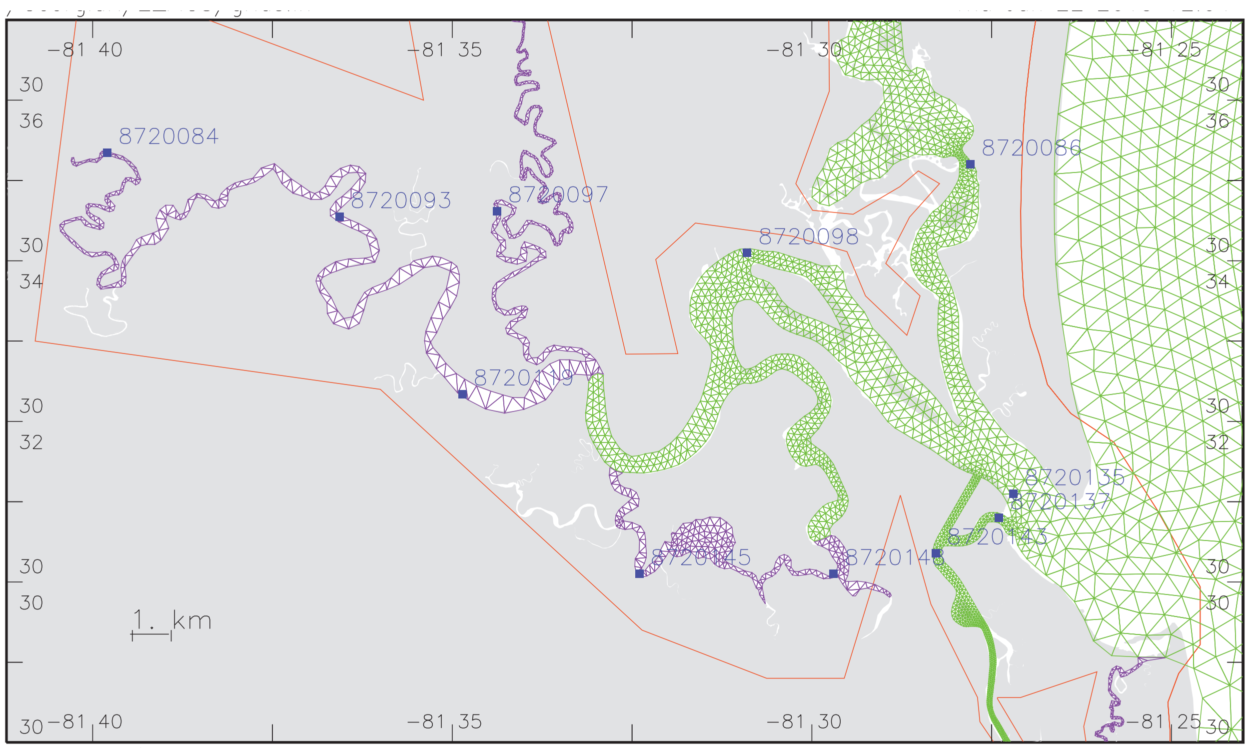


Figure 5. Region around the Nassau River, Fla., showing the tide stations (blue), original unstructured grid (green), the additional grids (purple), and the new bounding polygon (red).

This process was repeated for all the areas around tide stations not included in the original VDatum, leading to a set of separate grids, one for each added area. The additional gridded areas created this way, of which there are 95, are shown in Figure 6. The final add-on grid product was `grid_unadbc_20140924.grd`, and contained all the new gridded regions within one file.

In the final step, the additional gridded areas were joined with the original grid to make a 'fused' grid. The joining consisted of first identifying the closest node pairs, then fusing the two areas together by removing one of the two nodes in the pair, renaming the nodes at cell vertices, and renumbering the nodes. To complete the process, the boundary nodes were then computed and added to the ADCIRC-formatted grid file. For example, the uncorrected original grid for MHHW, `MHHW_MSL_filled.grd`, was fused with the add-on grid, `grid_unadbc_20140924.grd`, to obtain the grid `hhw_unc_fused_ibc.grd`. Note that the datum value at each node in the add-on areas is zero. Details of the fusion process are explained in the next section.

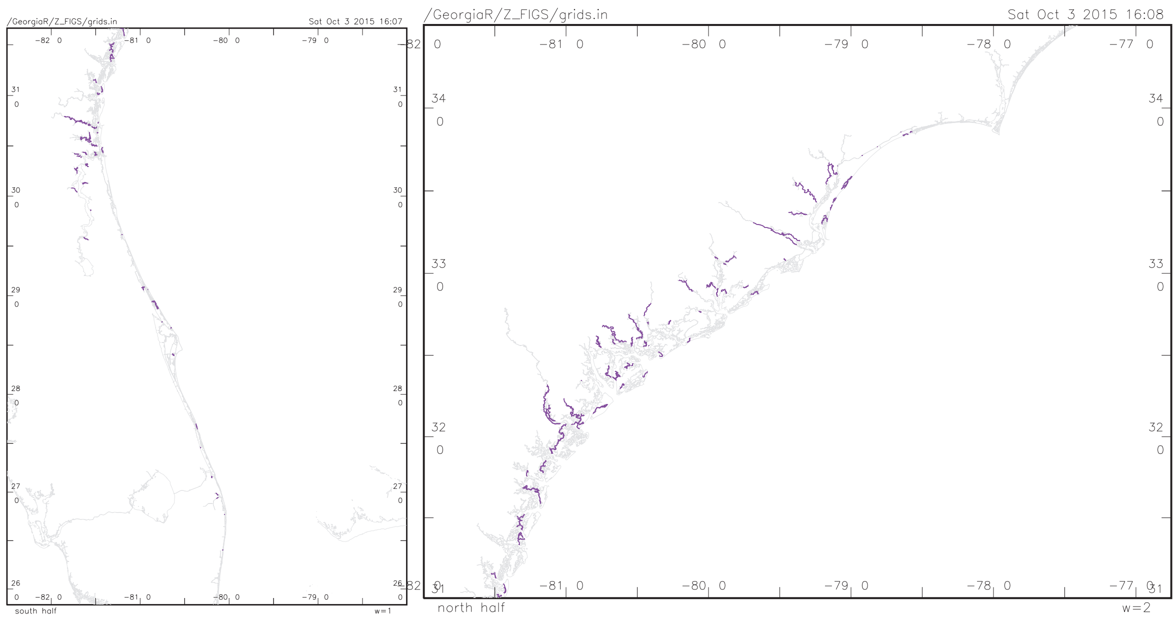


Figure 6. Location of the 95 additional grids (purple) in (a) Fla. Waterways VDatum and the Fla. Shelf and (b) S.C. Coast VDatum.

3.2. Grid Fusion

The process for creating the final, error-corrected tidal datum grid for each datum field (HHW, MHW, MLW, MLLW, DTL, and MTL) was a four-step process:

- Fill values in the add-on grids
- Fuse the add-on grids to the original, uncorrected grid
- Compute the error field for the fused grid
- Add the error field to the original field.

First, the add-on grid was filled by spatial interpolation using as the only boundary conditions the uncorrected datum values at the closest boundary nodes in the original, uncorrected grid. (In some preliminary calculations, the observed tidal datum values at stations inside the grid were also used as boundary conditions, but this produced some non-uniform values in the final solution in certain areas of the grid. This approach was then abandoned.)

Next, the add-on grid, filled as described in the previous step, was fused to the original, uncorrected grid. In the fusion process, the nodes in the add-on grid that lay closest to nodes in the original grid (within 1.0 km) were identified (Figure 7). Then the add-on grid and the original grid were combined by renumbering the add-on, removing one node from each closest pair, and renumbering the cells (`/disks/NASUSER/khess/V3/VPROGS/ADCIRC/Fuse/fuse.f`).

Then, an error field was created by spatially-interpolating the differences between the observed values and the values at the nodes in the uncorrected, fused grid. The interpolation method was the Tidal Constituent And Residual Interpolation (TCARI) (Hess, 2002).

Finally, the error field was added to the uncorrected, fused grid to create the final, corrected grid.

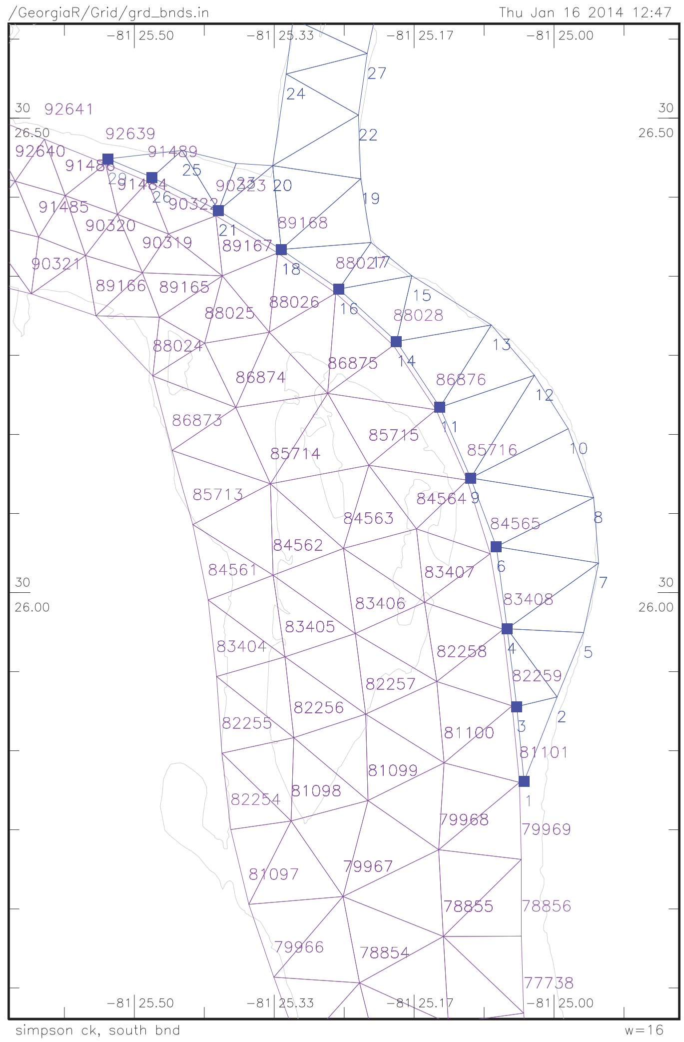


Figure 7. Region of Florida showing cells in the original grid (purple), the add-on grid (blue), and the nodes in the add-on grid identified as closest (blue squares).

3.3. Grid Shift at the ICWW

Another alteration to the hydrodynamic model grid was a shifting the grid cells southward in the Intra-Coastal Waterway (ICWW) in the region near the border with the North Carolina VDatum, where the position of the waterway does not match either the coastline or the waterway in the North Carolina model grid (Figure 8).

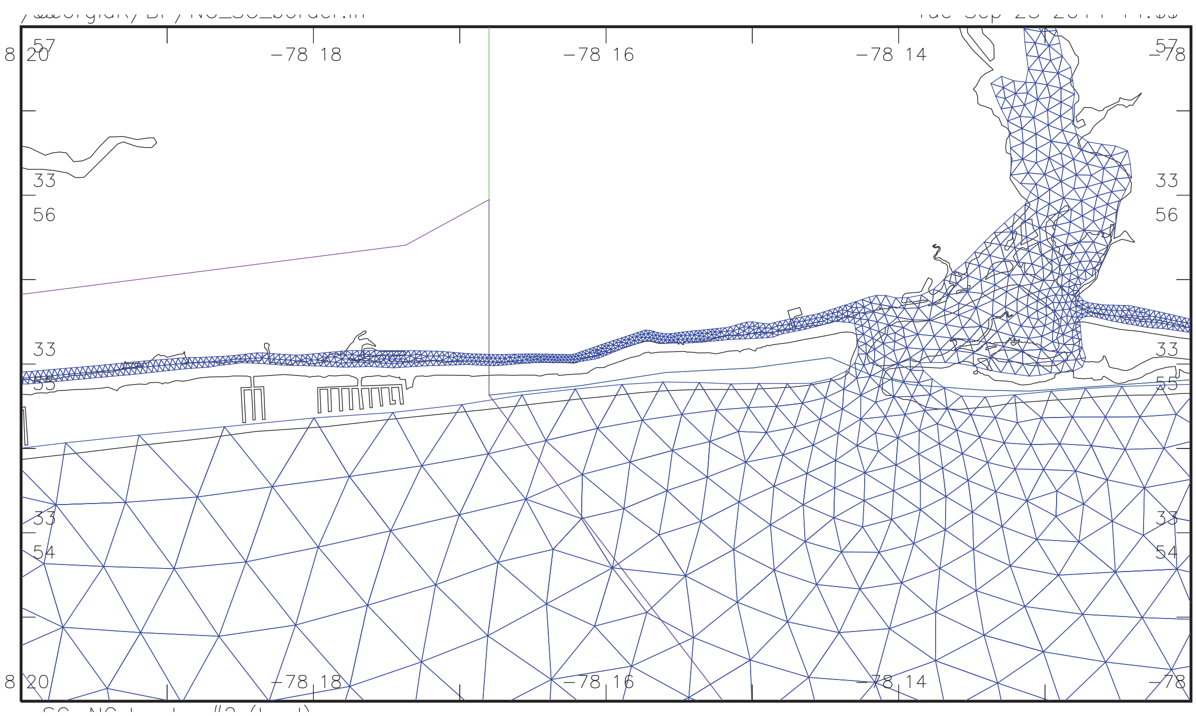


Figure 8. Original grid (blue) in the vicinity of the border with North Carolina, showing the mismatch with the accepted coastline (black). Also shown are the bounding polygon for N.C. (green), and the bounding polygon for S.C. Coast (purple).

The applied shift of the grid to the south is a linear interpolation between specified values (Table 2) at given longitudes. Also, the shift is applied only above a certain latitude: it is 0.0 at, or south of, latitude 33.70 and increases linearly to full value at, and north of, latitude 33.85. Let x,y be the original position of a grid node (longitude, latitude), y_s be the revised latitude of the grid node after shifting, and tabular values for longitude be X_n and for downward shift be S_n. Then, if the latitude of a grid node lay between 33.70 and 33.85 degrees, the following formula was applied.

$$y_s = y - C[\, S_{n-1}(X_n - x)/(X_n - X_{n-1}) - S_n(x - X_{n-1})/(X_n - X_{n-1})]$$

where $C = \max\{0, \min[1, (y - 33.70)/(33.85 - 33.70)]\}$.

A portion of the revised grid is shown in Figure 9.

Table 2. Values (degrees) used for shifting the grid nodes.

n	Longitude = X_n	Southward Latitude Shift = S_n
1	-78.540	0.0000
2	-78.520	-0.0005
3	-78.517	0.0000
4	-78.510	0.0005
5	-78.385	0.0007
6	-78.380	0.0000
7	-78.370	0.0011
8	-78.280	0.0009
9	-78.170	0.0011
10	-78.150	0.0000

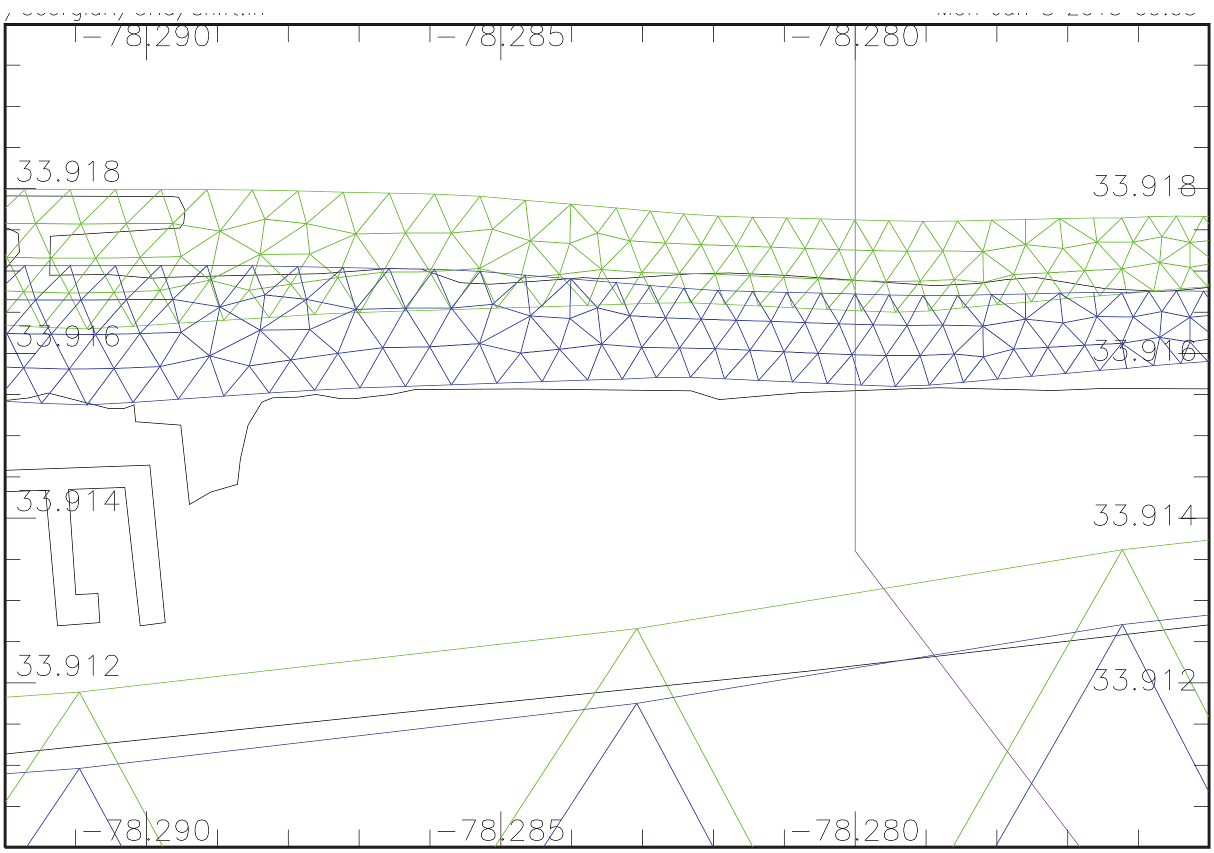


Figure 9. Model grids in the vicinity of the border with the NC VDatum region. Shown are the original grid (green), shifted grid (blue), the coastline (black), and the bounding polygon (purple).

4. MARINE GRIDS

The marine grids are regular grids that contain the tidal datum transfer information. The updated marine grids were developed for the three regions using the updated, corrected ADCIRC grids containing the datums. The program `vgridder18.f` was used to create the marine grids. The marine grids were populated using the most recent version of the population program, `vpop26.f`. Some land points immediately adjacent to the water were also populated to provide information of shoreline surveying by lidar. These added points (called the buffer layer) extend shoreward approximately 500 m over land.

Changes in the methodology for this update included:

- revised bounding polygons, including the use of the EEZ,
- new non-tidal polygons,
- higher resolution grids, and
- revised gridding and population algorithms.

4.1. Bounding Polygons

The original bounding polygons are shown in Figure 1, and the revised polygons in Figure 2. The revisions to the polygons included (1) the expansion of the area outward over the continental shelf to a distance of approximately 75 nautical miles (from the original 25 nm); (2) changes in the S.C. Coast VDatum bounding polygon at the border with the North Carolina VDatum region, which is also being updated (Wang et al., in preparation); (3) a small change in the bounding polygon at the southern border of the Fla. Shelf VDatum to make the borderline have a constant latitude; (4) changes in the eastward boundary of the Fla. Shelf bounding polygon so it coincides with the EEZ, and (5) extension of some sections to include the additional water grid cells.

4.2. Non-Tidal Areas

South Florida contains several non-tidal areas, as determined by CO-OPS, where the tide range is less than 0.09 m. The Fla. Waterways VDatum has two of them (Figure 10), one covering the Banana and Indian Rivers inland of Cape Canaveral, Fla. and the other at the southern end of the St Johns River, Fla. A third non-tidal area around Lake Okeechobee, Fla., is not within the bounding polygon. Some changes were made in the original non-tidal boundary around Port Canaveral to better match the barrier island and to accommodate the lock system at the west entrance of the port.

It is noted that one CO-OPS tide station (872-1832 at Melbourne, Fla.) falls within the Canaveral non-tidal area, but has a listed mean range of 0.07 m.

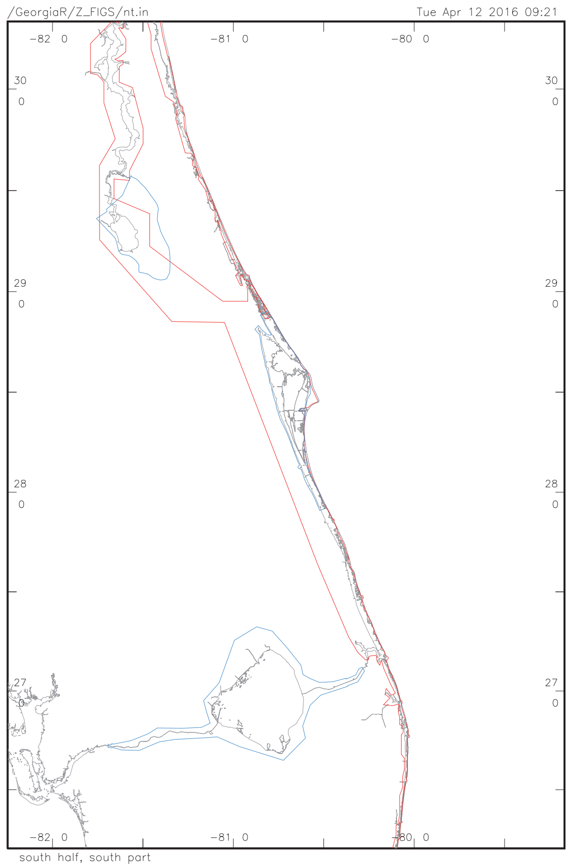


Figure 10. Non-tidal areas (blue) and the Fla. Waterways VDatum bounding polygon (red).

4.3. Marine Grid Resolution

The spatial resolution of the new marine grids was increased to better define the intricate waterways in this part of the coast. The new spacing is 0.0010 deg in both the latitudinal and the longitudinal directions. The previous spacing was 0.0015 in each direction. The parameters for all grids are shown in Table 3.

Table 3. Marine grid parameters. X0 and Y0 are the longitude and latitude (deg) of the south-westernmost point, DELX and DELY are the spacing (deg) in the horizontal and vertical directions, and IMAX and JMAX are the number of points in the horizontal and vertical directions.

Region	X0	Y0	DELX	DELY	IMAX	JMAX
Fla. Waterways	-81.862	26.169	0.001	0.001	1841	5281
Fla. Shelf	-81.468	26.169	0.001	0.001	2490	5278
S.C. Coast	-81.327	31.442	0.001	0.001	4070	2508

4.4. Algorithms

Finally, several changes were made to the gridding and populating algorithms. The changes were needed because, in previous versions of the gridding and populating programs, land areas adjacent to non-tidal areas were populated with incorrect values. The details of changes are given in Appendix B.

4.5. The Updated Grids

The revised grids (GTX files) were generated using the updated programs (`vgridder18.f` and `vpop26.f`). The grids for the three regions and the four tidal datums are shown in Appendix C.

Differences between the previous versions of the grids and the revised versions were computed. Since the two grids had different spatial resolutions and covered slightly different areas, the comparisons were between the previous value and the revised value that was spatially-interpolated to the location of the previous point. Only the MHHW fields were examined. Most of the differences were small, but a few ranged up to as much as 35 cm.

There were two main reasons for the differences: addition of water grids and changes in the tide stations. As an example, consider a portion of the river systems in the Fla. Waterways region (Figure 11). The larger difference (Fig. 11, at latitude 30° 43') is due to the addition of the river grids to the west. The region of the other large difference (Fig. 11, at latitude 31° 0') is due to the fact that there are tide stations in the revised version that did not exist for the previous version.

Other reasons for the differences were: increased spatial resolution of the GTX grids, revised datum values at the stations, revision of the precise positions of the tide stations, and changes in the methodology for populating the water and over-land points.

Note: Tidal datums in the previous version of VDatum in the area just north of Cape Canaveral, from latitude 28° 30' N to 29° 30' N and eastward from the shore out to longitude 80° 15' W, appear to be in error. The source of the errors is the inadvertent inclusion of the tidal datums at NOS tide station 872-1223 (Turtle Mound, Florida), located westward of the barrier island, in the calculations of the tidal datum fields on the Fla. Shelf.

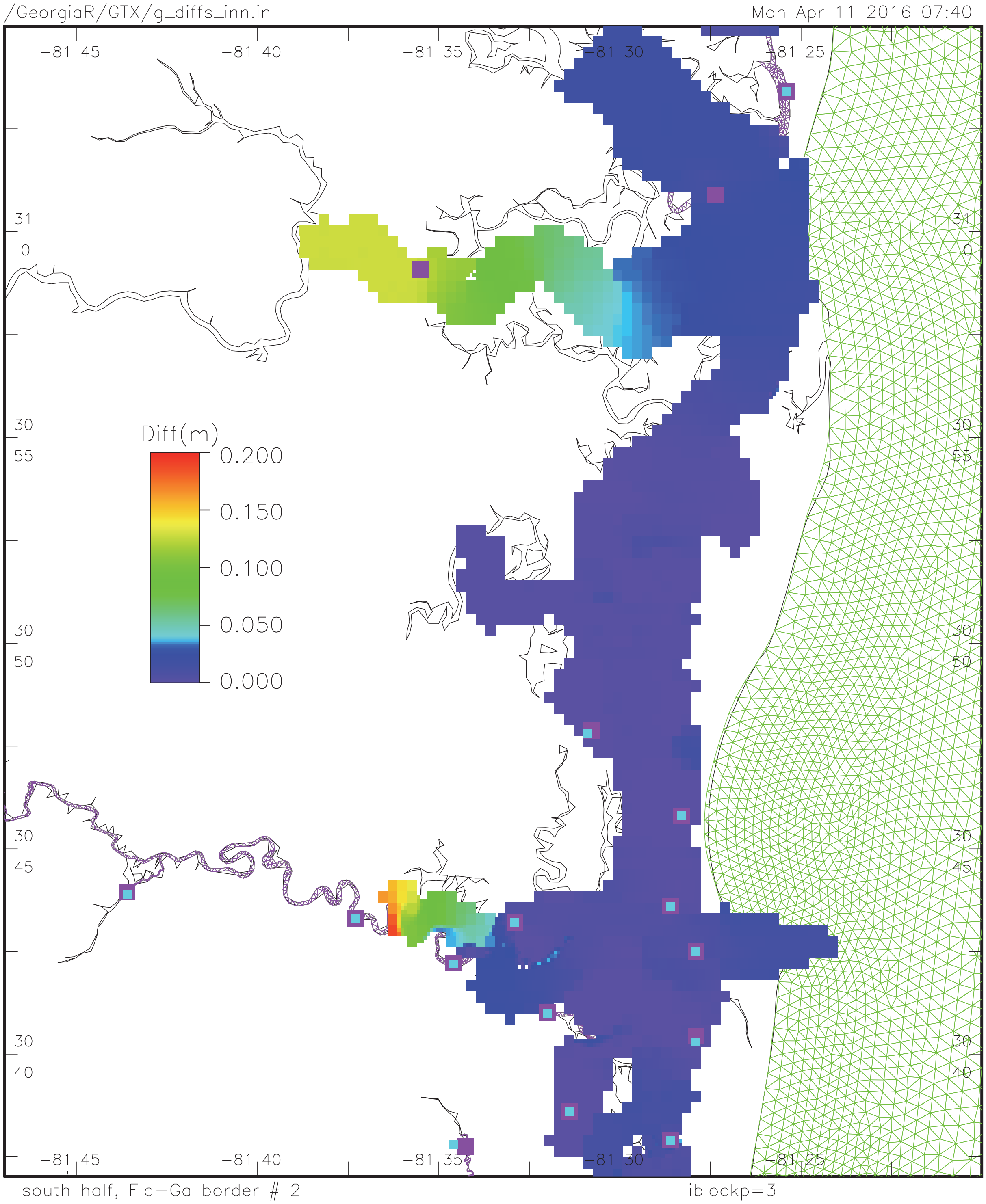


Figure 11. MHHW differences in the GTX files for a region around the Florida-Georgia border. The original hydrodynamic model grid is shown in green, and the additional gridded area in purple. Tide stations from the updated data (purple) and the previous (light blue) are also shown. Tide stations shown in solid purple have no previous data.

5. TESTING AND UNCERTAINTY ANALYSIS

5.1. Testing

After the new tidal datum fields were developed, they were tested according to the VDatum standards (NOS, 2012). The approach is to use a sequence of tests, performed in order, that inspect the data for validity. The files must pass each step in the testing sequence before going on to the succeeding test.

5.1.1 Polygon Overlap Test

The first test is for potential overlap of bounding polygons using the program `test_ovlp8.f`. This program checks each vertex in a bounding polygon to see whether it falls within another bounding polygon. Note that vertices are allowed to lie upon the side of another polygon, or to coincide with a vertex in another polygon. There should be no overlap between polygons, but they may share sides.

The tests included the polygons from the three regions, plus the polygons from the adjacent region to the south (Florida Bay) and the two regions to the north (North Carolina shelf and North Carolina waterways).

The results showed that the new polygons do not overlap, nor do they overlap with the adjacent polygons.

5.1.2 Polygon Coverage Test

Another test is for compatibility of the area within the GTX grid and the bounding polygon. That is, program `one5.f` inspects each GTX grid to insure that it completely covers the area within the bounding polygon. That is, the bottom row must have a latitude that is below the lowest point in the bounding polygon, the uppermost row must have a latitude that is above the topmost point in the bounding polygon, and so on. Otherwise an input location within the bounding polygon may request data from a point outside the grid mesh. If the files do not pass this test, either the bounding polygon or the GTX mesh, or both, must be corrected before any subsequent tests can be performed.

The tests showed that all three polygons were completely inside their GTX files.

5.1.3 Tidal Order Test

In this test, values of the tidal datums at each non-null point in the GTX file are examined by program `one5.f` to determine whether the magnitudes are in the logical order; i.e., whether the MHHW value is greater than the MHW value, the MHW value is greater than the MLW value, and the MLW value is greater than the MLLW value. The number of occurrences of situations where the order is not as it should be is reported.

The test showed that all points in the GTX files pass this requirement.

5.1.4 Tidal Station Datums Test

The next test is for compatibility of the GTX files with the official tidal datums at each water level station in the VDatum region. This is accomplished using the program `one5.f`, which reads a file of datums (`merged_20150413.dat`) for CO-OPS stations in the U.S. The program will compare the value of the tidal datum obtained by interpolation from the VDatum GTX files with the corresponding value from the observations. If there are significant mismatches between the GTX values and the datums at tide stations, then the GTX files should be regenerated.

The largest error found was 0.0104 cm, at Station 8720220 in the Fla. Waterways region. The results are shown in Table 4.

Table 4. Results of station datums tests. Summary of errors (cm) for the three regions.

Region	Statistic	MHHW	MHW	MTL	DTL	MLW	MLLW
Fla. Waterways	Num. Stations	132	132	132	132	132	132
	Mean Error	0.0001	-0.0002	0.0000	-0.0001	-0.0001	0.0000
	Mean Abs. Error	0.0014	0.0013	0.0016	0.0017	0.0014	0.0014
	RMS Error	0.0020	0.0019	0.0024	0.0027	0.0020	0.0021
	Stand. Deviation	0.0020	0.0019	0.0024	0.0027	0.0020	0.0021
	Max. Abs. Error	0.0102	0.0070	0.0080	0.0080	0.0078	0.0104
	Station w/MAE	8720220	8720220	8722512	8722588	8720220	8720220
Fla. Shelf	Num. Stations	12	12	12	12	12	12
	Mean Error	0.0002	0.0002	0.0004	0.0005	-0.0001	0.0000
	Mean Abs. Error	0.0003	0.0003	0.0004	0.0005	0.0001	0.0000
	RMS Error	0.0009	0.0009	0.0010	0.0011	0.0004	0.0001
	Stand. Deviation	0.0009	0.0009	0.0009	0.0010	0.0004	0.0001
	Max. Abs. Error	0.0030	0.0030	0.0030	0.0030	0.0015	0.0005
	Station w/MAE	8720291	8720291	8720291	8720291	8721604	8721604
S.C. Coast	Num. Stations	145	145	145	145	145	145
	Mean Error	0.0002	0.0002	0.0003	0.0001	-0.0002	-0.0002
	Mean Abs. Error	0.0012	0.0011	0.0009	0.0010	0.0012	0.0012
	RMS Error	0.0018	0.0016	0.0015	0.0016	0.0018	0.0017
	Stand. Deviation	0.0018	0.0016	0.0015	0.0016	0.0018	0.0017
	Max. Abs. Error	0.0044	0.0040	0.0040	0.0040	0.0040	0.0044
	Station w/MAE	8661989	8670424	8660642	8665101	8662071	8664878

5.1.5 Low Water Datum Test

This test (`one5.f`) checks that all water points inside a non-tidal polygon, if any, are zero. Only the Fla. Waterways region has non-tidal polygons, and all points inside the polygons, except in the lwd.gtx file, had zero datums.

5.1.6 Continuity Test

This test applies when a new region is adjacent to another VDatum region, or more specifically, when the bounding polygon of the new region has any side in common with the bounding polygon of an existing region. Here the program `test_con14.f` is used to compare transformations across the water regions of interface between the two regions.

The largest difference was in the border between the Fla. Waterways and the Fla. Shelf regions, where a difference of 2.57 cm was found. The results are shown in the Table 5.

Table 5. Results of continuity tests. Differences (cm) at water boundaries between pairs of regions.

Boundary	Statistic	MHHW	MHW	MTL	DTL	MLW	MLLW
Fla. Waterways and Fla. Shelf	Max. Diff (cm)	1.73	1.51	0.51	0.62	2.23	2.57
	Max. at Long.	-81.2270	-81.2270	-80.9170	-80.9170	-81.2270	-81.2270
	Max. at Lat.	29.7047	29.7047	29.0814	29.0814	29.7047	29.7047
	Pts. Tested	250	250	250	250	250	250
Fla. Shelf and S.C. Coast	Max. Diff (cm)	0.07	0.06	0.02	0.02	0.04	0.05
	Max. at Long.	-81.2338	-81.2338	-81.2338	-81.2010	-81.0955	-81.1963
	Max. at Lat.	31.4440	31.4440	31.4440	31.4440	31.4440	31.4440
	Pts. Tested	698	698	698	698	698	698
Fla. Shelf and Fla. Bay	Max. Diff (cm)	0.14	0.33	0.02	0.14	0.34	0.39
	Max. at Long.	-79.7323	-79.6075	-79.9908	-79.5964	-79.6120	-79.5941
	Max. at Lat.	26.1715	26.1715	26.1715	26.1715	26.1715	26.1715
	Pts. Tested	230	230	230	230	230	230
S.C. Coast and N.C. Shelf	Max. Diff (cm)	0.25	0.26	0.11	0.15	0.20	0.24
	Max. at Long.	-77.5514	-77.5528	-77.3873	-77.3675	-78.2783	-78.2783
	Max. at Lat.	33.0824	33.0840	32.8952	32.8726	33.9117	33.9117
	Pts. Tested	721	721	721	721	721	721
Fla. Waterways and Fla. Bay	Max. Diff (cm)	0.04	0.05	0.01	0.00	0.04	0.04
	Max. at Long.	-80.1040	-80.1040	-80.1040	-80.1040	-80.1040	-80.1040
	Max. at Lat.	26.1715	26.1715	26.1715	26.1715	26.1715	26.1715
	Pts. Tested	1	1	1	1	1	1

5.2. Uncertainty Analysis

5.2.1 Overview

As part of the implementation process, the uncertainty must be established to update the discussion on the VDatum website (http://vdatum.noaa.gov/docs/est_uncertainties.html). The uncertainties in the data and in the transformations, expressed as the standard deviation, or *σ*, for the Chesapeake Bay VDatum region is shown in Figure 12. The maximum cumulative uncertainty (MCU) is the square root of the sum of the square of the uncertainties from ITRFxx through to a tidal datum, following the tidal transformation with the maximum uncertainty (here MSL to MHHW or LMSL to MLLW).

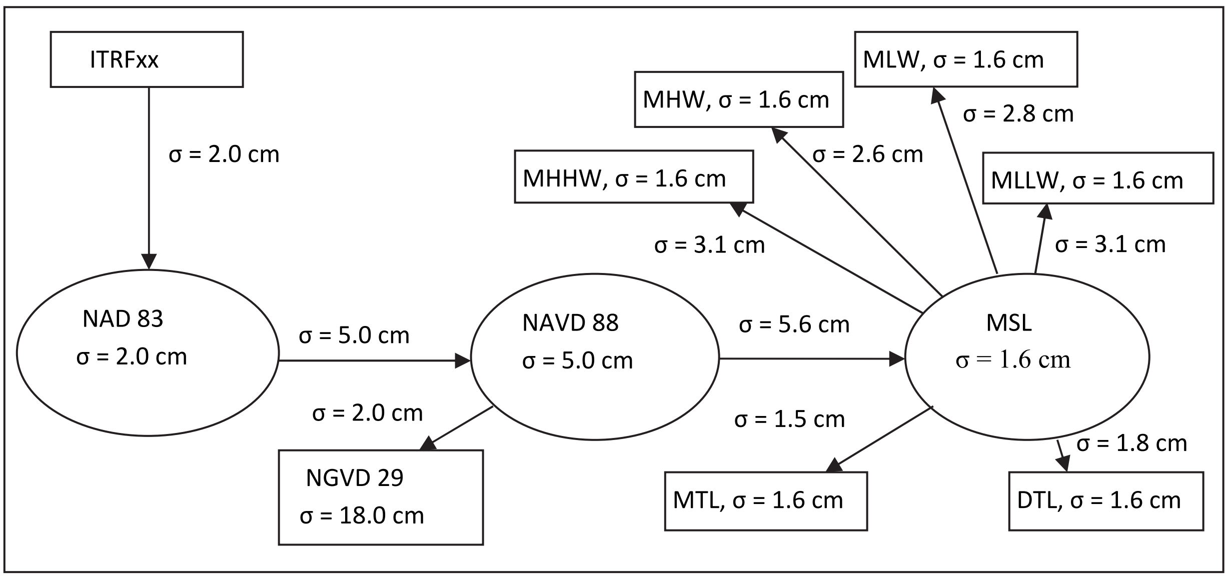


Figure 12. Schematic showing how VDatum handles the transformation (arrows) of a value from an ITRFxx ellipsoid to several vertical datums (boxes) through the core datums (ovals). Estimated errors in the transformations for the Chesapeake Bay VDatum region are shown as standard deviation values (σ) and are placed next to the arrow relating to each transformation. Also included are the estimated uncertainties for each individual vertical datum, shown as the σ values inside the ovals/boxes.

The maximum cumulative uncertainty, or total propagated uncertainty, is estimated here as the geometric sum of the uncertainties for the four transformations and the four sources of data. Some of these uncertainties are assumed to be constants nationwide (Table 6). The others, which are not constants, are discussed below.

Table 6. Uncertainties (cm) assumed to be constants nationwide.

TRANSFORMATION UNCERTAINTY			SOURCE DATA UNCERTAINTY		
ITRFxx to NAD 83	NAD 83 to NAVD 88 (GEOID)	NAVD 88 to NGVD29	NAD 83	NAVD 88	NGVD 29
2.0	5.0	2.0	2.0	5.0	18.0

5.2.2 Tidal Datum Transformations

The standard method of calculating tidal datum transformation uncertainty is to compare the observed values at the tide stations with the interpolated values from the uncorrected hydrodynamic model grid. For this update, however, the standard method cannot be used for the stations within the new gridded areas, because they have no uncorrected model values to use for comparison. Therefore, jackknifing (https://en.wikipedia.org/wiki/Jackknife_resampling) was used for all points in the two regions with added grids (Fla. Waterways and S.C. Coast). With this approach, the error at each station is the difference between the observed value, and the value of the spatially-interpolated (using TCARI) datum field that was generated using all stations except the one for which the estimate is made. At this time, it is unknown how jackknifing error and the standard comparison error are related.

In addition, at some stations located far up streams that have very small tidal ranges, jackknifing produced unreasonably large errors. Therefore, at those stations (there were 22; see the next paragraph) the error at the adjacent downstream station was substituted. This produced more reasonable statistical error results (Table 7).

Table 7. Summary of statistics for the estimated errors (cm) for tidal datum transformations in the three VDatum regions.

REGION	STATISTIC	MHHW	MHW	MTL	DTL	MLW	MLLW
Fla. Waterways	Num. Sta.	133	133	133	133	133	133
	Mean Error	1.60	1.33	0.47	0.57	-0.39	-0.46
	Mean Abs. Err.	3.00	2.80	0.92	1.17	3.41	3.68
	RMS Error	5.28	4.71	1.57	1.87	5.31	5.62
	Std. Dev.	5.04	4.52	1.50	1.78	5.30	5.60
	Max. Abs. Err.	27.62	23.97	8.93	9.77	22.74	24.38
	Max @ Sta.	8720757	8720757	8721136	8721136	8720398	8720398
Fla. Shelf	Num. Sta.	12	12	12	12	12	12
	Mean Error	-1.74	-1.24	-1.24	-0.89	-1.21	0.10
	Mean Abs	4.08	3.33	1.24	1.12	2.49	2.91
	RMS Error	5.28	4.52	1.88	1.72	4.34	4.25
	Std. Dev.	4.99	4.35	1.41	1.47	4.17	4.25
	Max. Abs. Err.	14.00	12.55	5.20	4.80	13.40	12.10
	Max @ Sta.	8722491	8722491	8722491	8722491	8720291	8720291
S.C. Coast	Num. Sta.	145	145	145	145	145	145
	Mean Error	0.26	0.10	0.95	1.07	1.80	1.88
	Mean Abs	4.18	3.92	1.70	1.92	5.63	5.84
	RMS Error	7.37	7.01	2.58	2.83	9.39	9.49
	Std. Dev.	7.36	7.00	2.40	2.61	9.21	9.30
	Max. Abs. Err.	29.46	29.55	10.78	12.48	41.24	42.06
	Max @ Sta.	8670424	8670424	8667074	8667074	8670424	8670424

The 22 stations where the error at the adjacent station was substituted are, in S.C., 866-1593, 866-2216, 866-2405, 866-3535, 866-3539, 866-4531, 866-4589, 866-5257, 866-5814, 866-6659, 866-8701, 866-9072, and 866-9415. In Ga., 867-3381. In Fla., 872-0001, 87-20059, 872-0084, 872-0189, 872-0213, 872-0434, 872-2472, and 872-2496.

5.2.3 TSS Transformation Fields

Along with the tidal datum fields, the topography of the sea surface (TSS) transformation field was also updated. Details are given in White et al. (in review).

The uncertainty in the TSS transformation between NAVD 88 and MSL is derived by combining the uncertainty in the NAVD 88 height transformations at tidal bench mark locations ($\sigma_{heights}$) and the uncertainty in the interpolation of height values between stations ($\sigma_{interpolation}$). The total uncertainty (σ_{tss}) in the topography of the sea surface is therefore:

$$\sigma_{tss} = (\sigma^2_{heights} + \sigma^2_{interpolation})^{1/2}$$

In order to determine the uncertainty in the NAVD 88 height transformations at tide stations, $\sigma_{heights}$, we examined the differences between the accepted NOAA values and the values interpolated using VDatum at the same location. The uncertainty is determined as the SD of the differences. Values are given in Table 8.

To evaluate $\sigma_{interpolation}$, the uncertainty in the interpolation method, an approach was used whereby each individual station was selectively removed from the interpolation (i.e., jackknifing). The difference at each station between the interpolation results with and without that station was then used as a measure of how much the results could vary in relation to data availability. While this method also reflects the importance of a station and/or station density, we felt that the results obtained with this approach serves as a measure of the overall interpolation accuracy. Note that the substitution of the error at adjacent stations for some stations located far upstream was also used (see Sect 5.2.2). The uncertainty measure is defined as the Root Mean Square Error of the differences. Values are given in Table 8.

Table 8. TSS (NAVD 88 to MSL) errors (cm) for the three updated regions.

Region	Height Error	Interpolation Error	Total TSS Error
Fla. Waterways	0.00068	4.50	4.50
Fla. Shelf	0.00076	4.10	4.10
S.C. Coast	0.00065	9.41	9.41

5.2.4 Geoid Transformation

In earlier estimates of uncertainty, the geoid uncertainty, or uncertainty in the transformation from NAD 83 to NAVD 88, was considered a constant (see Table 6). However, for GEOID09, uncertainties are listed by state (Roman et al.). They are, for Fla. and Ga., 1.4 cm, and for S.C., 1.2 cm. Therefore, for both the Fla. Waterways and the Fla. Shelf regions, we use 1.4 cm, and for the S.C. Coast region, we use 1.3 cm (the simple average of the values for the two states).

5.3.5 Final Tabulation

Combining data from Tables 7 and 8, and using the national values (Table 6), we summarize the uncertainties for the three regions in Table 9. Note that because the tidal transformations only are being considered, the uncertainty in the NGVD 29 data is not used.

Table 9. Transformation uncertainties and source data uncertainties (cm) for the three regions. Format of this table follows that on the VDatum uncertainty webpage. Notes: (*) Tidal datum error values obtained by jackknifing. (N) This region contains non-tidal areas.

REGION	TRANSFORMATION UNCERTAINTY									
	A. ITRF to NAD83	B. NAD83 to NAVD88 (Geoid09)	C. NAVD88 to MSL	MSL to MHHW	MSL to MHW	MSL to MTL	MSL to DTL	MSL to MLW	MSL to MLLW	D. Max tidal
Georgia/South Carolina – Sapelo Island GA to the SC/NC border (*)	2.0	1.3	9.4	7.4	7.0	2.6	2.8	9.4	9.5	9.5
Florida/Georgia – Shelf , Ft Lauderdale FL to Sapelo Island GA(*)	2.0	1.4	4.1	5.3	4.7	1.6	1.9	5.3	5.6	5.6
Florida/Georgia – Inland Waterways , Ft Lauderdale to Sapelo Is (*,N)	2.0	1.4	4.5	6.1	5.5	1.4	1.7	6.2	6.4	6.4

Table 9 (continued).

REGION	SOURCE DATA UNCERTAINTY				MCU
	E. ITRFxx	F.NAD83	G. NAVD88	H. Tidal Datums	
Georgia/South Carolina – Sapelo Island GA to the SC/NC border (*)	0.0	2.0	5.0	1.4	14.8
Florida/Georgia – Shelf , Ft Lauderdale FL to Sapelo Island (*)	0.0	2.0	5.0	1.4	9.1
Florida/Georgia – Inland Waterways, Ft Lauderdale to Sapelo Is (*,N)	0.0	2.0	5.0	1.4	9.5

The MCU is computed by the equation:

$$MCU = (\sigma_A^2 + \sigma_B^2 + \sigma_C^2 + \sigma_D^2 + \sigma_E^2 + \sigma_F^2 + \sigma_G^2 + 2\sigma_H^2)^{1/2}$$

where uncertainties for A through H are shown in Table 9. Note that the source data uncertainty for tidal datums is used twice, once for MSL and once for the datum with maximum transition uncertainty.

For comparison purposes, we present the MCU values from the previous version and those from this update (Table 10). It is apparent that the MCU for the Ga.-S.C area went up, while the MCUs for Fla.-Ga. went down. For the Ga.-S.C area, the major cause of the larger value was that TSS error increased from 4.9 cm to 9.4 cm. For the Fla.-Ga. Shelf, the major cause of the smaller value was that TSS error decreased from 9.1 cm to 4.1 cm. For the Fla.-Ga. Waterways, there were only modest changes in the TSS and tidal conversions, but the Geoid model error was reduced from 5.0 cm (the nationwide value, Table 6) to the state value of 1.4 cm.

Table 10. Comparison of the previous values of the TSS (NAVD88 to MSL) errors, tidal errors, and MCUs with those from the update.

VDatum Region	NAVD88 to MSL	Max. Tide to MSL	MCU (cm) Dec 2013	NAVD88 to MSL	Max. Tide to MSL	MCU (cm) Present
Georgia/South Carolina/North Carolina – Sapelo Island GA to New River NC	4.9	8.3	12.5	9.4	9.5	14.8
Florida/Georgia – Shelf, Fort Lauderdale FL to Sapelo Island GA	9.1	5.1	13.1	4.1	5.6	9.1
Florida/Georgia – Inland Waterways, Ft Lauderdale to Sapelo Is	3.7	6.5	11.1	4.5	6.4	9.5

6. SUMMARY

6.1. Overview

The revision of the east Florida, Georgia, and South Carolina VDatum resulted in the inclusion of many additional tide stations in the upper reaches of rivers and streams. Several aspects of the update went quite smoothly:

- The CSDL VDatum archive contained all the useful and necessary data from previous VDatum models,
- The SMS software was easily used to generate new grids to the upstream areas of rivers,
- Additional high-resolution digitized shoreline was produced by RSD in a timely manner, and
- Revisions in non-tidal area polygons were accomplished cooperatively.

Some other aspects of the updates had some difficulties:

- The new digitized shoreline had to be manually integrated with the existing shoreline file for the region, a tedious endeavor,
- All CO-OPS tide station positions had to be scrutinized, and in some cases corrected, to insure that they lay inside the water, and
- The method for estimating uncertainty in the added grid areas using jackknifing has raised several questions, and warrants further discussion.

There are two topics to be discussed in further detail. The first is the inclusion of numerous tide stations in the upper reaches of rivers; this created several difficulties. The second is the revision of the bounding polygons for the extension to 75 km and the consideration of the U.S. Exclusive Economic Zone (EEZ); these were handled relatively easily.

6.2. Extension into Rivers

At the outset of the current revision, it was noted that not all the existing locations that had tidal datum information were used in the previous versions of VDatum. Many stations were excluded because they were located in the upper reaches of rivers and were not included in the original hydrodynamic model grid. Therefore, it was decided to include all tide stations within each VDatum region, even those up rivers. In retrospect, this decision created several problems, some of which have not encountered in previous VDatum developments. These aspects are discussed below.

Shoreline

The inclusion of tide stations in the upper reaches of rivers required, in many cases, the expansion of the digitized shoreline file to include the additional rivers. Most of the new shoreline was generated by a direct request to NGS and was made available from the Continually Updated Shoreline Product (CUSP) web portal. The new shoreline data covered only portions of the rivers, and had to be manually integrated with the working shoreline file for the region.

Tide Station Locations

Using the revised shoreline file, the positions of the tide stations in the CO-OPS database was checked to make sure that the station was located inside a body of water. However, numerous stations were found to lie outside water. Using CO-OPS station descriptions and satellite images, their positions were then manually revised.

Grid Generation for Added River Areas

New unstructured grids for the added river areas were constructed in the ADCIRC format using the SMS software. Since it was decided not to make additional hydrodynamic model runs, no bathymetry was used. However, a cursory inspection showed that many of the areas lacked any bathymetric data. Also, the gridded position of the Intracoastal Waterway near the South Carolina-North Carolina border was found to not match that in the North Carolina hydrodynamic model grid, so some adjustment in its position was made in the Florida grid.

Non-tidal Areas

Some of the areas within the Fla. Waterways VDatum region are designated by CO-OPS as being non-tidal. That is, their mean range is less than 0.3 ft. In a few areas, especially around Port Canaveral, Fla., the precise location of the polygon was altered to better account for the presence of canals and docking facilities. In addition, one tide station (872-1832 at Melbourne, Indian River, Fla.) had significant tidal datums, but since it is located in a non-tidal area, its data was not used in VDatum development.

Method for Estimating Datums

For the stations in the added river grids, a completely new method to estimate datums had to be developed. First, each datum field was extrapolated using the TCARI method. The boundary conditions were the uncorrected, model-derived values from the existing model grid. Then, this set of uncorrected grids was fused with the existing uncorrected grid. Next, the error values at all tide stations were generated using the latest datum values. Then, a field of errors was interpolated over the fused grid using TCARI. Finally, the error field was added to the uncorrected datum field to obtain the final, corrected field. Several new computer programs had to be written to implement these procedures.

Method for Estimating Uncertainty

The standard VDatum method for estimating uncertainty cannot be used for the stations within the new grid, because they have no uncorrected model values to use for comparison. Therefore, jackknifing was used. With this approach, the error at each station is the difference between the observed value, and the value of the spatially-interpolated (using TCARI) datum field that was generated using all stations except the one for which the estimate is made. At this time, it is unknown how jackknifing error and the standard comparison error are related.

In addition, at some stations located far up streams that have very small tided ranges, jackknifing produced unreasonably large errors. Therefore, at those stations (there were 22) the error at the adjacent downstream station was substituted. This produced more reasonable statistical error results.

6.3. New Bounding Polygons

During VDatum development, it was decided to extend the offshore region of coverage to out to 75 km, from the existing 25 nm (46 km). Therefore, the bounding polygons were revised outward accordingly. Also, the border of the S.C. Coast VDatum with the North Carolina VDatum region was moved southward so its new position fell in a portion of the coast with relatively simple geography. In addition, it was also decided to restrict coverage to within the U.S.'s Exclusive Economic Zone (EEZ). This was accomplished using a digitized EEZ polygon. Finally, the Fla. Shelf's bounding polygon was revised to have constant latitude along its southern boundary. This will require a corresponding adjustment of the polygon for the Florida Bay VDatum.

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APPENDIX A. TIDE STATIONS AND DATUMS

Shown are station number, longitude and latitude, tidal datums, and region. Table A.1 is for the Fla. Waterways, Table A.2 is for the Fla. Shelf, and Table A.3 is the S.C. Coast.

Table A.1. Tide stations in Fla. Waterways. The quantity -9.999 denotes a missing value.

N	Station	Latitude	Longitude	MHHW	MHW	MLW	MLLW	NAVD88
1	8675622	31.390000	-81.288300	1.146	1.025	-1.054	-1.118	-9.999
2	8675761	31.373861	-81.333944	1.121	1.009	-1.104	-1.170	-9.999
3	8676329	31.285000	-81.385000	1.065	0.968	-1.126	-1.199	-9.999
4	8677406	31.144556	-81.496806	1.130	1.018	-1.154	-1.221	-9.999
5	8677832	31.056700	-81.423300	1.110	1.005	-1.076	-1.141	-9.999
6	8678124	31.014806	-81.455972	1.088	0.979	-1.021	-1.084	-9.999
7	8678322	30.984700	-81.591667	1.030	0.943	-1.128	-1.197	-9.999
8	8679511	30.798000	-81.513000	1.050	0.939	-1.022	-1.084	-9.999
9	8679758	30.763300	-81.471700	1.023	0.915	-0.984	-1.044	-9.999
10	8679945	30.726700	-81.476700	0.994	0.882	-0.922	-0.978	-9.999
11	8679964	30.720000	-81.548300	0.943	0.841	-0.945	-1.005	-9.999
12	8720001	30.786700	-81.840000	0.384	0.338	-0.523	-0.589	-0.267
13	8720004	30.721700	-81.621700	0.755	0.675	-0.800	-0.858	0.004
14	8720006	30.732500	-81.726700	0.613	0.555	-0.747	-0.793	-0.028
15	8720007	30.703700	-81.576700	0.992	0.887	-0.999	-1.055	0.130
16	8720011	30.708300	-81.465000	1.005	0.900	-0.916	-0.976	-9.999
17	8720023	30.683500	-81.533300	1.009	0.903	-1.007	-1.071	0.113
18	8720030	30.674000	-81.465000	0.995	0.888	-0.947	-1.004	0.161
19	8720051	30.643300	-81.523300	1.043	0.929	-0.999	-1.059	0.153
20	8720058	30.631700	-81.476700	0.990	0.883	-0.938	-0.995	0.147
21	8720059	30.629080	-81.570900	0.357	0.326	-0.474	-0.558	-9.999
22	8720084	30.589100	-81.663300	0.402	0.362	-0.522	-0.574	-0.106
23	8720086	30.586700	-81.463300	0.917	0.812	-0.830	-0.881	0.122
24	8720093	30.575800	-81.609500	0.607	0.551	-0.718	-0.779	0.016
25	8720097	30.577000	-81.573000	0.509	0.457	-0.617	-0.678	0.002
26	8720098	30.568300	-81.515000	0.785	0.694	-0.754	-0.811	0.073
27	8720119	30.539000	-81.581000	0.653	0.579	-0.718	-0.780	0.053
28	8720135	30.518300	-81.453300	0.911	0.807	-0.765	-0.823	-9.999
29	8720137	30.513300	-81.456700	0.881	0.774	-0.765	-0.822	-9.999
30	8720143	30.506000	-81.471300	0.868	0.764	-0.784	-0.828	-9.999
31	8720145	30.501700	-81.540000	0.695	0.628	-0.772	-0.835	0.061
32	8720148	30.501700	-81.495000	0.774	0.687	-0.803	-0.859	-9.999
33	8720168	30.463300	-81.431500	0.862	0.757	-0.791	-0.829	0.139
34	8720186	30.441000	-81.438000	0.792	0.701	-0.756	-0.799	0.107
35	8720189	30.437400	-81.642500	0.487	0.442	-0.468	-0.493	0.089
36	8720196	30.416700	-81.453300	0.696	0.622	-0.686	-0.724	-9.999
37	8720198	30.406000	-81.509200	0.609	0.548	-0.547	-0.579	-9.999
38	8720203	30.413000	-81.544000	0.552	0.493	-0.565	-0.593	0.104
39	8720211	30.400000	-81.412000	0.785	0.695	-0.727	-0.774	0.173
40	8720213	30.420000	-81.728300	0.448	0.405	-0.392	-0.420	0.068
41	8720214	30.396700	-81.395000	0.831	0.731	-0.733	-0.782	0.187
42	8720215	30.399000	-81.624000	0.434	0.394	-0.397	-0.420	0.098
43	8720216	30.399000	-81.699000	0.437	0.406	-0.388	-0.413	0.051
44	8720217	30.391700	-81.661700	0.426	0.387	-0.378	-0.403	0.109
45	8720218	30.396700	-81.430000	0.755	0.673	-0.706	-0.753	0.163
46	8720219	30.386700	-81.558300	0.544	0.504	-0.539	-0.576	0.121
47	8720220	30.393300	-81.432200	0.748	0.666	-0.691	-0.735	0.182
48	8720221	30.390000	-81.506700	0.605	0.543	-0.558	-0.588	0.131
49	8720224	30.395000	-81.431700	0.761	0.678	-0.707	-0.752	0.187

N	Station	Latitude	Longitude	MHHW	MHW	MLW	MLLW	NAVD88
50	8720225	30.383300	-81.633000	0.425	0.385	-0.379	-0.403	0.093
51	8720226	30.321100	-81.658300	0.269	0.254	-0.304	-0.338	0.078
52	8720232	30.376700	-81.448300	0.640	0.560	-0.610	-0.640	0.123
53	8720242	30.360000	-81.620000	0.410	0.381	-0.385	-0.418	0.085
54	8720267	30.323300	-81.438300	0.585	0.523	-0.626	-0.670	0.131
55	8720274	30.311150	-81.608900	0.346	0.314	-0.303	-0.327	0.043
56	8720296	30.278300	-81.705000	0.209	0.180	-0.153	-0.171	0.019
57	8720305	30.253300	-81.430300	0.572	0.506	-0.746	-0.792	0.064
58	8720333	30.228300	-81.663300	0.161	0.140	-0.125	-0.142	-9.999
59	8720357	30.192500	-81.690000	0.147	0.137	-0.133	-0.163	0.035
60	8720398	30.133500	-81.386000	0.642	0.566	-0.854	-0.910	0.050
61	8720406	30.120000	-81.758300	0.148	0.127	-0.116	-0.130	-0.013
62	8720409	30.134000	-81.630000	0.136	0.118	-0.104	-0.119	-9.999
63	8720434	30.080500	-81.761000	0.152	0.133	-0.121	-0.133	-0.014
64	8720496	29.990000	-81.663300	0.142	0.120	-0.119	-0.131	-0.007
65	8720503	29.978300	-81.628300	0.141	0.126	-0.138	-0.164	0.013
66	8720554	29.916700	-81.300000	0.739	0.637	-0.656	-0.710	0.170
67	8720576	29.891700	-81.310000	0.779	0.676	-0.689	-0.740	0.155
68	8720582	29.866700	-81.306700	0.738	0.637	-0.668	-0.726	0.131
69	8720596	29.858300	-81.553300	0.168	0.145	-0.144	-0.157	-0.014
70	8720623	29.793300	-81.271700	0.770	0.672	-0.710	-0.764	0.111
71	8720625	29.800000	-81.548300	0.184	0.169	-0.176	-0.200	-0.011
72	8720651	29.768300	-81.258300	0.686	0.591	-0.647	-0.703	0.111
73	8720653	29.763300	-81.560800	0.192	0.165	-0.155	-0.170	0.019
74	8720686	29.715000	-81.238300	0.659	0.564	-0.611	-0.667	0.140
75	8720692	29.704531	-81.227856	0.661	0.565	-0.544	-0.594	0.101
76	8720757	29.615000	-81.204700	0.251	0.207	-0.240	-0.284	0.050
77	8720767	29.595000	-81.681700	0.168	0.161	-0.154	-0.178	-0.005
78	8720774	29.643300	-81.631700	0.204	0.193	-0.194	-0.222	0.014
79	8720782	29.571400	-81.607550	0.145	0.125	-0.131	-0.141	0.009
80	8720832	29.476700	-81.675500	0.072	0.067	-0.063	-0.076	-0.082
81	8720833	29.478300	-81.136700	0.169	0.128	-0.139	-0.160	0.078
82	8720954	29.285000	-81.053300	0.118	0.095	-0.085	-0.110	0.149
83	8721136	29.083300	-80.966700	0.236	0.181	-0.169	-0.195	0.166
84	8721138	29.081700	-80.936700	0.507	0.425	-0.414	-0.458	0.226
85	8721147	29.063300	-80.915000	0.547	0.460	-0.466	-0.509	0.275
86	8721164	29.023300	-80.918300	0.431	0.364	-0.375	-0.418	0.196
87	8721191	28.988300	-80.900000	0.376	0.314	-0.292	-0.310	0.150
88	8721222	28.940000	-80.869000	0.214	0.164	-0.160	-0.167	0.151
89	8721223	28.926700	-80.825000	0.115	0.084	-0.054	-0.055	0.121
90	8721374	28.736000	-80.755000	-9.999	-9.999	-9.999	-9.999	0.173
91	8721415	28.676700	-80.650000	-9.999	-9.999	-9.999	-9.999	0.214
92	8721456	28.620000	-80.800000	-9.999	-9.999	-9.999	-9.999	0.214
93	8721533	28.513300	-80.611700	-9.999	-9.999	-9.999	-9.999	0.210
94	8721749	28.211700	-80.663300	-9.999	-9.999	-9.999	-9.999	0.224
95	8721832	28.100000	-80.611700	0.036	0.028	-0.022	-0.042	-9.999
96	8721994	27.873300	-80.496700	0.057	0.041	-0.041	-0.063	0.258
97	8722004	27.860000	-80.448300	0.367	0.309	-0.333	-0.374	0.368
98	8722029	27.811700	-80.463300	0.068	0.046	-0.047	-0.068	0.274
99	8722059	27.755000	-80.425000	0.078	0.060	-0.053	-0.068	0.279
100	8722125	27.631700	-80.371700	0.141	0.116	-0.112	-0.131	0.278
101	8722208	27.471700	-80.325000	0.256	0.216	-0.242	-0.290	0.273
102	8722212	27.470000	-80.288300	0.443	0.377	-0.404	-0.465	0.359
103	8722213	27.468300	-80.300000	0.344	0.291	-0.325	-0.376	0.334
104	8722219	27.456700	-80.323300	0.253	0.209	-0.227	-0.269	0.296
105	8722334	27.242000	-80.314000	0.175	0.143	-0.155	-0.192	0.274
106	8722357	27.200000	-80.258300	0.161	0.128	-0.134	-0.168	0.248

N	Station	Latitude	Longitude	MHHW	MHW	MLW	MLLW	NAVD88
107	8722371	27.173300	-80.189000	0.142	0.116	-0.123	-0.157	0.336
108	8722381	27.155000	-80.171700	0.194	0.162	-0.161	-0.201	0.276
109	8722383	27.151700	-80.195000	0.165	0.132	-0.136	-0.172	0.309
110	8722404	27.113300	-80.145000	0.222	0.187	-0.198	-0.238	0.307
111	8722414	27.093300	-80.136700	0.230	0.192	-0.204	-0.246	0.283
112	8722429	27.065000	-80.123300	0.263	0.226	-0.231	-0.271	0.374
113	8722445	27.036700	-80.106700	0.297	0.254	-0.260	-0.302	0.293
114	8722472	26.986700	-80.141700	0.364	0.311	-0.313	-0.368	0.313
115	8722478	26.975000	-80.113300	0.339	0.291	-0.290	-0.337	0.294
116	8722481	26.970000	-80.126700	0.340	0.295	-0.293	-0.340	0.372
117	8722486	26.960000	-80.104500	0.317	0.265	-0.251	-0.289	0.291
118	8722487	26.952800	-80.101700	0.315	0.269	-0.267	-0.305	0.274
119	8722488	26.951200	-80.103000	0.325	0.276	-0.270	-0.316	0.317
120	8722492	26.946700	-80.090000	0.353	0.307	-0.292	-0.337	0.344
121	8722495	26.944400	-80.073300	0.415	0.363	-0.365	-0.423	0.357
122	8722496	26.935000	-80.141000	0.336	0.291	-0.291	-0.341	0.299
123	8722512	26.911700	-80.080000	0.355	0.311	-0.317	-0.363	0.301
124	8722548	26.843300	-80.066700	0.448	0.399	-0.406	-0.450	0.305
125	8722557	26.826700	-80.055000	0.482	0.422	-0.434	-0.490	0.314
126	8722588	26.770000	-80.051700	0.465	0.410	-0.417	-0.464	0.295
127	8722607	26.733300	-80.042000	0.466	0.406	-0.414	-0.470	0.335
128	8722621	26.705000	-80.045000	0.456	0.399	-0.384	-0.431	0.304
129	8722654	26.645000	-80.044200	0.439	0.386	-0.365	-0.415	0.354
130	8722669	26.613300	-80.046700	0.467	0.417	-0.401	-0.441	-9.999
131	8722718	26.526700	-80.053300	0.446	0.398	-0.355	-0.403	-9.999
132	8722746	26.473300	-80.061700	0.441	0.395	-0.362	-0.404	0.298
133	8722761	26.446700	-80.065000	0.422	0.383	-0.339	-0.386	0.295
134	8722784	26.404300	-80.070000	0.413	0.376	-0.340	-0.389	0.267
135	8722802	26.370000	-80.071500	0.383	0.345	-0.307	-0.353	0.362
136	8722859	26.261600	-80.085000	0.409	0.370	-0.362	-0.407	0.272
137	8722861	26.258300	-80.081700	0.423	0.381	-0.378	-0.426	0.289
138	8722862	26.256700	-80.080000	0.425	0.385	-0.382	-0.434	0.309

Table A.2. Tide stations in Fla. Shelf. The quantity -9.999 denotes a missing value.

N	Station	Latitude	Longitude	MHHW	MHW	MLW	MLLW	NAVD88
1	8677344	31.131700	-81.396700	1.108	0.995	-1.023	-1.086	0.204
2	8720194	30.430000	-81.405000	0.979	0.854	-0.808	-0.865	-9.999
3	8720291	30.283300	-81.386700	0.935	0.820	-0.726	-0.776	0.180
4	8720587	29.856700	-81.263300	0.827	0.712	-0.693	-0.742	0.214
5	8721120	29.146700	-80.963300	0.719	0.606	-0.584	-0.631	0.242
6	8721604	28.415700	-80.593500	0.620	0.513	-0.520	-0.573	0.300
7	8721649	28.368300	-80.600000	0.636	0.528	-0.527	-0.575	0.281
8	8721804	28.138300	-80.578300	0.634	0.507	-0.518	-0.580	0.315
9	8722105	27.670000	-80.360000	0.617	0.516	-0.516	-0.573	0.348
10	8722491	26.952500	-80.070000	0.345	0.294	-0.299	-0.354	0.289
11	8722670	26.611700	-80.033300	0.457	0.414	-0.418	-0.460	0.288
12	8722899	26.188300	-80.093300	0.427	0.390	-0.395	-0.446	0.255

Table A.3. Tide stations in the S. C. Coast Region. The quantity -9.999 denotes a missing value.

N	Station	Latitude	Longitude	MHHW	MHW	MLW	MLLW	NAVD88
1	8659897	33.865000	-78.506700	0.870	0.751	-0.758	-0.813	-9.999
2	8659898	33.881700	-78.510000	0.823	0.704	-0.735	-0.785	-9.999
3	8660098	33.870000	-78.573300	0.817	0.700	-0.711	-0.760	0.103
4	8660147	33.860000	-78.580000	0.826	0.707	-0.717	-0.766	0.098
5	8660166	33.856500	-78.649000	0.731	0.632	-0.617	-0.656	0.017
6	8660265	33.835700	-78.633500	0.823	0.702	-0.722	-0.763	0.096
7	8660642	33.766700	-78.815000	0.355	0.289	-0.253	-0.302	-0.198
8	8660854	33.714100	-78.922000	0.308	0.261	-0.260	-0.312	-0.235
9	8660983	33.686700	-79.005000	0.315	0.273	-0.360	-0.402	-0.186
10	8661000	33.683300	-78.885000	0.825	0.751	-0.768	-0.868	-9.999
11	8661070	33.655000	-78.918300	0.881	0.762	-0.769	-0.826	0.136
12	8661093	33.660000	-79.153800	0.252	0.221	-0.286	-0.326	-9.999
13	8661139	33.651000	-79.094400	0.313	0.277	-0.381	-0.433	-0.282
14	8661299	33.608500	-79.151000	0.139	0.117	-0.175	-0.206	-0.729
15	8661419	33.578300	-79.003300	0.761	0.640	-0.658	-0.696	0.107
16	8661529	33.554900	-79.032300	0.773	0.646	-0.664	-0.703	0.119
17	8661559	33.547600	-79.042600	0.744	0.625	-0.682	-0.737	0.098
18	8661582	33.541700	-79.028300	0.757	0.636	-0.650	-0.698	0.122
19	8661593	33.535000	-79.388300	0.345	0.311	-0.410	-0.458	-0.132
20	8661609	33.530600	-79.043300	0.759	0.642	-0.660	-0.715	-9.999
21	8661684	33.511400	-79.065700	0.746	0.622	-0.704	-0.764	0.066
22	8661703	33.505500	-79.146000	0.508	0.456	-0.562	-0.614	-9.999
23	8661989	33.434800	-79.125800	0.676	0.564	-0.605	-0.676	-0.037
24	8661991	33.436800	-79.182000	0.565	0.497	-0.560	-0.605	-0.075
25	8662006	33.431700	-79.116700	0.864	0.745	-0.754	-0.810	-9.999
26	8662071	33.411600	-79.135900	0.579	0.482	-0.531	-0.586	-0.062
27	8662216	33.370000	-79.433300	0.639	0.569	-0.657	-0.699	-0.054
28	8662245	33.349300	-79.189000	0.745	0.639	-0.758	-0.816	0.009
29	8662299	33.333850	-79.192700	0.768	0.661	-0.769	-0.828	0.109
30	8662405	33.305000	-79.678300	0.227	0.182	-0.159	-0.179	-0.314
31	8662549	33.251700	-79.268300	0.643	0.555	-0.569	-0.613	0.049
32	8662670	33.245500	-79.521500	0.415	0.355	-0.347	-0.390	-9.999
33	8662746	33.235000	-79.203300	0.681	0.588	-0.574	-0.624	0.051
34	8662796	33.195000	-79.275000	0.698	0.596	-0.619	-0.674	0.008
35	8662799	33.184200	-79.405500	0.690	0.603	-0.636	-0.686	0.000
36	8662931	33.366700	-79.255000	0.603	0.524	-0.574	-0.606	-0.054
37	8662953	33.415000	-79.250000	0.563	0.496	-0.553	-0.596	0.000
38	8663461	33.106100	-79.394000	0.792	0.685	-0.702	-0.748	-9.999
39	8663535	33.095000	-79.808300	0.419	0.359	-0.480	-0.562	-0.380
40	8663539	33.095400	-79.952000	0.323	0.254	-0.259	-0.310	-0.556
41	8663618	33.078300	-79.460000	0.858	0.740	-0.740	-0.792	0.094
42	8663665	33.076700	-79.855000	0.432	0.371	-0.442	-0.520	-0.356
43	8663781	33.055000	-79.880000	0.443	0.380	-0.469	-0.544	-0.335
44	8664022	33.009000	-79.921300	0.685	0.598	-0.729	-0.792	-0.127
45	8664515	32.948200	-79.931300	0.824	0.720	-0.897	-0.959	-9.999
46	8664531	32.958500	-80.201300	0.422	0.353	-0.286	-0.294	-0.667
47	8664541	32.925000	-79.986700	0.708	0.622	-0.945	-1.025	-0.130
48	8664545	32.926700	-79.830000	0.919	0.814	-1.020	-1.079	0.013
49	8664561	32.922500	-79.836800	0.951	0.854	-0.930	-0.995	-9.999
50	8664589	32.918300	-80.011700	0.640	0.563	-0.870	-0.917	-0.148
51	8664611	32.914300	-79.746500	0.918	0.812	-1.163	-1.227	-0.016
52	8664662	32.913200	-79.953800	0.852	0.750	-0.898	-0.957	0.014
53	8664688	32.906700	-79.935000	0.839	0.736	-0.921	-0.979	-9.999
54	8664701	32.900000	-79.900000	0.930	0.821	-0.981	-1.043	0.024
55	8664782	32.885000	-79.845000	0.932	0.831	-0.907	-0.970	-9.999

N	Station	Latitude	Longitude	MHHW	MHW	MLW	MLLW	NAVD88
56	8664801	32.882500	-79.658000	0.838	0.722	-0.740	-0.792	-9.999
57	8664878	32.870900	-79.686700	0.855	0.733	-0.768	-0.815	-9.999
58	8664941	32.856700	-79.706700	0.839	0.721	-0.735	-0.786	-9.999
59	8664945	32.860000	-79.937500	0.856	0.753	-0.877	-0.936	-9.999
60	8664992	32.851500	-79.704700	0.813	0.709	-0.741	-0.797	-9.999
61	8665002	32.848300	-80.051700	0.883	0.786	-0.949	-1.009	0.018
62	8665099	32.836500	-80.021700	0.896	0.793	-0.939	-1.003	-9.999
63	8665101	32.835000	-79.986700	0.891	0.786	-0.913	-0.973	0.070
64	8665111	32.834000	-79.727800	0.848	0.732	-0.771	-0.823	-9.999
65	8665167	32.826700	-79.786700	0.870	0.753	-0.828	-0.885	0.089
66	8665192	32.821700	-79.900000	0.888	0.779	-0.862	-0.918	0.053
67	8665257	32.813300	-80.406700	0.160	0.129	-0.127	-0.148	-9.999
68	8665387	32.788000	-79.791400	0.858	0.741	-0.795	-0.854	0.103
69	8665424	32.675000	-79.951700	0.903	0.786	-0.864	-0.921	0.097
70	8665475	32.786700	-80.105000	0.784	0.688	-1.014	-1.089	-0.036
71	8665494	32.783300	-79.785000	0.864	0.745	-0.763	-0.816	-9.999
72	8665495	32.783300	-79.958000	0.872	0.763	-0.849	-0.908	-9.999
73	8665530	32.780500	-79.923500	0.867	0.758	-0.834	-0.891	0.066
74	8665552	32.776700	-79.811700	0.853	0.738	-0.767	-0.827	0.120
75	8665567	32.773300	-79.841700	0.857	0.743	-0.796	-0.853	0.110
76	8665589	32.768200	-80.064000	0.742	0.658	-0.946	-1.030	-0.012
77	8665599	32.770000	-80.067000	0.774	0.676	-0.945	-1.021	-9.999
78	8665637	32.763300	-79.856700	0.858	0.747	-0.800	-0.856	0.094
79	8665641	32.763300	-80.001700	0.795	0.697	-0.871	-0.938	0.019
80	8665737	32.753300	-80.450000	0.600	0.536	-0.694	-0.753	-0.352
81	8665763	32.746500	-80.164500	0.886	0.784	-1.158	-1.226	-0.020
82	8665814	32.743400	-80.556000	0.288	0.263	-0.396	-0.479	-0.180
83	8666017	32.714000	-80.436300	0.695	0.621	-0.894	-0.974	-0.270
84	8666101	32.706700	-80.156200	0.928	0.821	-1.266	-1.332	-0.007
85	8666131	32.702500	-80.277000	0.936	0.828	-1.222	-1.296	-0.006
86	8666167	32.700000	-80.426700	0.813	0.731	-0.982	-1.051	-9.999
87	8666217	32.695000	-80.223300	0.929	0.820	-1.159	-1.226	0.012
88	8666359	32.683000	-80.738000	0.459	0.405	-0.569	-0.675	-0.315
89	8666367	32.681400	-80.416900	0.828	0.741	-0.987	-1.054	-0.155
90	8666433	32.676000	-80.297000	0.952	0.833	-1.105	-1.165	0.033
91	8666467	32.670000	-79.916700	0.894	0.777	-0.863	-0.919	0.086
92	8666616	32.656400	-80.391700	0.888	0.803	-1.071	-1.136	-9.999
93	8666652	32.661700	-79.945000	0.877	0.761	-0.845	-0.901	0.085
94	8666659	32.651700	-80.683000	0.679	0.601	-0.871	-0.947	-0.189
95	8666699	32.646700	-80.256700	0.924	0.816	-1.052	-1.117	0.046
96	8666749	32.631700	-80.471700	0.581	0.531	-0.702	-0.769	-0.098
97	8666767	32.640000	-80.015000	0.895	0.781	-0.826	-0.885	-9.999
98	8666775	32.636700	-80.201700	0.912	0.801	-1.026	-1.090	-9.999
99	8666799	32.636700	-80.341700	0.936	0.830	-1.049	-1.113	-0.006
100	8666918	32.627000	-80.166600	0.910	0.801	-1.005	-1.069	0.054
101	8667062	32.603800	-80.132500	0.938	0.819	-0.887	-0.939	0.059
102	8667074	32.601700	-80.540500	0.825	0.735	-1.104	-1.184	-0.027
103	8667075	32.603300	-80.286700	0.925	0.815	-1.020	-1.084	0.041
104	8667172	32.583300	-80.783300	1.163	1.038	-1.421	-1.474	-0.051
105	8667178	32.586000	-80.227500	0.901	0.791	-0.934	-0.996	0.071
106	8667199	32.578300	-80.670000	0.913	0.816	-1.132	-1.197	-0.023
107	8667209	32.578300	-80.448300	0.907	0.814	-1.083	-1.144	-0.012
108	8667309	32.560000	-80.418300	0.963	0.858	-1.030	-1.097	-9.999
109	8667411	32.540000	-80.745000	1.127	1.009	-1.352	-1.415	-0.001
110	8667425	32.540000	-80.340000	0.954	0.842	-1.013	-1.078	0.035
111	8667630	32.501700	-80.296700	0.971	0.852	-0.899	-0.963	0.096
112	8667633	32.335700	-80.784100	1.156	1.047	-1.402	-1.464	-9.999

N	Station	Latitude	Longitude	MHHW	MHW	MLW	MLLW	NAVD88
113	8667676	32.493300	-80.338000	0.978	0.867	-0.949	-1.009	0.098
114	8667679	32.493300	-80.326700	0.963	0.853	-0.968	-1.028	0.081
115	8667733	32.483300	-80.600000	1.000	0.891	-1.137	-1.205	0.041
116	8667783	32.476700	-80.420000	0.981	0.872	-0.959	-1.023	-9.999
117	8667972	32.446700	-80.533300	1.008	0.897	-1.057	-1.121	0.058
118	8667982	32.440000	-80.552000	1.059	0.948	-1.126	-1.189	0.059
119	8667999	32.430000	-80.675000	1.115	0.998	-1.252	-1.317	0.033
120	8668092	32.414300	-80.702000	1.181	1.060	-1.269	-1.330	0.031
121	8668146	32.403300	-80.453300	0.999	0.881	-0.975	-1.039	0.094
122	8668155	32.401700	-80.653300	1.122	1.006	-1.102	-1.127	0.005
123	8668223	32.386700	-80.776700	1.111	0.998	-1.240	-1.302	0.035
124	8668227	32.391700	-80.438300	0.976	0.857	-0.935	-0.994	0.097
125	8668482	32.346000	-80.891000	1.224	1.097	-1.368	-1.439	0.022
126	8668498	32.340000	-80.465000	1.013	0.896	-0.964	-1.025	0.089
127	8668601	32.325000	-80.601700	1.127	1.004	-1.080	-1.147	0.080
128	8668701	32.303300	-81.122500	0.486	0.429	-0.494	-0.520	-1.038
129	8668918	32.266700	-80.736700	1.065	0.955	-1.126	-1.187	-9.999
130	8669072	32.234000	-81.013700	0.402	0.368	-0.647	-0.752	-0.352
131	8669133	32.225000	-80.771700	1.138	1.017	-1.201	-1.270	0.074
132	8669167	32.220000	-80.668300	1.047	0.904	-0.953	-1.020	0.083
133	8669338	32.185000	-80.753300	1.215	1.092	-1.188	-1.259	0.087
134	8669415	32.165000	-81.130000	1.080	0.993	-1.331	-1.407	-9.999
135	8669601	32.121700	-80.898300	1.126	1.012	-1.172	-1.233	-9.999
136	8669691	32.103300	-80.895000	1.102	0.989	-1.150	-1.214	0.062
137	8669801	32.081700	-80.878300	1.103	0.991	-1.073	-1.135	0.105
138	8670424	32.143300	-81.141700	1.211	1.119	-1.361	-1.424	-0.027
139	8670870	32.034000	-80.901700	1.123	1.009	-1.099	-1.165	0.070
140	8672667	31.793300	-81.181700	1.160	1.047	-1.197	-1.261	-9.999
141	8672875	31.766700	-81.278000	1.102	0.995	-1.226	-1.294	-9.999
142	8673171	31.723028	-81.141700	1.122	1.014	-1.109	-1.166	-9.999
143	8673381	31.695000	-81.272000	1.084	0.973	-1.269	-1.338	-9.999
144	8674301	31.575000	-81.190000	1.119	1.010	-1.093	-1.156	-9.999
145	8674975	31.486700	-81.320000	1.190	1.073	-1.213	-1.281	-9.999

APPENDIX B. POPULATION OF OVER-LAND POINTS

Introduction

The marine grid consists of rows (aligned east-west) and columns (aligned north-south) of points, with uniform spacing in each direction. Each point in the grid is designated as being land, water, or within a buffer layer.

In previous versions of the `vgridder.f` program, a point was selected as land or water as follows. All points are first set to water, then those points that lie within islands or within the land polygon were set to land. Next, for each point, a temporary cell with the grid point at the center was computed (Figure B.1). The sides of this cell (i.e., the perimeter) are oriented north-south and east-west, and are located halfway between rows and columns of the original grid. The grid point was set to water if any section of coastline passed through the temporary cell.

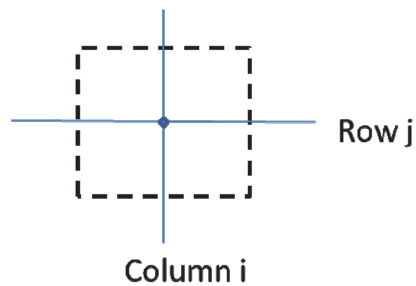


Figure B. 1. A typical grid point (blue diamond) within the marine grid, with a temporary cell (dashed lines) around it.

For the buffer layer, land points immediately adjacent to the water are populated to provide information of shoreline surveying by lidar. These added points, which form layers along the coast, are designed to extend shoreward approximately 500 m over land (Figure B.2).

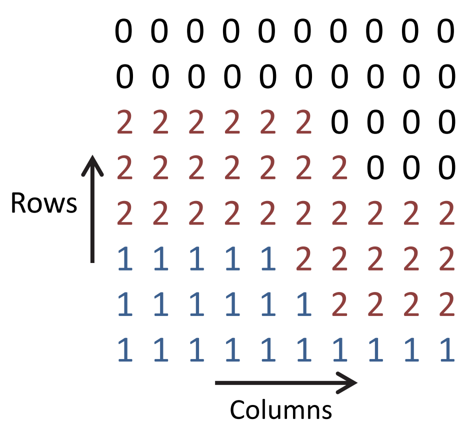


Figure B. 2. Sample marine grid with three buffer layers. Here '1' represents water points (blue), '2' for buffer layer points (red), and '0' for land points (black).

Some geographic regions have significant non-tidal areas. Mean tide ranges that are less than 3 cm are defined by CO-OPS as non-tidal. In the present population methodology, water points are filled with hydrodynamic model fields first, then buffer layer points are filled by extrapolation. Finally, water and buffer layer points within a non-tidal polygon are set to zero elevation.

Problem Areas

Problems were found in the Fla. Waterways VDatum region, which has non-tidal areas. For example, some points with Low Water Datum (LWD) values were adjacent to points with mean tide range greater than 3 cm.

First, we look at the case of zero added layers of points. As depicted in Figure B.3a, each row has one point which is outside the non-tidal polygon, but has a significant MHHW value (0.041 m) as compared to the adjacent point (with a MHHW value of 0.0 m) which lies within the non-tidal area. Note that these points fall on land, but are set to water in `vgridder15.f` because at least one location on the perimeter of the cell lies in water (see discussion above). And since these points represent water, they are populated (`vpop23.f`) with values from the closest hydrodynamic model nodes. However, it is highly desirable that these water points have zero tidal values to ensure a smooth interpolation outside the non-tidal area.

Second, we look at the case of three added layers of points. As depicted in Figure B.3b, there are additional filled grid points located eastward of the original points. These additional points also have significant values as compared to those in the non-tidal region. This is due to the way that that `vpop23.f` fills in. Again, it is desirable that these water points have zero tidal values to insure a smooth interpolation outside the non-tidal area.

Revisions to Computer Algorithms

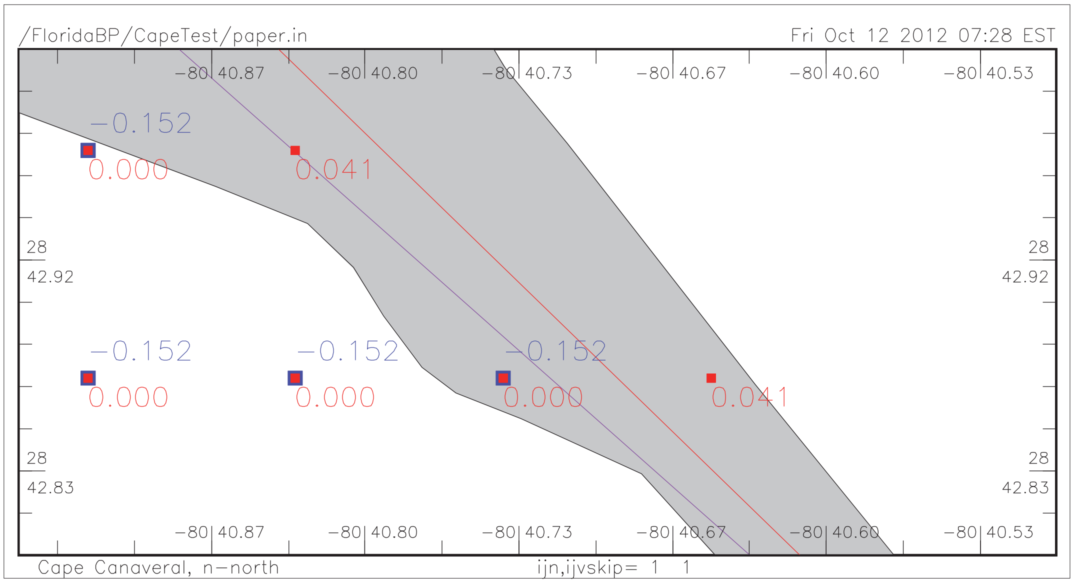
The solution to the above problems was to revise the gridding and population programs. A new program to generate the marine grid (`vgridder16.f`) was created. This version incorporates changes in (a) discriminating between land and water, (b) adding and remembering layers, (c) the order in which non-tidal points are set, and (d) allowing for manual adjustment of the initial land/water choice.

<u>Land and water</u> - In the new version, only points actually in water were set to water. The new selection prevents points that are actually on land but outside the non-tidal polygon from being set to water and thus potentially being populated with significant tidal datum values.

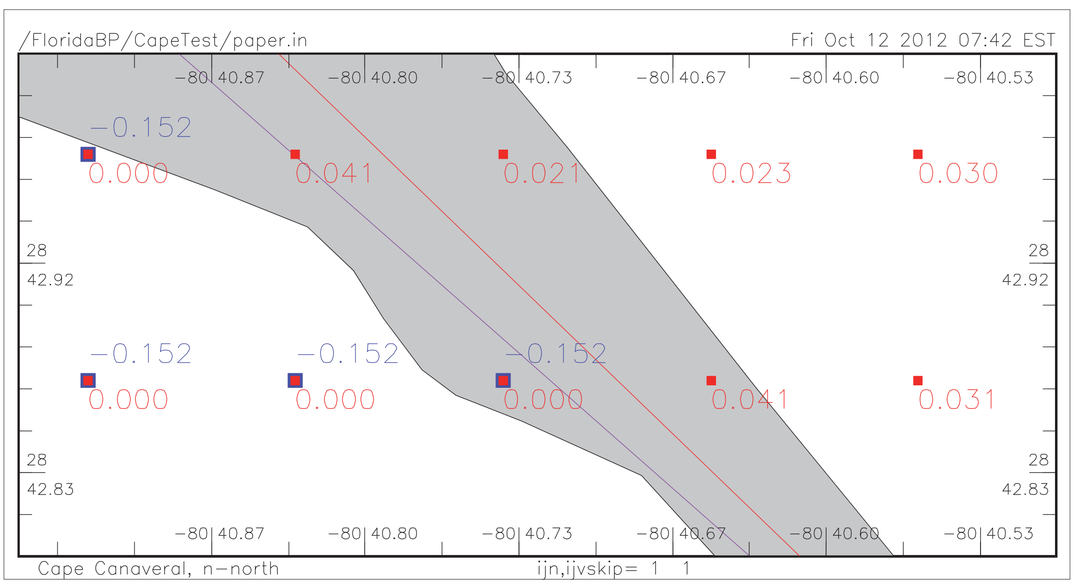
<u>Additional layers</u> - Also, as layers are added to the original water points, the new program saves the number of the layer (Figure B.4). The previous version saved only 0 for land, 1 for water and 2 for buffer layer. This information will be used in the population process (see below).

<u>Order in setting non-tidal points</u> – In the previous version of `vpop.f`, buffer layer points were filled before non-tidal points. This situation erroneously allowed for significant tidal values adjacent to non-tidal areas. In the new version of `vpop.f`, non-tidal points are filled before buffer layer points.

<u>Manual changes</u> - Finally, the new gridding program allows the user to change the status of a point from land to water, or vice versa, after the initial determination is made (but before layers are added). This feature is also used in the population procedure.



(a)



(b)

Figure B. 3. Plots showing area in southern Mosquito Lagoon, just north of Cape Canaveral, Florida, with problematic points. The inner (Fla. Waterways) region is to the west. The marine grid was populated with values for MHHW (red squares and values, m) and LWD (blue squares and values, m). The bounding polygon is shown as a red line, the non-tidal polygon as a purple line, and land as gray. In (a) the number of additional layers is 0, and in (b) the number is 3.

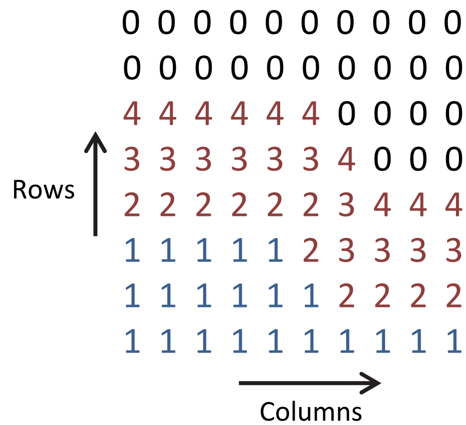
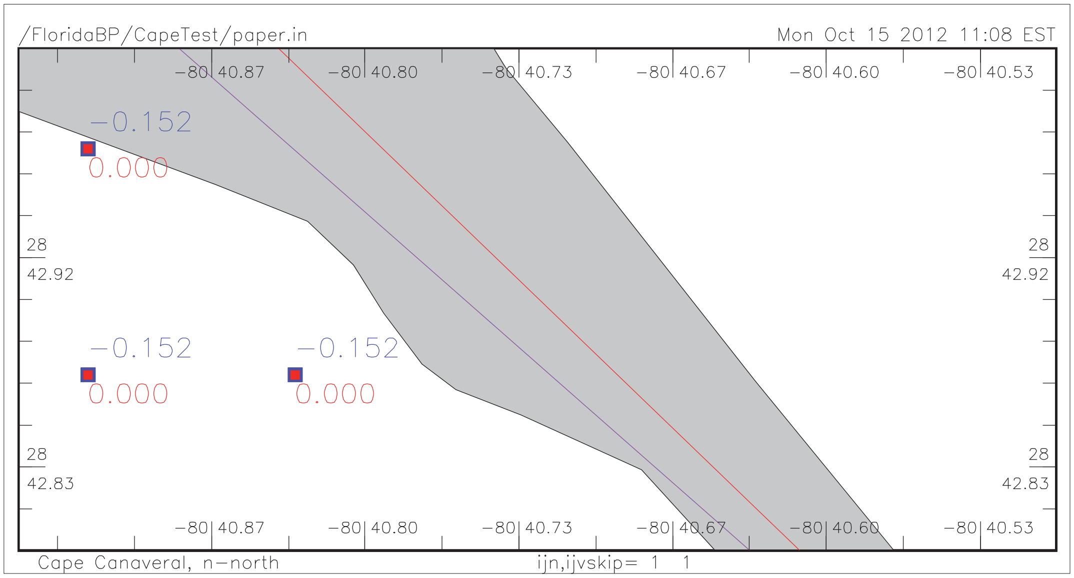
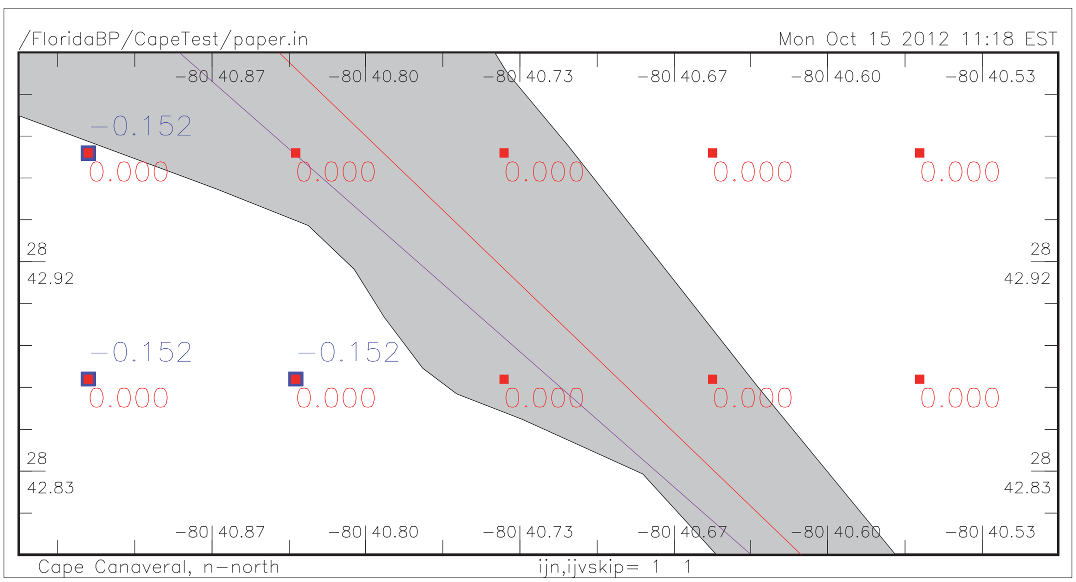


Figure B. 4. Revised grid indices (cf. Figure B.2). Here, 0 represents land, 1 is water, and 2 through 4 represent buffer layers 1 through 3.

The revised methodology for this program, `vpop24.f`, is demonstrated in the following figures. Figure B.5 shows its application to the problem areas shown in Figure B.1, and Figure B.6 shows the application to the points in the outer (Fla. Shelf) region. The new programs seem to have resolved the non-tidal points problem.



(a)



(b)

Figure B. 5. Plot showing revised inner marine grid in Mosquito Lagoon, Florida, populated with MHHW (red squares and values, m) and LWD (blue squares and values, m) values. The inner (coastal waterways) region is to the west, the bounding polygon is shown as a red line, the non-tidal polygon as a purple line, and land as gray.

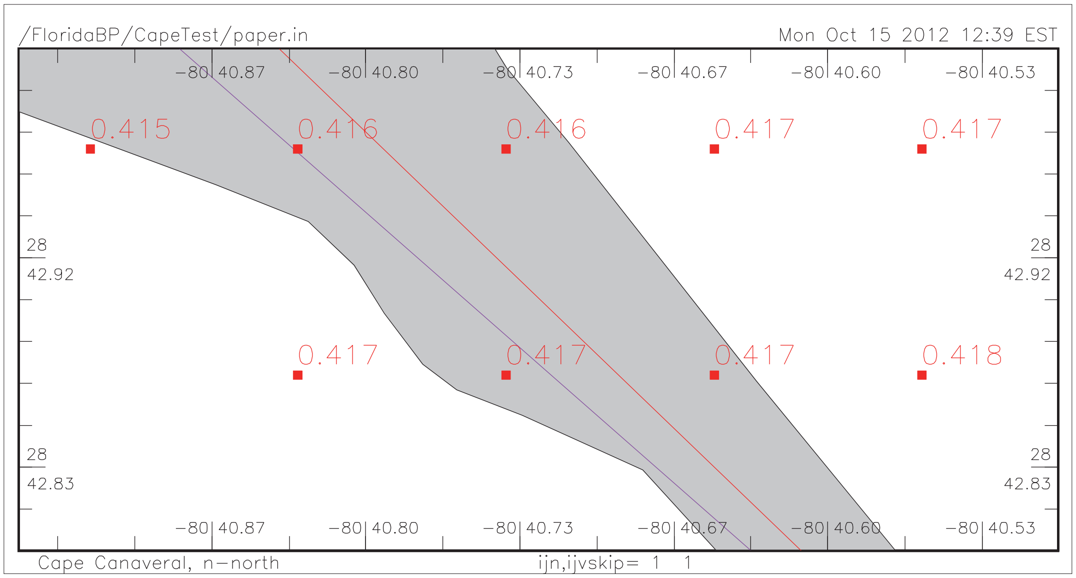
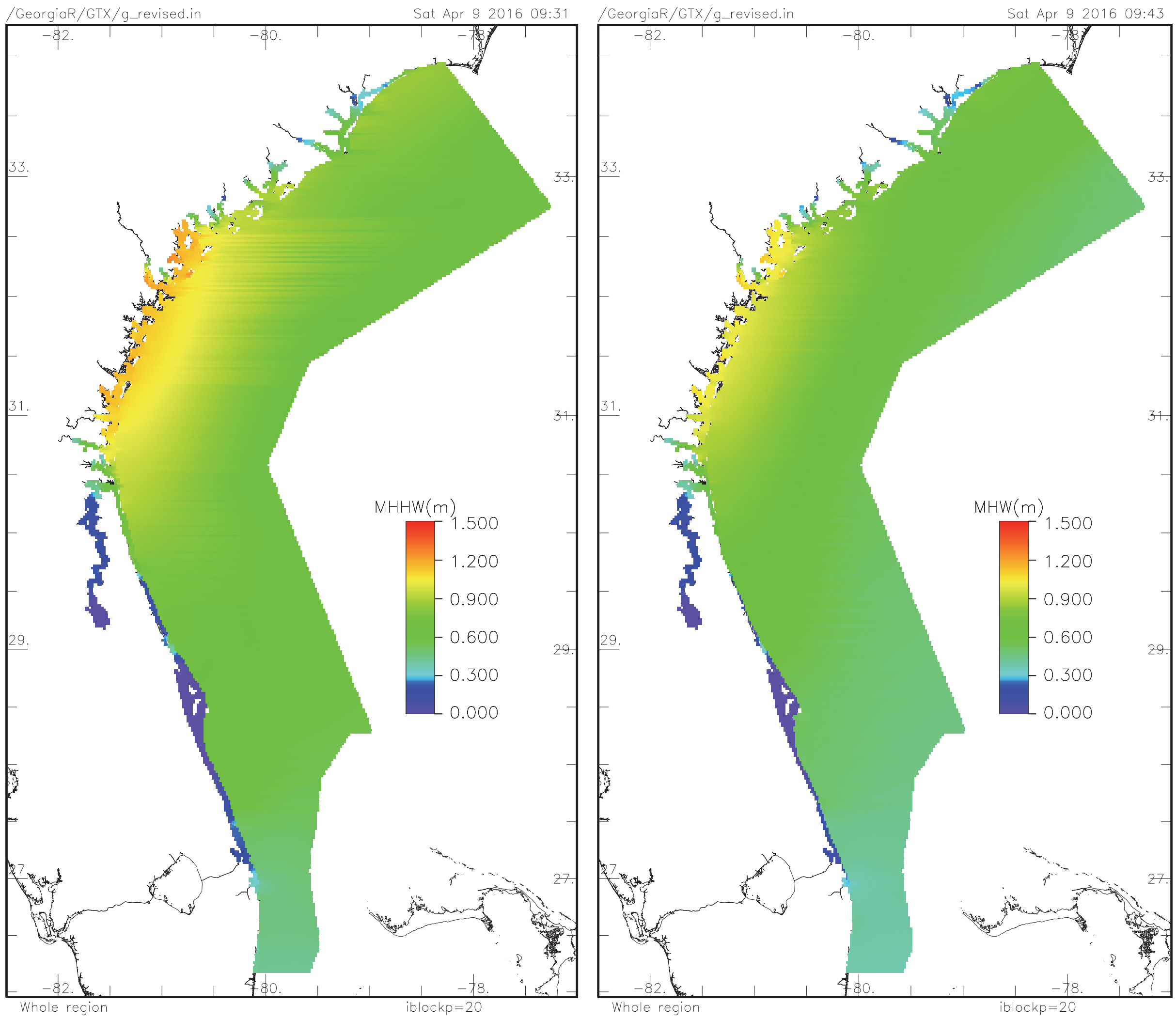


Figure B. 6. Plot showing revised marine grid near Mosquito Lagoon, Fla., populated with MHHW (red squares and values, m). There are no non-tidal points. The outer (shelf) region is to the east, the bounding polygon is the red line, the non-tidal polygon is the purple line, and land is gray.

APPENDIX C. UPDATED TIDAL DATUM FIELDS

Below are plotted the revised tidal datum fields (i.e., the GTX files) for four tidal datums.



(a) (b)

Figure C. 1. Revised datum fields in the three regions for (a) MHHW and (b) MHW.

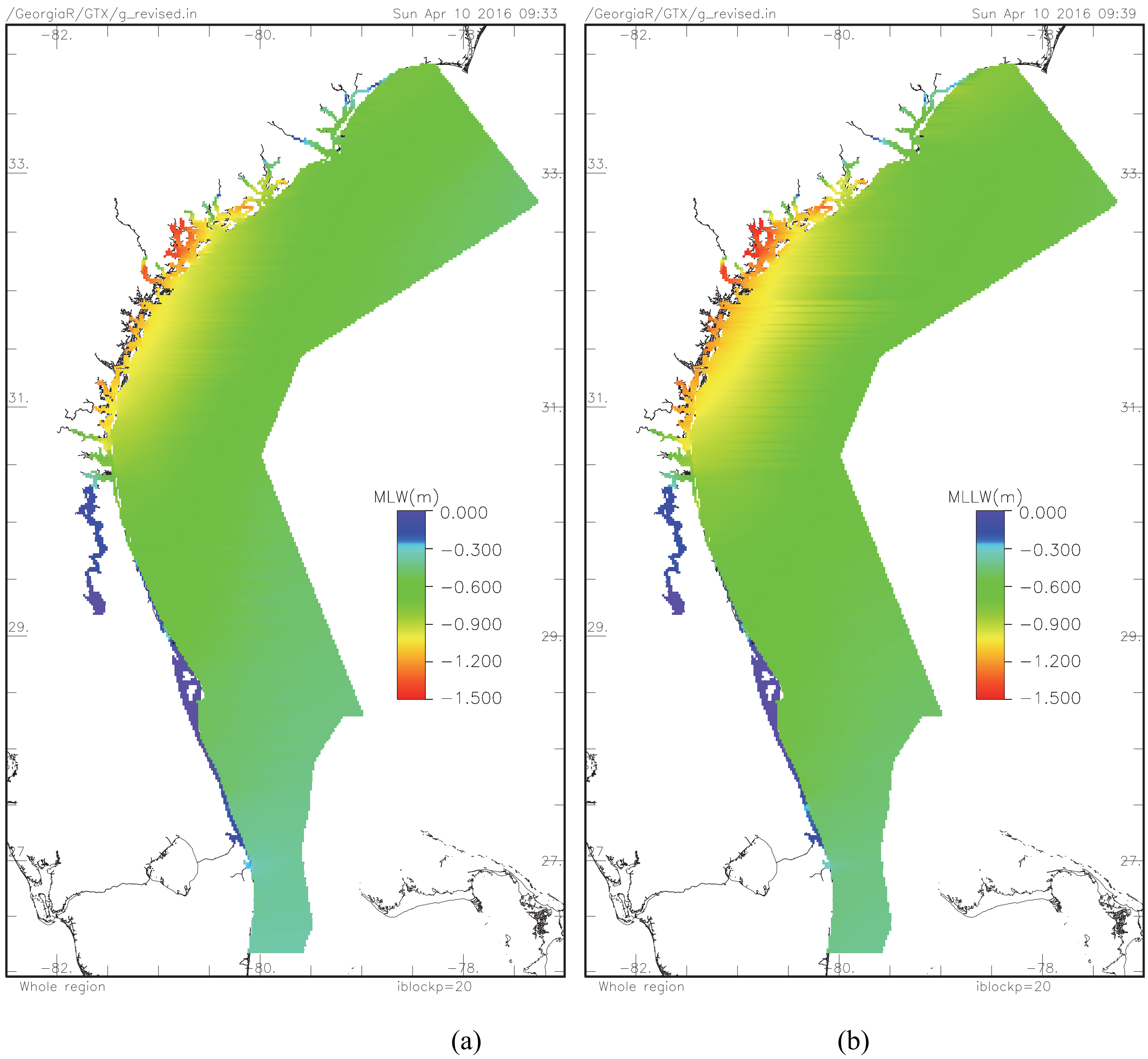


Figure C. 2. Revised datum fields in the three regions for (a) MLW and (b) MLLW.