
North Carolina Coastal Flood Analysis System Model Grid Generation

TR-08-05

Brian O. Blanton

Richard A. Luettich

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Model Grid Generation**

Submittal Number 1, Section 4

**A Draft Report for the State of North Carolina
Floodplain Mapping Project**

Technical Report TR-08-05

Date: 12 September 2008

Richard A. Luetlich, Institute of Marine Sciences
Brian O. Blanton, Renaissance Computing Institute

The simulation system for the North Carolina floodplain-mapping project uses a suite of state-of-the-art numerical wind, wave, and surge models to compute stillwater and wave setup elevations along the North Carolina coast. Bathymetric and topographic representations in the ADCIRC and SWAN models are derived from the Digital Elevation Model developed as part of the project. This report describes the computational model grids, and in particular details the methods used to generate the unstructured finite-element ADCIRC grid. This report is Section 4 of Submittal Number One, which the State of North Carolina, Division of Emergency Management has tendered for review to the Federal Emergency Management Agency.

Performance of this work was done under a contract between the University of North Carolina and the State of North Carolina.

Project participants related to this document:

University of North Carolina at Chapel Hill
Institute of Marine Sciences
Rick Luettich, Crystal Fulcher

Renaissance Computing Institute
Brian Blanton

US Army Corps of Engineers
Field Research Facility, Duck, NC
Jeff Hanson, Eve Devaliere

Dewberry
Federal Programs
Elena Drei-Horgan, Jeffery Gangai

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2 1 Numerical Model Grid Generation

The computation system for this project uses a suite of numerical models to compute still water elevations along the North Carolina coast. This report section describes the mesh and grid generation for the numerical models used to compute deep-ocean and near shore wave fields and coastal storm surge.

WaveWatch3

The oceanic wave field is computed using WW3 on its ¼ degree North Atlantic implementation. The numerical grid and bathymetry is provided by the National Centers for Environmental Prediction (NCEP) as part of this standard Atlantic configuration. No external grid or bathymetry generation is required.

SWAN

The SWAN numerical grids are specified as input parameters to each SWAN run. These parameters are fixed for all SWAN simulations, and represent the northern/southern and inner/outer grids as shown in Figures 1.2 and 2.1. *The grid generation is thus internal to SWAN at simulation time.*

For the NCFMP project, the SWAN simulations are performed on four numerical grids, an inner/outer pair for the southern (NC/SC border to Cape Lookout) and northern (Cape Lookout to the NC/VA border) sections of the North Carolina coast. Horizontal resolution for the outer and inner SWAN grids is 5 km and 200 m respectively. The inner grids fit entirely within the respective outer grids. The landward extent of the grids covers the landward extent of the ADCIRC grid. Resolution of the grids is based on experience with nearshore wave modeling in the North Carolina region (Devaliere et al, 2007). The along-shelf boundaries of the outer SWAN grids are placed in water deep enough to be minimally influenced by shallow-water effects.

The topography/bathymetry for the SWAN grids is derived directly from the underlying ADCIRC grid. The ADCIRC grid is sampled at the SWAN grid points to ensure compatibility between the two models. This sampling is done prior to all simulations and is provided to SWAN as an input file. SWAN is run in spherical/polar coordinates, with regular, rotated grids.

SWAN input control files contain a line, designated with the CGRID keyword, that specifies the numerical grid parameters. The format of this line, for the spatial grid specification, is:

```
CGRID REGULAR xpc ypc alpc xlenc ylenc mxc myc
```

where:

- REGULAR indicates that the computational grid is uniform and rectangular;

- xpc is the geographic location (longitude) of origin of the computational grid [deg]
- ypc is the geographic location (latitude) of origin of the computational grid [deg]
- alpc is the direction of the positive longitude-axis of the computational grid [deg]
- xlenc is the length of the computational grid in x-direction [deg]
- ylenc is the length of the computational grid in y-direction [deg]
- mxc is the number of cells in computational grid in x-direction (this number is one less than the number of grid points in this domain).
- myc is the number of cells in computational grid in y-direction (this number is one less than the number of grid points in this domain).

The CGRID line parameters for the SWAN configuration used are:

Grid	xpc	ypc	alpc	xlenc	ylenc	mx	my
Southern/Outer	281.50	32.50	35.00	3.25	1.50	65	30
Southern/Inner	281.75	33.00	35.00	2.50	1.20	1250	600
Northern/Outer	283.40	33.82	35.00	2.75	2.50	50	50
Northern/Inner	283.50	34.25	35.00	2.00	1.86	930	930

Text files containing the SWAN grid point coordinates are at:

ftp://fema:amef!123@weather.renci.org/NCFMP_Submittals/1/Grids/swan/v9.15/

The topographic, bathymetric field in these files is based on the v9.15 version of the ADCIRC grid and is revised each time the ADCIRC grid is revised. No scatter data was needed or used to specify the SWAN grids. Generation of the SWAN numerical grids is completely internal to the model code. For the purposes of submittal information, the SWAN grids have been generated external to the model using a code that takes the above parameters to output grid points. Detailed plots of the southern and northern grid pairs are shown in Figure 2.1.

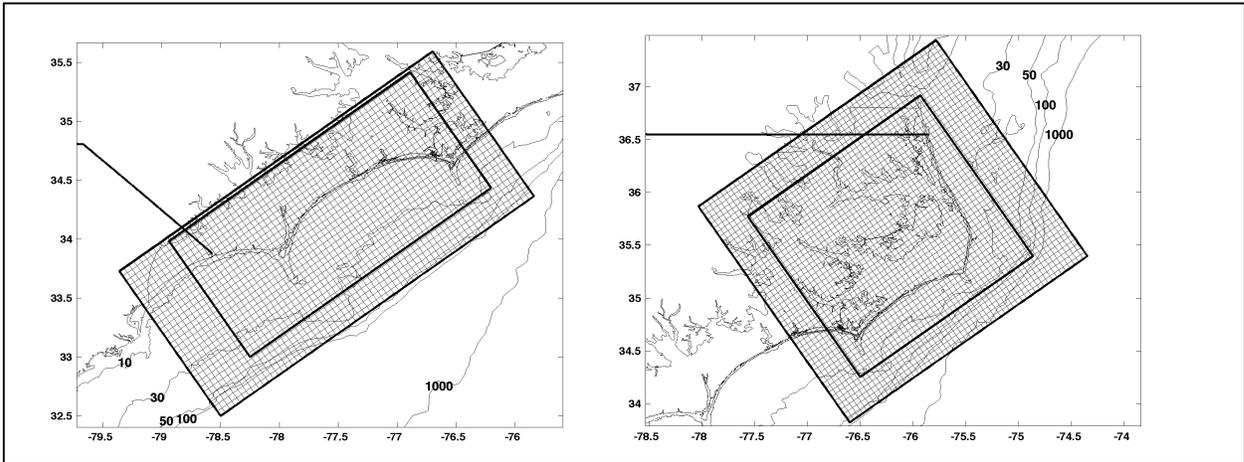


Figure 2.1. Southern (left) and Northern (right) SWAN grid pairs. The outer grids (5 km resolution) are shown with the boundaries of the inner (200 m resolution) grids.

The SWAN model simulates the spectral characteristics of wind-driven surface gravity waves. At each SWAN model node, the wave spectral characteristics are computed, based on applied forcing (wind stress), ADCIRC water levels, and adjacent model node wave characteristics. The spectral properties are thus computed on a spectral (radial/azimuthal) numerical grid. The spectral grid used for all simulations is specified in the SWAN input files as part of the CGRID grid specification line:

```
CIRCLE mdc flow fhigh msc
```

where:

- mdc is the number of cells in θ -space. This is the number of subdivisions of the 360 degrees of a circle, so $\Delta\theta = [360^\circ]/\text{mdc}$ is the spectral directional resolution.
- flow is the lowest discrete frequency that is used in the calculation [Hz].
- fhigh is the highest discrete frequency that is used in the calculation [Hz].
- msc is one less than the number of frequencies. This defines the grid resolution in frequency-space between the lowest discrete frequency (flow) and the highest discrete frequency (fhigh).

In the NCFMP SWAN simulations, the spectral grid parameters are:

```
mdc=24 flow=0.05 fhigh=1.0 msc=24
```

ADCIRC

The storm surge grid is comprised of a high-resolution grid covering the NC costal region that has been appended to a previously developed grid (Blanton et al, 2004) of the western North Atlantic, the Gulf of Mexico and the Caribbean Sea (Figure 2.2). Specifically, this grid covers the area from the 60 deg west meridian to the US mainland. In North Carolina, the grid extends inland to the 15m contour to allow for storm surge flooding. In this region, the grid has been designed to resolve major bathymetric and topographic features such as inlets, dunes and river courses as identifiable on satellite images, NOAA charts, and various available DEM and shoreline datasets. QA/QC is performed as the grid is developed by visual comparison between the bathy/topo representation of the grid and that in the original maps or data. The grid is also adjusted by hand to maintain element shapes that are as close to equilateral as possible, although this is done based on a qualitative inspection of the grid and not on specific quantitative criteria. Ultimate QA/QC on the grid is based on model performance, e.g., comparison of tides with published values from NOAA, comparison of maximum water levels with high water marks from previous storms, etc., that are being done for the present study and have been done for past studies (see below). There are 493554 nodes and 971632 elements in the v9.15 grid.

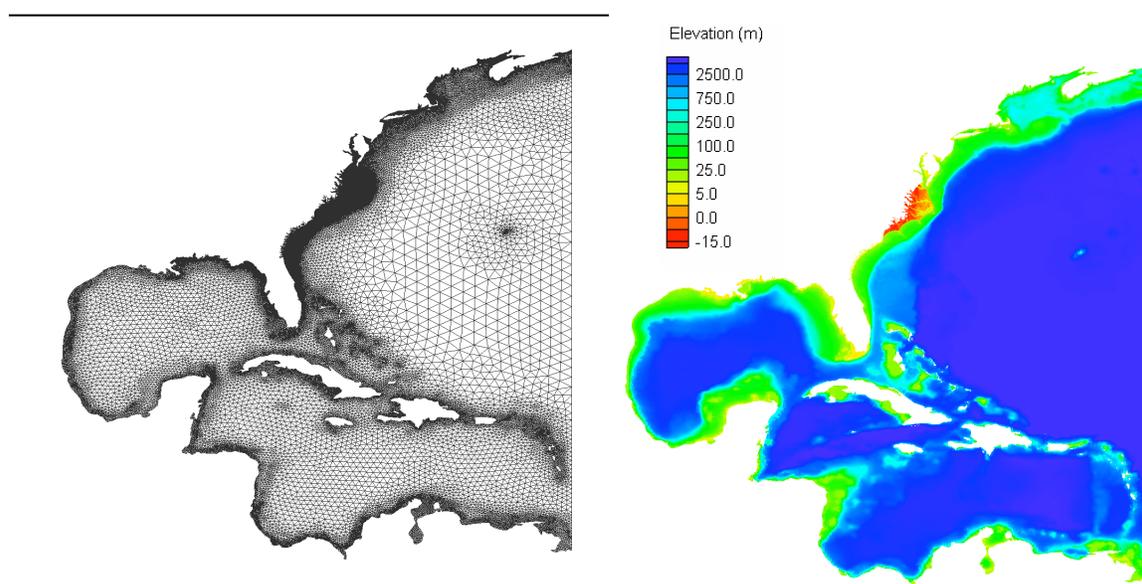


Figure 2.2: Overall grid and bathymetry/topography used for the ADCIRC storm surge modeling. The eastern boundary of the grid is the 60 deg W meridian. Bathymetry and topography are oriented with positive values being below datum.

The high resolution portion for North Carolina (Figures 2.3-2.6) represents a major extension of grids built for several previous studies in the vicinity of Beaufort Inlet, NC and the sounds and coastal waters to the north (Luettich et al, 1999; McNinch et al, 2000; Hench et al, 2002; Hench and Luettich, 2003; Hess et al, 2004; Carr et al, 2005; Reynes et al, 2007).

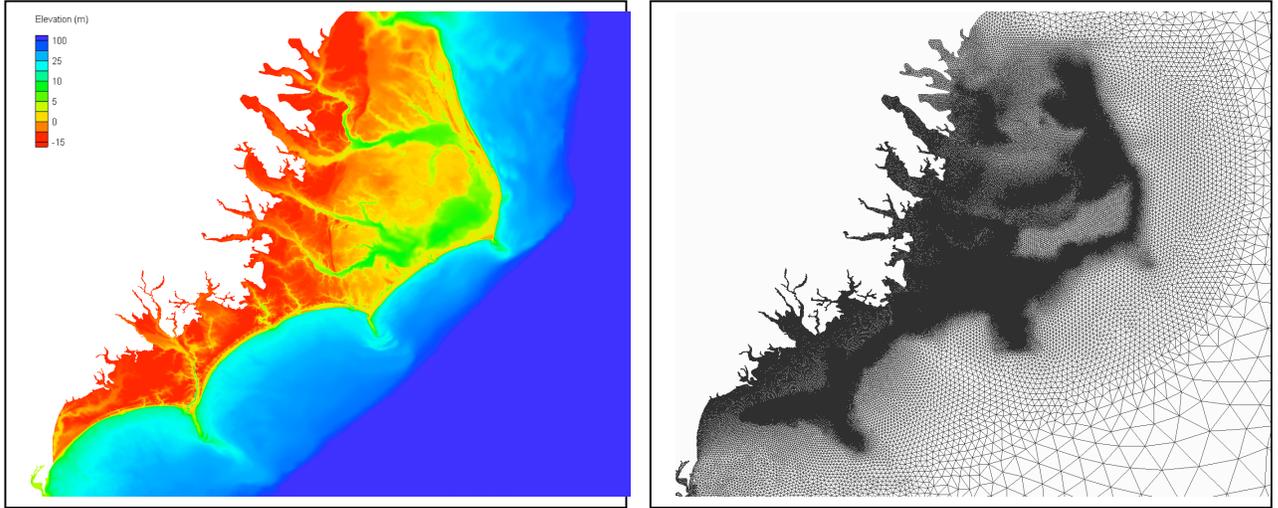


Figure 2.3: Expanded view of the entire North Carolina coastal region as represented in the grid and bathymetry/topography used for the ADCIRC storm surge modeling. Bathymetry and topography are relative to NAVD 88 with positive values being below datum.

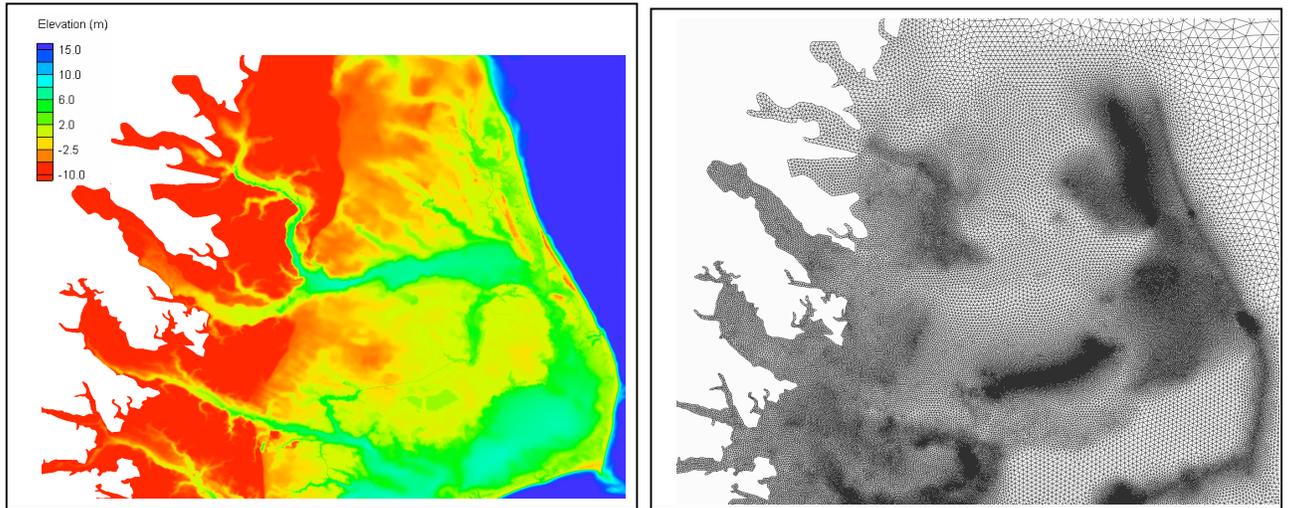


Figure 2.4: Detailed view of the northern North Carolina coastal region as represented in the grid and bathymetry/topography used for the ADCIRC storm surge modeling. Bathymetry and topography are relative to NAVD 88 with positive values being below datum.

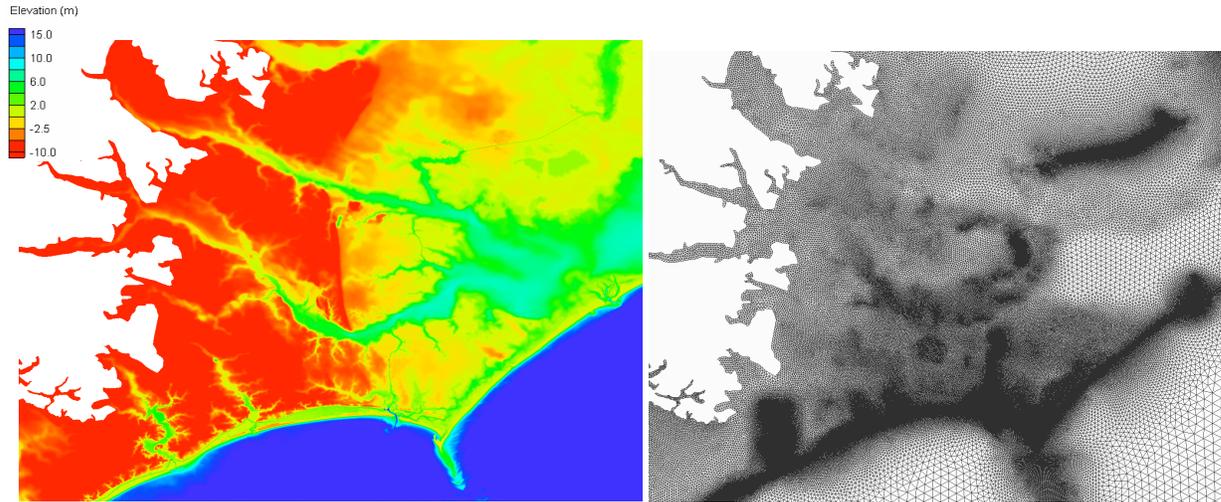


Figure 2.5: Detailed view of the central North Carolina coastal region as represented in the grid and bathymetry/topography used for the ADCIRC storm surge modeling. Bathymetry and topography are relative to NAVD 88 with positive values being below datum.

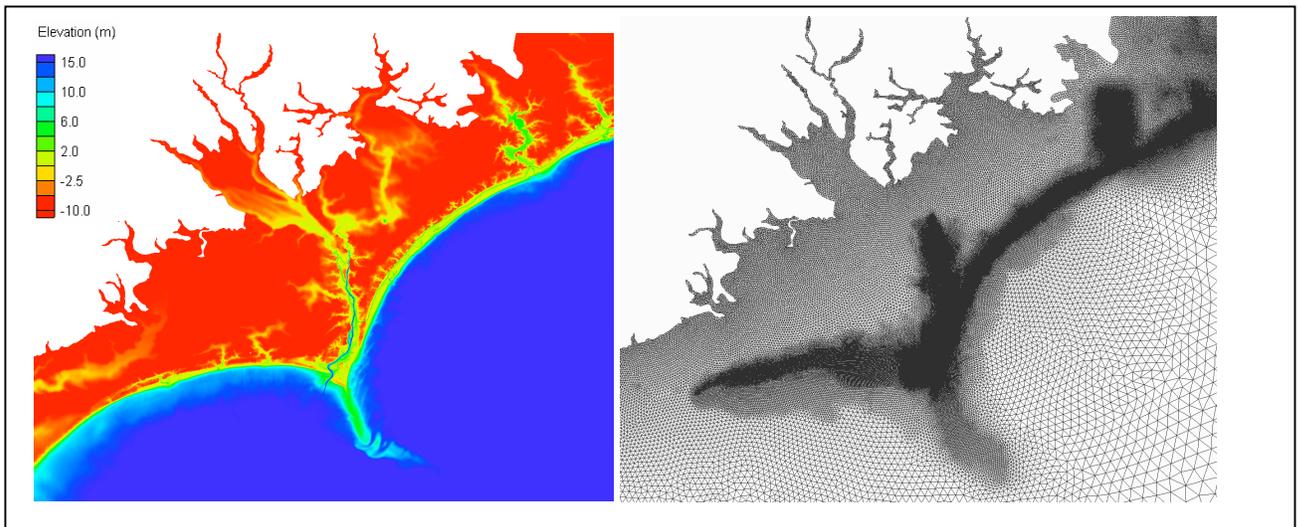


Figure 2.6: Detailed view of the southern North Carolina coastal region as represented in the grid and bathymetry/topography used for the ADCIRC storm surge modeling. Bathymetry and topography are relative to NAVD 88 with positive values being below datum.

The final version (v9) of the ADCIRC grid includes sufficient resolution to realistically represent the numerous inlets through the North Carolina barrier islands, the back barrier sounds and the US Inter Coastal Waterway that runs north-south through the North Carolina sounds. Over 50% of the grid cells have nodal spacing between 50 m – 500 m, Figure 2.7 with the highest resolution found in the immediate North Carolina coastal region. The large elements (> 500 m nodal spacing) are largely outside of the coastal North Carolina region.

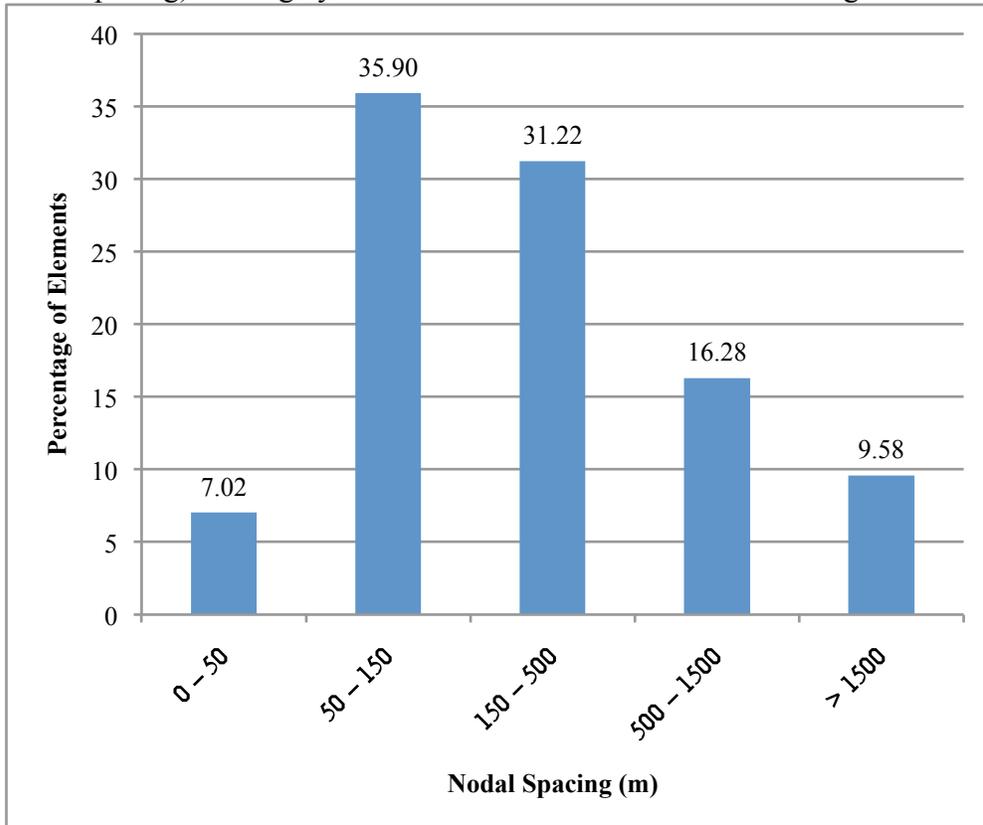


Figure 2.7: Summary statistics of the nodal spacing in the grid used for the ADCIRC storm surge modeling.

The DEM used to provide bathymetry and topography for the v9 grid has been developed in NAVD 88 as discussed in section 2 of this report. While this DEM provides unprecedented, integrated land to water coverage of coastal North Carolina, it was found that the 10 m resolution together with the paucity of data in the underlying DEMs (particularly the CRM) led to poor representation of many of the estuaries and sounds, particularly along the Intercoastal Waterway. To address this, NOAA Nautical Charts were used to hand-enter water depths (after correcting to NAVD 88) directly to the ADCIRC v9 grid, thereby overriding the values interpolated from the DEM, (Figure 2.8). While we are investigating the feasibility of including these points into future versions of the DEM, for efficiency purposes they were applied directly to the ADCIRC grid for the present project.

The use of “override bathymetry” had minimal impact in open areas such as Pamlico Sound, but provided a significant improvement in many of the more complex regions, e.g., behind barrier islands. Figure 2.9 provides an example of the latter in the Wrightsville Beach region and demonstrates how channel representations are substantially improved via this procedure. The bathymetric representation in the DEM (interpolated to the ADIRC v9 grid) is shown in the middle left panel. The ICWW and its connection to the coastal ocean are both poorly resolved. By setting the bathymetric depths in the channels (blue dots in the middle right panel) to the override values, representation of the ICWW and other channels is substantially improved, based on comparison to the NOAA charts for the region.

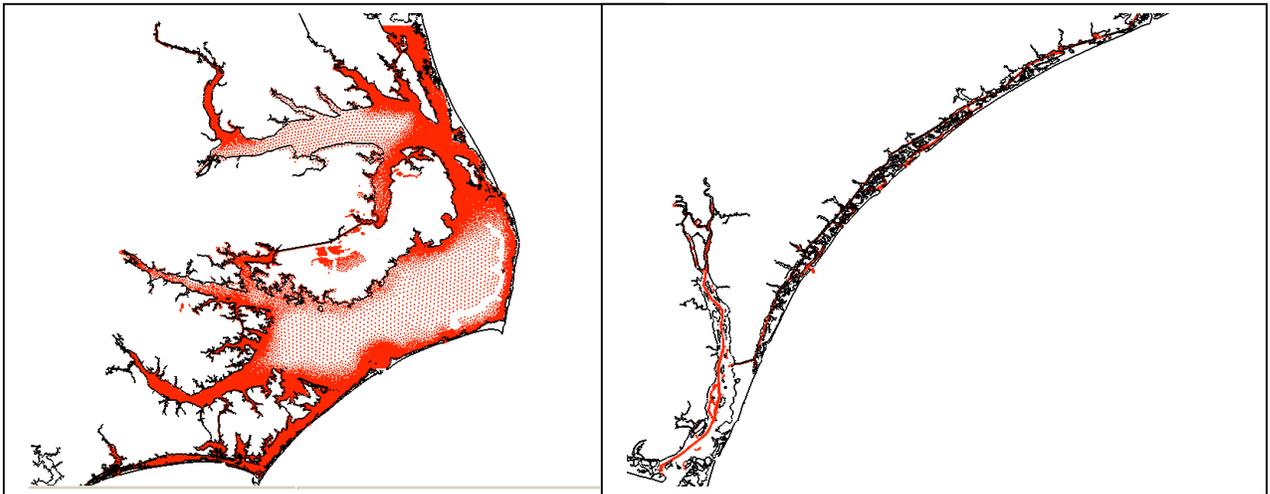


Figure 2.8: Red dots indicate v9 grid points that used hand entered “override” depths rather than depths interpolated from the DEM. These points are entirely in the water and replace values in the DEM that are derived from the CRM, which is suspect in estuarine waters.

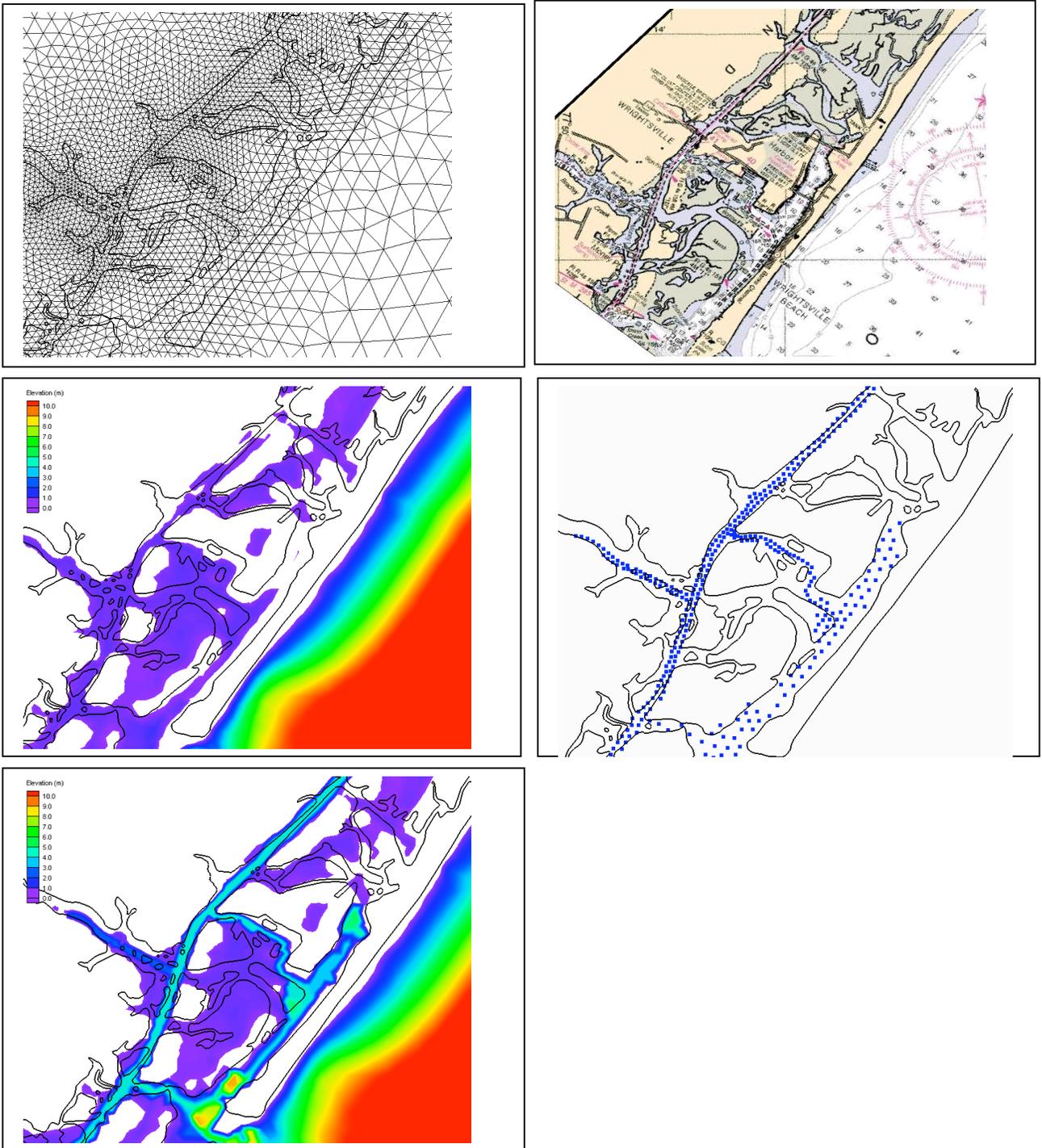


Figure 2.9: Example of the effect of using “override bathymetry” based on hand-entered values from NOAA charts in the ADCIRC v9 grid. The top left panel indicates the v9 grid in the vicinity of Wrightsville Beach, NC. The top right panel shows the NOAA charts in this area. The middle left panel indicates the bathymetric representation interpolated directly from the DEM. In this figure the colored areas are below the water line. The middle right panel indicates the location of nodes (in blue) where depths were replaced with “override bathymetry” values. The lower left panel indicates the final bathymetric representation using the “override bathymetry” values and shows that the ICWW and other channels are now reasonably

represented in the model. Note in the final three panels the black lines represent an approximate coast line for reference purposes only.

Since this project ultimately requires results in the NAVD 88 datum and all of the topographic data and some of the bathymetric data were available in NAVD 88, all DEMs and model results are reported relative to the NAVD 88 vertical datum. However, the ADCIRC model runs natively in a MSL datum and therefore the v9 – NAVD 88 grid had to be converted to MSL. The conversion was accomplished by performing a spatial interpolation between all of the locations (e.g., historical tide gauge sites) where the both NAVD 88 and MSL are known. This was done using the same interpolation algorithm used to develop VDATUM and provided a spatial varying correction that ranged from 21 cm near the Cape Fear River to 0 cm in inland areas (see Figure 2.10). The inverse conversion will then applied to the water level results to transform them back to NAVD88.

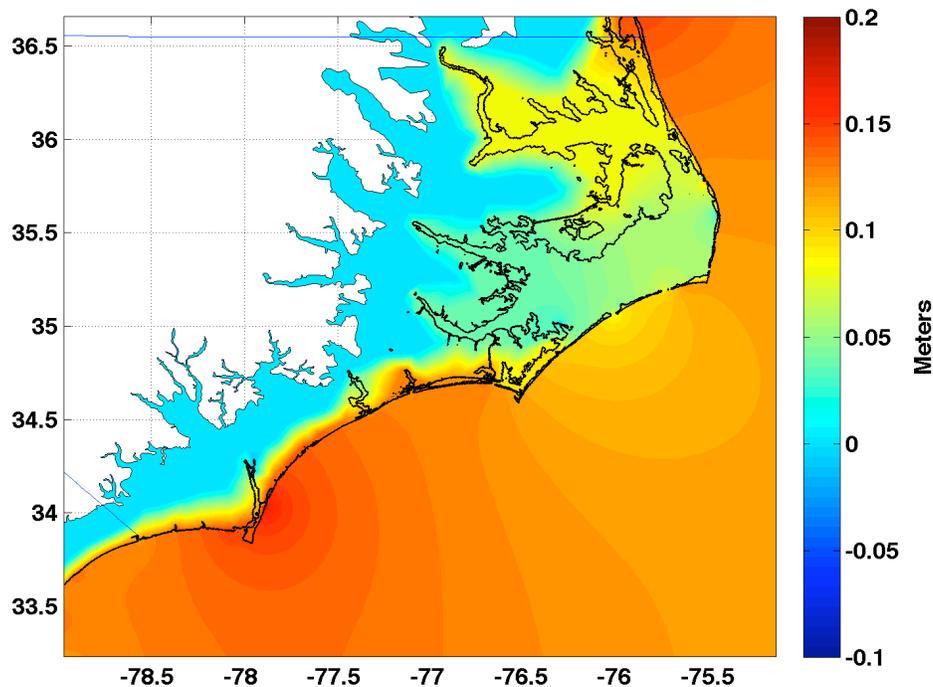


Figure 2.10: Spatial distribution of conversion field for translation between NAVD88 and MSL datums. This field is based on the VDATUM approach applied to the entire coast of North Carolina. The region above datum is assigned a conversion value of 0 meters, and linear interpolation is applied to fill in the land translation factors smoothly from the coast/water region up land. This field is applied to the vertical grids, which are in NAVD88, to translate to MSL. Surge results are translated from MSL to NAVD88 using the same conversion field.

ADCIRC requires the specification of Manning’s n friction coefficients in parts of the grid that are on land and in shallow water (typically < 2.5m depth) and a quadratic bottom friction coefficient in parts of the grid that are in deeper water. In addition roughness lengths and canopy

cover must be specified on land to account for vegetation and other land use characteristics to properly compute the wind stress in areas that have inundated. A directional wind reduction factor is applied based on the specified roughness lengths and canopy cover. A constant quadratic bottom friction coefficient ($=0.003$) was determined based on tidal calibrations done for the present and previous studies in the region. Manning's n , roughness lengths and canopy cover were determined from the USGS National Land Cover Database and FEMA HAZUS tables as described in Westerink et al, 2008.

Software used in ADCIRC grid generation

The majority of the grid development and manipulation work was done with SMS version 9.2.4 (build date May 1, 2007). SMS is distributed through Environmental Modeling Systems, Inc. (www.ems-i.com).

Chart Navigator Viewer version 5.08 (distributed by Maptech, Inc., www.maptech.com) is used to create pdf-files of NOAA Nautical charts. The PDF versions of the charts are used as the background image in SMS for alignment of grid features.

The process to interpolate the DEM onto the grid is a two step process. First the DEM is read in and converted to direct access format using the FORTRAN program `write_direct_access.f`. The second step is the actual interpolation and it is performed using the FORTRAN program `TestDEM.f`.

Finally, at the “override bathymetry” nodes, the FORTRAN program `choose_depths_v3.f` was used to replace the DEM based bathymetry values with values from the data file of hand entered depths.

Boundaries for the grid are created by the FORTRAN program `bnd_extr.f` version 2.1.

All FORTRAN codes used for grid development are available through the ADCIRC website, <http://www.adcirc.org>.

2 References

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3 Appendix

Template SWAN INPUT file.

```
*****HEADING*****
PROJ 'NCFMP SYS' '-RUNID>'
*****MODEL INPUT*****

SET NAUTICAL
SET MAXERR 3
MODE NONSTATIONARY
COORDINATES SPHERICAL

$ propagation scheme
$PROP : WILL USE DEFAULT FOR STATIONARY COMP., USE PROP BSBT FOR NONSTATIONARY COMP
PROP BSBT

$ COMPUTATIONAL GRID SPECIFICATION
CGRID REGULAR 281.50 32.50 35.00 3.25 1.50 65 30 CIRCLE 24 0.05 1.0 24

$ BATHY SPECIFICATION
INPGRID BOTTOM 278.498 31.503 0. 1814 1171 0.007 0.007 EXCEPTION -999.0
READINP BOTTOM 1.0 '-BATHYFILE>' 3 0 FREE

$ WIND SPECIFICATION
INPGRID WIND 278.498 31.503 0. 53 75 0.132 0.108 NONSTAT <START_DATE_TIME> <SWAN_WIND_DT> HR <STOP_DATE_TIME>
READINP WIND 1.0 SERIES 'wind.file.list' 4 0 1 FREE

$ WATER LEVEL SPECIFICATION
INPGRID WLEVEL 281.50 32.50 35.00 65 30 0.05 0.05 NONSTAT <START_DATE_TIME> <WATERLEVEL_TIMESTEP> HR <STOP_DATE_TIME>
READINP WLEVEL 1.0 '-WATLEVFILE>' 3 3 1 FREE

$ BOUNDARY SPECTRA
$ combined spec bcs from MW3
BOUNDnest2 WVIII OPEN

$ Initial condition startup
INITIAL DEFAULT

$ White-capping specification
WCAP K0H 2.36E-5 3.02E-3 2.0 1.0 1.0

$ Specify friction handling
FRIC JON

$ Specify numerical parameters
NUM ACCUR 0.04 0.04 0.04 96. 10

***** Output REQUESTS *****
BLOCK 'COMPGRID' NOHEAD 'HSIGN.OUTER.1.CGRID' LAY 3 RPER OUTPUT <START_DATE_TIME> <SWAN_OUTPUT_TIMESTEP> HR
BLOCK 'COMPGRID' NOHEAD 'HSIGN.OUTER.1.CGRID' LAY 3 HSIGN OUTPUT <START_DATE_TIME> <SWAN_OUTPUT_TIMESTEP> HR
BLOCK 'COMPGRID' NOHEAD 'FORCE.OUTER.1.CGRID' LAY 3 FORCE OUTPUT <START_DATE_TIME> <SWAN_OUTPUT_TIMESTEP> HR

$ define subsequent nested grids (NGRID) and output spectra on them (NESTOUT)
NGRID 'INNER1' 281.75 33.00 35.00 2.50 1.20 1250 600
NESTOUT 'INNER1' 'INNER.1.1.bcs' OUTPUT <START_DATE_TIME> <SWAN_OUTPUT_TIMESTEP> HR

$ Compute NONSTAT
COMPUTE NONSTAT <START_DATE_TIME> <SWAN_NONSTATIONARY_TIMESTEP> HR <STOP_DATE_TIME>
STOP
```