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ADVANCED ESTIMATION OF COASTAL STORM SURGE: APPLICATION OF SWAN+ADCIRC IN NORTHEAST FLORIDA/GEORGIA STORM SURGE

William Miller[1], Ashley Naimaster[2], and Christopher Bender[3]

ABSTRACT

The Federal Emergency Management Agency (FEMA) commissioned the Georgia/Northeast Florida Storm Surge Study (GANEFLSSS) as part of the recent effort to update coastal Flood Insurance Rate Maps. The study area includes coastal Georgia and Florida — from the Georgia-South Carolina border south to the border of Volusia and Brevard counties in Florida. The GANEFLSSS uses the two-dimensional (2D) SWAN+ADCIRC model, which simulates both waves and circulation with tightly-coupled SWAN and ADCIRC models on an identical, unstructured model mesh. The combination provides real-time feedback between the models. The SWAN+ADCIRC model inputs meteorological, tidal, and river inflow forcing to calculate depth-averaged currents, water levels, and waves. Model set-up considerations included optimal model mesh resolution, selection of spatially variable parameters, and model specific parameters and inter-model interactions. The validation effort included both astronomical tide and historical storm simulations. The selection criteria for the storms included the quantity of available water level and wave data, and storm surge magnitude. The study methodology and model application provides significant advances over the previous Flood Insurance Study conducted in the project area. Preliminary comparisons to measured water level and wave data indicate the SWAN+ADCIRC model developed during the study can simulate tide and storm conditions in the project area.

1. INTRODUCTION

The Federal Emergency Management Agency (FEMA) commissioned the Georgia/Northeast Florida Storm Surge Study (GANEFLSSS) as part of the recent effort to update coastal Flood Insurance Rate Maps. Working as part of the BakerAECOM LLC team, Taylor Engineering focused on the storm surge model setup and execution component of the study. The GANEFLSSS aims to apply storm surge modeling and statistical analysis to update the, 2-, 1-, and 0.2-percent annual chance stillwater elevations in the study area defined in Figure 1. Storm surge analysis includes the cumulative effects of storm winds, waves, and tides, and typically follows either a historical water level time series or a synthetic storm surge modeling approach. The former involves examining tide gauge records to determine water elevation frequency directly. The latter simulates historical storms

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or a large suite of synthetic storms with hydrodynamic and wave models to determine stillwater elevation frequency.

A poor spatial distribution of tide gauges and limited data records within the GANEFLSSS project area render the historical water level time series approach infeasible. Therefore, the GANEFLSSS follows other recently completed and ongoing FEMA coastal surge studies in the Gulf of Mexico and southeast U.S. coast by selecting a synthetic storm surge modeling approach.

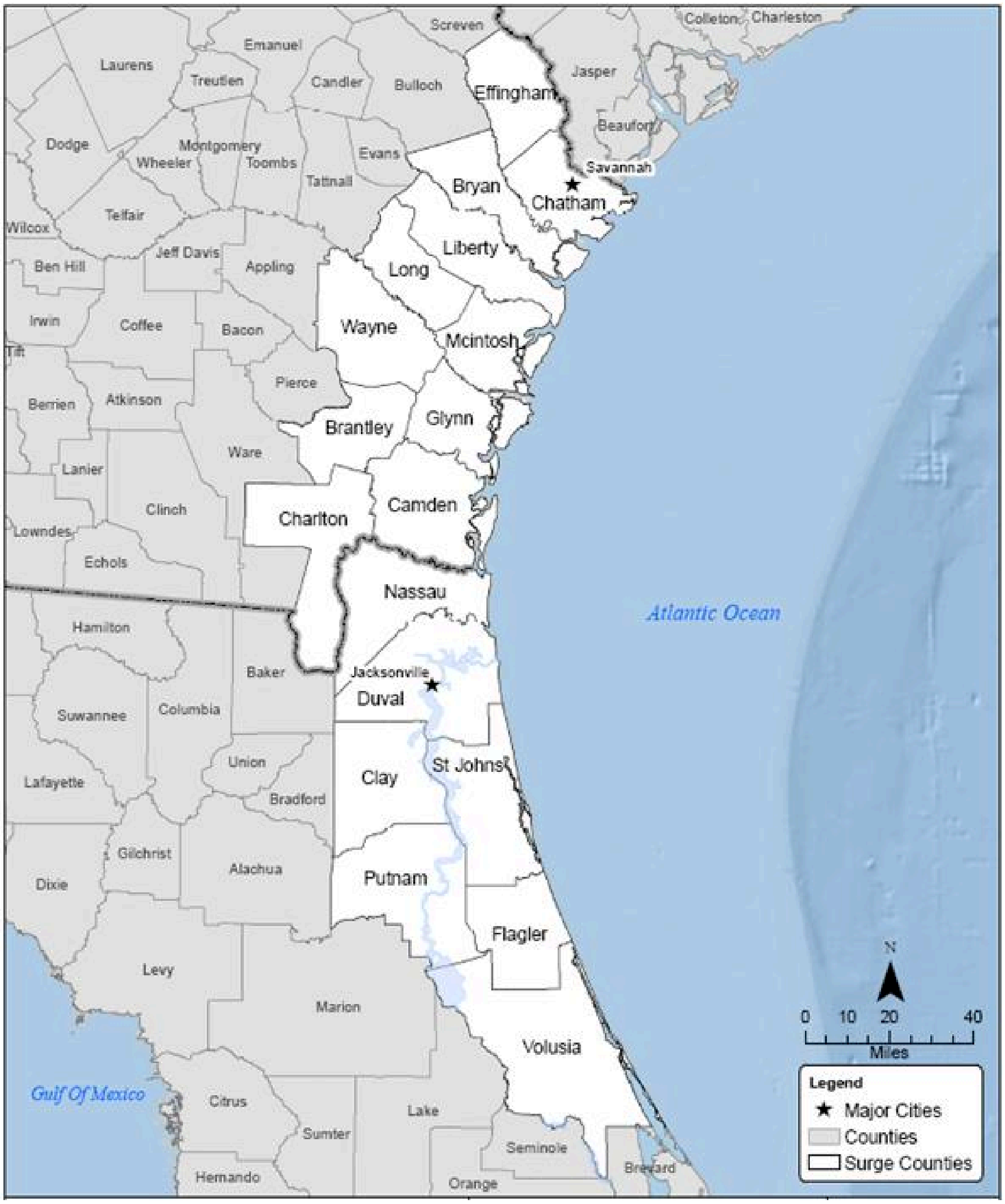


Figure 1 GANEFLSSS project area.

The project area also features a relatively large tide range — up to 7 feet (ft) — which requires the consideration of tide effects in the synthetic storm development and application. This approach differs from some recent FEMA surge studies that have applied the synthetic approach and added tide effects during the post-processed frequency analysis.

2. SURGE MODELING TECHNICAL APPROACH

Momentum transmitted to the water column by winds and waves provides the main forcing mechanisms for coastal storm surge (Resio and Westerink, 2008). Thus, appropriate models for simulating coastal storm surge must incorporate the essential physical processes of wind- and wave-induced momentum transfer. Generally, such models may require either structured mesh models — composed of rectangles or smooth, regular curvilinear quadrilaterals — and unstructured mesh models — composed of variable nodal spacing. By employing variable nodal spacing, unstructured meshes allow computational efficiency with detailed representation of complex coastal domains (i.e., large elements in areas with few features and small elements to resolve fine features where needed). The GANEFLSSS considered application of finite difference and finite element hydrodynamic models. Models that rely on finite difference methods — Sea, Lake, and Overland Surge from Hurricanes (SLOSH) (National Hurricane Center, 2011), for example — require structured meshes. Finite element models, such as Advanced Circulation (ADCIRC), generally apply unstructured meshes. SLOSH models run very quickly (e.g., several storm days run on a desktop computer in an hour), but they typically achieve hindcast accuracies within ±20 percent (Glahn, 2009). Recent advances in the ADCIRC finite element surge model achieve hindcast accuracies approaching 10 percent (FEMA, 2008). The GANEFLSSS selected ADCIRC to simulate hydrodynamics to provide high resolution in areas of interest such as shoreline, dunes, and inlets. The selection of the ADCIRC model maintains consistency with recent and ongoing FEMA coastal surge studies in Texas, Louisiana, Mississippi, northwest Florida, South Carolina, North Carolina, and studies further north along the Atlantic coast.

2.1 Model Details

The ADCIRC hydrodynamic model solves the vertically-integrated continuity and conservation of momentum equations for water level and current velocity (Luettich et al., 1992). The model accounts for known physical processes by including element wetting and drying algorithms, incorporating astronomic tidal constituents and riverine flow as boundary conditions, and applying spatially-varying parameterization of bottom friction, air-sea drag, and eddy viscosity for turbulence closure. The parallelized version of the ADCIRC code can run on high performance computing clusters (HPCC) to produce solutions far more rapidly than the single processor version.

Application of the ADCIRC model allows a choice of wave models. The GANEFLSSS selected the Simulating Waves Nearshore (SWAN) (Booij et al., 1999) to develop offshore and nearshore waves in the project area. Dietrich et al. (2011) provides a general description of the SWAN spectral wave model. In brief, SWAN applies a wave energy balance equation to predict the wave energy density spectrum in coastal areas. The model accounts for depth- and current-induced refraction and changes to the wave number caused by variations in mean current and depth. A source term within the SWAN model accounts for wind-induced wave growth; wave energy lost due to whitecaps, surf breaks, and bottom friction; and wave energy exchanged between spectral components in deep and shallow water through nonlinear effects. Booij et al. (1999) provide descriptions of SWAN parameterization of the above terms and processes.

Until recently, most coastal surge studies modeled hydrodynamics and waves separately on different model meshes. Typically, the hydrodynamic model output (water levels and currents) served as wave model forcing, then the wave model output (wave radiation stress) served as forcing for a second round of hydrodynamic modeling. The sequential hydrodynamic-wave-hydrodynamic modeling added wave-induced water level changes to the stillwater levels derived from the initial execution of the hydrodynamic model, but did not allow real-time feedback between the models during model execution. The absence of a feasible method to combine wave and detailed ADCIRC models for statewide or region-wide areas, and the lack of computational resources to model both waves and surge simultaneously dictated this independent multistep approach.

The 2009 release of SWAN+ADCIRC provided a tightly-coupled wave and hydrodynamic model that executes both SWAN and ADCIRC on an identical, unstructured model mesh and provides real-time feedback between the models (Zijlema, 2010). The modeling component of the study will apply the latest stable version of the SWAN+ADCIRC model. The ADCIRC model component of the SWAN+ADCIRC model supplies SWAN with the required input forcing data — wind speeds, water levels, and currents computed at the mesh vertices — at a specified time step. SWAN applies ADCIRC-supplied forcing data to recalculate the water depth and all related wave processes — wave propagation and depth-induced breaking, for example (Dietrich et al., 2011) — and passes information in the form of radiation stress back to the ADCIRC model, which then continues its hydrodynamic computations with the additional radiation stress information.

This tightly-coupled method advances the storm surge study methodology by improving computational efficiency. The model achieves improved efficiency by eliminating the need to interpolate model forcing information between multiple models. In addition, the tightly-coupled method applies direct real-time feed-back between the hydrodynamic and wave processes while the model's execute.

2.1 Model Design

Developing detailed unstructured model meshes ranging in size from several hundred thousand to over one million nodes requires many decisions related to nodal placement and connectivity. The ADCIRC hydrodynamic model (Luettich et al., 1992) performs water surface elevation and current velocity calculations at each node. Connectivity between nodes forms triangular elements through which water can flow. Nodal connectivity and placement determine how effectively the mesh represents the physical terrain and affects the numerical stability of the model calculations. Generally, the model should align mesh nodes to follow relevant physical features, such as elevated roadways or swales.

The mesh development team identified several goals to ensure sufficient terrain representation and enhance numerical stability. Goals included (1) incorporating hydraulically significant features that could convey or block storm surge flows, (2) incorporating bathymetric features that could influence wave propagation and (3) ensuring maximum accuracy in terrain elevations within the mesh resolution constraints dictated by computational resources and project schedule. Numerical stability considerations included element shape (equilateral triangles preferred), smooth wetting-and-drying fronts by setting elements along topographic contours, and minimizing topographic gradients within elements.

A high resolution mesh — node spacing as low as 30 m (100 ft) — resolved the significant topographic and bathymetric features required to simulate storm surge inundation and develop maximum water level values in the area of interest. To accommodate inundation from extreme storm events, the mesh extends inland to the 12.2-m (40-ft) topographic contour.

Following the methodology of recent ADCIRC storm surge studies, the GANEFLSSS extended the project area mesh boundaries to include the Gulf of Mexico, Caribbean Sea, and Western North Atlantic Ocean by incorporating the low-resolution East Coast 2001 (EC2001) mesh (Mukai et al., 2002). Extending the mesh simplified ocean boundary condition issues while it minimally increased the size of the mesh (a 12 percent increase in mesh nodes).

Figure 2 shows the entire SWAN+ADCIRC model extent and bathymetry. Figure 3 shows the model resolution near the GANEFLSSS project area. The counter-clockwise rotation of tropical storms dictates the extension of the mesh about 90 miles (mi) southward from the project boundary

(Volusia/Brevard County line) to accommodate surge inundation from extreme events. The extension prevents surge build up against the no-flow southern mesh boundary. If allowed to occur near the project area, surge build up may result in artificially high water levels within the project area. This additional inland mesh effectively covers a distance equal to roughly three times the radius to maximum winds of a large storm. Similarly, a smaller extension (30 mi) of the detailed mesh northward prevents water level build up against the northern model mesh boundary. Additionally, these extensions capture the complex network of coastal channels and inlets important to surge propagation.

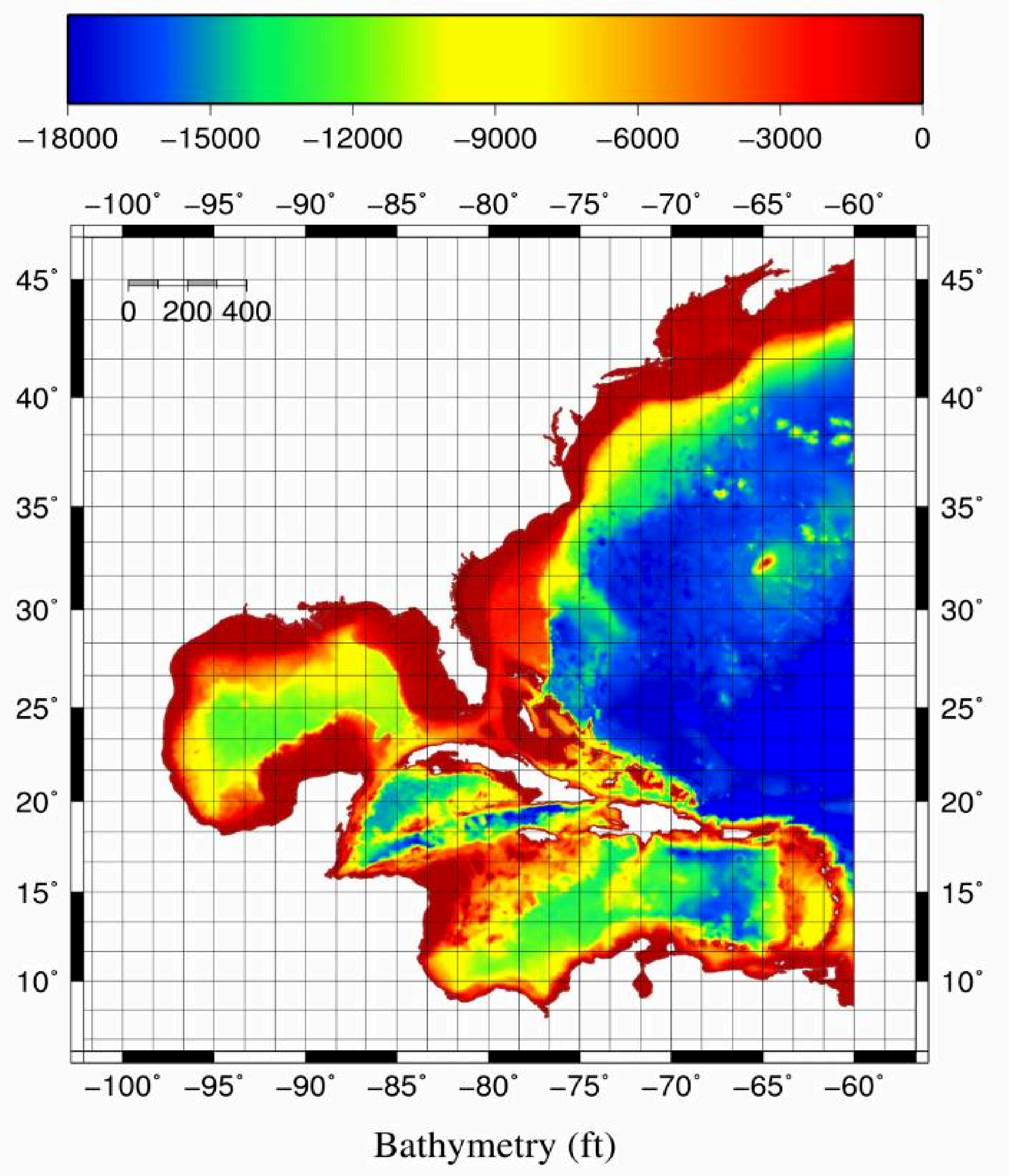


Figure 2 SWAN+ADCIRC model extent and bathymetry.

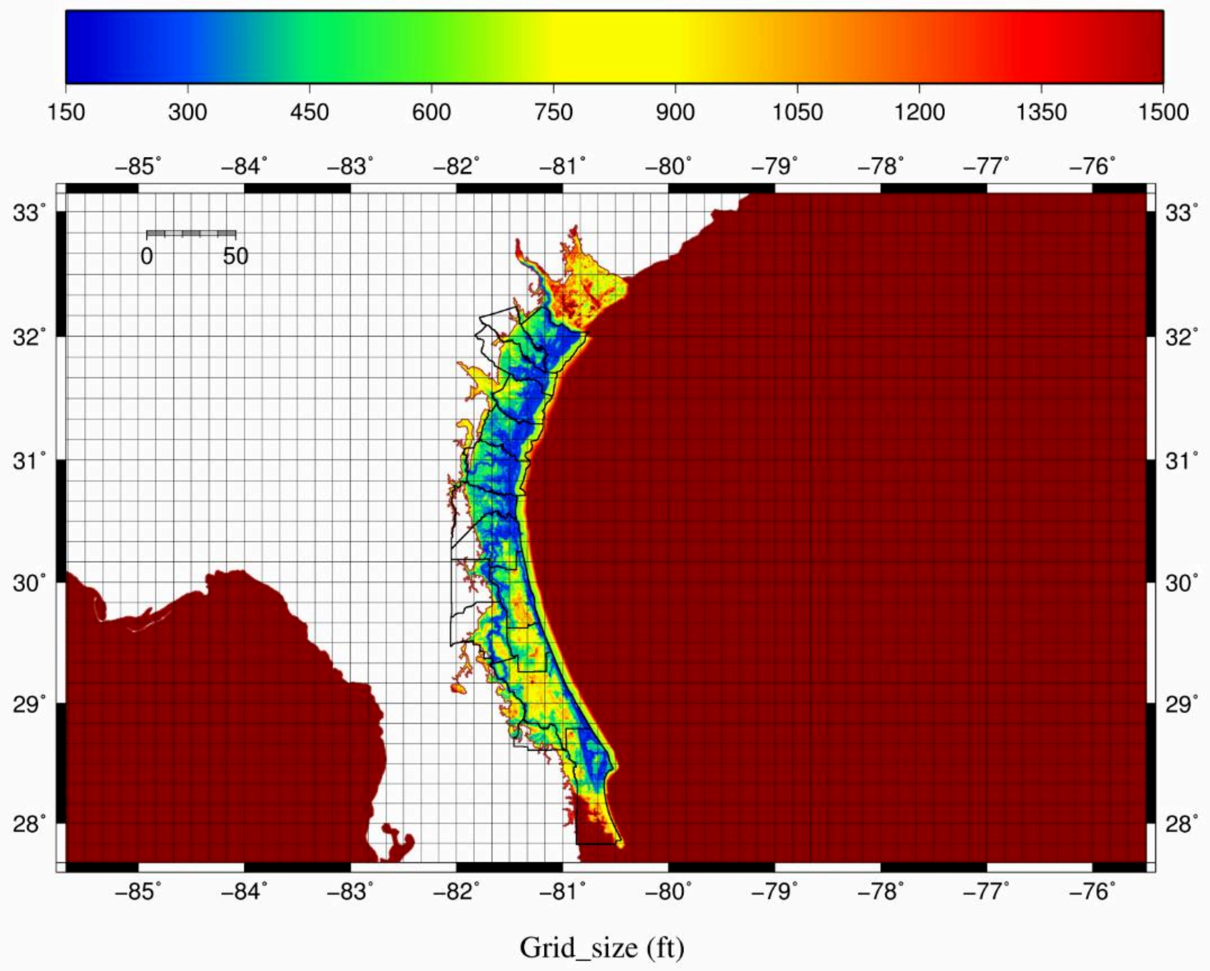


Figure 3 SWAN+ADCIRC model resolution near study area.

2.2 Mesh Development

The GANEFLSSS team developed a Digital Elevation Model (DEM) based on the most recent LiDAR data available and various sources of bathymetric data, including the University of Central Florida (UCF) Coastal Hydroscience Analysis, Modeling and Predictive Simulations (CHAMPS) Laboratory South Atlantic Bight (SAB) model mesh. A previous study developed a Coastal Features Database, which provided georeferenced polyline alignments of major railroad embankments, major roads, coastal structures, and conveyance pathways. The GANEFLSSS team applied Digital Orthophoto Quarter Quadrangle (DOQQ) aerial imagery for visual confirmation of land use type, and channel widths and alignments.

In parallel with the DEM development, the team used the Surface-water Modeling System (SMS) software by Aquaveo to develop a blueprint for the mesh design in the form of model mesh triangulation restraints provided by polylines (breaklines) and size functions. The breaklines capture important topographic features. The size functions describe local nodal spacing dependent on factors such as location, local elevations, terrain complexity, the potential for wave propagation, and human population densities. To develop the polylines, the GANEFLSSS team developed an automated feature extraction tool to identify key topographic and bathymetric features present within the LiDAR data to include in the mesh. The tool, based on watershed delineation software, aimed to flag features such as dune crests, roads, swales, and channel thalwegs.

Notably, the model mesh only includes topographic and bathymetric features present at the time of the LiDAR data acquisition. In addition, the storm surge and wave model will not simulate storm-induced erosion. Post-modeling treatments must account for such erosion.

The UCF CHAMPS Laboratory provided the inshore bathymetric portion of the GANEFLSSS mesh. The GANEFLSSS team provided UCF with polylines designating the shorelines of channels to include in the model, and UCF edited its SAB model mesh to fit within the GANEFLSSS channels and resolution requirements. UCF conducted initial model performance testing on the edited bathymetric mesh to verify that the edited mesh simulated tidal physics as well as the original mesh.

Finally, the team resolved the portion of the EC2001 mesh (Mukai et al., 2002) covering the nearshore zone through the continental shelf to accommodate SWAN wave transformation and breaking calculations. The relatively coarse resolution of the EC2001 mesh provides a reasonable mesh for regions far from the study area. Within the study area, the team selected the greatest resolution possible given the study's maximum node count, which allowed for 80 – 200 m (262 – 656 ft) resolution extending 4.8 km (3 mi) offshore, and for 4 km (2.5 mi) resolution at the eastern shelf edge. The team also applied, where available, offshore bathymetric data to the mesh. Otherwise, the bathymetric mesh interpolated values from the EC2001 mesh. Figure 2 presents the SWAN+ADCIRC model extent and bathymetry.

Marea Technology, LLC used the provided mesh, DEM, and vertical feature alignment datasets to interpolate the DEM onto the mesh. The interpolation directly assigned point elevations from the DEM to mesh nodes lying along vertical features to capture crests and valleys, and assigned area-averaged elevations for mesh nodes distant from vertical features. Due to the lower resolution of the mesh compared with the DEM, area-averaging elevations produced smoother topography and bathymetry in the mesh.

2.3 Initial Water Level

The ADCIRC model applies a reference sea level to solve its governing equations. By convention, the modeler establishes this level at the local mean sea level (MSL). The DEM, and thus the mesh, establishes the project area topography with reference to an idealized common equipotential surface — the geoid (NAVD88). Unfortunately, due to physical processes (e.g., currents and variations in air pressure, temperature, and salinity), the actual MSL surface does not coincide with the geoid.

In the GANEFLSSS area, NOAA benchmarks demonstrate that MSL ranges from -0.23 ft NAVD88 north at Fort Pulaski, GA to 0.92 ft NAVD88 at Cocoa Beach, FL just south of the project area. Nevertheless, to establish an initial water level to begin model calculations, the GANEFLSSS team had three options:

1. Maintain the mesh nodal elevations referenced to the geoid (NAVD88) and assume the geoid coincides with MSL (i.e., set the initial water level at 0 ft-NAVD88).
2. Maintain the mesh nodal elevations referenced to the geoid (NAVD88) and establish a representative MSL offset as the initial water level. An average difference between MSL and the geoid may establish this offset with an additional offset to account for steric effects. Recent FEMA coastal surge studies in Louisiana, Texas, Mississippi, Alabama, and South Carolina applied this general methodology.
3. Develop a MSL surface based on the dynamic sea surface topography over the project area and modify the mesh nodal elevations to reference the MSL surface. Then, execute the ADCIRC model and convert the water level results calculated in the MSL reference back to the geoid by reverse application of the MSL surface. Recent FEMA coastal surge studies in North Carolina and the Virginia/Delaware area applied this general methodology.

Each option has strengths and weaknesses. Option 1 provides the simplest approach and acceptable accuracy in geographic locations where the geoid closely coincides with MSL, but introduces inaccuracies where the geoid and MSL diverge (e.g., the GANEFLSSS area). Option 2 provides an effective methodology where the geoid and MSL have a generally uniform divergence throughout the project area, but introduces inaccuracies in a project area with a non-uniform divergence (e.g., the GANEFLSSS area). Option 3 accurately models the initial MSL water level throughout the project area, but it distorts the model mesh to accommodate a dynamic sea surface effect and, thus, potentially introduces non-physical flow effects based on the distortion.

The GANEFLSSS project team applied Option 2 with the mesh topography referenced to NAVD88 and a uniform initial water surface offset. (The formulation of the pre- and post-production statistical analysis will consider the MSL-to-geoid divergence and account for it to reduce its effect on the final water levels.) Within the GANEFLSSS project area, NOAA considers the Fort Pulaski, Fernandina Beach, FL, and Mayport Bar Pilots Dock, FL, in long-term sea level trend analysis. Among these stations, the Fort Pulaski, Fernandina Beach, and Mayport stations have continuous data from 1935 to the present.

Figure 4 plots MSL (relative to NAVD88) at the Fort Pulaski (MSL = -0.24 ft-NAVD88), Fernandina Beach (MSL = -0.53 ft-NAVD88), and Mayport (MSL = -0.56 ft-NAVD88) stations and other, shorter-term stations along the shoreline in the project area.

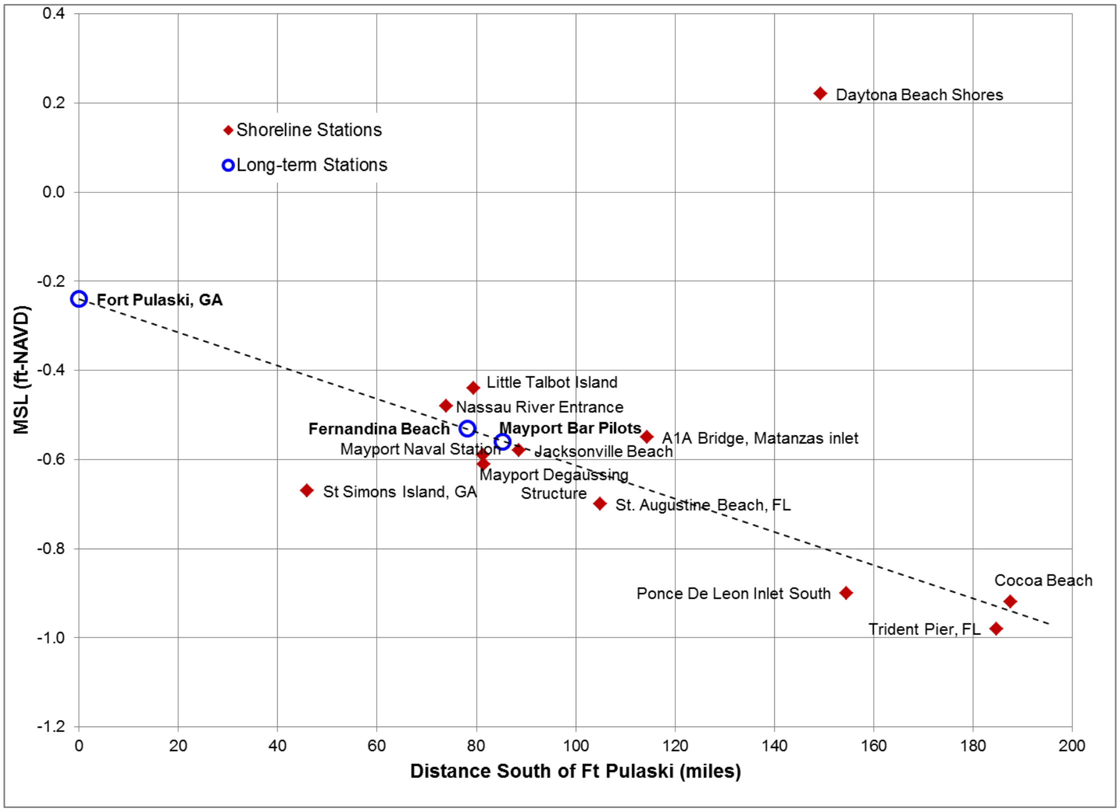


Figure 4 Spatially Varying Differences between MSL and NAVD88

The figure shows that the trend defined by the long-term stations — MSL lies farther below NAVD88 south from Ft. Pulaski — remains consistent southward (excluding outliers). Based on the plot, the project area has an average -0.56-ft MSL offset from 0 ft-NAVD. This average applies the three long-term stations and Cocoa Beach station to include a data point at the southern project limit.

Inclusion of the Ponce De Leon South or Trident Pier station instead of Cocoa Beach does not appreciably alter the average value calculated.

Seasonal water level variations (steric effect) may require an additional adjustment of the initial water levels in the GANEFLSSS model. NOAA historical data for the Mayport station (8720218) indicates the June through November average water level offset equals 0.19 ft and a maximum monthly value equal to 0.69 ft in October. Notably, the hurricane season spans from June 1 to November 31. The NOAA data for the other long-term stations shows average hurricane season offsets within 0.02 ft of the Mayport station value and maximum monthly values within 0.13 ft. The ongoing Joint Probability Method-Optimal Sampling (JPM-OS) analysis and development will treat the tidal influence in the project area and may treat the seasonal water level variation.

3. MODEL VALIDATION

3.1 Validation Storm Selection

Application of the synthetic storm surge modeling and statistical analysis approach requires validation of the storm surge and wave models with historical information. The ADCIRC and SWAN models have undergone extensive calibration of the physics represented in the model through studies of oceans, bays, and estuaries around the world. For each new SWAN+ADCIRC model grid, a validation of the grid demonstrates model performance. For this study, the ongoing validation phase includes a comparison of the water level results with tide data — tide validation — and water level and wave results for several historical hurricanes — validation storms — that affected the GANEFL project area.

The ongoing tide validation applies a 72-day simulation with 8 tide constituents applied to the ADCIRC model. The team compared tidal constituent tidal amplitude and phase from the ADCIRC model results to historical NOAA data at stations throughout the project area. Notably, in the past 50 years, the GANEFLSSS area has experienced only two significant hurricane landfalls, both of which occurred over 30 years ago (hurricanes Dora in 1964 and David in 1979). This limited storm activity presented a challenge to selecting validation storms. Briefly, the study team applied a set of selection criteria to discriminate between candidate historical storms. Criteria included storm track and landfall proximity to the study area, surge level reached in study area, the number of available water level data points, and the number of available wave data points. Based on these criteria, the GANEFLSSS selected Hurricane Dora (1964), Hurricane David (1979), Hurricane Frances (2004), Tropical Storm Tammy (2005), and Tropical Storm Fay (2008) as the project validation storm suite (Figure 5). Comparisons of SWAN+ADCIRC model results with measured water level and wave data will demonstrate the model's capability to reproduce storm wave and water levels in the GANEFLSSS project area. Notably, at the time of the manuscript submittal, the GANEFLSSS validation effort was incomplete.

3.2 Preliminary Model Validation Results: Tides

Preliminary model simulations for the ongoing GANEFLSSS SWAN+ADCIRC model validation show good agreement with available measured data for comparisons to tides (no meteorological forcing) and the validation storms.

For the tide validation, the ADCIRC model executed a 72-day tide run including a 15-day ramp-up beginning on January 1, 2010, followed by a 56-day data collection period. Eight dominant astronomical tidal constituents (Table 1) forced the model at the open Atlantic Ocean boundary (at approximately 60°W). The LeProvost database (LeProvost et al., 1994) provided amplitudes and phases at the open ocean boundary for each tidal constituent. The model does not include riverine forcing. Table 1 includes the average measured amplitude for each constituent for the 42 stations examined in the present study. The table lists the constituents in descending order of the average amplitude. By far, the M2 constituent (responsible for the semi-diurnal tides in this region) dominates all other constituents.

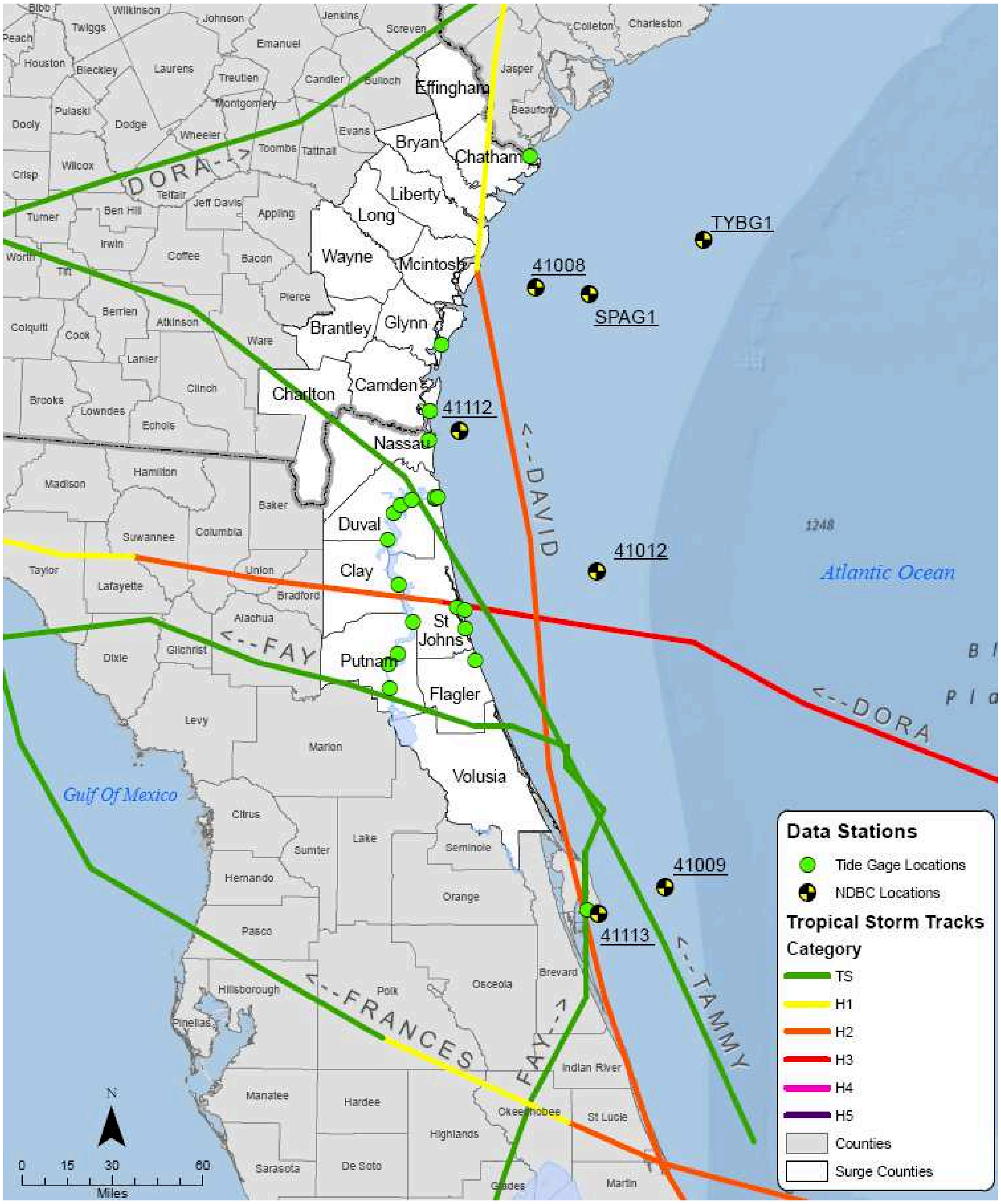


Figure 5 GANEFLSSS validation storm suite and measurement data locations.

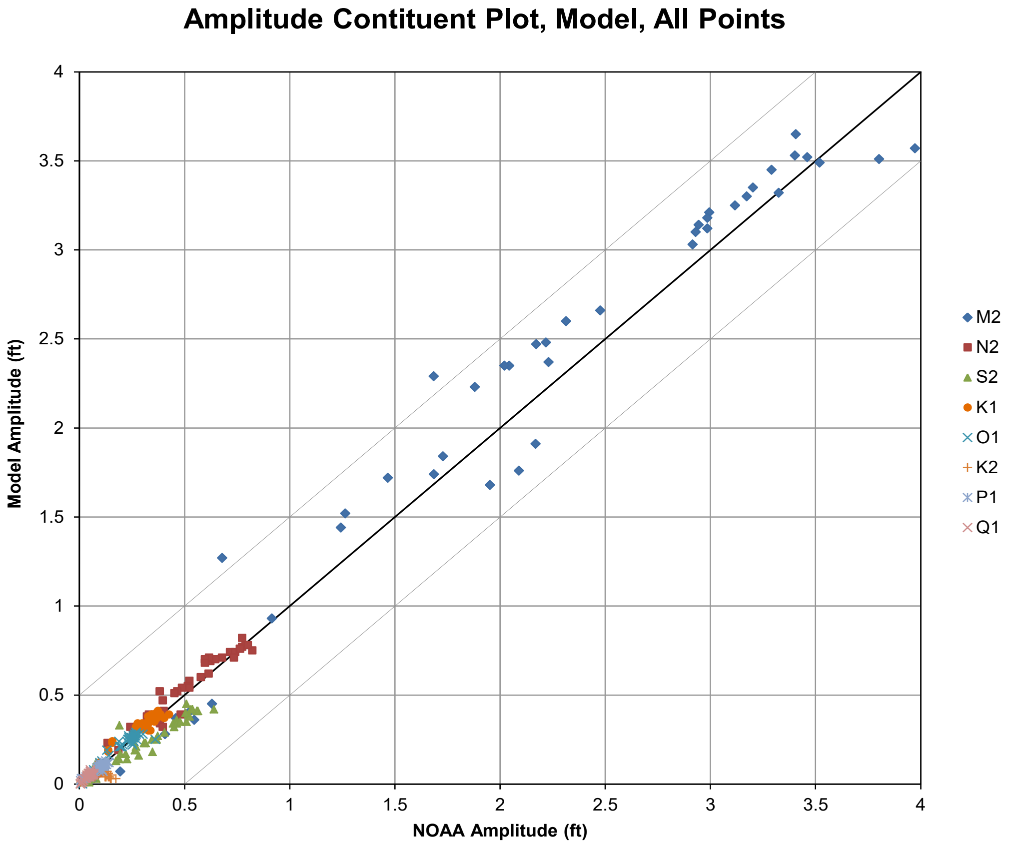
A harmonic analysis of the ADCIRC time histories simulated during the 56-day data collection period yielded model amplitudes and phases information at each of the stations with available data (42 stations) for each tidal constituent listed in Table 1. Figures 6 and 7 compare the

NOAA measured to ADCIRC modeled amplitudes and phases. The amplitude plot (Figure 6) includes a 0.5-ft error band and the phase plot (Figure 7) includes a 20-degree error band. In each figure, perfectly modeled tides would follow the center reference line, which would indicate a one-to-one relationship between the measured and modeled results.

Table 1 Tidal Constituents Applied in SWAN+ADCIRC Tidal Validation

Constituent	**Average Amplitude (ft)**	**Period (hours)**	**Type**
M2	2.22	12.42	Principal lunar
S2	0.48	12.00	Principal solar
N2	0.33	12.66	Larger lunar elliptic
K1	0.28	23.93	Luni-solar diurnal
O1	0.21	25.82	Principal lunar diurnal
K2	0.09	11.97	Luni-solar semi-diurnal
P1	0.09	24.07	Principal solar diurnal
Q1	0.04	26.87	Larger lunar elliptic

Figure 6 shows good amplitude agreement over all stations and constituents with the exception of the K2 constituent. The model consistently underestimates the K2 constituent amplitude; however, the average amplitude of the dominant M2 constituent (2.22 ft) dwarfs that of the K2 constituent (0.09 ft). Therefore, the error in the K2 constituent has little effect on the model's capability to simulate the tides. Figure 7 shows reasonable agreement between measured and modeled phase, again with the exception of the K2 constituent.



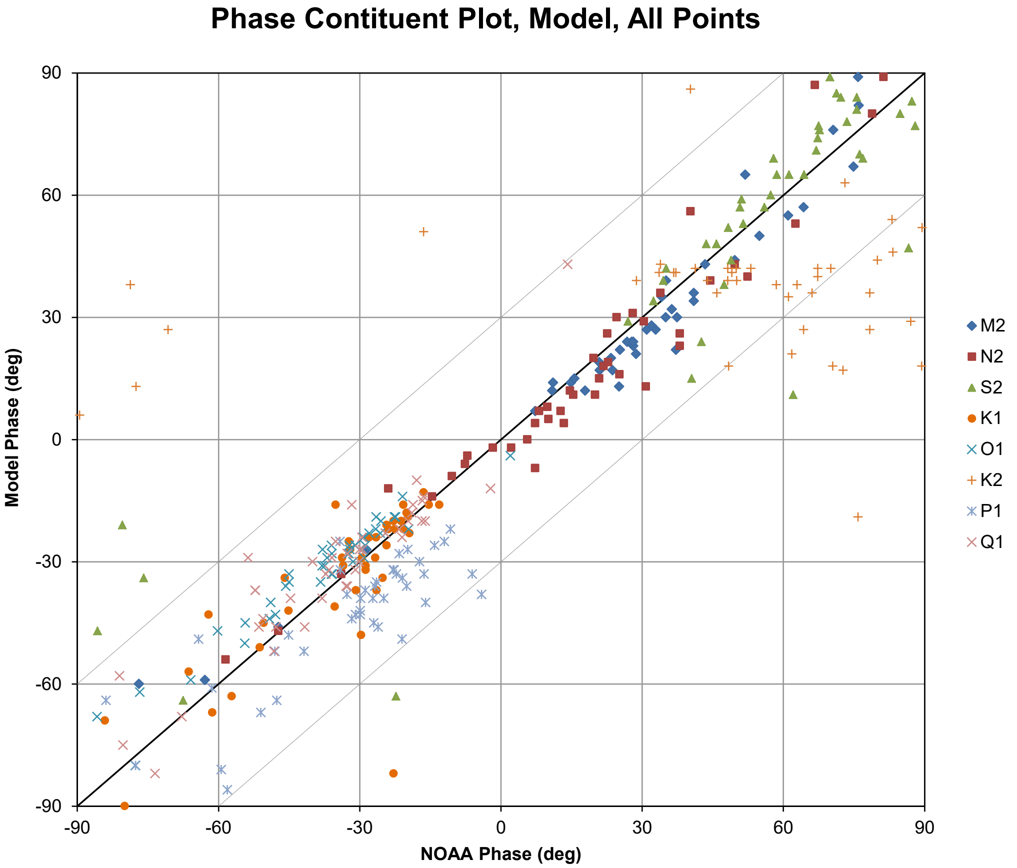


Figure 7 Comparison of measured-to-modeled phase for tide validation (preliminary results).

3.3 Preliminary Model Validation Results: Storms

Storm validation demonstrates the SWAN+ADCIRC model's capability to reproduce observed hydrodynamic conditions in the study area during severe storms. Figure 5 plots the tracks of the five validation storms applied in the GANEFLSSS with storm intensity indicated by color. The GANEFLSSS project team executed SWAN+ADCIRC simulations for each of the five storms and processed the model output to allow comparison to measured data. For each storm validation run, the ADCIRC model executed a 15-day ramp-up with tidal forcing followed by four to nine additional days for the storm simulation with tidal and meteorological forcing. The length of meteorological forcing depended on historical storm duration; hurricanes Dora, David, and Frances required nine days of winds, while Tropical Storm Tammy required four days, and Tropical Storm Fay six days. The ADCIRC portion of the simulation specified a 1-second time step for all simulations. The model applied OWI winds at 15-minute intervals. SWAN wave computations occurred on 20-minute intervals, with six maximum iterations per interval.

Contour plots of maximum water level display the SWAN+ADCIRC model results at peak water level for the validation storms across the entire project area. The contour plots allow examination of the water level features near the coast, along important waterways, and over inundated inland areas. Figure 8 plots the maximum SWAN+ADCIRC water level for the entire project area, and shows maximum water levels near 8 ft-NAVD for northern Florida and southern Georgia during Hurricane Dora. The plot includes a brown line that indicates the limit of the SWAN+ADCIRC model.

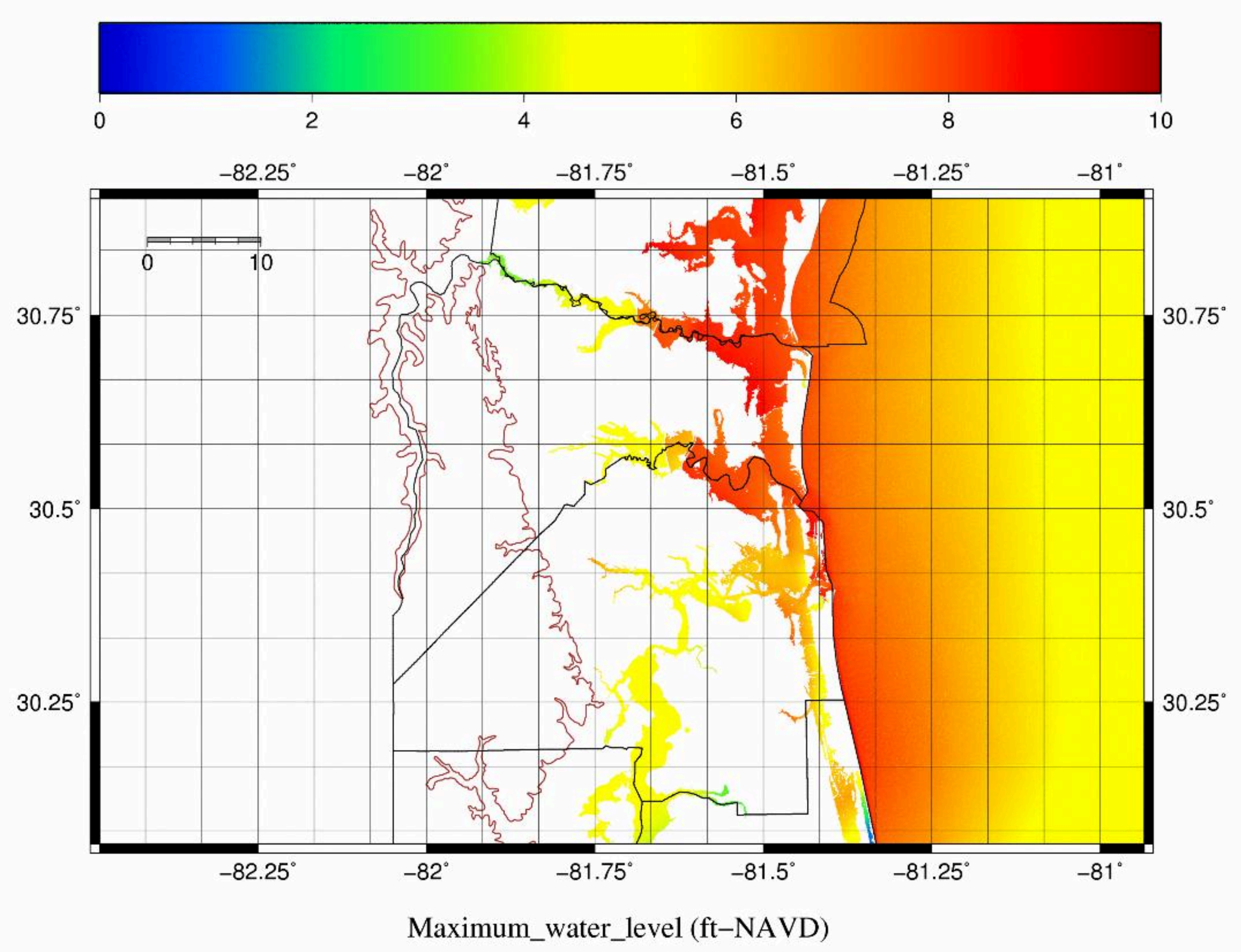


Figure 8 SWAN+ADCIRC maximum water levels from Hurricane Dora — Nassau and Duval counties, Florida (preliminary results).

Preliminary comparisons of the SWAN+ADCIRC model results and measured hydrographs indicated reasonable model performance. Figure 9 compares the SWAN+ADCIRC modeled and NOAA preliminary (unverified) measured Fernandina Beach hydrographs for Hurricane Dora. Figures 10 compares the SWAN+ADCIRC-modeled and the NOAA-verified measured hydrograph at Fort Pulaski for Hurricane David. The plots show good agreement during the pre-storm tide-dominated period and reasonable agreement during the peak water levels. Figures 9 and 10 indicate two of the highest measured water levels for the project area where a significant hurricane has not made landfall in many decades. Additional work will compare the available measured water level data for the five validation storms with the SWAN+ADCIRC model results to ensure reasonable model performance.

In addition to comparisons to hydrodynamic conditions, storm validation demonstrates the SWAN+ADCIRC model’s capability to reproduce wave conditions in the study area during severe storms. Figure 11 presents SWAN+ADCIRC model maximum wave height and direction vectors from Hurricane Dora. The plots show waves in excess of 30 ft in offshore areas with reduced wave heights for waves in nearshore and inland waterway areas.

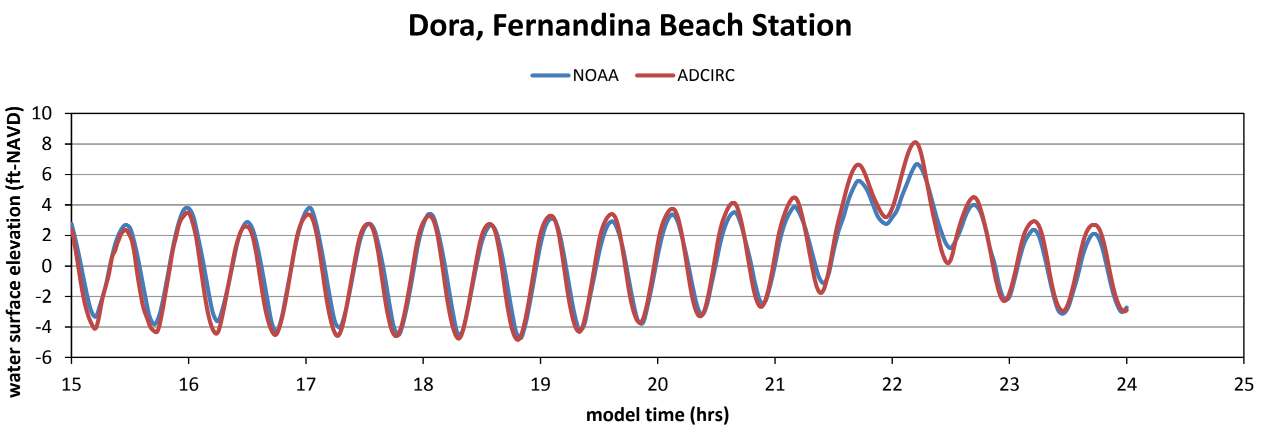


Figure 9 Hurricane Dora hydrographs at Fernandina Beach — NOAA Station 8720030 (preliminary

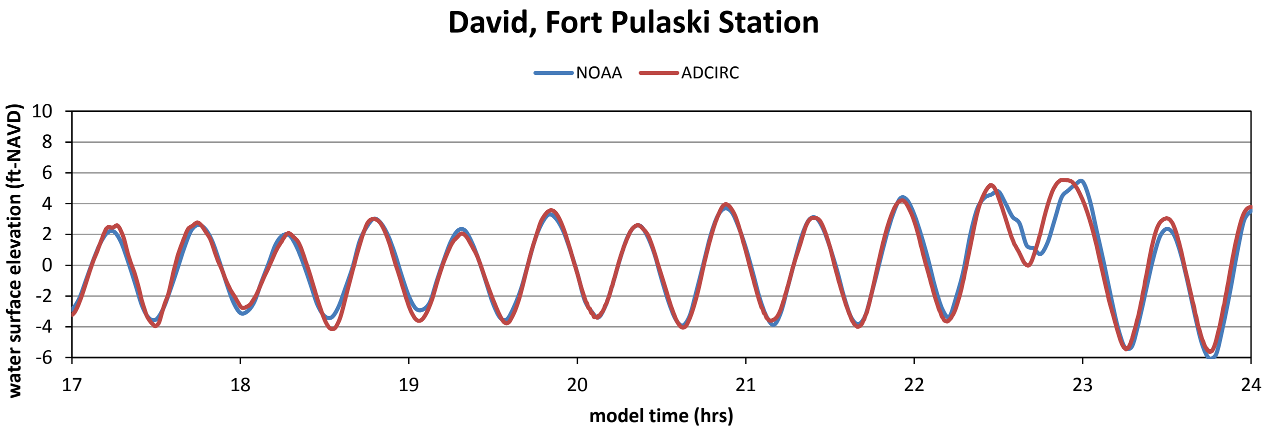


Figure 10 Hurricane David hydrographs at Fort Pulaski — NOAA Station 8670870 (preliminary results).

In addition to comparisons to hydrodynamic conditions, storm validation demonstrates the SWAN+ADCIRC model's capability to reproduce wave conditions in the study area during severe storms. Figure 11 presents SWAN+ADCIRC model maximum wave height and direction vectors from Hurricane Dora. The plots show waves in excess of 30 ft in offshore areas with reduced wave heights for waves in nearshore and inland waterway areas.

Figure 12 shows the wave parameter time series for a four-day span for Tropical Storm Tammy at NDBC Station 41012 located offshore of St Johns County in northern Florida. The plot shows measured wave height and peak wave period data, along with the SWAN+ADCIRC-modeled wave height, peak wave period, and mean wave period results. The comparison shows good agreement between the measured and simulated wave heights, and peak wave periods with SWAN+ADCIRC generally underestimating the measurements. The SWAN+ADCIRC model estimates maximum wave heights near 16 ft with a peak period of 10 seconds. The plot shows that the SWAN+ADCIRC model does a reasonable job simulating the wave height and peak wave period as the storm moves through the project area.

Figure 13 shows the wave parameter time series for a four-day span for Tropical Storm Fay at NDBC Station 41112 located in relatively shallow water near the Florida and Georgia border. The plot shows measured wave height and peak wave period data, along with the SWAN+ADCIRC-modeled wave height, peak wave period, and mean wave period results. The SWAN+ADCIRC model estimates maximum wave heights near 14 ft with a peak period of 10 seconds. The wave height and peak wave period comparisons show good agreement between the measurements and modeled results.

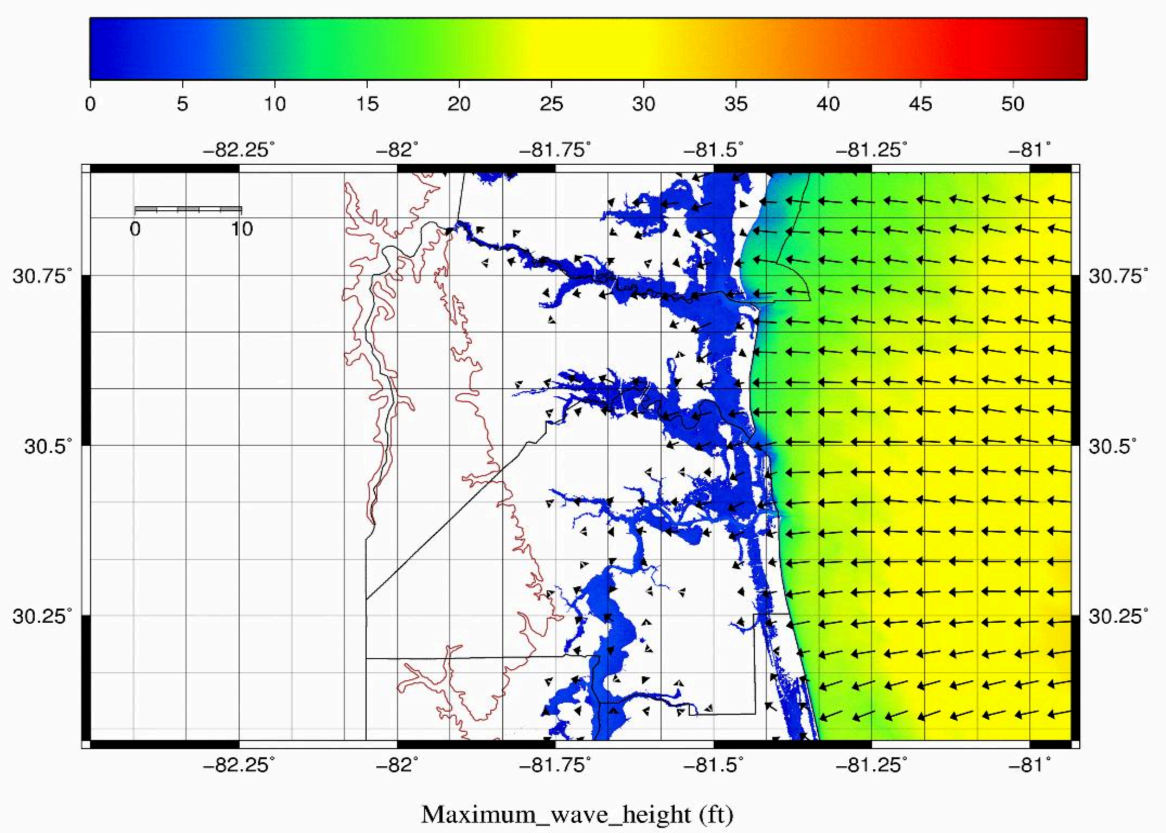


Figure 11 SWAN+ADCIRC maximum wave height and direction vectors from Hurricane Dora — Nassau and Duval counties, Florida (preliminary results).

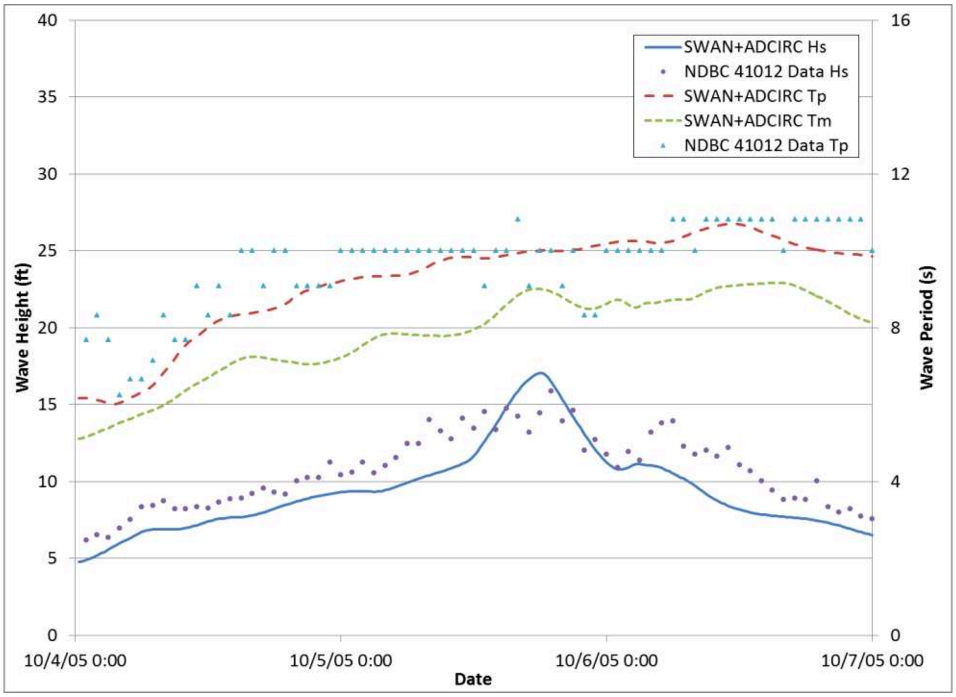


Figure 12 Time series of modeled and measured wave conditions from Tropical Storm Tammy — Station 41012 (preliminary results).

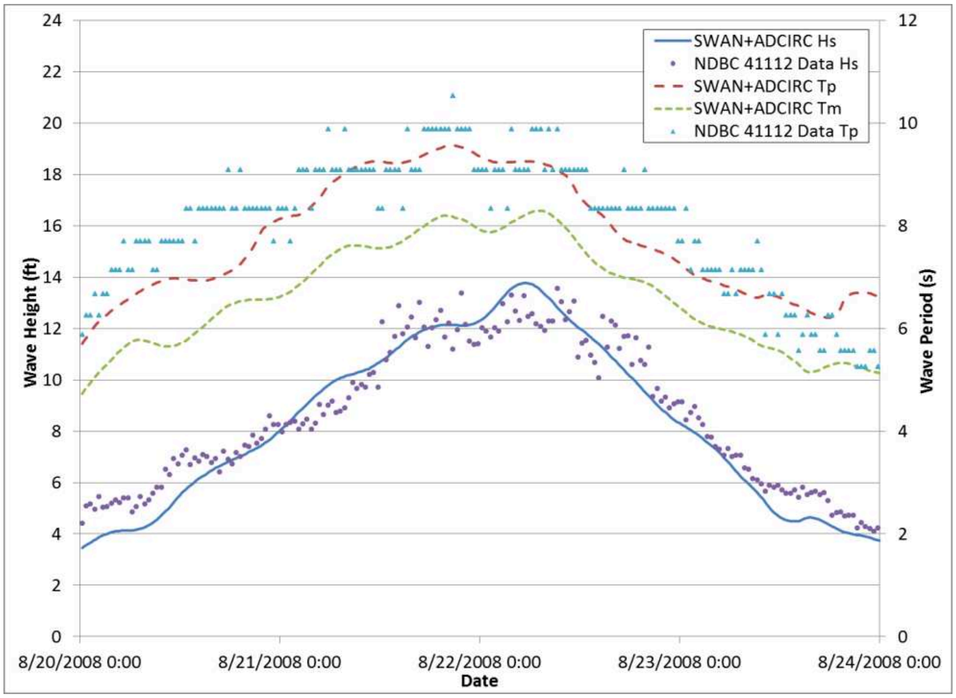


Figure 13 Time series of modeled and measured wave conditions from Tropical Storm Fay — Station 41112 (preliminary results).

4. CONCLUSIONS

To provide FEMA with reliable water level information to update the coastal Flood Insurance Rate Maps, the BakerAECOM LLC GANEFLSSS team has developed a detailed, high-resolution SWAN+ADCIRC model mesh of the coast of Georgia and Northeast Florida. After completing model validation to tides and storm water levels and waves, the team will apply the advanced SWAN+ADCIRC combined wave and hydrodynamic model to develop the 2-, 1-, and 0.2-percent annual chance stillwater elevations in the study area. This model advances the science of storm surge modeling most notably by improving the representation of physical processes with real-time, internal wave-to-hydrodynamic model feedback within the model execution.

The variation between the mesh reference geoid and MSL and the MSL variation throughout the GANEFLSSS project area presented an ADCIRC model execution challenge to the GANEFLSSS team. The team has resolved this challenge by incorporating the MSL variation into the JPM-OS formulation and post-production statistical analysis.

Finally, preliminary tide and storm validation results demonstrate that the GANEFLSSS model mesh will satisfactorily reproduce tides, storm surge, and wave conditions within the project area.

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