Executive Summary: NACCS Modeling Component

The document summarizes the application of a suite of high-fidelity numerical models for the North Atlantic Coast Comprehensive Study (NACCS). The effort was conducted to provide information for computing the joint probability of coastal storm forcing parameters for the North Atlantic Coast of the United States because this information is critical for effective flood risk management project planning, design, and performance evaluation. The numerical modeling study was performed using the high-fidelity models within the Coastal Storm Modeling System (CSTORM-MS). The NACCS numerical modeling study produced nearshore wind, wave and water level estimates and the associated marginal and joint probabilities. Documentation of the statistical evaluation is provided in a separate Executive Summary.

The first major step in the numerical modeling effort was to select a suite of storms to simulate that are statistically significant to the region of interest. The NACCS coastal region is primarily affected by tropical, extratropical, and transitional storms. It is common to group the storms into statistical families of tropical and extratropical with transitional storms that were once tropical being mostly categorized as tropical. In this study, both tropical and extratropical storms were strategically selected to characterize the regional storm hazard. Extratropical storms were selected using the method of Nadal-Caraballo and Melby (2014) using an observation screening process. The tropical storm suite was developed using a modified version of the joint probability method (JPM) methodology (Ho and Myers 1975) with optimized sampling (JPM-OS) methods from Resio et al. (2007) and Toro et al. (2010). In this process, synthetic tropical storms are defined from a joint probability model of tropical cyclone parameters. The cyclone parameters describe the storm size, intensity, location, speed, and direction. This approach to statistical sampling is specifically designed to produce coastal hydrodynamic responses that efficiently span practical parameter and probability spaces to the study area.

With the storms selected, Oceanweather, Inc. (OWI) generated extratropical wind and pressure fields for the 100 historical extratropical events identified in the storm selection process for the NACCS effort for two working grids: the original Wave Information Study (WIS) Level II domain as well as a 0.125-deg domain covering 36-45N and 78-66W (NACCS domain covering Virginia to Maine). OWI performed a reanalysis of the storm core of winds generating the maximum ocean response and included the assessment/assimilation of coastal station data such as National Weather Service reporting stations and National Ocean Service stations not considered as part of the WIS effort. Background fields were sourced from the NCEP/NCAR reanalysis for the 1948-2012 periods, preserving the enhancements applied in the WIS effort. Storms prior to 1948 were developed from the NCEP 20th Century Reanalysis project. Matching pressure fields on both grids were sourced from reanalysis products and interpolated onto the WIS/NACCS grids. Each extratropical storm event produced by OWI contains 8 days of wind/pressure fields with the majority of the reanalysis effort concentrated on the coastal domain of the storm with high wind forcing.

In addition to the extratropical storm wind and pressure fields developed by OWI for the NACCS study, OWI provided developmental support and analysis associated with the generation of synthetic tropical storm wind and pressure fields. ERDC provided OWI with storm parameters associated with 1050 tropical synthetic events and OWI was responsible (with input from ERDC) to expand these landfall parameters into a full storm track time history for each event. The development of a track path both pre- and post-landfall followed the same basic methodology as was applied in OWI's contribution to the FEMA Region IV Georgia/North Florida Surge study. Storm speed remained constant for the storm duration by applying the landfall speed specification supplied by ERDC. Post-landfall, the storm heading was preserved for a suitable amount of time (usually 24 hours) to allow sufficient spin-down time for the response (surge and wave) models. Prior to landfall, an analysis of mean track paths for 3 regional stratifications supplied by ERDC was evaluated to recommend a suitable turning rate (by stratification, if needed) of storm heading so that synthetic track paths were consistent with the historical record. Generation of synthetic tropical storm wind and pressure fields from 3-5 days prior to landfall/closest approach to 1 day post-landfall was accomplished with a tropical Planetary Boundary Layer (PBL) model. Wind (WIN) and pressure (PRE) output files of 10-meter wind and sea level pressures were made on two target grids. The same WIS Level II and NACCS domains described in the extratropical wind and pressure field development were applied with the synthetic tropical storms.

With the storms selected and wind and pressure fields generated, the next major step was to apply CSTORM-MS to each event because this system provides a comprehensive methodology to simulate coastal storms and produce accurate surge and waves in the coastal zone. CSTORM-MS was applied with WAM for producing offshore deep water waves mainly intended for providing boundary conditions to the nearshore steady-state wave model STWAVE; ADCIRC to simulate the surge and circulation response to the storms; and STWAVE to provide the nearshore wave conditions including local wind generated waves. The CSTORM-MS coupling framework options used for the NACCS numerical modeling study tightly links the ADCIRC and STWAVE models in order to allow for dynamic interaction between surge and waves. Each model was validated separately prior to going into production mode.

An evaluation was conducted to assess the quality of the offshore wave model WAM estimates for several historical extratropical and tropical events. The testing also provided a means to evaluate the grid system, model resolutions, and forcing conditions. Validation was conducted by simulating five tropical and 17 extratropical storms based on high water level measurements and extreme wave dominated events and comparing to measured wave conditions for each event. The wave model results were evaluated at as many as thirty point-source measurements in the

Atlantic Basin. The evaluation consisted of time, scatter, Quartile-Quartile graphics and a battery of statistical tests performed at each site for each grid level and for each of the twenty-two selected storm events. These results indicated that WAM provided high quality wave estimates compared to the measurement sites. From these tests, the need to initiate the Level1 WAM historical storm simulations at a minimum of 10-days prior to the occurrence of the storm peak was also determined. This assured the nearshore wave climate contained sufficient far-field wave energy generated by synoptic-scale events in the entire Atlantic Ocean basin. The pre-production assessment also provided a means to develop and test the fully-automated system, generation of boundary condition information for STWAVE, and tools for quality checking the final model results used in the production portion of the work.

The ADCIRC mesh developed for the NACCS study encompasses the western North Atlantic, the Gulf of Mexico and the western extent of the Caribbean Sea with 3.1 million computational nodes and 6.2 million elements. Validation of this mesh was accomplished by comparisons of model simulated water levels to NOAA/NOS measured water-surface elevations. Model validation was conducted with the analysis of a long term tidal simulation as well as 5 tropical and 2 extratropical storm events. From the harmonic analysis conducted for the long-term simulation it was determined that the model accurately predicts response to tidal forcing. Model accuracy was tested for the 7 validation storm events and showed that the model agrees with measured water-surface elevations (time series and high water marks) at measurement locations throughout the study domain. Model accuracy is a function of the quality of the ADCIRC mesh, the accuracy of the bathymetry within the mesh, the representation of bottom friction characterized in the model, and the accuracy of the wind forcing. Small differences in modeled and measured water surface elevations for the validation storms are attributed to these factors.

Nearshore wave transformation for the NACCS was accomplished using the spectral wave model STWAVE applied to ten domains encompassing coastal Virginia to Maine. Prior to the production phase, STWAVE results were evaluated against measurements for the same 5 tropical and 2 extratropical storms used in the evaluation of ADCIRC. The evaluation consisted of time, scatter, Taylor diagrams, and a suite of statistics. Comparisons were most favorable for the most recent storms, likely due to development of more accurate wind and offshore forcing, more advanced buoy technology, and a larger measurement population size in recent time. STWAVE was also more accurate in estimating wave height than mean wave period. Although some sites did demonstrate persistent poor performance, STWAVE provided overall good wave estimates compared to measurement sites given the large extent and complexity of the model region.

Once the models were validated, NACCS production began on the suite of 1150 storms for three conditions. With the 3450 CSTORM-MS simulation requirement, a semi-automated process was needed to efficiently and accurately set up and execute this large simulation suite. Therefore, semi-automated production scripts for setting up CSTORM-MS simulations (CSTORM-PS) were created, tested, and verified for historical extratropical storms, historical tropical storms, and synthetic tropical storms and were executed for all production simulations. Because of the magnitude of this study, a visualization component (CSTORM-PVz) was created within the CSTORM-MS framework and automation scripts were generated to produce graphics, descriptive statistics, and digital reports for all NACCS results.

The products of this detailed, large-domain modeling study are intended to close gaps in data required for flood risk management analyses by providing statistical wave and water level information for the entire North Atlantic coast, while providing cost savings compared to developing coastal storm hazard data for individual local projects. The CSTORM-MS platform provides the raw model data (winds, waves, and water levels) as well as processed data (visualization products and statistics) and is available through the internet-based CHS. These data are available for engineering analyses and project design for coastal projects from Maine to Virginia.