North Carolina Coastal Flood Analysis System Computational System

TR-08-04

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North Carolina Coastal Flood Analysis System Computational System

Submittal Number 1, Section 3

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

Technical Report TR-08-04
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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. The model suite consists of the Hurricane Boundary Layer (HBL) wind model for tropical storms (hurricanes) and OceanWeather Inc's Planetary Boundary Layer (PBL) model for extra-tropical storms; the wave-field models WaveWatch3 (WW3) and Simulating Waves Nearshore (SWAN), and the storm surge and tidal model ADvanced CIRCulation for Model for Oceanic, Coastal and Estuarine Waters (ADCIRC). This modeling approach is very similar to recent FEMA-sponsored projects in Louisiana and Mississippi. Each model in the system is linked through scripts that manage the simulation process on a high-performance computer at RENCI.

This technical report describes the computational model system, numerical model grids, and development of the tropical storm statistical representation. This constitutes Section 3 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.

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1 Computational System

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 elevations along the North Carolina coast. The model suite consists of the Hurricane Boundary Layer (HBL) wind model for tropical storms (hurricanes) and OceanWeather Inc's Planetary Boundary Layer (PBL) model for extra-tropical storms; the wave-field models WaveWatch3 (WW3) and Simulating Waves Nearshore (SWAN), and the storm surge and tidal model ADvanced CIRCulation for Model for Oceanic, Coastal and Estuarine Waters (ADCIRC). This modeling approach is very similar to recent FEMA-sponsored projects in Louisiana and Mississippi. Each model in the system is linked through scripts that manage the simulation process on a high-performance computer at RENCI. An overview of the models used is given in Table 1.1.

Table 1.1: Models used in Coastal Flood Analysis System

Model	Objective	Geographic Setup	Computational Resources (approximate, per track)
HBL/PBL	Provide wind/pressure	Regional-scale; depending on other grids	Linux cluster, Serial, ~1-hour
WW3	Provides oceanic wave field to SWAN	NCEP Western North Atlantic, 0.25 deg	IBM BG/L, 256 cpus, 1-hour
SWAN	Computes near shore wind-driven wave field, provides wave-induced force to ADCIRC	Coastal North Carolina, outer/coarse and inner/fine nested setup	2 coarse grids 2 fine grids 2-6 hours, 10-192 cpus
ADCIRC	Computes wind and wave driven storm surge	Western North Atlantic, with high-resolution in NC coastal and shelf waters.	500k nodes 256 cpus 2-6 hours
Integrated System	Synchronize timings, negotiate coupling, stage simulation parts through job manager		12-24 hours, depending on track length

Wind/Pressure: Hurricane Boundary Layer (HBL) and Planetary Boundary Layer (PBL) models

Two different models are used to simulate different types of storms that create significant flood events in North Carolina. Other flood causing events (e.g. riverine flooding and direct rainfall) are not wind and pressure related and thus not considered in this project.

The Hurricane Boundary Layer (HBL) model (provided through project partner Applied Research Associates, Vickery, et al, 2000; Vickery, et al, 2008) is used to compute wind and pressure fields for the four historical tropical storms for the hindcasts and for all of the synthetic storms. This model computes atmospheric pressure and 10-meter, 10-minute wind velocity for a defined spatial region that depends on which model (WW3, ADCIRC and SWAN) that will use HBL's solution as input. The input to HBL is a storm track, which consists of time (year-month-day-hour), position (lat-long), central pressure, B, RMW, and far field pressure. The HBL model validation process is well documented as presented in Vickery, et al, 2000, and Vickery, et al, 2008. An example of the HBL wind and pressure field is shown in Figure 1.1 for one position of one of the probabilistic storm tracks. The Oceanweather Inc Planetary Boundary Layer (PBL) model (in its kinematic configuration, known as IOKA) is used for extratropical simulations. From the standpoint of the surge/wave modeling system, there is no distinction made between a tropical and extratropical wind field.

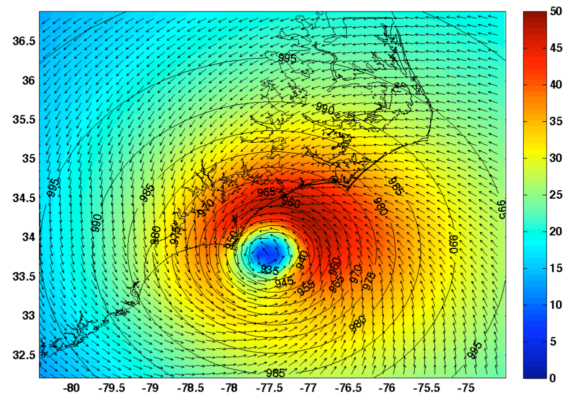

Figure 1.1: Example of HBL model wind and pressure fields for one time near landfall.

Waves: WaveWatch3 (WW3) and SWAN

Two wave models are used in the model suite. WW3, an offshore wave model, simulates the wave fields produced by the evolution of the storm prior to entering the coastal region. These offshore waves provide the necessary boundary forcing for the higher-resolution nearshore wave model SWAN. .

The third-generation numerical wave model WaveWatch3 (WW3) (Version 2.22; Tolman, 2002) is used to produce the offshore wave boundary conditions (directional wave spectra). WW3 solves the wave action spectral density equation for wave-number/direction spectra. It was developed and maintained by the NOAA National Centers for Environmental Prediction (NCEP), Marine Modeling and Analysis Branch, and is used by NOAA for operational numerical wave simulations. For this project, WW3 is run with standard North Atlantic operational default settings, including the Tolman and Chalikov (1996) source functions, nonlinear interaction terms, JONSWAP bottom friction, and linear wind interpolation. The model is run over the standard operational Western North Atlantic grid at 0-50deg N, 98-30 deg

W with 0.25-deg spatial resolution. A separate obstruction grid simulates sub-grid scale wave blocking due to islands and continental coastline features. The Hurricane Boundary Layer (HBL) model wind fields provide wind stress forcing for WW3. 30-minute wave parameter and directional wave spectra are saved along the outer boundaries of the near-shore SWAN wave model grids, at 0.25-deg resolution (Figure 1.2). The model source code and bathymetry grids are available from the NOAA Wave Modeling home page at http://polar.ncep.noaa.gov/waves/index2.shtml.

The coastal wave model Simulating Waves Nearshore (SWAN) is a third-generation, phase-averaged numerical wave model for the simulation of waves in waters of deep, intermediate and finite depth (Booij et. al., 1999, Rogers et. al. 2002, Zijlema and van der Westhuysen, 2005). It is used in this project to compute the wave-induced stresses needed for total storm surge computation by ADCIRC. Wave breaking in shallow water adds to the mean currents that push water towards the coast. SWAN is configured using a nested approach, with outer grids providing boundary conditions to inner grids, the latter running at higher resolution (Figure 1.2). SWAN is forced along the outer boundaries by the WW3 wave spectra and over the entire near shore domain by the HBL wind fields. The saved output at all computation points includes the wave radiation stress and significant wave height. Model coupling between SWAN and ADCIRC is achieved by running the wave models using dynamic water levels provided by ADCIRC, and outputting wave radiation stress fields for use by ADCIRC in computing the wave contribution to coastal surge.

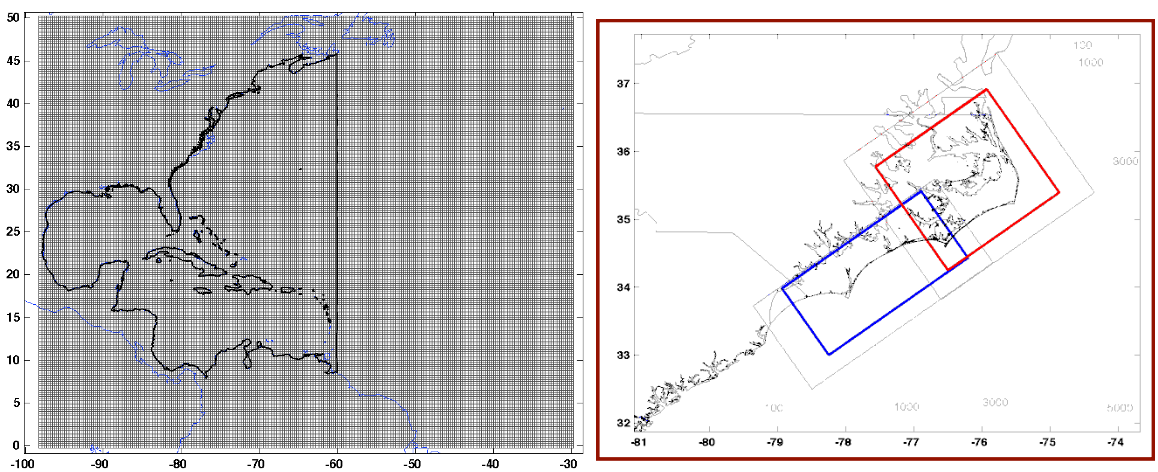

Figure 1.2: Left: WaveWatch3 model domain (grid) is shown with the ADCIRC model boundary for reference. Right: SWAN northern and southern outer (thin) and inner, high-resolution (thick) grid outlines. The inner grids are nested within the outer grids through the outer grid solution. The WW3 simulations provide boundary conditions for the SWAN outer grids. SWAN inner grids receive boundary conditions (wave spectra) from the SWAN outer grids.

The version of SWAN used in this project is 40.51, patch level B, dated 7-09-2007. This code version has been modified by RENCI for 1) improved performance and efficiency on RENCI computational resources; and 2) to address several bug fixes not provided in the source code distribution. There is *no* modification of SWAN physics or numerics. The modified source code will be included in the project archive. An overview of the specific code changes follows, with the code file indicated in bold.

- **ocpmix.ftn**: Several changes to code that reads dates from input files. In several cases, the file paths were limited to 36 characters, which was too few for our purposes. We have extended these file path lengths to 80 characters.
- **rencimod.ftn**: This is a new module added by RENCI. It contains the RE_READ subroutine that performs buffered reads of the data stream. Instead of reading 4 bytes at a time from a file, this routine uses a 4-kilobyte buffer. Individual read statements either read directly from the buffer if data is available in the buffer, or read 4 kilobytes more into an empty buffer, then read from it. This achieves better input performance and efficiency because of the BG/L diskless architecture, in which each read requires a Remote Procedure Call (RPC) to one of the disk server nodes. An additional modification was then made to the output subroutine code that globalizes the individual solution files to use the RE_READ code described above.
- **swanmain.ftn**: The water level exception value was changed to 999. A bug was fixed in the code segment that reads the WaveWatch3-formatted boundary condition files.
- **swanparll.ftn**: A call to the BlueGene/L library function setrteopts was added. This call changes the buffer space allocated by the FORTRAN library for each open file from a default of 1 megabyte to 4 kilobytes. This is required to prevent the compute-node processes from running out of memory. A bug was fixed in the domain decomposition code that caused a numeric overflow for "large" grid-element/processor-count combinations. This was limiting the degree of parallelism for the high-resolution SWAN simulations that could be achieved on the BlueGene/L computer.
- **swanpre1.ftn**: Increased the maximum number of allowed "COMPUTE" commands from 50 to 1000.
- **swanpre2.ftn**: Changed an input file name length limit from 36 characters to the length of the variable storing the file name.
- **swmod1.ftn**: Changed the maximum "Title" length from 36 to 80 characters. Also changed some other character string values such as the name of the nest file from 36 to 80 characters. Increased the maximum number of allowed "STAT" commands from 50 to 1000.

An overview of the physics and numerics configuration is given in the Table 1.2 below. SWAN model documentation is available at http://vlm089.citg.tudelft.nl/swan/index.htm.

Table 1.2 Documentation of Model Numerics

Item	**INNER Grids**	**OUTER Grids**
Time-stepping mode	stationary	non-stationary
Timestep	30 minutes	30 minutes
White capping	KOMEN	KOMEN
Bottom friction dissipation	JONSWAP	JONSWAP
Boundary conditions	outer SWAN grid	WaveWatch3

The SWAN input template file for the outer, northern grid is given in the appendix, as an example. Run-specific input files are archived with each simulation.

Surge: ADCIRC

The storm surge simulations are performed using the state-of-the-art coastal circulation model ADCIRC (Luettich et al, 1992, Westerink et al, 2008), version 47.22. ADCIRC is based on the two-dimensional, vertically integrated shallow water equations that are solved in Generalized Wave Continuity Equation form. The equations are solved using a Galerkin finite element discretization in space with linear basis functions applied on triangular elements and a three level finite difference discretization in time. Information on the land surface elevation (from the DEM), frictional characteristics, roughness lengths and canopy cover are specified at the corner points (nodes) of each triangle as described in section 2.3 Also at the nodes, wind stress and atmospheric pressure are input from HBL, as well as radiation stresses from SWAN in the coupled part of each simulation. Application of ADCIRC in this North Carolina study is consistent with other recent FEMA-sponsored projects in the Gulf of Mexico. The model domain covers the North Atlantic region west of 60 deg W. The ADCIRC grid in the North Carolina region is shown in Figure 1.3.

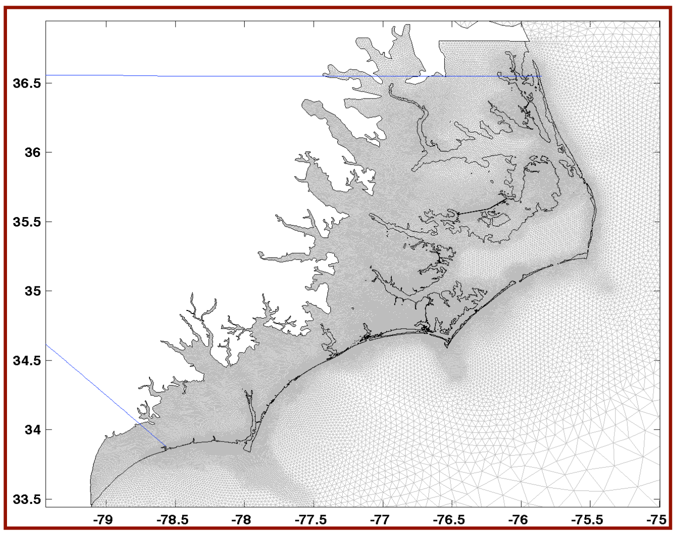

Figure 1.3: ADCIRC grid in the North Carolina coastal region.

The inland extent of the grid is the 15-m topographic elevation line. Nearshore resolution is typically about 100 m and grades out to resolution on the outer continental shelf of 2-10 km.

Computational Resources (RENCI)

The coupled simulations are performed on RENCI's IBM BlueGene/L called Ocracoke, a 4096-cpu high-performance computer. Execution of the model system is controlled through a set of scripts, written in the scripting language *perl*, that stage each simulation, synchronize model timings, and negotiate the physical coupling between ADCIRC and SWAN. The scripts also interact with the high-performance computer to schedule simulations and verify completion of each model. The script data flows between models are shown in Figure 1.4. The colored arrows indicate specific data communications (through input/output files) that accomplish the coupling between models. The wave/surge coupling between the ADCIRC water level and SWAN wave-breaking force is shown with the green and cyan paths, respectively.

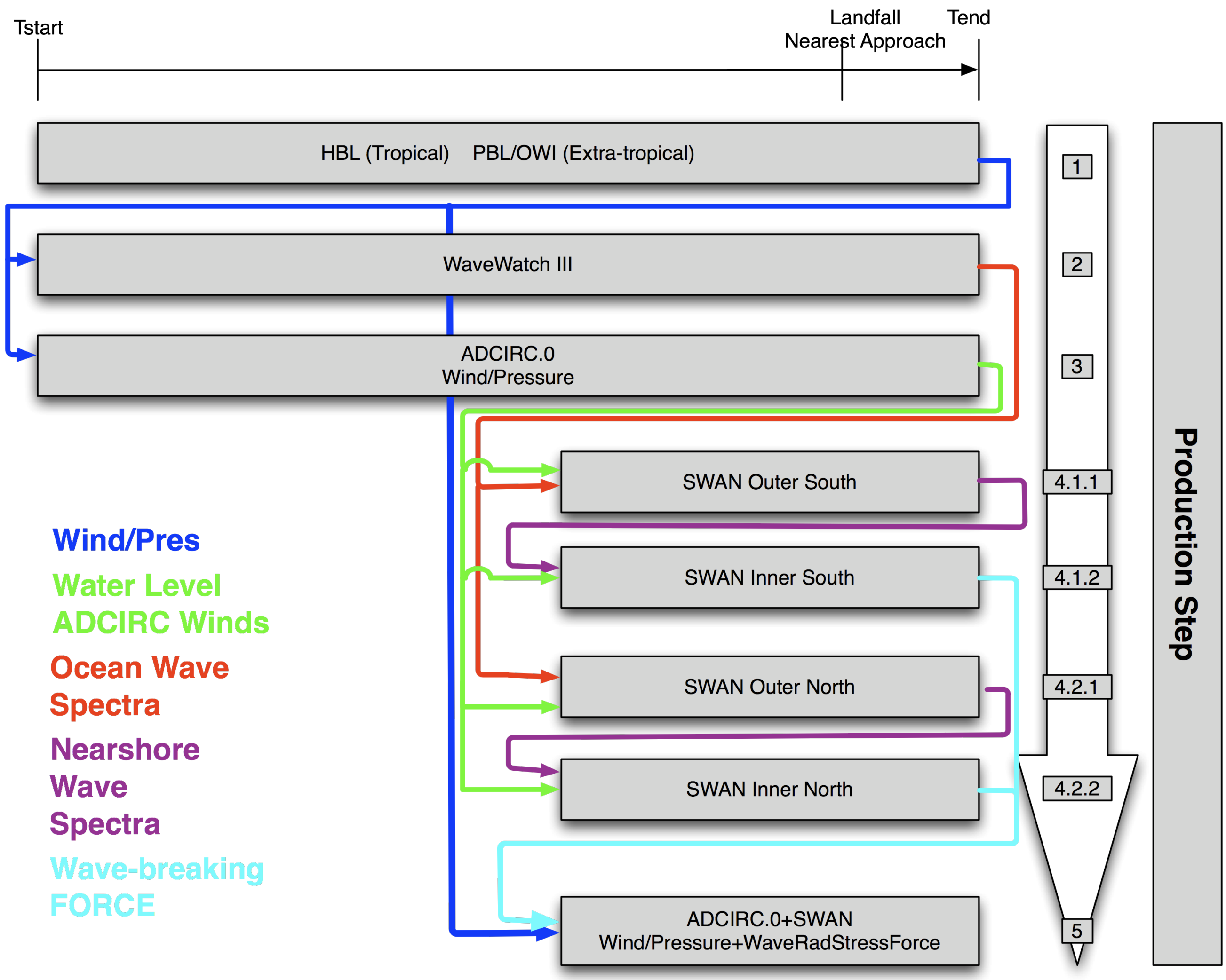

Figure 1.4: Workflow diagram for project computational system, showing the general timing and data transport between the models.

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