2A.13 OPERATIONAL MODELING AND VALIDATION OF THE HURRICANE STORM SURGE USING ADCIRC

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1. INTRODUCTION

This paper describes validation efforts of observed water levels during hurricane storm surge events against simulations by the Advanced CIRCulation (ADCIRC) hydrodynamic finite element model. An operational version is also briefly discussed, and efforts to improve coastal topography using LIDAR data are also presented.

2. DESCRIPTION OF ADCIRC MODEL

The ADCIRC model was initially developed under the Dredging Research Program, a 6-year program funded by the Office of the Chief of Engineers. The model was developed as a family of 2- and 3-dimensional finite element based codes (Luettich et al. 1992; Westerink et al. 1992) with the capability of:

1) Simulating tidal circulations and storm surge propagation over very large computational domains while simultaneously providing high resolution in areas of complex shoreline and bathymetry.
2) Properly representing all pertinent physics of the 3-dimensional equations of motion. These include tidal potential, Coriolis, and all nonlinear terms of the governing equations
3) Providing accurate and efficient computations over time periods ranging from months to years.

The ADCIRC model was rigorously tested to demonstrate proficiency in meeting these three goals. First, model simulations were favorably compared against analytical solutions of a quarter annulus flow regime and a steady-state wind setup and release slosh test. Next, the model was applied to the North Sea Benchmark data set. Results showed the model acceptably reproduced elevations and currents at 11 elevation and 8 velocity stations. Finally, ADCIRC successfully replicated surface elevations and currents for both tides and storm surges for the East Coast, Gulf of Mexico, and Caribbean Sea. The grid representing the Atlantic basin contains 30,000 nodes, with high-resolution node to node spacing of 0.8 km near coastal regions. Because the computational domain covers the entire East and Gulf Coast, simulations and forecasts may be performed for any tropical cyclone without having to modify grids or adjust boundary conditions.

3. SIMULATIONS AND FORECASTS OF THE HURRICANE STORM SURGE

When performing storm surge simulations, the 2-D shallow water version is used. The two equations of motion are solved in conjunction with the Generalized Wave Continuity Equation which improves numerical accuracy and minimizes advection errors. ADCIRC is coupled to a moving coordinate planetary mixed layer model which simulates the hurricane generated winds and atmospheric pressure fields (Cardone, Greenwood, and Greenwood 1992).

To reproduce historical tropical cyclones, the “besttrack” dataset (also called “HURDAT” by some scientists) from the National Hurricane Center is used for input. The besttrack dataset contains a historical record of storm location, wind, and pressure in 6-h increments.

To perform operational storm surge forecasts, additional procedures are required. The first step is retrieving the National Hurricane Center's (NHC) tropical marine advisory forecast through a "Family of Services" data provider satellite link. The marine advisory forecast, which is issued every 6 h at 03, 09, 15, and 21 Zulu time, contains projected intensity (defined as the maximum sustained wind speed in knots) storm center locations, and storm size (in terms of Radius of 34 knot wind) out to 72 h.

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The next step involves "parsing" the track and intensity forecasts from the advisory which will be used to initialize the storm surge forecasts. This is accomplished by using a perl script. Perl, which stands for "Practical Extraction and Report Language," is a programming language optimized for scanning arbitrary text files and extracting information from the text files. Fortunately, NHC advisories contain consistent phrasing such that forecast latitude and longitude, as well as intensity, can be easily extracted. For example, current intensity always follows the phrase "MAX SUSTAINED WINDS," and predicted intensity always follows the phrase "MAX WIND."

Once the predicted track and intensity is extracted, these values are interpolated using an Akima spline to 6-h increments, and a besttrack format file is generated for the storm surge simulation. Since central pressure (*p*) is not predicted by NHC, it is computed from:

$$p = 1013 - (0.1478V_{\max})^{1.55}$$

where 1013 is the standard atmospheric pressure in millibars and $V_{\max}$ is the maximum sustained wind speed from the NHC advisory.

ADCIRC has been optimized to run on different computer platforms, from workstations to supercomputers. Currently, the ADCIRC model is run on the Cray YMP at Waterways Experiment Station, and on the Cray C98 at the Mississippi Supercomputing Research Center at the University of Mississippi.

4. COMPARISONS OF ADCIRC AGAINST STORM SURGE OBSERVATIONS

In a continuing effort to validate ADCIRC, observed water level observations for many hurricanes in the past two decades have been archived. These observations were obtained from the National Oceanographic Data Center (NODC), and the monthly National Climatic Data Center's *Storm Data* publication. *Storm Data* is a list of severe weather observations (including storm surges) across the United States, and is published on a monthly basis by the National Climatic Data Center. The reports are generated through: 1) National Weather Service (NWS) phone calls to damaged regions; 2) reports volunteered to the NWS from emergency management groups (such as the Army Corps of Engineer, the Federal Emergency Management Agency, and the U.S. Geological Survey), law enforcement agencies, the general public, and other credible organization; and 3) information provided to NWS offices by newspaper clippings. Since storm surge observations are not archived in a systematic fashion, this combined NODC/*Storm Data* may be one of the most complete storm surge data sets to date.

Verification of the ADCIRC storm surge simulation was performed for Hurricane Fran (1996) as its eyewall brushed the North Carolina coast on 5 September 1995. A storm surge of 8 to 12 feet was observed on Topsail Island just north of Cape Hatteras. Figure 1, which depicts the storm surge simulation by ADCIRC in this region, is in general agreement, producing a 6 to 7 foot storm surge. The prediction is a little low because this version of ADCIRC does not include tidal constituents for North Carolina; observations of hydrographs show that Fran hit during high tide, hence 2 to 3 feet can be superimposed on the ADCIRC prediction. Also, because of the large domain of the grid, the resolution and depiction of the shoreline is still a bit crude, and, furthermore, no overflow is allowed on land. This will be addressed in the next section.

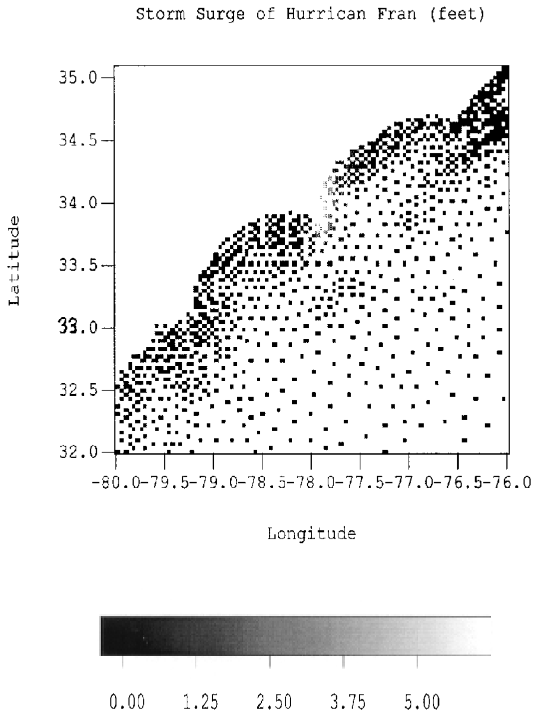

Figure 1. ADCIRC simulation of storm surge induced by Hurricane Fran (1996) at hour 24 in the model run, showing a maximum storm surge of 7 ft just north of Cape Hatteras (the gray node regions). Tide is not included in this simulation, which will add another 3 feet to the surge. Each "dot" represents a finite element node, and this picture is a magnified view of a tiny portion of the ADCIRC grid domain.

5. INCORPORATION OF LIDAR DATA INTO ADCIRC

While the 30,000-node domain is the simplest to use for ADCIRC simulations, for precision storm surge simulations a high-resolution finite element grid needs to be generated for a specific coastal estuary. Furthermore, high-resolution topographic maps are required to properly simulate water penetration over land. However, inaccurate topographic data sometimes corrupts the storm surge simulations. If land elevation measurements are off by even 5 feet, the storm surge simulation results are useless, and if used in conjunction with emergency preparedness planning, may be catastrophic as shown in the following example.

During Hurricane Hugo (1989), a public school used as a shelter in McClellanville in Charleston County, South Carolina flooded to a depth of approximately six feet with several hundred evacuees during landfall. Fortunately, there were no fatalities during this incident. Building drawings provided by the school board listed the elevation of the ground floor at 20 ft, whereas the actual elevation was 10 ft (Chung 1991). While this was an extreme error, in general topographic elevation maps and Digital Elevation Maps may contain errors of several feet due to the sampling procedures used to generate the height elevations.

The construction of precise representations of the land surface may be accomplished through different methods. One method is precision land survey using ground crews. The method is costly and time consuming. Another method is to use Light Detection and Ranging (LIDAR) surveying. LIDAR is the optical analogue of RADAR (Radio Detection And Ranging). In other words, LIDAR is the same as RADAR, except the energy source, a laser, is in the optical part of the electromagnetic spectrum. LIDARs are active remote sensors since they include the light source on which the measurement depends. This method is cost-effective, and can be completed in less time than a traditional survey.

LIDAR surveying has been used successfully to construct detailed topographic maps of road and railroad right of ways and beaches. FEMA and NASA have teamed together to develop a system capable of topographic accuracies from 1 to 1.4 feet. Their system has been successfully used for habitat characterization, floor plain assessment, and elevation models for telecommunication applications.

An example of LIDAR's usefulness is shown in Fig. 2, which depicts how coastal Mississippi would look if inundated by 10 feet of water. This LIDAR dataset will be used to generate a prototype high-resolution topographic ADCIRC grid for coastal Mississippi. With this new grid, validation studiies for Hurricane Camille (1969), Elena (1983), and Georges (1998) will be performed, and Maximum Envelope Of Water (MEOW) maps will be generated for different hurricane tracks and categories. This effort will be discussed at the conference.

6. ACKNOWLEDGMENTS

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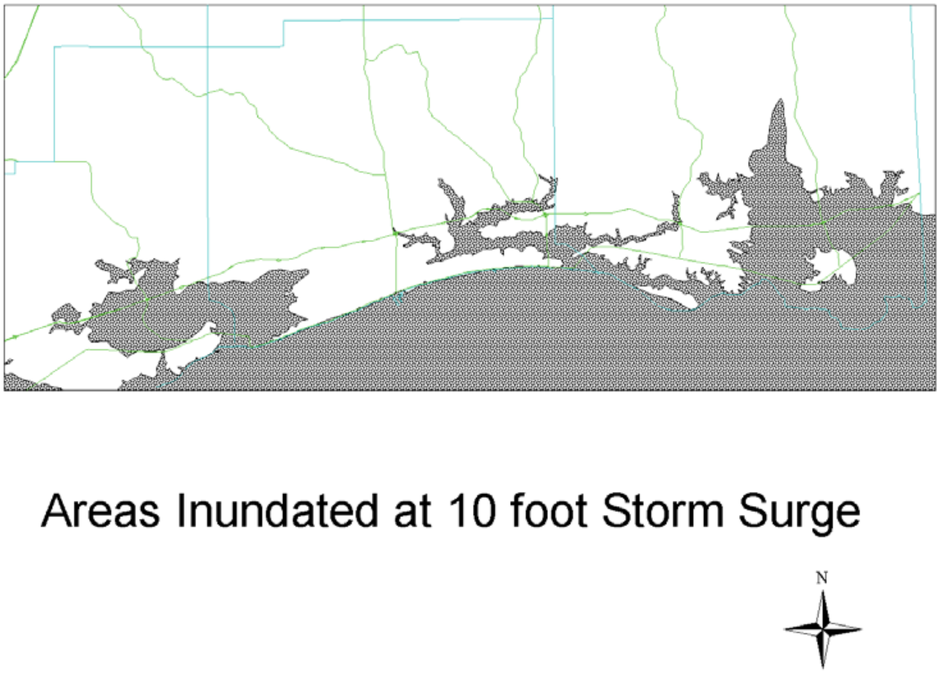

Figure 2. Depiction of coastal Mississippi inundated by 10 feet of water based on LIDAR-based topographic data.