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STORM SURGE MODELING FOR THE NEW YORK CITY METROPOLITAN REGION

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1. INTRODUCTION

New York City (NYC) and the adjacent part of New Jersey and Long Island surround a complex of waterways influenced by tides and weather. Much of the region is less than three meters above sea level, with about 260 square kilometers at risk for storm surge flooding from a 100-year flood for both tropical systems and nor-easter cyclones. To make matters worse, sea level has been rising at about 0.3 meters per century here; therefore, a 100-year flood may become a 30-year flood by 2090s. This is a conservative estimate since global warming is expected to increase the rate at which sea level will continue to rise to around 0.90 meters per century. This rise, combined with the likelihood of more frequent and intense storms, may turn a 100-year flood to a 40-80 year flood by the 2020s and even possibly a 4-year flood by the 2080s (Rosenzweig and Solecki 2001).

Minor to moderate flooding has occurred in the NYC area for recent storms such as the December 1992 nor'easter, which illustrates the vulnerability of the region. During this event persistent 30-40 kt easterly winds over several tidal cycles pushed ocean water westward towards NYC and resulted in water levels at the Battery on the south side of Manhattan peaking at about 2.6 m (8.5 feet) above mean sea level. The water level only surpassed the sea wall by 1-2 feet for a few hours, yet the flooding entered the NYC subways and PATH system to New Jersey, thus requiring a shutdown of these transportation systems. If the storm had peaked only two feet higher, lives could have been lost (U.S, Army Corps of Engineers et al. 1995). Accordingly, coastal flooding around NYC is a major forecast problem for the NOAA National Weather Service (NWS).

Considering the millions of people who live in the NYC region and the billions of dollars at risk, motivation exists to explore new modeling and observational technology in order to improve storm surge forecasting around NYC. For several years storm surge models have been utilized for landfalling hurricanes along the U.S. East Coast, such as the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model developed by the Techniques Development Laboratory of the NWS (Jelesnianski et al. 1992).

The Pennsylvania State University-National Center for Atmospheric Research (NCAR) Mesoscale Model Version 5 (MM5) has been used for real-time predictions down to 4-km grid spacing across coastal New England for several years (Colle et al. 2003). The goal of this project is to use a state-of-the-art atmospheric model together with an ocean model to predict the storm surge for coastal New England during the warm and cool seasons.

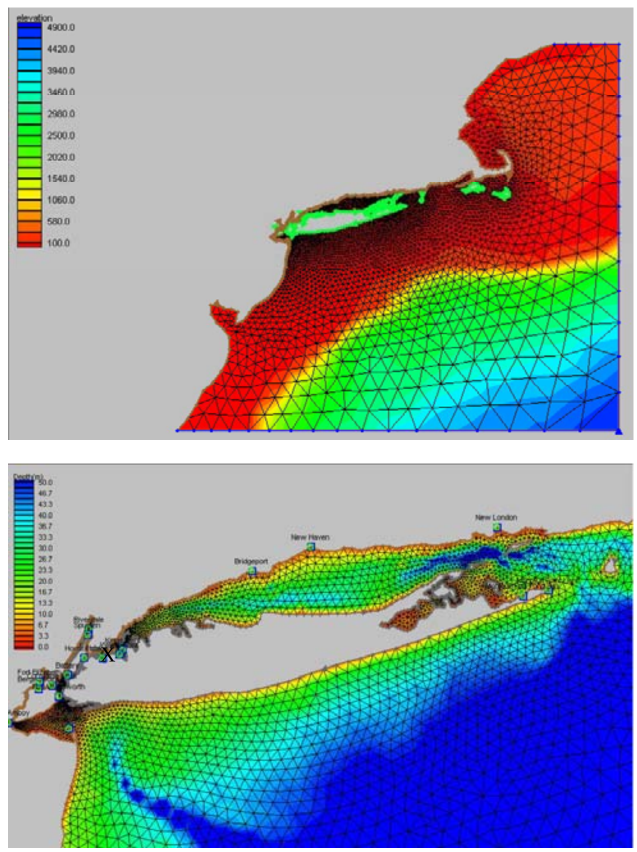

Figure 1. (a) Full domain used for the storm surge model (ADCIRC) showing the triangular grids and bathymetry (color shaded in meters), which overlaps with the 12-km MM5 domain. (b) Zoom-in of a portion of the ADCIRC domain around NYC and Long Island.

2. MODEL SETUP

The MM5 uses the Grell convective parameterization (Grell et al. 1994), simple ice microphysics (Dudhia et al. 1989), and the Medium Range Forecast (MRF) planetary boundary layer scheme (Hong and Pan 1996). Other details for the SBU real-time MM5 can be found in Colle et al. (2003).

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The surface winds and sea-level pressure from the 12-km MM5 domain are used to force the Advanced Circulation Model for Coastal Ocean Hydrodynamics (ADCIRC) model, which solves time-dependent, free-surface circulation and wind-driven transport problems in a barotropic configuration (Luettich et al. 1992). ADCIRC was developed to simulate wind driven and tidal circulations in coastal waters, and has been applied for forecasting hurricane storm surge for New Orleans, LA (Brouwer 2003). The triangular elements for the SBU Storm Surge (SSBS) model of ADCIRC range from 70-km several hundred kilometers offshore to nearly 8-m around NYC (Fig. 1b). Nearly all of entire coastline of New York Harbor is bulkheaded, and the height is not precisely known, so their height was set to one meter above sea level.

3. HURRICANE FLOYD (1999)

3.1 MM5 simulation

Hurricane Floyd made landfall along the southern North Carolina coast at 0900 UTC 16 September 1999 with 50 m s^{-1} surface-sustained winds, which is a category 2 on the Saffir-Simpson scale. The winds associated with Floyd weakened rapidly to tropical storm force as it moved quickly northeastward along the East Coast.during a 12-18 h period. The most damaging aspect of Floyd was the swath of heavy (20-40 cm) precipitation that fell across interior North Carolina northeastward to southern New England. Atallah and Bosart (2003) describe the observational evolution of Floyd, while Colle (2003) illustrates a high-resolution MM5 simulations of the event; therefore, only a brief depiction of Floyd is illustrated here.

Floyd was initialized as a 976 mb cyclone a few hundred kilometers south of North Carolina at 0000 UTC 16 September (not shown), which is nearly 25 mb weaker than observed at this time, since both the Eta analysis did not have the horizontal resolution to duplicate the tight pressure gradient near the hurricane center. However, this error was reduced to a few mb as the storm moved northward towards NYC by forecast hour 21 (Colle 2003).

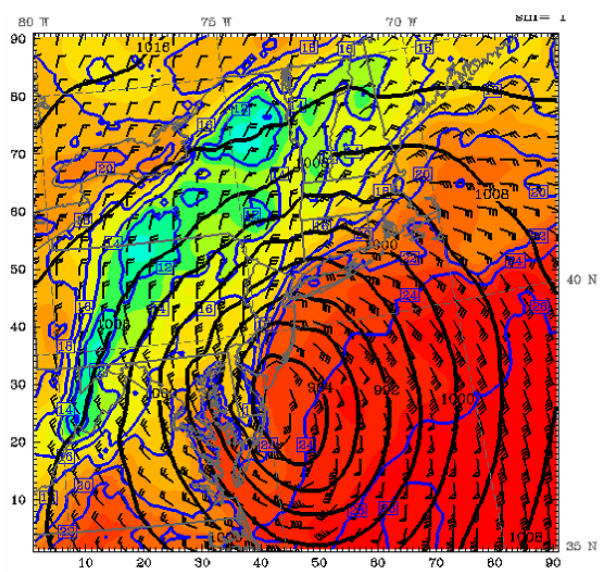

Figure 2. 12-km MM5 simulation valid at 2100 UTC 16 September 1999 (hour 21) showing surface winds (full barb = 10 kts), sea-level pressure (black every 4 mb), and surface temperature (blue every 2 ^{o}C and shaded).

By 2100 UTC (Fig. 2), the position of Floyd was located along the mid-Atlantic coast, about 30 km to the south and within 1-2 mb of the observed (not shown). By this time the coastal temperature gradient had increased across southern New England, where there was significant flow deformation acting on the temperature field. The position of the front in the MM5 was within 20 km of the observed; however, the MM5 temperature gradient was 20-30% weaker than observed since the 24 ^{o}C isotherm did not extend northward to the coast. Meanwhile, there was strong surface easterlies around NYC, and this easterly fetch across Long Island Sound was pushing water westward towards NYC. Overall, the complexity of the wind field around NYC illustrates the need to force an ocean model with wind data over the region rather than a single point at a buoy.

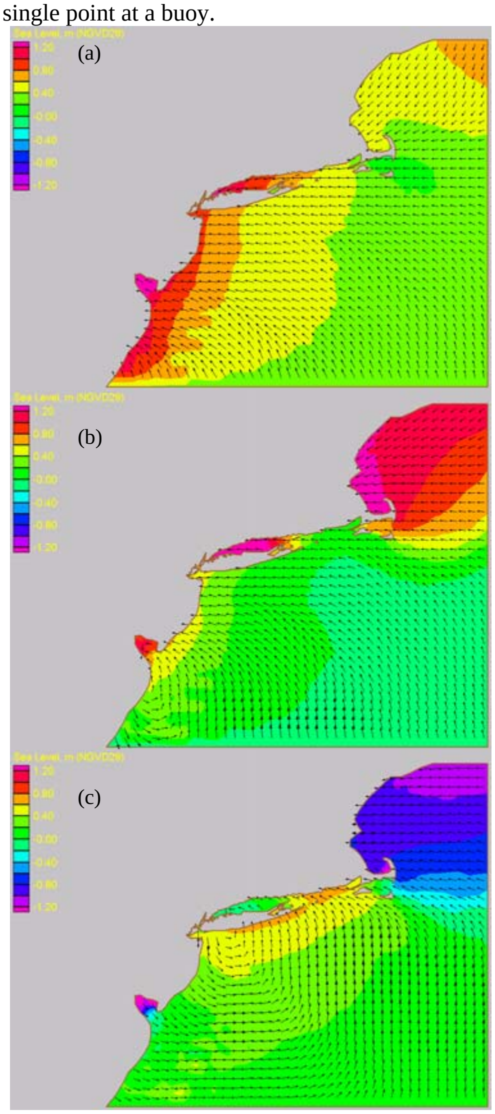

Figure 3. Surface winds and water height relative to sea-level (shaded in meters) for (a) 1800 UTC, (b) 2100 UTC, and (c) 0300 UTC 17 Sept. 1999.

3.2 ADCIRC Simulation

The ADCIRC model was started three days before 0000 UTC 16 September 1999 in order to spin up the model. This spinup consisted of including the tidal forcing and its constituents.

The MM5 winds and sea-level pressure were used in the ADCIRC simulation starting at 0000 UTC 16 September 1999. At 1800 UTC September 1999 (Fig. 3a), Floyd was located over southern Virginia, which resulted in 30-35 kt easterlies along the mid-Atlantic coast. A weak to moderate storm surge of 1.0-1.3 m above mean sea-level was occurring along the mid-Atlantic, with the highest water levels within Delaware Bay. By 2100 UTC 16 September (Fig. 3b), Floyd was along the southeast New Jersey coast and the highest water level of around 1.3 m was located within western Long Island Sound. The surge around Long Island relaxed as Floyd crossed the Long Island and the winds became more southerly by 0300 UTC 17 September (Fig. 3c). During the next few hours offshore northwesterly flow pulled water away from the coast, resulting in water levels of about 0.5 m below mean tidal level around Long Island (not shown).

Figure 4 shows a zoom in forecast around the NYC area at 1800 and 2100 UTC 16 September 1999. The highest surge was concentrated over western Long Island Sound into the East River, located just east of Manhattan (Fig. 4a). At 1800 UTC, there was a large source of water from the ocean to the south towards New York Harbor, while as the storm approached by 2100 UTC, most of the higher water originated over western Long Island Sound. In order to flood the sea walls of southern Manhattan requires a surge over about 2 meters, which occurred briefly for the 1992 nor-easter, but not for Floyd.

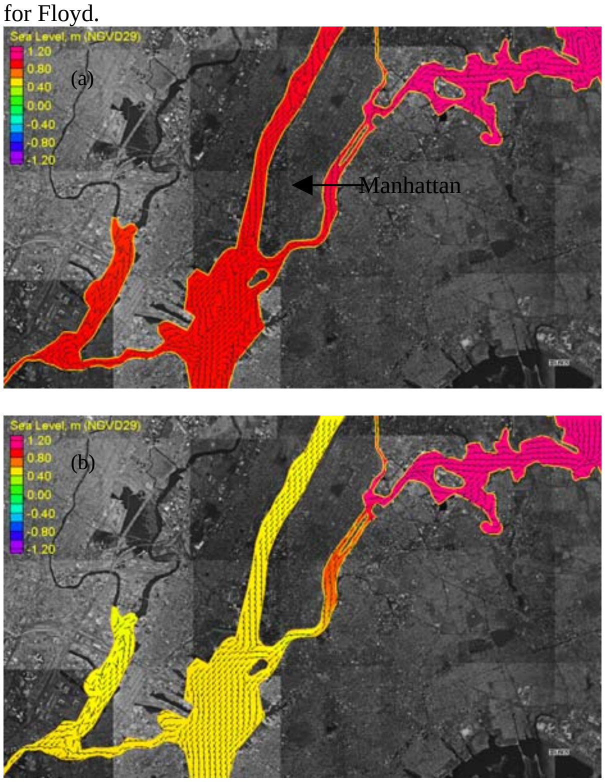

Figure 4. Zoom-in around NYC of the water-level (shaded in m) and currents for (a) 1800 UTC and (b) 2100 UTC for the box in Fig. 3a.

For many of the stations around NYC the storm surge model predicted the maximum water height within 10% (Fig. 5). At the Battery, NY (cf. Fig. 1b for location), the model correctly predicted both the phase and the amplitude of highest surge at 1800 UTC 16 September; however, the model maintained the water heights too high during the next 6 hours. At Willets Point along the north shore of Long Island (see x on Fig. 1b for location),

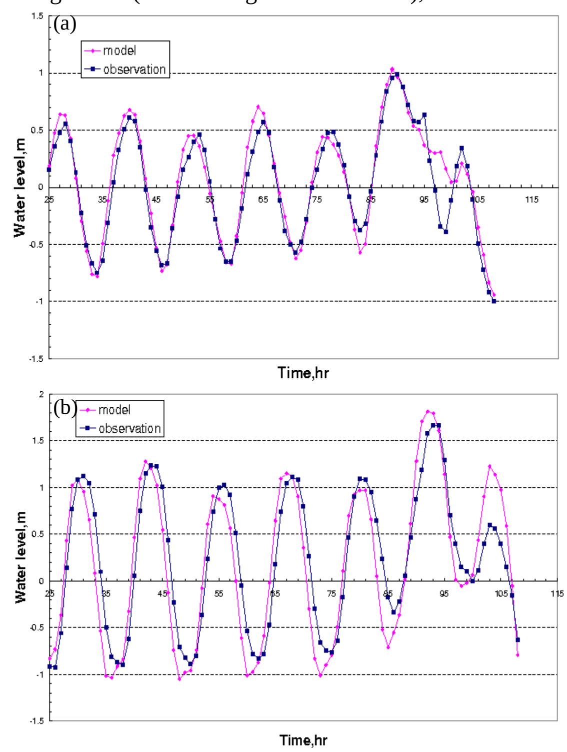

Figure 5. Time series of water height versus hour for the (a) Battery and (b) Willets Point for the model (pink) and observed (blue).

the water level exceeded 1.5 m above mean sea-level, which is about 0.75 m above mean tidal level. The model tidal phase is fast by 1-2 hours, suggesting a model bias in this area.

Additional storms have been simulated using the modeling system, such as the 25 December 2002 nor-easter, which had easterly winds in excess of 30 kts. The model also reproduced the surge for this event around NYC (Fig. 6.).

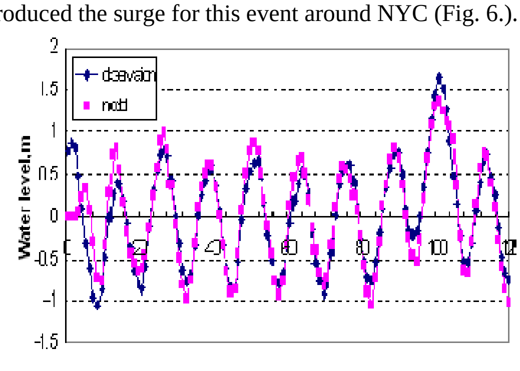

Figure 6. Same as Fig. 5a, but for the 25 December 2002 nor-easter.

4. SUMMARY

Application of the SBSS modeling system to the tropical storm Floyd event shows that the model is capable generating a realistic storm surge for the NYC metropolitan region. Additional simulations have been completed in which the wind speed was nearly doubled for Floyd as it moved up the coast in order to simulate a stronger system. More moderate flooding occurred for this scenario, which will be presented at the conference.

In order to evaluate the model for longer periods, a real-time storm surge modeling system has also been developed, which is run every 0000 UTC for 48-hours using ADCIRC and the 12-km MM5. This results put on the web (http://http://stormy.msrc.sunysb.edu/). On this page the 48-h water level and wind forecasts are shown for several coastal sites as well as the observations.

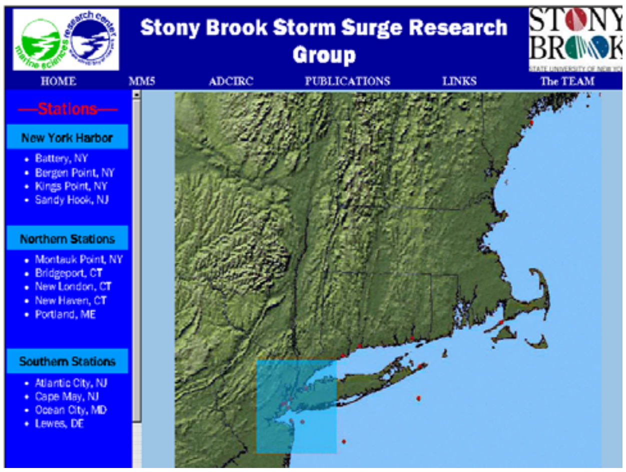

Figure 7. Real-time storm surge web page for NYC area (http://http://stormy.msrc.sunysb.edu/).

4. ACKNOWLEDGEMENTS

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