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DOWNSCALING STORM SURGE MODELS FOR ENGINEERING APPLICATIONS

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Coastal storms and hurricanes produce wind, surge, flooding, and wave actions that have damaging effects on the built and natural environment. The succession of events that begins with various meteorological phenomena and results in a levee breach or bridge failure is mathematically complex and operates over multiple scales of time and space. While the after-effects of coastal storms are readily apparent, there exists no well-defined modeling approach that begins with historical or synthetic storm tracks and captures the sequence of intermediate mechanisms that enables one to predict the performance of a collection of critical civil infrastructure systems over a geographic region of interest. We present a new approach that addresses an important step in this process by enabling localized storm surge predictions from large-scale simulations.

A key limiting factor in moving from the science of storm surge modeling to its practical application in engineering infrastructure assessment is one of scale: storm surge models necessarily operate over vast parts of the globe because that is the scale at which storms and hurricanes operate. However, from a critical infrastructure perspective, assessment of performance and overall resilience necessarily happens over a much smaller geographic region, perhaps dealing with individual components, such as levees and bridges, and their collective behavior. And yet surge loads, as well as other hurricane effects, are necessary to simulate effects on infrastructure at a more local level.

From an engineering perspective, assessment of infrastructure and its resilience necessitates many such large-scale simulations for a single hurricane event: this need is due to the nature of engineering analysis and design. First, one must consider different designs, arrangements, configurations, and materials, each time subjecting the system to a given storm load. Second, there are numerous failure scenarios to consider even for a single infrastructure system, such as levees: for each breach location, and for all such breaches in their various combinations, the impact of flooding and other damage must be assessed in order to make collective risk and reliability judgments. These quantitative results can be used to improve the design and layout of critical infrastructure components and overall system-wide resilience.

Because of the particularly important and computationally limiting issue of “differences in scale,” we have developed a modeling approach whereby large-scale runs of ADCIRC (Luettich et al., 1992), a FEMA-approved storm-surge modeling code, can be used to provide initial- and boundary-conditions for similar runs on a smaller geographic region. To demonstrate the value of this methodology, we consider an array of possible levee failures induced by storm surge in a hypothetical coastal community, as shown in Fig. 1, with subsequent flooded areas outlined in white atop a local street network (Simon, 2011). The process begins with an initial large-scale simulation of a storm event followed by subsequent local simulations, each with varying local topographies representing possible levee failure scenarios (which might be determined from other engineering analysis techniques). While the initial simulation requires 400 CPU-hours of run-

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time, subsequent local simulations require only a time proportional to their size, which is typically a tiny fraction of the initial simulation time.

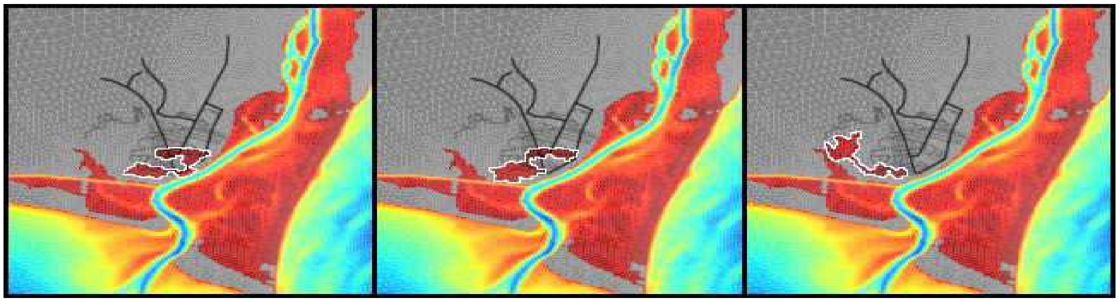

Figure 1 Storm surge simulations under different levee failure scenarios.

The methodology draws on the domain decomposition technique used in parallel ADCIRC (Tanaka et al., 2011), which divides a finite element mesh into subdomains, each of which communicates water surface elevation, velocities, and wet/dry status of nodes along their interfaces. The implementation is realized as a new boundary condition type by modifying the existing non-periodic elevation boundary condition in the implicit formulation of the generalized wave continuity equation, forcing wet/dry status on boundary nodes after its evaluation within a subdomain, and then taking advantage of the explicit nature of the momentum equation solver to (re-)assign boundary velocities outright. The inclusion of wet/dry status constitutes an improvement over a prior technique (Simon, 2011), and has been shown to be both accurate and well posed (Drolet and Gray, 1988) via extensive testing on both small, benchmark problems and large-scale simulations with subdomains of various sizes and geometries along the North Carolina coast. So long as a subdomain is large enough to fully contain the altered hydrodynamics, topographic changes may be made within it without the need to calculate new boundary values. Accurate results are obtained even when boundary conditions are forced only intermittently, and convergence is demonstrated by progressively increasing the frequency at which they are applied. Our presentation will include a description of the overall methodology, performance results, and accuracy, as well as detailed case studies along the North Carolina coast.

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