PERFORMANCE EVALUATION OF SUBDOMAIN MODELING USING THREE CASE STUDIES

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INTRODUCTION

Hurricane storm surge events such as Katrina (2005), Ike (2008), Sandy (2012), Harvey (2017), and Ian (2022) have flooded communities along the US Gulf and Atlantic coastlines, pushing protective structures to their limits around coastal infrastructure. Devastating effects from these events underscore the critical need for high-fidelity simulations to assess the vulnerability of coastal infrastructure to storm surges. The United States Army Corps of Engineers (USACE) routinely engages in large-scale coastal flood hazard studies to evaluate the effectiveness of critical hardened coastal engineering structures (such as levees, floodwalls, and navigation gates) and natural and nature-based features (such as beach and dune systems, wetlands and mangrove stands) for their impact on the coastal resilience of their communities.

In these studies, modeling efforts often rely on high-fidelity ocean models, such as the Advanced Circulation (ADCIRC) Model (Luettich et al. 1992, Westerink et al. 2008), a well-validated, highly accurate circulation and surge model used extensively by USACE, the Federal Emergency Management Agency (FEMA), the National Oceanographic and Atmospheric Administration (NOAA), and others for general circulation studies as well as for storm surge studies. The USACE uses ADCIRC to simulate large-scale domains incorporating the range of project alternatives being evaluated. These domains are then forced by hundreds of design storm events in an effort to inform more comprehensive risk-based analyses. However, the computational demands of these simulations remain challenging due to the size of the domain and number of storm events, particularly when evaluating numerous design alternatives, thus giving rise for the need for more efficient deterministic computational methods without sacrificing the needed engineering accuracy.

Baugh et al. (2015) address this issue of computational cost by developing an approach to storm surge simulation called subdomain modeling (SM). SM allows for local modifications with less computational cost compared to re-running an entire full domain for each design scenario and storm load. However, while SM preserves the accuracy of solutions obtained from full simulations, it was designed to facilitate only minor adjustments to finite element meshes (i.e. including project alternatives as a set of raised nodes with no additional refinements or complexities) and has not been evaluated for its performance as a framework for larger and more substantial mesh refinements. This study aims to assess the performance of SM within the context of three real-world case studies for Dyke Marsh, Coastal Texas, and New York/New Jersey as provided by USACE-Engineering Research and Development Center (USACE-ERDC). This abstract presents a representative sample of results from the Dyke Marsh case study, while complete findings from all three studies will be included in a comprehensive presentation.

METHODS

While standard ADCIRC requires running a separate full domain for each project configuration, SM allows for using boundary conditions generated from a base without-project full domain to enforce subdomains that include the various project configurations. Thereby reducing the number of full domain simulations to one base simulation, with multiple with-project subdomain simulations (Figure 1). This reduction in full domain simulations, results in a decreased burden on computational resources as compared with standard ADCIRC.

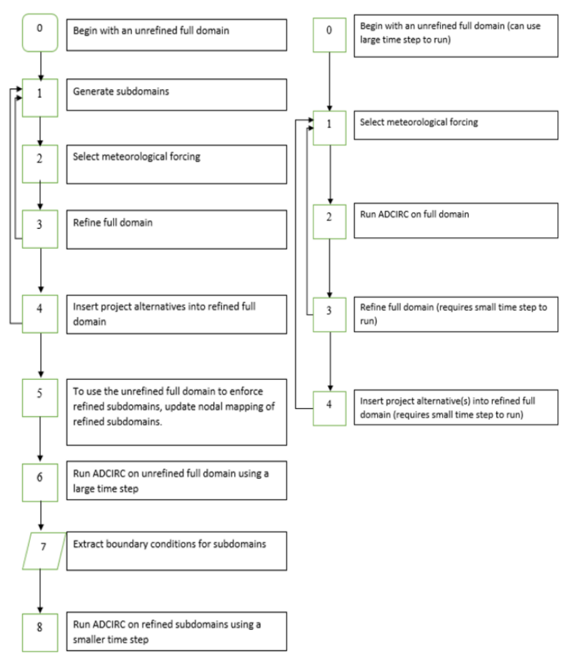

Figure 1 the workflow for subdomain modeling (left) compared with the workflow for standard ADCIRC (right)

The performance of SM is assessed by: (1) determining the extent of computational savings associated with SM as opposed to standard ADCIRC, and (2) assessing the accuracy of subdomain solutions when compared with equivalent full domain solutions.

RESULTS

Table 1 shows a comparison between computational hours (CPU hours) expended by standard ADCIRC which requires simulating full domains only and CPU hours expended using SM. Depending on the size of the subdomain used, it may be noted that SM results in computational savings of at least 50 percent.

Table 1 Computational costs and savings (in CPU hours) associated with a standard ADCIRC workflow versus subdomain modeling for the Dyke Marsh Case Study

	Without Subdomain Modeling	Subdomain Modeling with L Subs	Subdomain Modeling with M Subs	Subdomain Modeling with S Subs
Total CPU hours	27,577	13,933	12,804	7,770
% reduction in computational costs		50	54	72

An empirical relationship is established to determine the reduction in computational cost achievable through SM. This relationship is based on a comparison of computational costs between standard ADCIRC and SM and requires knowledge of the number of alternatives (N), full domain nodes (n_f), and subdomain nodes (n_s). With this information, the reduction in cost (P_R) can be calculated using equation (i):

$$P_R = 1 - \frac{n_f + N n_s}{(N+1) n_f} \quad \text{(i)}$$

Subdomain solutions are compared to full domain solutions using contour maps that depict the absolute difference in maximum elevations and the root mean square (RMS) error in elevation time series. These maps visualize the spatial disparity between subdomain and full domain solutions. Representative comparisons for the Dyke Marsh case study are presented for a synthetic tropical storm labeled as 0057. Comparisons between the solutions from the refined with-project subdomain solution and its corresponding full domain indicate minor (less than 2 inch) maximum differences for the small (S) subdomain (Figure 2) and RMS errors of less than 0.5 inches (Figure 3).

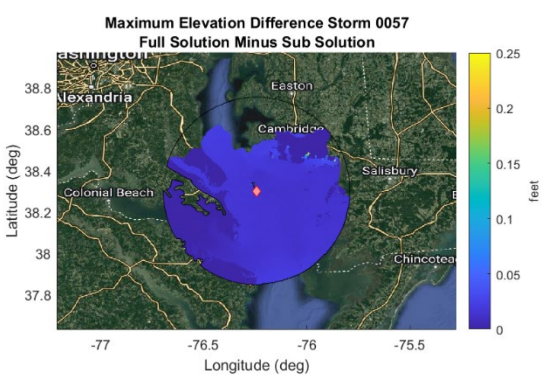

Figure 2 Maximum differences between the solutions from the refined with-project subdomain (small) and the solutions from the refined with-project full domain

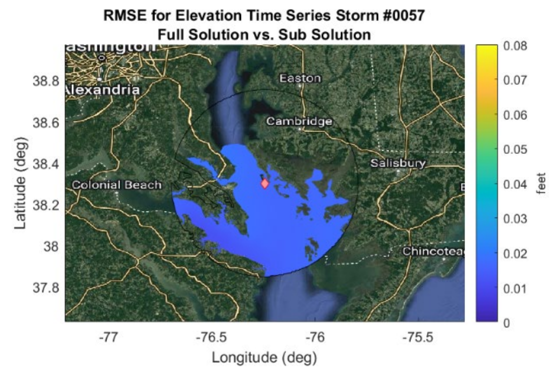

Figure 3 RMSE between the solutions from the refined with-project subdomain (small) and the solutions from the refined with-project full domain.

SUMMARY AND FUTURE APPLICATIONS

Results from this study show that SM proves to be a beneficial tool offering significant computational savings, of upto 70 percent for the Dyke Marsh study, depending on the subdomain size. Furthermore, SM produces solutions that are comparable with their equivalent full domain solutions, with absolute maximum differences of around 2 inches and RMS error values of about 0.5 inches regardless of subdomain size.

Furthermore, the capabilities of SM can be extended to incorporate riverine flow inputs, enabling seamless modeling of multiple design and input conditions for compound flooding applications through integration with models like HEC-RAS (Hydrologic Engineering Center's River Analysis System), GSSHA (Gridded Surface Subsurface Hydrologic Analysis), and AdH (Adaptive Hydraulics).

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