Using a Multi-Resolution Approach to Improve the Accuracy and Efficiency of Flooding Predictions

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Outline

Part I
• Validate winds, waves and water levels during Matthew on a mesh with floodplains coverage over a large extent

Part 2
• Multi-resolution approach to improve the accuracy and efficiency of flooding predictions
Part I
Introduction

Matthew
- Category-5 storm
- Impacted the south-east coast of the U.S. during October 2016
- Shore-parallel storm
- Large variations in water levels lasting several days
Methods

• Coupled ADCIRC + SWAN model
• ADCIRC
  – Solves the generalized wave continuity equation (GWCE) for water levels ($\zeta$)
  – Solves the depth-averaged momentum equations for currents (U,V)
  – Geographic space is represented using Piecewise-linear, continuous, Galerkin finite elements
• SWAN
  – Solves the action balance equation
Methods

- The HSOFS unstructured mesh
  - Riverside, AECOM & NOAA - 2015
  - 500m average coastal resolution
  - 1.8 million vertices
Methods

- Winds from OWI
  - Data-assimilated fields
  - Basin grid at resolution of 1/4°
  - Region grid at resolution of 1/20°

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Error</th>
<th>GAHM</th>
<th>WF</th>
<th>OWI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Pressure</td>
<td>RMSE (hPa)</td>
<td>6.72</td>
<td>4.23</td>
<td>2.14</td>
</tr>
<tr>
<td></td>
<td>Bias</td>
<td>-0.16</td>
<td>-0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>Wind Speed</td>
<td>RMSE (m/s)</td>
<td>5.60</td>
<td>2.98</td>
<td>2.29</td>
</tr>
<tr>
<td></td>
<td>Bias</td>
<td>-0.29</td>
<td>0.16</td>
<td>0.06</td>
</tr>
</tbody>
</table>
Model Validation – Observations

<table>
<thead>
<tr>
<th>Saffir-Simpson Category</th>
<th>Symbol</th>
<th>Wind Speed (ms(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>▷</td>
<td>59-69</td>
</tr>
<tr>
<td>3</td>
<td>▶️</td>
<td>50-58</td>
</tr>
<tr>
<td>2</td>
<td>◆</td>
<td>43-49</td>
</tr>
<tr>
<td>1</td>
<td>◈</td>
<td>33-42</td>
</tr>
</tbody>
</table>

Symbol Legend:

- WL
- WL + MET
- MET
- MET + WH
- WH
Model Validation – Waves

16 stations, RMSE of 0.46m, Bias of 0.11
Model Validation – Water Levels

241 stations, RMSE of 0.28m, Bias of 0.04
Model Validation – High Water Marks

622 peaks
$R^2 = 0.78$
RMSE = 0.28m
Bias = -0.03
Best fit slope = 0.96
Part I - Conclusions

- Matthew’s effects are well represented by the model even when applied on the relatively-coarse HSOFS mesh

Part II
Motivation

#1 Need for Higher Resolution

#2 Need for Faster Forecasts
Motivation

Need for higher resolution

1. Experience from hindcasts of Hurricane Matthew
Motivation

Need for higher resolution
1. Forecasting during Hurricane Florence (2018)
   - HSOFS mesh was used when the storm was far away (up till Advisory 41)
   - As the storm approached the NC coast, NC9 mesh was employed (starting from Advisory 42)
Motivation

#1 Need for Higher Resolution

#2 Need for Faster Forecasts
Motivation

Need for Faster Forecasts

1. Ensemble Possibilities
   - For each advisory, there is uncertainty in the storm parameters, which translates directly into uncertainty in the predicted surge
   - SLOSH computes Probabilistic Storm Surge (P-surge) in real-time
     - Includes uncertainty in track/landfall location, forward speed, intensity, and historical errors
     - Results are approximately 30 minutes after full advisory release time
   - ASGS runs only a few variations (e.g., veer-left, veer-right)
   - Faster simulations will allow for more scenario-testing, which can help in reducing uncertainties in the forecast results (Leutbecher and Palmer, 2008)

   - Made landfall in southeast Texas
   - When the storm was in Gulf, high-res mesh (6.7 million elements) for Texas was used
   - Tidal spin-up on this mesh even on 1120 cores at TACC, took 18 hours
   - By this time, the storm had already moved inland
The Multi-Resolution Approach

Current Forecasting Technique

- Save the state of the simulation right at the nowcast point (end of the hindcast)
- Reload this saved state during the next advisory cycle to avoid having to start the simulation from the beginning
- The system thus always builds on previous results
- The hot-starts have to be always done on the same mesh
- This prevents use of high resolution meshes without having to run tidal spin-up that take several hours of computational time

Source: Fleming, 2008
The Multi-Resolution Approach

Steps
• Use a relatively coarse resolution when the storm is far
• As the storm approaches the coastline, switch to a fine-resolution mesh without doing a cold-start
• Map results from the coarse to the fine mesh and continue the simulation on the fine mesh

Main Objectives
• Reduce the computational load by using a coarser resolution mesh when the storm track is uncertain
• Increase the accuracy of predictions by using a higher resolution mesh as the storm approaches landfall
• Increase the simulation possibilities including ensemble generation during operational forecasting
The Multi-Resolution Approach

Adcirpolate

• A toolset for interpolating between meshes
• Developed by our collaborators at U.T. Austin
• Implemented via the Earth System Modeling Framework (ESMF)
  • Allows for parallel interpolation between unstructured meshes
• Interpolation is done bilinearly in region destination points
• Extrapolation is done for the remaining points with nearest source to destination
• Proper checks to take care of wetting/drying state of elements
• Convert the hot-start file from the coarse mesh simulation to a hot-start file for the fine mesh simulation
The Multi-Resolution Approach

Initial Results

• When Matthew is away from NC (first 6 days), use the coarse/source mesh
• As the storm approaches NC, use adccirpolate to map the coarse/source data onto the fine/destination mesh
• Continue simulation on fine mesh for 3 days

Source Mesh: 616,113 nodes

Destination Mesh: 784,911 nodes
Initial Results

coarse

fine

mixed
Initial Results

1 Oregon Inlet

2 Hatteras

4 Wilmington

3 Beaufort
Initial Results

- On 532 cores,
  - Coarse Mesh
    - 9 days of winds 24 mins
  - Mixed Approach
    - 6 days of winds on coarse mesh 17 mins
    - Switching 1 min
    - 3 days of winds on fine mesh 10 mins
    - So total = 28 mins
  - Fine Mesh
    - 9 days on winds 30 mins

- Results from the mixed run are close to the ‘true’ solution of all 3 days on the fine mesh
Thank You!