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

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Motivation

• Need for Higher Resolution
  1. Experience from hindcasts of Hurricane Matthew (2016)
    • HSOFS mesh with an average coastal resolution of 500 m
    • 622 peaks analyzed. $R^2 = 0.78$, $RMSE = 0.28m$, $Bias = -0.03$, Best fit slope = 0.96
Motivation

• Need for Higher Resolution
  
  2. Forecasting during Hurricane Florence (2018)
  
  • HSOFS mesh used when the storm was far away (up till Advisory 41)
  • NC9 mesh was employed (starting from Advisory 42) as storm approached NC coast

• Need for Faster Forecasts
  
  Ensemble Possibilities
  
  • For each advisory, there is uncertainty in the storm parameters
  • ASGS runs only a few variations (eg. veer-left, veer-right)
  • Faster simulations will allow for more scenario-testing

Maximum water levels corresponding to Advisory 58
Goals and Objectives

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
Goals and Objectives

Goal

• Coarse Resolution Mesh
  – HSOFS (1.8 million vertices)

• Fine Resolution Meshes for the U.S. Gulf and Atlantic coasts
  – Each 3-4 million vertices
    1. Western Gulf
    2. Northern Gulf
    3. Eastern Gulf
    4. South and Central Atlantic
    5. Northern Atlantic
High Resolution Mesh for FL to NC

Mesh Development

• By combining FEMA meshes
  – South FL
    • 2,249,093 nodes
  – North-east FL and GA
    • 2,968,735 nodes
  – East-central FL
    • 1,406,543 nodes
  – South Carolina
    • 542,809 nodes
  – North Carolina
    • 624,782 nodes
• HSOFS used in open-water regions
High Resolution Mesh for FL to NC

Mesh Development

• Nodal Attributes
  1. Eddy viscosity
  2. Tau0
  3. ManningsN
  4. z0Land
  5. VCanopy
  6. elemental_slope_limiter
  7. advection_state
High Resolution Mesh for FL to NC

Mesh Development

- 5,641,135 nodes
High Resolution Mesh for FL to NC

Results

- Maximum Water Levels

Hurricane Matthew (2016)

Hurricane Florence (2018)
High Resolution Mesh for FL to NC

Results

• Time Series of Water Levels

Hurricane Matthew
High Resolution Mesh for FL to NC

Results

• Time Series of Water Levels

Hurricane Florence
High Resolution Mesh for FL to NC

Validation

Hurricane Matthew

Bias 0.03
$R^2 = 0.76$
$RMSE = 0.29$
No of values = 600

Hurricane Florence

Bias -0.05
$R^2 = 0.91$
$RMSE = 0.22$
No of values = 190
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 coarse to the fine mesh and continue simulation on fine mesh
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

Test Case

- Scatter at 0.5m resolution
- Average spacing is 20m for coarse and 10m for fine mesh
The Multi-Resolution Approach

Test Case

- Switching after 1 day when water levels at boundary is 1.4 m
- Total run period is 2.25 days
The Multi-Resolution Approach

Test Case

WL at end of coarse run

WL at start of fine run

Coarse
Mixed
Fine
The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- HSOFS when storm is far away
- High-res mesh when storm approaches the coastline
- Switching time understood by looking at water levels

<table>
<thead>
<tr>
<th>Storm</th>
<th>No. of Days of Simulation</th>
<th>Run Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HSOFS</td>
<td>High-Res</td>
</tr>
<tr>
<td>Matthew</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Florence</td>
<td>3</td>
<td>6</td>
</tr>
</tbody>
</table>
The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- Matthew – Max. Water Levels

Difference in maximum water levels between the approach and a full run on the fine mesh
The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- Florence – Max. Water Levels

Maximum water levels using the approach

Difference in maximum water levels between the approach and a full run on the fine mesh
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Applying the approach during Matthew and Florence

- Matthew – Time Series at Inland Locations
The Multi-Resolution Approach

Applying the approach during Matthew and Florence

• Florence – Time Series at Inland Locations

Coarse Mesh

Fine Mesh

Bathy-topo

Mixed

Fine
The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- Analysis

  • Accuracy Comparison
    - Observations as truth
    - No loss in accuracy

<table>
<thead>
<tr>
<th>Error</th>
<th>Matthew</th>
<th></th>
<th>Florence</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mixed</td>
<td>Fine</td>
<td>Mixed</td>
<td>Fine</td>
</tr>
<tr>
<td>Stations</td>
<td>580</td>
<td>580</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td>Best Fit Slope</td>
<td>0.93</td>
<td>0.93</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>R²</td>
<td>0.77</td>
<td>0.78</td>
<td>0.88</td>
<td>0.91</td>
</tr>
<tr>
<td>ERMS (m)</td>
<td>0.29</td>
<td>0.29</td>
<td>0.26</td>
<td>0.22</td>
</tr>
<tr>
<td>$B_{MN}$</td>
<td>-0.06</td>
<td>-0.07</td>
<td>-0.06</td>
<td>-0.05</td>
</tr>
</tbody>
</table>
The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- Analysis
  - **Accuracy Comparison**
    - Fine Mesh Results as truth
    - Comparison at nodes that are inland \((z<10\text{m})\) and wetted in both meshes
    - Mixed approach wets more nodes with gain in accuracy

<table>
<thead>
<tr>
<th>Error</th>
<th>Matthew</th>
<th>Florence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse Mixed</td>
<td>Coarse Mixed</td>
</tr>
<tr>
<td>Stations</td>
<td>1,981,764</td>
<td>2,664,921</td>
</tr>
<tr>
<td>Best Fit Slope</td>
<td>0.99</td>
<td>1.0</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.91</td>
<td>0.96</td>
</tr>
<tr>
<td>ERMS (m)</td>
<td>0.22</td>
<td>0.13</td>
</tr>
<tr>
<td>(B_{MN})</td>
<td>-0.014</td>
<td>-0.002</td>
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</tbody>
</table>
The Multi-Resolution Approach

Applying the approach during Matthew and Florence

- Analysis
  - Run Time Comparison
    - 24 to 33% save in time without compromising on accuracy (comparison to observations)

<table>
<thead>
<tr>
<th>Storm</th>
<th>Run Time in minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mixed</td>
</tr>
<tr>
<td></td>
<td>Coarse</td>
</tr>
<tr>
<td>Matthew</td>
<td>29</td>
</tr>
<tr>
<td>Florence</td>
<td>19</td>
</tr>
</tbody>
</table>
Future Work

• Utilize Watershed boundaries to create sub-meshes from the high-resh mesh
  – Use different sub-meshes (instead of 1 big high-res mesh) depending on where the storm is at that point in time
  – Should save more time

• Explore other factors to use as triggers for switching
Thank You