Optimizing the Placement of Unstructured Mesh Resolution for ADCIRC in Coastal Regions

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COASTAL RESILIENCE CENTER
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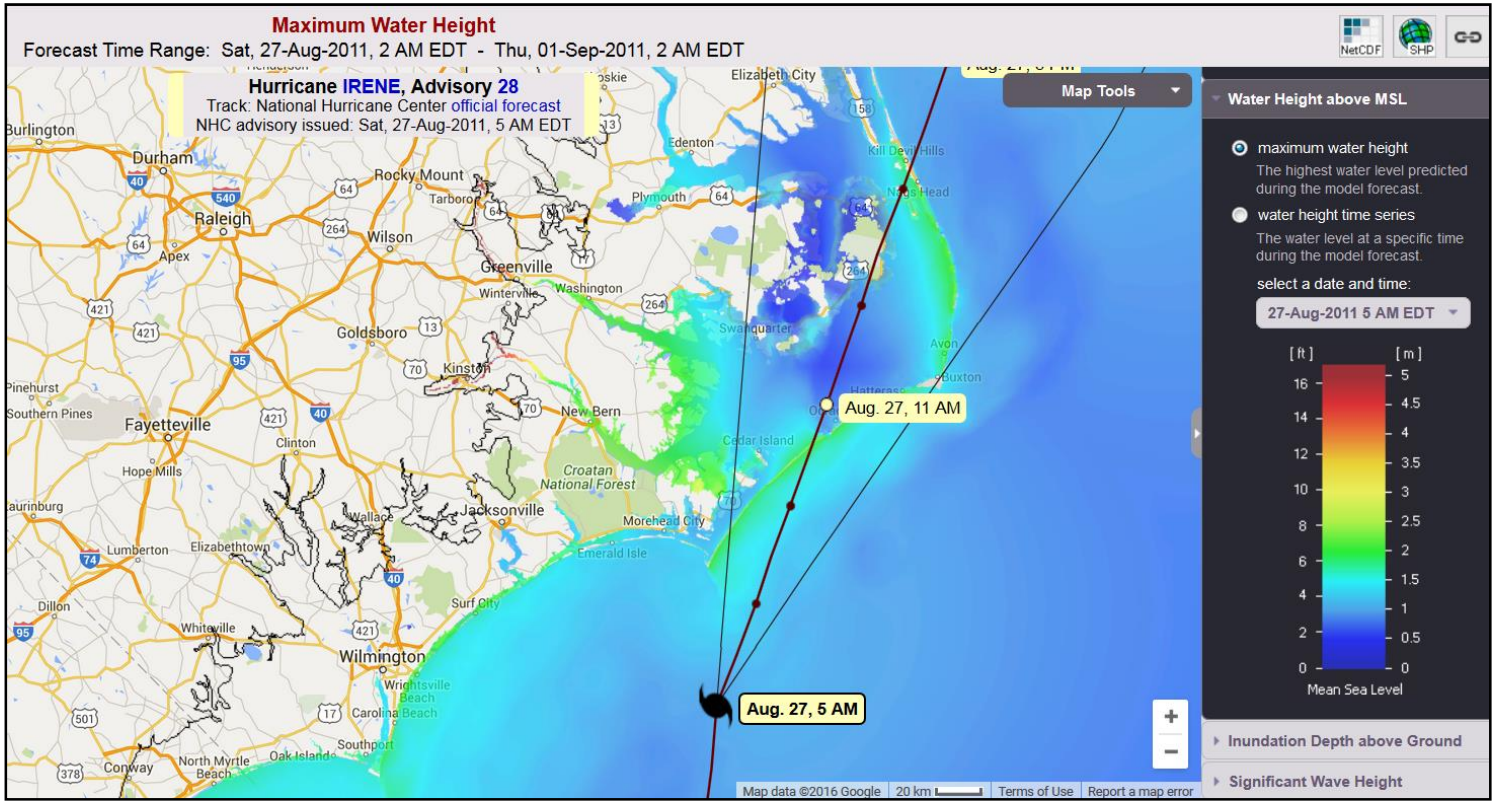
Background and Motivation

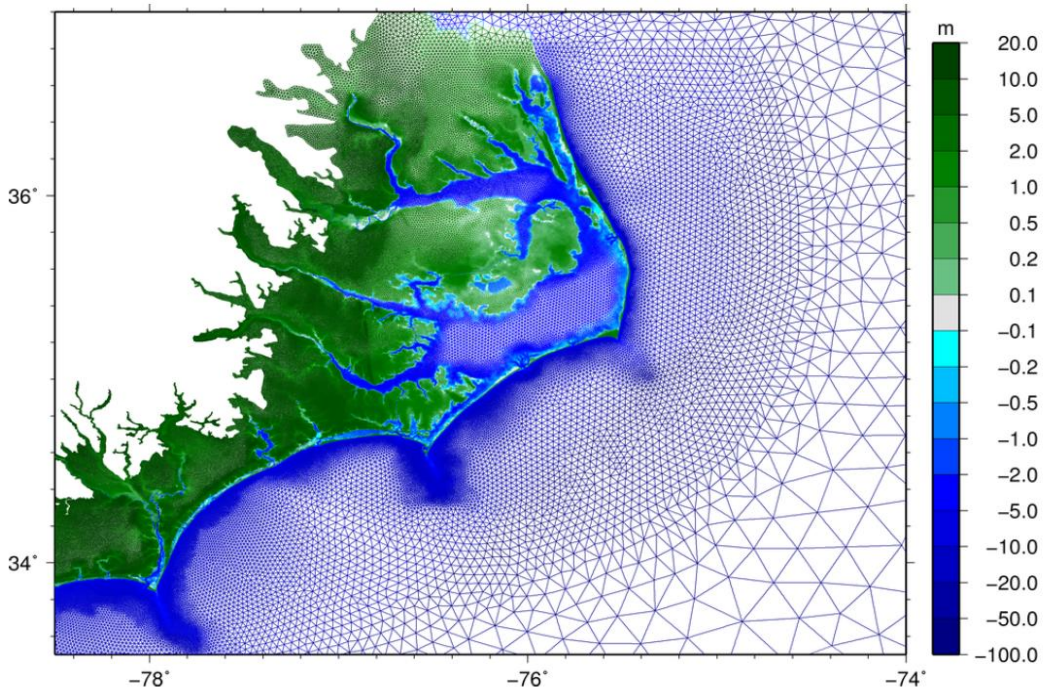
- ADCIRC Surge Guidance System (ASGS) provides forecast guidance for winds, waves and storm surge during a hurricane
- For NC Coast, ADCIRC is run twice daily during normal conditions, and four times daily during severe storms



Source: http://nc-cera.renci.org/

Background and Motivation

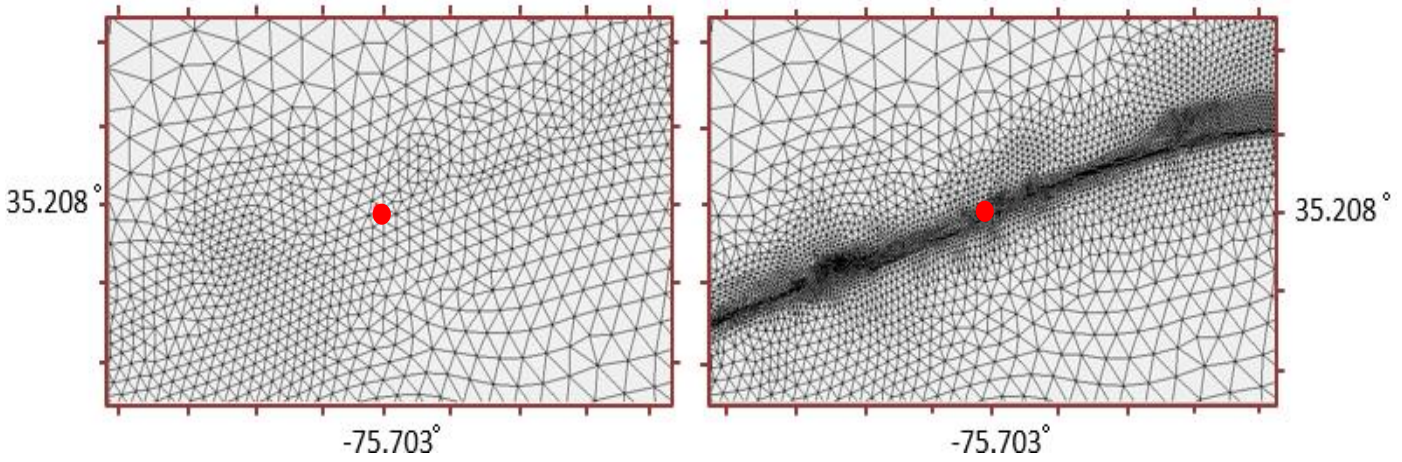
- The high-resolution mesh that exists for North Carolina is the NC9 mesh
- Originally developed for the FEMA flood mapping study, which involved running hundreds of simulations of hypothetical storms
- Main consideration was efficiency while running hypothetical storms
- Total of 1,230,430 elements
- Over 50% of the elements have spacing between 50 m – 500 m and the largest elements (> 500 m) are largely outside of the coastal NC region



Background and Motivation

- The NC9 mesh is computationally expensive and hence used only during storm events
- For daily forecasts, the smaller NC6b mesh is used
- Both NC9 and NC6b have fairly the same spatial extent but NC9 has higher resolution on some of the inner flood plains and on the outer banks

Mesh	Total Elements
NC6b	575,512
NC9	1,230,430



Difference in mesh resolution at USCG Hatteras Station (marked red)
NC6b (left) and NC9 (right)

Background and Motivation

- Increasing the mesh resolution *should* increase the model accuracy
  - Published studies: Blain *et al* (1994), Hagen *et al* (2001), Dawson *et al* (2006) and many others
  - Anecdotal experience: Representation of fine-scale features affecting flow
- Is it possible to increase the mesh resolution in nearshore regions (thereby increasing the accuracy of predictions) without also increasing the overall cost of the simulations?
  - Take resolution from regions with small errors
  - Add resolution to regions with large errors
  - Keep constant the total number of vertices / elements

Goals and Objectives

GOAL:

- Increase accuracy for simulations on the NC9 mesh without increasing its total computational cost

OBJECTIVES:

- Develop tools to automatically identify the regions with large/small errors
  - By finding Accuracy Errors relative to a “true” solution obtained from a high resolution mesh
  - By finding Mass Conservation Errors on an element basis
- Targeted mesh refinement – Future Work
  - Decrease resolution (remove elements) in regions with small errors
  - Increase resolution (add elements) in regions with large errors

Interpolation Tools for Newer Meshes

We want to change the NC meshes

- Need tools to interpolate bathymetry / topography to newer meshes
- Newer meshes need to be comparable to older meshes

Use the NC DEM

- Developed as part of FEMA study
- Best available data from various sources
- 1/3 arc-second (~10 meter) cell spacing
- Finished v2.4 in 2008

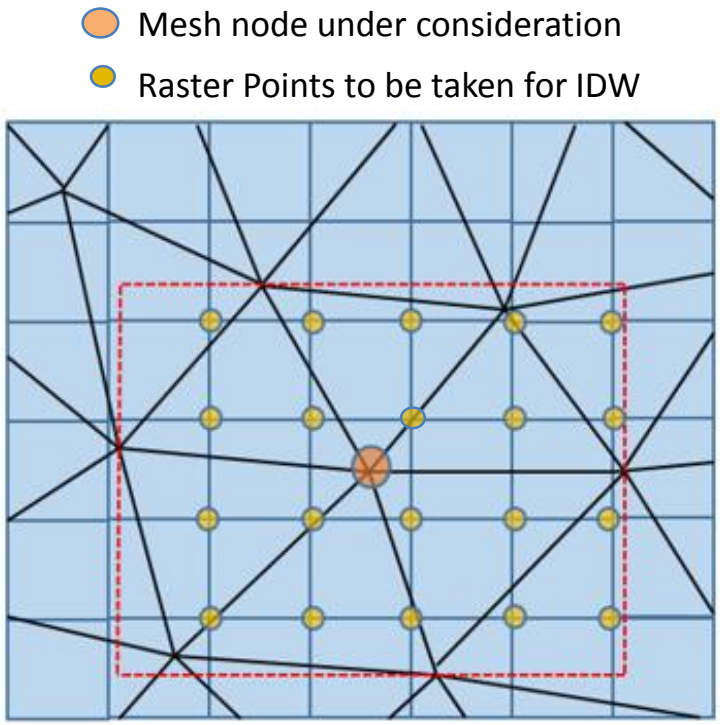
How was the existing NC9 mesh developed?

- High-resolution grid covering the NC costal region was appended to a previously developed grid (Blanton et al, 2004)
- The NC v2.6 DEM was used to provide bathymetry and topography
- Use of NOAA Nautical charts
- SMS version 9

Interpolation Tools for Newer Meshes

How can we update these tools for our study of mesh resolution?

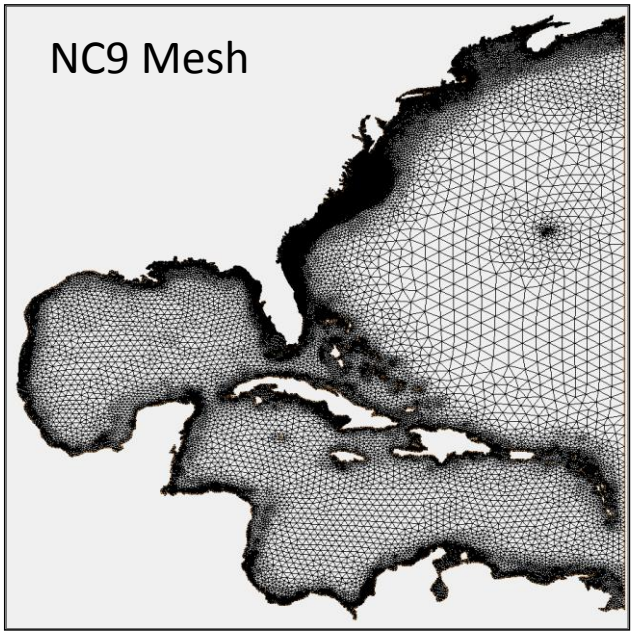
- The existing NC9 mesh was re-interpolated using an interpolation algorithm that resulted in bathy/topo values that best matched the values in the original mesh
- Raster used : NC v2.6 DEM
- Interpolation technique:
  - ADCIRC Cell Averaging for most vertices
  - Special treatment:
    - ADCIRC Cell Maximum for dune crests
    - ADCIRC Cell Minimum for channel centerlines



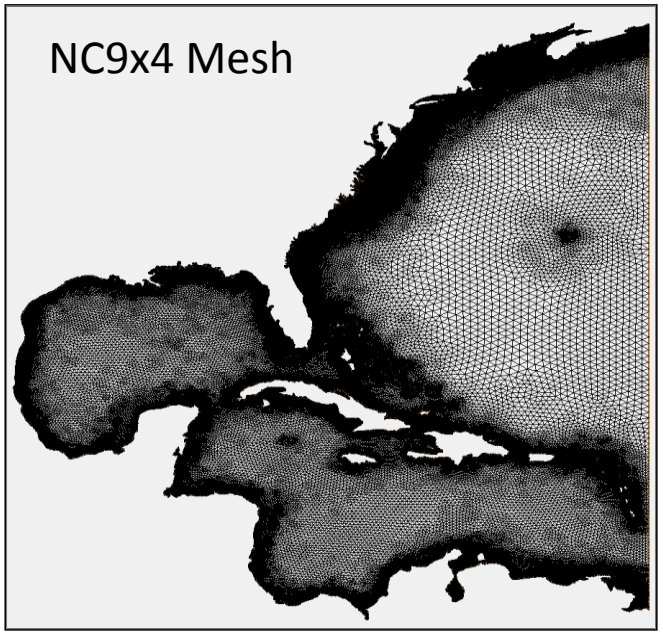
ADCIRC Cell Averaging

Finding Accuracy Errors in the NC9 Mesh

- Assuming that the solution will converge to a “true” solution as the mesh resolution is increased, a mesh having four times the resolution of NC9 was created using SMS – NC9x4
- By comparing to an over resolved mesh, we will get some idea of the accuracy errors in the original solution
- We are also considering the use of a NC9x16 mesh in the future



1,230,430 Elements

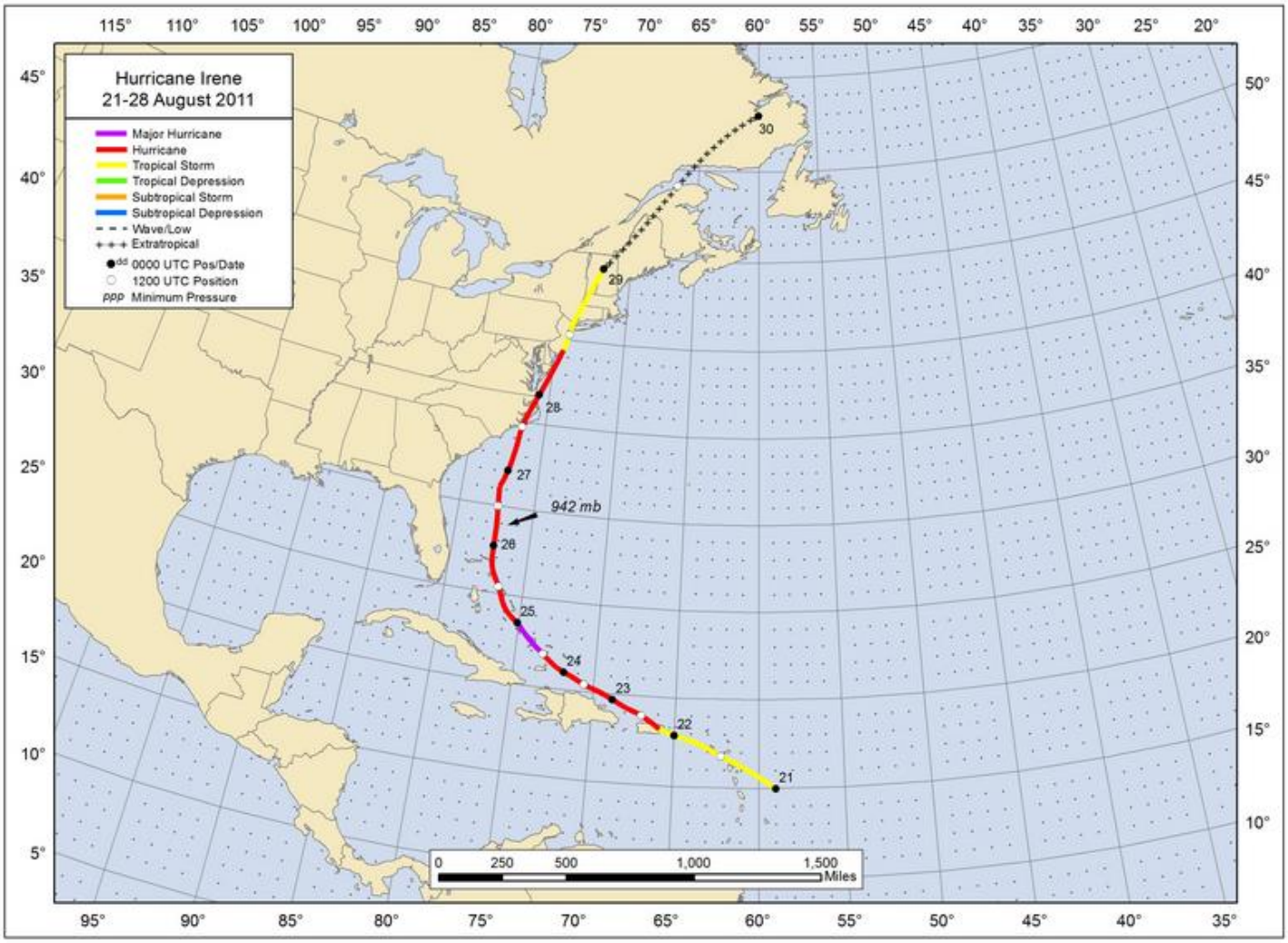


4,921,720 Elements

Finding Accuracy Errors in the NC9 Mesh

- Water levels obtained from ADCIRC runs on this mesh for Hurricane Irene was compared against water levels from the NC9 mesh
- This was done by mapping the global water levels file (fort.63) of NC9 mesh on to the NC9x4 mesh by linear interpolation
- We will also be looking at other storms (Sandy, Arthur) in the future
- For Irene:
  - Made its first landfall on the outer banks of North Carolina at about 7:30 a.m. on August 27, 2011
  - Tides only simulation for 15 days: August 6, 12:00 a.m. to August 21, 12:00 a.m.
  - Winds for 8 days: August 21, 12:00 a.m. to August 29, 12:00 a.m.
  - Thus, a total 23 days simulation

Finding Accuracy Errors in the NC9 Mesh

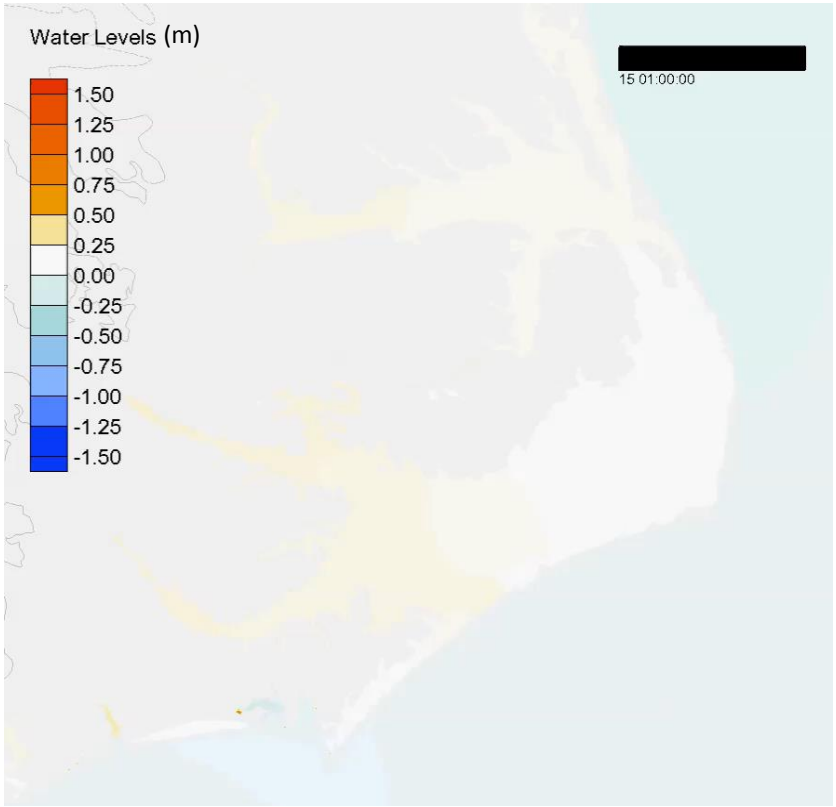


Best track positions for Hurricane Irene, 21-28 August 2011
Source: Tropical Cyclone Report by National Hurricane Centre

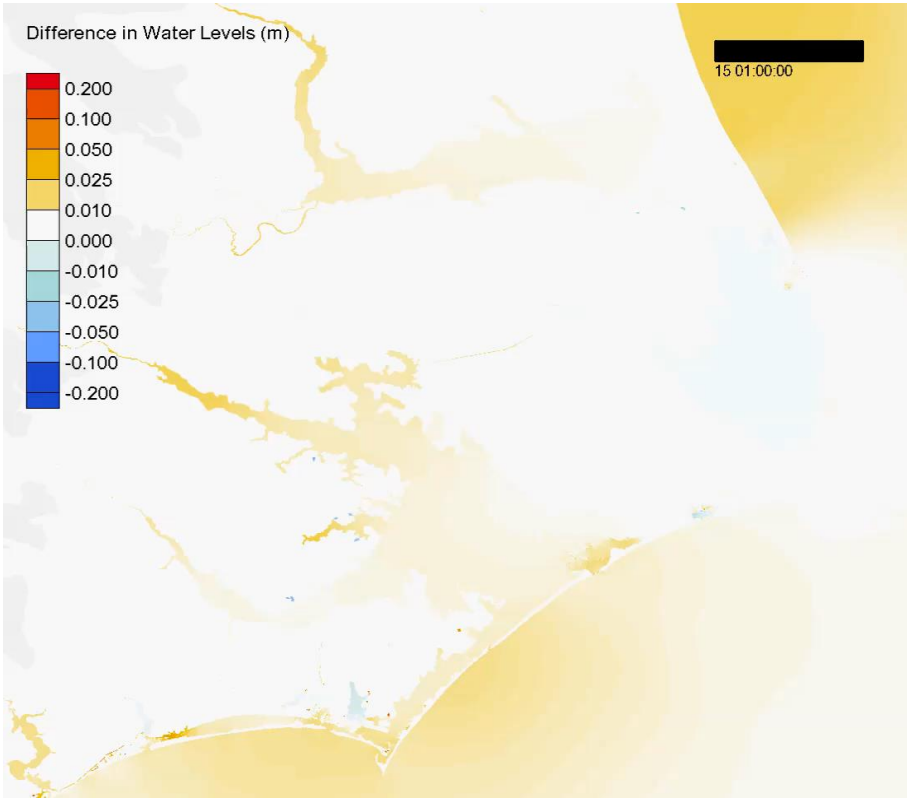
Finding Accuracy Errors in the NC9 Mesh

Accuracy Errors In the NC9 Mesh

- NC9 (interpolated onto NC9x4) - NC9x4 (True solution)

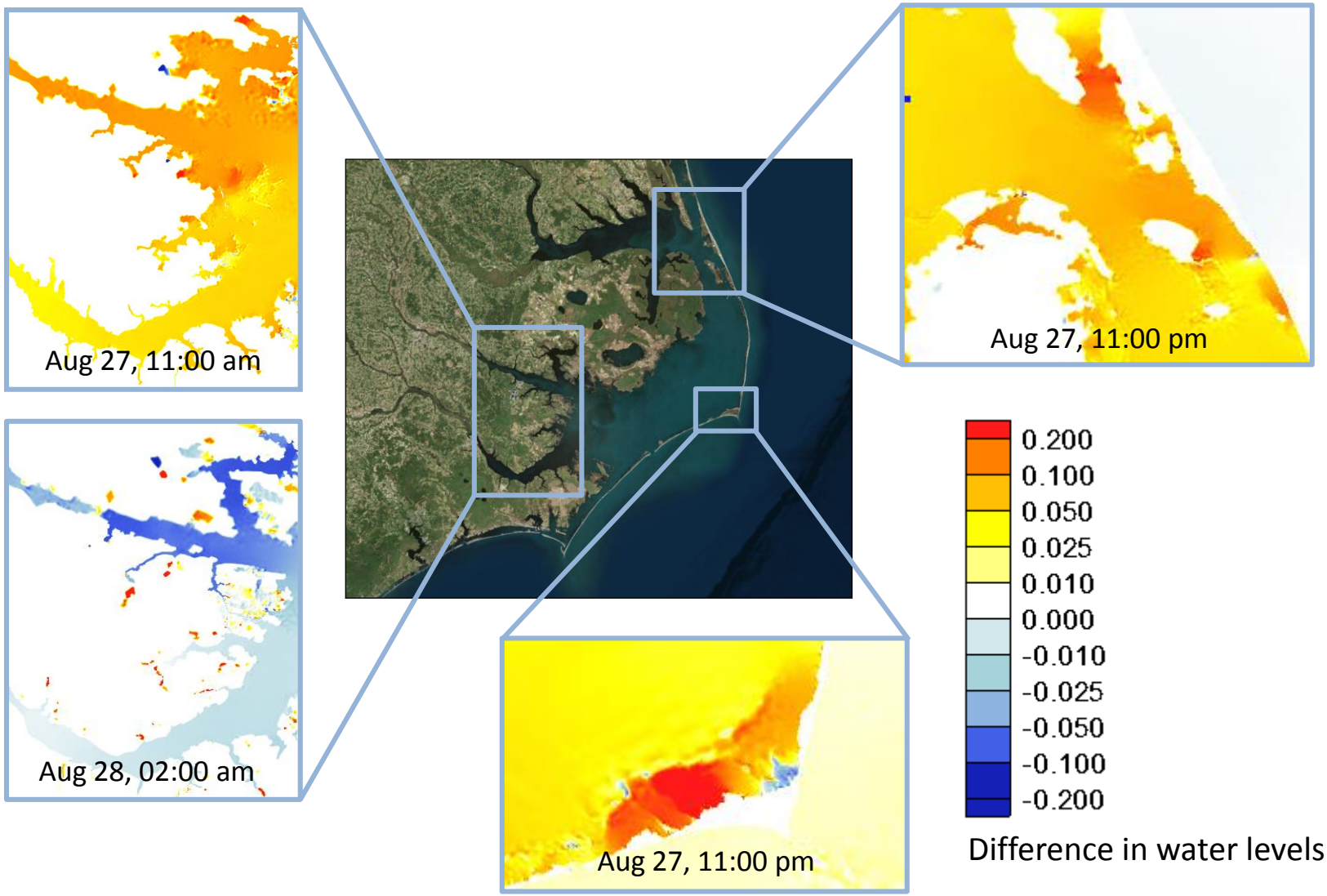


Water levels during Hurricane Irene (m)



Difference in water levels during Hurricane Irene (m)

Finding Accuracy Errors in the NC9 Mesh



Computing Mass Residuals

- ADCIRC conserves mass globally, but not locally
  - CG method integrates over the entire domain
- The idea is to compute the errors in mass conservation on an element basis and use them as a criteria for mesh refinement, as has been shown in published studies:
  - Berger *et al* (2002), Dietrich *et al* (2008)
- Increasing the mesh resolution in regions of large errors *should* reduce the errors at those regions
- Moreover, elements could also be moved from regions with low errors to regions with high errors, thus improving accuracy without increasing the total number of elements

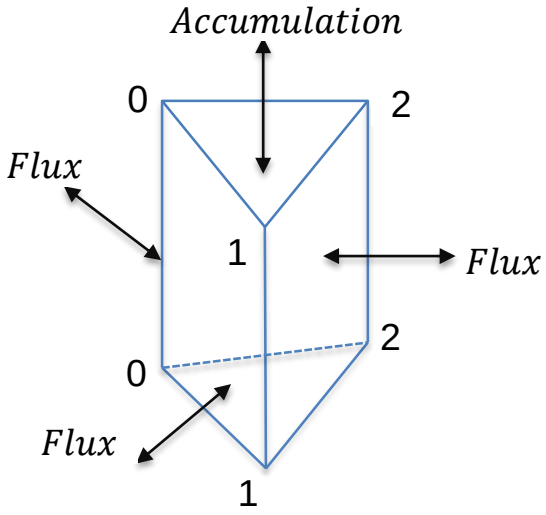
Computing Mass Residuals

- Depth-Averaged Continuity Equation

$$\frac{\partial \zeta}{\partial t} + \nabla . (HU) = 0$$

- The residual was normalized by the still-water volume of the element to obtain

$$\varepsilon_v = \frac{\sum_e [\overline{\zeta_t} - \overline{\zeta_{t_0}}]_e A_e + \sum_k \frac{1}{2} \left[Q_{net}^{t+\Delta t} + Q_{net}^{t}\right] \Delta t}{A_e \bar{h}}$$

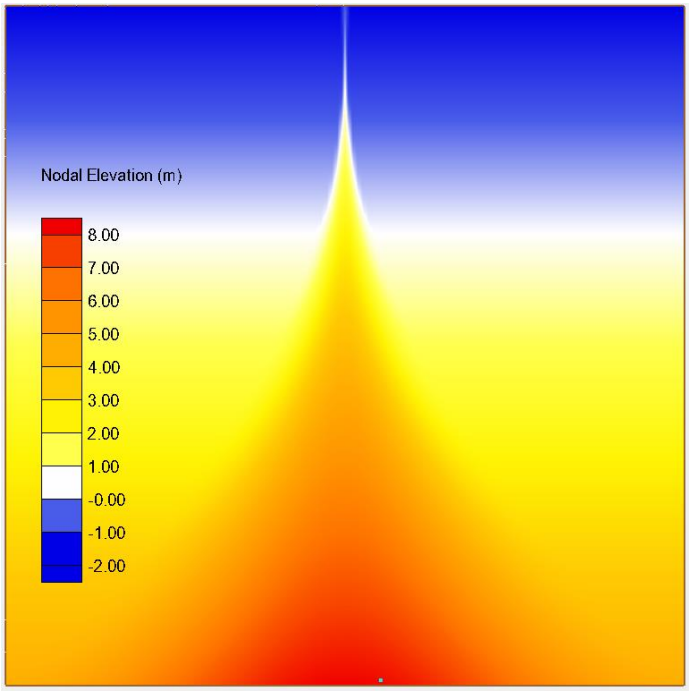


- Accumulation $\frac{A_e \, (\overline{H_2} - \overline{H_1})}{dt}$
- Sum of Fluxes

$$Each\ Flux = side\ x\ Avg.Normal\ Vel.\ x\ Avg.Height$$

Computing Mass Residuals

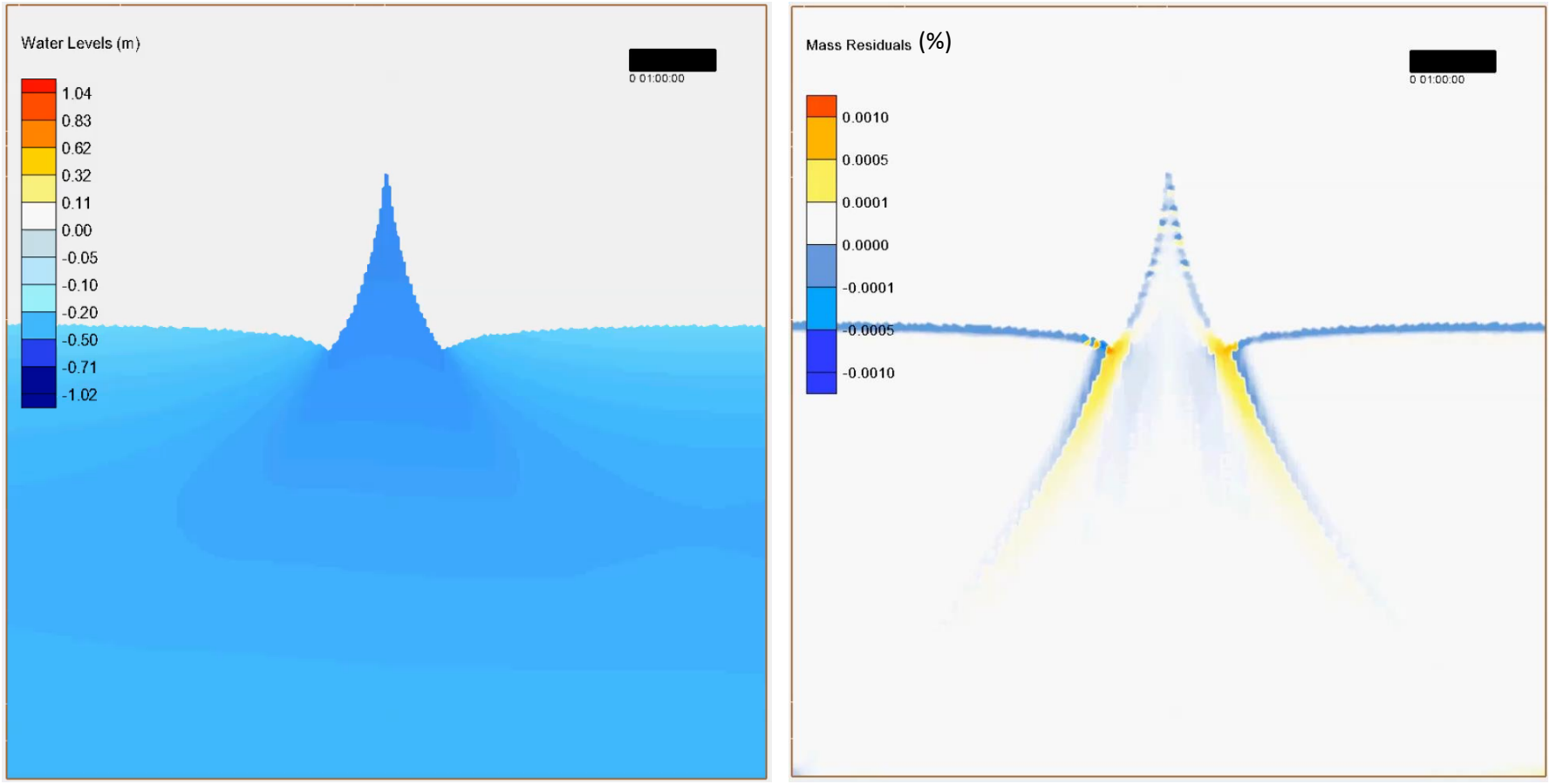
- The mass residuals were first calculated on an Idealized Channel Test Case to check if the residuals occurred at expected regions and to get an idea about wetting and drying fronts



Idealized Channel Test Case

- 64,415 nodes
- 4 Days simulation
- At bottom, it is a ocean boundary
- At the other three boundaries, it is a land boundary with tangential slip
- Bathymetry ranges from 8 m at bottom boundary to -2 m at top boundary
- Mesh resolution is around 80 m at the ocean boundary and reduces to 20 m on the top boundary
- 12 hour tidal signal is given as the input

Computing Mass Residuals

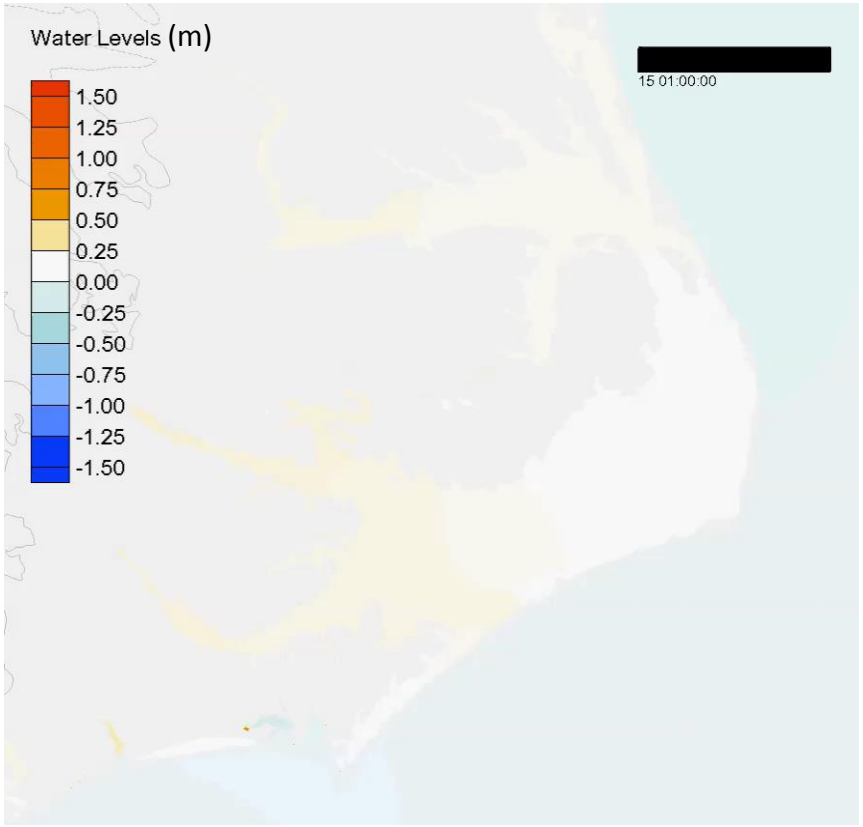


Water Levels in meters (left) and Mass Residuals as percentage of still water volume (right)

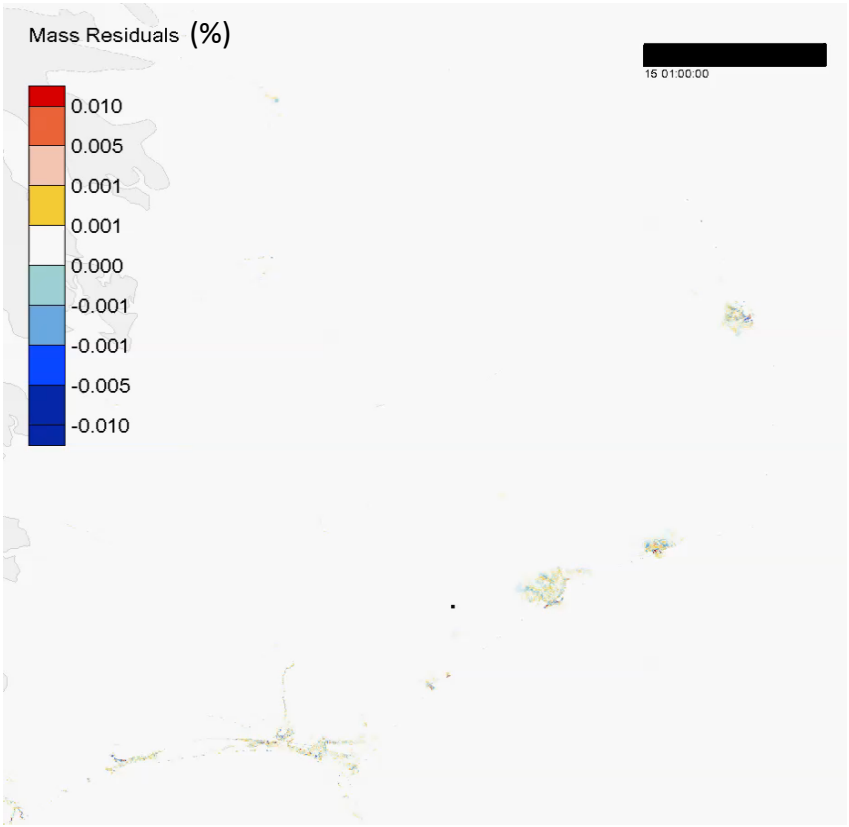
- For the mass residuals, positive values means added mass and negative means lost mass.

Computing Mass Residuals

Mass Residuals on the NC9 mesh

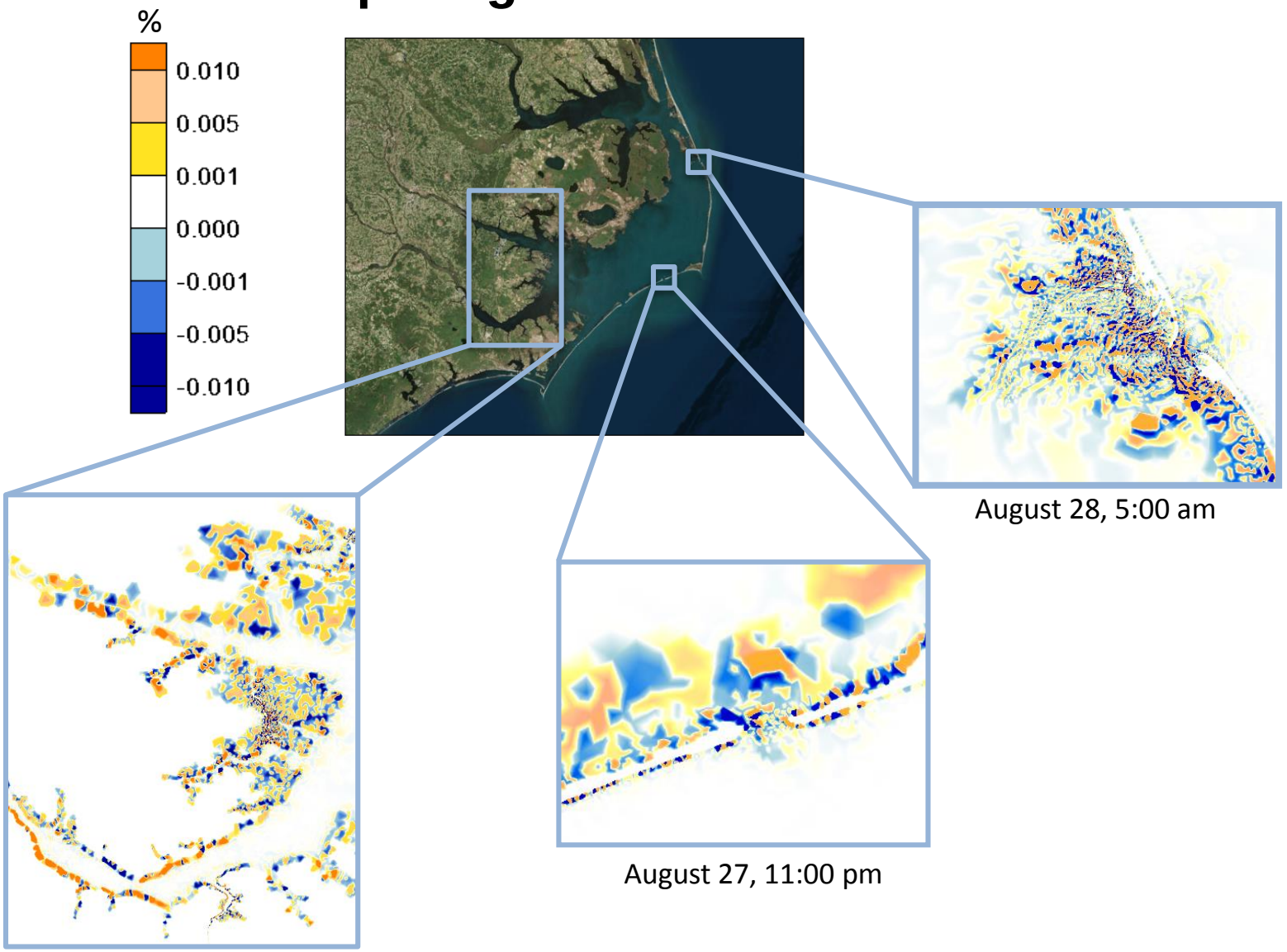


Water Levels during Hurricane Irene (m)



Mass Residuals as % of the still-water volume

Computing Mass Residuals



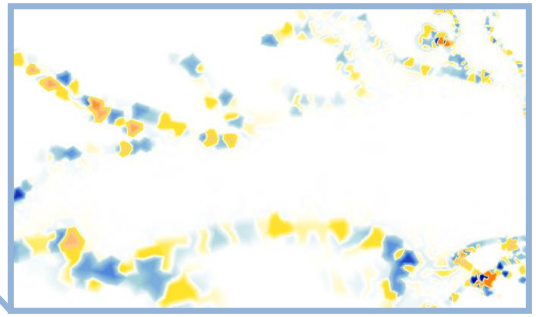
Mass Residuals at selected locations

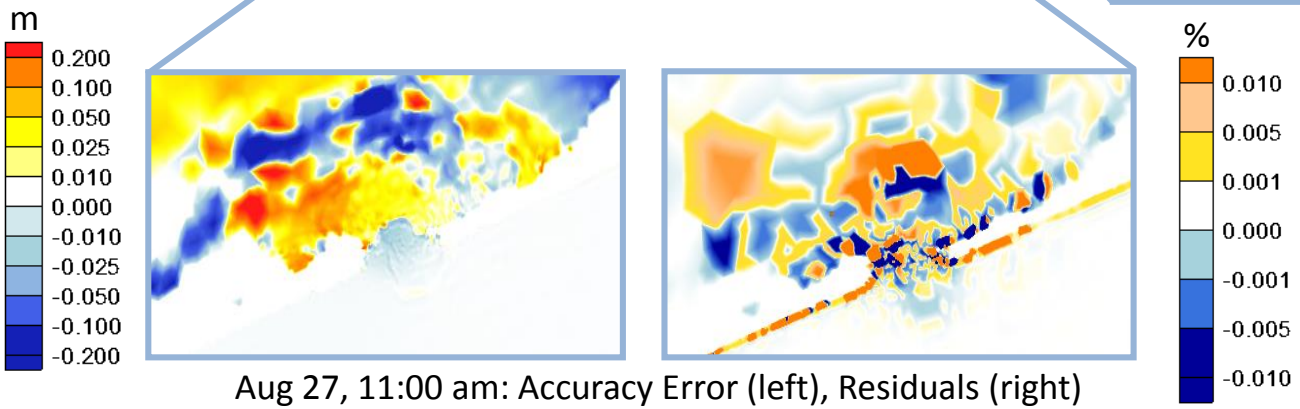
Conclusions

- Comparing the Accuracy and Residual plots, it can be seen that the high values of mass residuals occur in regions where there are large accuracy errors
  - For example: the inner flood plains, the sound-side of outer banks
- Similarly, the low values of mass residuals occur in regions where there are small accuracy errors
  - For example: the open ocean

Future Work

Aug 27, 9:00 pm: Accuracy Error (top), Residuals (bottom)
Current Resolution: 720 – 1150 m





Aug 27, 11:00 am: Accuracy Error (left), Residuals (right)
Current Resolution: 75 – 250 m

Thank You