Let it Rain on your mesh Integrating Hydrologic and Hydraulic Modeling to Simulate Hurricane Flooding in Coastal Areas

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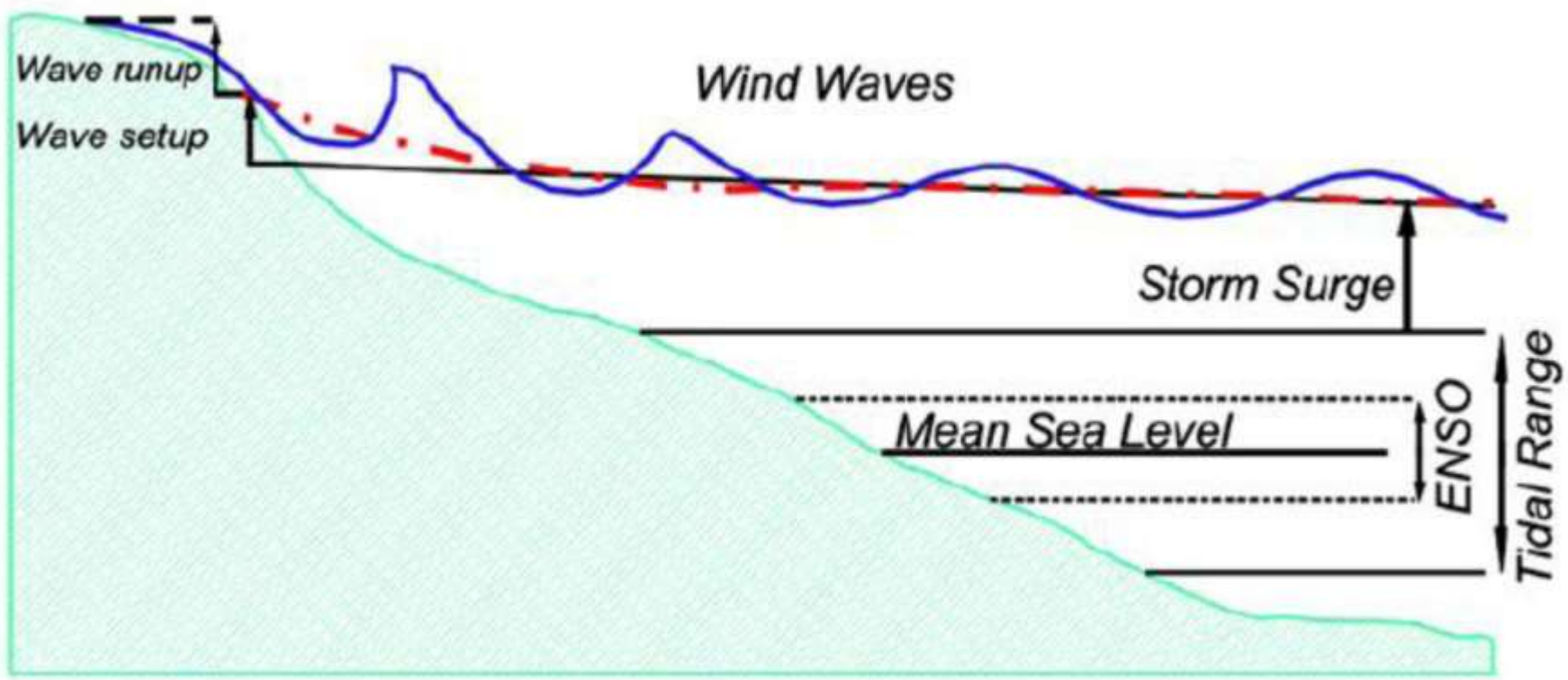
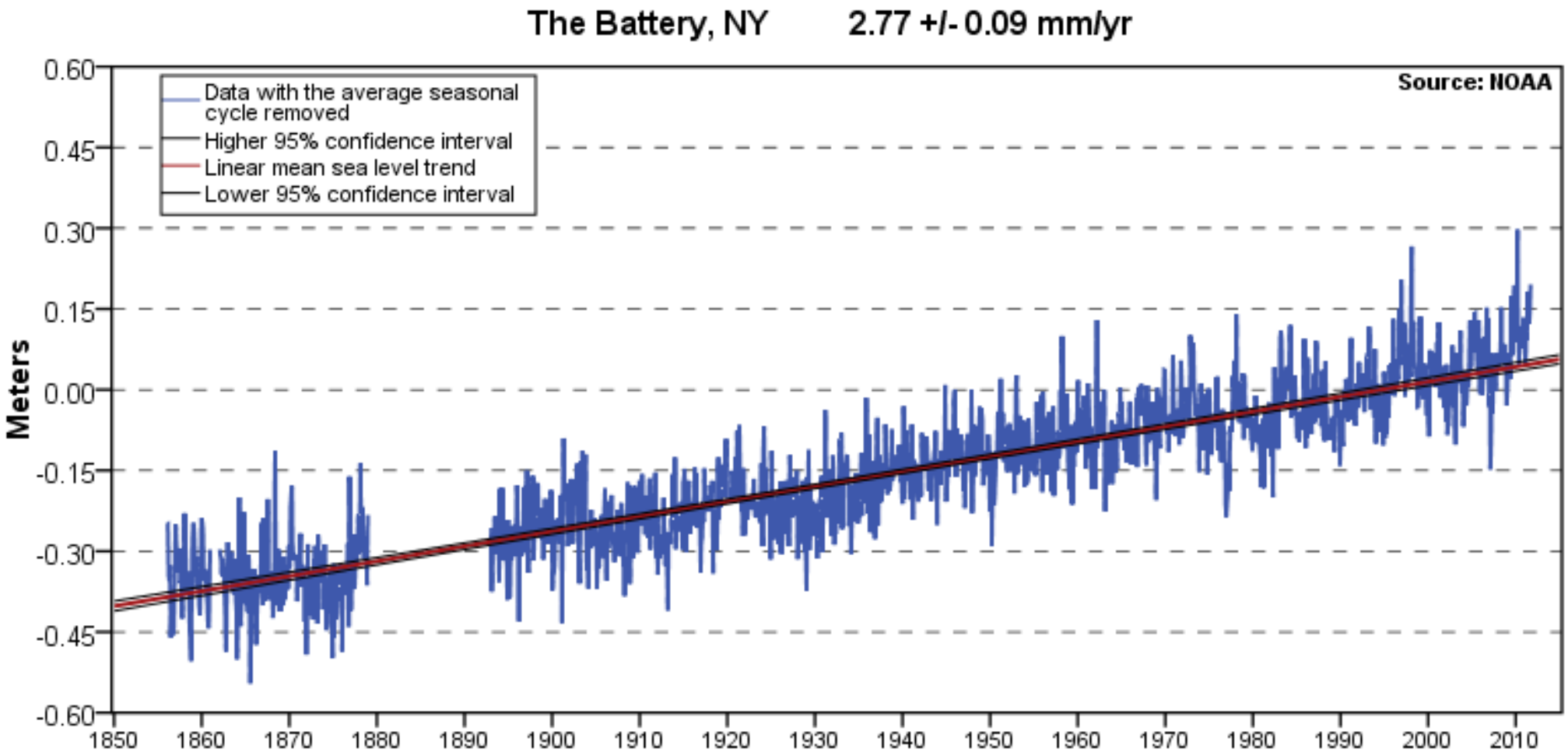
Flooding caused by Hurricanes and Tropical Storms

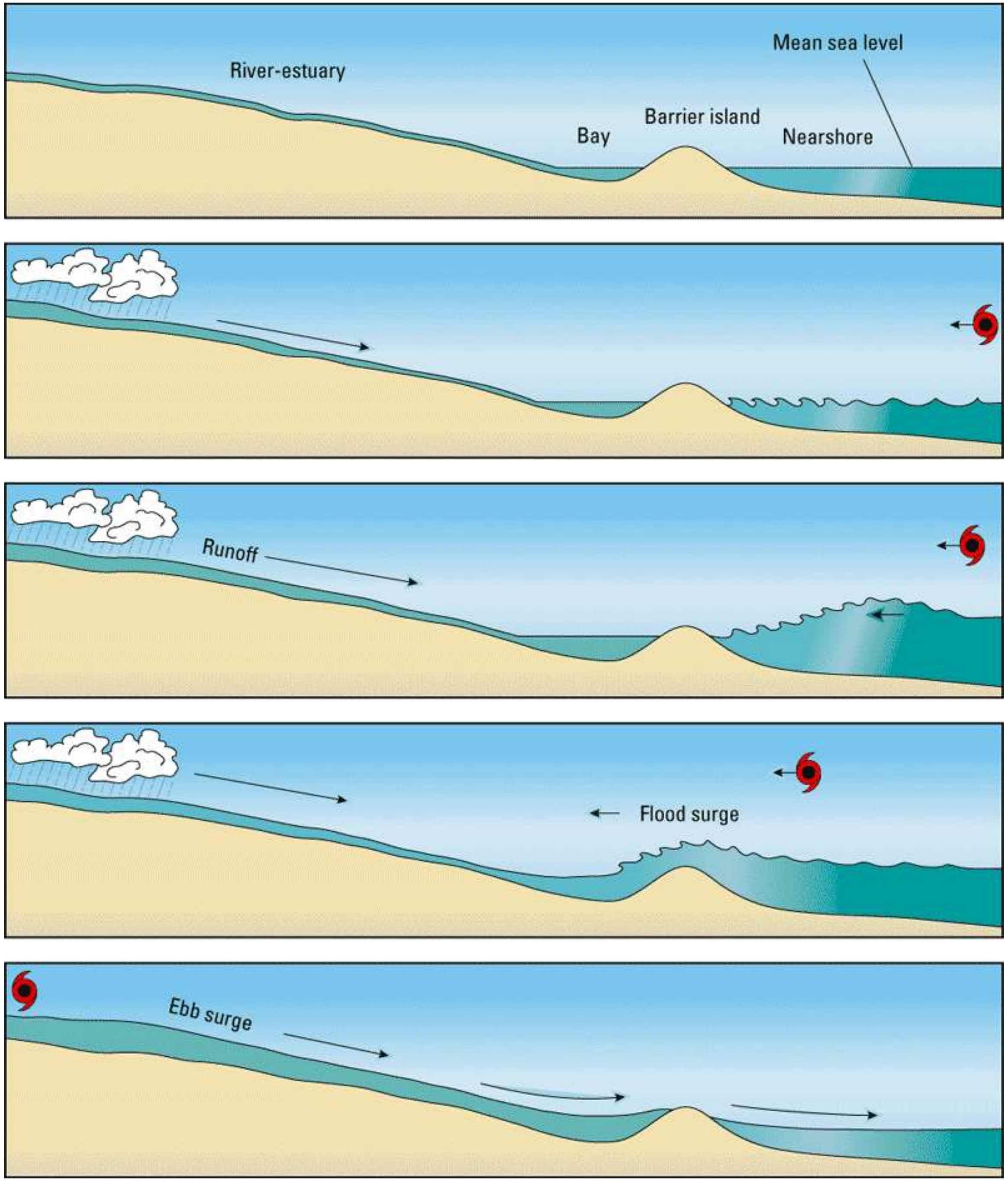
- Storm surge / Sea level rise
- River flooding
- Local rainfall / runoff

Sturm Surge


Wave runup
Wave setup
Wind Waves
Storm Surge
Mean Sea Level
ENSO
Tidal Range

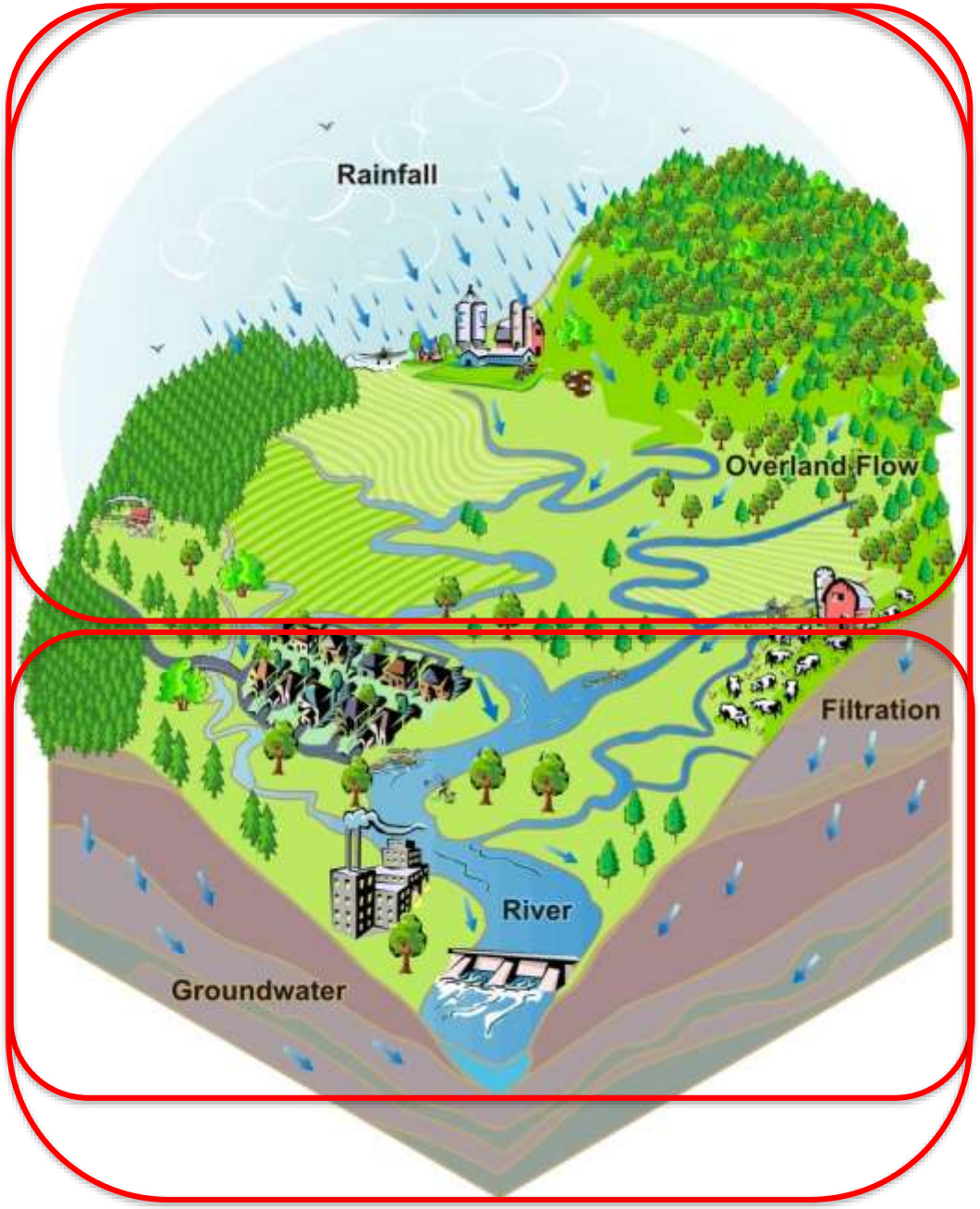
Sea Level Rise





http://pubs.usgs.gov/pp/2007/1751/professional-paper/tile7-8/hurricanes.html

Hydrologic model
→ Runoff, losses, and Q(t) hydrograph



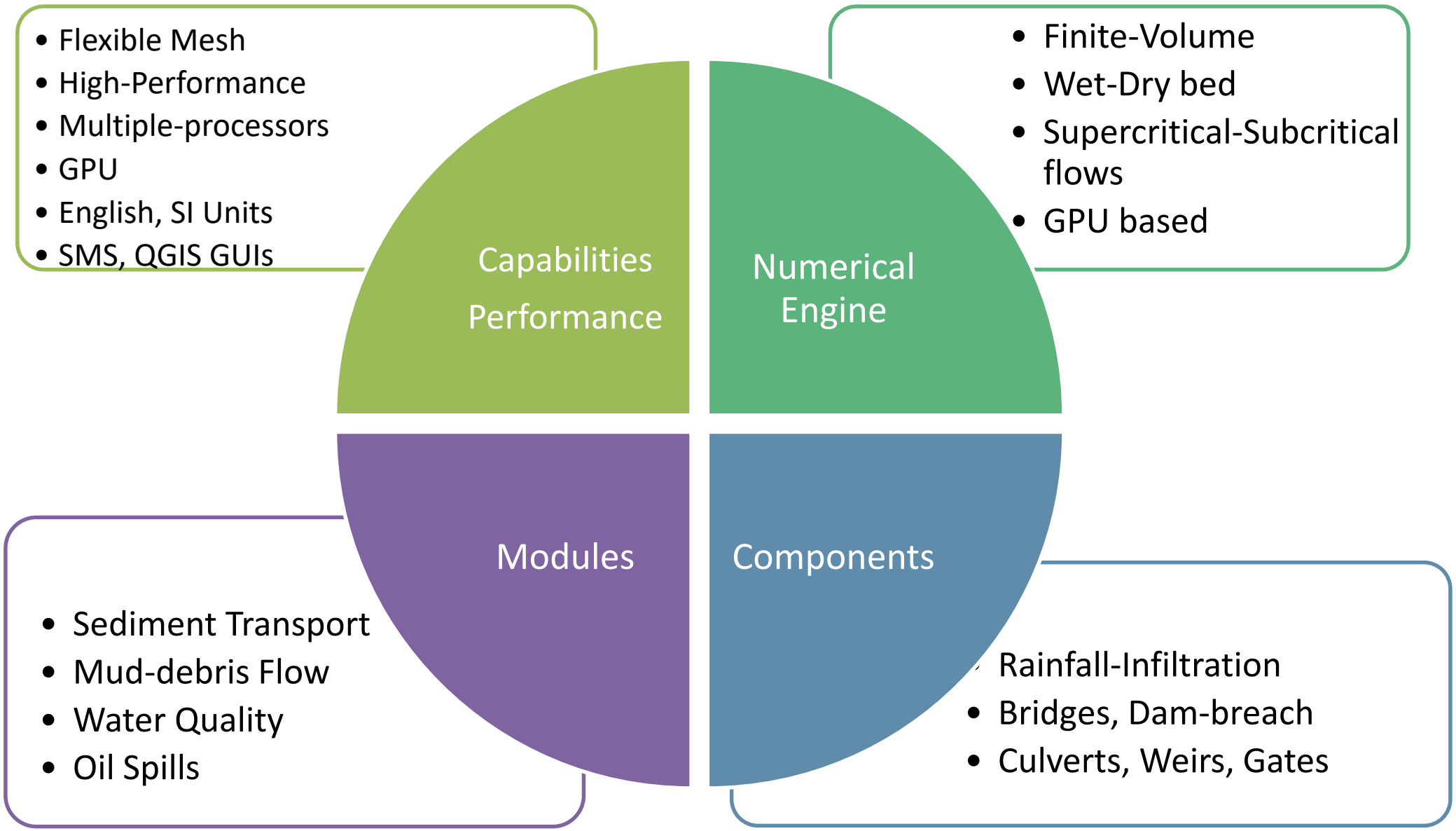
Integrated Hydrologic and Hydraulic model
→ Runoff, losses, and Flood routing [depths and velocities]

Hydraulic model
→ Flood routing [depths and velocities]

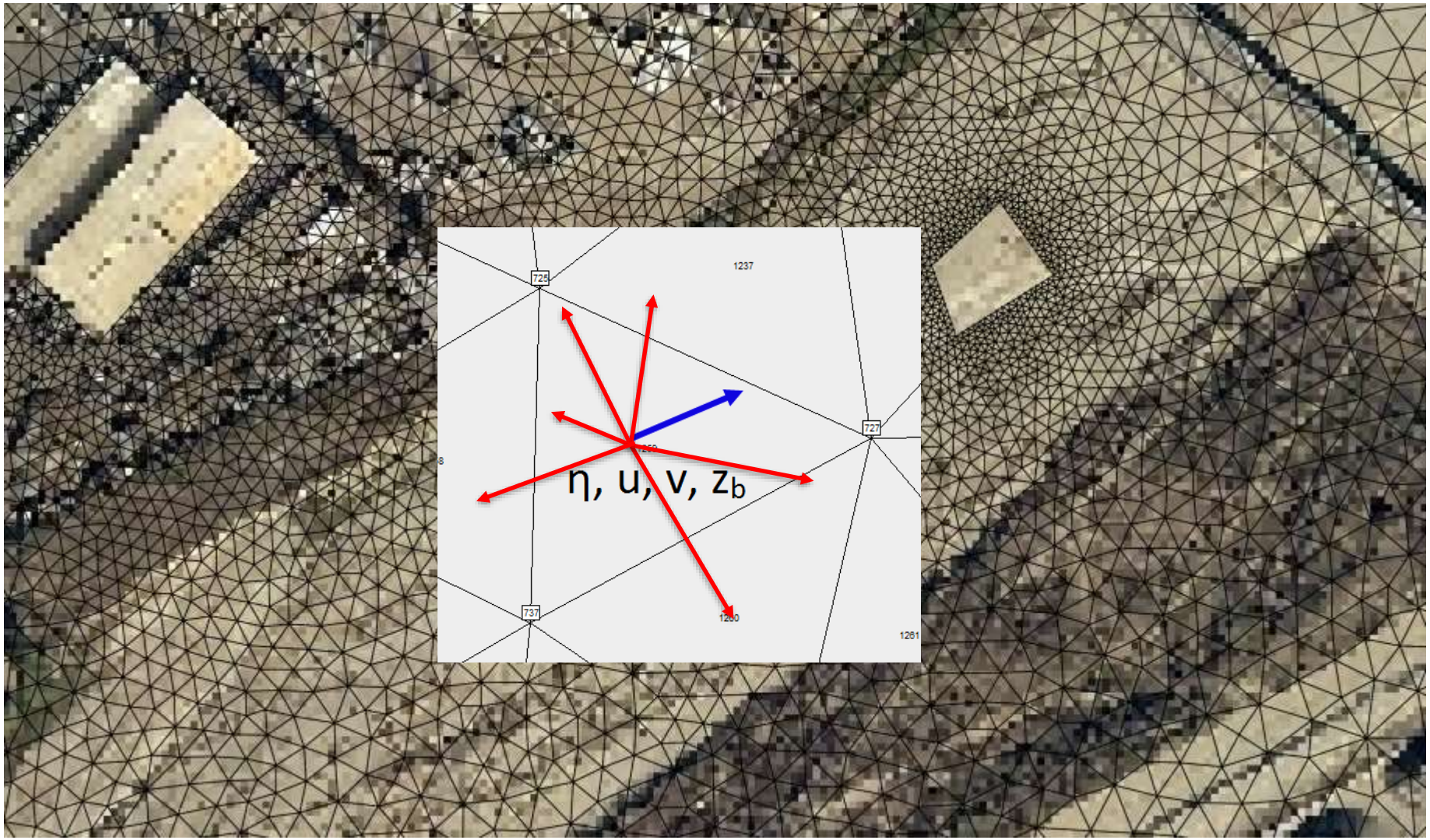
Integrated Hydrologic-Hydraulic Modeling Challenges

- Urban environment (buildings, streets, etc.)
  - Resolve complex terrain and geometry
  - Wetting-drying
- Structures (levees, walls, roads)
  - Geometrical adaptation to arbitrary polylines
- Multiple inflow/outflow boundaries
  - Water may enter and leave mesh during simulation
  - Discharge and stage BCs
- Combined forcing
  - Extreme rainfall + storm surge
- Extremely long model runtimes
  - Large meshes required
  - Rapid changes in depths and velocities

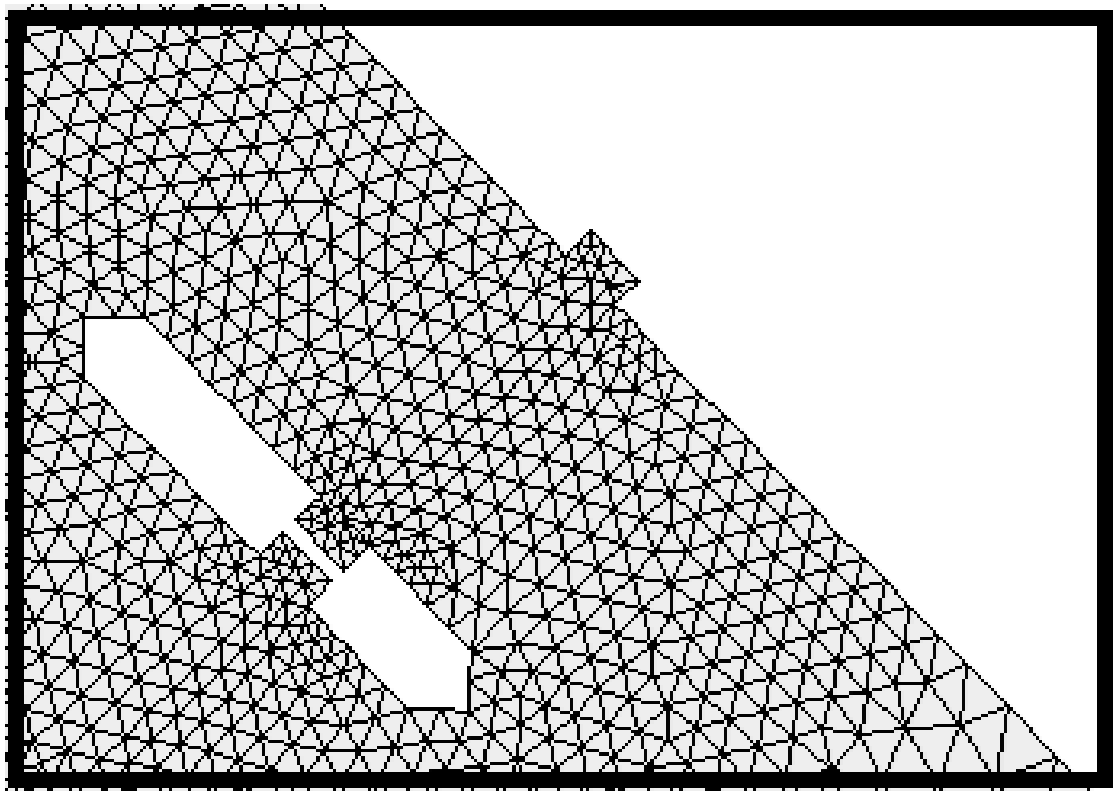
RiverFlow2D Hydrologic-Hydraulic Model

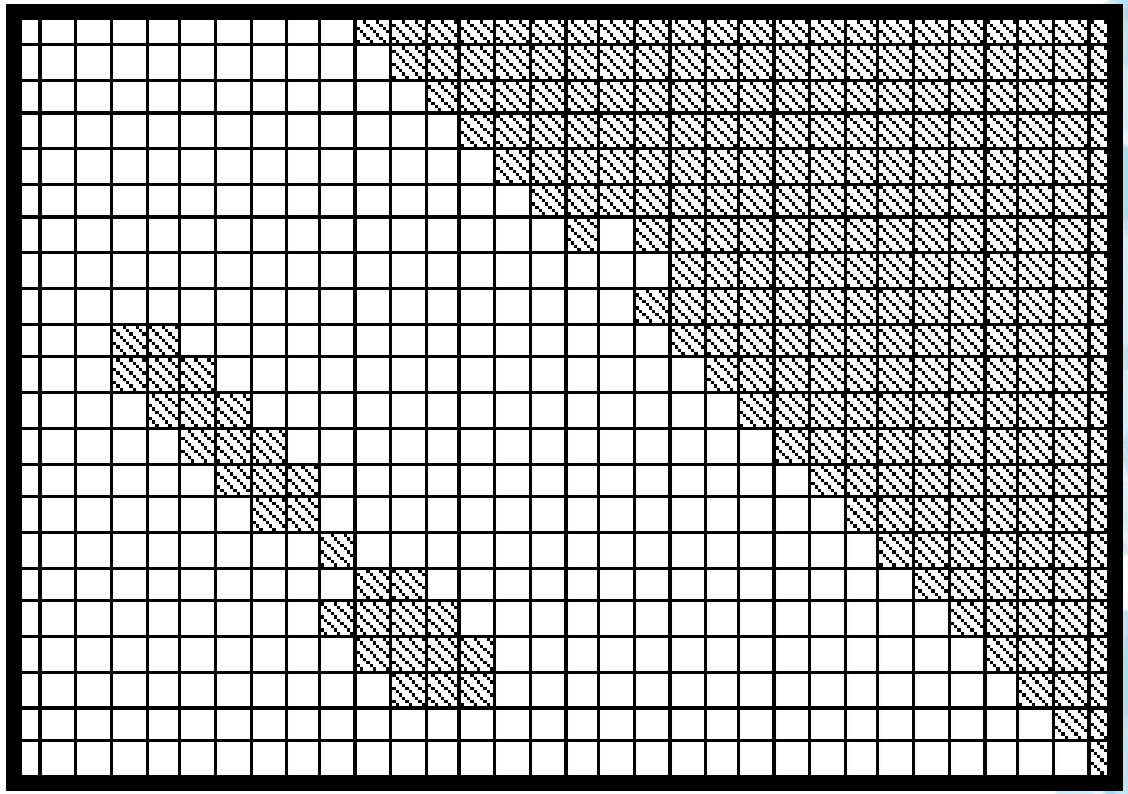


Flexible Mesh



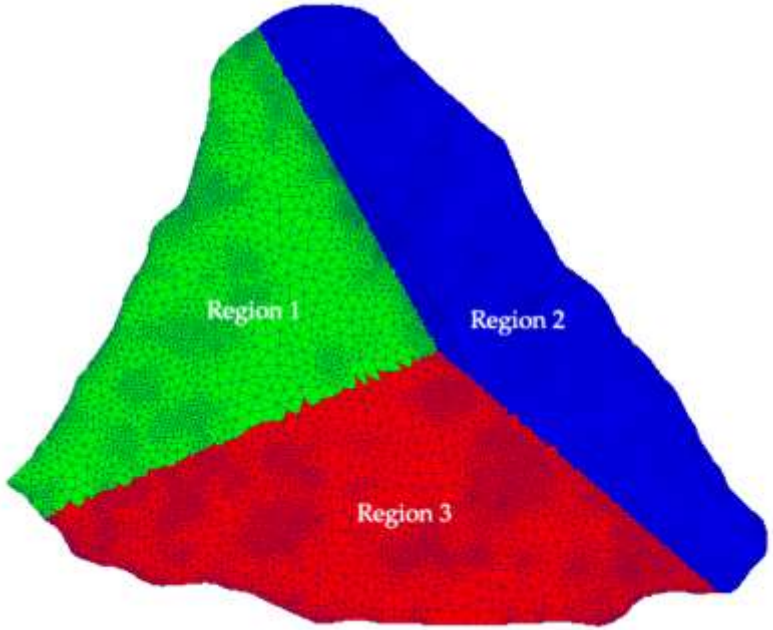
Accuracy



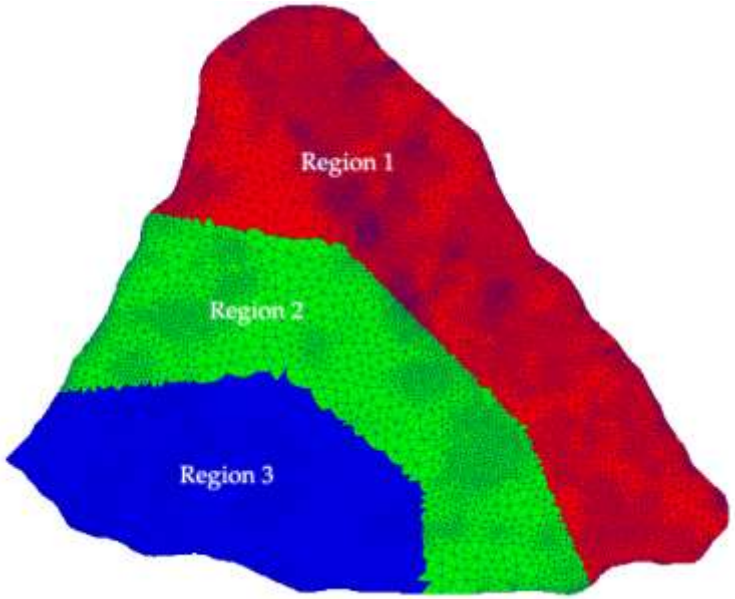


HYDROLOGIC COMPONENT

- Rainfall/Evaporation
  - Spatially distributed, varied in time
  - Rainfall input: Radar, gauges, etc.
  - ASCII Grid or polygon input



- Infiltration loses
  - Spatially distributed parameters/methods
  - Horton
  - Green-Ampt
  - SCS-CN



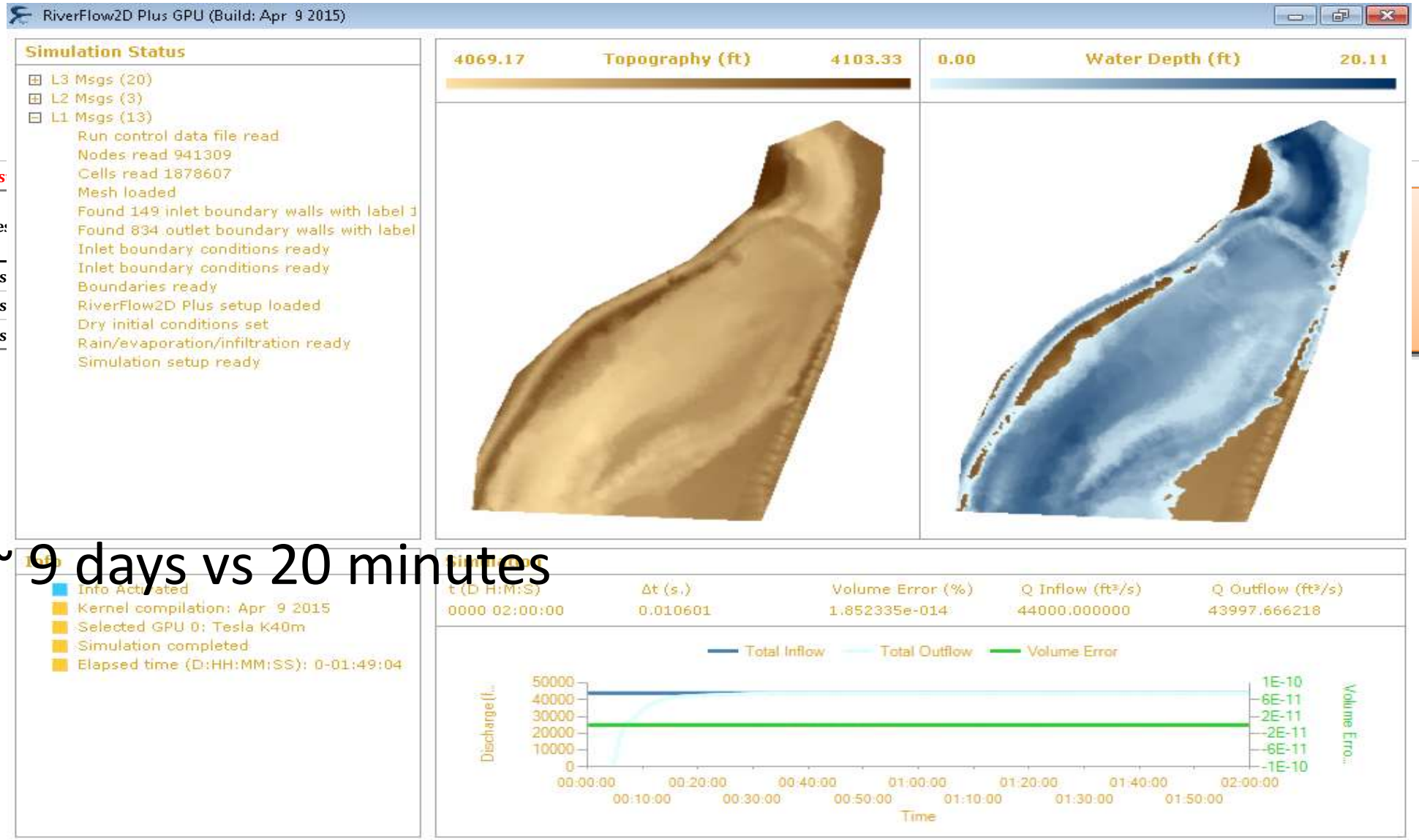
Addressing Computational Challenge with RiverFlow2D GPU

- CPU → Central Processing Unit (OpenMP)

- GPU → Video Cards
- GPUs → 5000+ processors (cores)
- Requires specialized programming (NVIDIA CUDA)

GPU CARD	Number of Cores	Memory GB	Cost US$
GTX 1080 Ti	3,584	11	700
Tesla K80	2,496	12	3,000
Tesla P100	3,584	16	6,000
Tesla V100	5,120	16	19,500

Evolution of RiverFlow2D GPU Performance



~ 9 days vs 20 minutes

RiverFlow2D GPU in the Cloud

- Google or Amazon Cloud Services
- Create Virtual Machines with top of the line GPU hardwa
- Cost effective: < US$ 2/hour
- Drawback…Data transfer to and from the Cloud…

NVIDIA

Hurricane Sandy flooding Simulations

- Oct. 2012
- 5-7 in. rainfall

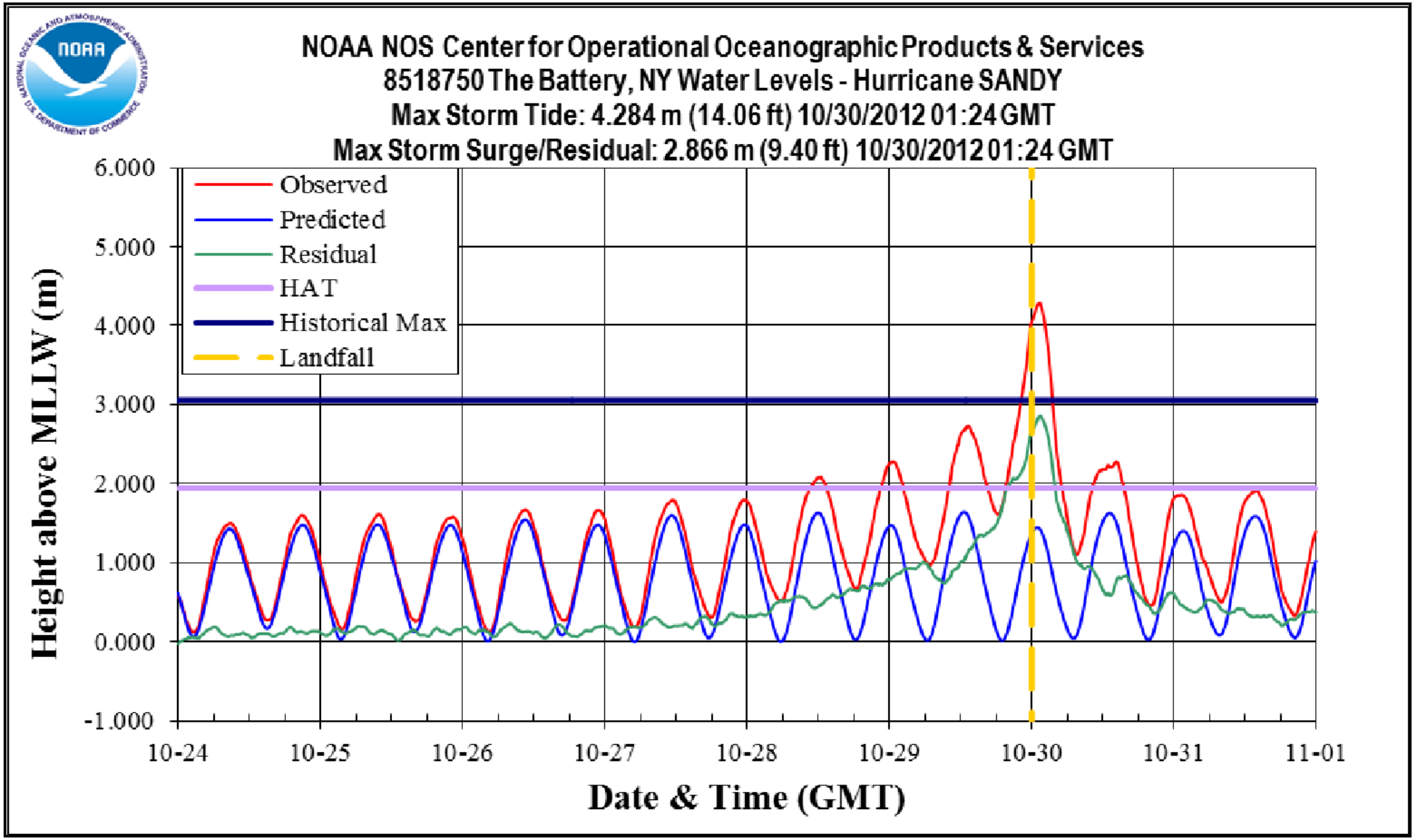
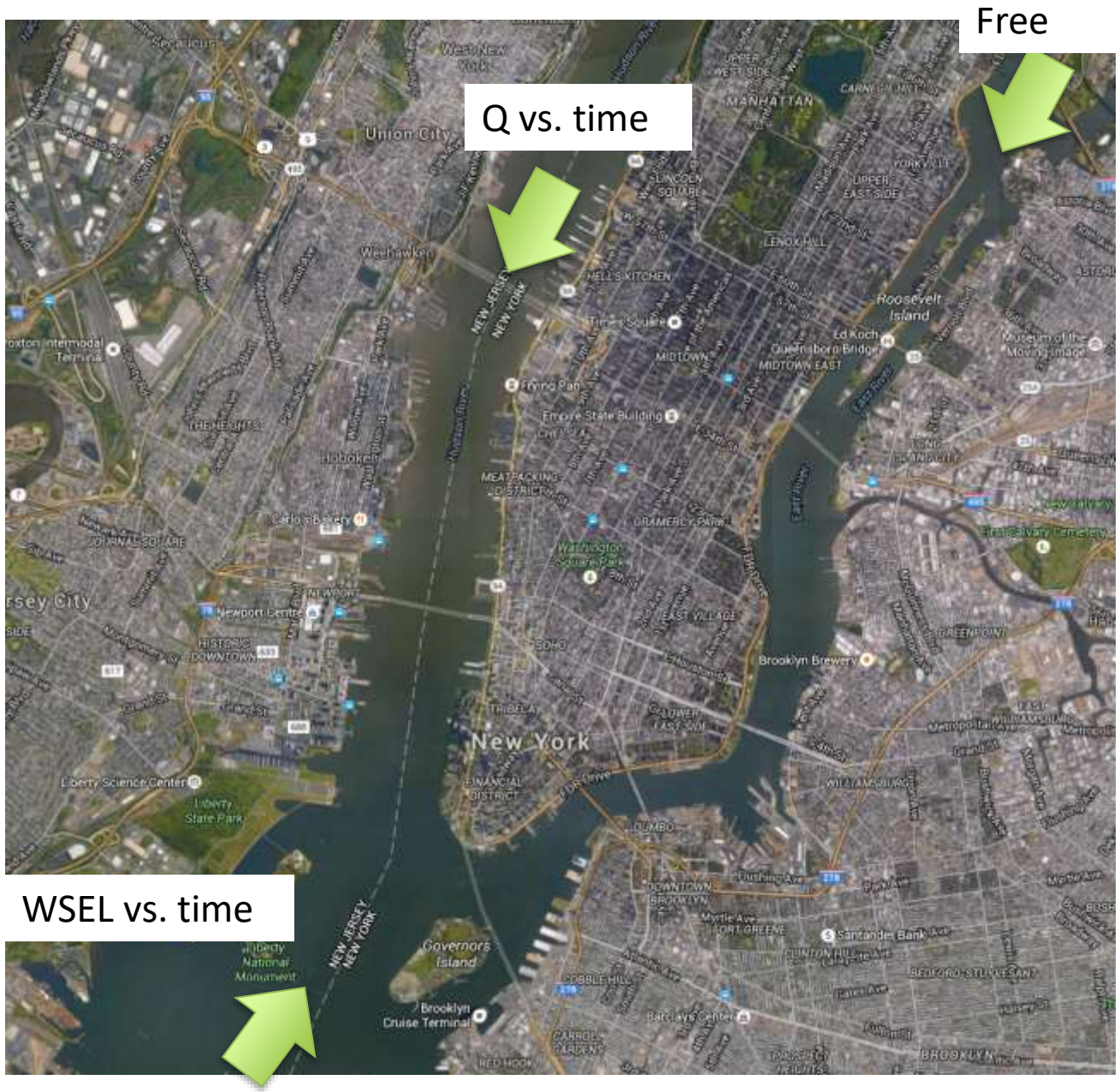
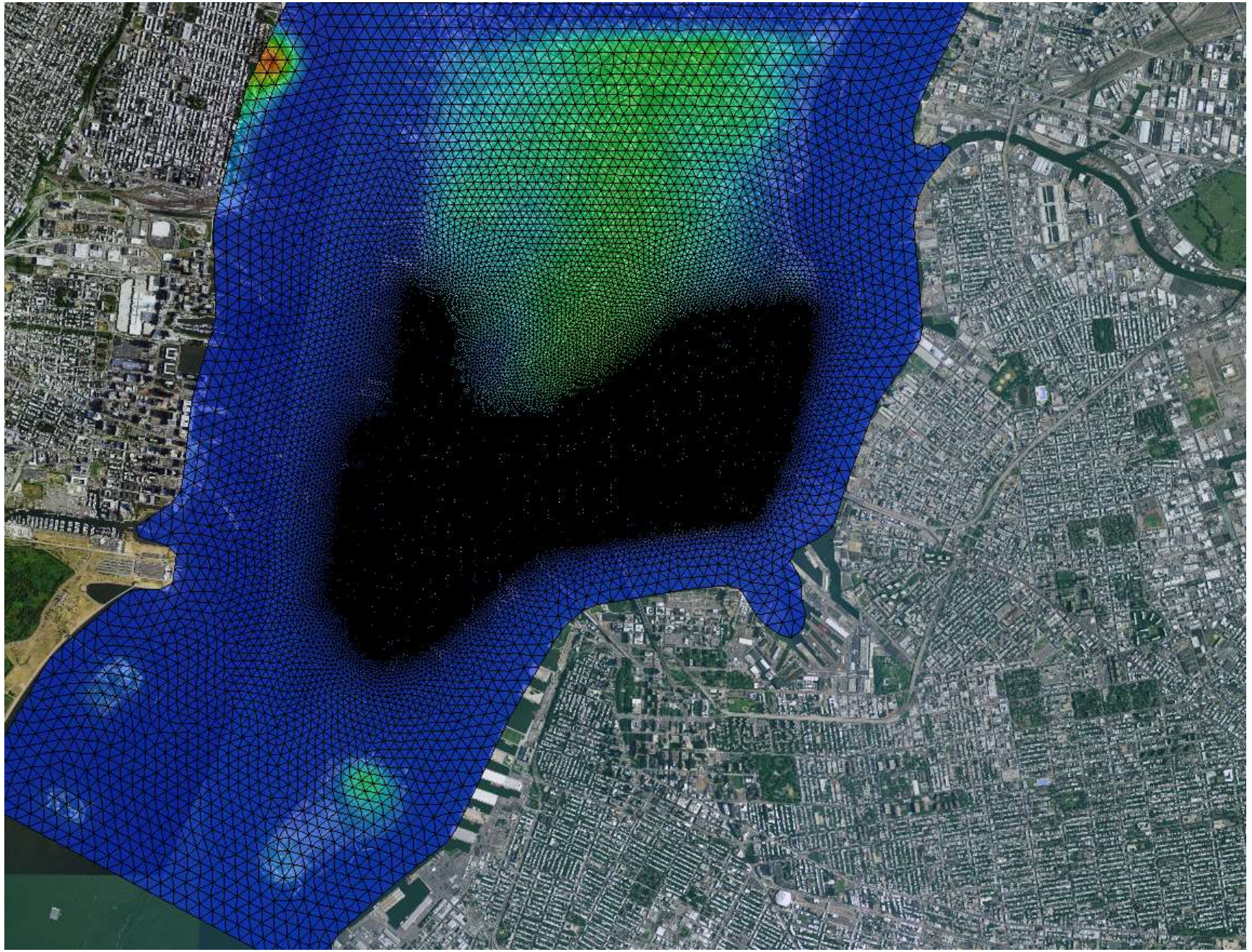
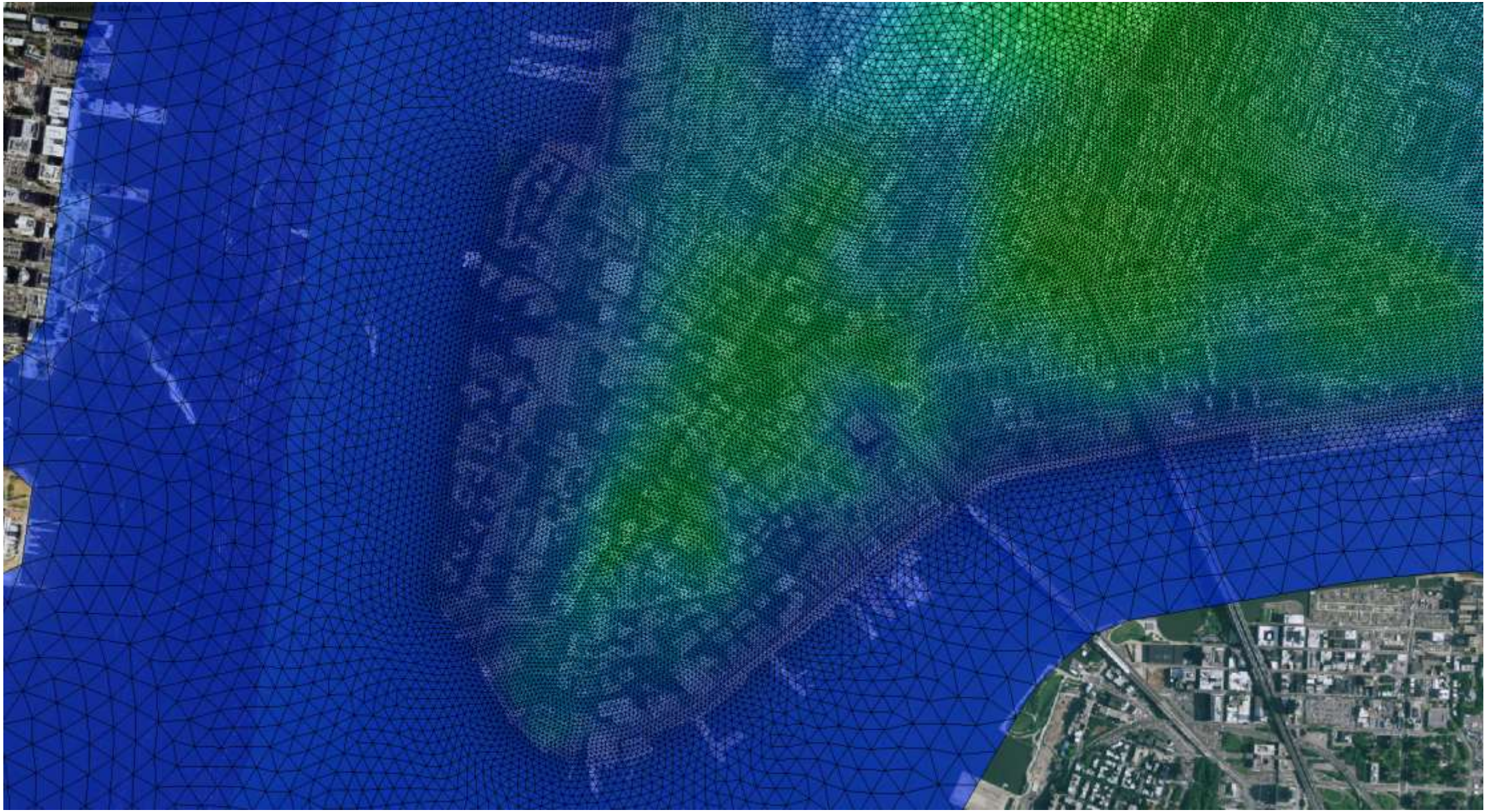


Figure 54: Water levels above Mean Lower Low Water (MLLW) at The Battery, NY. Lines denoting Highest Astronomical Tide (HAT) and Historical Maximum Water Level are displayed. Maximum recorded water level value exceeded the historical maximum value. Sandy made final landfall near Atlantic City, NJ on 10/30/2012 00:00 GMT as a Category 1 hurricane.

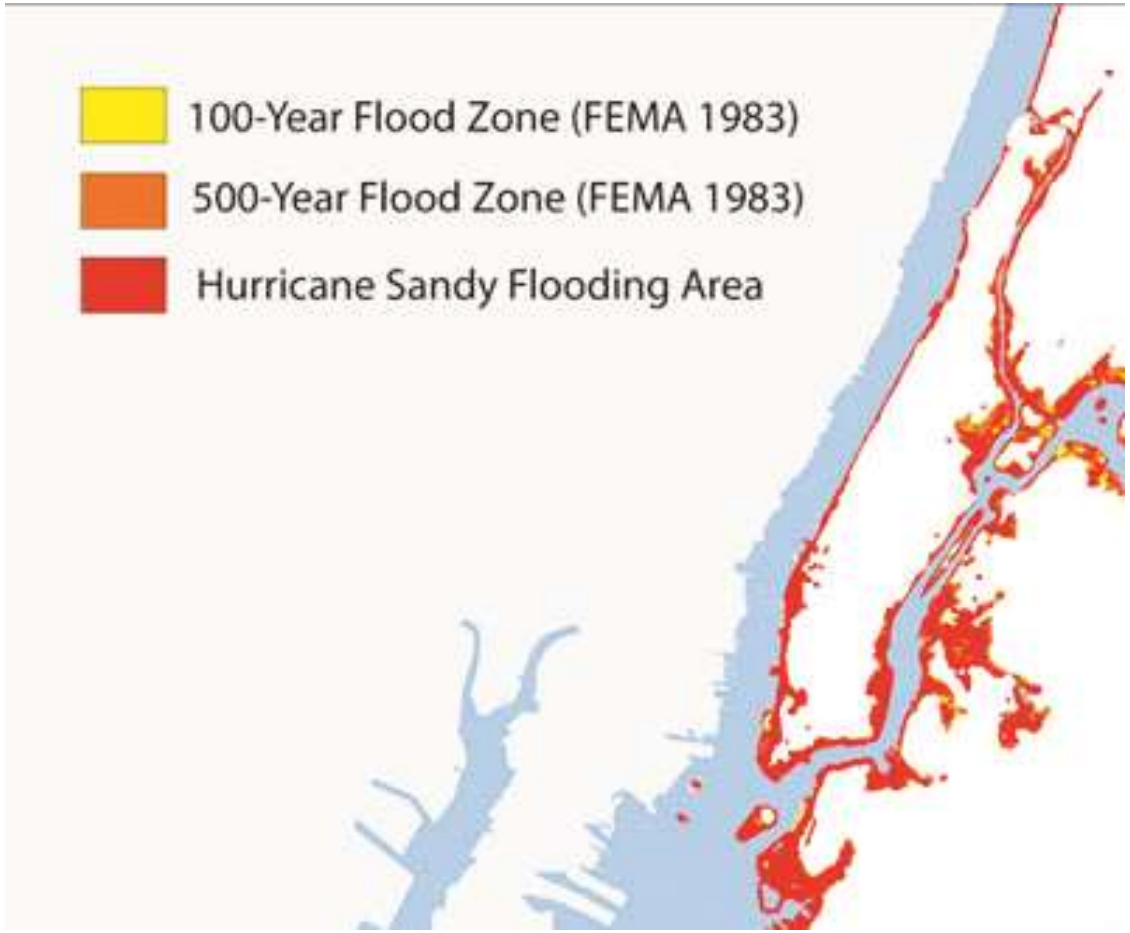
- ddd

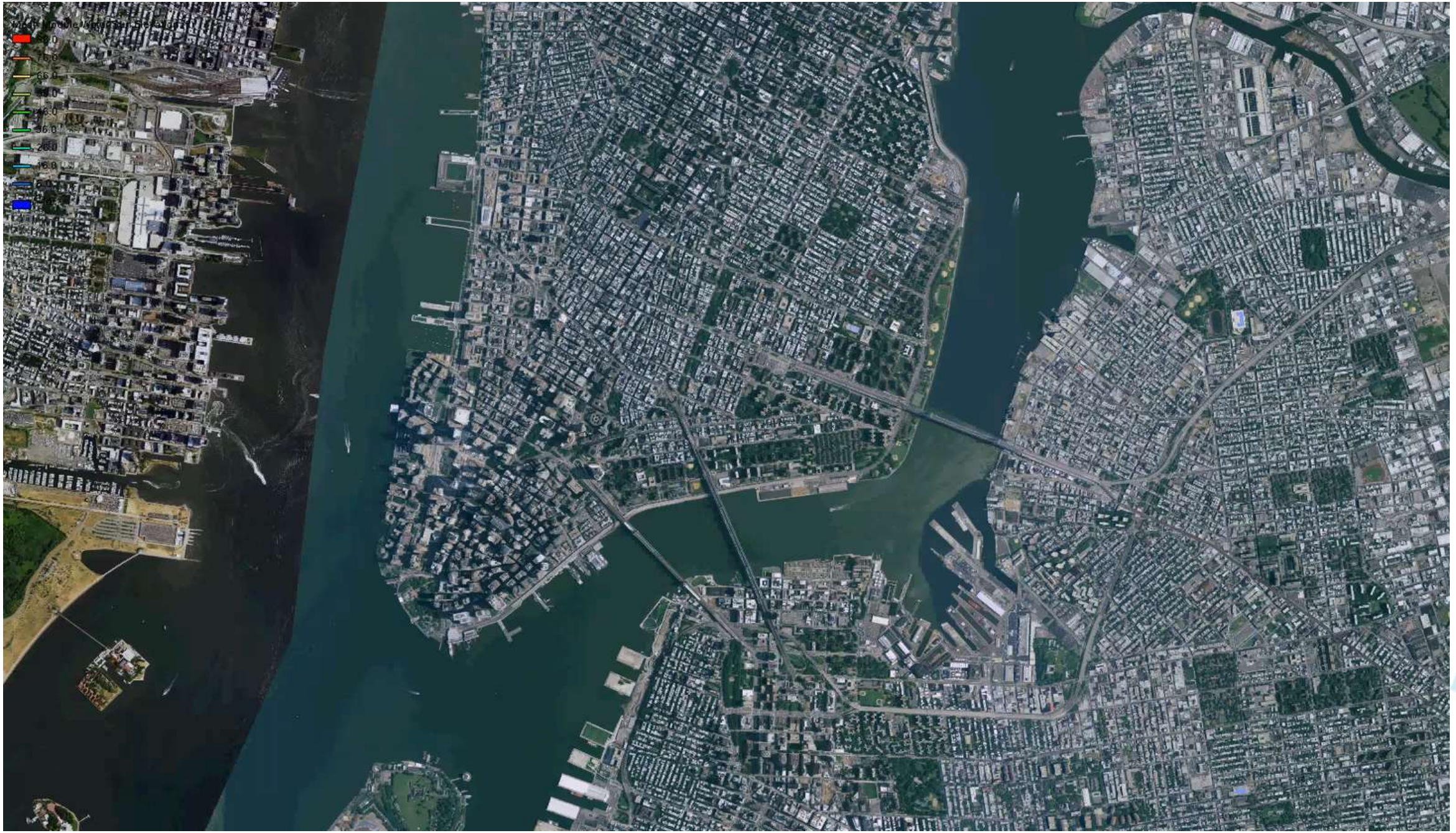

Free
Q vs. time
WSEL vs. time
Union City
Weehawken
Hoboken
Jersey City
New York
Governors Island
Liberty State Park
Liberty Science Center
Brooklyn Cruise Terminal
Brooklyn Bridge Park
Roosevelt Island
Ed Koch Queensboro Bridge
Empire State Building
Flying Pan
Brooklyn Brewery
Newport Centre
Barclays Center
Santander Bank
MANHATTAN
MIDTOWN
MIDTOWN EAST
HELL'S KITCHEN
LENOX HILL
UPPER EAST SIDE
SOHO
TRIBECA
DUMBO
BROOKLYN
GREENPOINT
NEW JERSEY
NEW YORK

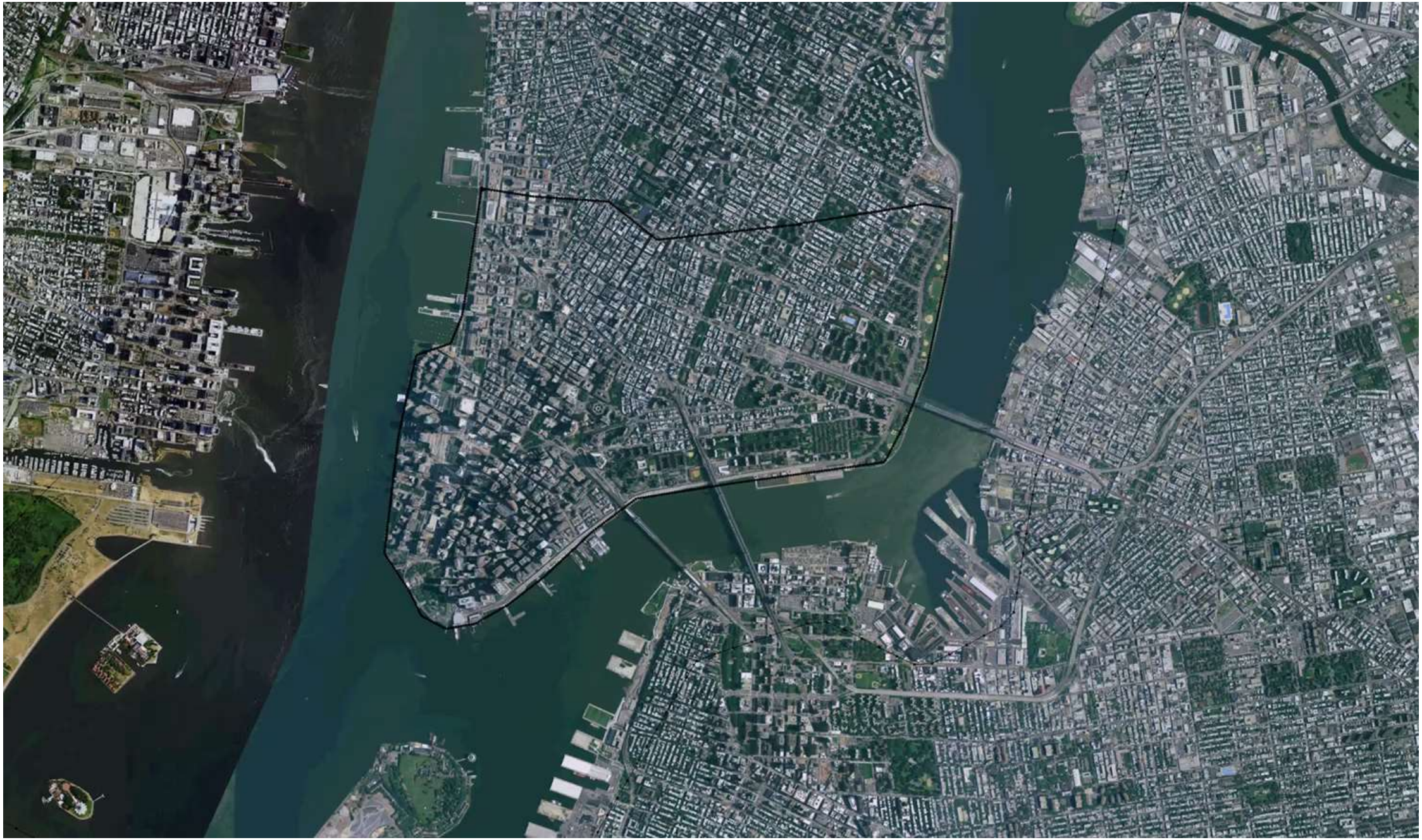




Observed Flooding vs RiverFlow2D Flooding Area

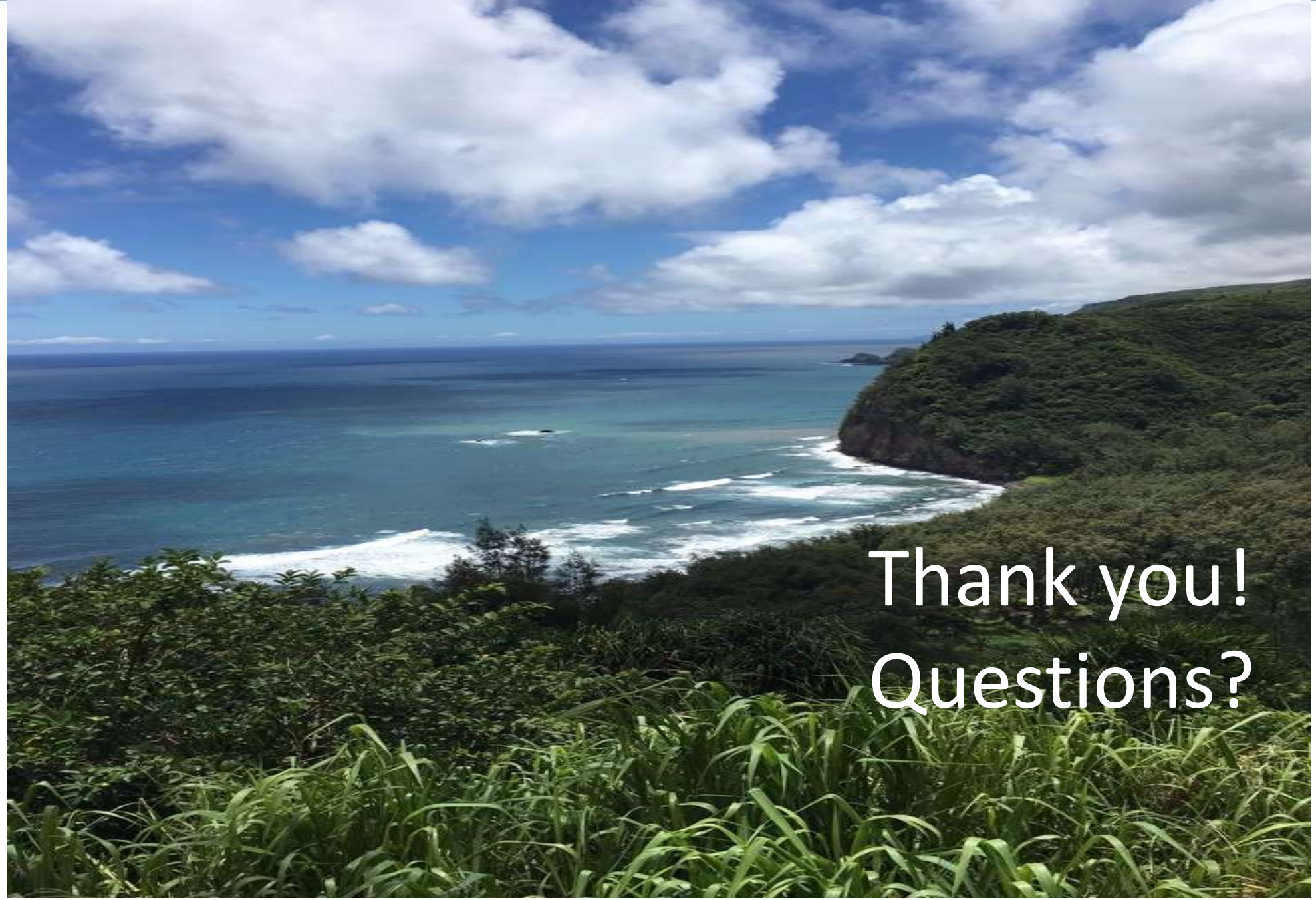






Final Comments

- Integrated hydrologic-hydraulic modeling is more realistic
- Taking advantage of GPU technology makes possible using high resolution and large meshes
- Use of Cloud services (e.g. Google, Amazon) minimizes modeling costs


Thank you!
Questions?