Development and Validation of a Storm Surge and Wave Model for Lake Huron (Great Lakes, USA)

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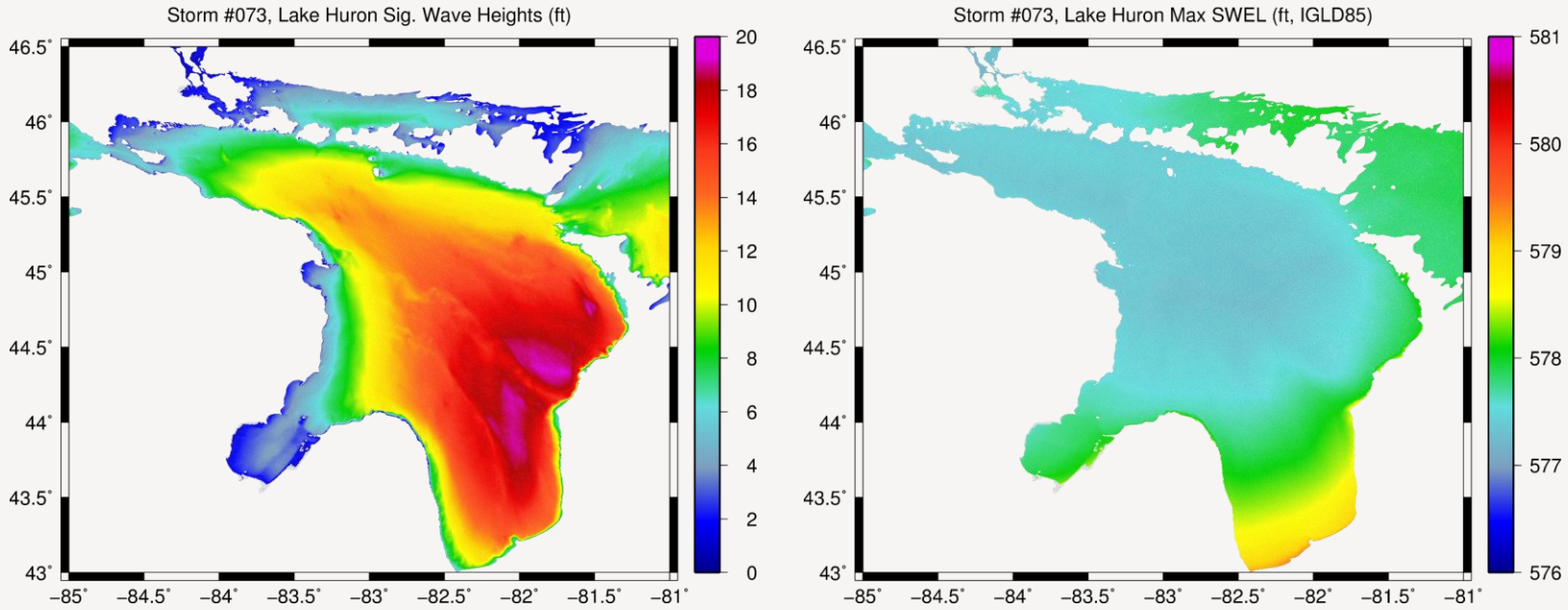
Presentation Overview

Summary

- An efficient, high-resolution storm surge and wave model was developed for Lake Huron to produce accurate nearshore water levels and wave conditions in support of a revised FEMA Flood Insurance Study.

Outline

- Introduction and motivation
- Mesh development
- Sensitivity analyses
  - *ADCIRC parameter testing*
  - *SWAN parameter testing*
- Model validation
- Model application/production



Introduction and Motivation

FEMA Region V: Update Flood Insurance Rate Maps along U.S. portion of Lake Huron

“Coastal” processes dominate along shoreline

2D offshore models → 1D nearshore/overland model

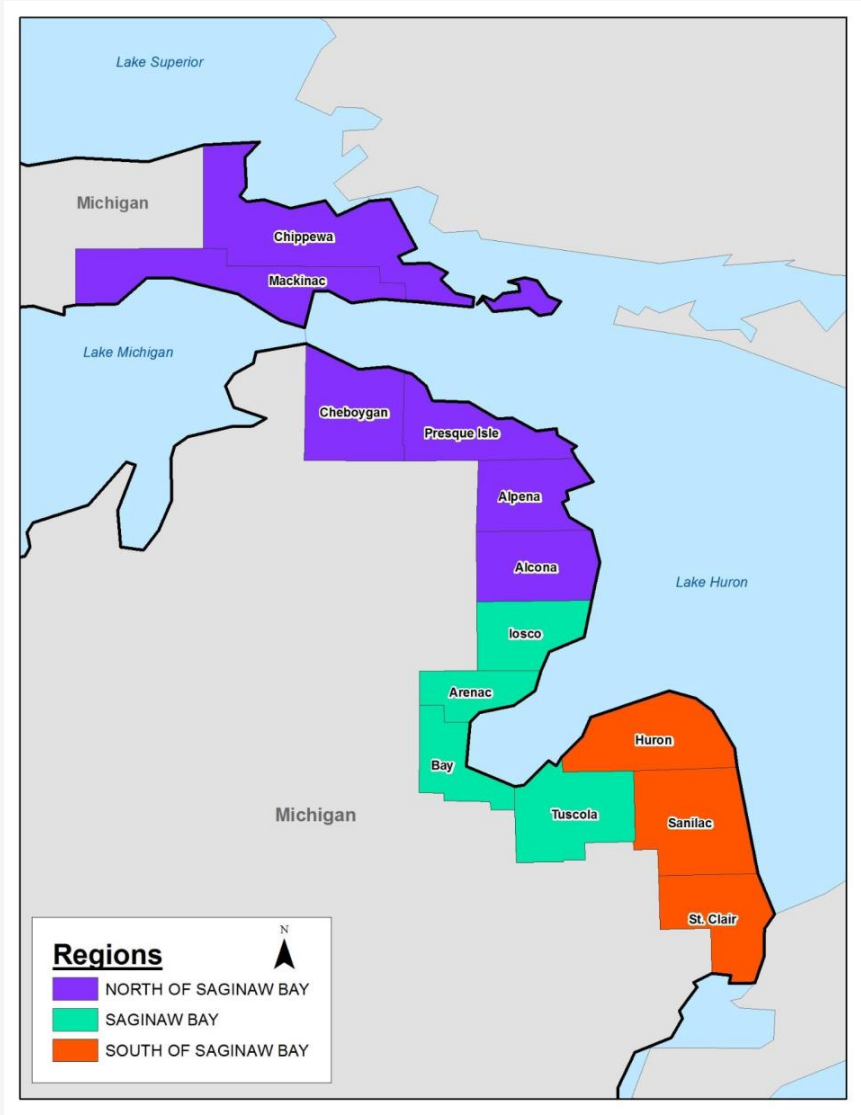
DHS Independent Technical Review of past effort

- Surge/wave models not coupled
- Insufficient model resolution
- Directional filtering not applied to nearshore wave conditions

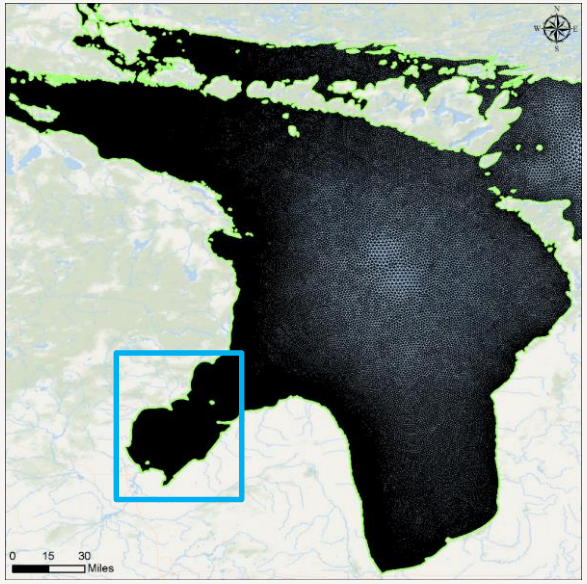
Short duration project schedule

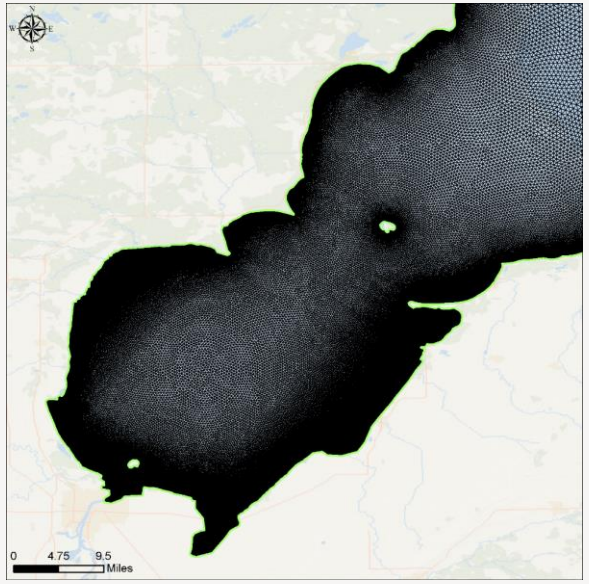
- Increase efficiency
- Maintain accuracy

New ADCIRC+SWAN model developed



Unstructured Mesh





Total # of Nodes = 667,396

Total # of Elements = 1,298,483

Minimum Element Size = ~15 m

Maximum Element Size = ~2 km

Data Sources

Bathymetry/topography

- NOAA/NGDC Digital Elevation Data
- NOAA Electronic Navigational Charts
- NOAA/USACE-JALBTX LiDAR

Ice coverage

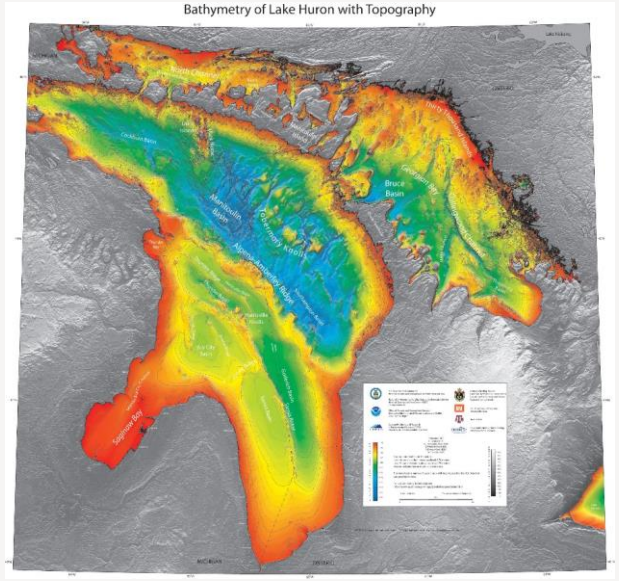
- NOAA Great Lakes Ice Atlas

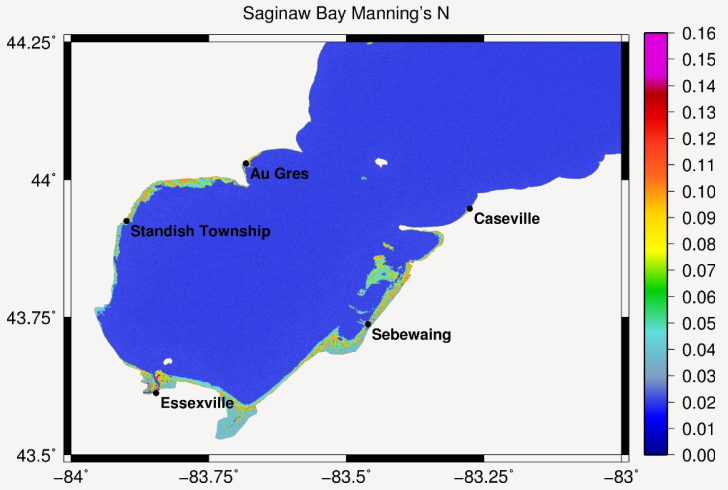
Wind fields

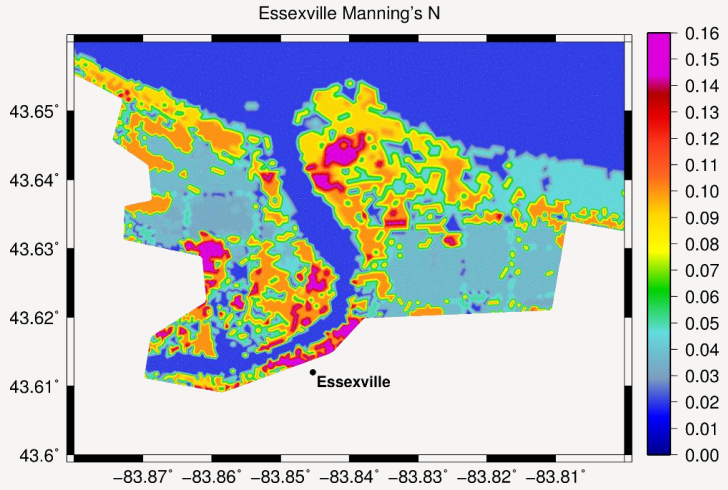
- NCAR/NCEP CFSR (1979 and later)
- EOF method for pre-1979 events

Bottom friction

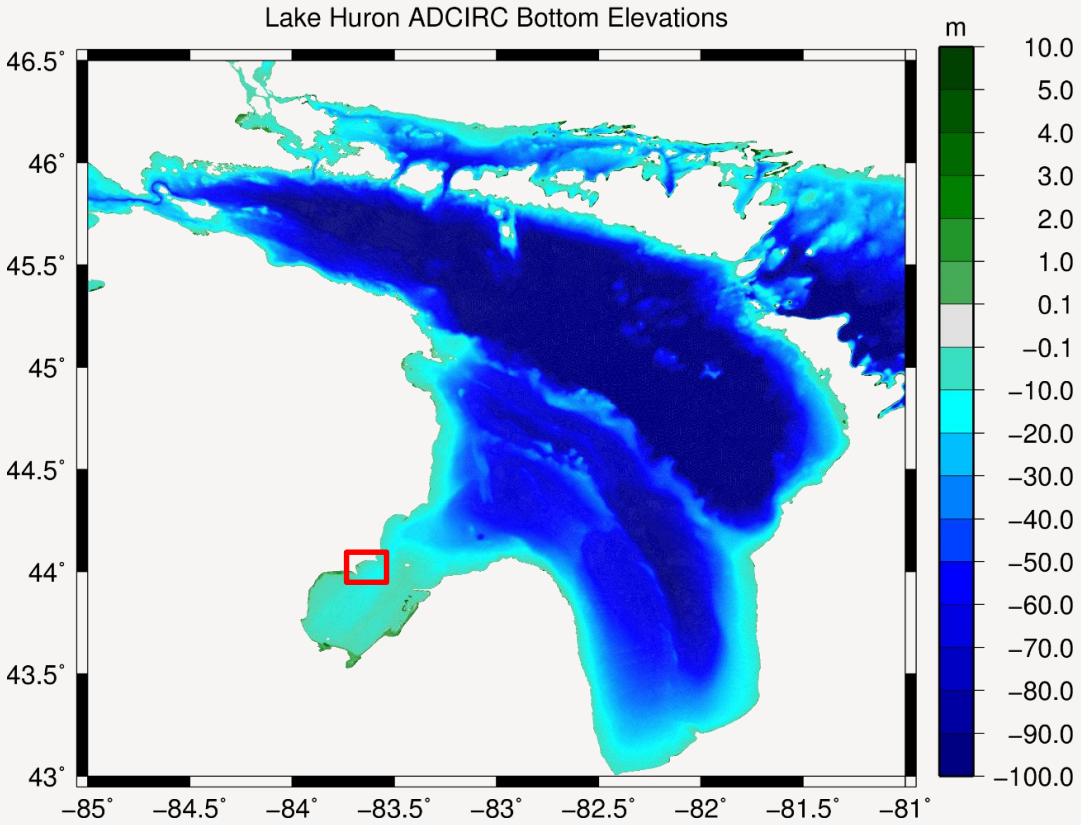
- MRLC National Land Cover Database

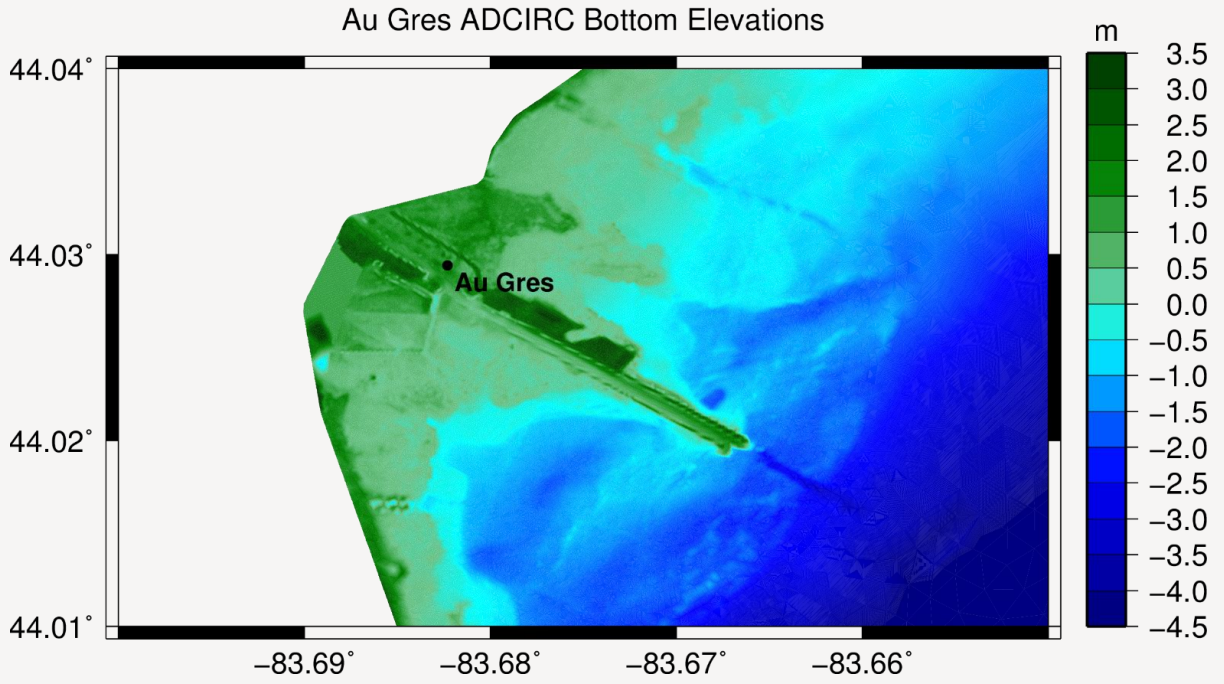






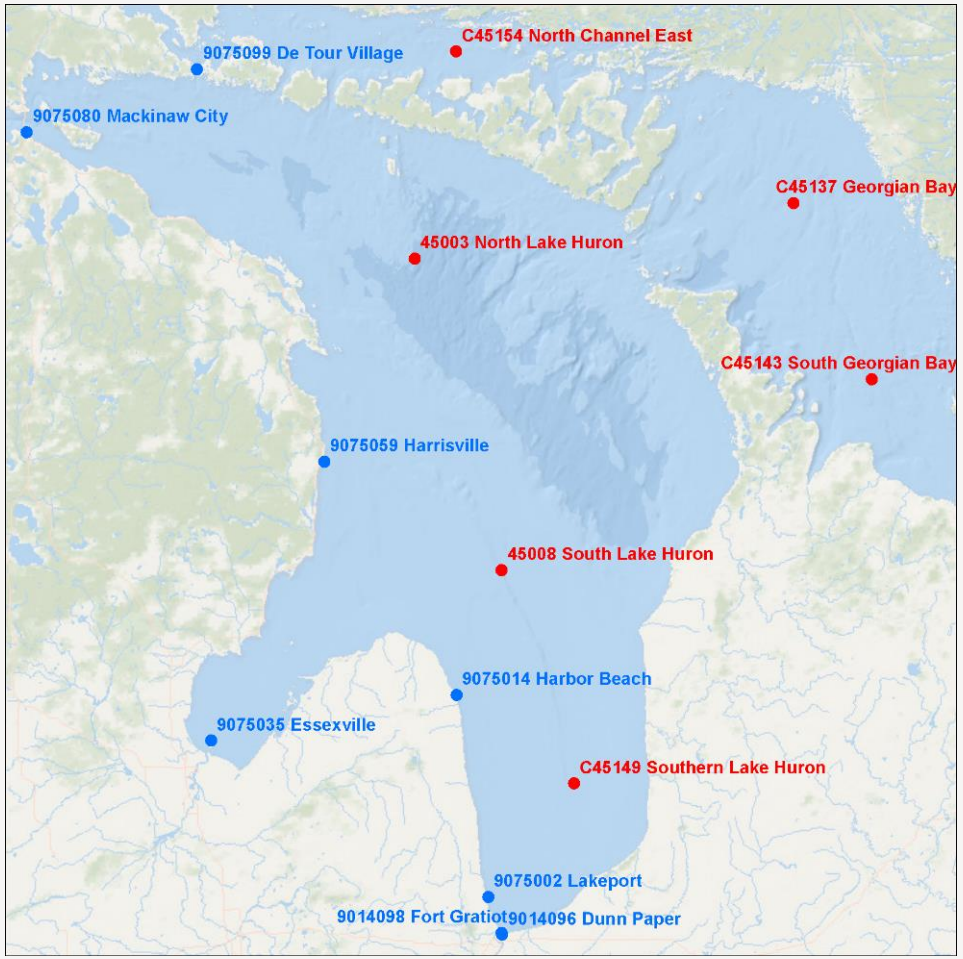
Mesh Elevations





Storm Selection Methodology

- Combination of wind and water level events at gauge locations and hindcast wind data
- Peaks over threshold (POT) procedure to identify events
- Perform analysis for winds and water levels at multiple locations
- Screen for duplicates
- Total of 151 events for the period 1960-2009



Blue = water level stations

Red = wind/wave buoys

Model Testing & Validation

- Ten validation events
- Encompass all gauges as ‘target’ gauges
- Variety of wind, water level, and combination event types
- With and without ice coverage

Event number	Event date	Event type	Ice coverage	Target gauge(s)
41	01/07/1980	WL	yes	--
51	03/21/1983	Wind & WL	yes	Essexville
59	11/20/1985	WL	no	Mackinaw City
60	02/08/1987	WL	yes	Harbor Beach, Lakeport, Fort Gratiot
63	12/15/1987	Wind &WL	no	Harrisville, Essexville
77	11/05/1990	Wind & WL	no	--
79	12/03/1990	Wind & WL	no	--
110	11/10/1998	WL	no	De Tour Village
120	12/12/2000	WL	yes	--
141	12/01/2006	WL	no	Harbor Beach, Lakeport, Fort Gratiot

Model Testing & Validation - ADCIRC

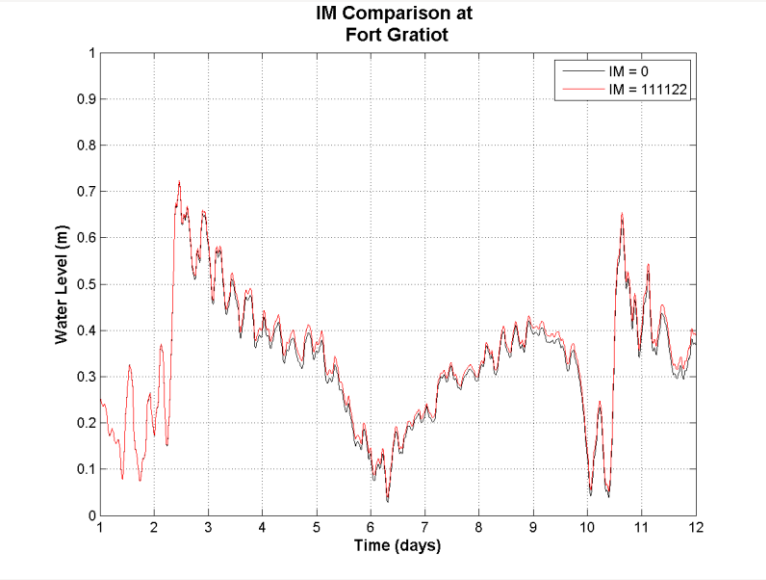
Goal: Increase efficiency, maintain accuracy

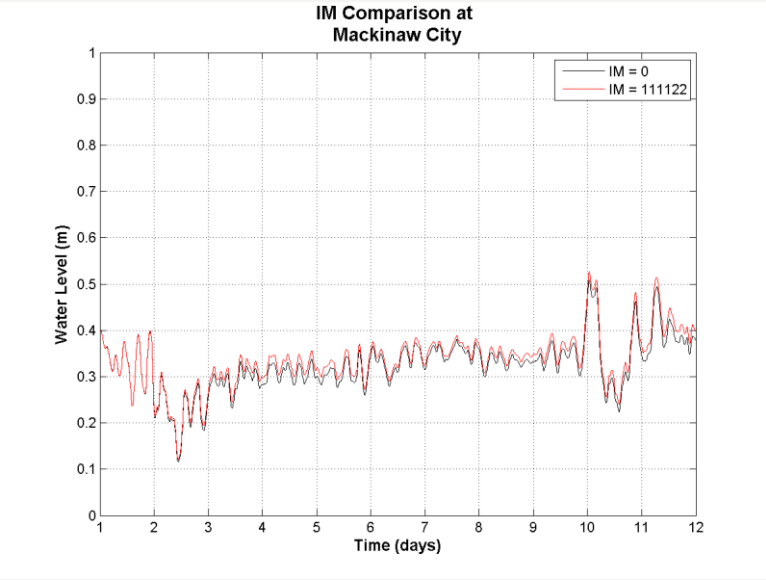
Computational Scheme

- All other model parameters consistent
- 12-day simulation using 120 processing cores
- ADCIRC only simulations; not coupled with SWAN
- Implicit solver (IM = 0): 6 hr 18 min runtime
- Explicit solver (IM = 111122): 2 hr 14 min runtime
- 65% reduction in runtime!

Time Step

- All benchmark simulations were run with 1-sec time step
- Tried 2- and 1.5-sec time steps but went unstable





Model Testing & Validation - SWAN

Goal: Increase efficiency, maintain accuracy

Time Step

- 900-sec vs 1800-sec vs 3600-sec

Maximum Iterations

- 2, 4, 6, 8, or 20 iterations

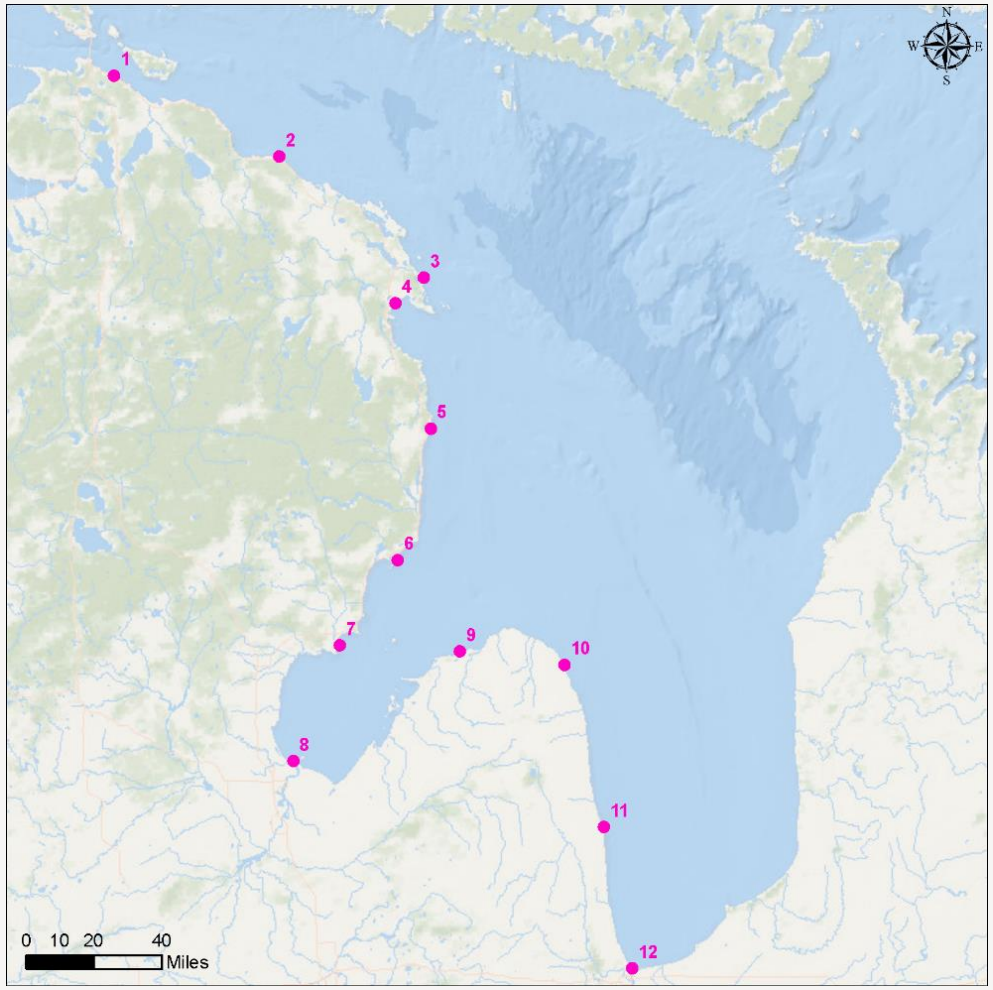
Directional Resolution

- MDC = 36 (10-degree resolution) vs. MDC = 72 (5-degree resolution)

Each parameter can significantly influence both model accuracy and efficiency – balance needed!

Initial settings: 900-sec time step, maximum iterations (MXITNS) = 2, directional resolution (MDC) = 36

12-day simulation using 120 processing cores



Nearshore wave test locations

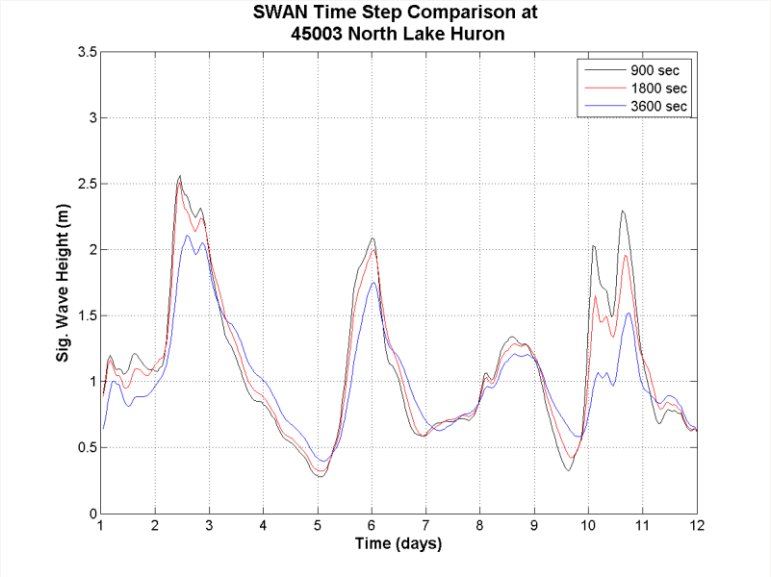
Model Testing & Validation – SWAN Time Step

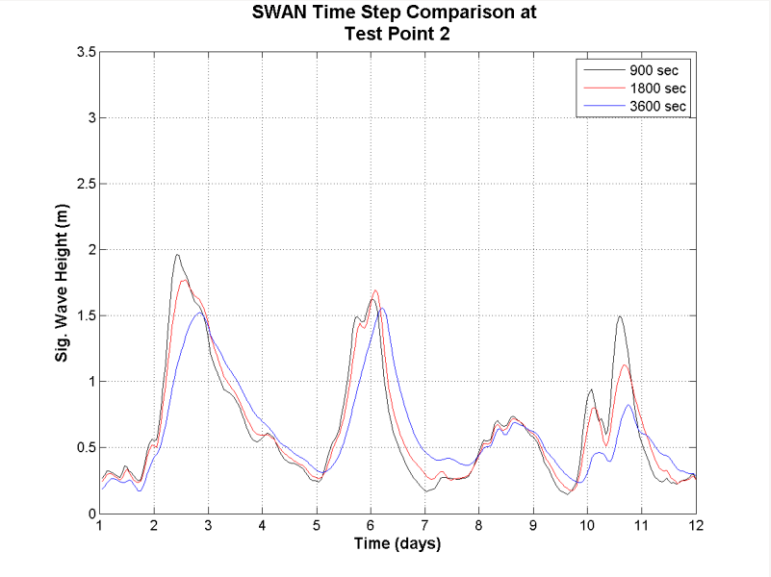
Wind data is fed into model every hour (3600 sec)

Gulf Coast/Atlantic FEMA studies commonly use wind increment of 15 min (900 sec)

- Due to rapidly changing hurricane systems and availability of high-resolution, 15-min Oceanweather wind fields

Can we increase the time step (reducing runtime) and maintain reasonable accuracy?





Notable difference in results

Runtimes decreased by several hours

(Max Iterations = 2)

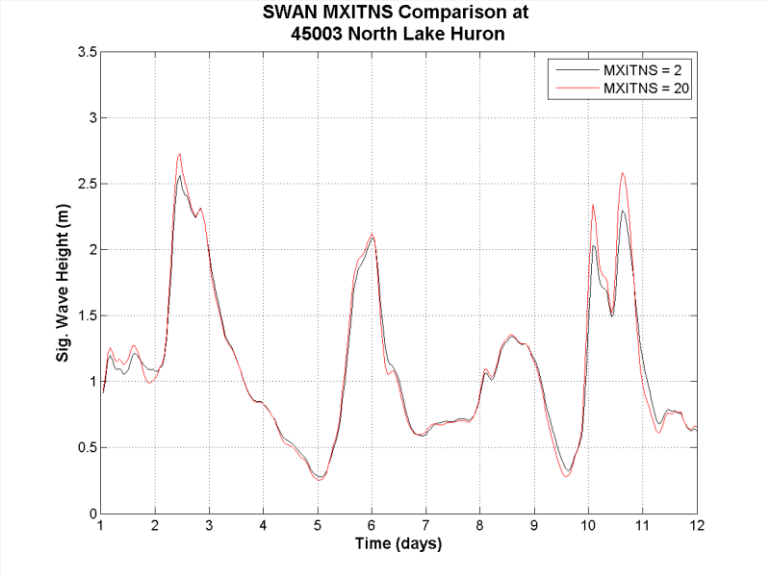
Model Testing & Validation – SWAN Maximum Iterations

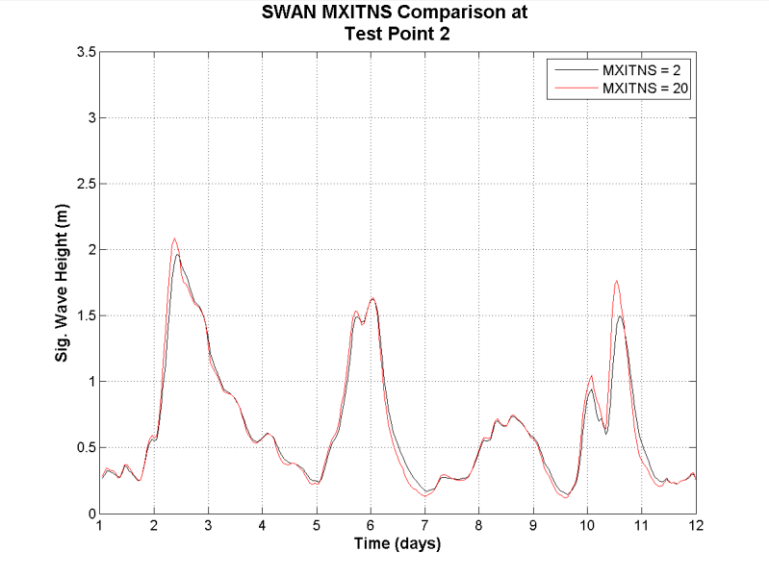
Initial simulations used MXITNS = 2

Try order of magnitude increase (MXITNS = 20) as first attempt

Significantly increases runtime

Increase in runtimes could be offset by increase in time step



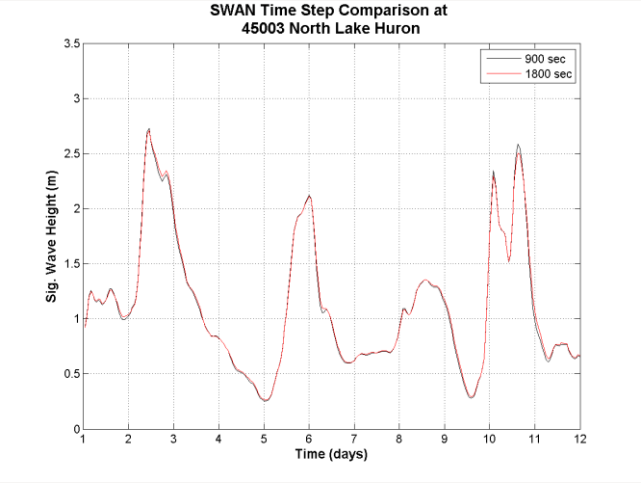


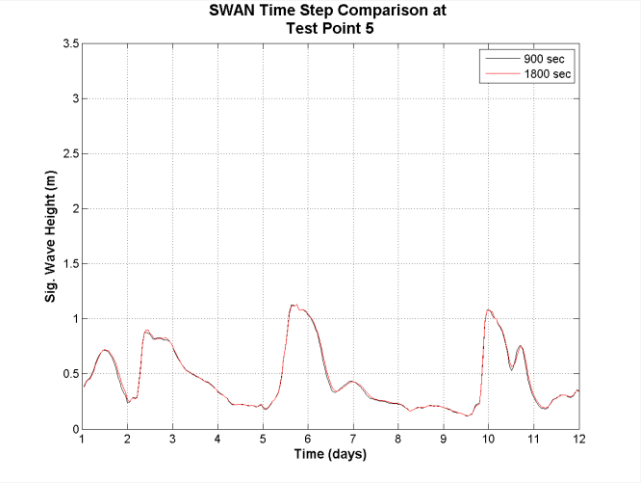
Some differences noted

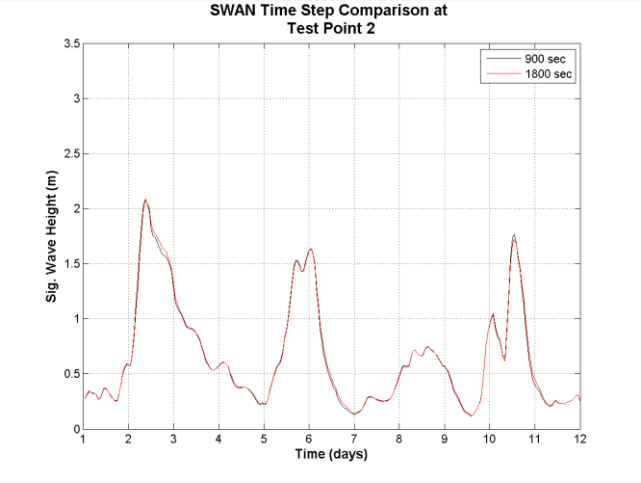
Runtimes increased by several hours

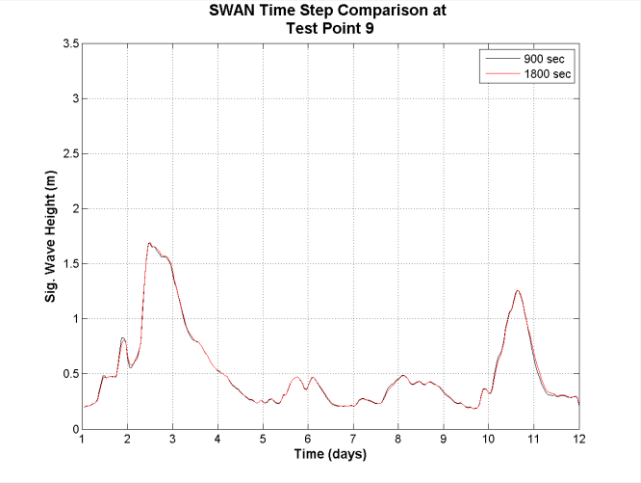
(Time Step = 900 sec)

Model Testing & Validation – SWAN Time Step Revisited







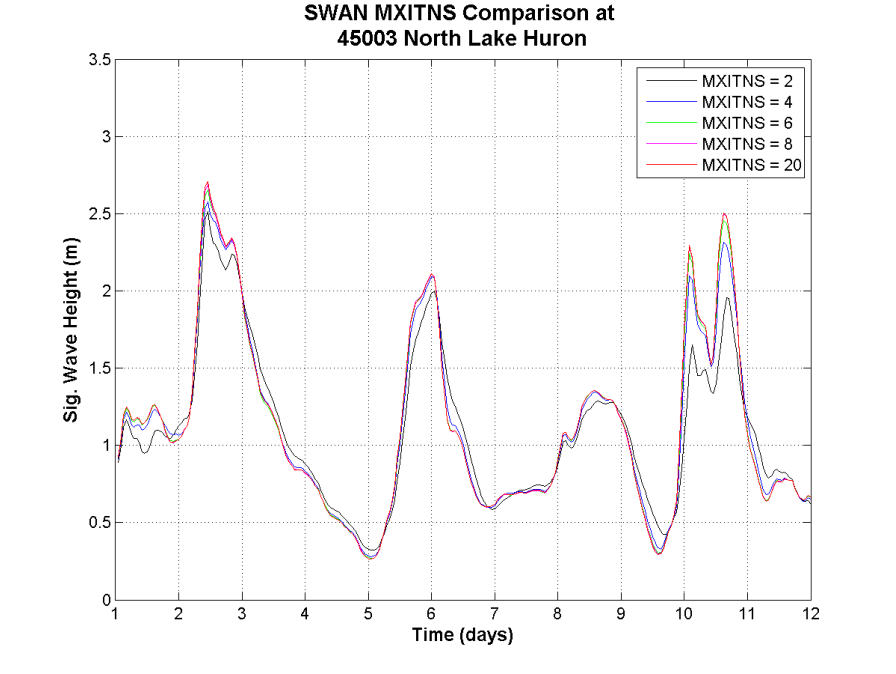


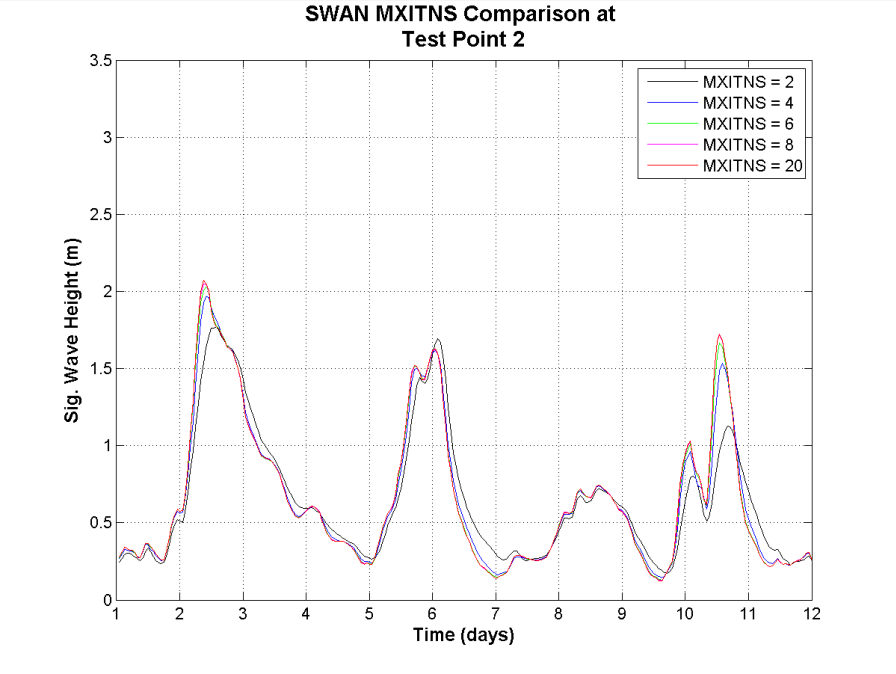
Practically same result

Runtime improved

(MXITNS = 20)

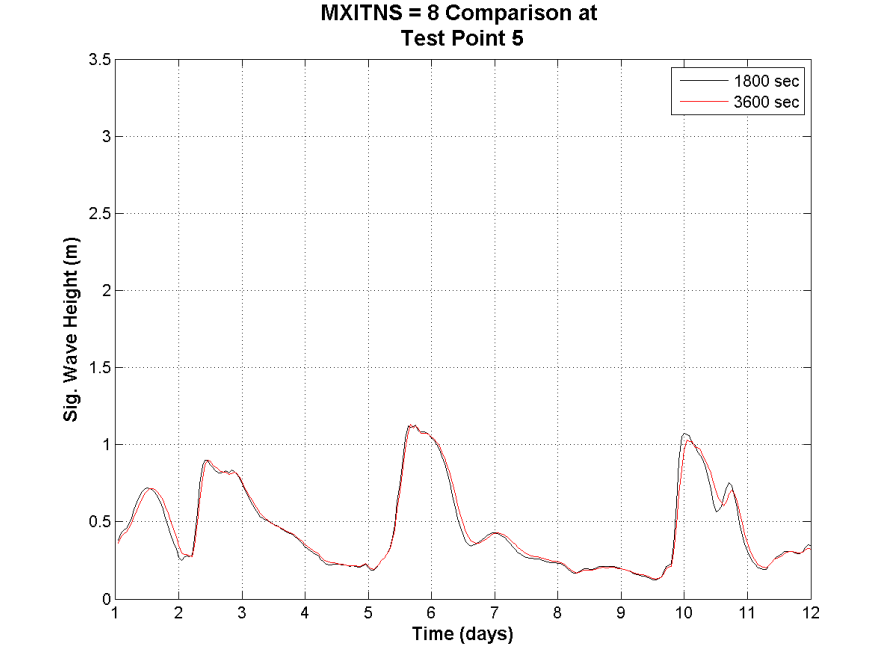
Model Testing & Validation – SWAN Max Iterations Revisited

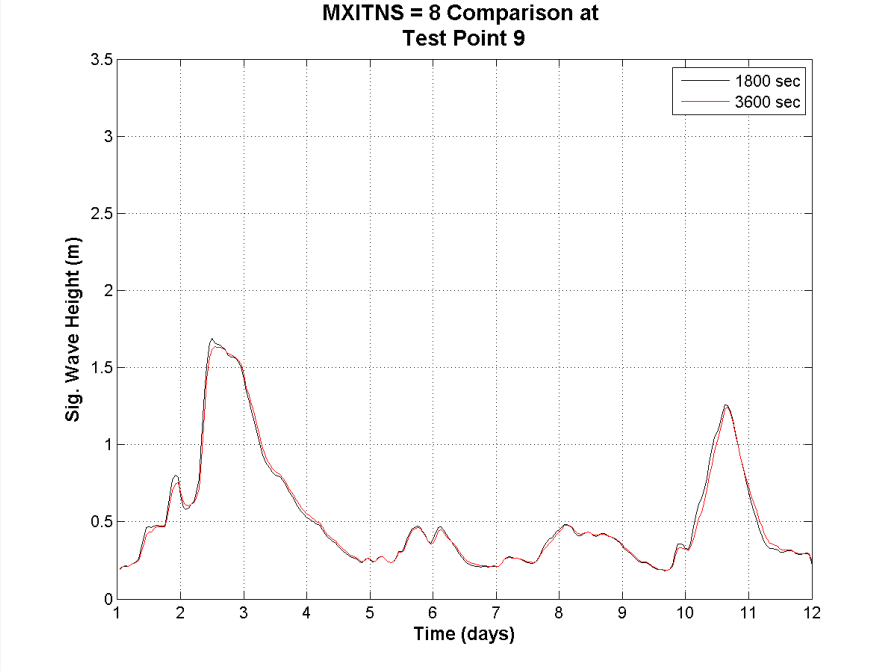




Results seem to converge with MXITNS = 8 (Time Step = 1800 sec)

Model Testing & Validation – SWAN 1800 sec vs. 3600 sec





Reasonably similar results; significantly improved runtimes

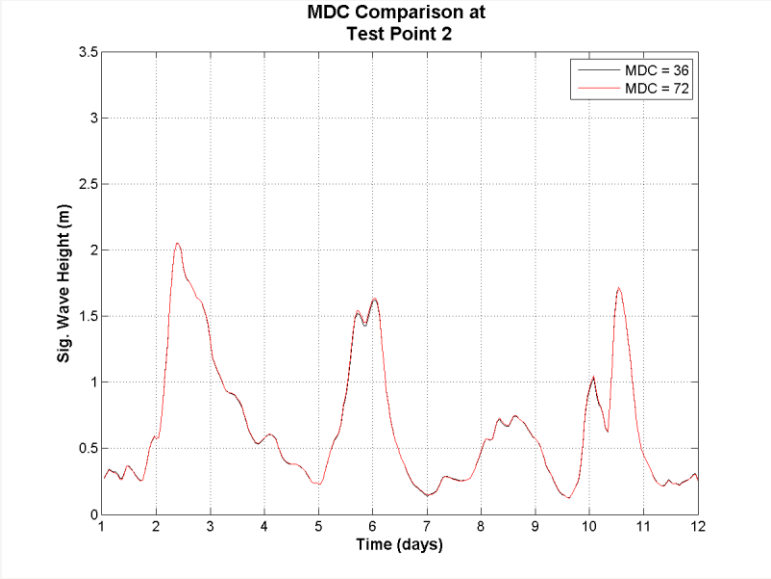
Model Testing & Validation – Directional Resolution

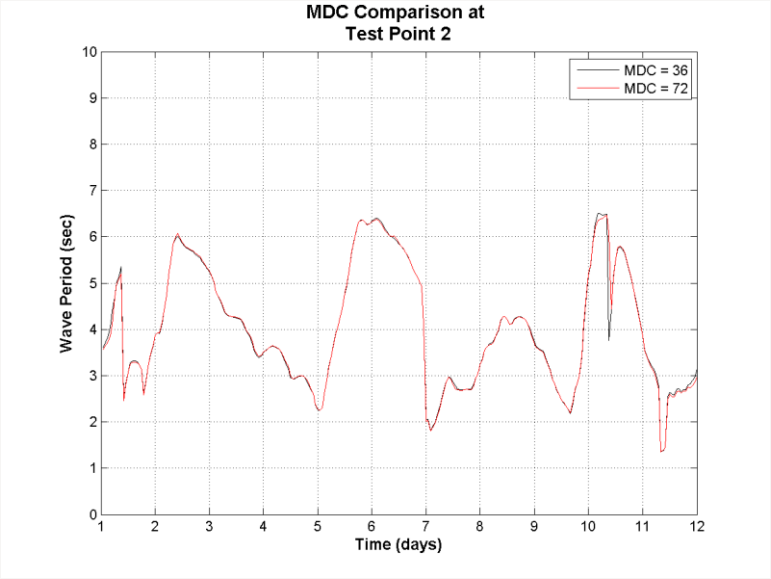
Initial simulations used MDC = 36 (10-degree resolution)

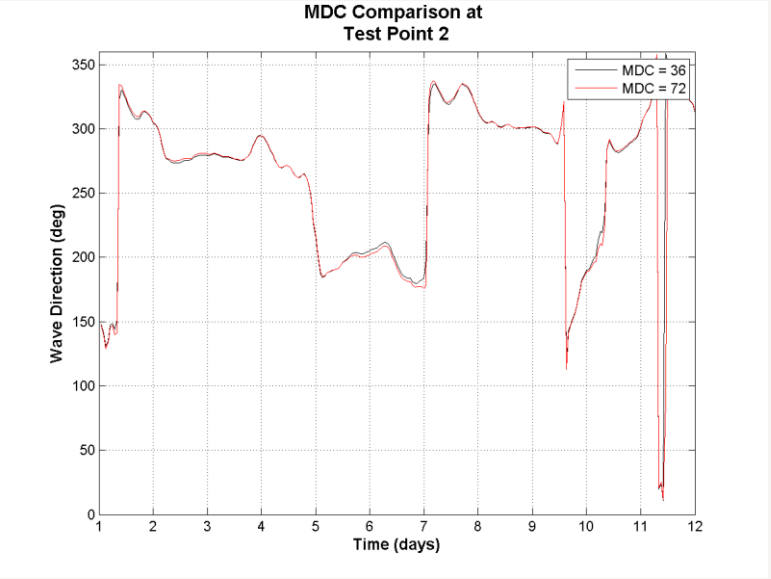
Test MDC = 72 (5-degree resolution)

Increased runtime by several hours

Results are very similar, so MDC = 36 chosen for validation/production to save on runtimes







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Model Testing & Validation – Final Results

Pre-Sensitivity Analysis: 900-sec time step, Max Iterations (MXITNS) = 2, Directional Resolution (MDC) = 36, ADCIRC = Implicit Solver (IM = 0)

- Runtime = 15 hr 53 min

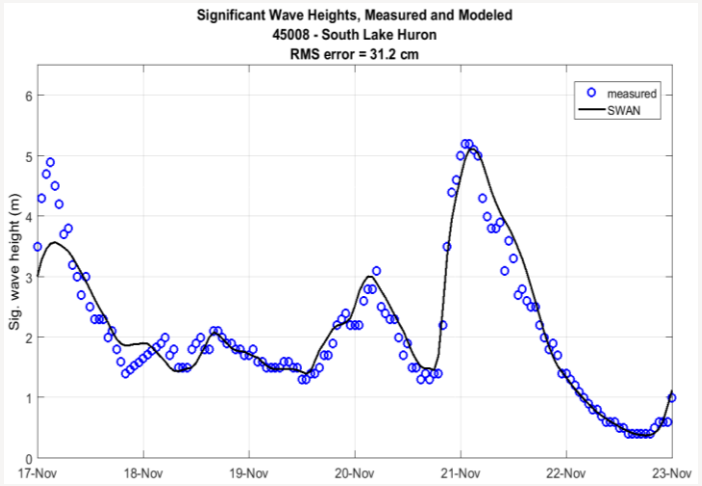
Post-Sensitivity Analysis: 3600-sec time step, Max Iterations (MXITNS) = 8, Directional Resolution (MDC) = 36, ADCIRC = Explicit Solver (IM = 111122)

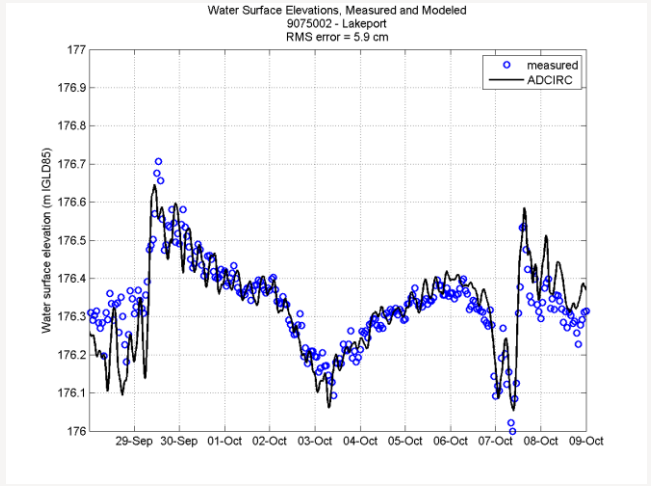
- Runtime = 5 hr 45 min

Maintains accuracy, yet 64% more efficient

Results for 10 Validation Events:

- Water Levels
  - *RMSE = 0.06 m*
  - *Bias = 0.007 m*
- Waves
  - *RMSE = 0.36 m*
  - *Bias = -0.16 m*





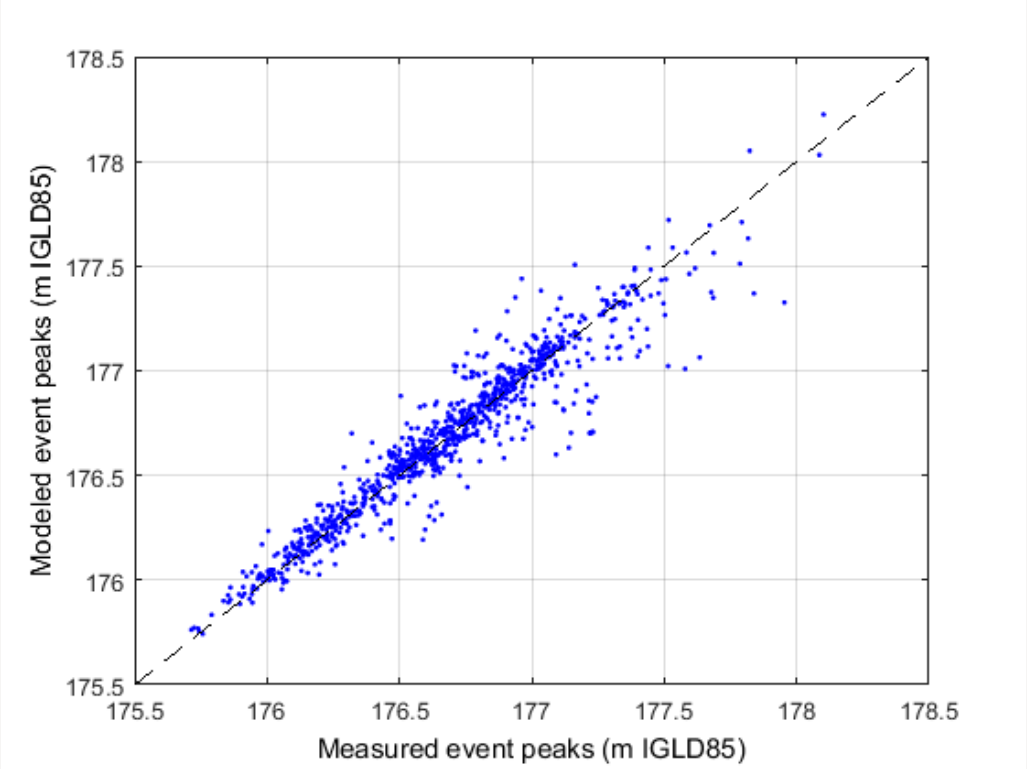
Production Runs (151 Storm Events) – Model Accuracy

Water levels – modeled versus measured

Station		RMS error (m)	Bias (m)
9075014	Harbor Beach	0.054	0.018
9075080	Mackinaw City	0.061	0.011
9075099	De Tour Village	0.051	0.026
9014098	Fort Gratiot	0.106	0.069
9075002	Lakeport	0.072	0.011
9075035	Essexville	0.103	-0.003
9075059	Harrisville	0.054	0.027
Average		**0.071**	**0.023**

Wave heights – modeled versus measured

Station		RMS error (m)	Bias (m)
45003	North Lake Huron	0.317	-0.024
45008	South Lake Huron	0.310	0.051
Average		**0.313**	**0.014**



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Presentation Summary

Conclusion

- An efficient, high-resolution storm surge and wave model was developed for Lake Huron to produce accurate nearshore water levels and wave conditions in support of a revised FEMA Flood Insurance Study.

Summary

- Goal: Increase efficiency, maintain accuracy
- ADCIRC parameter testing
  - *Implicit vs. explicit solver*
- SWAN parameter testing
  - *Time step: 900-, 1800-, and 3600-sec*
  - *Max Iterations: 2 – 20*
  - *Directional Resolution: 10-deg vs. 5-deg*
- Low RMSE and Bias

Questions?