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The State of the Art and Science of Coastal Engineering

Validation of Unstructured WaveWatch III for Nearshore Waves

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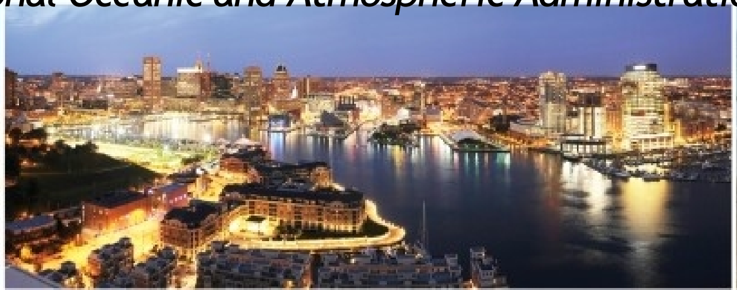


Motivation

Flexibility and high resolution for nearshore wave-driven processes:

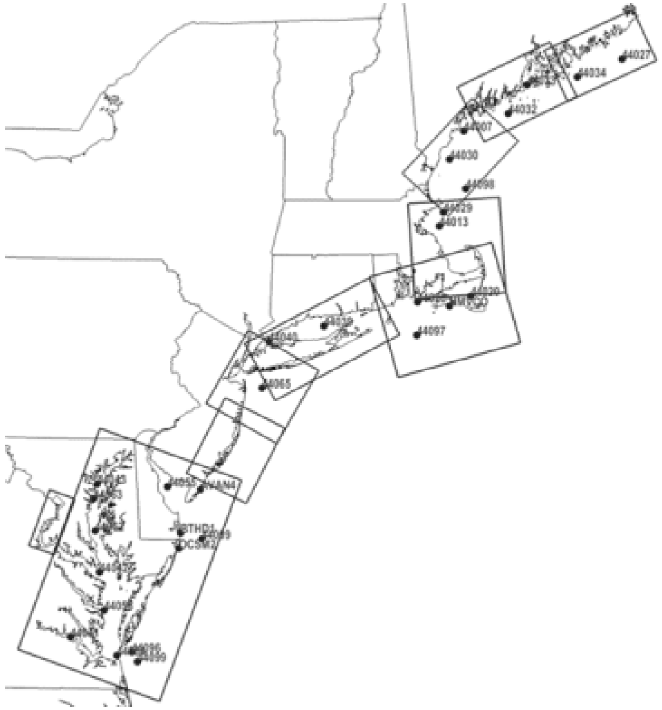
- Nearshore circulation
- Wave set up
- Sediment transport

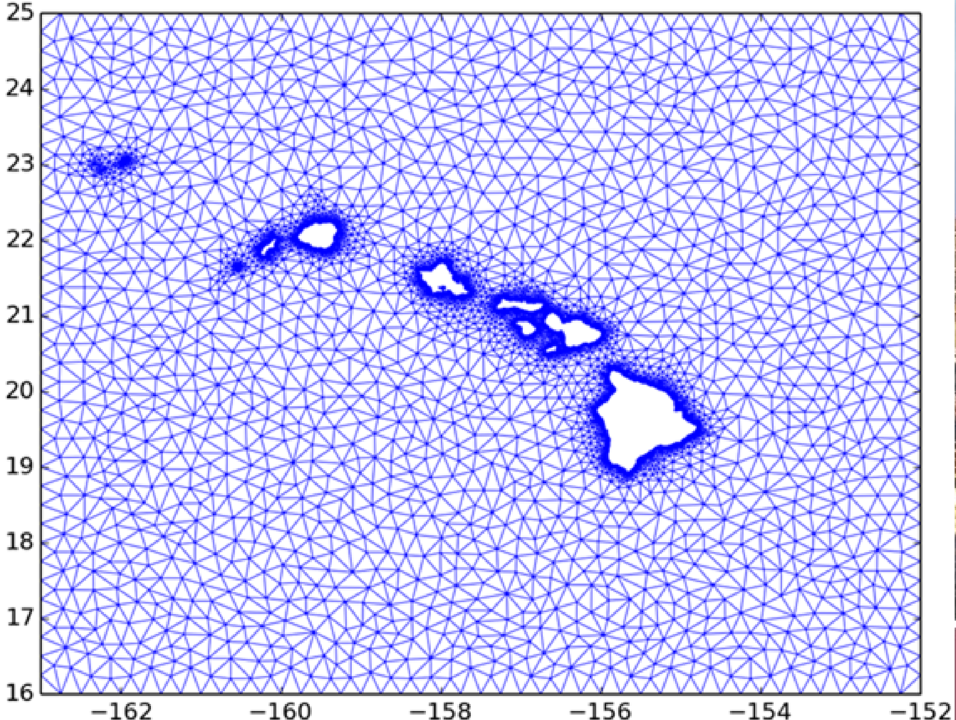
Accuracy and Efficiency

Unstructured WW3

Drivers:

- Multi-scale coverage ~ 3 orders of magnitude
- Implicit solution scheme and domain decomposition for efficient computations
  - explicit integration scheme limits Δt
  - 1m resolution ~ $\Delta t \approx 0.3\ s$
- Collaboration between ERDC and NCEP

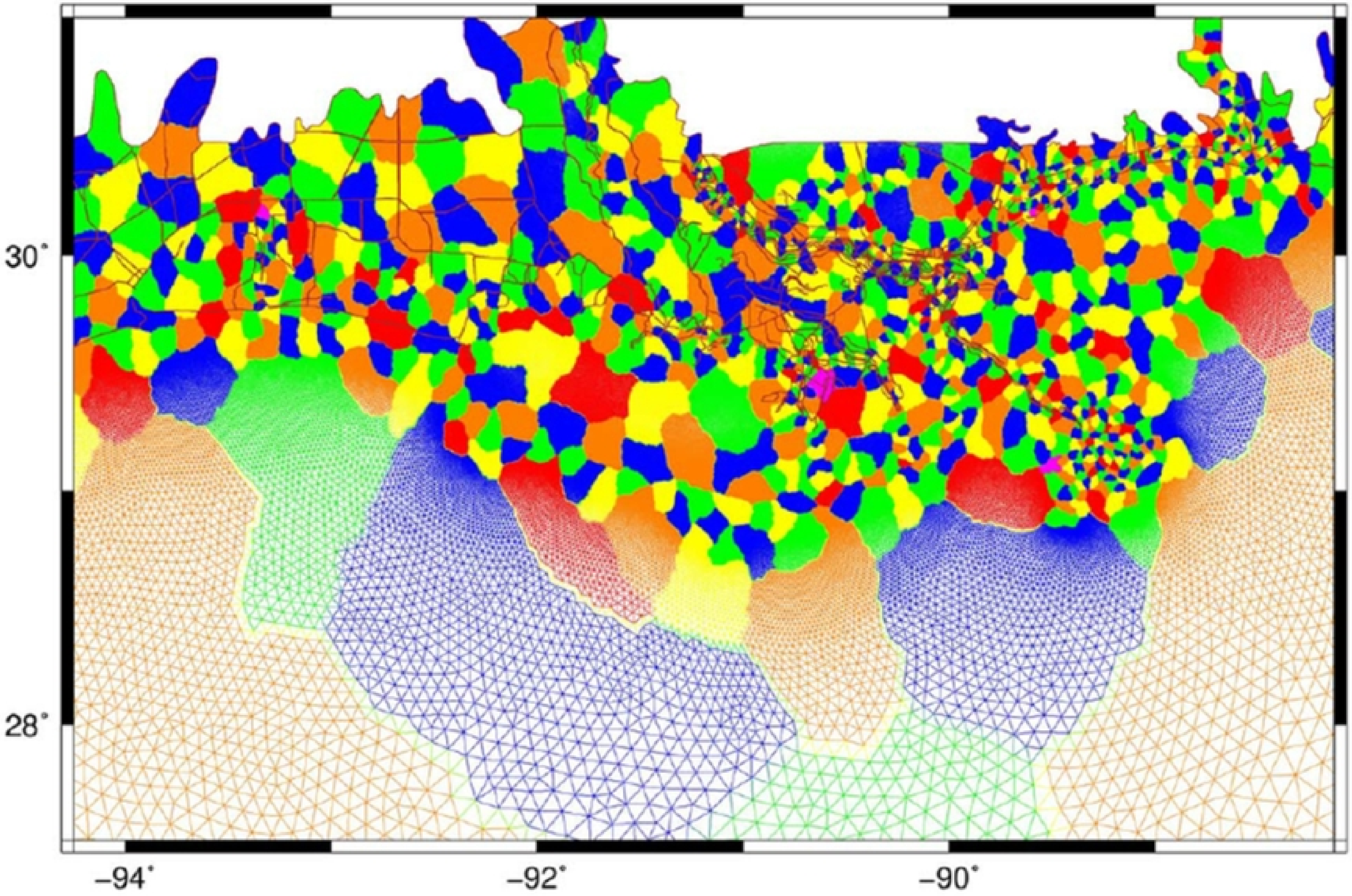




Parallel Computing in WW3

- WW3 was inherently designed to run parallel based on global arrays, but parallel propagation is limited by number of spectral bins
- Constraint relaxed by introducing a Multigrid option (Multigrid decomposition)
- Hybrid approach to parallelization involves spectral partitioning for advection in geographical space and domain decomposition for spectral advection and the source terms integration
- Replacement of global arrays with local arrays, optimize the model with respect to memory management, and implement parallel output within the domain decomposition framework

Domain Decomposition in ADCIRC/WW3 based on METIS/ParMETIS



New Developments in Numerical Integration of the Wave Action Equation

- Fully implicit integration of the advection part of the WAE
- New convergent action limiter ~ mix of Komen et al. + Hersbach and Janssen
- New integration of the action limiter, so only limits the source terms
- No numerical limiters on the wave breaking source term -- limit the wave height with the Miche criterion (Battjes & Janssen does not work on steep slopes)
- New Block-Jacobi and Block-Gauss-Seidel solvers with improved convergence criteria and efficient parallel implementation

Extension of WW3 Tools for Unstructured Grids

Software

- Implicit/explicit domain decomposition
- PDLIB ~ parallel decomposition

Calibration/Validation Suite

- Laboratory
- Analytical cases
- US East Coast and Gulf of Mexico
- US Great Lakes
- USACE Field Research Facility, Duck, NC
- Mediterranean

USACE Field Research Facility (FRF)

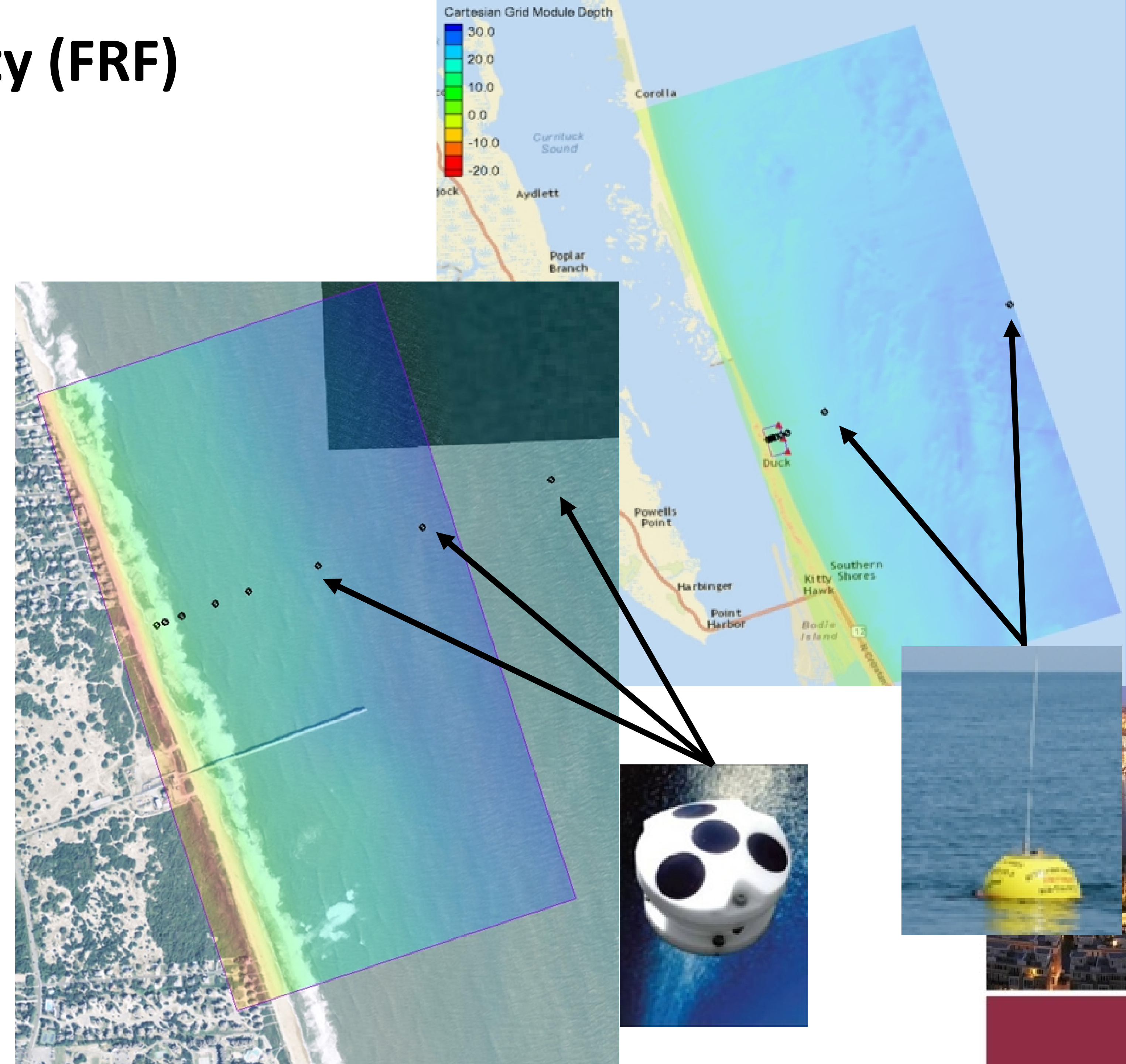
Outer Banks of North Carolina

Cross-shore array of directional wave measurements:

- Buoys: 26 and 17 m depth
- AWACs: 11, 8 and 5
- AquaDopps: 4 and 3 m depth

Winds/water levels ~ pier end

Regular bathymetry surveys



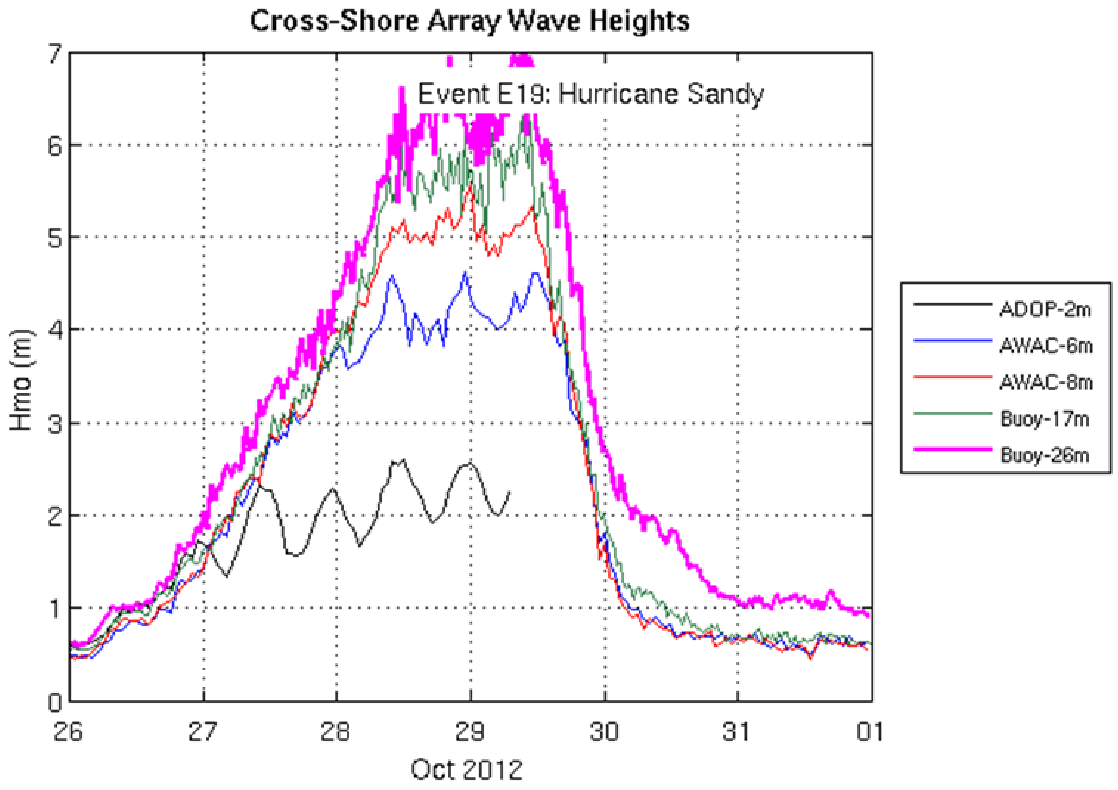
Storm Selection

Identified four storms:

- Hurricane Irene (Aug 2011)
- Nov 2011
- Hurricane Sandy (Oct 2012)

Criterion

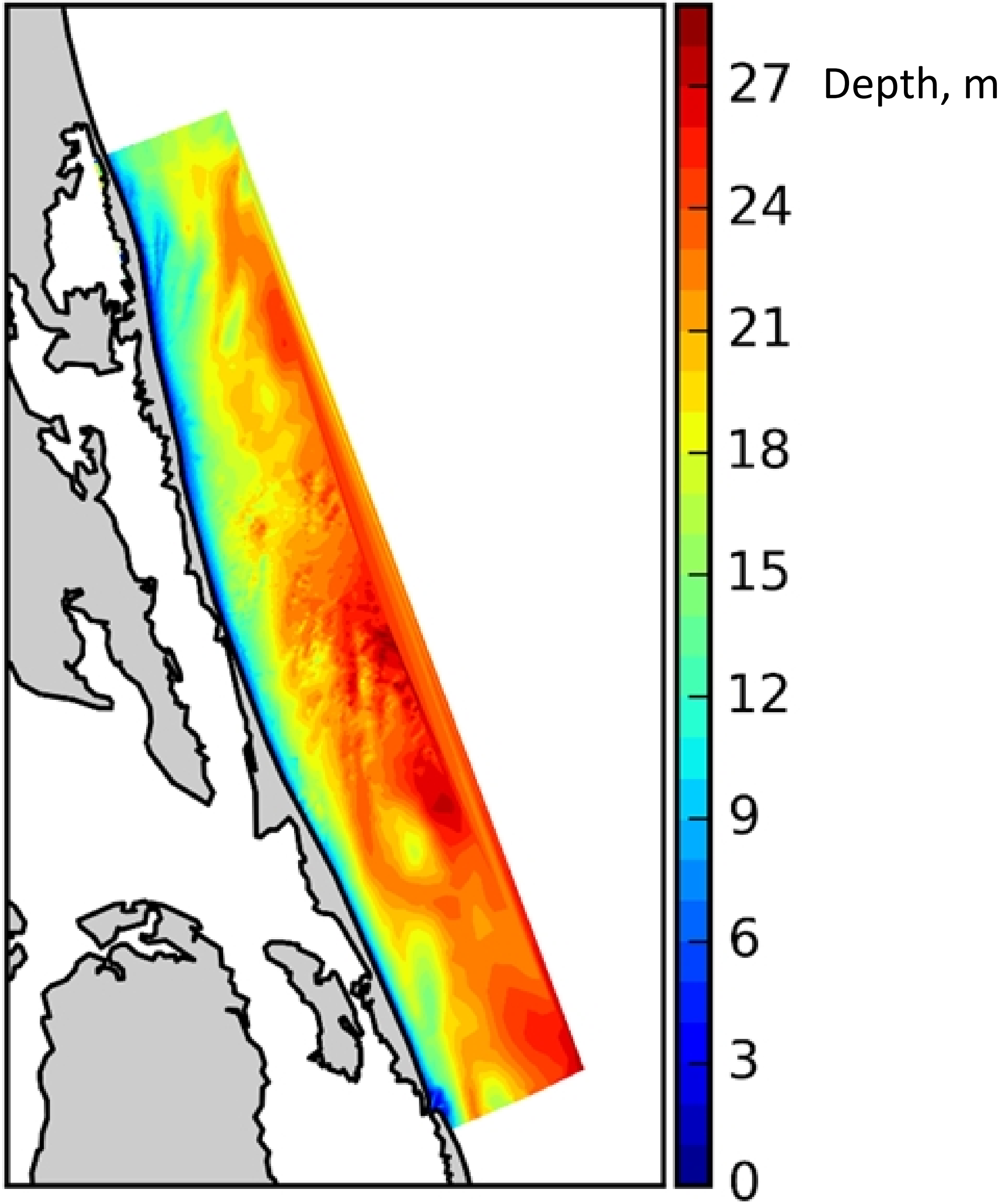
- Two largest events (Irene & Sandy ~ 7+ m waves)
- Combined sea/swell event, 2.75 m waves (Nov 2011)
- Cross-shore array & offshore buoy operational
- Future: Slanting fetch, 5 m waves (Feb 2013), BathyDuck (2015, extratropical + H. Joaquin), full year simulation



FRF Unstructured Grid

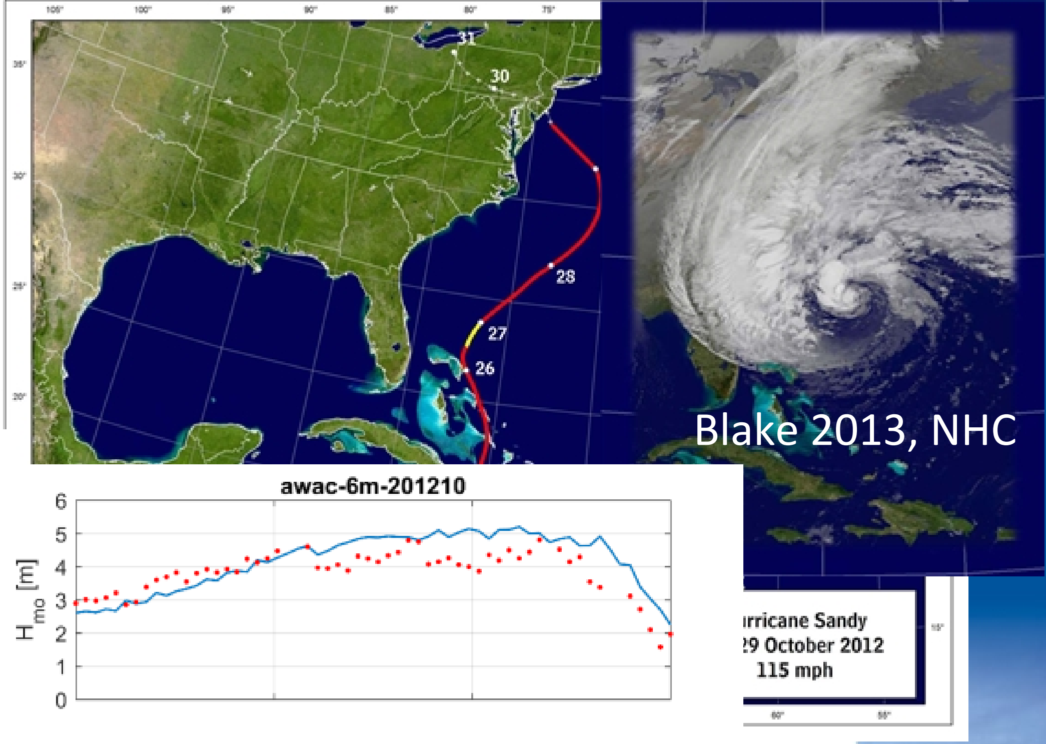
- 108,403 nodes, resolution 500–10 m
- 20 km x 100 km, 26-m depth to shore

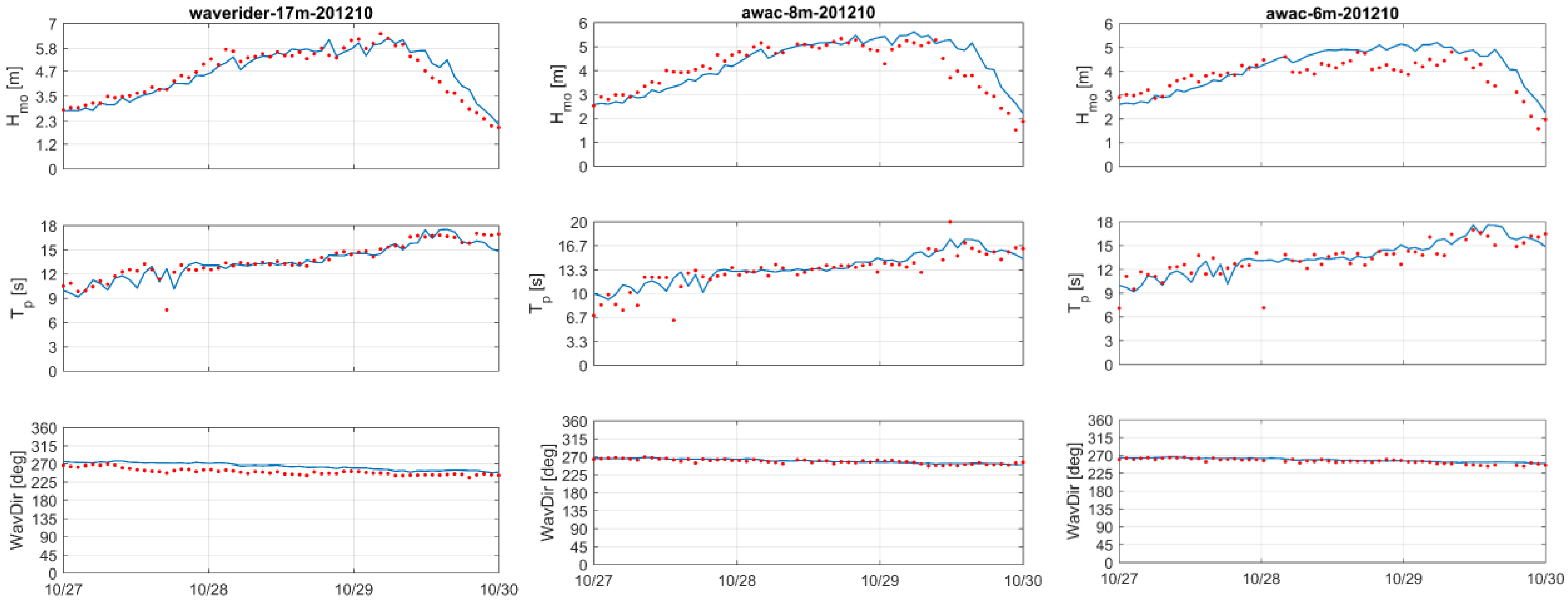
- ST4 Source Terms



Hurricane Sandy 2012

- 4th costliest hurricane in the U.S. ($70 bill)
- Maximum wave heights of 7 m at the FRF
- Storm bypassed the FRF





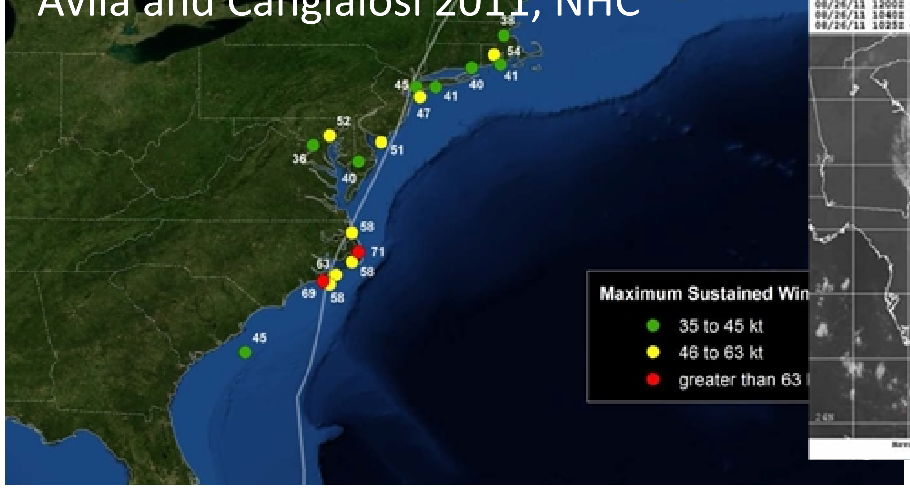
17 m depth

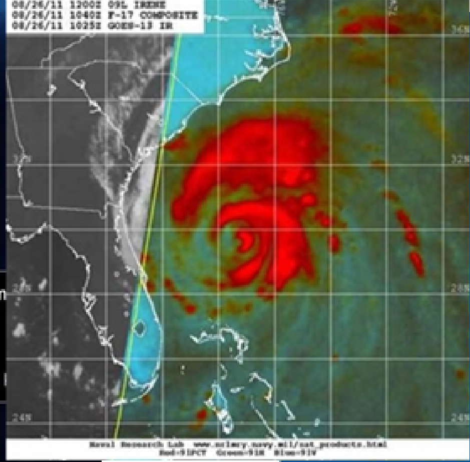
8 m depth

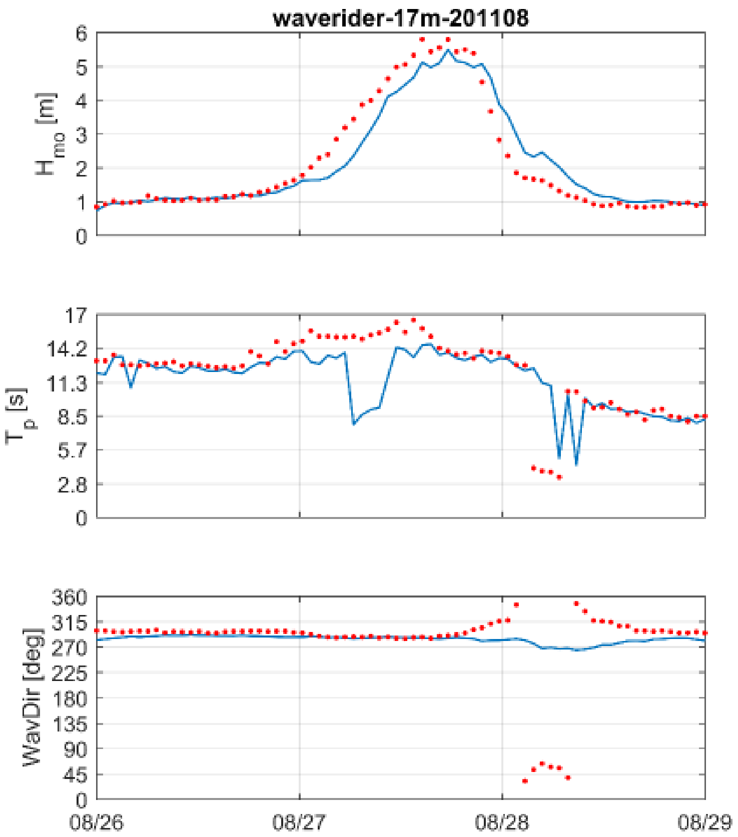
6 m depth

Hurricane Irene 2011

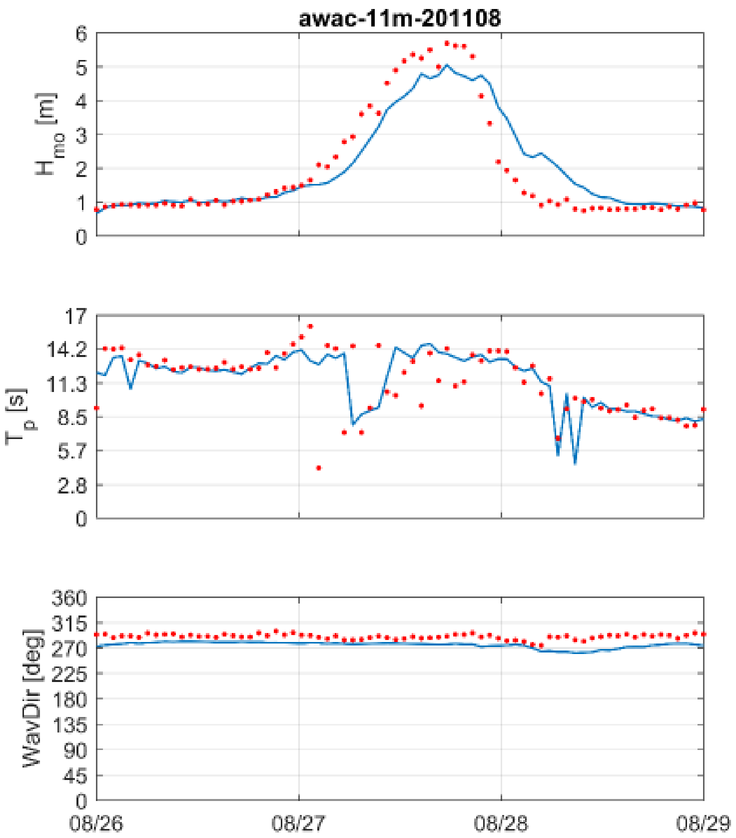
- 13^{th} costliest hurricane in the U.S. ($14 bill)
- Maximum wave heights of 8 m at the FRF
- Landfall in North Carolina as Cat 1
- Storm passed inland of the FRF



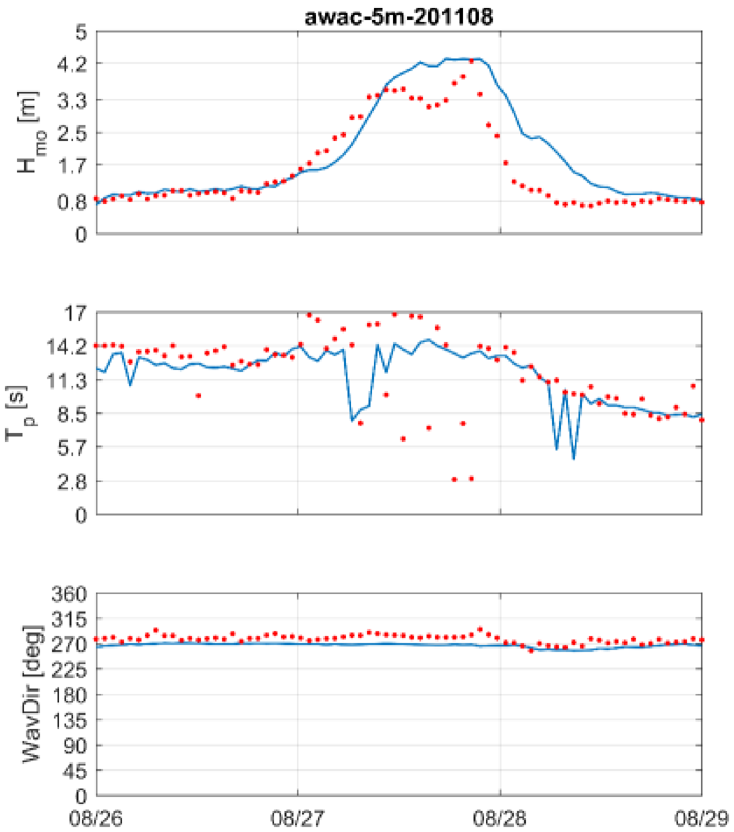




17 m depth

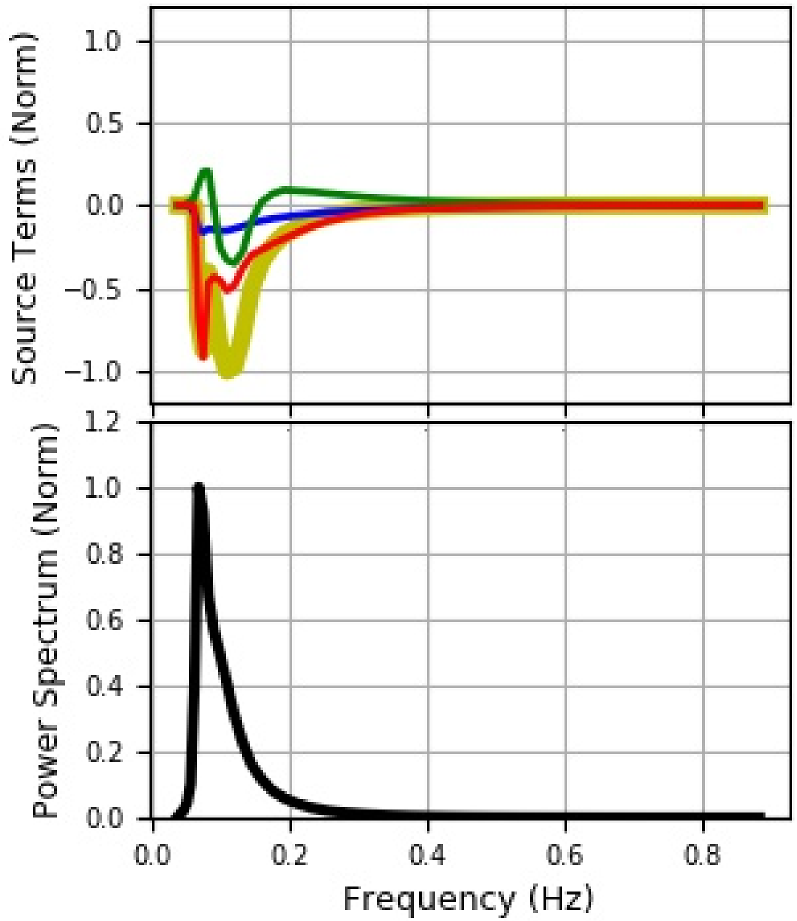


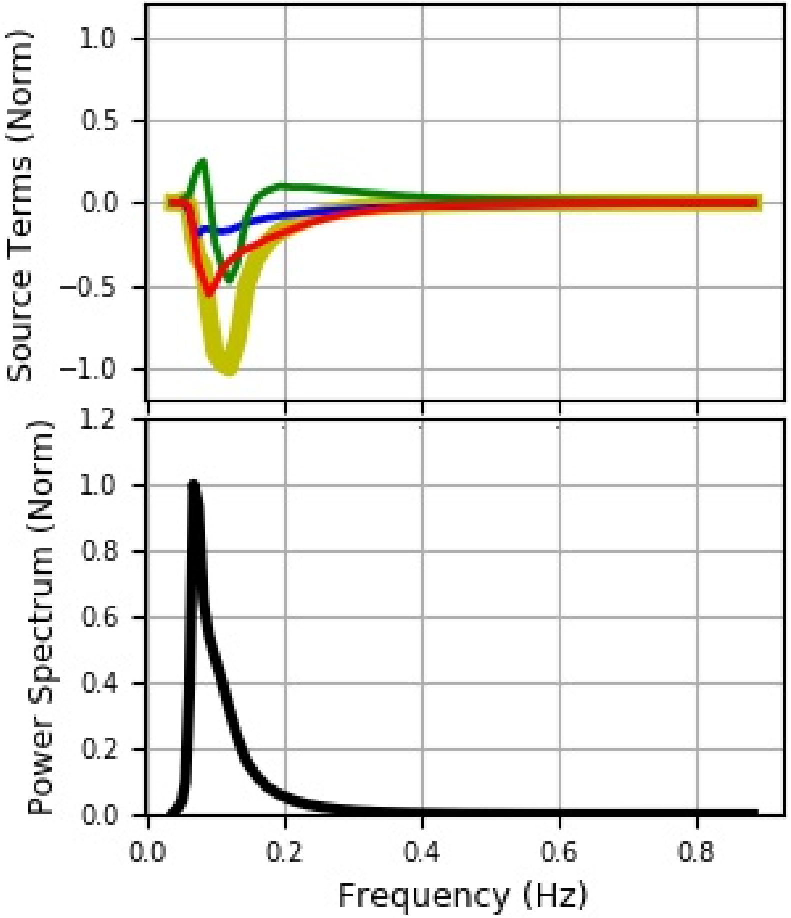
11 m depth



5 m depth

Hurricane Irene 2011 – Normalized Source Term Balance



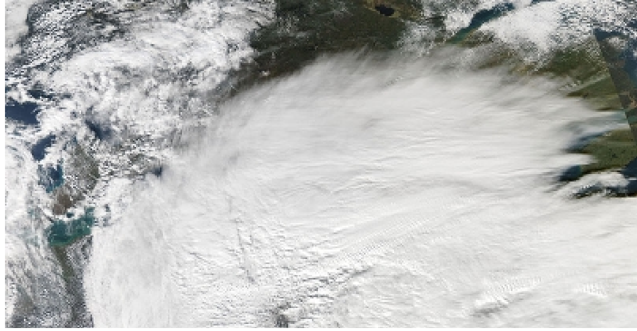


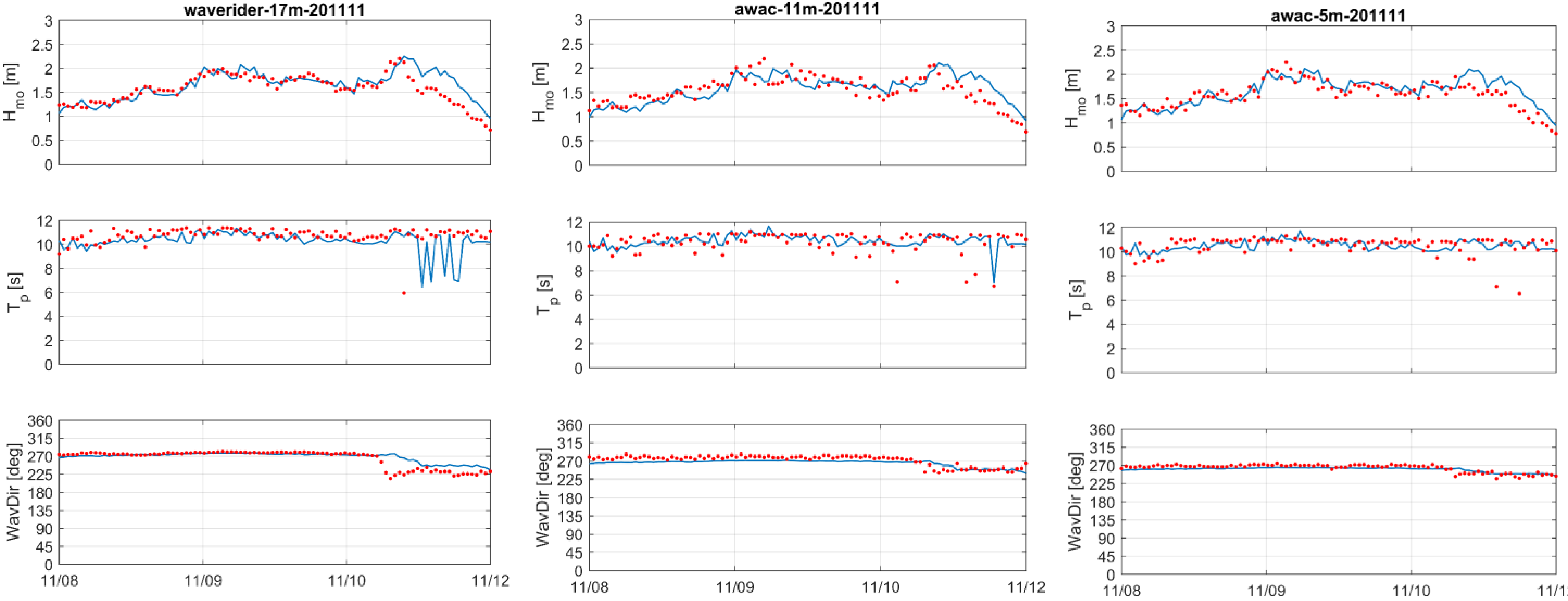
Smoothed Saturation Spectrum

Blue – S_{in}
Green -- S_{nl}
Red – S_{ds}
Yellow – Total

Extratropical Nov 8-12 2011

- Maximum wave heights of 2.8 m at the FRF
- Mixed sea/swell event





17 m depth

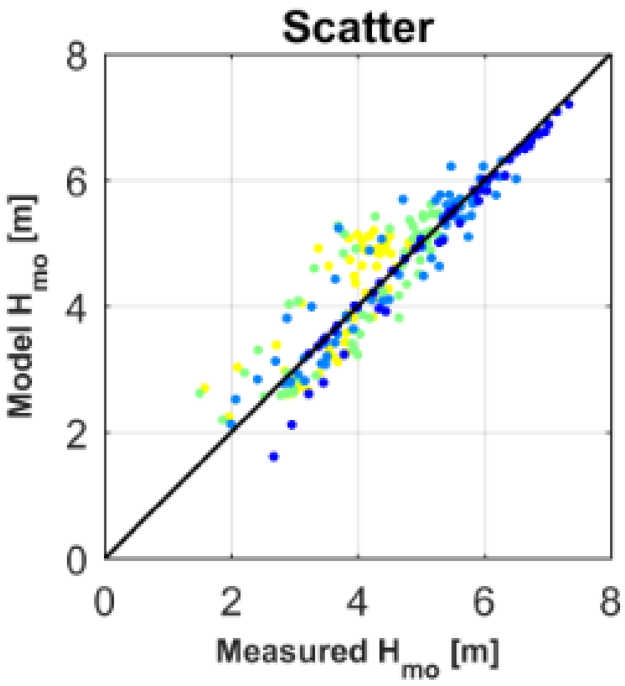
11 m depth

5 m depth

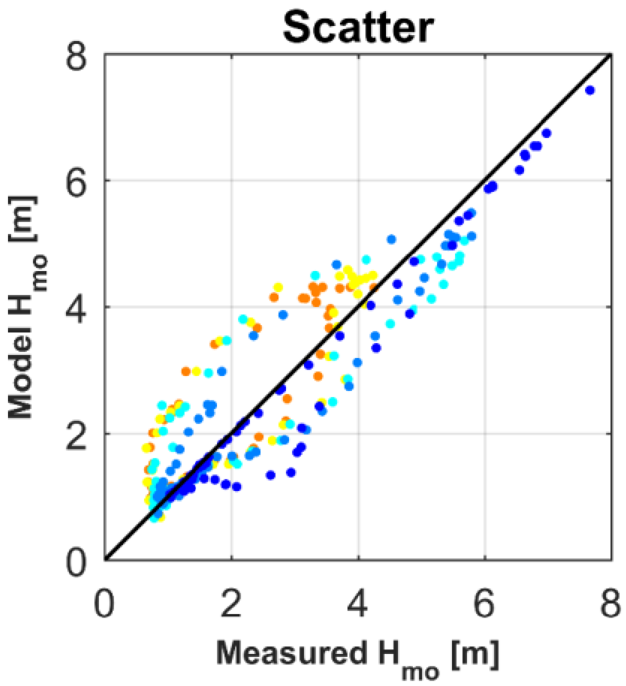
Errors

Storm	H_{mo} (m)/ T_p (s)		
	Mean	Bias	RMSE
Hurricane Sandy	4.46/13.4	0.08/0.1	0.49/1.1
Hurricane Irene	2.06/11.7	0.06/0.2	0.57/2.4
Nov 2011 extratropical	1.61/10.4	0.04/0.1	0.18/0.9

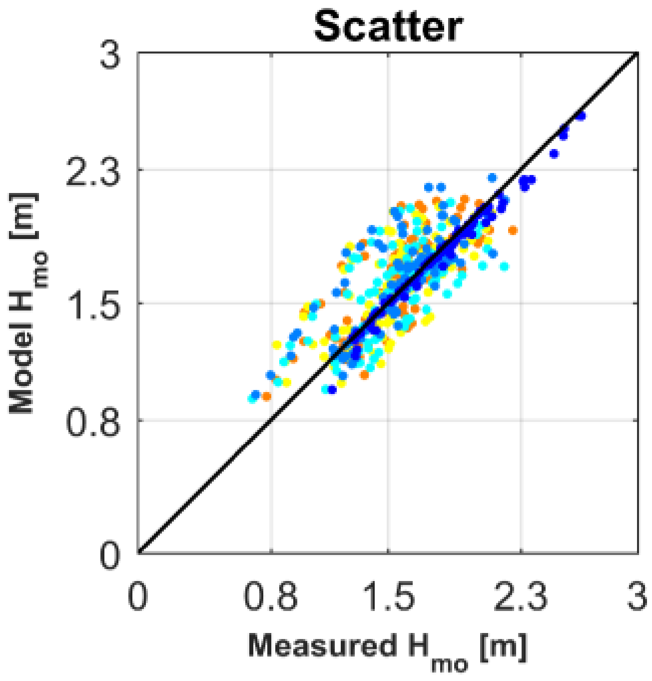
Sandy



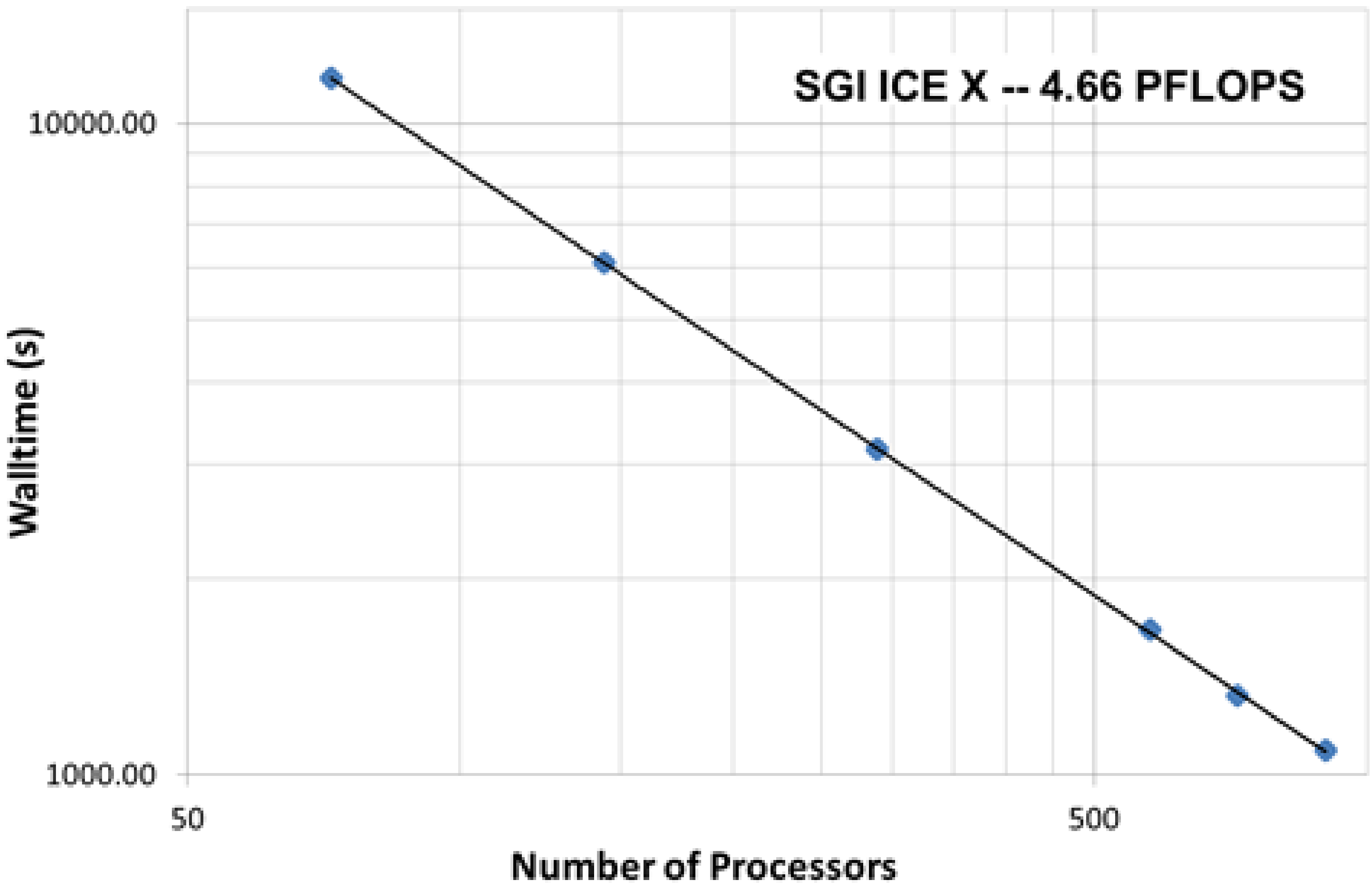
Irene



Nov 2011



Parallel Efficiency



Summary

WAVEWATCH III is a viable option for nearshore application:

- Implicit solver + domain decomposition
- Expand lateral boundary conditions
- Couple with CSTORM (circulation)
- NOAA is coupling w/ ADCIRC for large-scale/high-res hurricane simulations (2-10 million grid nodes)
- Investigate bottom friction and wave breaking
- Run a year-long validation