A High-Resolution Atmospheric, Wave and Circulation Forecast System for the Great Lakes Region

André van der Westhuysen[1], Eric Anderson[2], Greg Mann[3], Jian Kuang[1], John Kelley[4], Ed Myers[5], Ayumi Manome[2], Dave Schwab[6]

[1]IMSG at OAA/NWS/NCEP, College Park, MD
[2]NOAA/OAR/GLERL, Ann Arbor, MI
[3]WFO Detroit, MI
[4]NOAA/NOS/CO-OPS, Silver Spring, MD
[5]NOAA/NOS/OCS/CSDL, Silver Spring, MD
[6]Univeristy of Michigan, Ann Arbor, MI

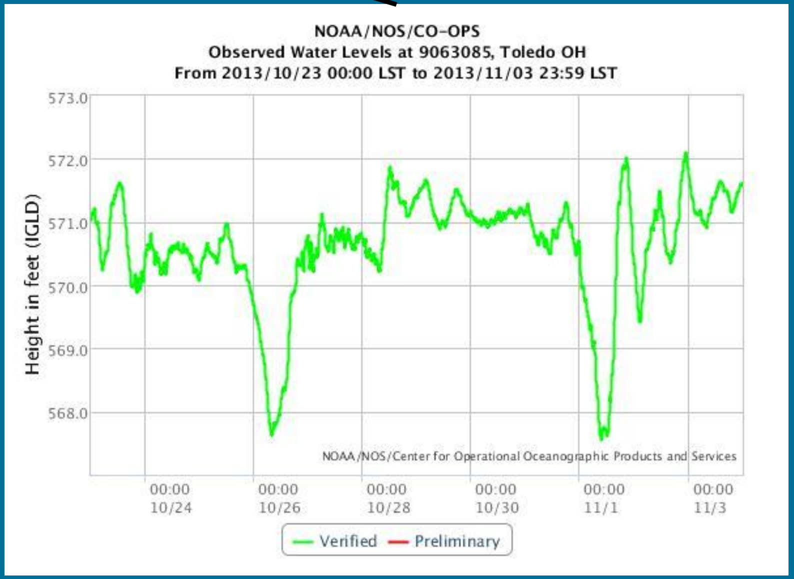
23rd U.S./Canada Great Lakes Operational Meteorology Workshop, Grand Rapids, MI, August 25-27, 2015

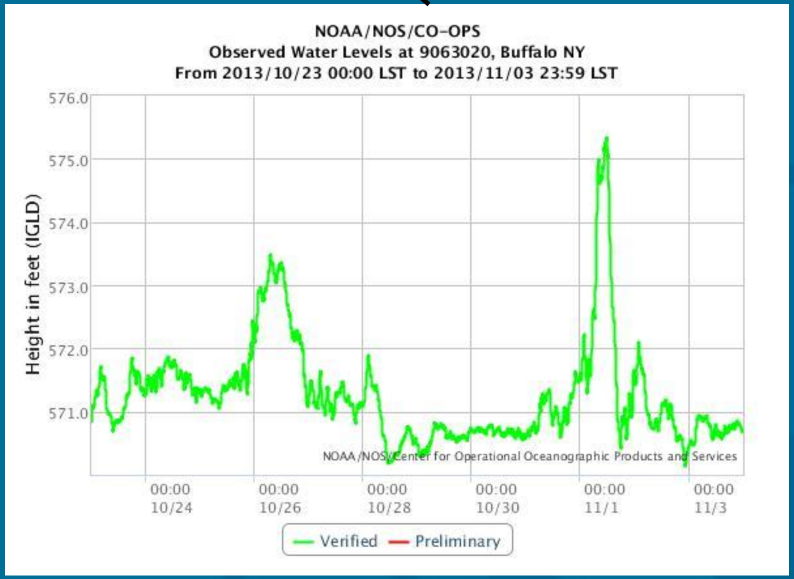
Content

1. Motivation and study aim
2. Model selection and computational meshes
3. Model Configurations
   a) Atmospheric
   b) Hydrodynamic
   c) Waves
4. Hindcast validation for uncoupled models
5. Conclusions

Motivation

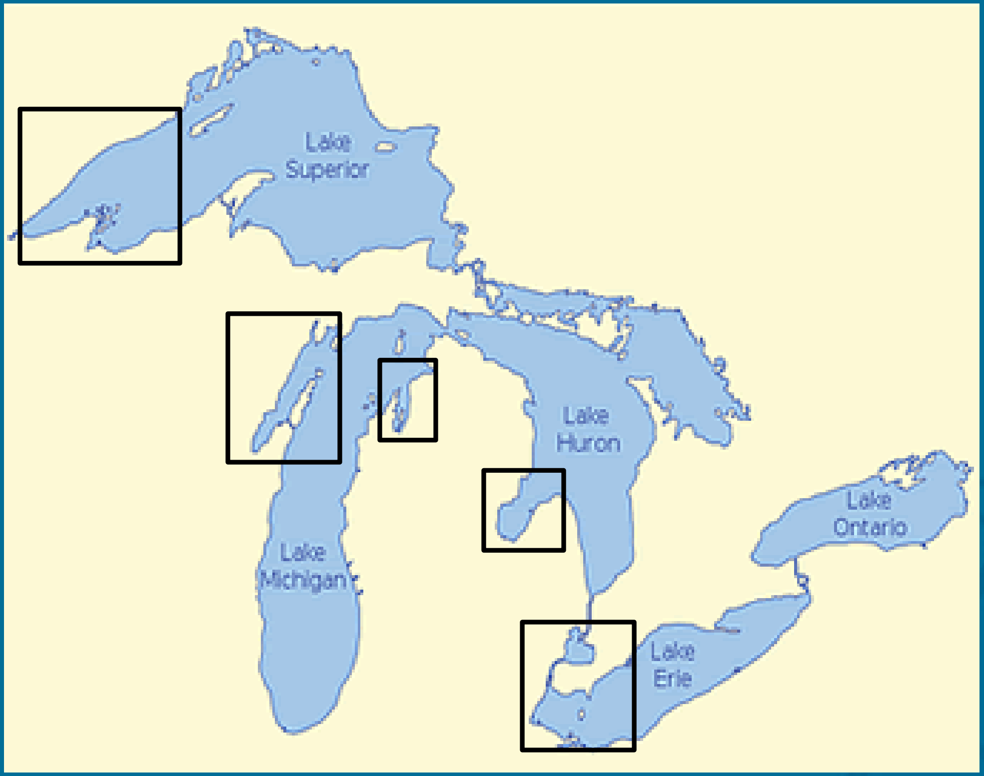
Lake Erie hindcast: Oct 23-Nov 3 2013





Study aim

Develop an **operational coupled wave and 3D circulation model**, run on a common unstructured grid, and forced by a **high-resolution atmospheric model** and **ice model.** Focus on coastal hazards in shallow regions.

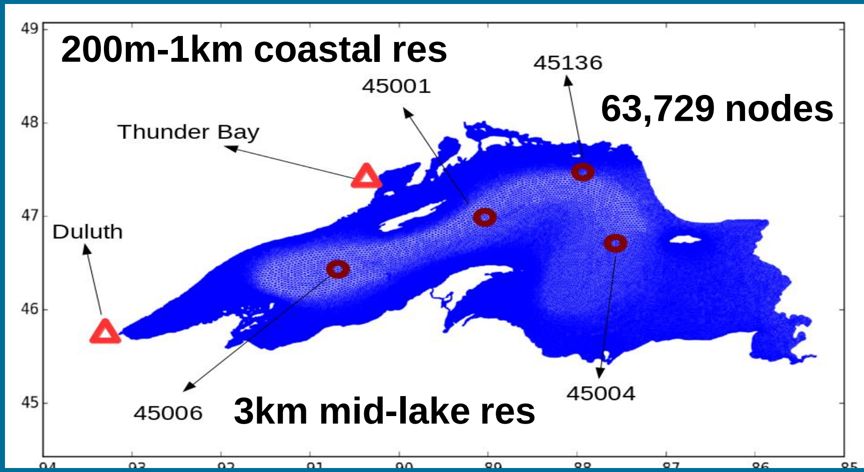


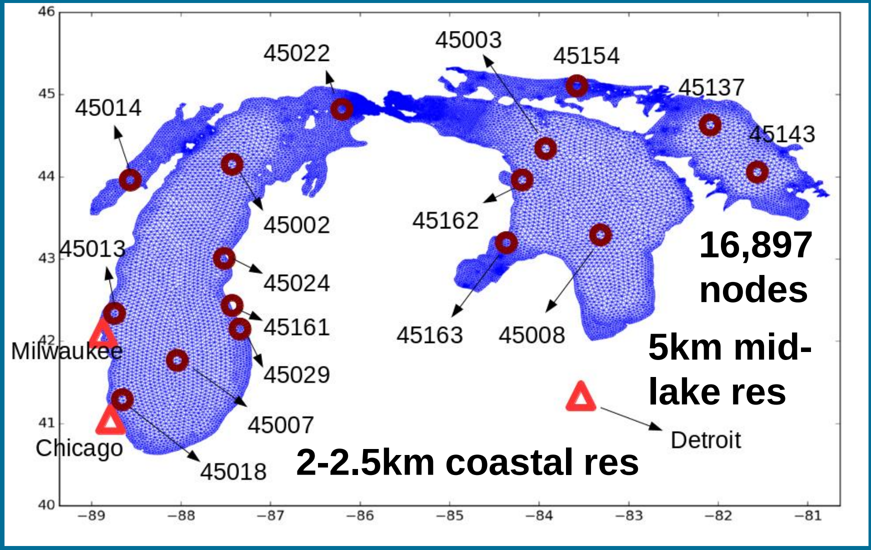
Model selection

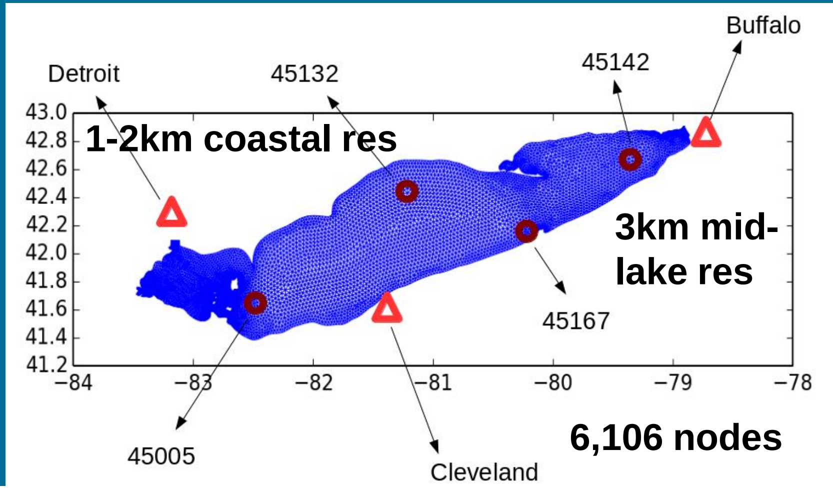
1. FVCOM hydrodynamic model (unstructured, 3D)
2. WAVEWATCH III wave model (unstructured)

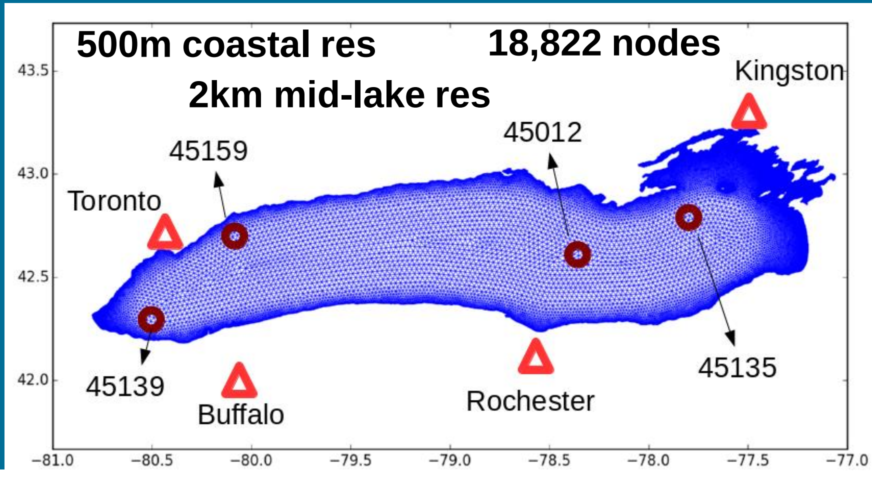
- Coupled via NOAA's NEMS coupler (ESMF-based).
- Forced by high-resolution operational atmospheric input from NCEP. During development phase, a high-res downscaled **WRF model** is employed.
- Ice coverage input from **National Ice Center**.

Computational meshes









2nd Generation Lake Erie and Michigan/Huron meshes are under development

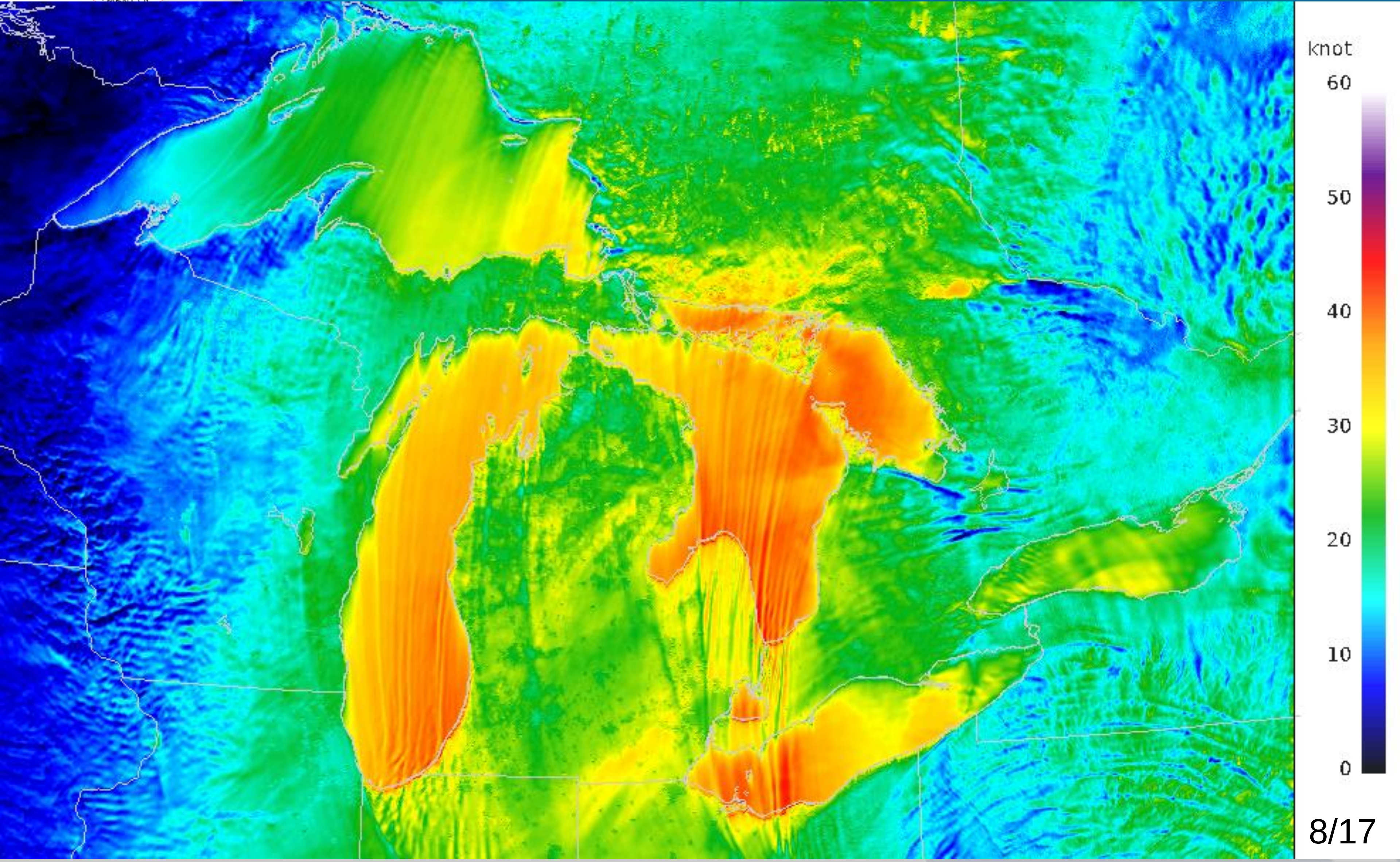
Atmospheric Model Configuration

- *Weather Research Forecast (WRF) model*
  - Varying resolution to test spectra of forecast inputs
    - *12 km - comparable to current NAM*
    - *4 km - comparable to NAM nest and HRRR (High-Resolution Rapid Refresh)*
    - *1 km - next generation mesoscale models*
- *Initial and Boundary conditions primarily from North American Regional Reanalysis (NARR)*
  - Analysis nudging applied to the upper ⅔ of model atmosphere to control synoptic-scale evolution

Atmospheric Model Configuration

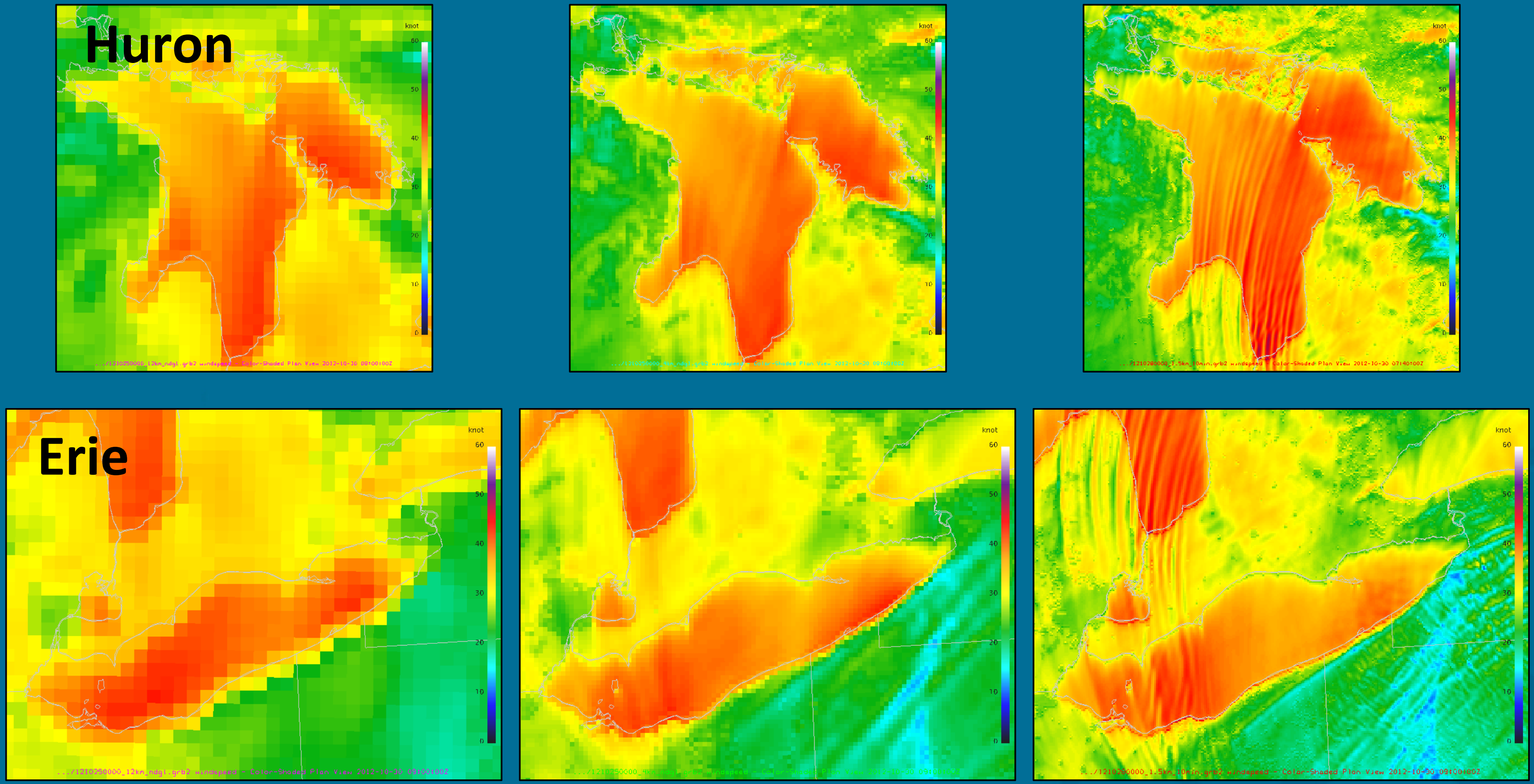
- *Research-grade simulations*
  - 12 km & 4 km domains stand alone. 1 km domain nested
- *High-amplitude episodes simulated / including run-up time to allow spin-up time for hydrodynamic models*
- *Physics options optimized for each episode*
  - Output validation conducted at marine observation sites.
  - Greatest gains from 12 km down to 4 km. Nearshore processes are improved further in 1 km solutions
  - Resolving the wind field structure and character more completely presents a new challenge to companion hydrodynamic applications

Atmospheric Model
Post Tropical Storm Sandy (Oct 2012)

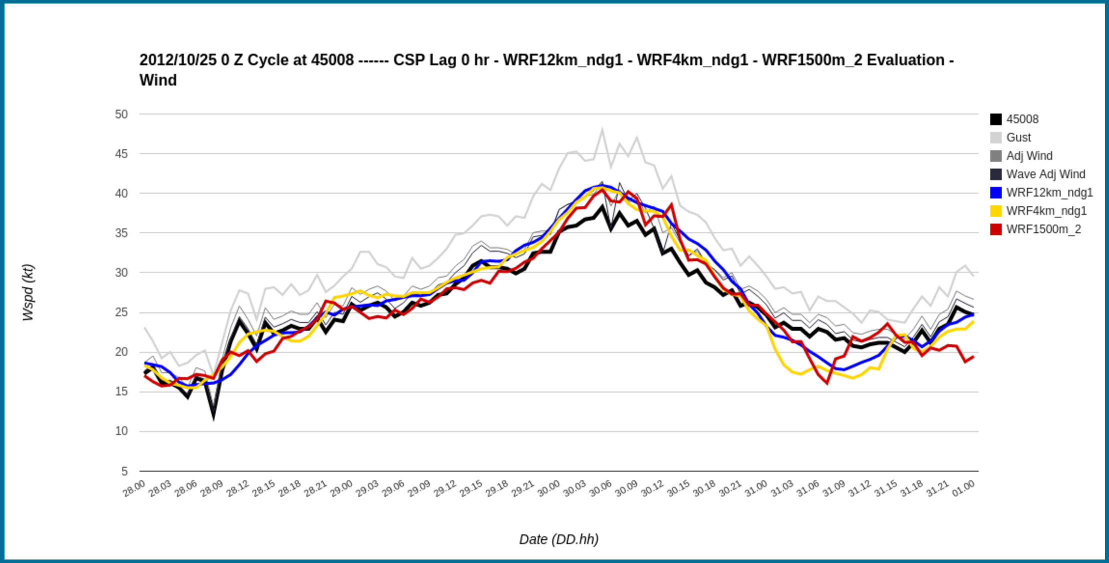


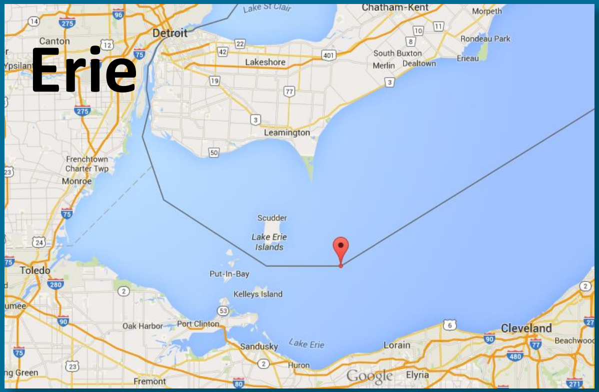
WRF U_{10} at various resolutions (S. Sandy)

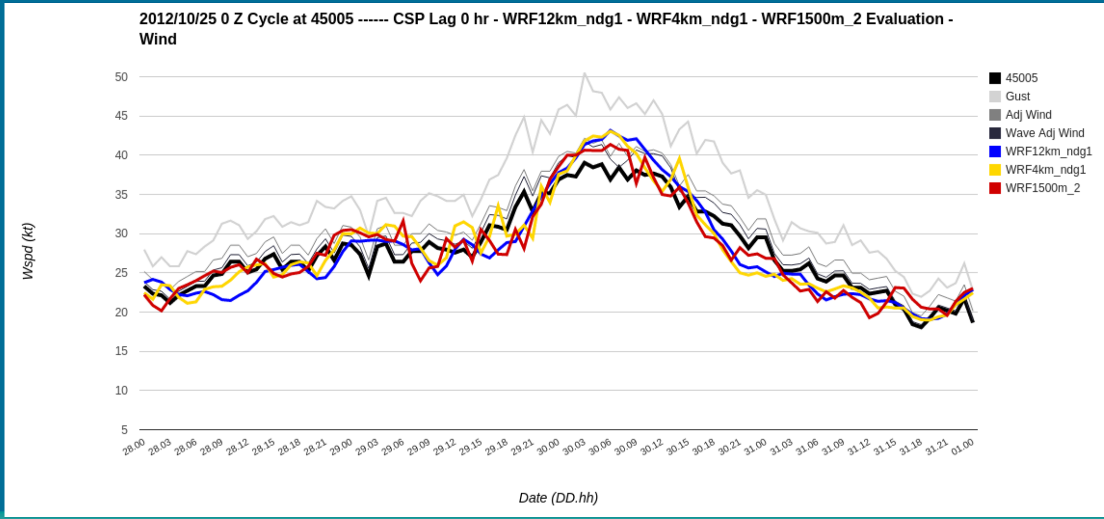
WRF 12 km | **WRF 4 km** | **WRF 1 km**



WRF model validation (S. Sandy)





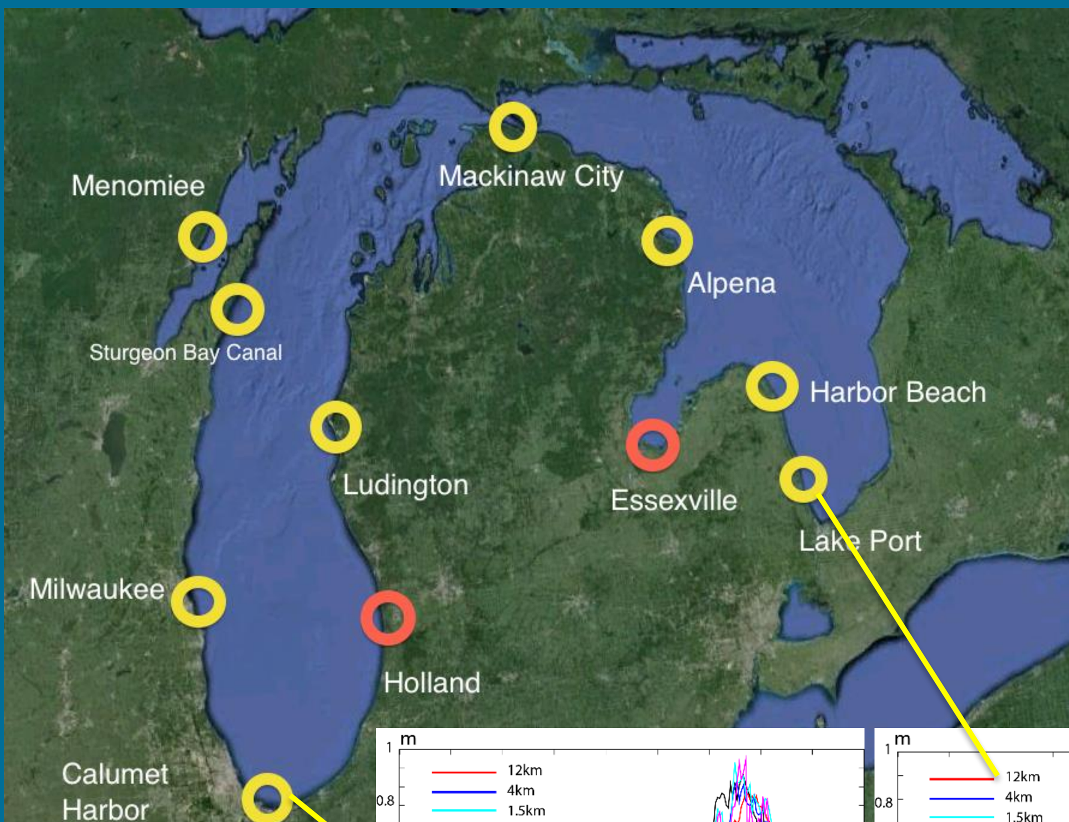


Hydrodynamic Model Configuration

- ***Unstructured grid Finite-Volume Community Ocean Model (FVCOM)***
  - **Primitive equations**
  - **Simulate 3D circulation, water level, temperature**
- ***Driven by meteorological forcing and lateral boundary conditions at major rivers:***
  - **WRF outputs at 12, 4, and 1 km resolution**
  - **Interpolated meteorology (GLERL NNM)**
    - *Based on the coastal observations and several buoy data. Currently used in operational hindcasts.*

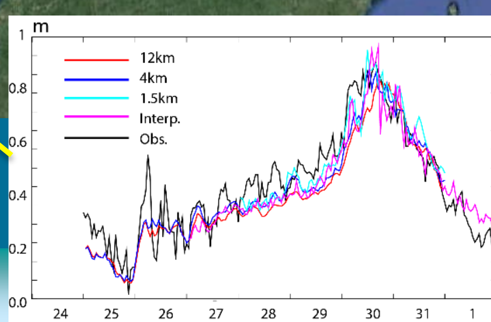
FVCOM water levels (S. Sandy)

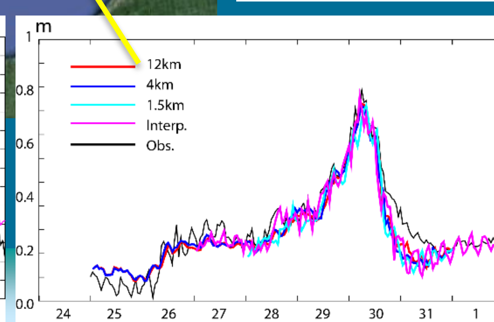
High-resolution WRF vs Interpolated Meteorology currently used in operational forecasts. WRF wins at 11 out of 13 gauge stations (O).



RMSE [cm]

	WRF			Interpolated Meteorology (conventional)
Name	12km	4km	1.5 km	
Lake Port	4.56	5.57	5.56	6.01
Harbor Beach	4.37	4.6	4.72	6.75
Essexville	15.5	16.9	19.31	11.41
Alpena	3.46	3.66	3.64	4.04
Mackinaw City	3.05	3.17	3.55	4.03
Ludington	2.56	2.72	2.81	4.01
Holland	3.22	3.21	3.69	2.74
Calumet Harbor	5.17	4.57	4.98	4.64
Milwaukee	3.51	3.27	3.62	3.65
Sturgeon Bay Canal	3.37	3.54	3.7	4.87
Menominee	6.5	6.73	7.54	6.8



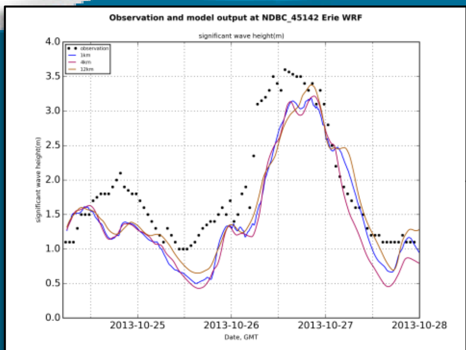


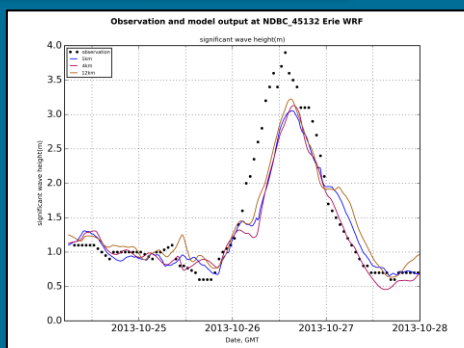
Wave Model Configuration

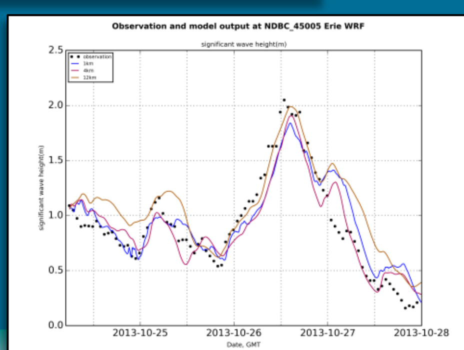
WAVEWATCH III version 4.18

- Third-generation, spectral wave model run operationally at NOAA/NCEP. Processes included:
  - Spatial propagation
  - Intra-spectral propagation (refraction and Doppler shifting)
  - Source terms (ST4 with Fillipot and Ardhuin 2012):
    - *Deep water: Wind input, Quadruplet nonlinear interaction, Whitecapping dissipation.*
    - *Shallow water: Bed friction, Depth-induced breaking.*
- Explicit numerical approach.
- Forced with WRF output at 12, 4, 1 km resolution.

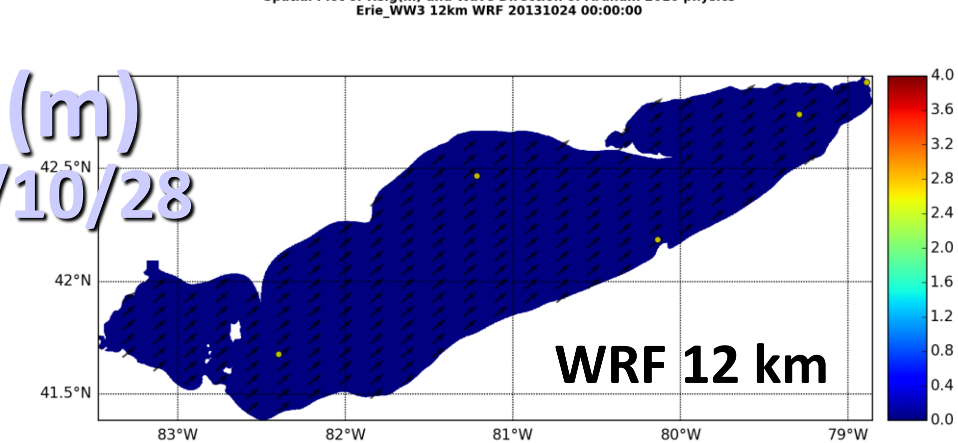
Lake Erie Hsig (m)
2013/10/24-2013/10/28

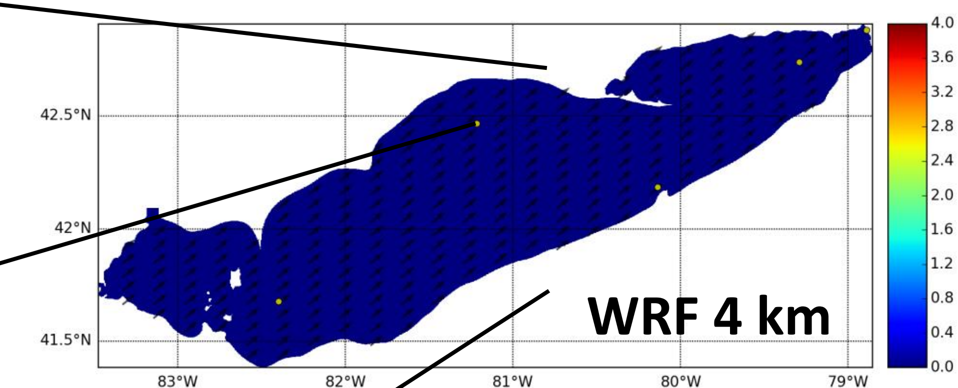


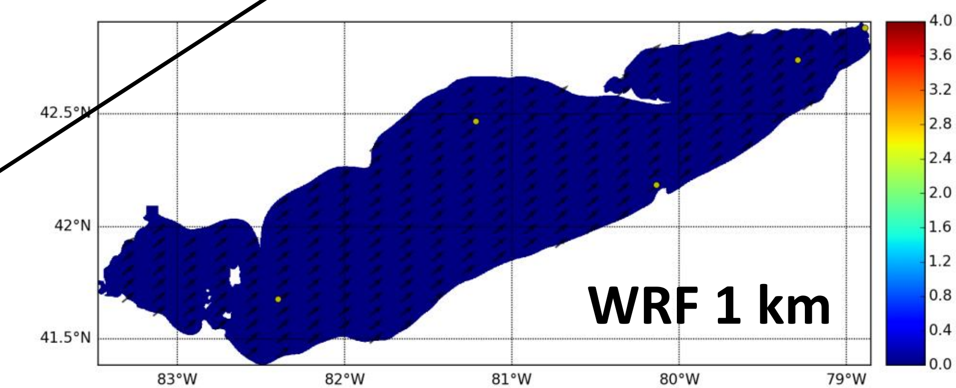




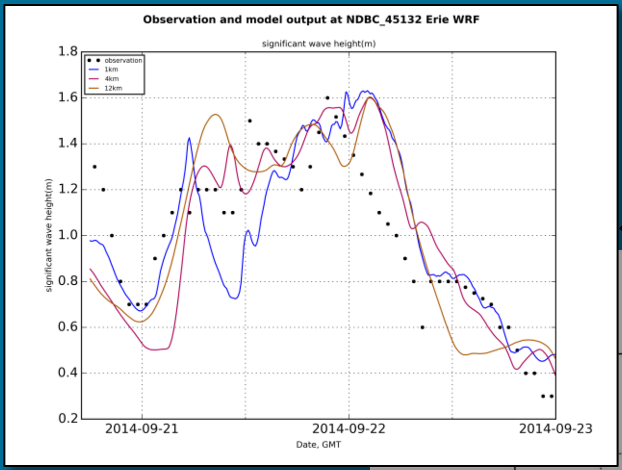
Red: 12 km
Black: 4 km
Blue: 1 km

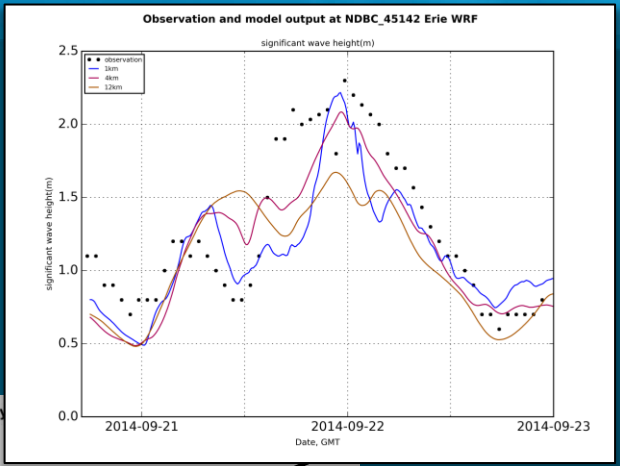


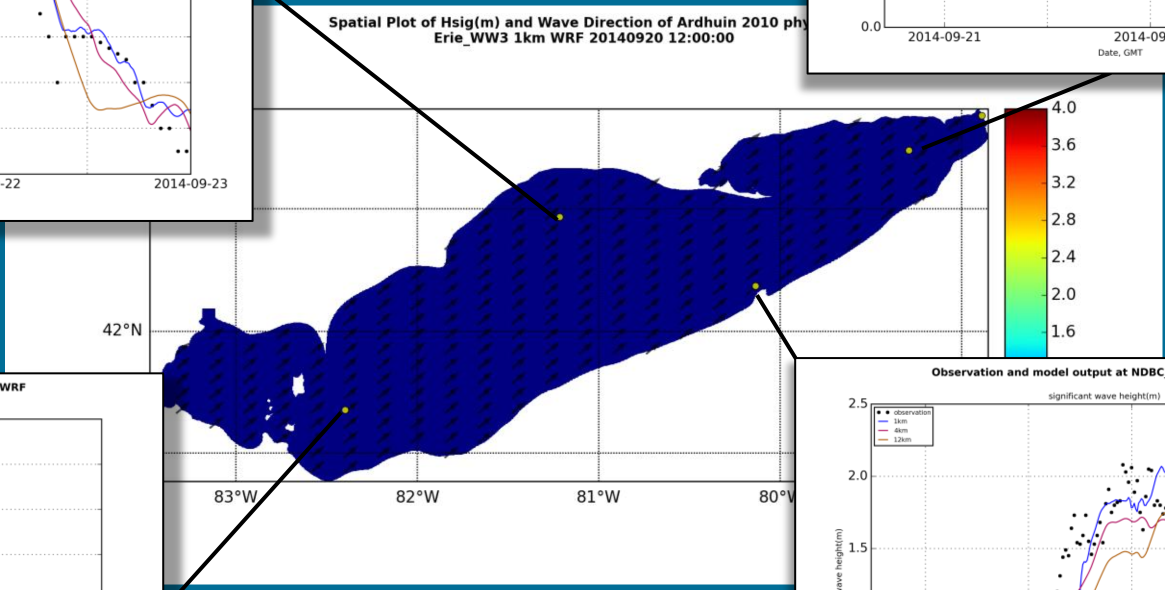


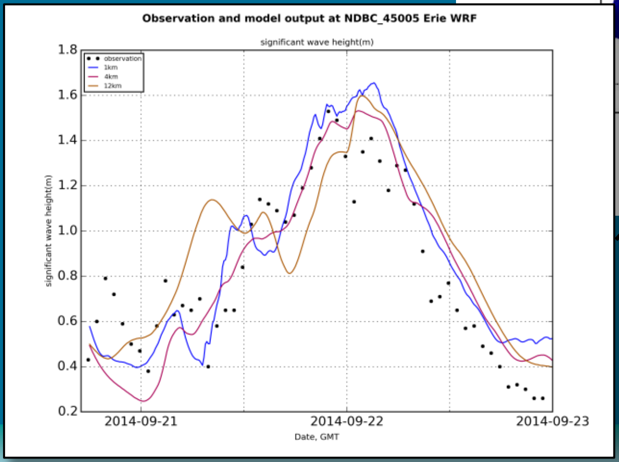


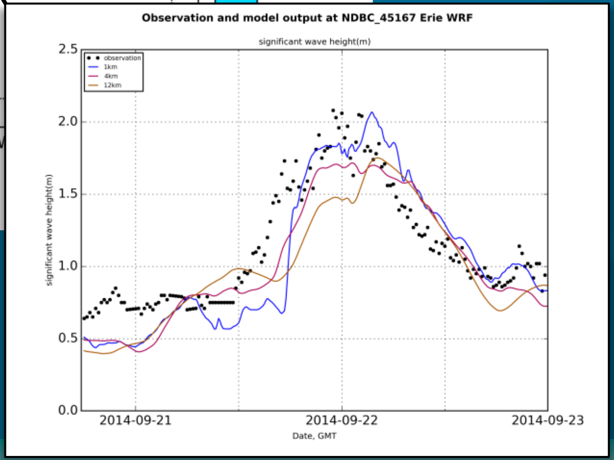
Lake Erie significant wave height (m)
2014/09/20-2014/09/23











Conclusions

1. Developing an operational coupled 3D circulation and wave model over the GL, run on shared unstructured grids, and forced by a high-resolution atmospheric model and ice fields.
2. High-resolution WRF model configured. Greatest accuracy increase found from 12 to 4 km res. Enhanced nearshore detail with 1 km.
3. FVCOM model shows good water level performance with high-res WRF model input, improving on GLERL NNM fields.
4. WAVEWATCH III shows encouraging performance. Differences visible in wave field detail and phasing from various WRF resolutions.
5. Next steps: Further refinement of model meshes and seasonal model runs.