Operational Forecasting of Wind-Waves at the Great Lakes for the US National Weather Service

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NCEP's Operational Wave Model Suite, serving the US National Weather Service

System Name	Acronym	Spatial Coverage	Horizontal Resolution	Cycle Frequency	Forecast Length h
Global Deterministic Wave System	Multi_1	Global	$1/2^{o} - 1/12^{o}$	4	180
Global Hurricane Wave System	Multi_2	Global	$1/2^{o} - 1/12^{o}$	4	126
Global Wave Ensemble System	GWES	Global	$1/2^{o}$	4	240
Great Lakes Wave Systems	GLW/GLWN	Great Lakes	2.5 kms	4/4	84/147
Nearshore Wave Prediction System	NWPS	Coastal WFOs	500 -50 m	Limited On demand	102

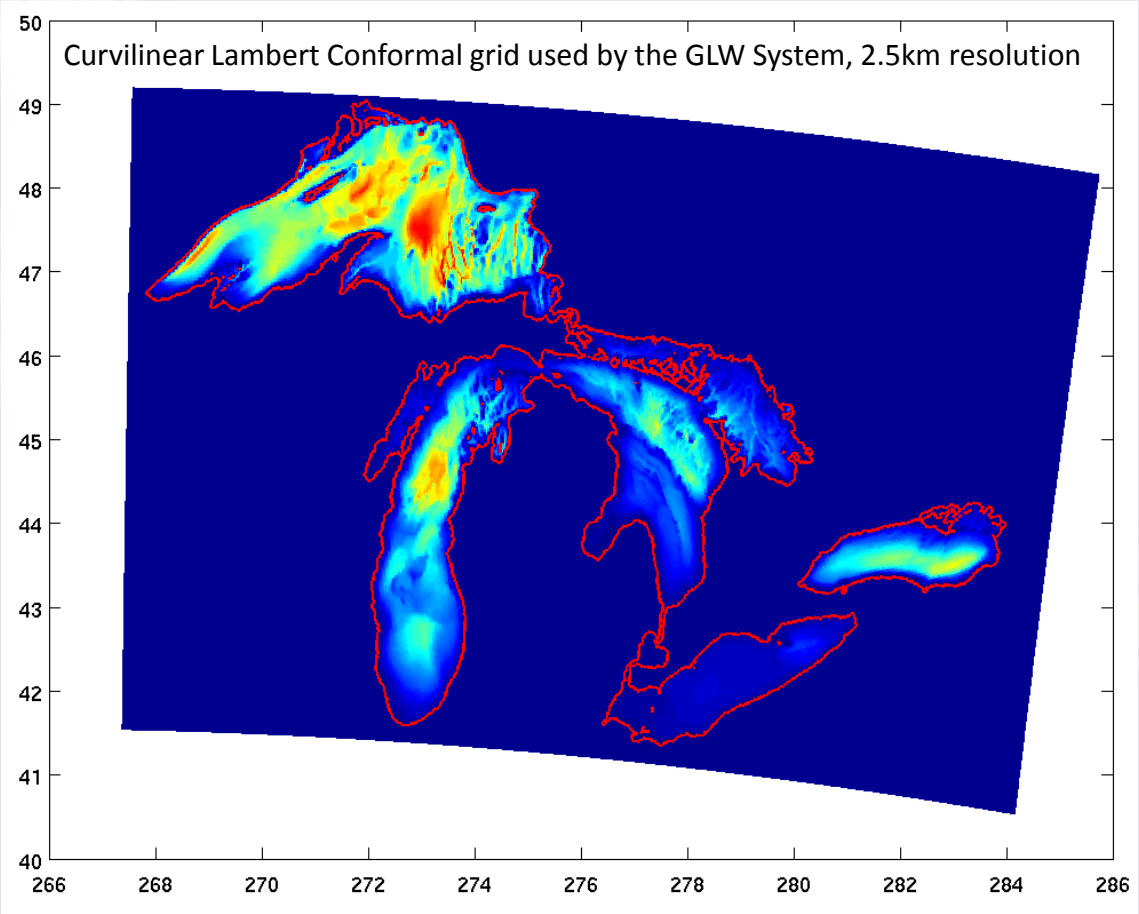
Brief History of The GLW Model

- 2004-2005: Great Lakes Wave system (GLW) prototyped at NCEP,
- 2006: GLW became operational running with winds from NCEP'S regional atmospheric model (then ETA),
- 2008: Operational implementation of the GLW using National Digital Forecast Database (NDFD) winds,
- Upgrades,
  - 2013: Major physics upgrade, tuning for severe sea-states,
  - 2015: Spatial grid resolution increase from 4km to 2.5km,
    - First implementation of a curvilinear grid for wave models at NCEP.
  - 2016: Next scheduled upgrade (likely around Aug-Sep).

The Great Lakes Wave System (GLW)

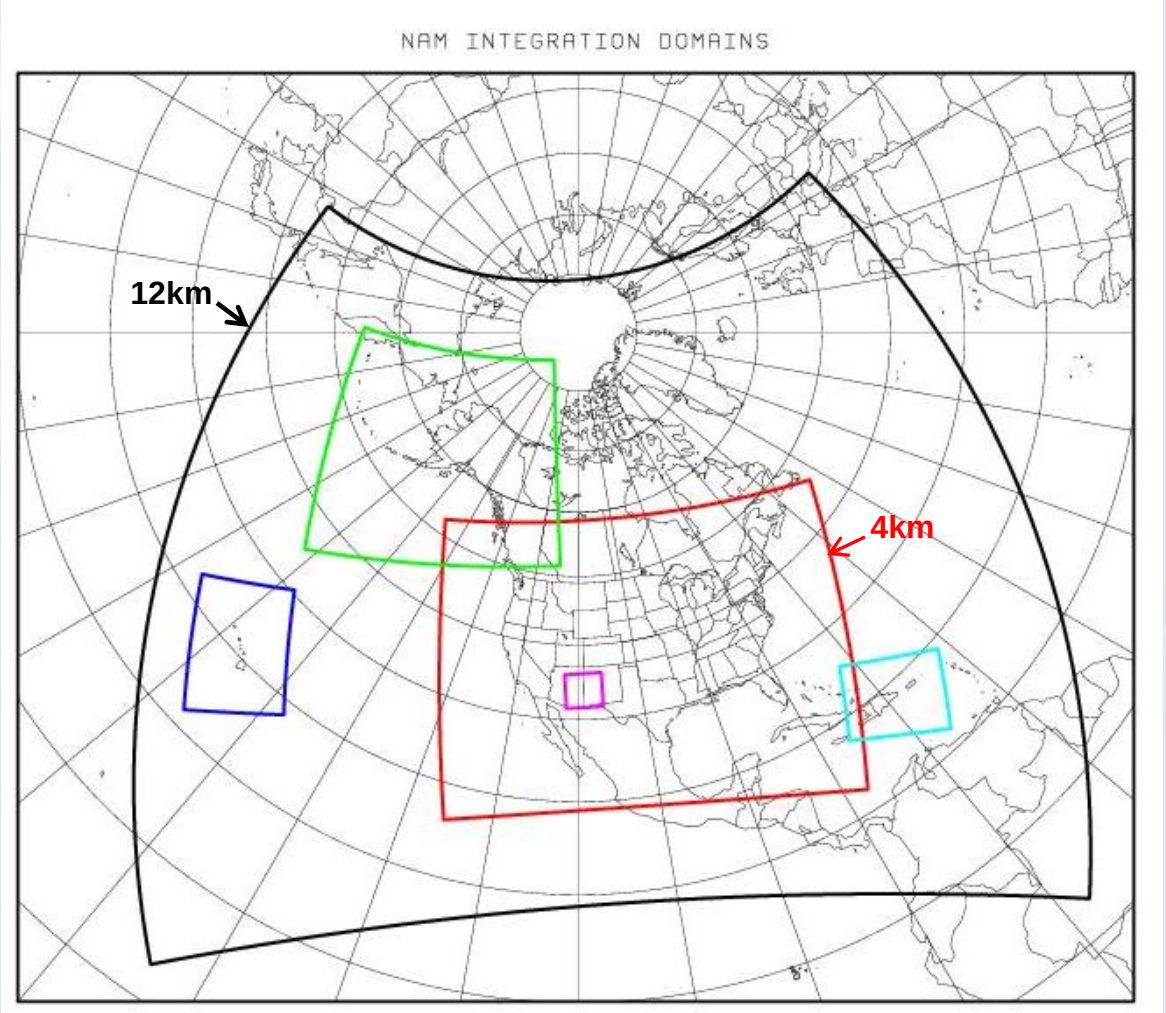
The GLW is …

- Part of operational National Weather Service (NWS) prediction suite,
  - Products and support 24 x 7.
- State-of-the-art wave model,
  - Single numerical grid, 2.5km spatial resolution.
- GLW has two components using different wind forcing:
  - GLW: North American Mesoscale (NAM),
  - GLWN: National Digital Forecast Database (NDFD).
- Ice analyses from NIC.



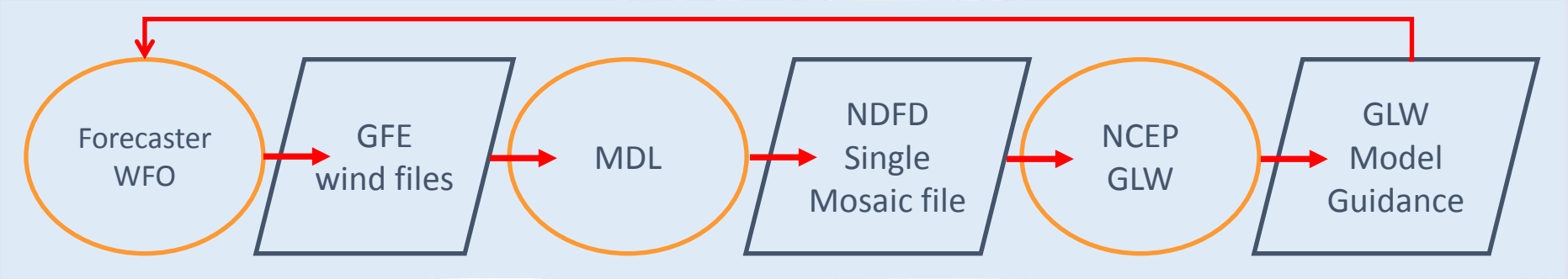
The NAM Driven GLW Component (GLW cycles)

- Runs 4 x daily cycles,
  - 0Z, 06Z, 12Z, 18Z.
- Forecasts out to 84h
- Surface winds from North American Mesoscale Model (NAM),
  - 0-36h: 1h, 2.5km (4km),
  - 39-60h: 3h 2.5km (4km),
  - 63-84h: 3h 5km (12km).
- Ice concentrations,
  - NIC analyses from 12Z.



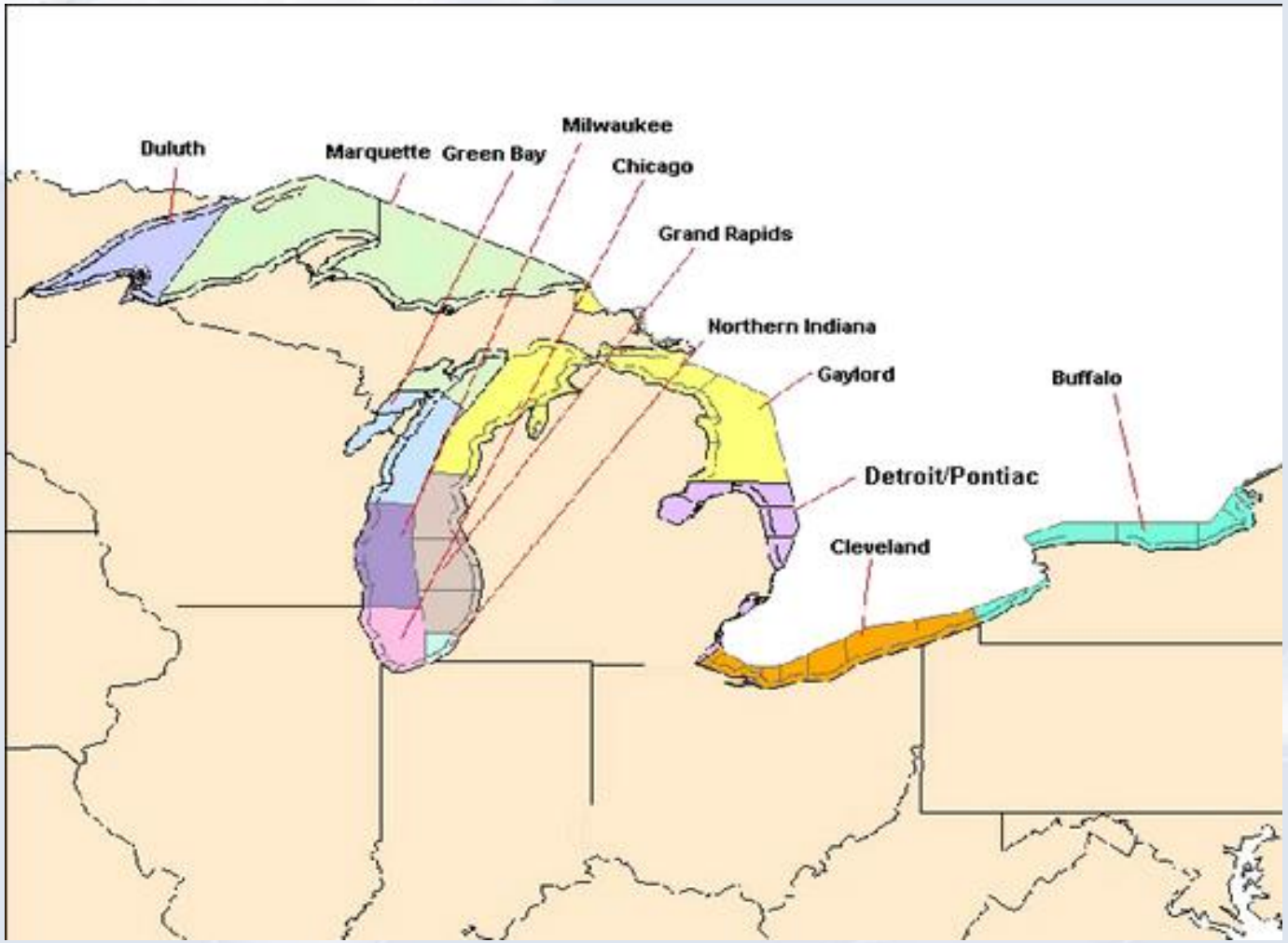
The NDFD-Driven GLW Component (GLWN cycles)

- First “on-demand” marine forecasting system at NCEP for the NWS,
- 3-step process involving 11 Great Lakes Weather Forecast Offices (WFOs), NOAA’s Meteorological Development Lab (MDL) and NCEP,



- Runs 4 x daily with cycles at 03Z, 09Z, 15Z and 21Z,
  - Wave forecasts out to 147h,
  - Ice analyses from NIC.
- Delivery time critical issuing wave forecasts at different WFOs,
  - Main source of wave guidance for WFOs: products expected on time,
  - Entire 3-step process has to be completed in ~30 min,
  - Development constraints: wave model only has ~10 min to run, no matter what.

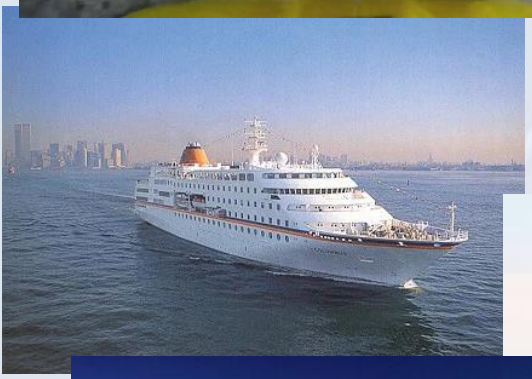
Main Customer Base



11 NWS Weather Forecast Offices (WFO) with Marine Responsibilities

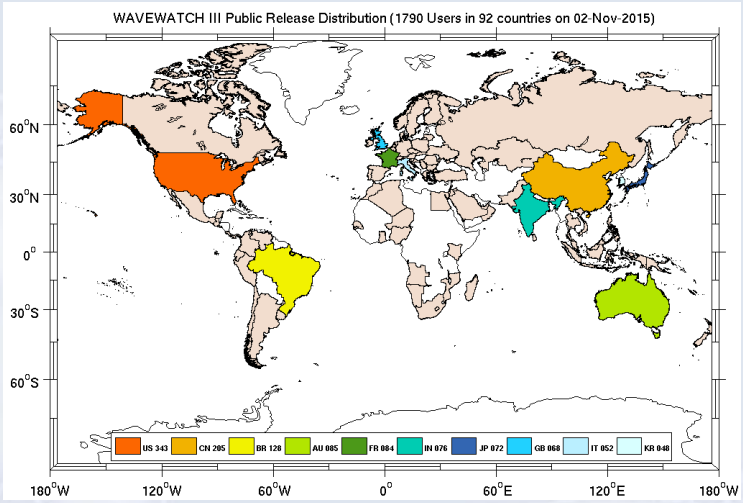
End users

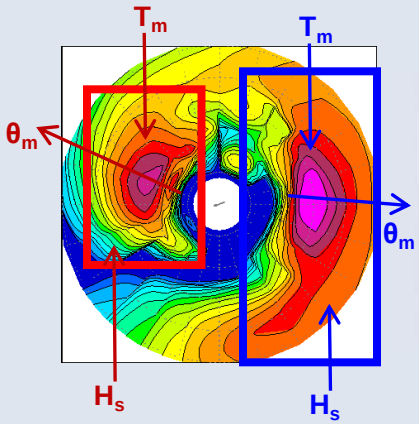
Reduce loss of life and property. Ensure end users, have a good time, safely.



Underlying Wave Model

- WAVEWATCH III: state-of-the-art numerical model for wave prediction.
- Developed at NCEP in 90's, became community model recently,
  - Collaborators from all over the world,
  - ~2,000 users in 92 countries (11/2015).
- WW3 is a spectral wave model,
  - Computes wave fields at fixed grid points
  - Statistical representation of waves via directional wave spectrum





- Model calculates how spectrum changes due to wind and ice, computes mean wave parameters used in forecasts:
  - Significant wave height (Hs),
  - Peak and Mean wave periods (Tp, Tm),
  - Peak and mean wave directions (θp, θm)

GLW Wave Model Products: Full Grid

H_s: Significant Wave Height

θ_p: Peak Wave Direction

T_p: Peak Wave Period

$H_{s\ (ws)}$: Windsea Wave Height

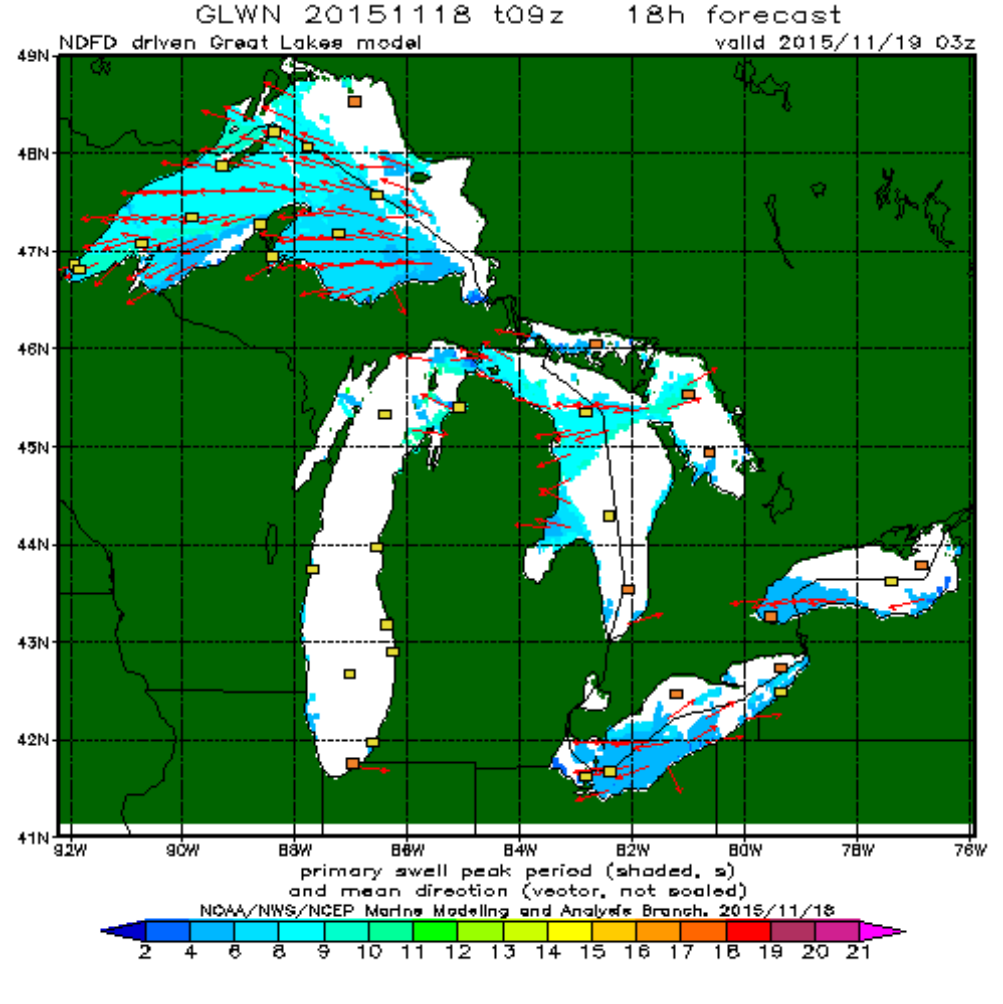
$\theta_{p\ (ws)}$: Windsea Peak Direction

$T_{p\ (ws)}$: Windsea Peak Period

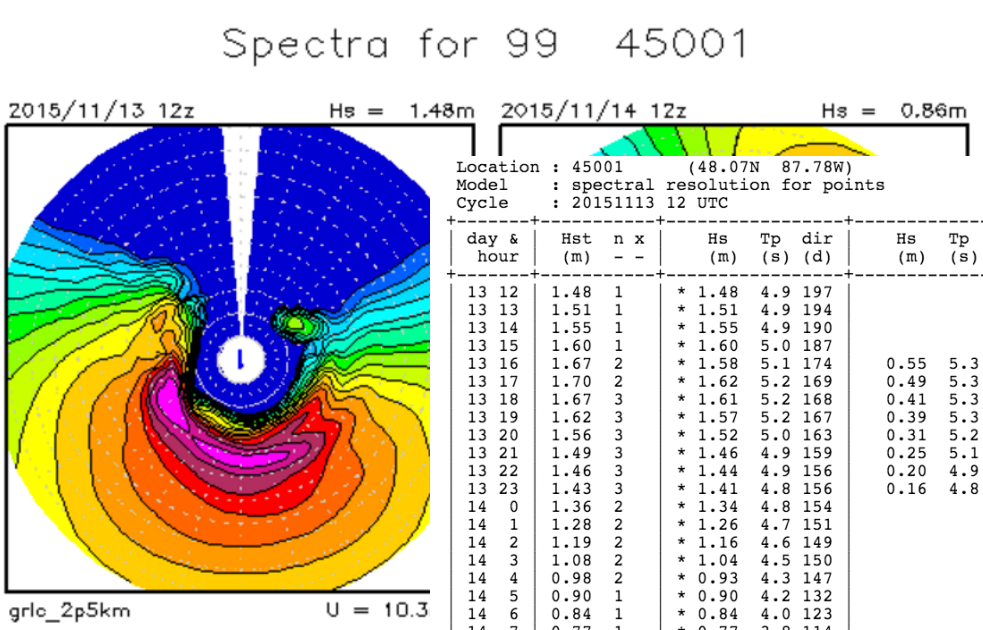
$H_{s\ (sw)}$: Swell Wave Height

$\theta_{p\ (sw)}$: Swell Peak Direction

$T_{p\ (sw)}$: Swell Peak Period



GLW Wave Model Products: Point Outputs



Wave energy density spectrum

Location : 45001 (48.07N 87.78W)
Model : spectral resolution for points
Cycle : 20151113 12 UTC

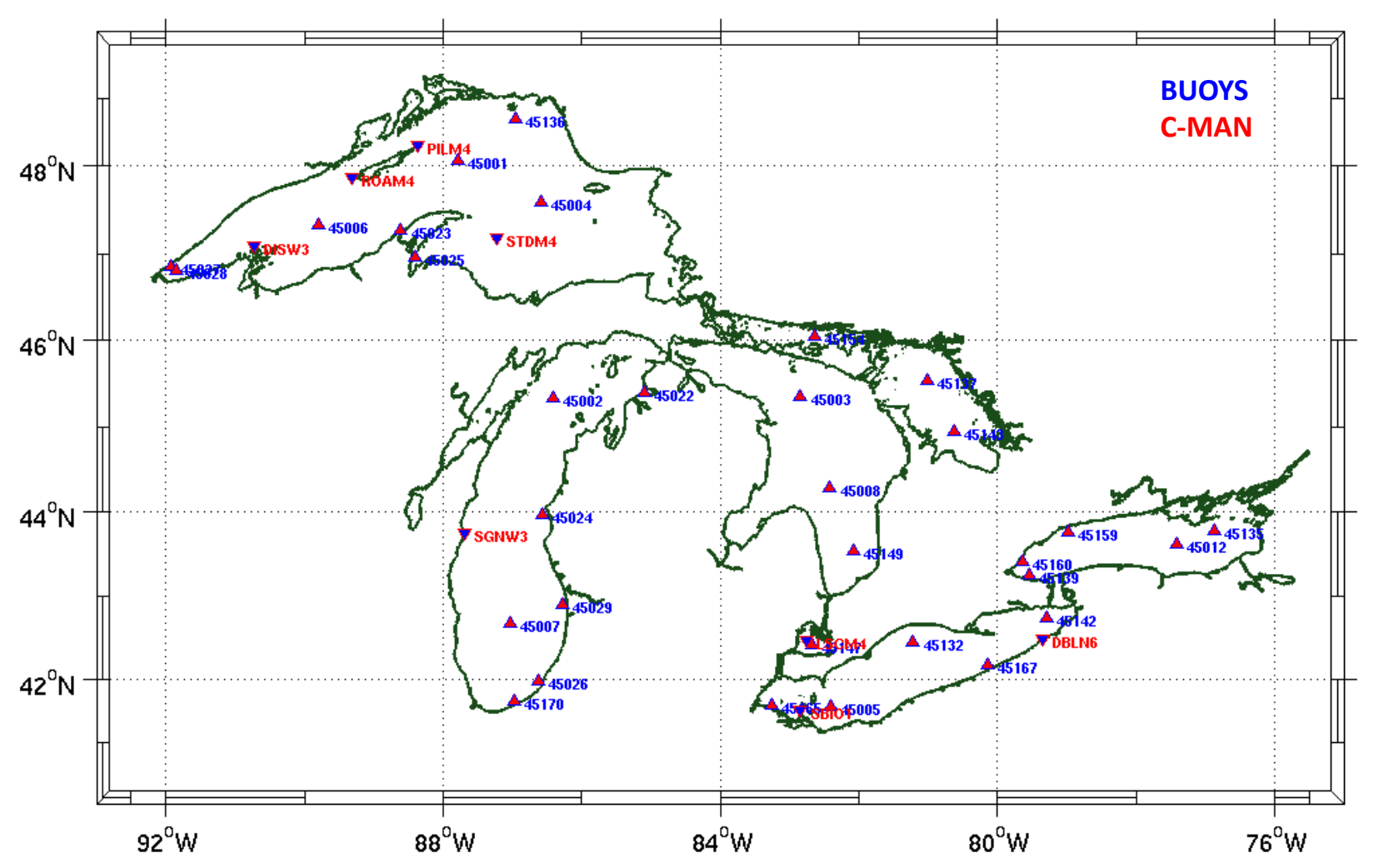
day & hour	Hst (m)	n x - -	Hs (m)	Tp (s)	dir (d)	Hs (m)	Tp (s)	dir (d)	Hs (m)	Tp (s)	dir (d)	Hs (m)	Tp (s)	dir (d)	Hs (m)	Tp (s)	dir (d)	Hs (m)	Tp (s)	dir (d)
13 12	1.48	1	* 1.48	4.9	197															
13 13	1.51	1	* 1.51	4.9	194															
13 14	1.55	1	* 1.55	4.9	190															
13 15	1.60	1	* 1.60	5.0	187															
13 16	1.67	2	* 1.58	5.1	174	0.55	5.3	242												
13 17	1.70	2	* 1.62	5.2	169	0.49	5.3	243												
13 18	1.67	3	* 1.61	5.2	168	0.41	5.3	243	0.16	6.2	63									
13 19	1.62	3	* 1.57	5.2	167	0.39	5.3	240	0.17	6.1	63									
13 20	1.56	3	* 1.52	5.0	163	0.31	5.2	240	0.18	6.6	63									
13 21	1.49	3	* 1.46	4.9	159	0.25	5.1	239	0.19	6.4	65									
13 22	1.46	3	* 1.44	4.9	156	0.20	4.9	238	0.19	6.2	65									
13 23	1.43	3	* 1.41	4.8	156	0.16	4.8	236	0.20	6.0	67									
14 0	1.36	2	* 1.34	4.8	154				0.20	5.9	67									
14 1	1.28	2	* 1.26	4.7	151				0.21	5.8	68									
14 2	1.19	2	* 1.16	4.6	149				0.24	5.7	68									
14 3	1.08	2	* 1.04	4.5	150				0.31	4.9	70									
14 4	0.98	2	* 0.93	4.3	147				0.31	5.0	68									
14 5	0.90	1	* 0.90	4.2	132															
14 6	0.84	1	* 0.84	4.0	123															
14 7	0.77	1	* 0.77	3.8	114															
14 8	0.71	1	* 0.71	3.6	102															
14 9	0.70	1	* 0.70	3.5	90															
14 10	0.72	1	* 0.72	3.5	81															
14 11	0.77	1	* 0.77	3.8	72															
14 12	0.86	1	* 0.86	4.1	64															
14 13	1.00	1	* 1.00	4.4	57															
14 14	1.22	1	* 1.22	4.8	51															
14 15	1.41	1	* 1.41	5.1	46															
14 16	1.62	1	* 1.62	5.3	47															
14 17	1.84	1	* 1.84	5.6	51															
14 18	2.03	1	* 2.03	6.0	54															
14 19	2.22	1	* 2.22	6.4	56															
14 20	2.35	1	* 2.35	6.7	59															
14 21	2.40	2	* 2.35	6.9	63	0.48	5.4	343												
14 22	2.42	2	* 2.39	7.0	63	0.37	5.5	343												
14 23	2.35	1	* 2.35	7.1	63															
15 0	2.21	2	* 2.18	7.1	64	0.31	5.9	332												

Hst : Total sigificant wave height.
n : Number of fields with Hs > 0.05 in 2-D spectrum.
x : Number of fields with Hs > 0.15 not in table.
Hs : Significant wave height of separate wave field.
Tp : Peak period of separate wave field.
dir : Mean direction of separate wave field.
* : Wave generation due to local wind probable.

Spectral Bulletin

- Windseas
- Swells

GLW Wave Model Products: Point Outputs



GLW Wave Guidance: Current Skill

Putting this all together

Excellent skill

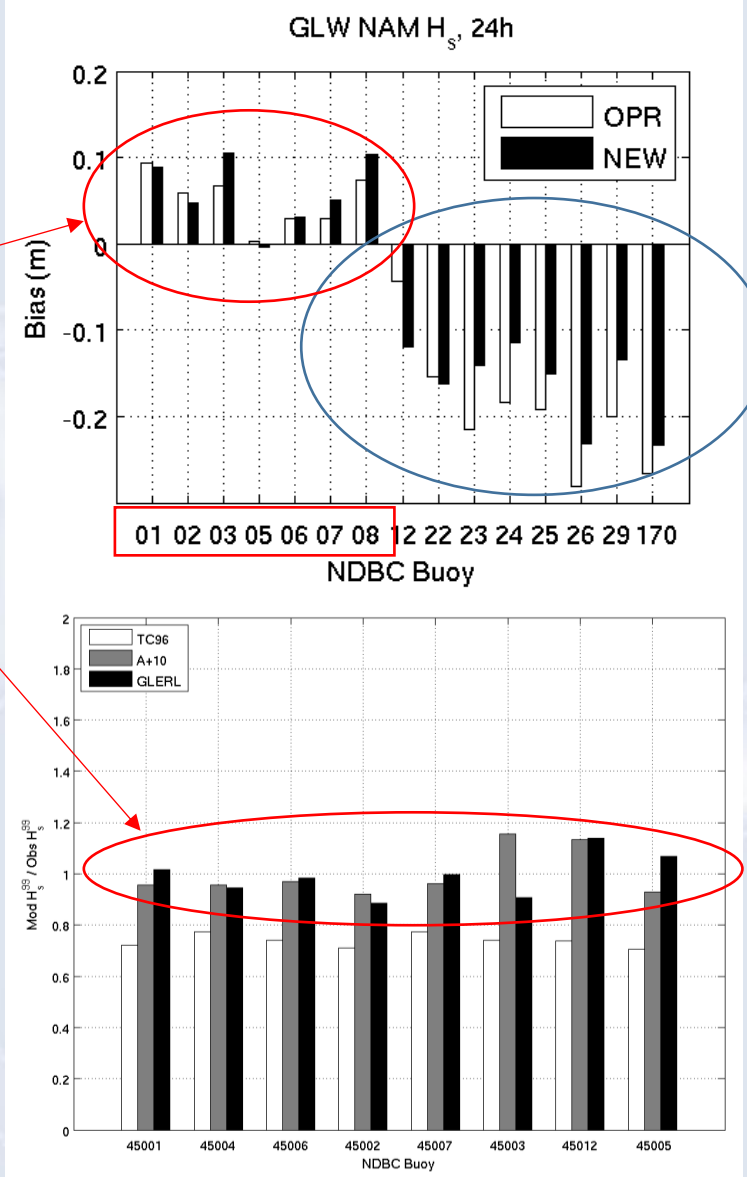
- Deep water waves,
- Both ambient and severe storm conditions,

Requires improvement,

- Nearshore wave conditions.

Other limitations,

- 4 daily cycles miss fast-changing weather in GL.



Upcoming 2016 Upgrades

- Increase on-time availability to forecasters,
  - Better represent rapidly changing conditions reflected in NDFD data,
  - Attend best needs of different forecast issuance at all 11 WFOs.

  → Hourly GLWN runs out to 24h in addition to current cycles
    - *Will require shutting down GLW (NAM) cycles.*

- Improve skill of nearshore wave forecasts,

  → Increase nearshore spatial resolution,

  → HR unstructured grid with 2.5km → 250m cells.

  → Alternative source-terms (improved shallow water physics),

  → NIC will provide HR files with ice concentrations,

  → Wind Downscaling,

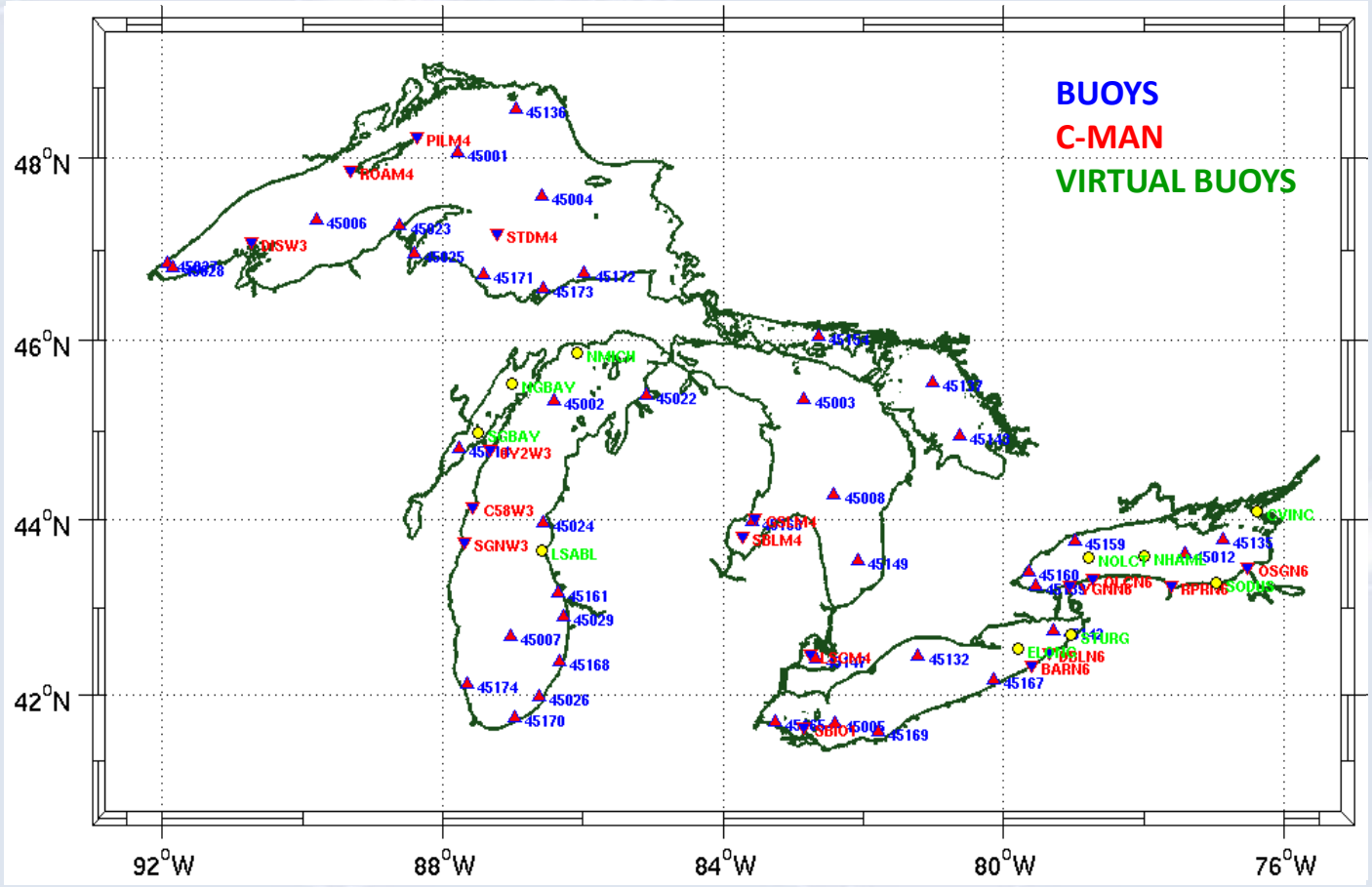
New Features: Short-Range Cycles

- Add 20 new short-range forecast cycles

	START	Range							NOAAPORT		
Cycle	0	24	48	72	96	120	144	147	Top Hour	Current	Bottom Hour
00	11:10:00 PM								11:30:00 PM	11:22:00 PM	11:00:00 PM
01	12:10:00 AM								12:30:00 AM	12:22:00 AM	12:00:00 AM
02	1:10:00 AM								1:30:00 AM	1:22:00 AM	1:00:00 AM
03	2:10:00 AM								2:43:00 AM	2:27:00 AM	2:13:00 AM
04	3:10:00 AM								3:30:00 AM	3:22:00 AM	3:00:00 AM
05	4:10:00 AM								4:30:00 AM	4:22:00 AM	4:00:00 AM
06	5:10:00 AM								5:30:00 AM	5:22:00 AM	5:00:00 AM
07	6:10:00 AM								6:30:00 AM	6:22:00 AM	6:00:00 AM
08	7:10:00 AM								7:30:00 AM	7:22:00 AM	7:00:00 AM
09	8:10:00 AM								8:43:00 AM	8:27:00 AM	8:13:00 AM
10	9:10:00 AM								9:30:00 AM	9:22:00 AM	9:00:00 AM
11	10:10:00 AM								10:30:00 AM	10:22:00 AM	10:00:00 AM
12	11:10:00 AM								11:30:00 AM	11:22:00 AM	11:00:00 AM
13	12:10:00 PM								12:30:00 PM	12:22:00 PM	12:00:00 PM
14	1:10:00 PM								1:30:00 PM	1:22:00 PM	1:00:00 PM
15	2:10:00 PM								2:43:00 PM	2:27:00 PM	2:13:00 PM
16	3:10:00 PM								3:30:00 PM	3:22:00 PM	3:00:00 PM
17	4:10:00 PM								4:30:00 PM	4:22:00 PM	4:00:00 PM
18	5:10:00 PM								5:30:00 PM	5:22:00 PM	5:00:00 PM
19	6:10:00 PM								6:30:00 PM	6:22:00 PM	6:00:00 PM
20	7:10:00 PM								7:30:00 PM	7:22:00 PM	7:00:00 PM
21	8:10:00 PM								8:43:00 PM	8:27:00 PM	8:13:00 PM
22	9:10:00 PM								9:30:00 PM	9:22:00 PM	9:00:00 PM
23	10:10:00 PM								10:30:00 PM	10:22:00 PM	10:00:00 PM

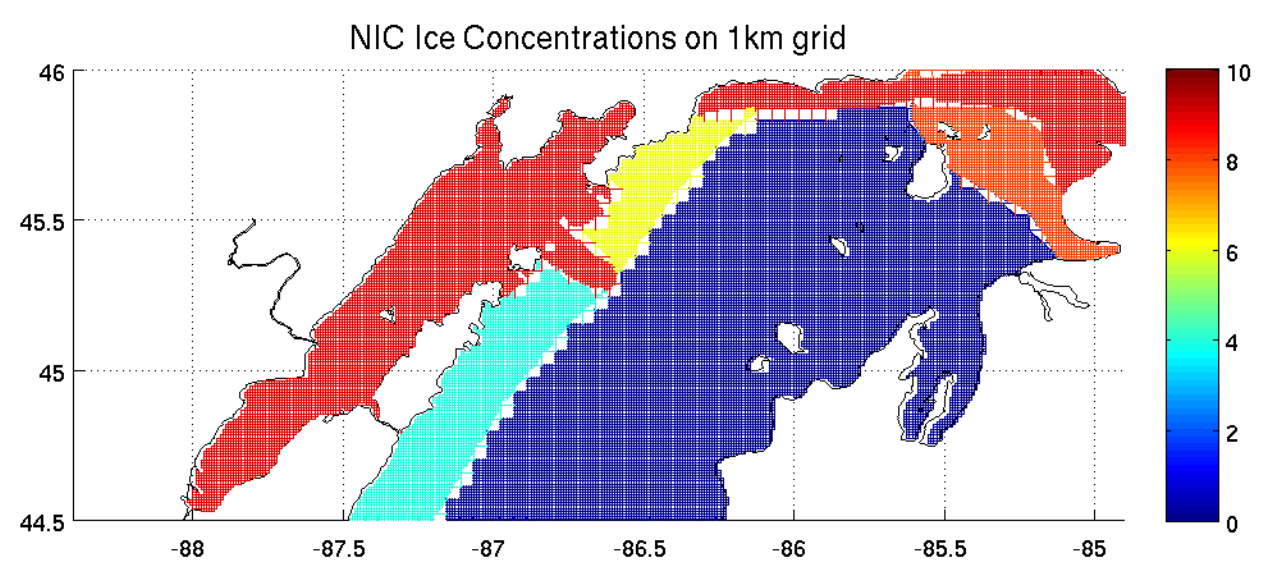
New Features: Expand Point Outputs

- Now: 40, only 29 going through AWIPS
- Proposed: 68 (40 buoy, 17 CMAN, 11 VBY), update AWIPS



New Features: 500m Ice, Time Filter

- Switch from 5km to 500m NIC ice concentrations

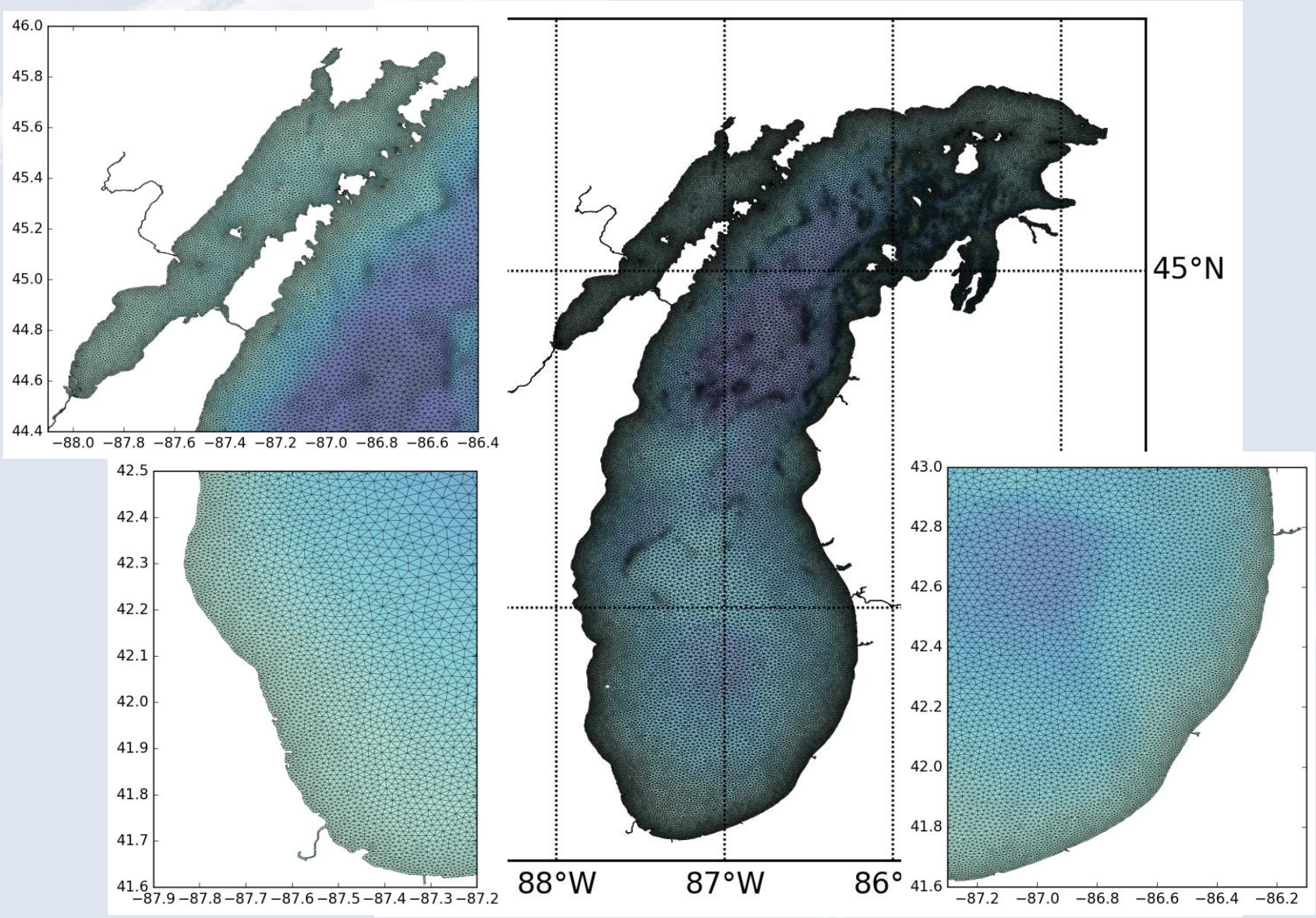


- Add time filter to make ice cover conservative towards keeping lanes open
  - Close lanes if ice persistent > 3 days at any grid point

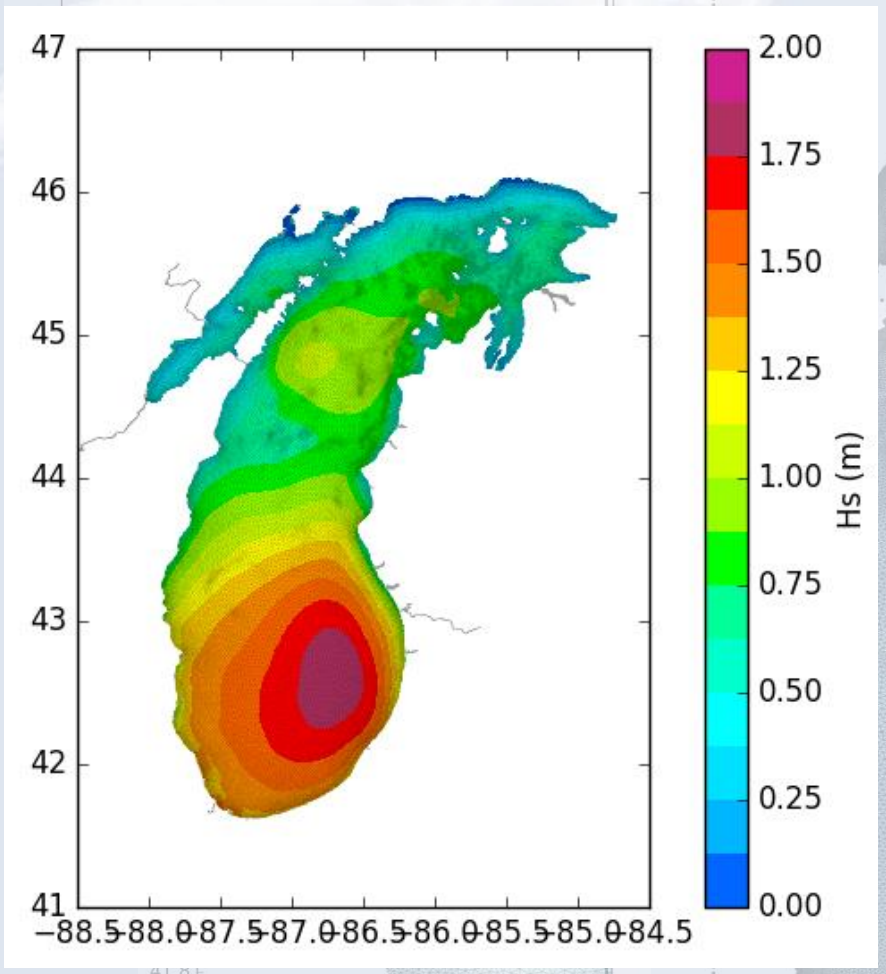
New Features: High Resolution Grids

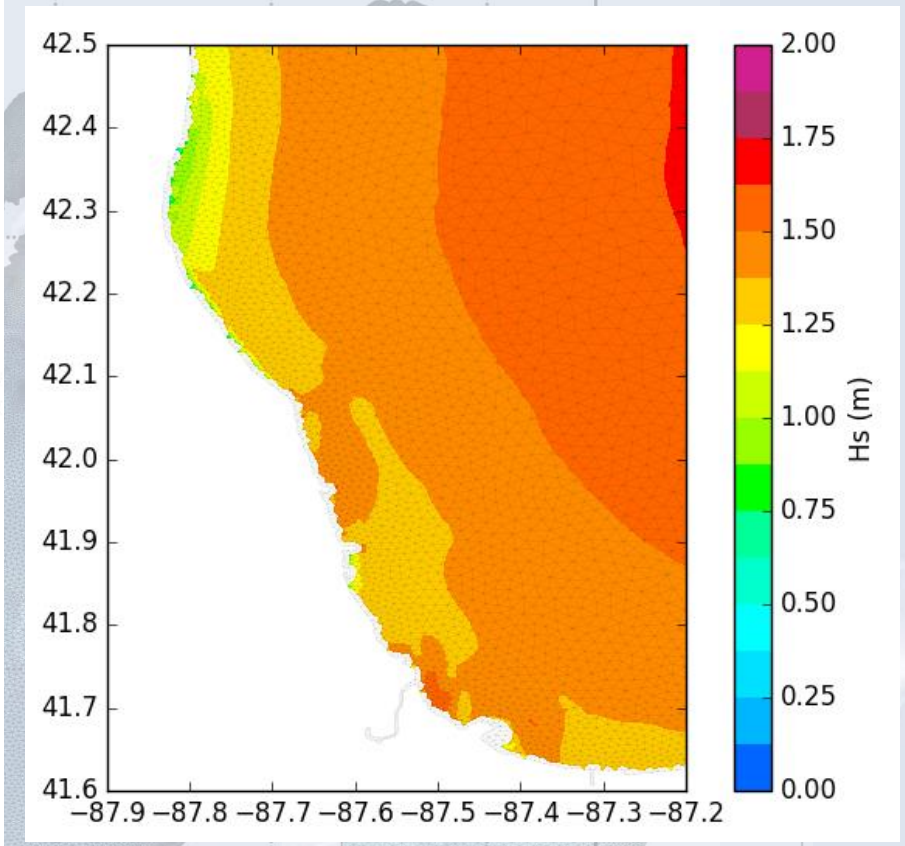
- Use triangular, unstructured meshes for GLW,
- Triangular grids became an option for GLW due to collaboration with researcher who wrote the unstructured grid codes in WW3,
  - Dr Aron Roland, Technical University Darmstadt, Germany,
- Chosen resolution:
  - ~2.5 km cell sides in deep waters,
  - ~250 m cell sides at the coast.
- Will require much more computer power,
- Slightly longer path for transition to new Cray supercomputer,
  - Memory management issues in WAVEWATCH III code.

New Features: Unstructured Grids



Unstructured Grids: Prelim Tests (Sep 2015)





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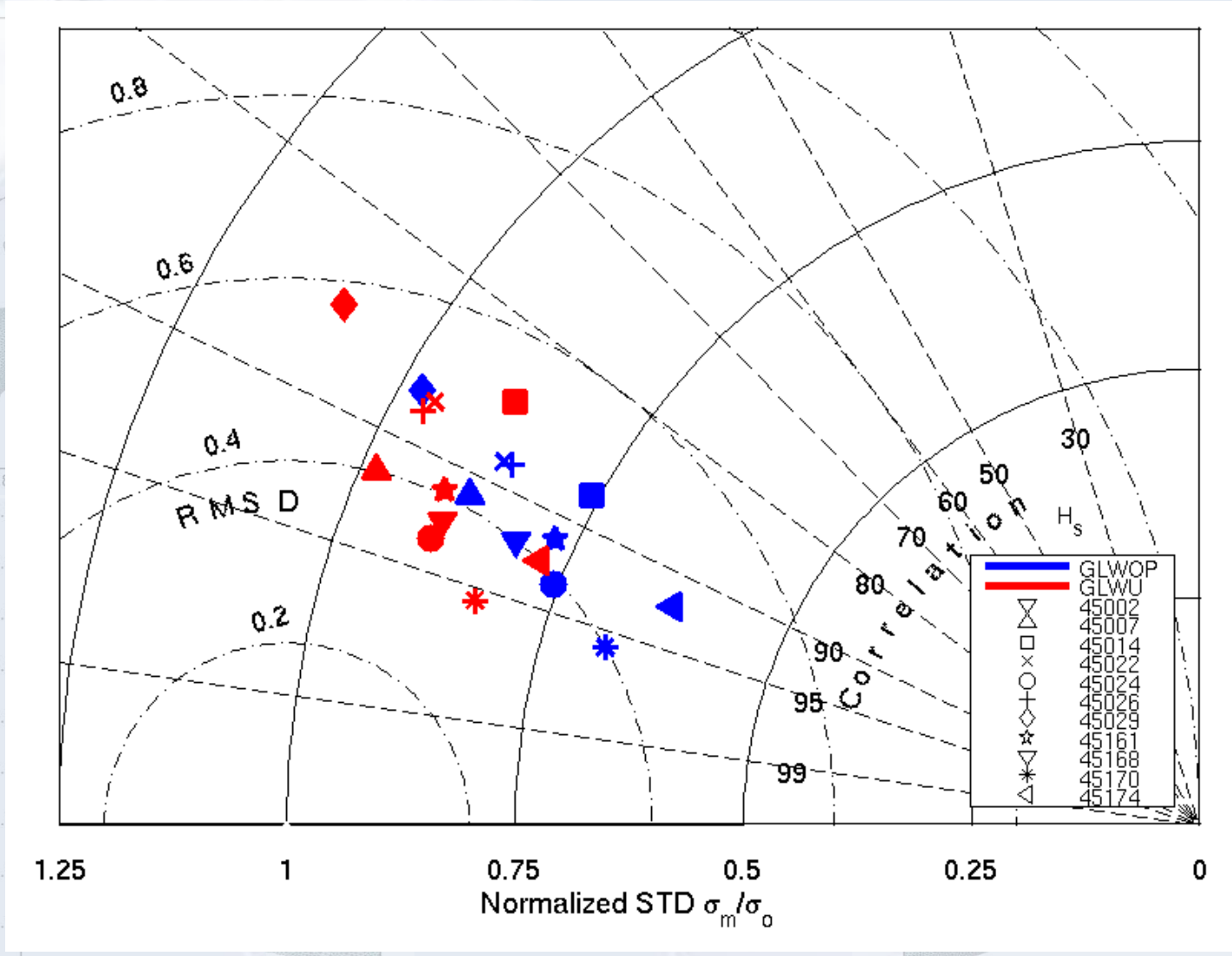


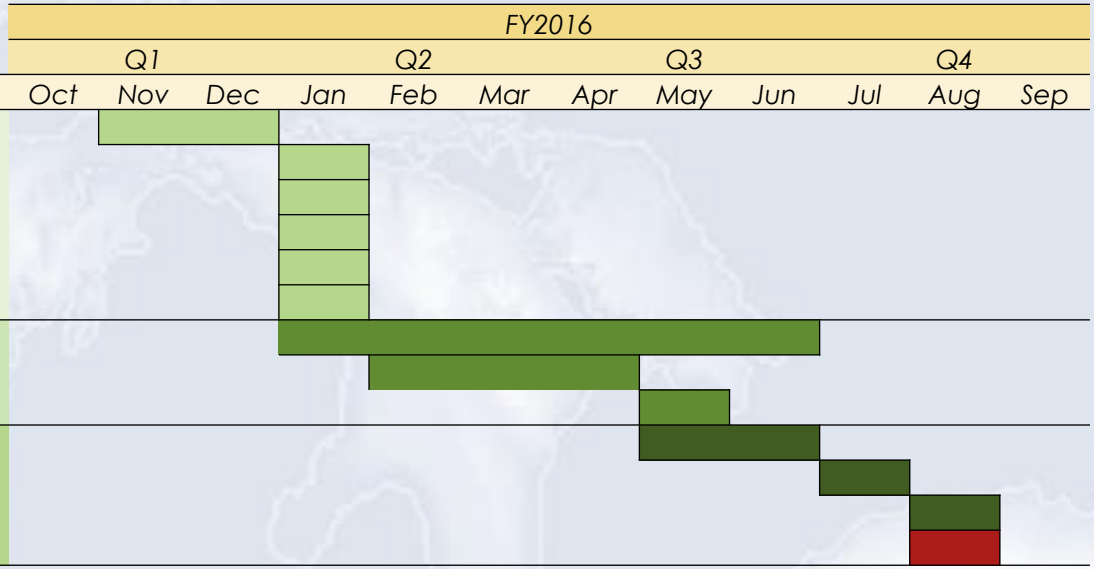
New Features: Improve Nearshore Physics

- Proposed tweaks:
  - Adjust wind-growth source terms for shallow waters,
  - Adjust deep-water breaking parameterizations,
  - Adjust depth-induced breaking approaches.

- Tentative tweaks;
  - Change from JONSWAP bottom friction to moveable bed,
  - Alternative propagation schemes,
  - Closer look at wind downscaling.

Implementation Procedures for GLW v3.4.X

- Proposed Schedule



Cycle	Task
Development	Design
	Discuss
	Science Testing
	Charter
	Plans for Retrospective
	NCO EE Meeting
EMC Testing	EMC Parallel
	Run Retrospective
	CCB
Implementation	NCO IT Testing
	Evaluation Parallel
	NCEP Director Briefing
	Implement

Beyond Q2FY16 Upgrades

Future plans

- GLWENS - Great Lakes Wave Ensemble System
  - Tandem with Environment Canada,
- Data assimilation using buoys and altimeters,
- Water levels,
- Fully coupled deterministic system
  - Research project conducted as part of the Coastal Storms Project, in association with GLERL.

GLW Data Access

Operational Data Servers,

- Gridded and point output data distributed by AWIPS,
- All operational outputs via NCEP NOMADS and FTP
  - 24 x 7 support, available to general public
  - ftp://ftp.ncep.noaa.gov/pub/data/nccf/com/wave/prod/glwn.YYYYMMDD
  - http://nomads.ncep.noaa.gov:9090/dods/wave/glw (OpenDAP)
  - http://nomads.ncep.noaa.gov/cgi-bin/filter_glw.pl (grib filter)

Non-Operational Data Servers

- Graphical outputs via development web site
  - http://polar.ncep.noaa.gov/waves,
  - Gridded maps of wave heights and meteorological parameters,
  - Spectra, source terms and bulletins,
  - **No** 24 x 7 support, available to general public.

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Questions, Suggestions, Requests?

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