



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

Jose-Henrique Alves

Marine Modeling and Analysis Branch

SRG at Environmental Modeling Center, NOAA/NCEP



Presentation Outline

Overview: NCEP's WAVEWATCHIII in the Great Lakes

- Pre-History
 - SOO Dinosaurs
- Ancient History
 - The First GLW/NAM Model
- Middle Ages
 - The first GLWN/NDFD model
- Renaissance
 - How new science gave our credibility a boost
- The Future



Pre-History: The WW3 Myth

Pre-History of WAVEWATCH III in the Great Lakes

- **First implementation of WAVEWATCH III**
 - WFO at Marquette, Michigan,
 - Tom Hultquist 2004 (Dinosaur? Chanhassen, MN)
 - Several case studies with RAMS,
 - Results were promising, established loosely the feasibility of running WAVEWATCH III operationally for the Great Lakes.



The First GLW/NAM Model

2005: Great Lakes Wave system (GLW) pre-operational prototype is tested at NCEP

08/2006: Great Lakes Wave system (GLW) is made operational

- 4 X daily forecasts at 00Z, 06Z, 12Z and 18Z
- Initialization using 0h nowcast from previous run, with 6h hindcast forced with NDAS, then 84h forecasts.
- WFOs feedback
 - Forecasts under more severe storms: unremarkable



The First GLWN/NDFD Model

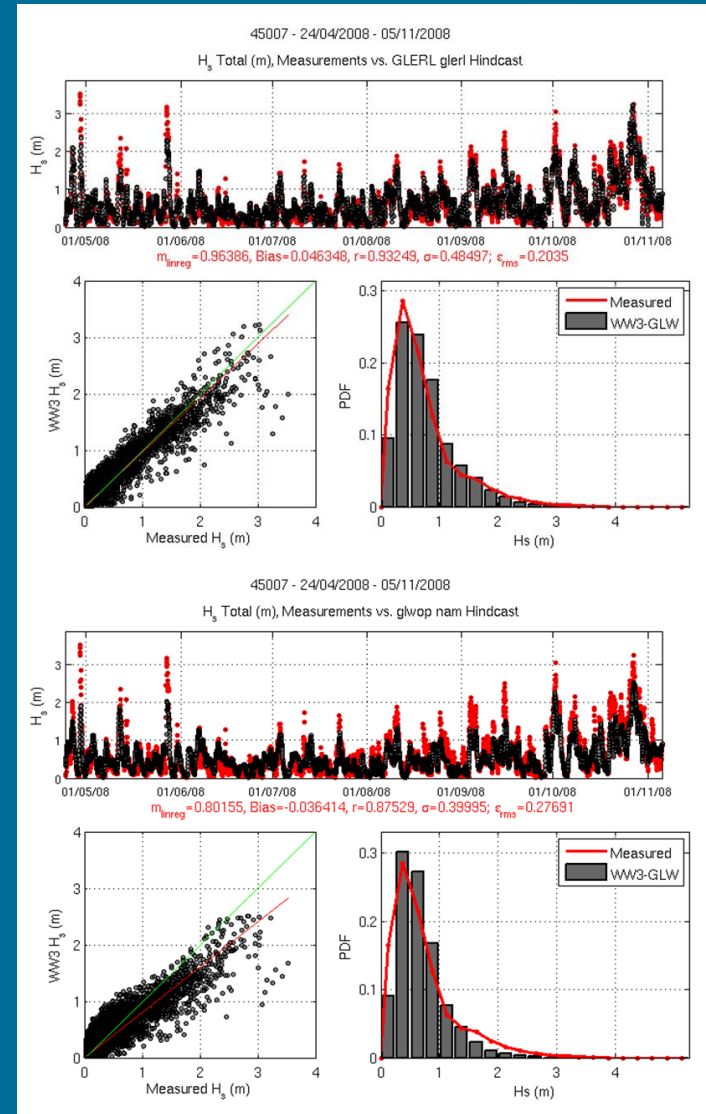
GL WFOs suggest using NDFD winds to overcome low wave heights during storms

2009: Operational implementation of the GLWN

- A new model was born: 2nd wave system for GL,
- Identical settings to GLW/NAM: shared spectral resolutions, spatial grids, ice coverage etc,
- Staggered schedule: 03Z, 09Z, 15Z and 21Z,
- Extended forecast horizon (up to 144h).
- Results for severe storms still unremarkable

The Middle Ages: Chasing GLERL

- GL WFOs indicated GLERL wave model superior to WW3
- Developers outlined reasons
 - Main hypothesis: TC 96 source terms:
 - Limitations in short fetches, early growth and rapidly changing/intensifying winds,
 - TC96 tuned in WAVEWATCH III to provide good predictions of deep-water H_s (m),
 - Poorer performance in basins with short, irregular wind fetches,
- Conclusions
 - TC96: major obstacle in making the GLW model a reliable source of wave forecasts, particularly during severe sea-states,
 - GLERL wave model, the dinosaur that eluded extinction...





Winds of Change

Great Lakes Wave (GLW) Forecast System

- No upgrades since 2009...
- System largely unused by NWS forecasters.
- In contrast, many new developments in wave model technology
 - New physics parameterizations dealing with shorter fetches
 - New grid types more adequate for complex basins, with smaller scale features (curvilinear, unstructured).
- Higher resolution wind fields available
 - NAM 4km
 - Envisaged: NDFD 2.5km
- A keen Developer, a committed SOO

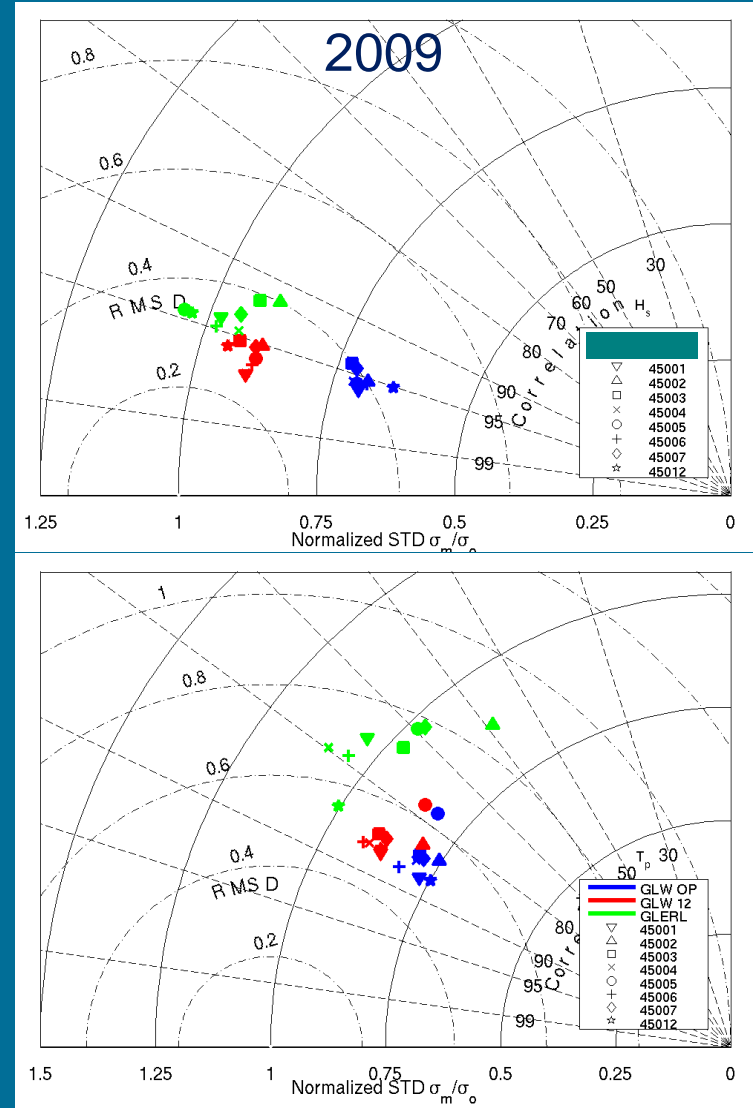


Renaissance of 2011: GLW Reborn

- Taking advantage of new technology in WW3, tests made to prove TC96 was main problem
 - Newly developed Arduin et al (2010) physics package:
 - New wind input source term
 - New term for dissipation due to wave breaking.
- Establishment of a development team led by NCEP, Detroit SOO (GL WFO POC), and GLERL
 - Numerical experiments, challenging GLW model configuration,
 - GLERL surface wind analyses: minimize uncertainties, emphasize differences in model runs,
 - GLERL wave model outputs as a reference (e.g., can we put this dinosaur to rest?)

The GLW System Reborn

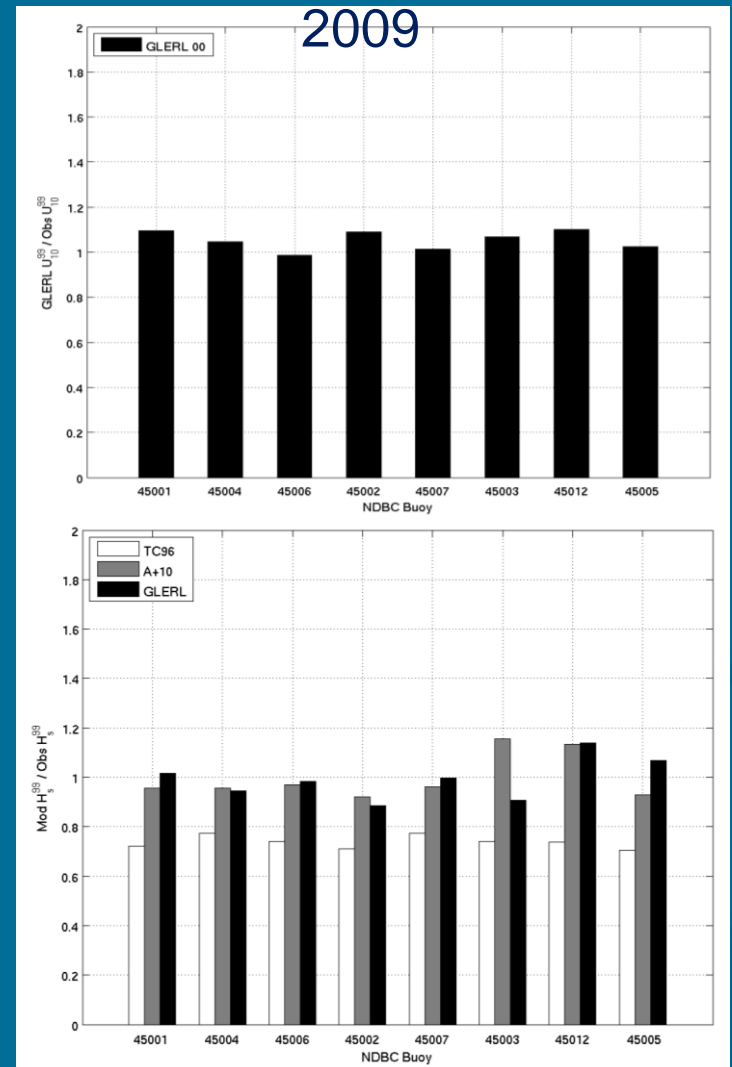
- WW3 with A+10 Physics
 - Breakthrough-level improvement to GLW in term of Hs
 - Improved GLW's already good bulk statistics (bias, RMS error, correlation)
 - Matched GLERL STD
 - Higher precision in tracking observations
 - Much improved wave periods relative to GLERL



Bridging the Severe Storm Gap

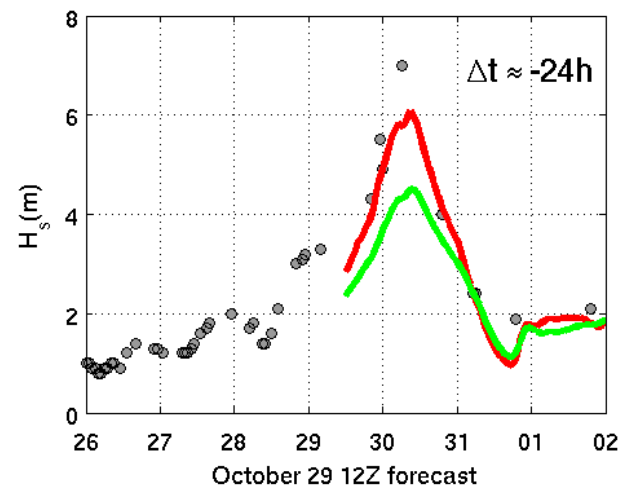
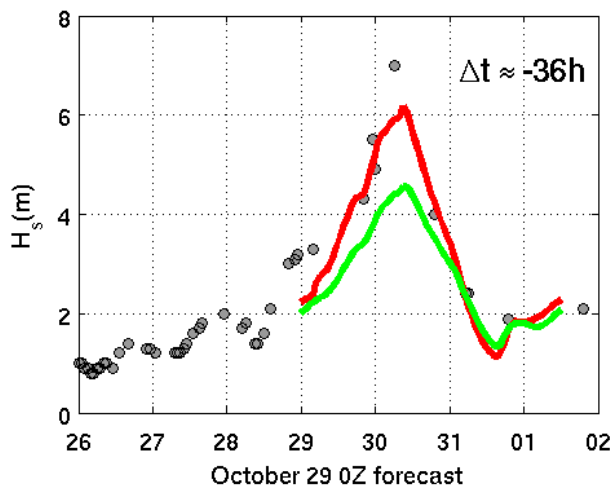
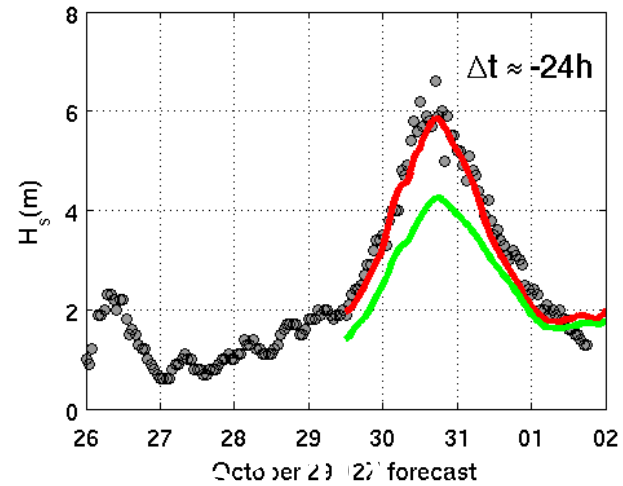
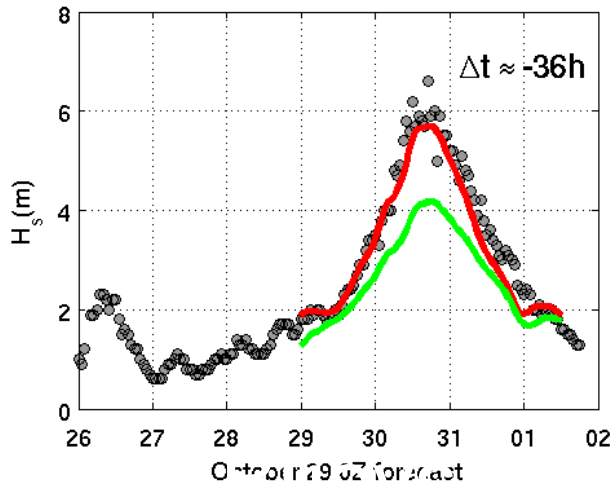
Performance in Severe Storms

- Metric: 99%, normalized by obs
- GLERL wind analyses have a superb quality
 - great accuracy in upper wind speeds at 99%
- WW3 with A+10 Physics
 - Breakthrough-level improvement in predicting 99% wave heights



GLW Nailing a PTS: Sandy Waves

NCEP Great Lakes Wave Models, Forecasts during Post-Tropical Storm Sandy, Oct 2012



* EMC Parallel better, awaiting implementation



Publications

- The GLW taskforce published a paper with main results of effort in Weather and Forecasting (2014)

Jose-Henrique G. M. Alves, Arun Chawla, Hendrik L. Tolman, David Schwab, Gregory Lang, and Greg Mann, 2014: The Operational Implementation of a Great Lakes Wave Forecasting System at NOAA/NCEP. *Wea. Forecasting*, **29**, 1473–1497.
doi: <http://dx.doi.org/10.1175/WAF-D-12-00049.1>

The Operational Implementation of a Great Lakes Wave Forecasting System at NOAA/NCEP*

Jose-Henrique G. M. Alves

System Research Group Inc., and NOAA/NCEP/Environmental Modeling Center, College Park, Maryland

Arun Chawla and Hendrik L. Tolman

NOAA/NCEP/Environmental Modeling Center, College Park, Maryland

David Schwab and Gregory Lang

Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan

Greg Mann

NOAA/NWS/Weather Forecast Office, Detroit, Michigan



Q1FY14 GLW Upgrade

GLW system (NAM and NDFD) upgrades

- New physics package
 - Replacement of TC96 with A+10
- Unification of systems
 - One GLW, two configs
 - Systems were run as separate jobs by NCO, were unified for better maintenance, usage of resources,
 - GLW/NAM (“early”) + GLWN/NDFD (“late”)
 - 4 + 4 Cycles/day (early, glw; late; glwn)
- HR regular spherical grid
 - 0.05 x 0.035 (~4km), 327 x 235
 - Single domain covering all major lakes (Superior, Michigan, Huron, Erie, St. Clair)



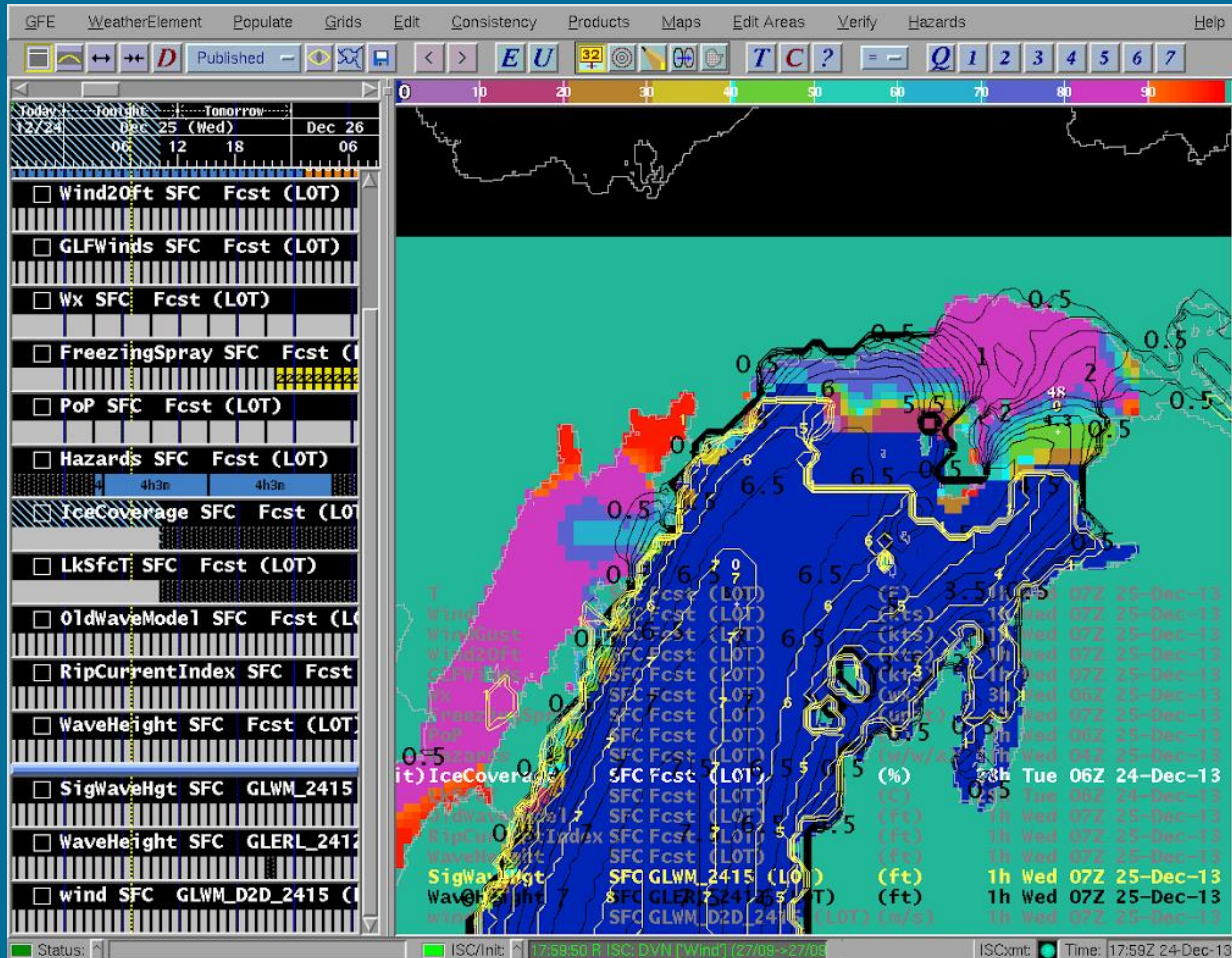
Collaborating Towards a Better GLW

Planning for the FY15 Upgrade: Constructive Dialog

- **Intense feedback from field offices in GL**
 - New system finally caught your attention!
 - Sometimes heated debate...
 - Generally very constructive outcomes,
 - Priority of development work to issues relevant to forecasters.
- **WFO alerted for several issues**
 - GLW still using ice “concentrations” from NAM model,
 - Turns out ice in NAM is a very conservative ice mask,
 - Bug unnoticed: no validation data (buoys pulled), and little feedback from field,
 - NDFD wind update cycles skipped.

The Ice Concentrations Bug

- The ice concentrations bug (courtesy of Eric Lenning, Chicago, IL)



The NDFD Mosaic

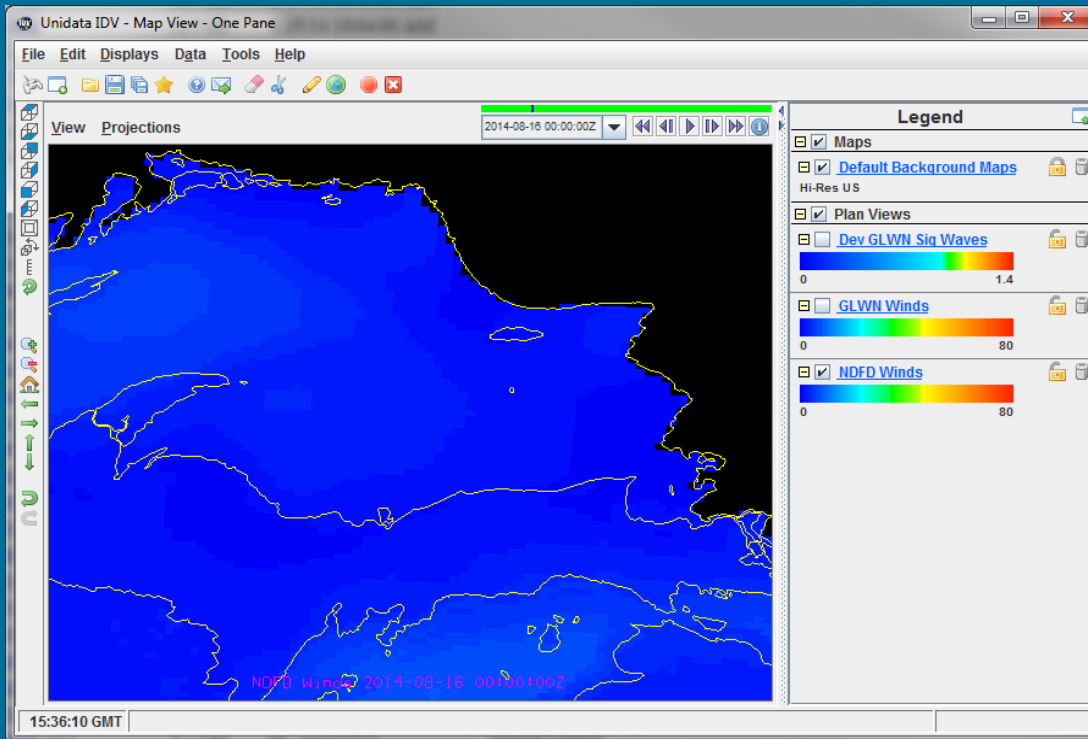
Several bugs were found in the process

11 WFOs (DLH MQT APX GRB MKX LOT IWX GRR DTX CLE BUF) send data to MDL, then to NCEP



- **Files were clobbered, duplicate records, missing data**
 - Issue with file names at NCEP: only hour, records arriving at H:01 and H:59 were jammed into the same file → Added minute to name
- **Transition to 2.5km: files much larger, delivery not on time for GLWN runs**
 - MDL servers too old, network without required bandwidth
 - Tim Boyer reshuffled send times, GLWN runs delayed (not ideal)
- **NDFD mosaic not covering lake points at Canadian coasts**

The NDFD Mosaic



- NDFD mosaic not cover lake along Canadian coast
 - Courtesy Mike Dutter (Marquette, MI)
- Unrealistic Hs
- Winds were masked in GLW
 - Solved Hs error
- Persisting issue?



Q2FY15 Development Cycle

Development Path for New Upgrades

- **Other persisting sticky issues**
 - GLW still using ~4km grids (no nearshore value),
 - GLW still using 12km NAM (4km available),
 - GLWN still using 5km NDFD (2.5km available),
- **Alongside WFOs, prioritized item to be upgraded**
 - Higher resolution wind intake: 5km to 2.5km NDFD
 - Higher resolution wave model grid, outputs: ~4km to ~2km
 - Intake of ice concentrations instead of sea-ice mask.

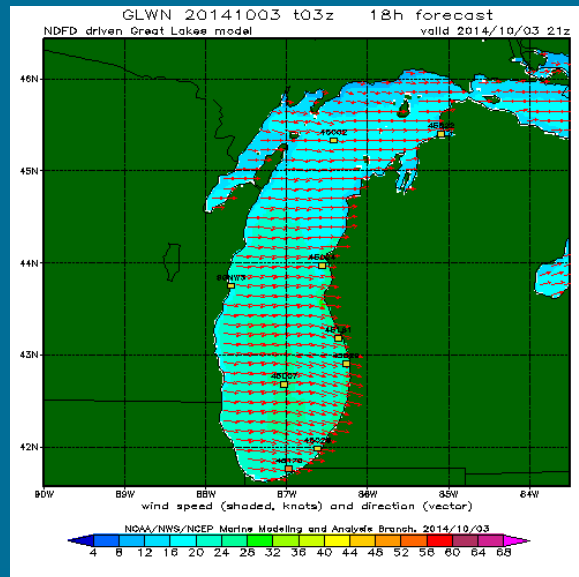
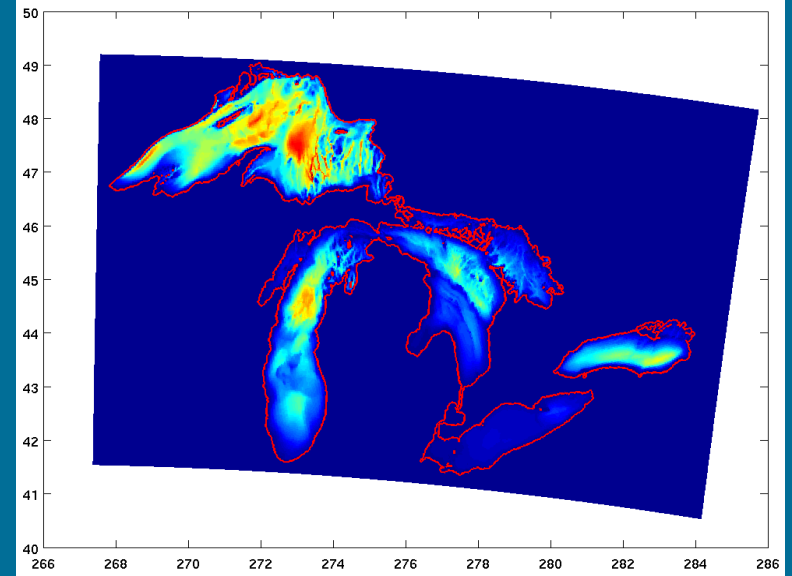
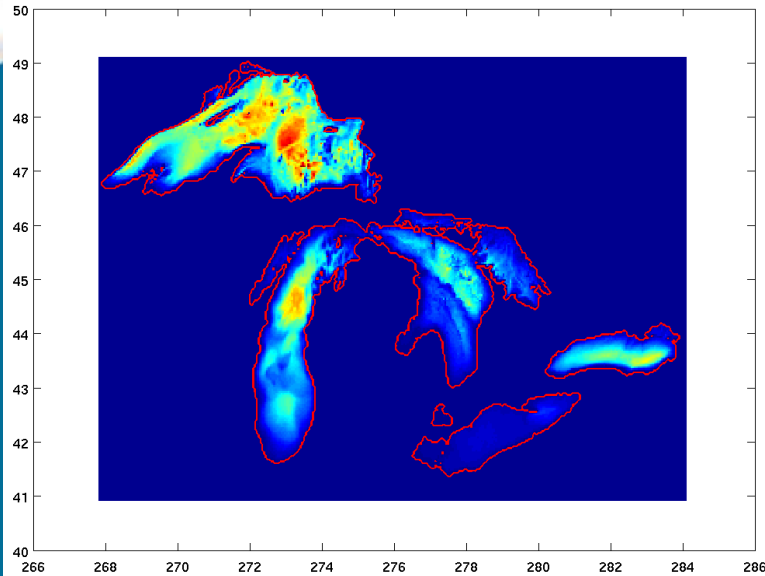


Tests for the Q2FY15 Upgrade

Impact of spatial resolution increase

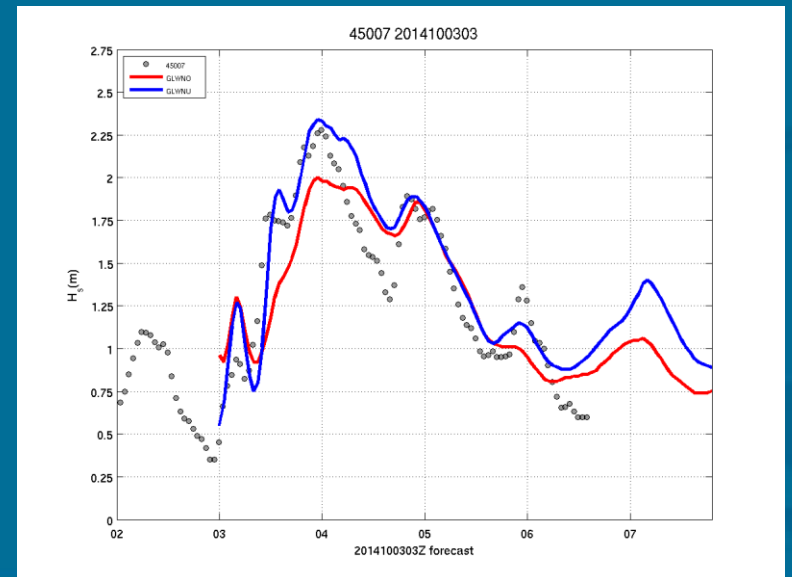
- Old Grid (lon x lat): 0.05 x 0.035 (~ 4km), 327 x 235,
- New Lambert Conformal Grid: 2.5km, 688 x 468.

The GLW Curvilinear Grid



Effect of
higher
resolution grid

Strong
westerlies
Oct 3rd 2014





Tests for the Q2FY15 Upgrade

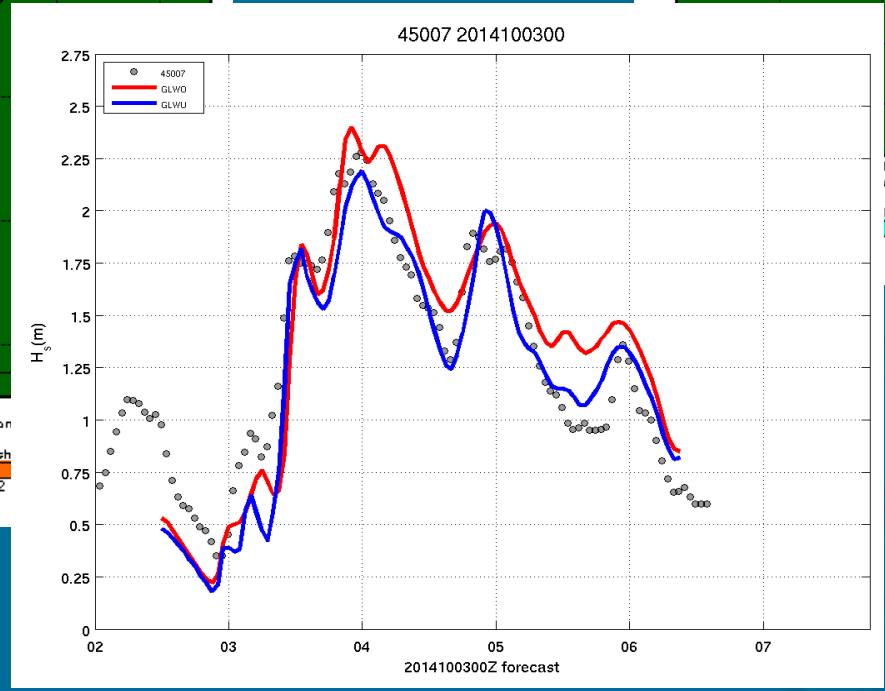
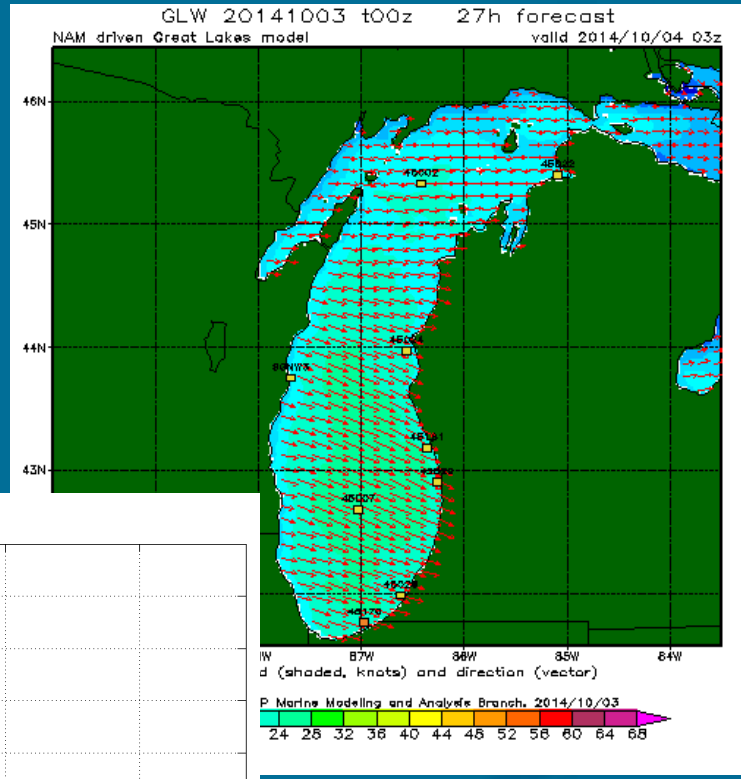
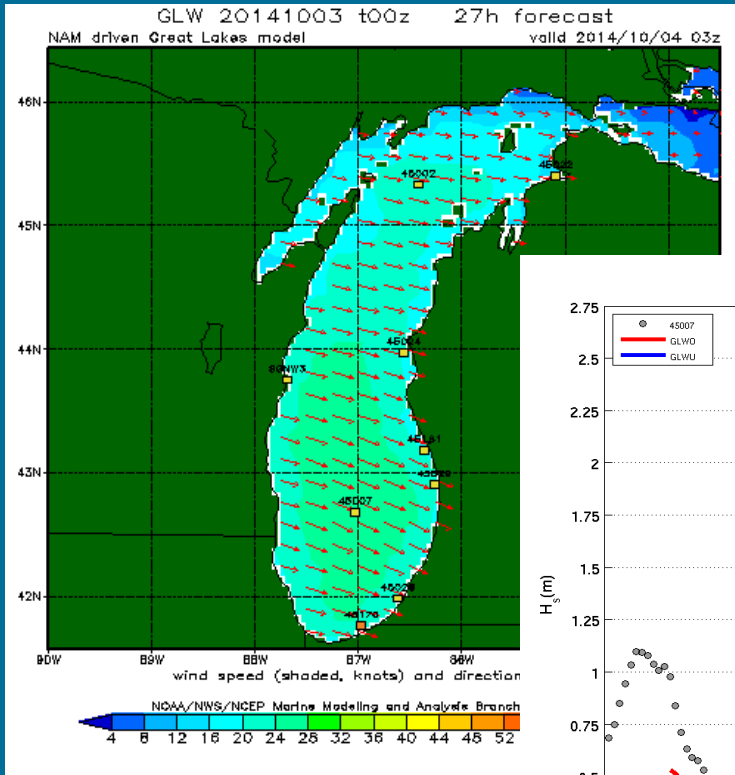
Assessment of intake of new wind data from NAM

- Up to then, GLW used 12km NAM data up to 84h
- Changed to a combination of NAM smartinit at 2.5km and 5km to 84h
 - 0-36h 1hrly 2.5km (from 4km NAM)
 - 39-60h 3hrly 2.5km (from 4km NAM)
 - 63-84h 3hrly 5km (from 12km NAM)



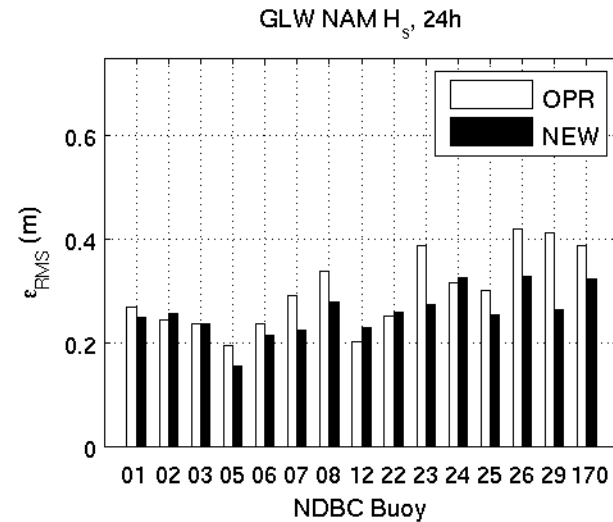
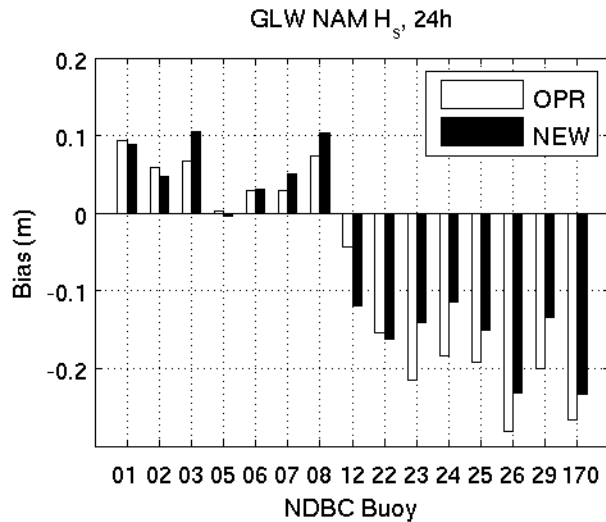
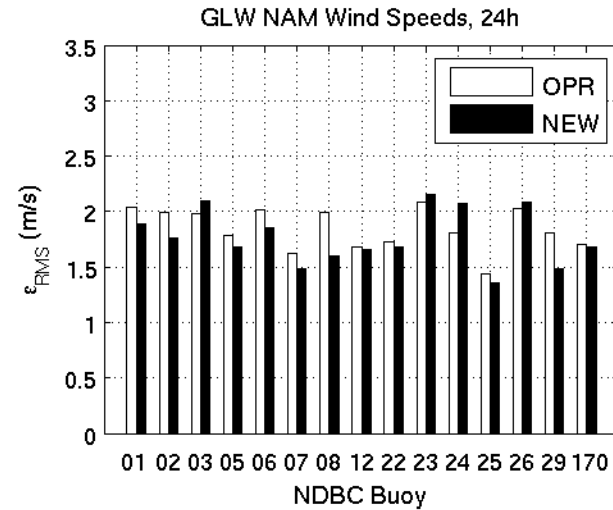
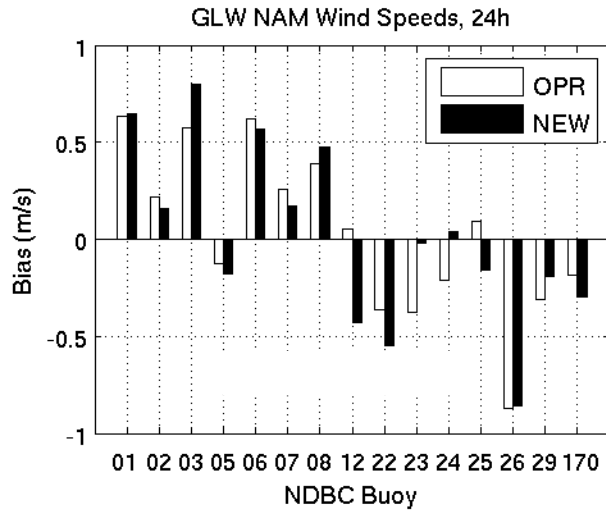
Tests for the Q2FY15 Upgrade

- Impact of a change in winds
 - Current operations: 12km NAM
 - Upgrade: 2.5km from NAM 4km





Tests for the Q2FY15 Upgrade





Tests for the Q2FY15 Upgrade

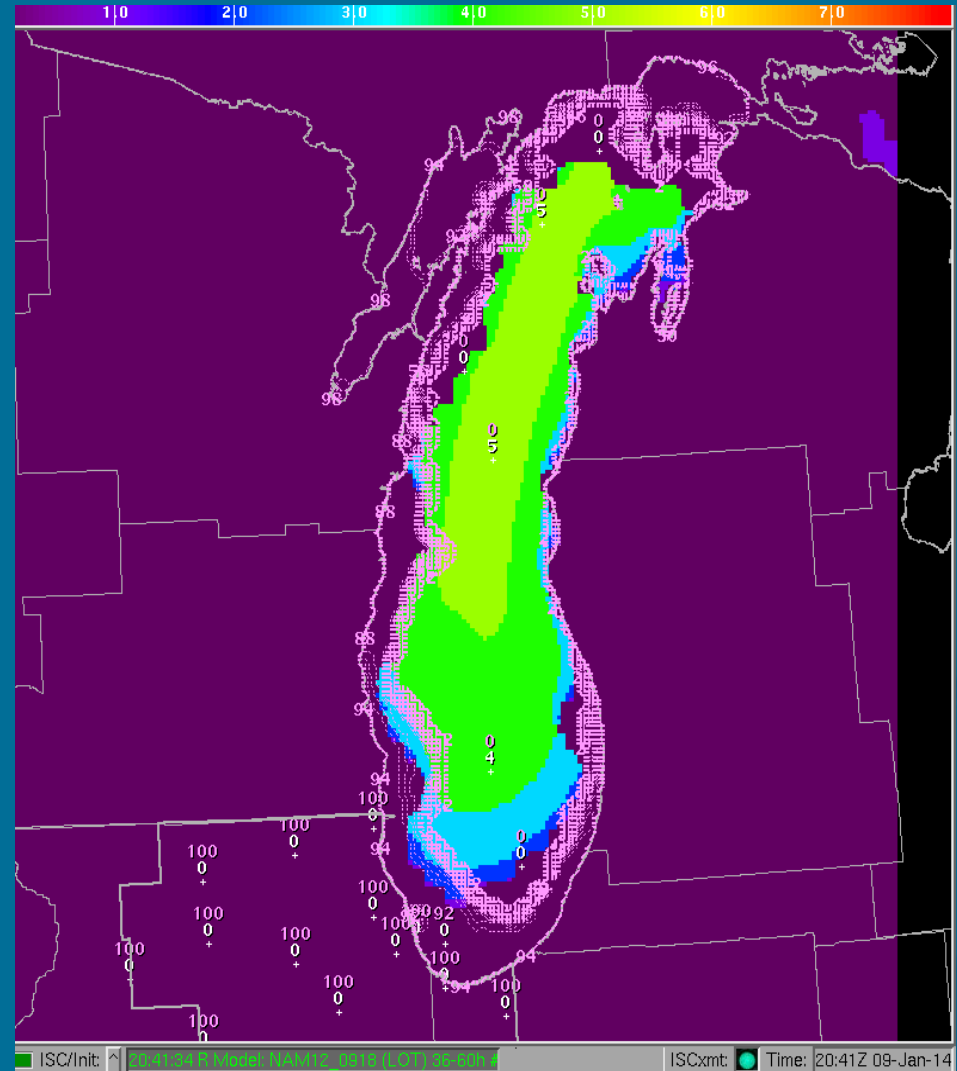
Intake of new ice concentrations

- Initially using NAM ice mask (no actual concentrations),
- Change to NIC concentrations, and climatology + IMS mask fallback,

- Work in collaboration with Bob Grumbine

Tests for the Q2FY15 Upgrade

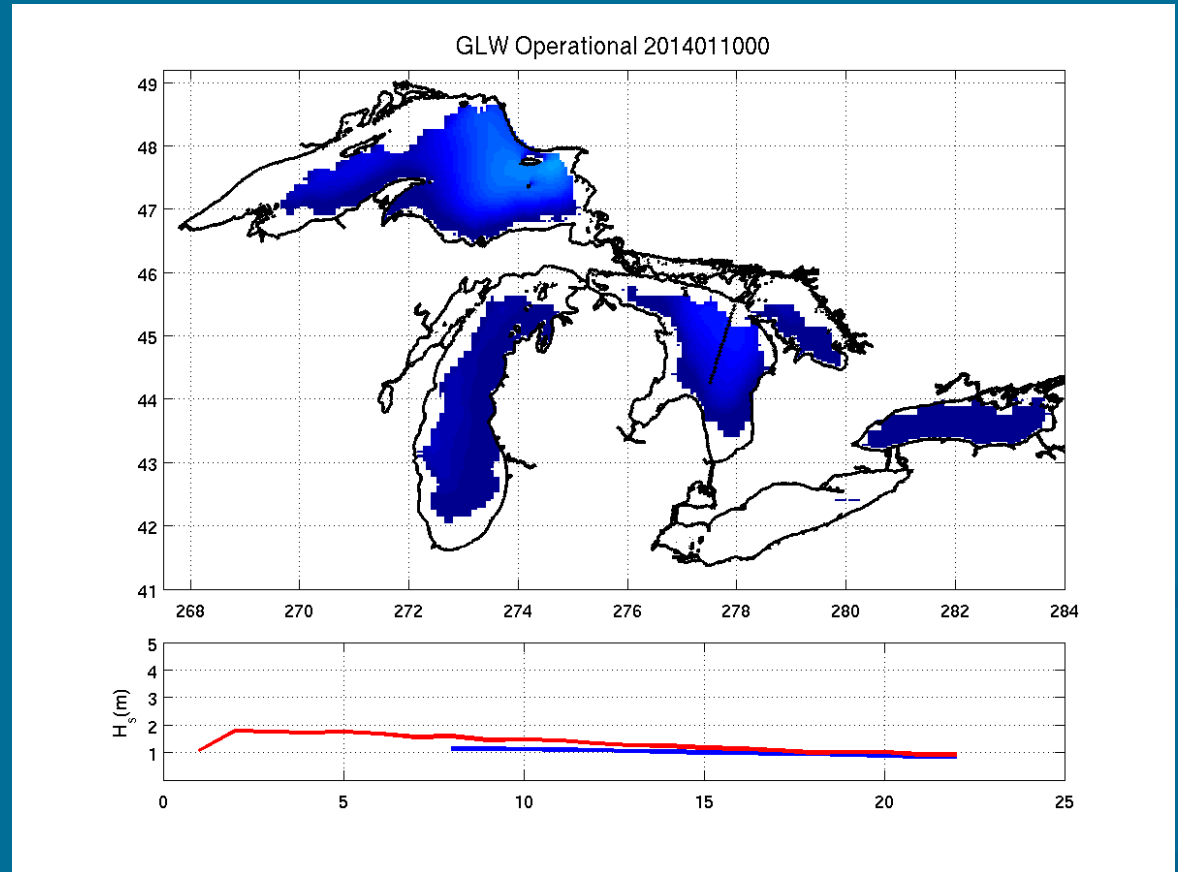
- Ice concentrations bug
 - Image provided by Eric Lenning (Chicago SOO): focal issue
 - NAM ice mask (IMS) is extremely conservative
 - Large areas where there should be waves are masked out



Tests for the Q2FY15 Upgrade

Intake of NIC ice concentrations

- Verification of new approach for Jan 2014
- Hs swath from altimeter track
- New approach provides better description of measured swath
- Actual Hs value from altimeter requires investigation





The Q2FY15 Upgrade

What changed

- **Spatial resolution increased from ~4km to 2.5km**
 - Old Grid (lon x lat): 0.05 x 0.035 (~ 4km), 327 x 235
 - New Lambert Conformal Grid: 2.5km, 688 x 468
 - Matches point-by-point NDFD and NAM-smartinit grids at the lakes
 - Request from WFOs: higher resolution near coastal regions
- **Intake of new wind data from NAM**
 - Old GLW used 12km NAM data up to 84h
 - Changed to combination of NAM smartinit at 2.5km, 5km to 84h
- **Intake of new ice concentrations**
 - Old GLW: NAM ice mask (no actual concentrations)
 - Changed to NIC concentrations, and climatology+IMS fallback.



The Q2FY15 Upgrade

Achieved benefits

- Significant improvement resolving coastal features
 - Including better representation of nearshore wind fetch geometry.
- Improve storm wave forecasting and nearshore wave growth
 - Higher resolution wave model grid and NAM wind input.
- Improve wave forecasts in when ice present (Winter)
 - Improved ice concentration data intake
- Extension of GLWN to forecast hour 147
 - Attend Great Lakes WFOs current requirements.

Implemented: 28 January 2015

- New data stream added to NOAAPORT (AWIPS): 28 April 2015



Where we are now: towards FY16

Focus for next upgrade

- Target: Q2FY16
- Problems identified by Great Lakes WFO SOOs
 - GLWN not using all relevant changes by forecasters to NDFD,
 - Nearshore wind speed bias in NAM and NDFD,
 - Nearshore wave-height bias in GLW and GLWN,
 - Ice concentrations inconsistencies, 5km grid,
 - Not fully resolving coastal features important to some WFOs,



Upcoming Q2FY16 Upgrades

Mitigation Plan

- Changes being made to GLWN system
 - NDFD mosaic update
 - Hourly GLWN runs to 36h + current cycles
 - *Will require shutting down GLW (NAM) cycles*
 - Nearshore wind bias
 - Downscaling (NAM and/or Greg Mann)
 - Nearshore wave bias
 - Alternative source-terms (focus shallow water physics),
 - Ice concentrations
 - Requested NIC, HR files with concentration and thickness
 - Coastal features
 - HR curvilinear grid 1.25km or unstructured grid



Beyond Q2FY16 Upgrades

Future plans

- **GLWENS - Great Lakes Wave Ensemble System**
 - Tandem with Environment Canada,
- **Great Lakes RTMA wind and wave analyses,**
- **Data assimilation using buoys and altimeters,**
- **Add Water levels,**
- **Addition of a fully coupled deterministic system (so-called “next-gen system”), Great Lakes suite becomes:**
 - GLWN hourly SRF,
 - GLWENS – with combined NWS/EC products,
 - Coupled WW3/fvcom/WRF.



GLW Q1FY16 Upgrades

Questions, Suggestions, Requests?



Base FVCOM grid being used to develop a specialized wave model grid for hourly GLWN runs (courtesy Eric Anderson, GLERL/NOAA).