



# USACE WAVE INFORMATION STUDY (WIS)

A multi-decade hindcasts to meet tomorrow's coastal engineering needs today

**WIS Team:** Catie Dillon, Mitch Brown, Bob Jensen (Emeritus),  
Mary Bryant ,Ty Hesser, Ali Abdolali, Tripp Collins

[WISInfo@usace.army.mil](mailto:WISInfo@usace.army.mil)

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Catie Dillon

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# USACE WAVE INFORMATION STUDY (WIS)

## Overview

1. WIS Description and Purpose
2. History of WIS
  1. WIS Origin
  2. Wind Specification
  3. Modeling Technology
  4. Computational Platforms and Operations
3. WIS Operations
4. WIS Evaluations
5. WIS Applications and Projects
6. WIS Portal Walkthrough
7. WIS Future: NuWIS



# USACE WAVE INFORMATION STUDY (WIS)

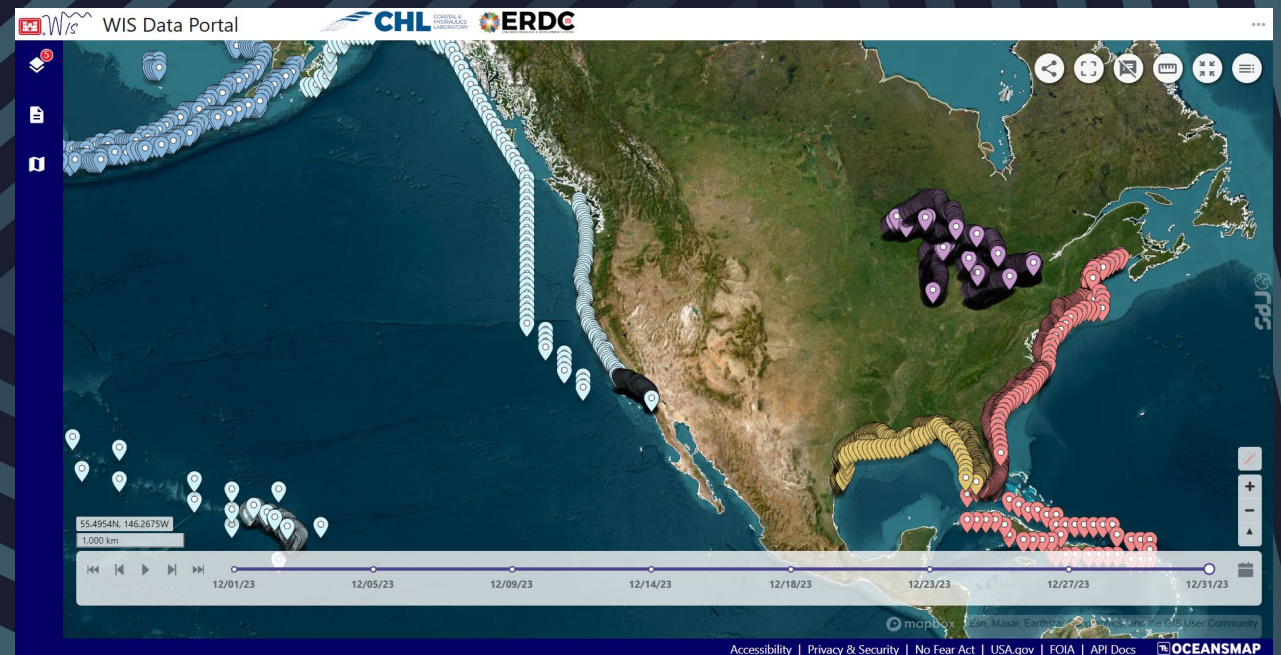
## WIS Description and Purpose

### What is WIS?

- A national resource of long-term wave climatologies for all U.S. coastal waters funded through the Coastal Ocean Data System (CODS) program.

### Why do we need WIS?

- USACE needs wave information for any coastal project
- In-situ observations cannot be placed everywhere and there are gaps in the data coverage due to O&M, funding, and catastrophic events. WIS's mission is to fill the spatial and temporal gaps.



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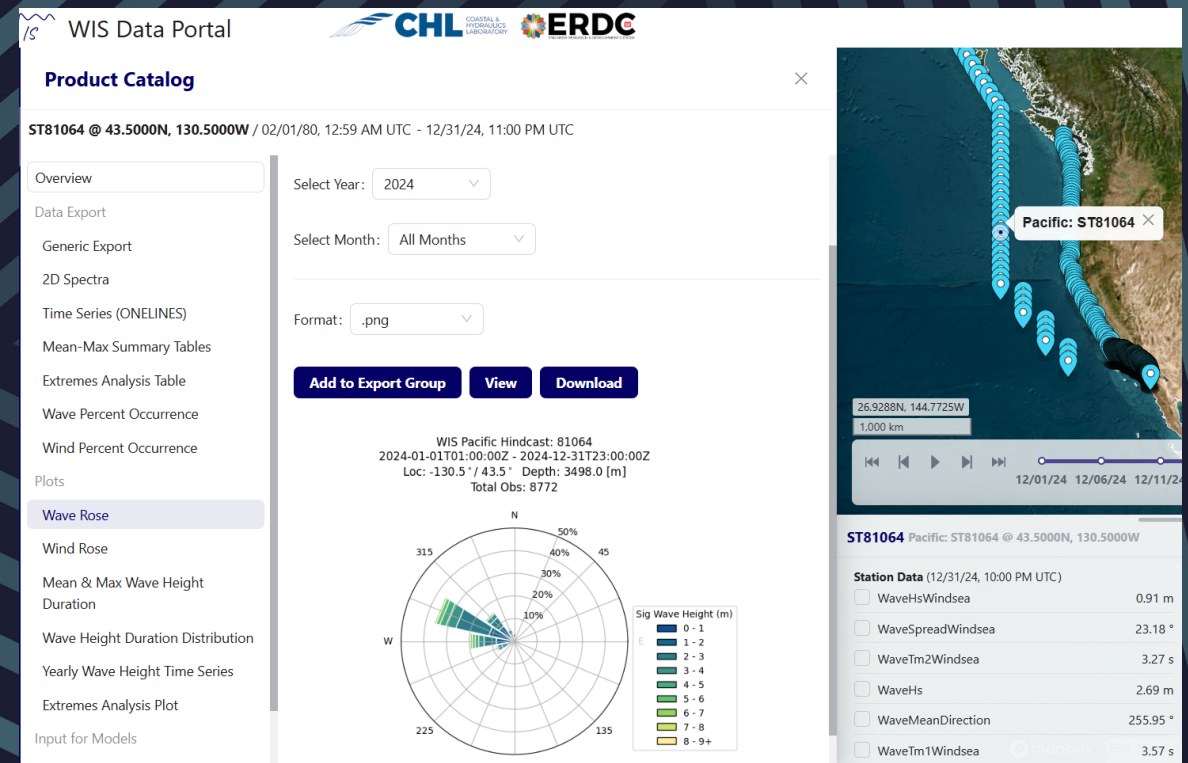
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# USACE WAVE INFORMATION STUDY (WIS)

## WIS Description and Purpose

### What are the products of WIS?

- WIS provides wave estimates along all US coasts, including the Great Lakes, US Territories, Alaska, and Hawaii.
- The hindcast is updated annually.
- Hindcast wave estimates are provided as both files and plots, easily accessible via the WIS data portal, Thredds server or API.
- Wave estimates include up to 25 integral wave parameters describing the wave height, period, and direction at output locations
- Directional wave spectral output is also available



# USACE WAVE INFORMATION STUDY (WIS)

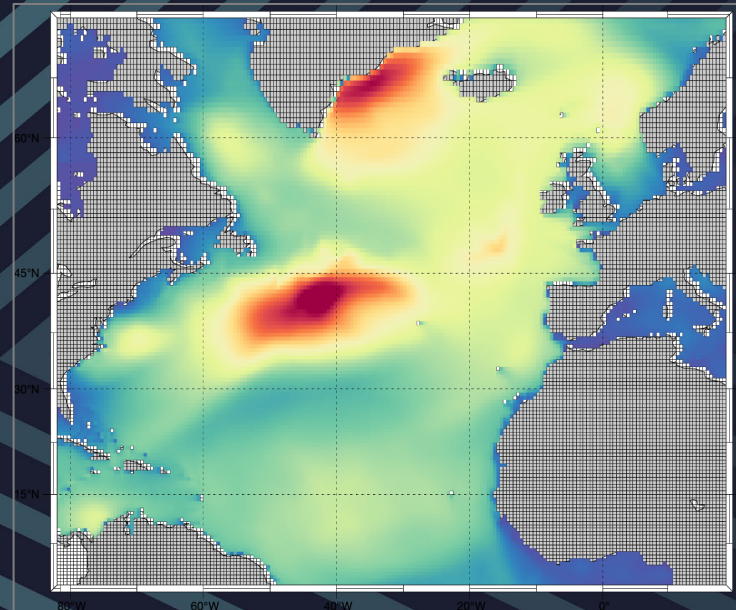
## WIS Description and Purpose

### How is the WIS hindcast operated?

- WIS uses high-resolution wind and ice concentration fields, and third generation phase average wave modeling technologies.

### Why should I trust the outputs of WIS?

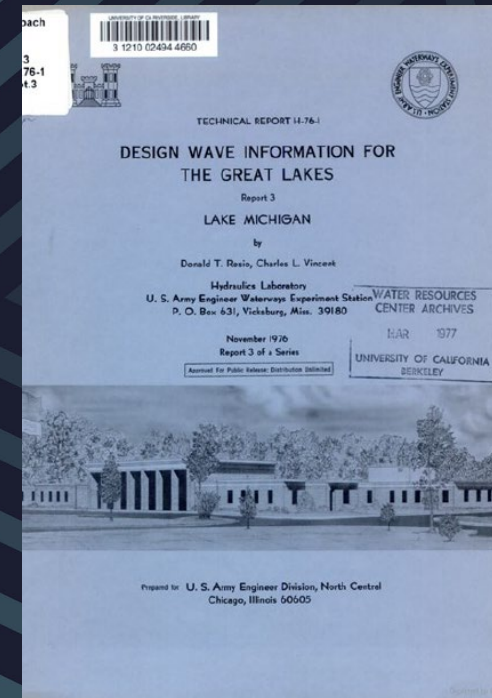
- WIS is evaluated to point-source measurements, drifter buoys, and satellite-based altimetry, to ensure that we provide high quality wave estimates.



# USACE WAVE INFORMATION STUDY (WIS)

## History of WIS: Origins

- Started in early 1970's with reimbursable work in the Great Lakes by Donald Resio and Charles Vincent
- As other districts and divisions became interested in the work, WIS expanded.
- ~1979 WIS became an established Work Unit and with the collaboration and establishment of the Scripps Institute Coastal Data Information Program (CDIP), the WIS hindcast was able to improve with the placement of long-term measurement sites for evaluation.
- The WIS hindcast development, methodology, and results were published as a series of 36 reports from 1980 to 1996.



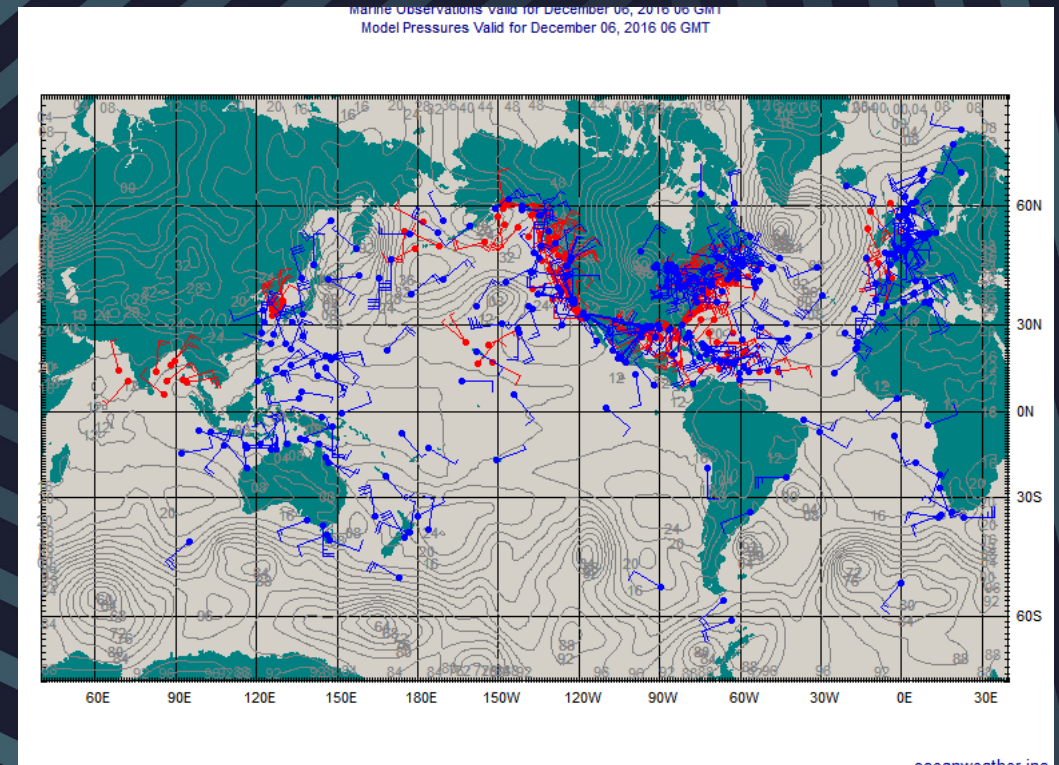
First of the WIS Reports by Resio and Vincent



# USACE WAVE INFORMATION STUDY (WIS)

## History of WIS: Wind Specifications

- Interpolated from land-based meteorological stations (Great Lakes)
- Generated winds from digital surface pressure archives (Atlantic)
- Used Numerical Weather Prediction wind fields (NCEP / FNMOC)
- OWI: AES-40 / MSC-50 (Atlantic)
- OWI: NCEP/NCAR Re-Analysis 1 + Scatterometer + tropical cyclones (Pacific)
- CFSR: Great Lakes
- ERA5: starting 2020



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# USACE WAVE INFORMATION STUDY (WIS)

## History of WIS: Wave Model Technologies

### WIS Model Evolution:

- 2nd Generation Deepwater Wave Model (Resio and Vincent, 1978)
- Added shallow-water mechanisms to original 2nd Generation model (~mid-1980's)
- Added wave transformation method to carry waves into coastal waters (10m)
- 3rd Generation Wave Models (WAM, WAVEWATCH III and SWAN) (1990's)

### Phase Averaged Spectral Models

- 2nd Generation wave models use parametric formulations for source terms
  - Requires tuning (for different wind field specification)
  - Sets limit on the spectral shape
- 3rd Generation wave modeling technology was developed based on the Sea-Wave Modeling Project (SWAMP)
  - Use full 2-D spectra for the source terms
  - No a priori limit to spectral shape
  - Allows the spectrum evolve based on the source terms



# USACE WAVE INFORMATION STUDY (WIS)

## History of WIS: Wave Model Technologies

- The WAMDI Group (1988) developed a community wave model WAM to be used operationally at the European Centre for Medium Range Weather Forecasts (ECMWF)
- From WAM source terms, WaveWatchIII was developed (Tolman 1997, 1999a, 2009)

All 3<sup>rd</sup> generation phase averaged spectral wave models solve the Energy (or Action) Balance Equation for the time rate change in a two-dimensional wave spectrum given by  $F(f,\theta,x,y,t)$

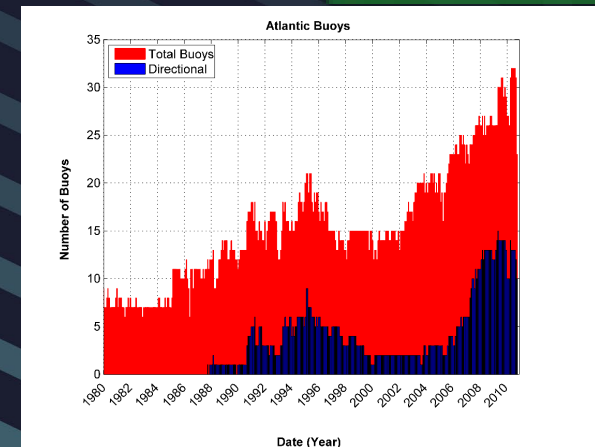
$$\underbrace{\frac{\partial F}{\partial t} + \vec{C}_g \cdot \nabla F}_{\text{Advection}} = \sum_{i=1}^n S_i = S_{TOT} = \underbrace{S_{in} + S_{ds} + S_{nl} + S_{w-b} + S_{br} + \sum_{j=1}^m S_j}_{\text{Source and Sink Terms}}$$



# USACE WAVE INFORMATION STUDY (WIS)

## History of WIS: Computational Platforms and Operations

- Computer platforms limited in the 1970's – 1990's
  - Memory bounded
  - No Internet / IO-magnetic tapes
  - Labor intensive
  - Expensive publication of data reports
- From the 1990's
  - Computer resources improved
  - Increased the number of WIS output stations
  - Internet established the first WIS website based on static products
  - Operations became semi-automated hindcasts (yearly updates)
- As observational measurement availability increased, WIS was able to expand its evaluation



# USACE WAVE INFORMATION STUDY (WIS)

## History of WIS: Technology Advancements

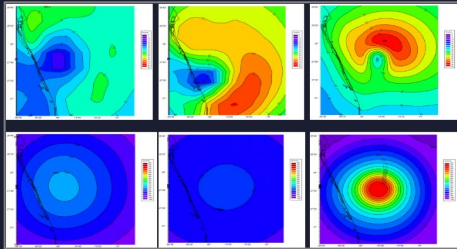
- The WIS Hindcast aims for temporal consistency
  - Wind field specification does not change over the period of record
  - Wave model technology does not change over the period of record
  - Grids and all other factors associated with the hindcast do not change
- Replacement of the WIS Hindcast Archive
  - Aware of technological advancements occurring in the waves community
  - Parallel testing and evaluations of new winds and/or new wave model technology
  - Metrics to determine the net impact of these advancements
- If improvements are found
  - The entire hindcast is re-run replacing the entire archive
  - Use of version control of the final archived set of estimates
- **REPLACEMENT PERFORMED IN 2011 FOR ALL WIS DOMAINS**



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Operations

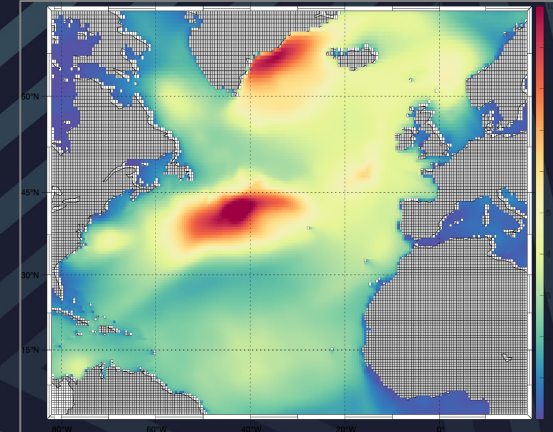
Get wind and ice fields



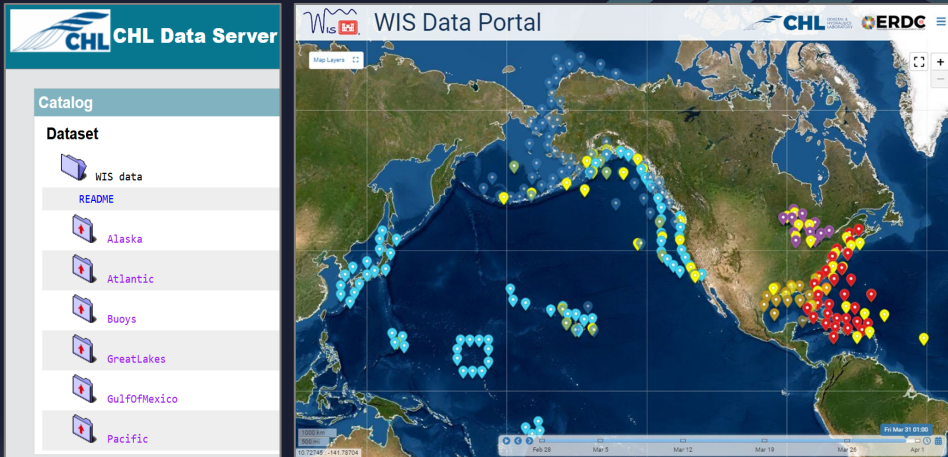
Update buoy locations for annual run



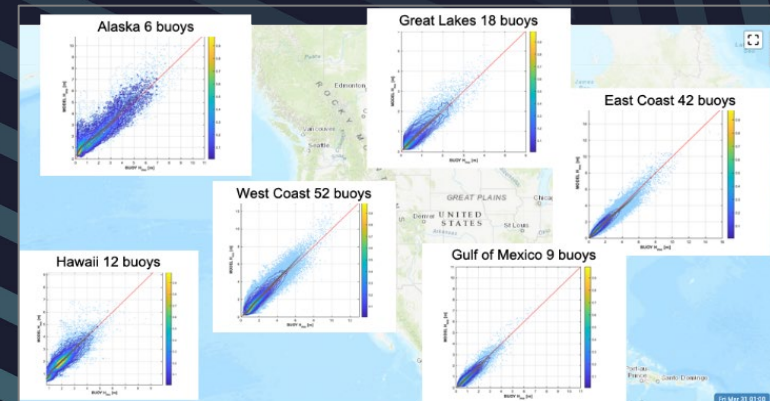
Setup and run WW3 and WAM



Update Server and Generate Products



Evaluate results



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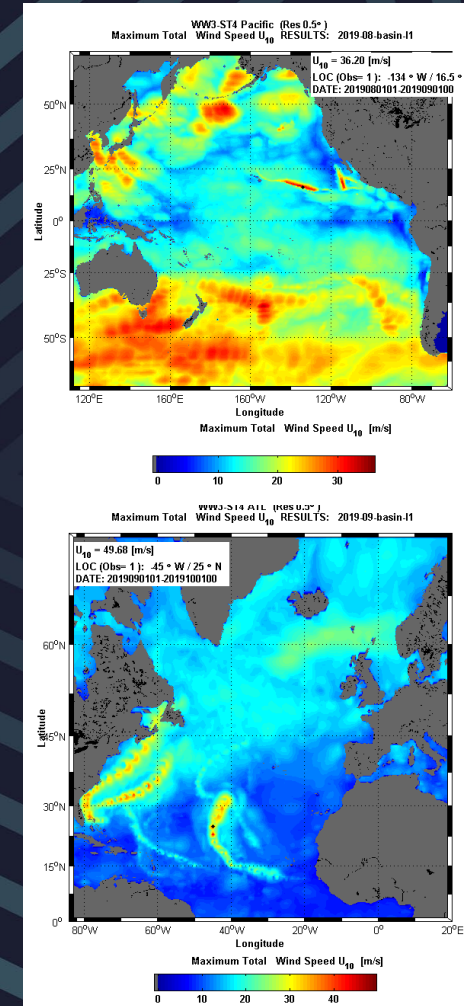


# USACE WAVE INFORMATION STUDY (WIS)

## WIS Operations: Current Wind Specification

### Atlantic, Gulf, and Pacific

- Contract Purchase
- Adapted from NCEP/NCAR Re-Analysis-1 (pre-2020) and ERA5 (post-2020) fields
- Value Added
  - Scatterometer (QUIKSCAT) adjustments (pre-2020/NCEP/NCAR)
  - Embedded tropical cyclones
  - Kinematic analysis of major storm events (~10/domain)



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Operations: Current Wind Specification

### Great Lakes

- Climate Forecast System Reanalysis: CFSR
- Interpolated to the wave model grid
- Retained the Land/Sea Mask: Terrain-Marine Interface
- Found to be spatial coherent
  - Orographic Effects
  - Steering by land masses

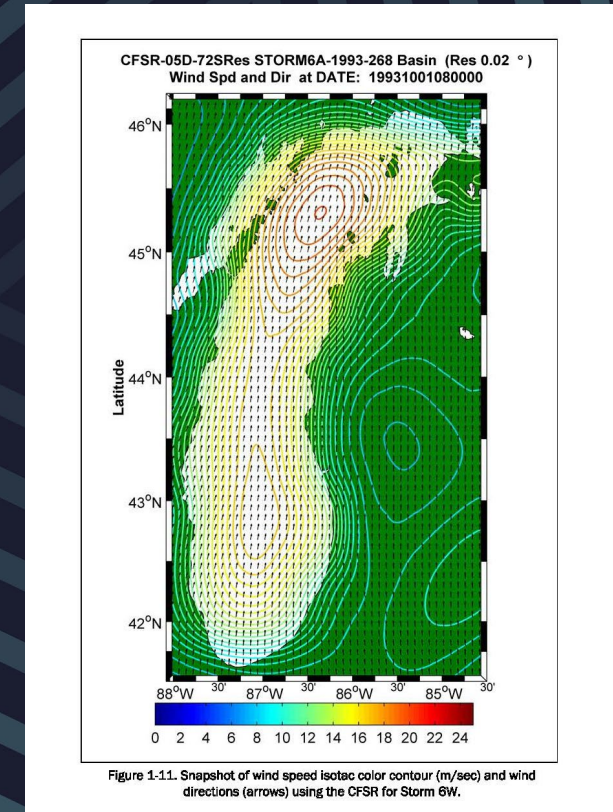
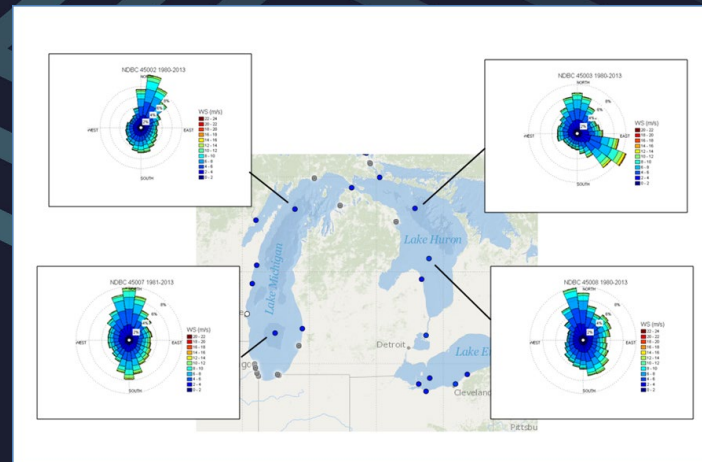


Figure 1-11. Snapshot of wind speed isotach color contour (m/sec) and wind directions (arrows) using the CFSR for Storm 6W.



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Operations: Current Ice Specification

### Western Alaska

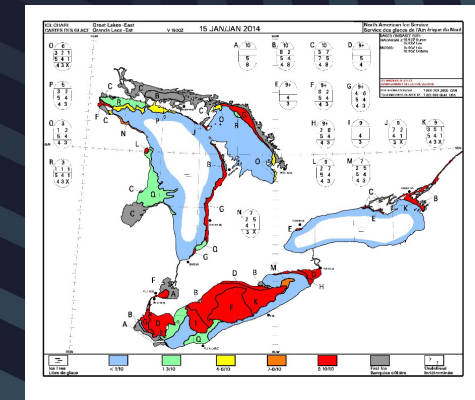
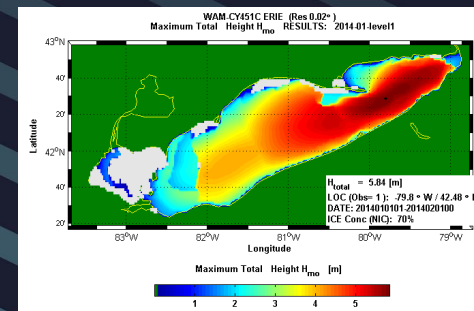
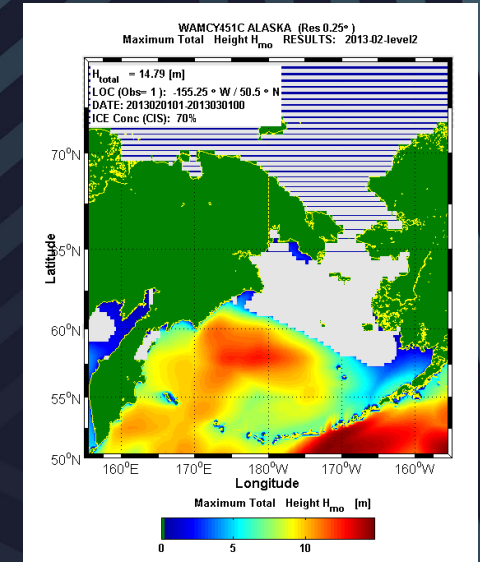
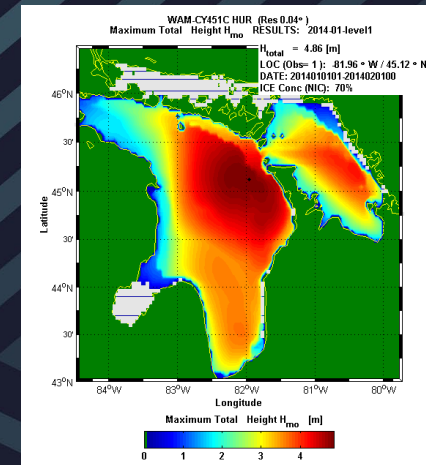
- Ice Product- Climate Forecast System Reanalysis (pre2020)
- Ice Product- ERA5 (post2020)
- Gridded ice concentration fields

### Great Lakes

- National Snow & Ice Data Center (NSIDC) ice product
- Images (verification / digital)

Set ice concentration threshold value (70%)

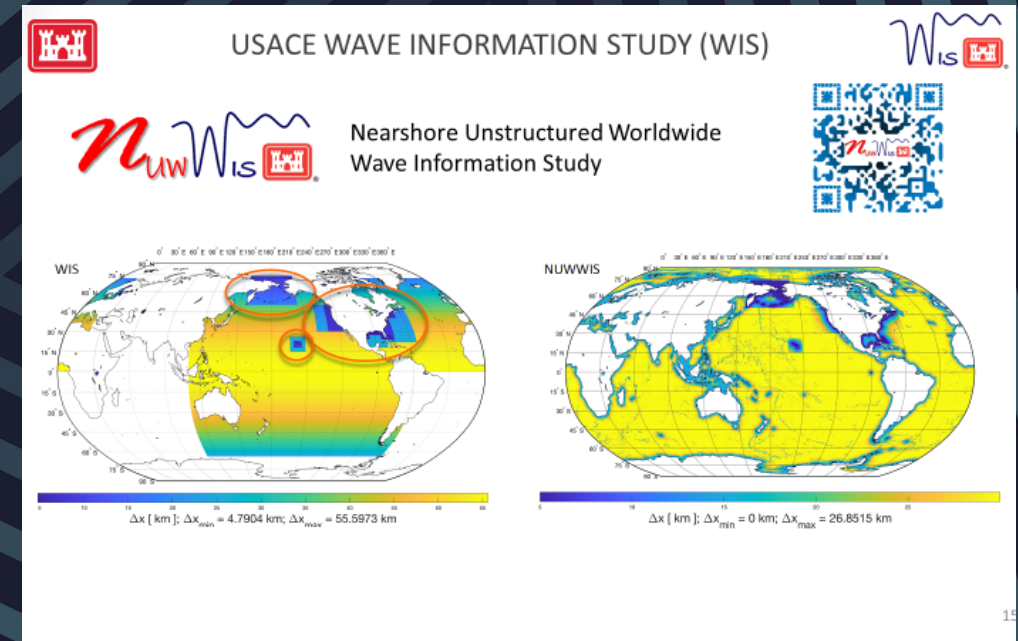
- If met or exceeded set water to land



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Operations: Current Wave Model Technology

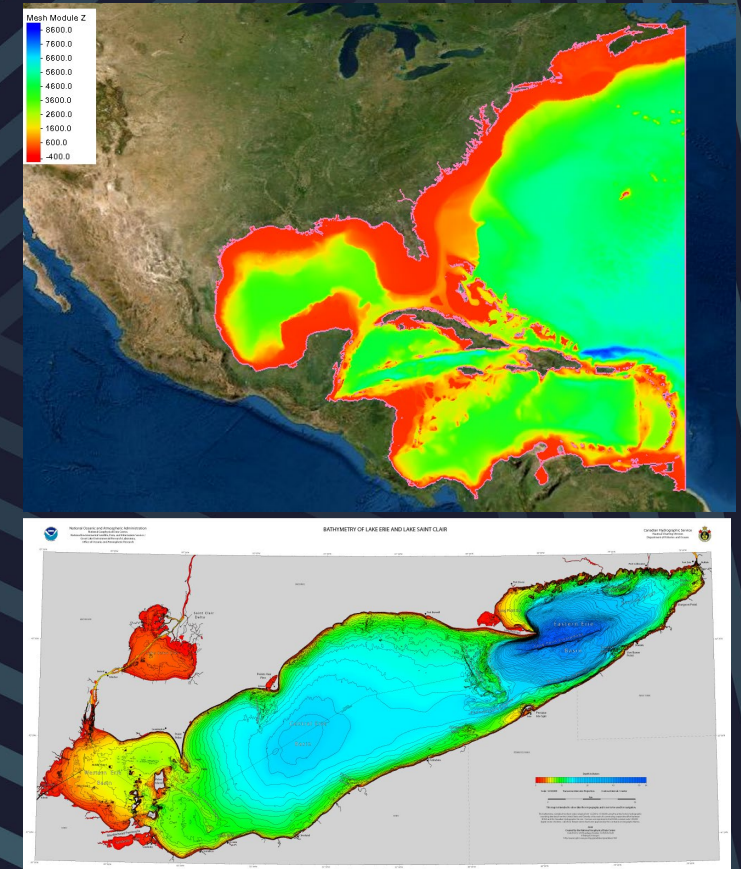
- **WAVEWATCH III:** Atlantic and Pacific
- **WAM:** Gulf / Western Alaska / Great Lakes
- Why Two Models?
  - Model evaluations were performed for each domain (3-yr POR) Model selected based on comparisons to measurements
  - At the time only WAM had ice field implementation (Western Alaska and Great Lakes)
- Current R&D effort is looking into the use of a global unstructured WAVEWATCH III domain



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Operations: Wave Model Bathymetry and Grids

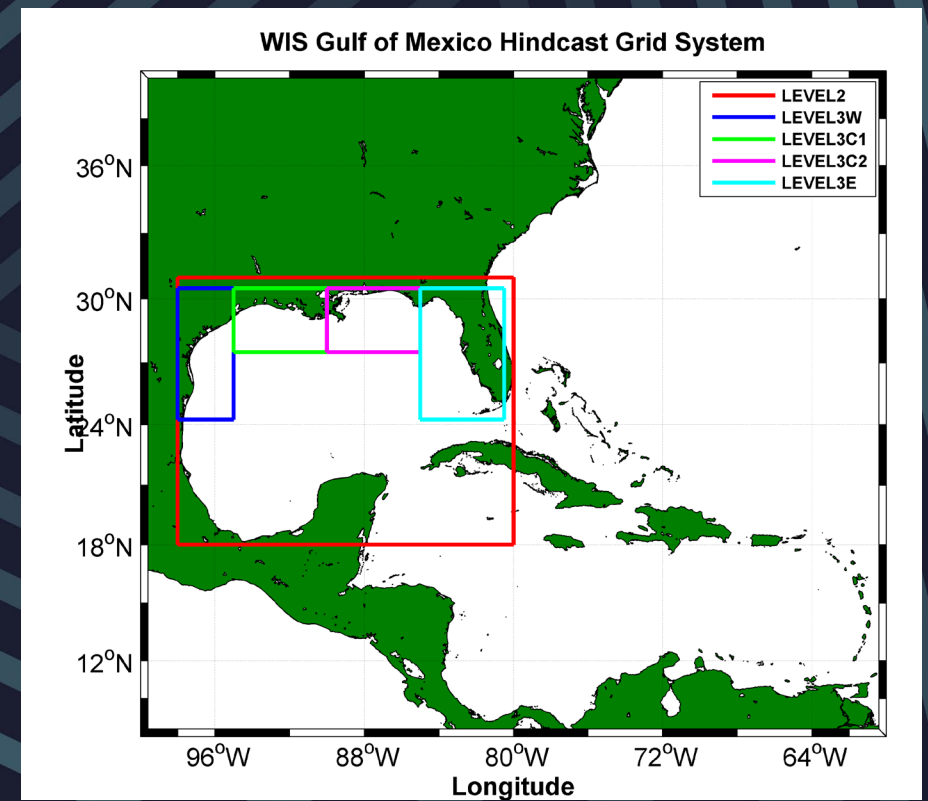
- Atlantic, Gulf of Mexico and Pacific
  - General Bathymetric Chart of the Oceans: GEBCO
  - Providing elevation data on a 15 arc-second interval grid
  - Data are an average of multiple surveys
  - Near coastal areas: GEOphysical DAta System: GEODAS
- Great Lakes
  - NOAA-GLERL (available at NOAA/NCEI)
- Resolution Selection
  - Based on processes modeled
  - Based on input wind fields



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Operations: Wave Model Nesting

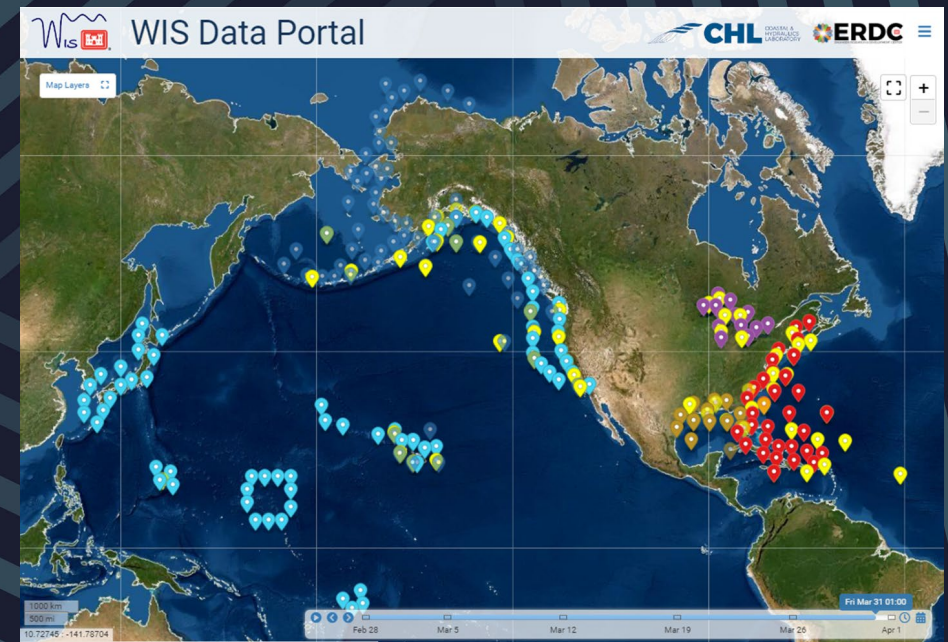
- Spherical / Cartesian Grids
  - Grid nesting minimizes computational load running wave model
  - Higher resolution coastal areas (where needed)
- Requires- 2D spectra
  - Generation of output Boundary Condition
  - Acceptance of input Boundary Condition
- Model Differences
  - WAM: one way nesting
  - WAVEWATCH III: two-way nesting



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Operations: Output Stations

- Defined by Basin/Level/Station Number
- Do not change over POR
- Threshold of water depths ~10m
- Why 10m and so far from the coast?
  - No universal consensus for finite depth mechanisms (e.g. Sw-b, Sbr, etc).
  - Temporal changes in water depth not defined (e.g. tides and surge)
  - Local effects not appropriately modeled to spatial grid resolution
  - Increase in computational requirements



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Operations: Evaluation sites

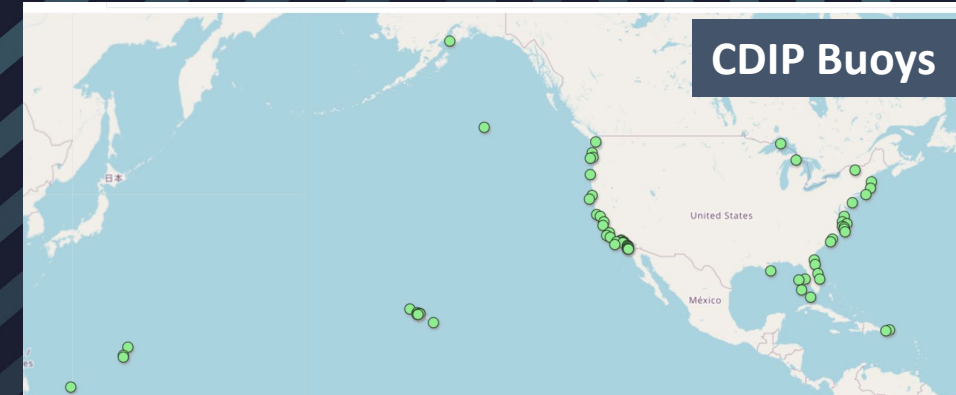
- Point source measurements (e.g. buoys)
  - NOAA National Data Buoy Center (NDBC)
  - Coastal Data Information Program (CDIP)
  - Meteorological Service of Canada (MEDS)
  - Partner sites (e.g. Federal, State, Local and University's)
- Critical to have:
  - Metadata describing the data set
  - At a minimum frequency spectra



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Evaluation: Point Source Measurement

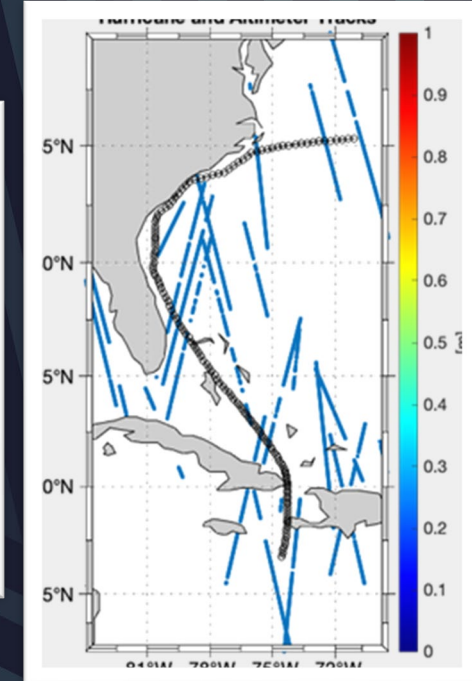
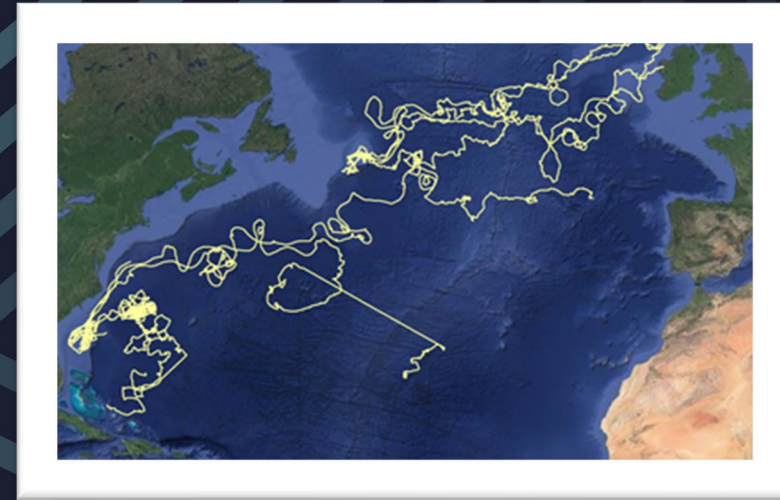
- Buoys move location over time from re-deployments
- Could move greater than the grid resolution dimension
- Need to update the evaluation site list on a yearly/monthly basis
- Minimize the errors associated with differences in positions



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Evaluation: Far Field

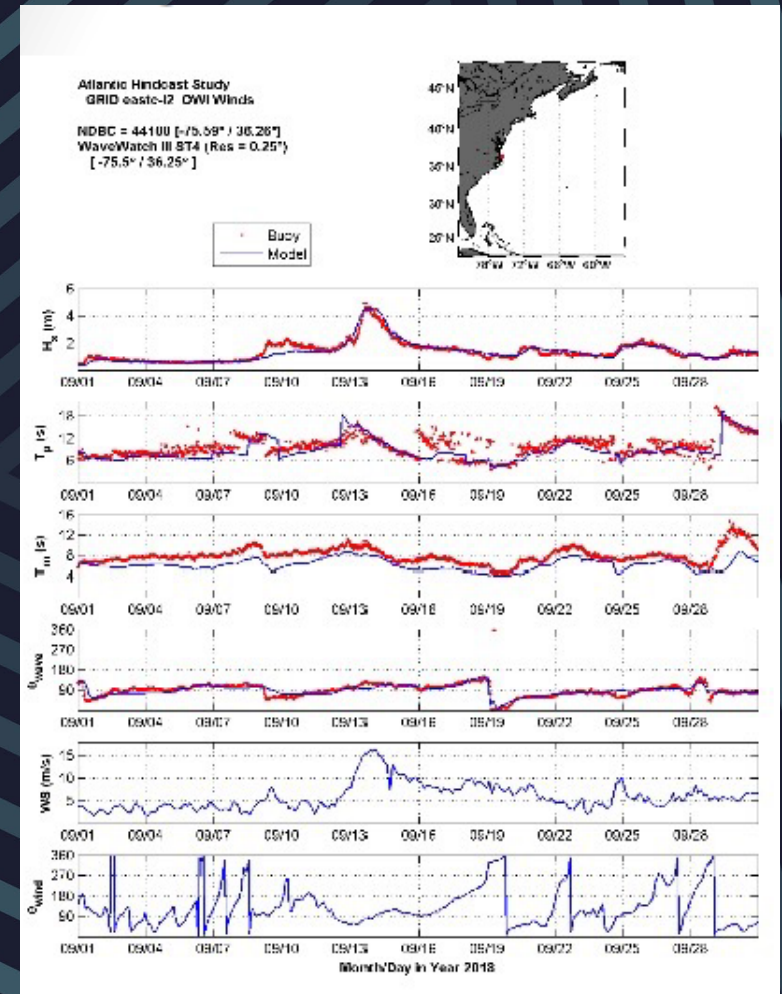
- **Satellite-based Altimetry**
  - Estimates Significant Wave Height
  - Excellent spatial coverage
  - With multiple satellites more coverage
  - Limited in time based on return cycle
  - Cover areas where no buoy data exist
- **Wave Measurements from drifting buoys**
  - Coverage in far-field / Currents
  - Returns frequency spectra / Four Directional Moments
  - Cover areas where no moored buoys exist



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Evaluation: Time Series

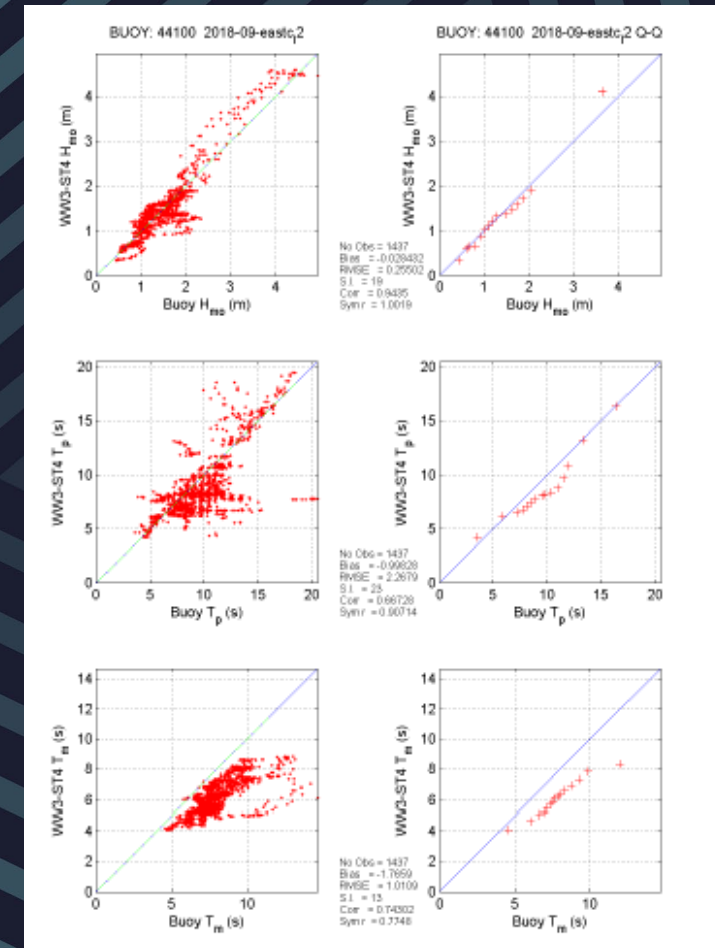
- Shows how variables change over time
  - How the data adjusts over the course of the data points as well as the final results
- Usually requires a large number of data points to ensure consistency and reliability, ensuring a representative sample size and that analysis can cut through noisy data.
- Highlights trends or patterns, isolates outliers and can account for seasonal variance.
- Time series data can be used for forecasting – predicting future data based on historical data



# USACE WAVE INFORMATION STUDY (WIS)

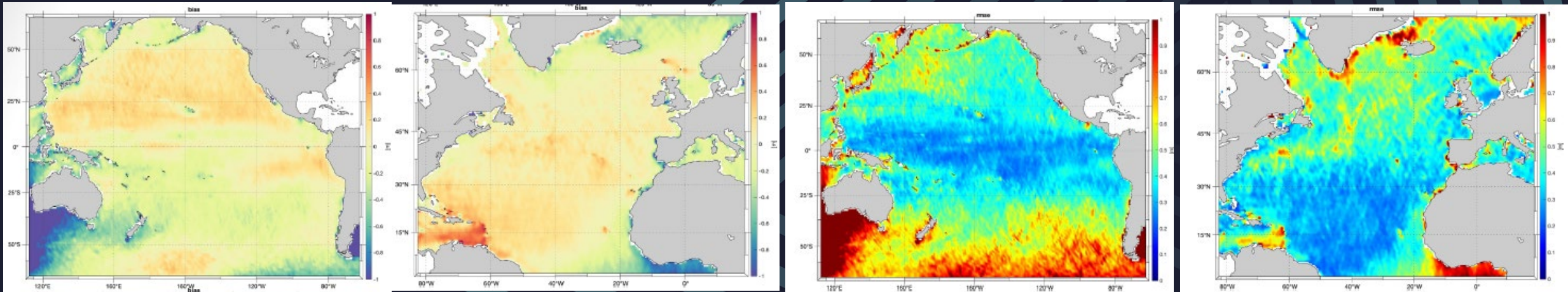
## WIS Evaluation: Validation Statistics

- Mean – the average of a data set
- Bias – anything that leads to a systematic difference between the true observations and the model estimates. Highlights flaws in the model process, which generates results that don't accurately represent the population.
- 1-1 plots to compare means
- Quantile-Quantile (Q-Q) plot to test quantiles against each other
- RMSE (RMSE) –the differences between values predicted by a model and the observations
- Correlation Coefficient – the strength of the linear association between two variables. Always a value between -1 and 1.



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Evaluation: Altimeter Validation



- Positive bias for most of North Pacific – attributed to bias in far field winds
- Positive bias in Caribbean region – attributed to land effects
- RMSE of 0.4 or less for most of the US West Coast
- Higher RMSE and bias where gulf stream tracks in N. Atlantic.

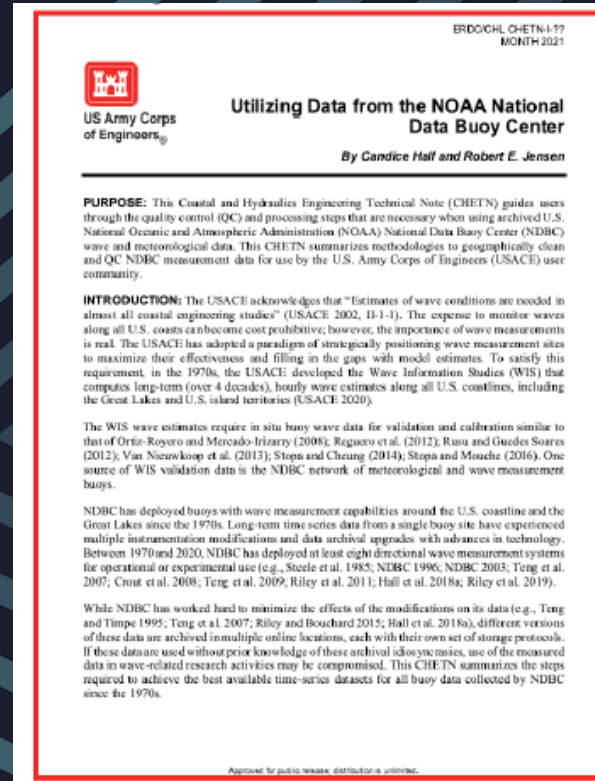


# USACE WAVE INFORMATION STUDY (WIS)

## QCC Measurement Archive

### Clean Data assimilation / Uncertainty Quantifications

- Observational data storage errors – develop a clean, quality controlled measurement archive
- Combining NDBC website (no metadata –QA/QC)
- National Centers for Environmental Information (NCEI) website (low QA/QC, real-time feed)
- CDIP-direct link to website
- Canadian wave data: Marine Environmental Data Section Archive (MEDS)



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# USACE WAVE INFORMATION STUDY (WIS)

## WIS Operations

1. Archive on CHL Data (Thredds) Server  
Reduction of time required for yearly updates
2. Standard Portal Products  
Updated automatically when hindcast completed
3. Update of the QCC Wave Measurements Archive

**WIS Project Mission**

Wave Information Studies provides a national resource of long-term wave climatologies for all U.S. coastal waters using high-resolution wind fields, mean daily ice concentration fields (where appropriate), third generation phase average wave modeling technologies, that are extensively evaluated to point-source measurements and satellite-based altimetry providing high quality wave estimates. The multi-decade hindcasts and storm event archives are generated to meet tomorrow's coastal engineering needs today.

**Problem**

- Knowledge of the wave climatology is required for planning, design, construction, and maintenance of USACE projects in the coastal zone
- Information is scarce due to the lack of measurements at locations over timescales long enough to be statistically significant
- This lack of information is a critical problem for USACE operations, and project maintenance near the coast

**Solution**

- Generation of long-term coastal wave estimates using spectral wave models forced by high quality wind fields, to retain continuity
- Validate the model estimates to measurements
- Provide easy access to the estimates and tailored products specific to project needs

**Impact**

- Fully automated hindcast system with limited manual intervention
- Model simulations cost-effective compared measurements
- Timely web site updates with new wave estimates



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Applications

- **Forcing** for numerical nearshore wave modeling, e.g. STWAVE
- Communicate **wave climate** for a given area to the public
- To produce seaway statistics for use in **ship motion models**
- To produce summary statistics for **wave climate** at a given project
- Investigate design wave conditions for **design of coastal structures** at design phase and feasibility phases
- Nearshore extreme wave heights and periods for **revetment design**
- Investigate wave conditions for rapid estimates of potential **coastal flooding** at higher water levels for EM
- Investigate offshore wave conditions for **wave run-up simulations**
- Correlation of offshore WIS data to nearshore wave data, particularly looking at **rip currents**
- As part of a **geomorphic vulnerability index**, WIS provided wave climate information to help identify vulnerable locations around Lake Michigan.
- Offshore wave information used for both **extreme analysis and typical conditions**. Determination of a representative **storm hydrograph**. Creation of wave/period roses.
- Transformed the WIS hindcasts to the nearshore and estimate the **sediment transport capability** of a site for the beneficial use of dredged sediment.



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Applications: FY21 to present

- Port of Nome Modification, Phase 1 design (Alaska District)
- Barrow Coastal Erosion, Phase 1 design (Alaska District)
- Akutan Harbor Tribal Partnership Program Study (Alaska District)
- Dutch Harbor Navigation Channel Feasibility Study (Alaska District)
- Elim Harbor Tribal Partnership Program Feasibility Study (Alaska District)
- St George Harbor GI Feasibility Study (Alaska District)
- Westward Beach Shore Protection Coastal Engineering Study (Los Angeles County Department of Beaches and Harbors)
- Adamson Wall Shore Protection Coastal Engineering Study (Los Angeles County Department of Beaches and Harbors)
- Little Diomedes Helipad Improvements (State of Alaska DOT)
- East Hagatna, Guam Section 14 Study (Honolulu District)
- Ofu Airport, Am Samoa Section 14 Study (Honolulu District)
- Agat Mayors Office, Guam Section 14 Study (Honolulu District)
- Agat Bay Regional Shoreline Assessment (Honolulu District)
- American Samoa Climate Change Vulnerability Study (Honolulu District)
- Laupahoehoe Harbor Breakwater Repair Final Design Report, Island of Hawaii (Honolulu District)
- Haleiwa Harbor and Shore Protection Project, RSM and Section 1122 Beneficial Use Studies (Honolulu District)
- Hilo Harbor Breakwater Resiliency Study (Honolulu District)
- St George Breakwater Repairs and dredging improvements
- Kodiak Island Airport Runway Extension (Alaska District)
- Kwajalein Atoll Shoreline Protection (Honolulu District and Garrison)
- Monroe County Roadway Vulnerability Assessment East San Pedro Ecosystem Restoration Feasibility Study (FS)
- San Diego County Shoreline CSRM FS
- Carpinteria Shoreline CSRM FS
- Saipan, Beach Rd. CSRM FS (for Pacific Ocean Division)
- Bay Mills Feasibility Study (Detroit District)
- Holland Rip Current Study (Detroit District)
- Grand Haven Wave Absorber Design (Detroit District)
- Keweenaw Stamp Sands Feasibility Study (Detroit District)
- Lexington Harbor Planning Assistance to States Study (Detroit District)
- Community fact sheets for outreach events with the State of Michigan (Detroit District)



# USACE WAVE INFORMATION STUDY (WIS)

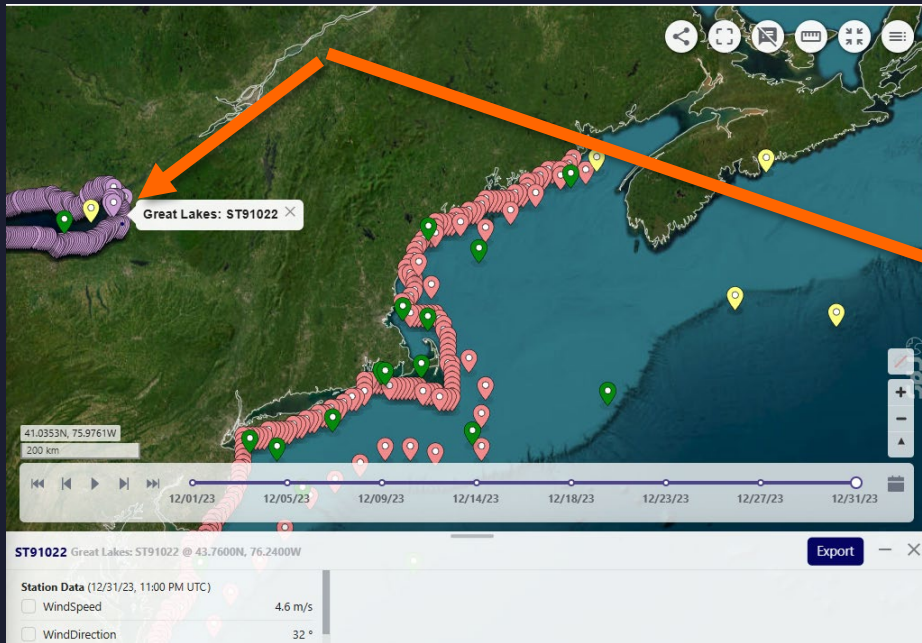
## WIS Sources

1. WIS Program website:  
<https://wis.erdcdren.mil>. Informational (no data), link to the WIS Portal.
2. WIS Data Portal:  
<https://wisportal.erdcdren.mil/>. Interactive, data download.
3. WIS API  
<https://wisportal.erdcdren.mil/data/apidocs/>
4. CHL Data Server (Thredds):  
<https://chlthredds.erdcdren.mil/thredds/catalog/catalog.html>



# USACE WAVE INFORMATION STUDY (WIS)

## WIS Data Portal Walk Through



### WIS Export

ST91022 @ 43.7600N, 76.2400W / 01/01/79, 01:00 AM UTC - 01/01/24, 12:00 AM UTC

- Overview
- Data Export
- Generic Export
- 2D Spectra
- Time Series (ONELINES)
- Mean-Max Summary Tables
- Extremes Analysis Table
- Wave Percent Occurrence
- Wind Percent Occurrence
- Plots
- Wave Rose
- Wind Rose
- Mean & Max Wave Height Duration
- Wave Height Duration Distribution
- Yearly Wave Height Time Series
- Extremes Analysis Plot
- Input for Models

#### Overview

### Great Lakes Station ST91022

The Wave Information Studies (WIS) is a US Army Corps of Engineers (USACE) sponsored project that generates consistent, hourly, long-term (40+ years) wave climatologies along all US coastlines, including the Great Lakes and US island territories.

**Extents Spatial:** 43.7600N, 76.2400W

**Extents Temporal:** 01/01/79, 01:00 AM UTC - 01/01/24, 12:00 AM UTC

**Extents Depth:** 11.0

#### Time Series (ONELINES)

Link to file: WIS Online file format (PDF)

Preset Dates Custom Dates

Select Year: 2023

Select Month: All Months

**Add to Export Group** **Download**

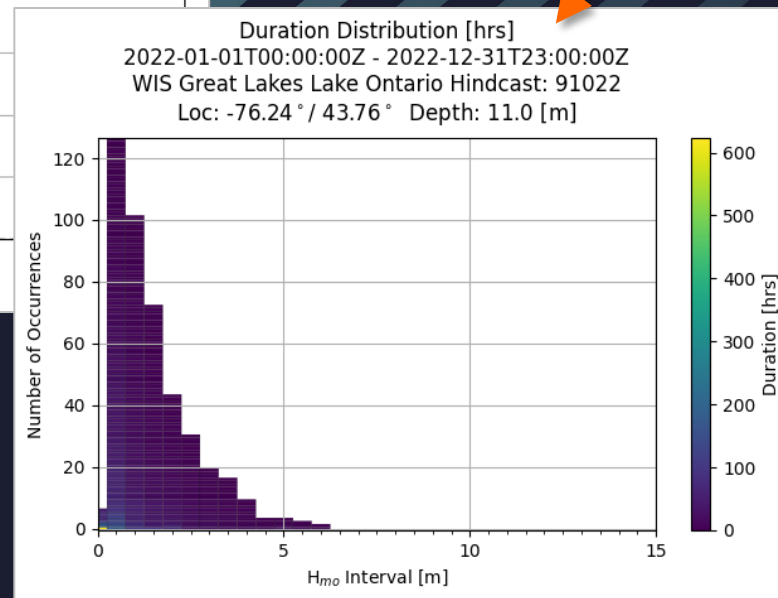
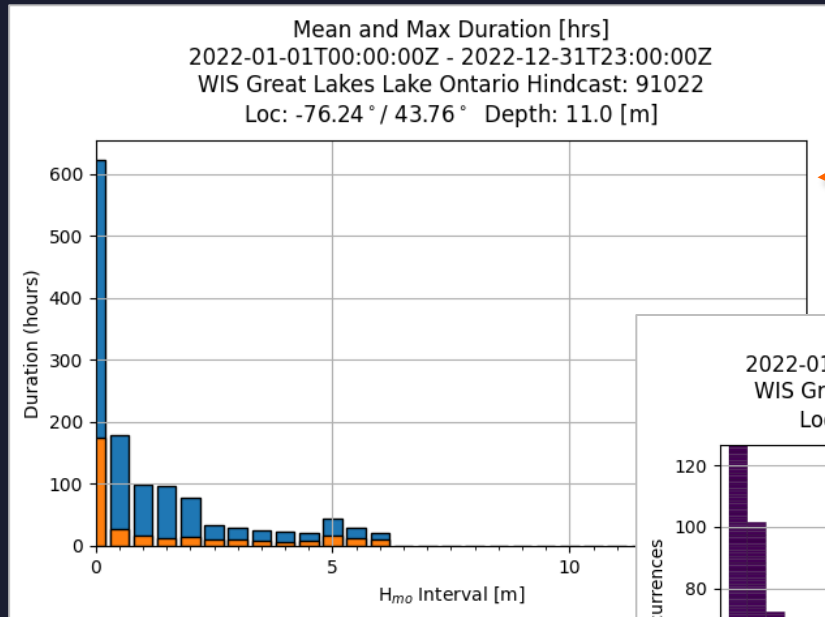


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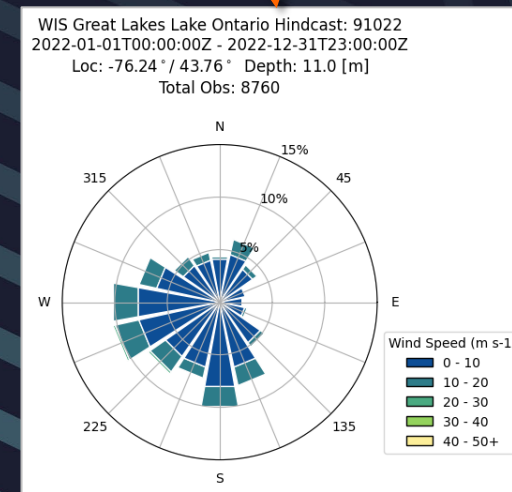
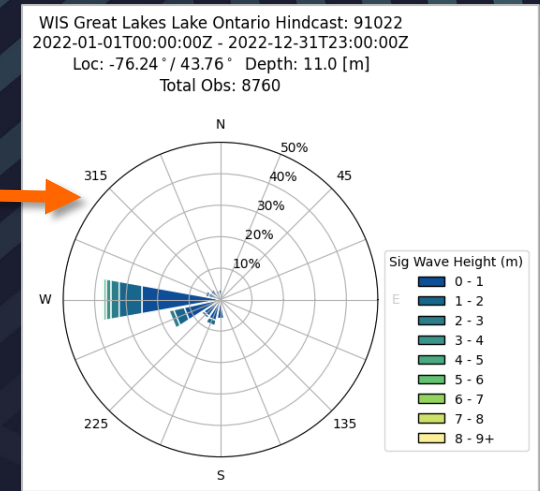
CHL

# USACE WAVE INFORMATION STUDY (WIS)

## WIS Data Portal Walkthrough



- Plots
- Wind Rose
  - Wave Rose
  - Mean & Max Wave Height Duration
  - Wave Height Duration Distribution

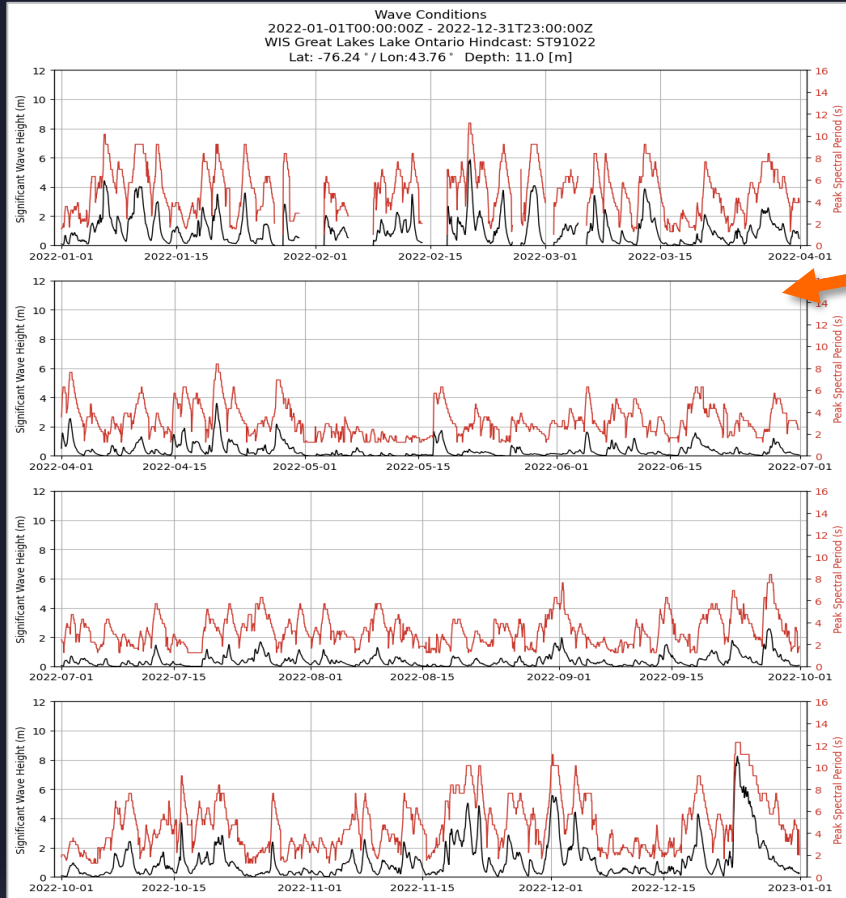


Catie Dillon

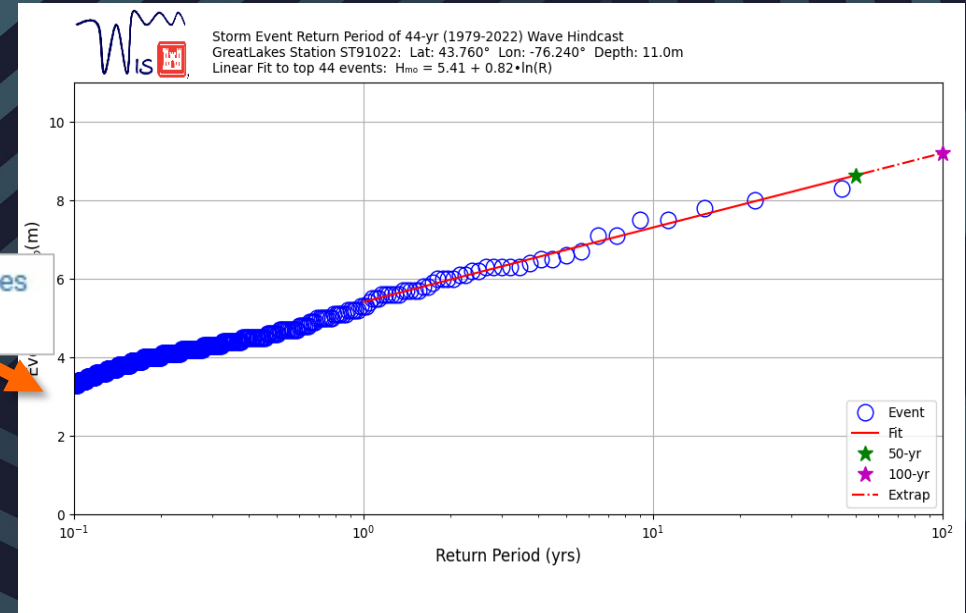
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# USACE WAVE INFORMATION STUDY (WIS)

## WIS Data Portal Walkthrough



Yearly Wave Height Time Series  
Extremes Analysis Plot



Top 10 Events based on Peak  $H_{m0}$

Event	Date/Time(UTC)	$H_{m0}$	$T_p$	$\theta_{mean}$	Event	Date/Time(UTC)	$H_{m0}$	$T_p$	$\theta_{mean}$
1	2019/11/01 11:00	8.0	12.1	260.0	6	2021/12/12 04:00	7.1	11.8	261.0
2	2019/02/25 12:00	7.8	12.1	260.0	7	2018/04/04 23:00	6.7	11.2	260.0
3	2003/11/13 17:00	7.5	11.9	260.0	8	2013/01/31 16:00	6.6	11.2	260.0
4	1979/04/06 20:00	7.5	11.9	259.0	9	2013/01/20 16:00	6.5	11.1	260.0
5	2000/12/18 07:00	7.1	11.2	259.0	10	2011/10/16 02:00	6.5	11.1	260.0

An event is defined as any period when  $H_m > 1.00m$        $\theta_{mean}$  is direction that waves are arriving from



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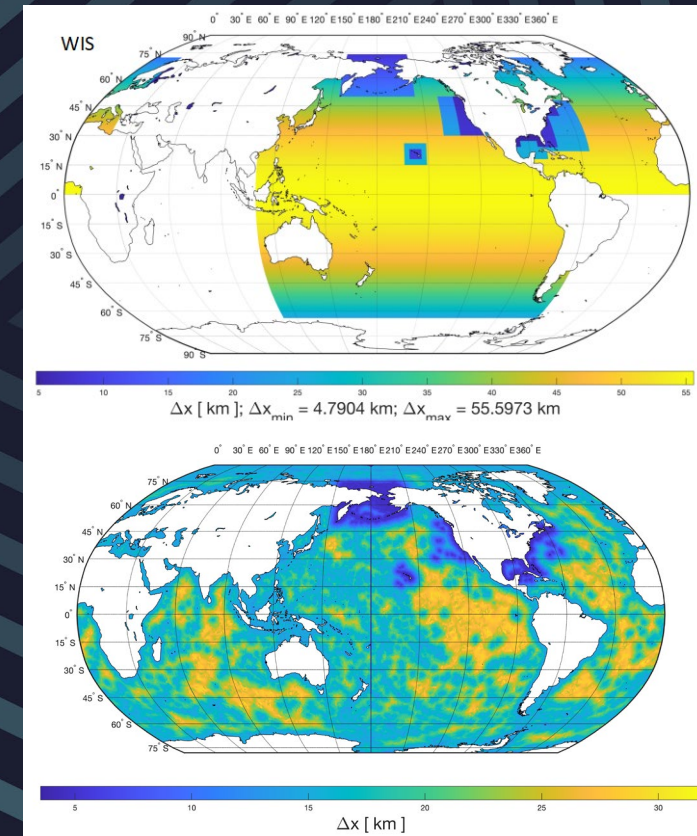
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# USACE WAVE INFORMATION STUDY (WIS)

## WIS Future: NuWIS

*“We anticipate future needs as well as advances in model capabilities, computational resources, and emerging observational data sources.”*

- Multiple Objectives:
  - A complete modernization of the hindcast approach
  - Test and transition WIS over to unstructured with implicit solver WW3 on a global domain
  - Transition the OWI-corrected ERA5 wind forcing onto a global domain without increasing cost
- Reduce the number of individual domains and model technologies.
- Output Nearshore wave estimates



Unclassified

# USACE WAVE INFORMATION STUDY (WIS) QUESTIONS?

WIS Program website:  
<https://wis.erdcdren.mil>.

Informational (no data), link to the WIS Portal.

WIS Data Portal:  
<https://wisportal.erdcdren.mil/>.

Interactive, data download.

WISInfo@usace.army.mil



Catie Dillon

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