USING HINDCAST WEATHER DATA TO PREDICT THE AVAILABLE TIME FOR SAFE DREDGING OPERATIONS

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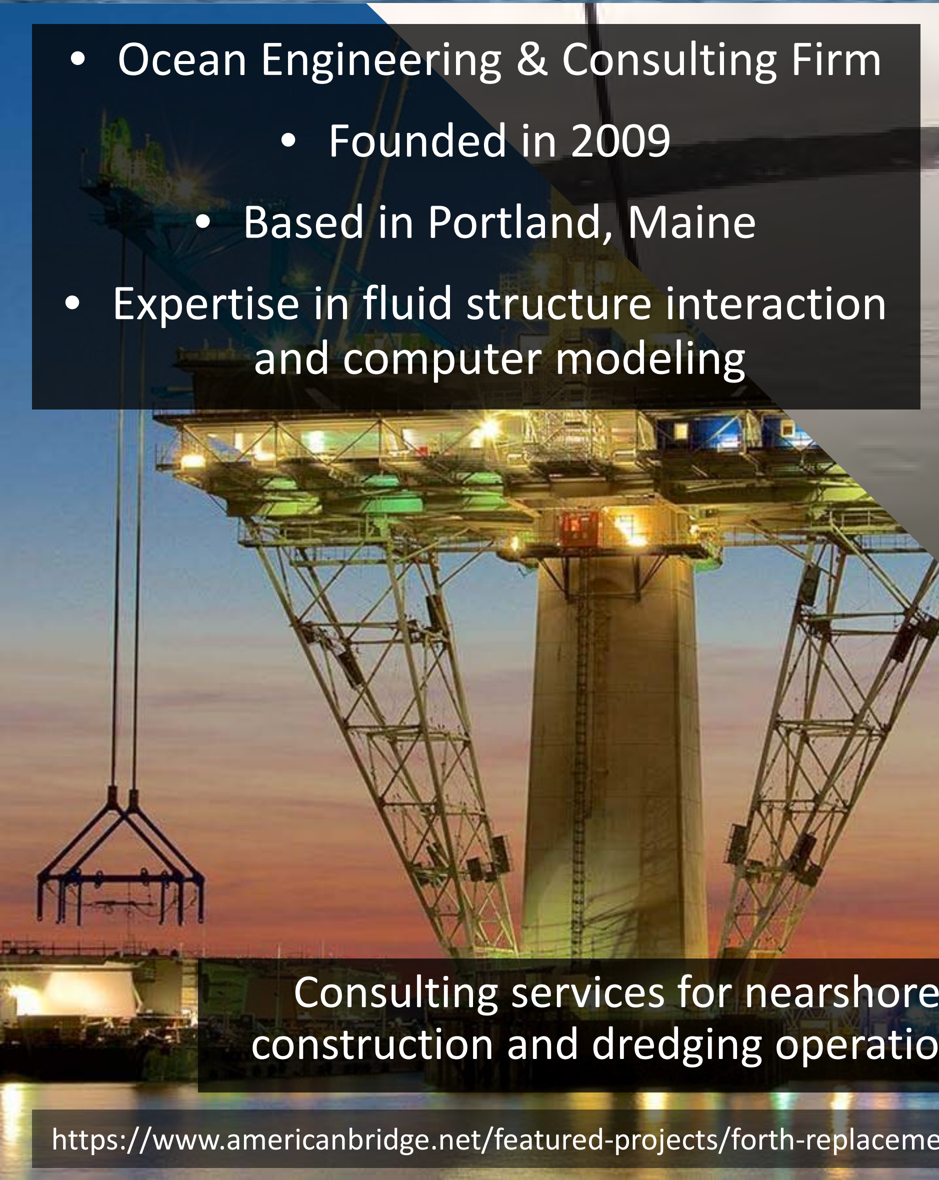
Maine Marine Composites LLC

- Ocean Engineering & Consulting Firm
- Founded in 2009
- Based in Portland, Maine
- Expertise in fluid structure interaction and computer modeling



Consulting services for nearshore construction and dredging operations

https://www.americanbridge.net/featured-projects/forth-replacement-crossing-queensferry-crossing/

Design and analysis for local aquaculture growers

Research and development of offshore renewable energy technology

Problem Statement

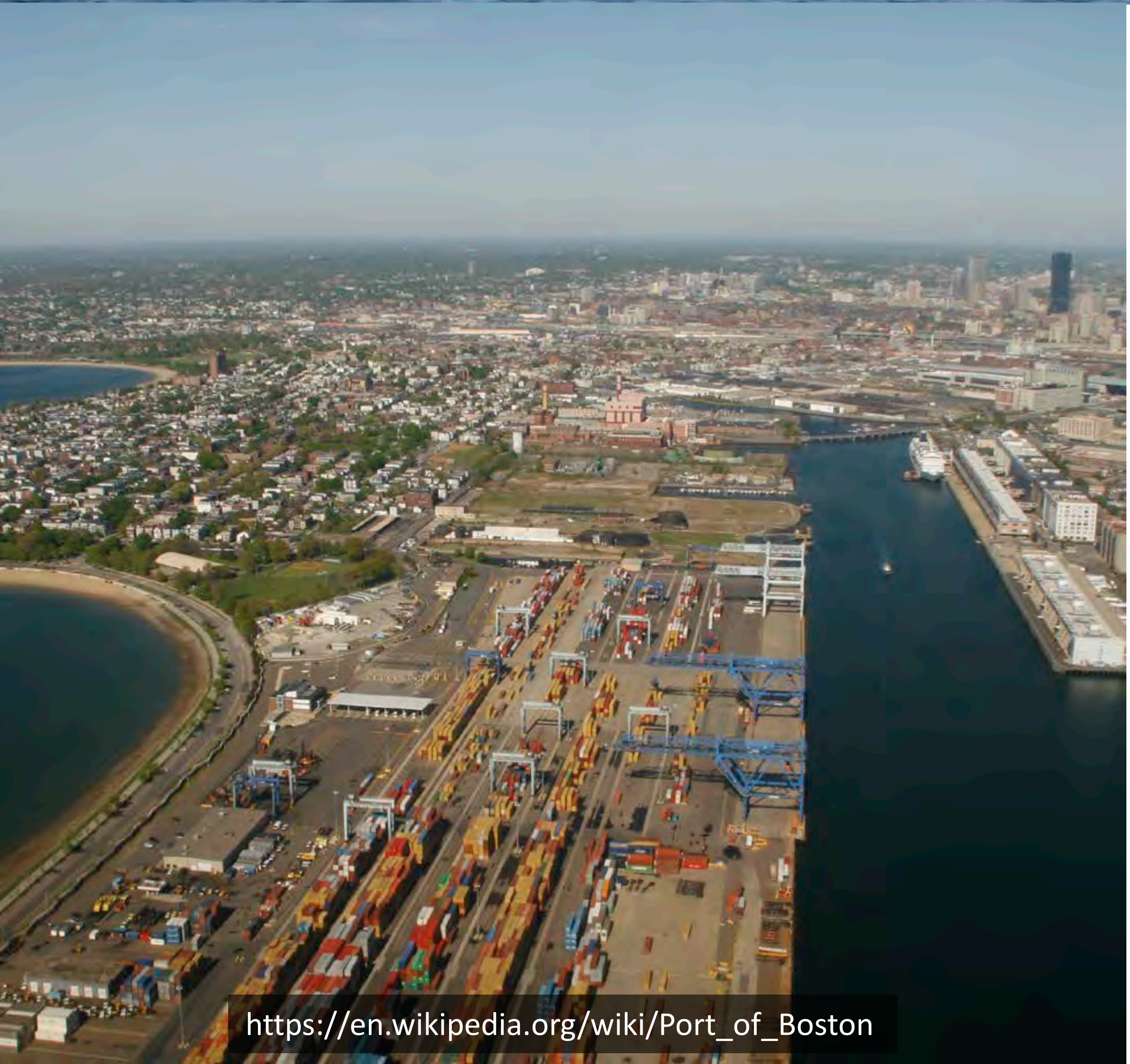
How often will the weather conditions in and around Boston Harbor allow dredging to take place?

- Quickly and efficiently evaluate operating windows in Boston Harbor
- 20 years of historical weather data
  (170,000 hourly records)
- Evaluate the motions of the dredge barge
- Provide insight for project planning, budgeting, and scheduling

Outline

- Phase 1
  Metocean Hindcasting
- Phase 2
  Hydrodynamic Simulation
- Phase 3
  Operating Window Prediction

Boston Harbor Deepening Project


https://en.wikipedia.org/wiki/Port_of_Boston

- Background:
  - Nation's 11th largest metropolitan area
  - Partnership with U.S. Army Corps of Engineers provide port with deep draft channels
- Motivation
  - Much New England cargo currently landed/loaded in Port of New York & New Jersey
  - Shifting to Boston saves time and cost, reduces highway miles & emissions
- Deepening Boston's channels allows larger ships to call
  - Cashman has been dredging the harbor since 2018
- Smooth, efficient dredging operations require understanding of local ocean conditions
  - Estimate costs
  - Forecast personnel requirements
  - Acquire/construct additional dredging barges if necessary
- Dredging cranes require a stable barge

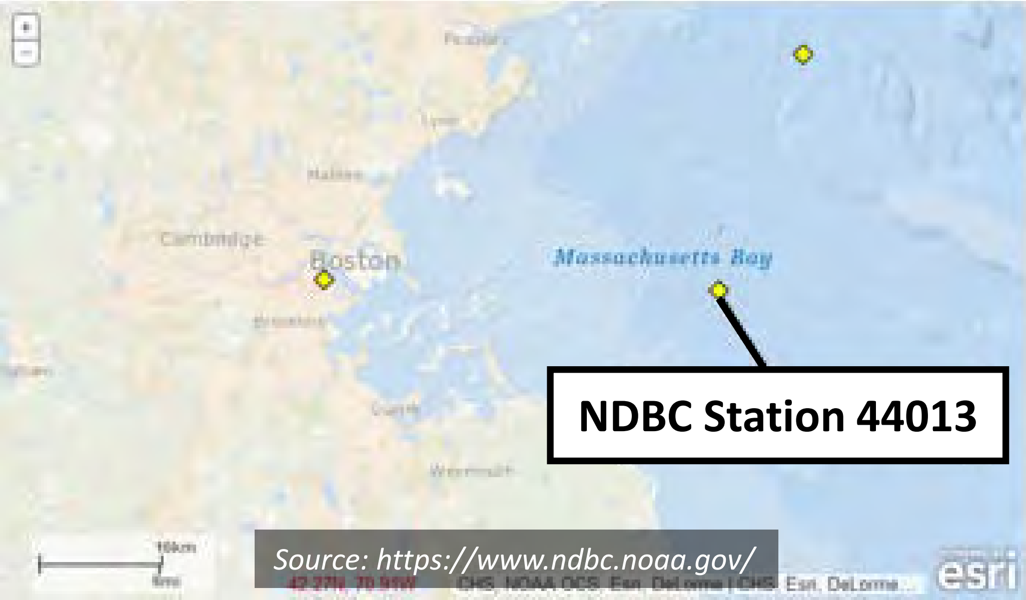
Phase 1

Metocean Hindcasting

Metocean Hindcasting

<u>"Metocean"</u>

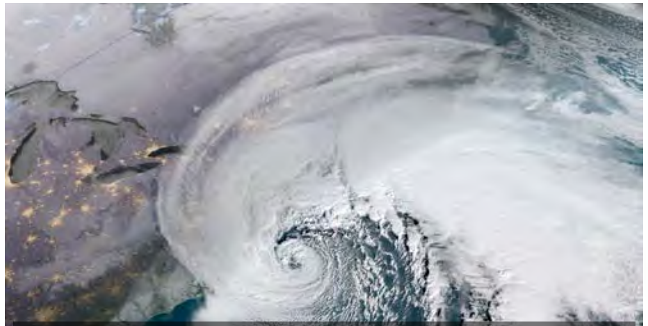
- Ocean and coastal engineering term
- Meteorological data: wind, temperature, humidity, etc.
- Oceanographic data: waves, tides, currents, etc.
- Cross-correlations: fetch-driven waves, etc.



<u>Data Source</u>

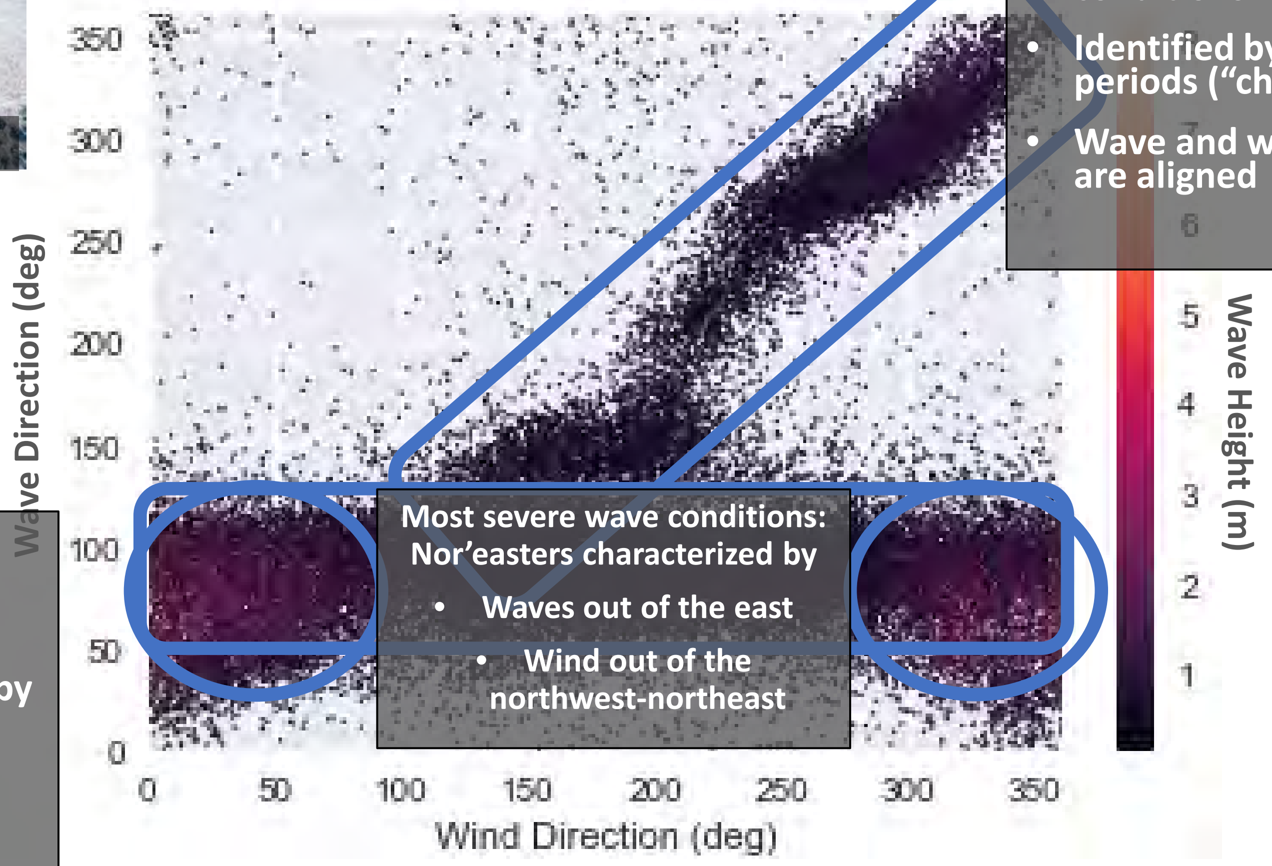
- NOAA NDBC weather station 44013, located 16 nm east of Boston
- Provides real time and historical metocean data
- Twenty years of historical data were used
  - Significant wave height
  - Dominant wave period
  - Wave direction
  - Mean wind speed
  - Wind heading

Metocean Hindcasting



Source: https://en.wikipedia.org/wiki/Nor'easter

Wind + Wave Correlation



Fetch driven waves

- Caused by local wind conditions
- Identified by shorter wave periods (“choppier” seas)
- Wave and wind direction are aligned

Most severe wave conditions: Nor’easters characterized by

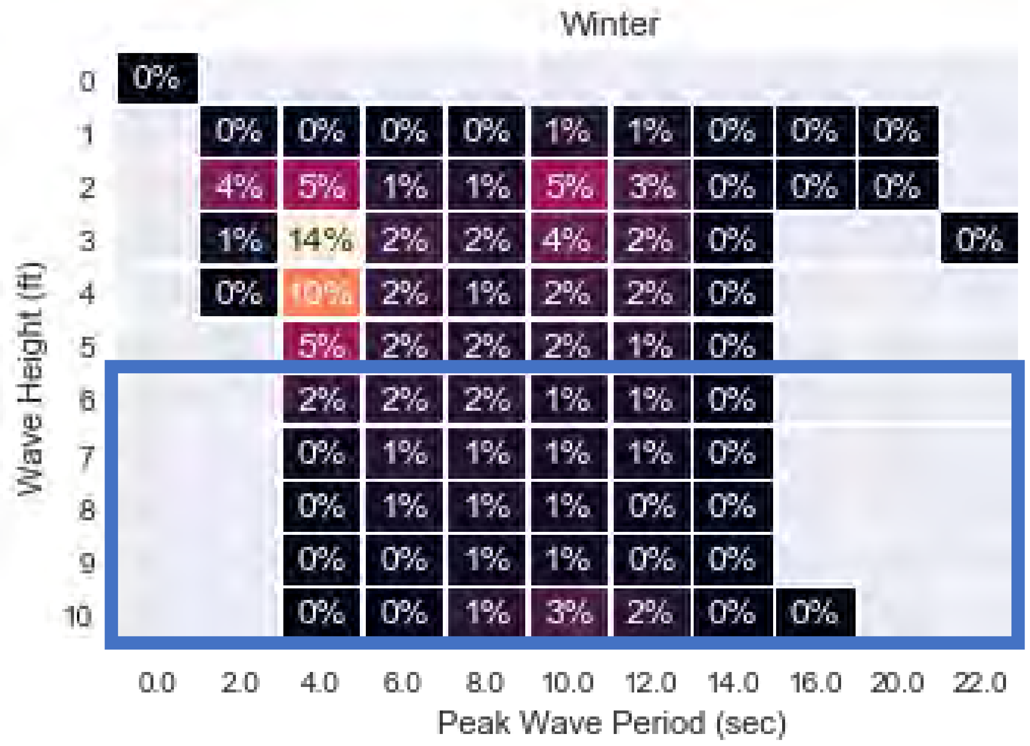
- Waves out of the east
- Wind out of the northwest-northeast

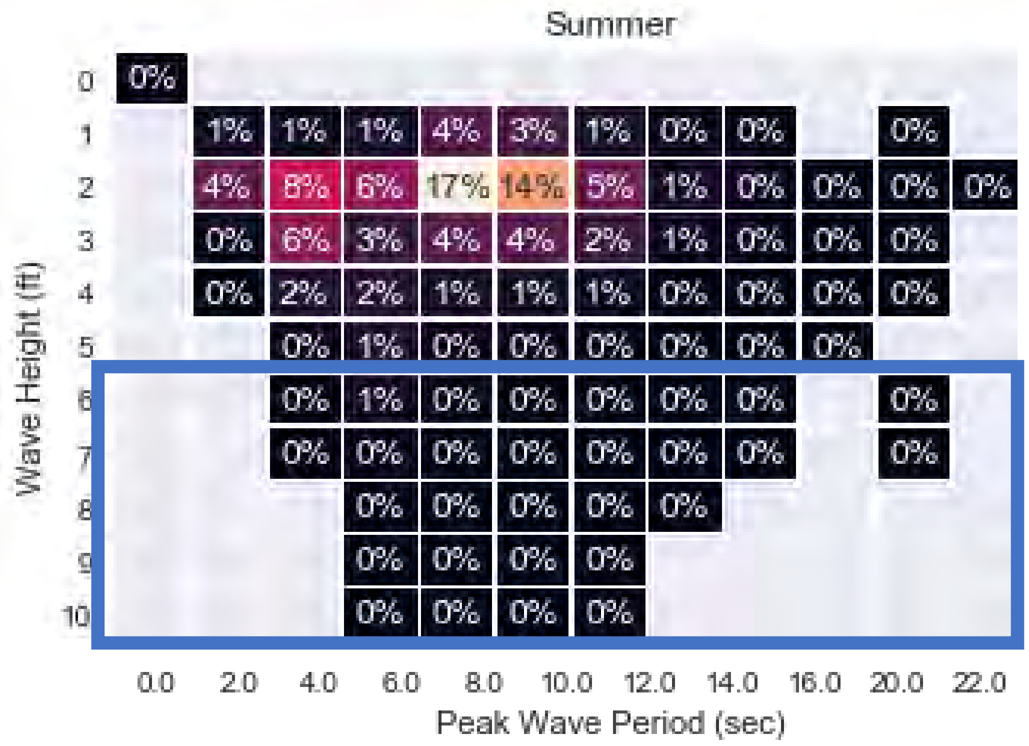
Swell-driven waves

- Waves coming from far out at sea
- Longer periods, caused by long build-up time
- Waves from the east, regardless of wind direction

Metocean Hindcasting

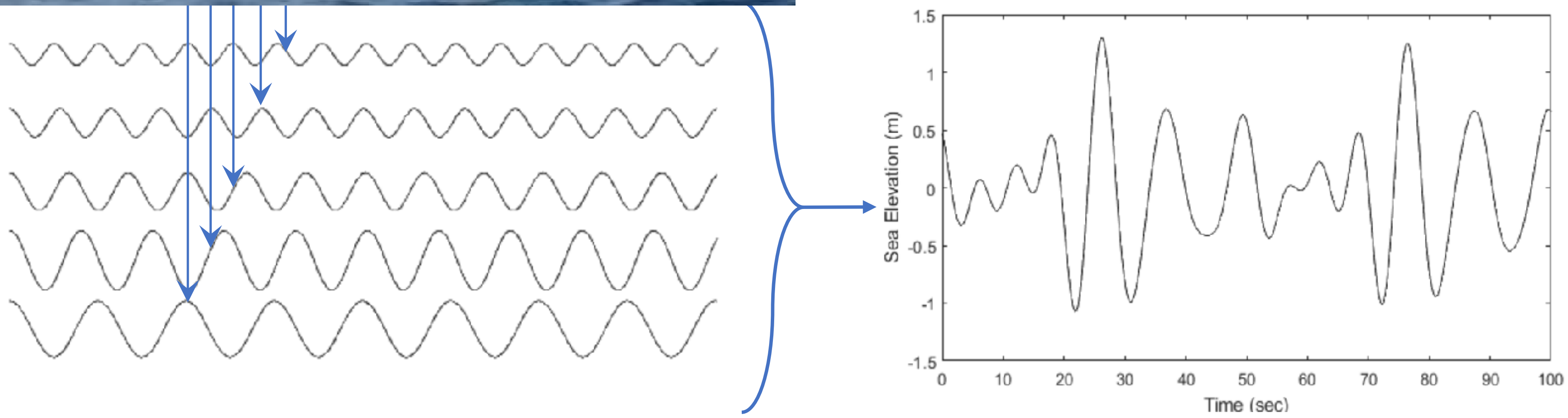
Seasonal Scatter Tables





Metocean Hindcasting

- Ocean waves are random!
- Wave data recorded as Spectrum
  - Defined by “Significant Wave Height” and “Dominant Wave Period”
- Spectral density is de-constructed into individual sinusoidal wave components (“Regular Waves”)
- Random phase lags are added and individual waves are overlaid to produce random time series



Phase 2

Hydrodynamic Simulation

Hydrodynamic Simulation

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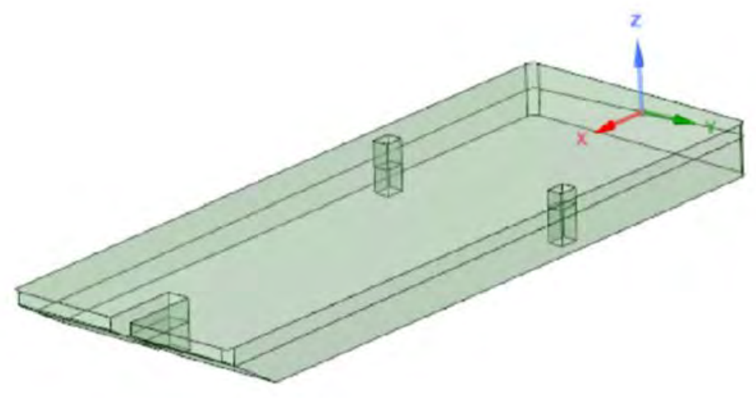
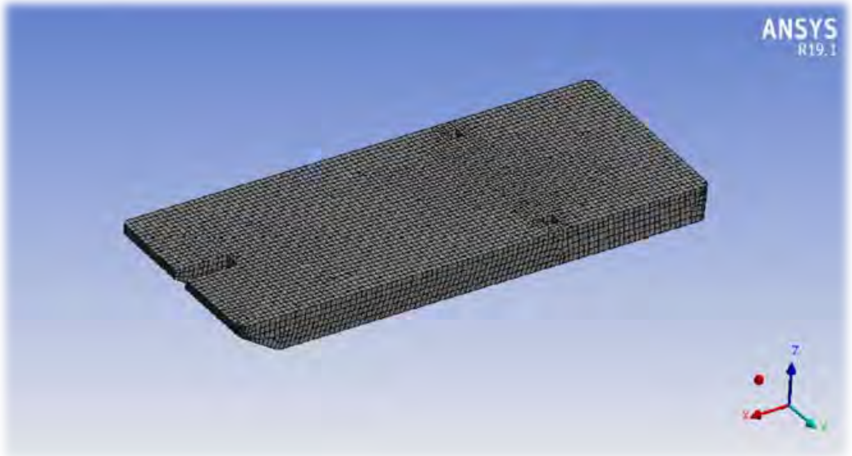
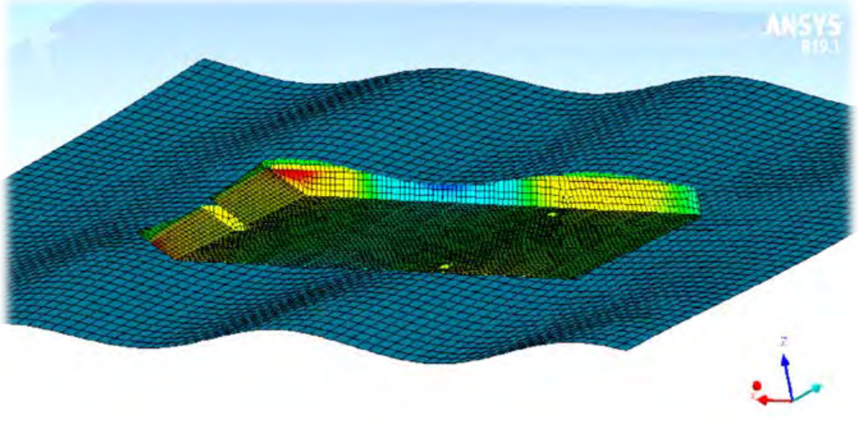


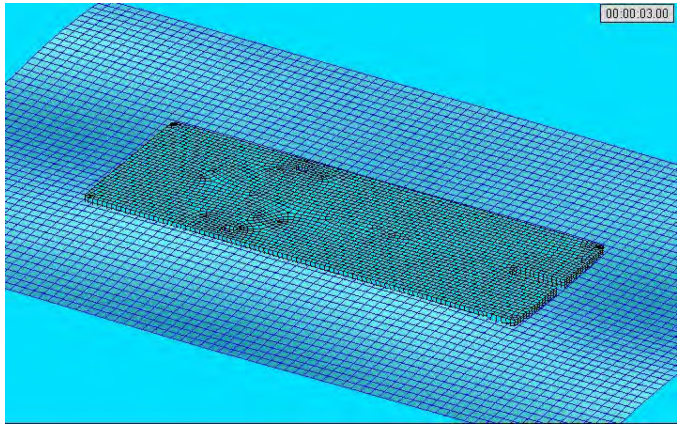




- Used commercial software package ANSYS Aqwa
- Panel Method: Solve for velocity potential and fluid pressure on submerged surfaces of bodies.
  - Simultaneously solve:
    - Diffraction Problem: *effects of incident waves on the body*
    - Radiation Problem: *effects of motion of body in each degree of freedom*
  - Obtain Hydrodynamic Parameters
    - Exciting Forces
    - Added mass & damping coefficients
    - Response Amplitude Operators (RAOs)

Solve for Barge Motion

Diffraction Problem



- Hold vessel in place
- Apply regular, sinusoidal ocean waves
- Determine how waves diffract around vessel
- Find surface integral of dynamic fluid pressure

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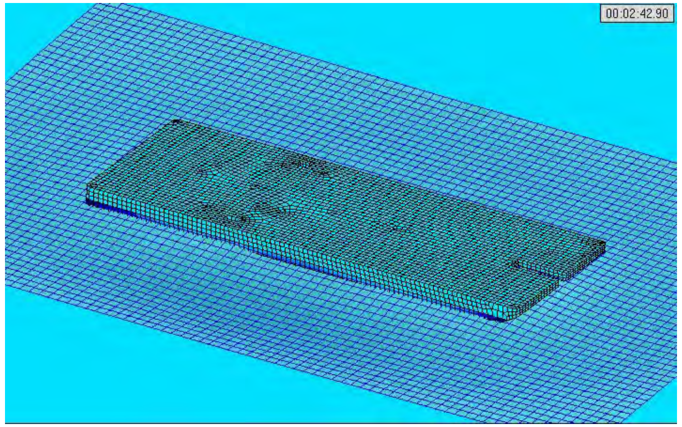
Radiation Problem



- Turn off ocean waves
- Turn on vessel motion at wave frequency
- Determine how waves radiate from vessel
- Find inertia and damping coefficients due to wave radiation

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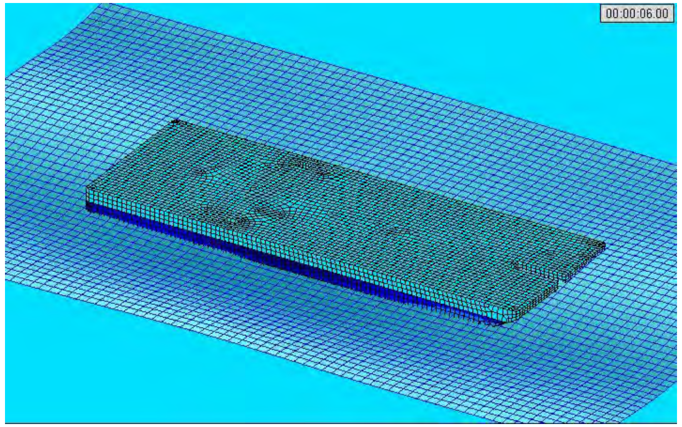
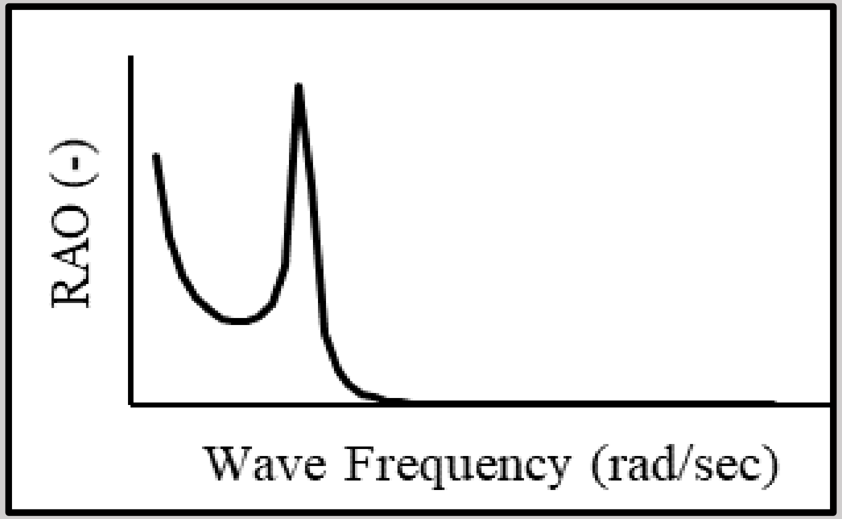
Barge Motion in Diffracted Wave Field

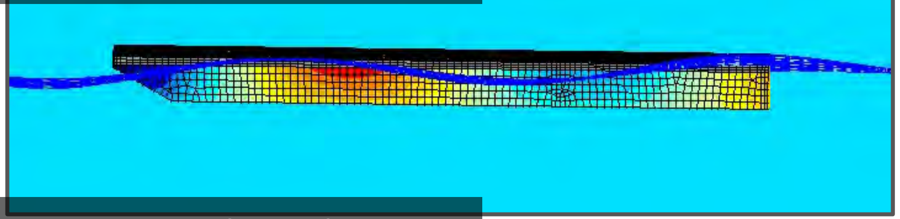


- Superimpose Radiation + Diffraction results
- Account for changing buoyancy forces
- Solve equation of motion
- Six coupled degrees of freedom

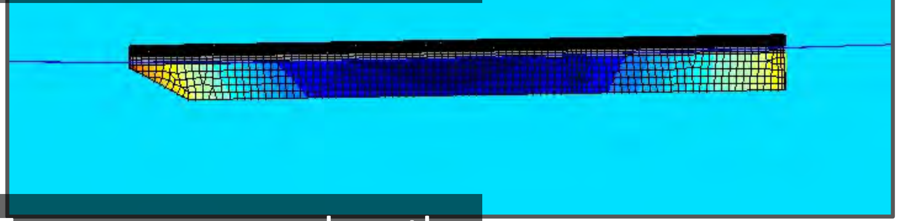
Response Motion of Barge



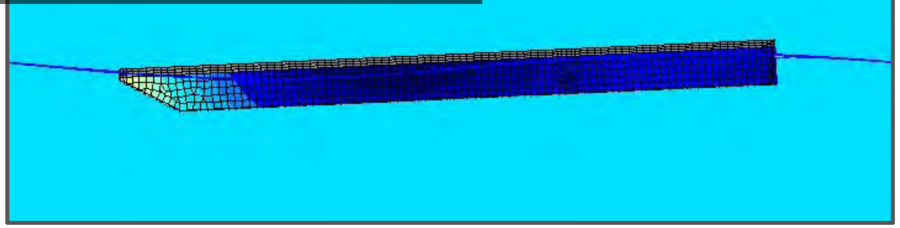
High Wave Frequency: wavelengths too short to induce significant barge motion



Low Wave Frequency: wavelengths too long to induce significant barge motion

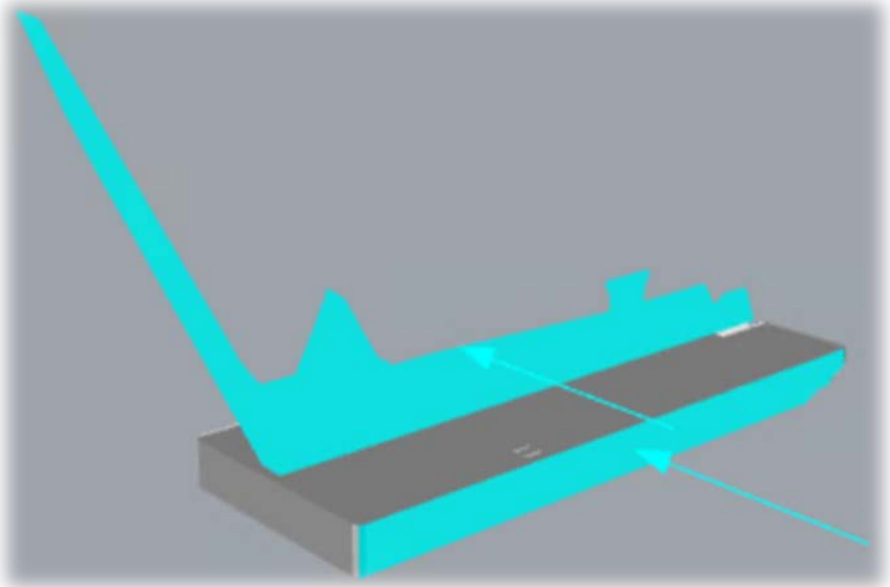


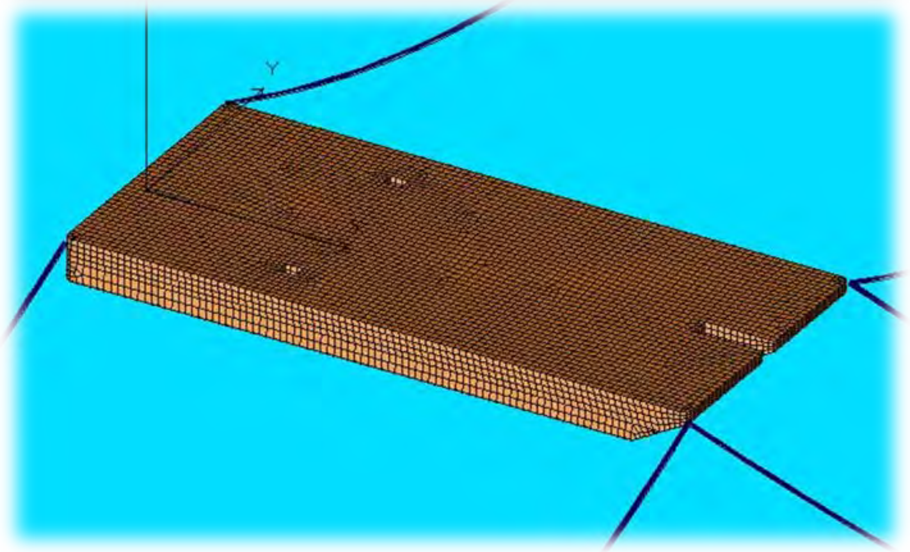
Resonant Wave Frequency: wavelength is just right to cause resonant motion



Additional Loading

- Wind loading
  - Army Corps of Engineers Unified Facilities Criteria Mooring Design guidelines
  - ABS mobile offshore drilling unit (MODU) rules
  - Account for size and position of all major topside structure
  - Empirical coefficients based on shape, height, orientation
- Moorings
  - Six wire rope moorings
  - Model linearized catenary stiffness
- Viscous roll damping
  - Not accounted for by radiation/diffraction theory
  - Typically 0-10% of critical damping, based on hull shape, bilge keels, etc

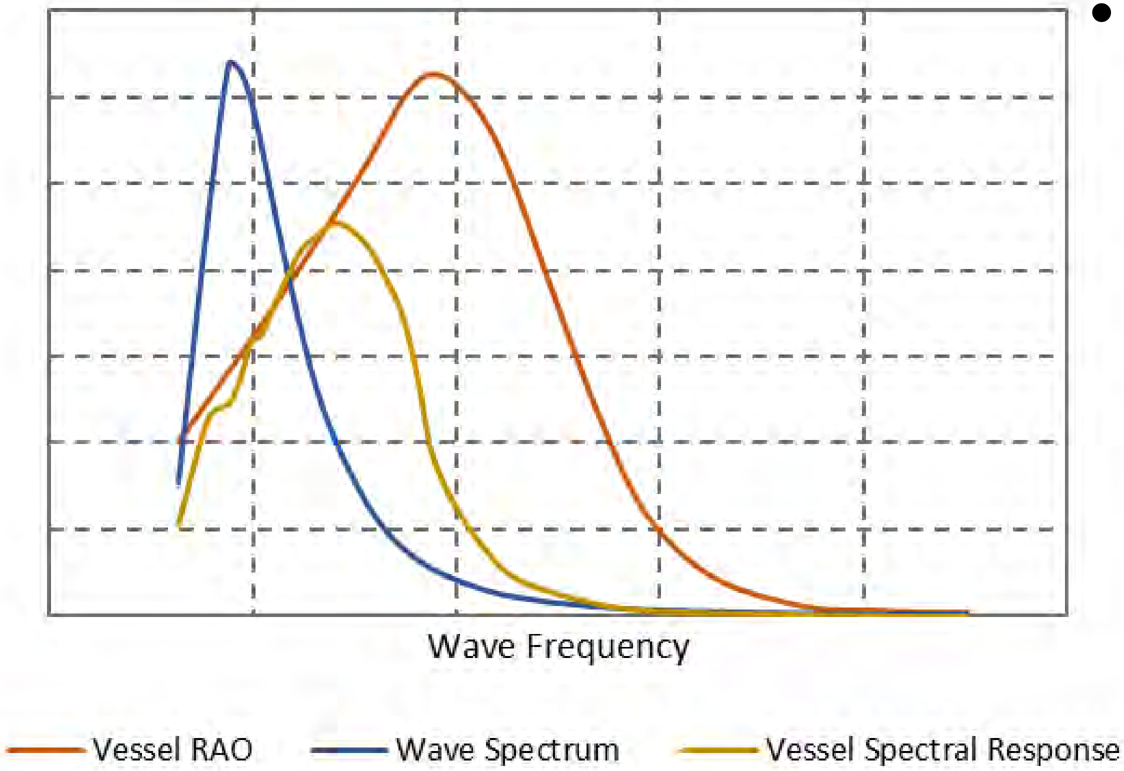




Phase 3

Operating Window Prediction

Spectral Response



- Steps to find vessel motion in random waves
  - Define wave spectrum (from Historical data)
  - Compute normalized vessel response (from Hydrodynamic Analysis)
  - Calculate spectral response
  - Calculate spectral response moments & significant response
    - $\mu_n = \int \omega^n R(\omega) d\omega$
    - $R_{sig} = 4\sqrt{\mu_0}$
  - Calculate statistical max expected response
    - $R_{max} = R_{sig}\sqrt{\frac{1}{2}\ln\left(\frac{T}{t_z}\right)}$

Operating Window Prediction

- Limiting criteria: BARGE ROLL ANGLE
  - If maximum expected roll angle exceeds allowable threshold, dredging cannot occur
  - Total Roll Angle = Static Heel + Wave-Induced Roll + Wind-Induced Roll
    - Static Heel computed by balancing weight distribution of barge and hydrostatic (buoyancy) forces
    - Wave-Induced Roll computed using radiation+diffraction simulation and spectral analysis
    - Wind-Induced Roll computed by balancing wind and hydrostatic (buoyancy) moments on barge
- Total Roll Angle computed for every wave-wind combination in the Scatter Tables

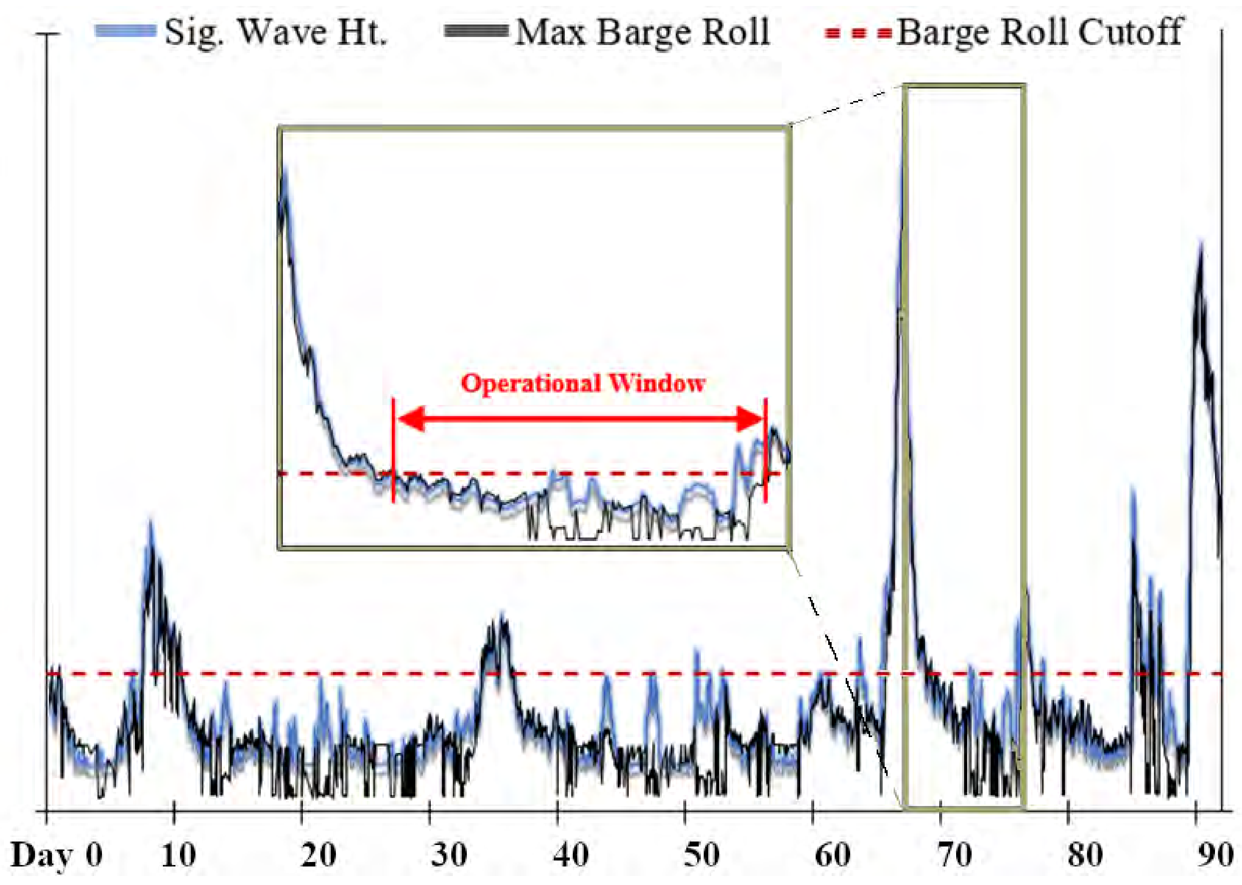
Operating Window Prediction

The maximum expected roll angle cannot exceed the maximum allowable roll angle for a duration of at least the minimum number of hours required to conduct dredging operations. The barge is assumed to always be operating in a head sea, as it can quickly be re-oriented to minimize roll.

Examine past 20 years of history

- Does barge roll angle exceed cutoff value?
- If not, does it remain below cutoff long enough?

Wave + wind conditions pre-sorted into scatter tables, and barge was analyzed at each cell. This process happens almost instantaneously!



Conclusions

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- Process for forecasting operation windows
  - Based on best practices in ocean engineering
    - NOAA-based NDBC data source
    - Radiation-diffraction analysis of barge
    - Standards-based wind load model
  - Fast, efficient, reliable: able to process 20 years of hindcast data quickly
    - Quickly examine variations to improve operations
      - What is optimal barge draft?
      - Crane position?
      - Structural modifications?

Thank you for your attention

Cashman Dredging

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