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Sandia National Labs: RDD&D Supporting the Marine Energy Industry

Water Power Technologies

Sandia National Laboratories
Vincent Neary
Marine Energy Technologies Lead, Water Power

U.S. DEPARTMENT OF ENERGY NNSA

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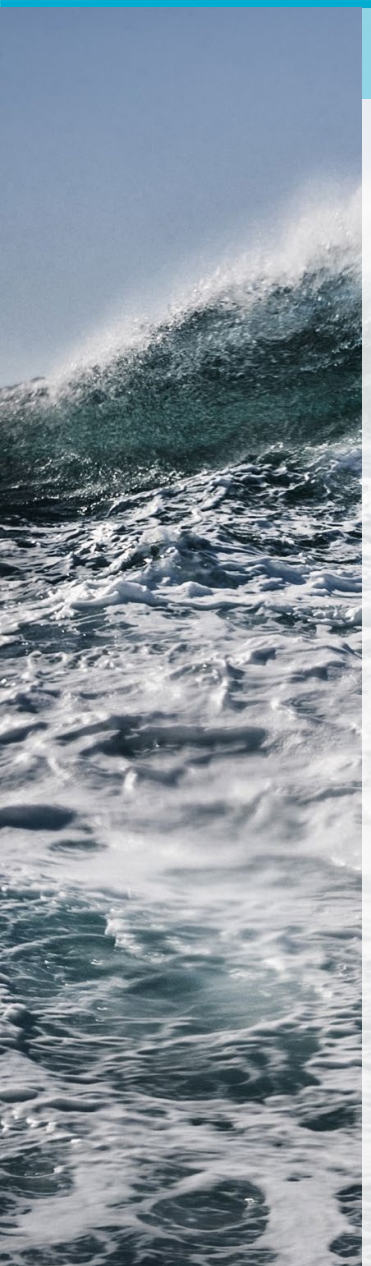
Water Power

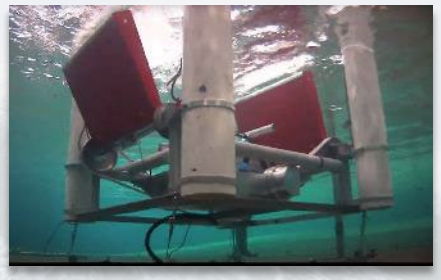
RENEWABLE ENERGY TECHNOLOGIES



Marine energy technologies harness energy from waves, currents, and ocean thermal gradients to generate clean, renewable energy.

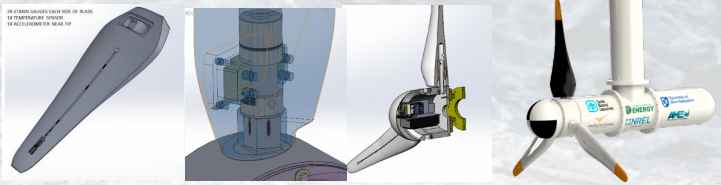
Dynamics and Controls

Incorporating reactive control experts from robotics, defense, energy systems, and aerospace.



Experimental Testing

A decade of experience in hydrodynamic load measurements, and MHK sites and laboratory testing facilities.



Materials and Coatings

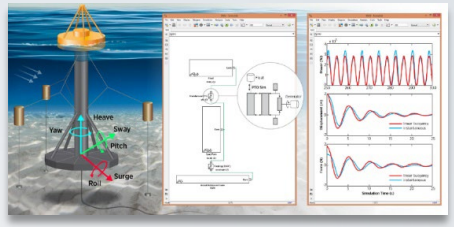
Prevention of corrosion & biofouling, composite performance, composite manufacturing, materials/coatings reliability.

Powering the Blue Economy

Supporting the development, simulation ,and testing of devices for aquaculture, desalination, ocean instrumentation, and with energy storage or for microgrid applications.

Code Development for Simulation & Analysis

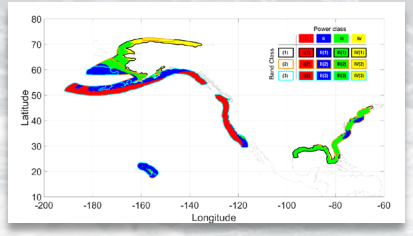
Develop and maintain open source code for marine renewable energy applications, including resource assessment, environmental effects analysis, device performance, hydrodynamic response, extreme conditions, and others.

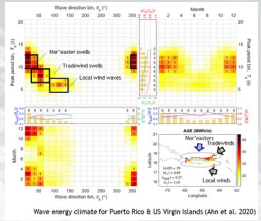


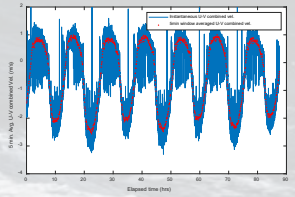
CACTUS
Code for Axial and Cross-flow Turbine Simulation

Marine Power & Load Characterization & Assessment

High-resolution hindcast modeling, methods and tools for characterizing marine power and load characteristics







International Marine Energy Standards

Development of standards for resource characterization and assessment, device testing, power performance and design.

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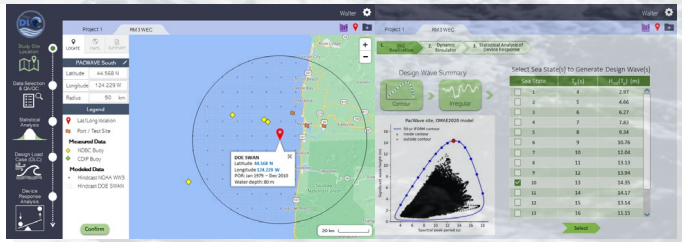
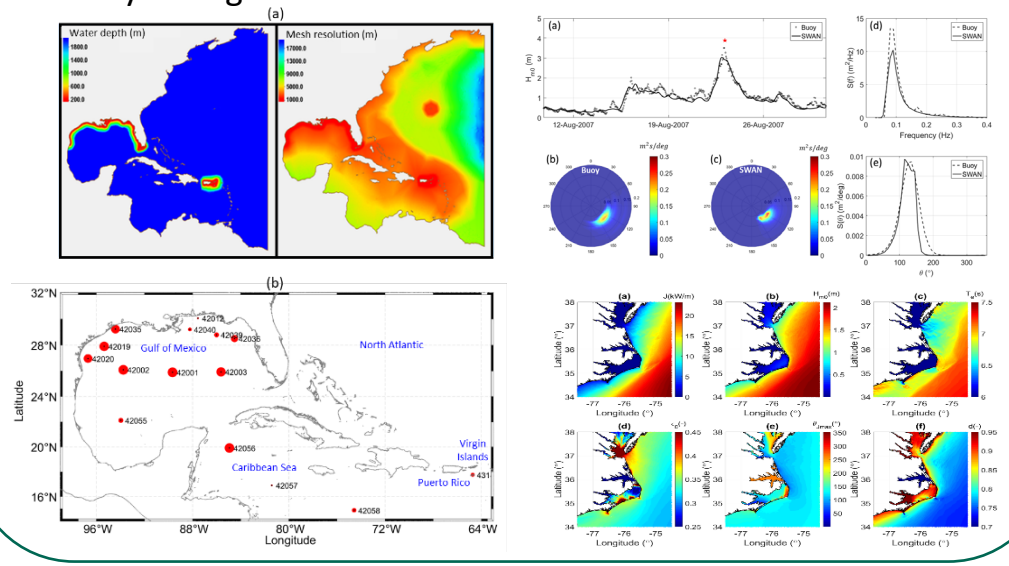
Design Load Case Generator
Graphical mapping & statistics tool to analyze design load cases for marine energy systems

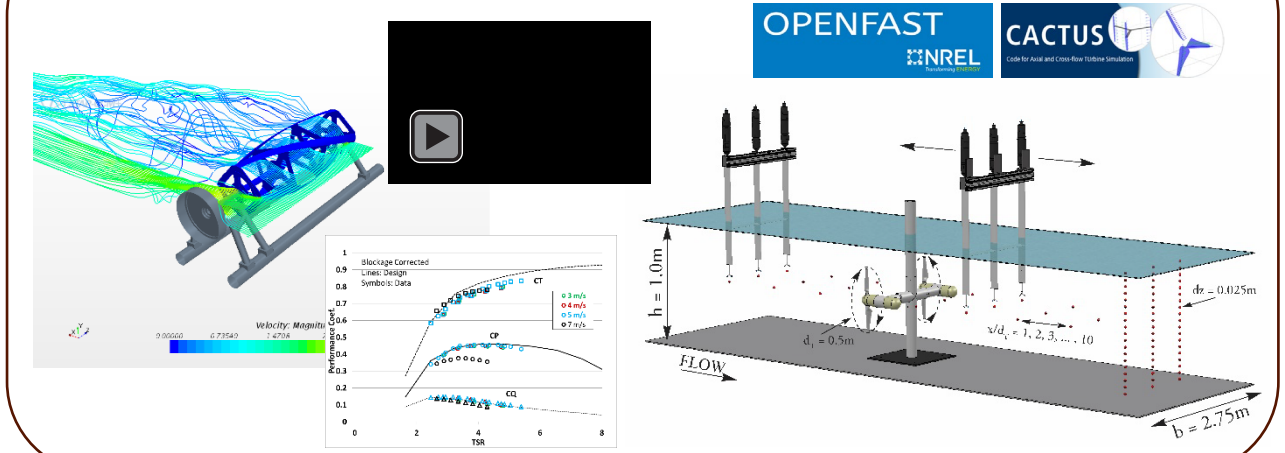


Marine energy power, load & technology performance characterization

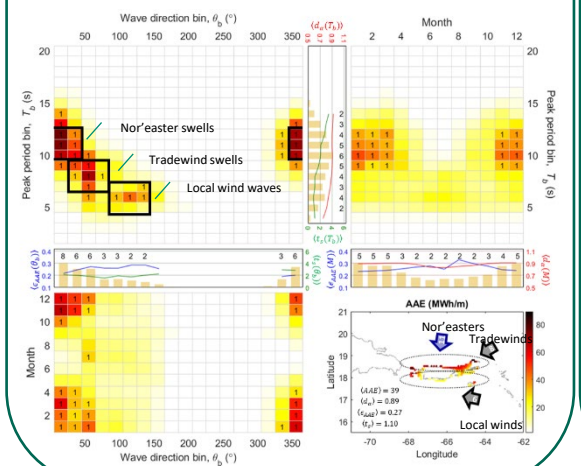
42-year high-resolution wave model hindcasts



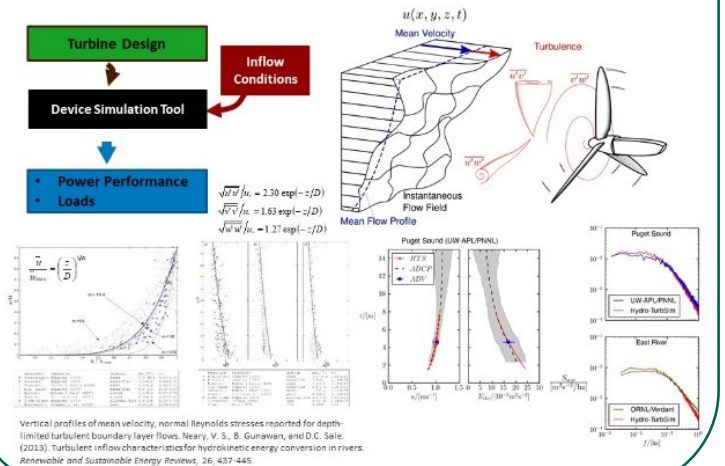
Numerical & physical modeling of hydrokinetic turbines



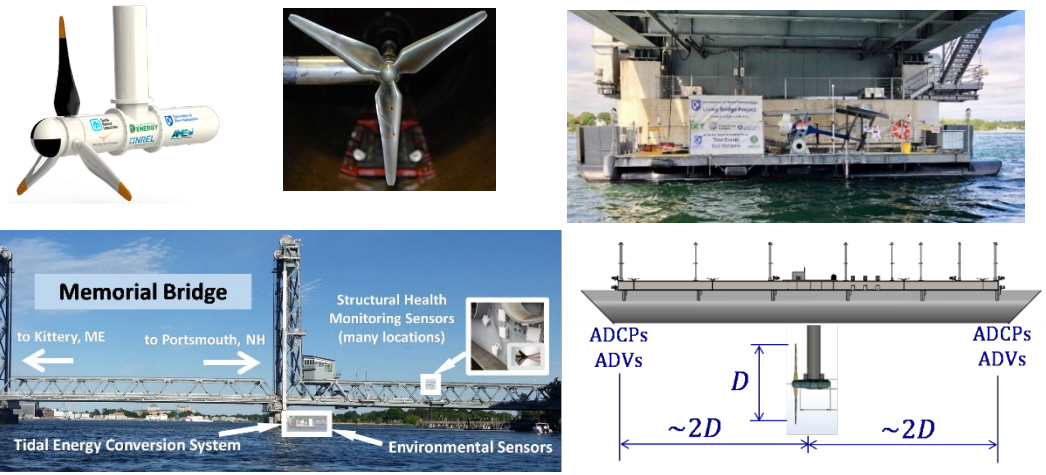
Wave site characterization



River & tidal site characterization



USDOE Instrumented Tidal Turbine Test Platform



Resource data and information dissemination

Marine Energy Atlas

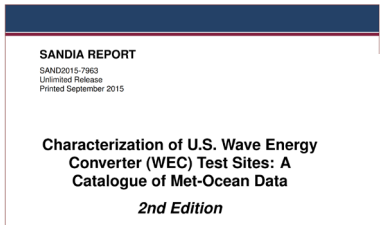
- All 6 IEC parameters, monthly averages and average annual values
- Hs(50, 5, 1-year)
- 200-300 m resolution within US EEZ
- Includes shallow nearshore waters

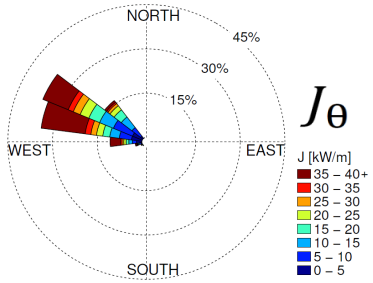
Hindcast Data Repository

- 2D spectra, ***O***(100) points each region
- Partitioned bulk parameters, ***O***(1,000) points each region
- IEC parameter time series, ***O***(1M) points

US WEC Test Sites Catalogue

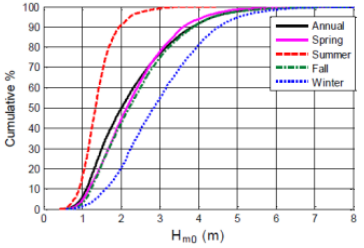
- Standard & consistent methods for processing, presenting and cataloguing test site information for WEC developers
- https://www.energy.gov/eere/water/downloads/characterization-us-wave-energy-converter-test-sites-catalogue-met-ocean-data.



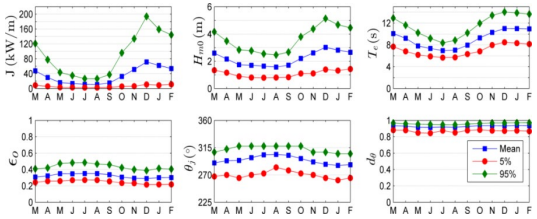


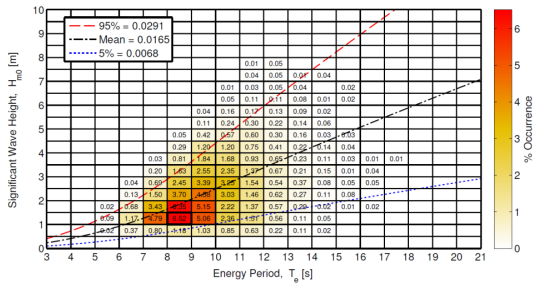
Wave roses

Cumulative frequency plots

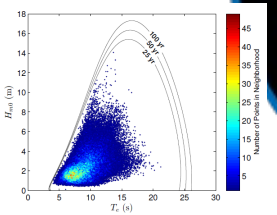


Seasonal variations (monthly averages)

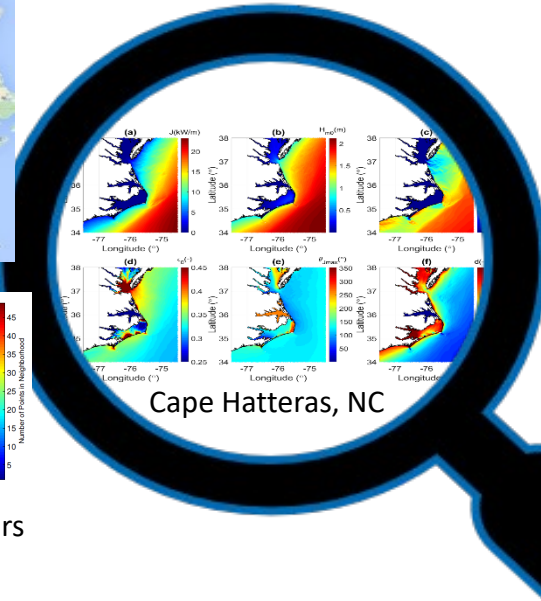




Sea state scatter plots



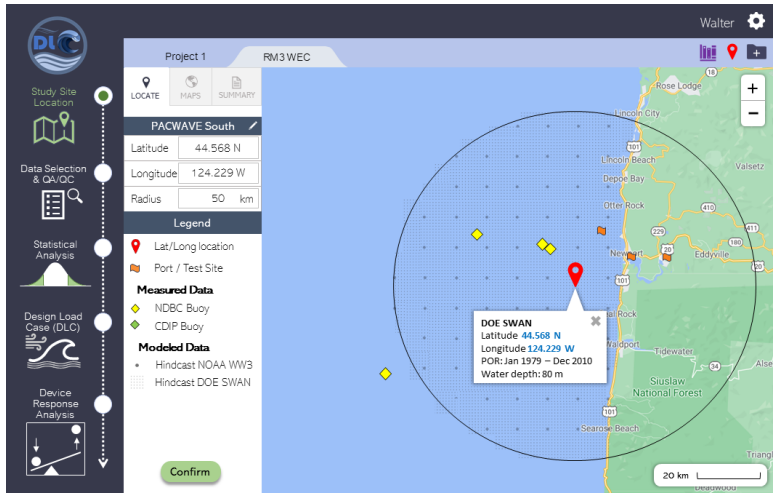
Environmental contours



Cape Hatteras, NC

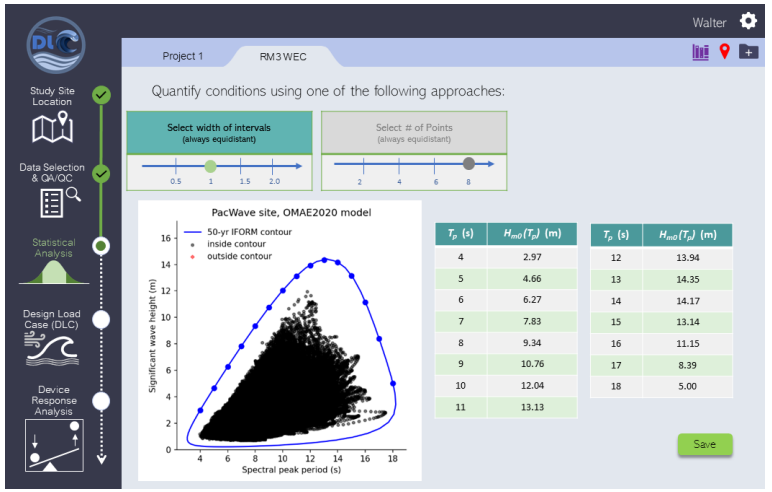
Design Load Case Generator

RENEWABLE ENERGY TECHNOLOGIES

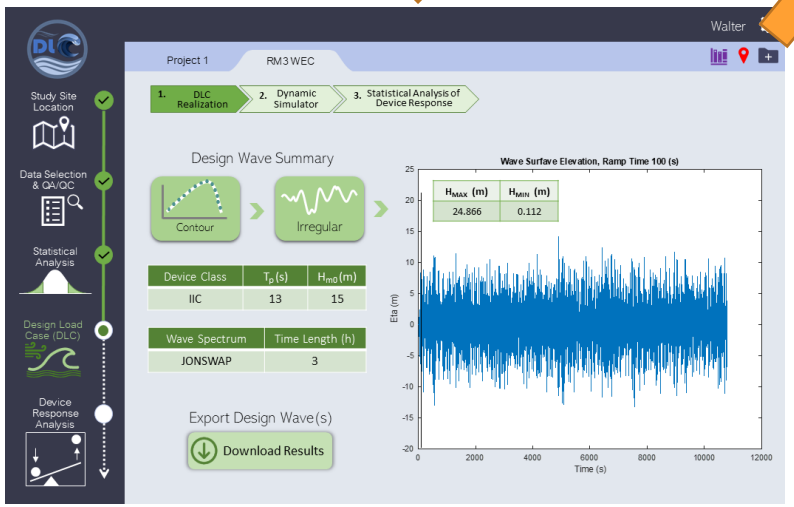


1. Find and select wave resource, power and load data.

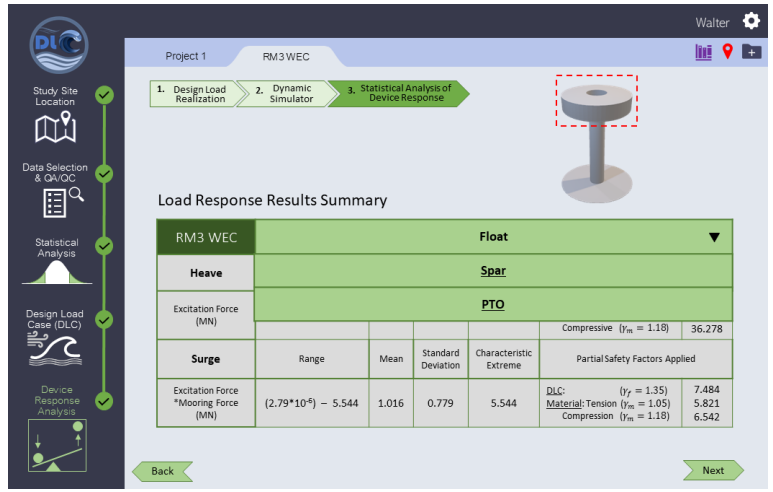
2. QA/QC data.



3. Compute extreme sea state stats.



4. Compute design load case wave train.



5. Design loads for IEC type-certification.

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Design Load Case Generator

Graphical mapping & statistics tool to analyze design load cases for marine energy systems

THANK YOU

Contact: vsneary@sandia.gov

EXTRA SLIDES

Resource metrics: IEC parameters, *f(x, y, t)* [IEC 62600-101:2015-06]

Omnidirectional wave power, *J*

$$J = \rho g \sum_{i,j} c_{g,i} S_{ij} \Delta f_i \Delta\theta_j \quad \text{[kW/m]}$$

- Total wave energy flux at point of interest
- Directionally unresolved

Directionally resolved wave power, J_θ

$$J_\theta = \rho g \sum_{i,j} c_{g,i} S_{ij} \Delta f_i \Delta\theta_j \cos(\theta - \theta_j)\delta \quad \text{[kW/m]}$$

- Wave energy flux vector through vertical plane of unit width

Direction of max J_θ

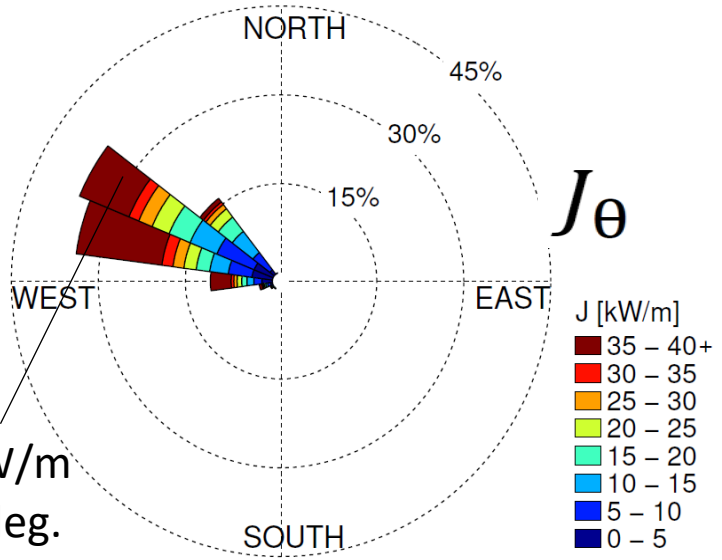
$$\theta_{\mathrm{Jmax}} \quad \text{[deg]}$$

- Bearing where most of the incident wave power coming from

Directionality coefficient, *d*

$$d = \frac{J_{\theta \mathrm{Jmax}}}{J} \quad \text{[-]}$$

- Measure of directional spreading



$J_{\theta max}$ ~36 kW/m
θ_{Jmax} ~300 deg.

Resource metrics: IEC parameters, *f(x, y, t)* [IEC 62600-101:2015-06]

Spectral moments

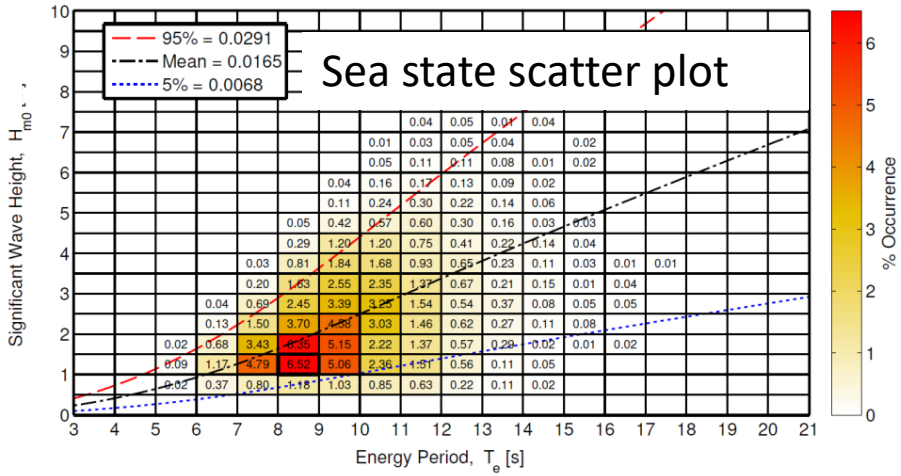
$$m_n = \sum_i f_i^n S_i \Delta f_i$$

- Used to derive important wave statistics

Significant wave height

$$H_{m0} = 4\sqrt{m_0} \quad [\text{m}]$$

- Proxy for H_s, combined with T_e to define sea states in scatter plots



H_{m0} T_e

Energy period

$$T_e \equiv T_{-10} = \frac{m_{-1}}{m_0} \quad [\text{s}]$$

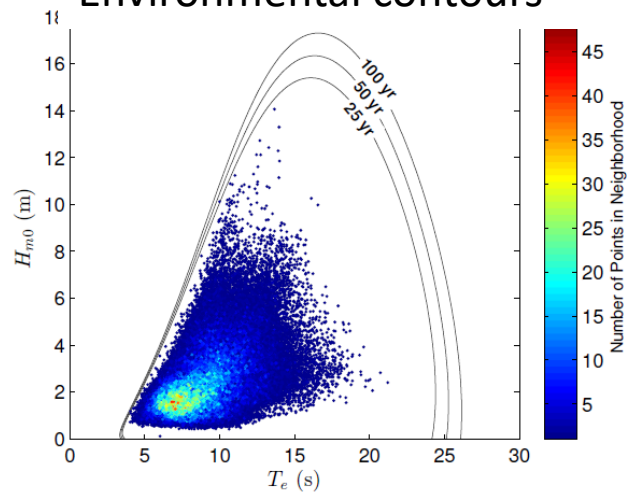
- Centroid of wave power spectrum, with H_{mo} to define sea states

Spectral width

$$\epsilon_0 = \sqrt{\frac{m_0 m_{-2}}{m_{-1}^2} - 1} \quad [-]$$

- Characterizes relative spreading of wave energy in spectra with frequency.

Environmental contours



H_{m0} T_e

Resource metrics: Extreme conditions, *f(x, y)* [Neary et al. 2017, 2019]

Extreme wave height

$H_{s(50)}$	$H_{s(5)}$	$H_{s(1)}$

[m]

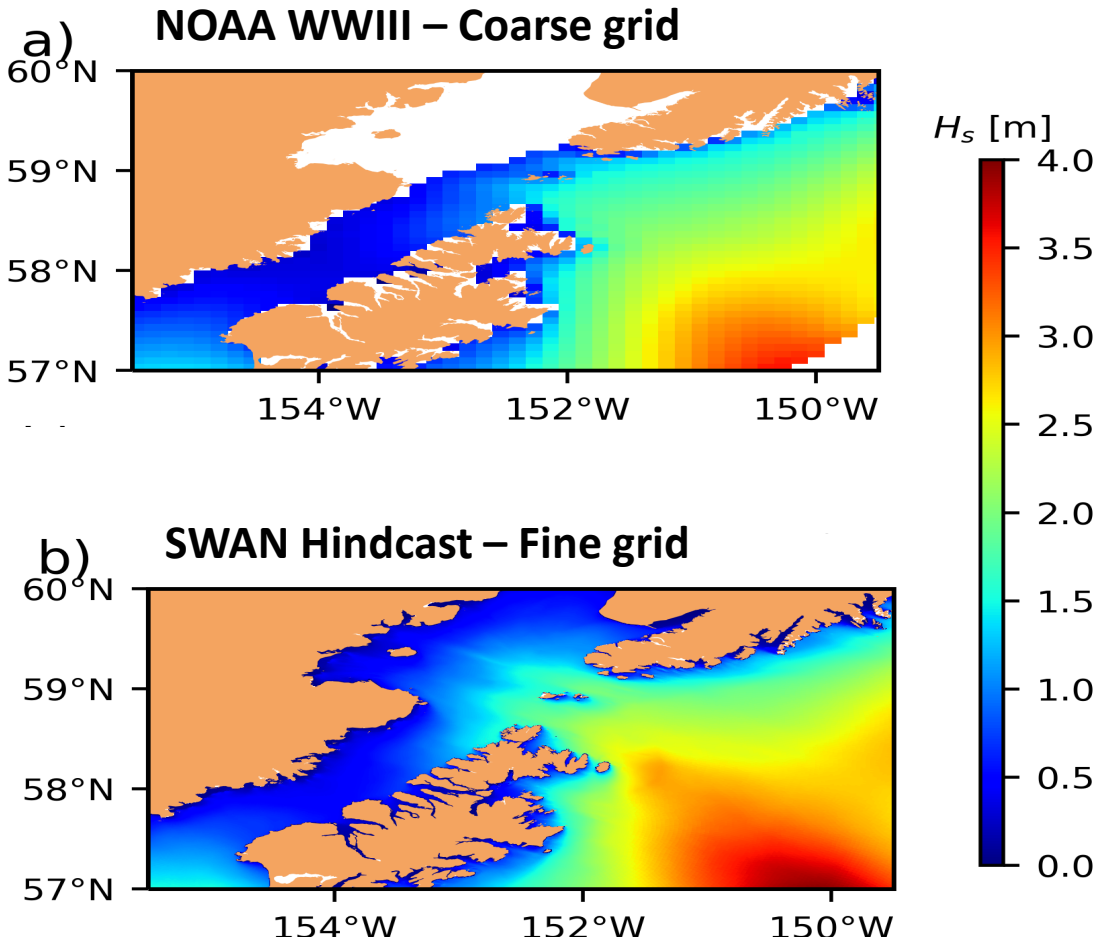
- Characterizes wave load [DNV RP-C205 2014]

Relative risk ratio

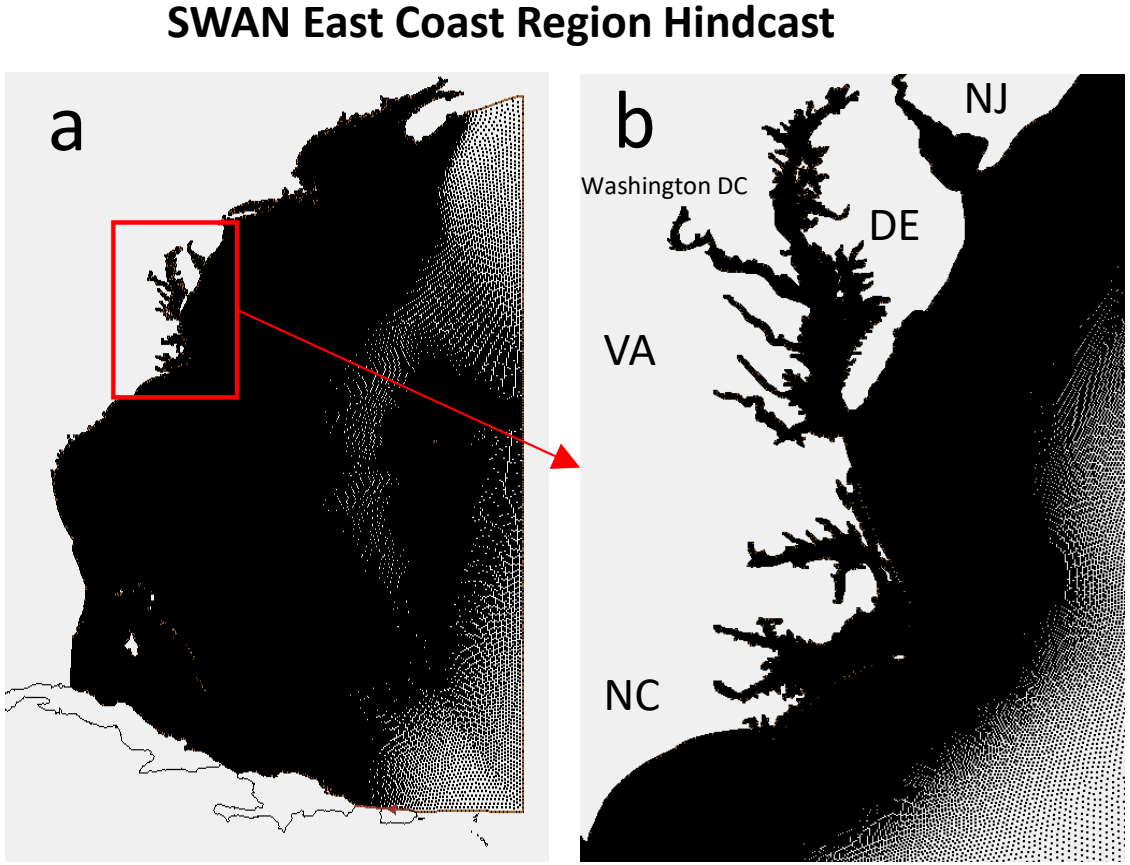
$$R = \frac{H_{s(50)}}{H_{s(mean)}}$$

[-]

- Characterizes risk relative to opportunity [Neary et al. 2017]

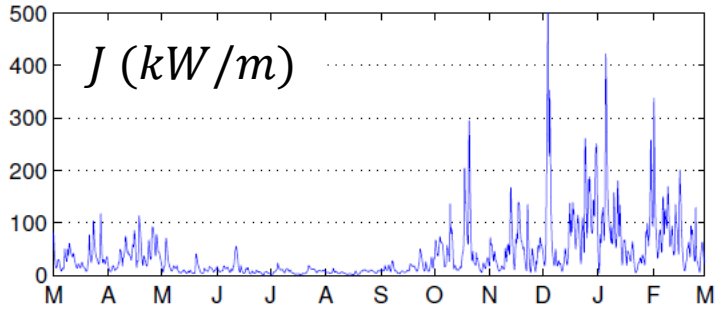


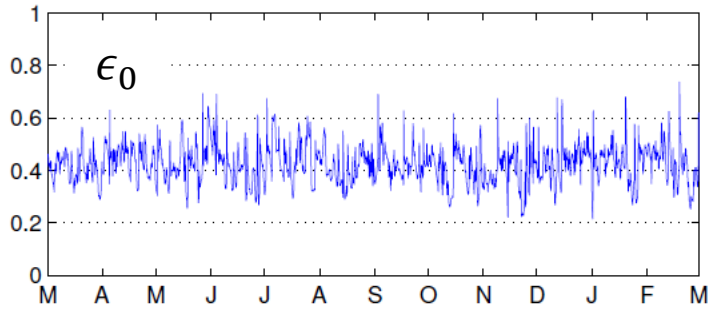
Significant wave height near Kodiak, Alaska, simulated by NOAA WWIII (a) and SWAN (b) [Yang & Neary 2019]

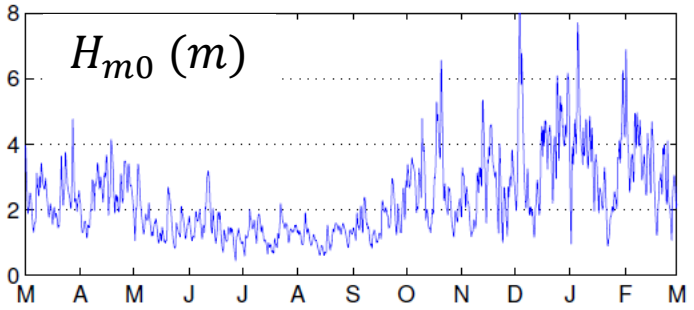


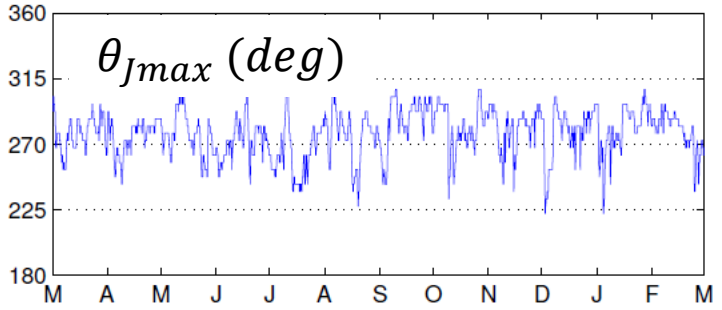
SWAN model grid for U.S. East Coast (a) and zoomed-in near the Chesapeake Bay region (b) [Allahdadi et al. 2019, Yang & Neary 2019]

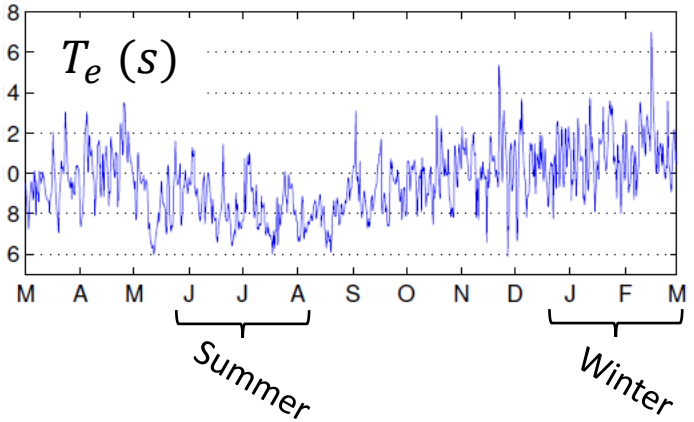
Open source tools-information: 6 IEC parameters at wave site (hourly time series)

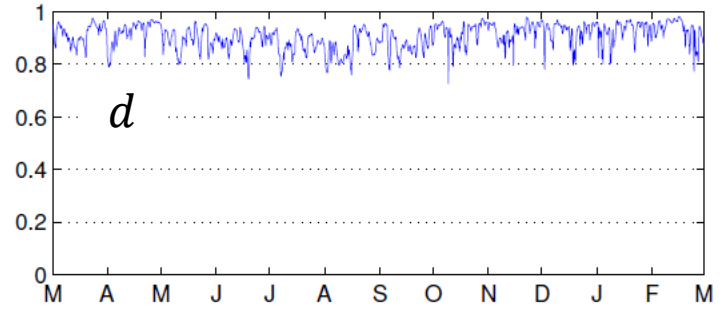




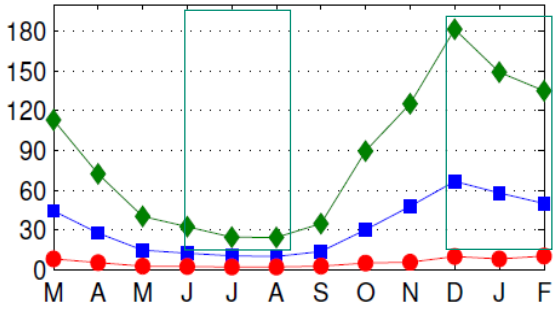




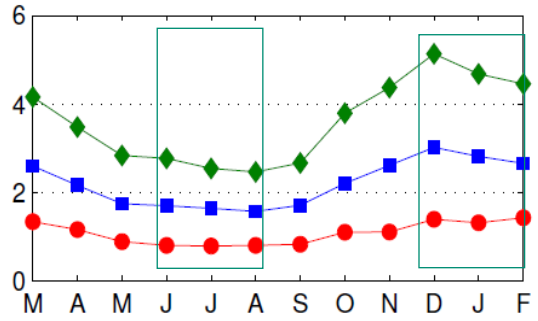




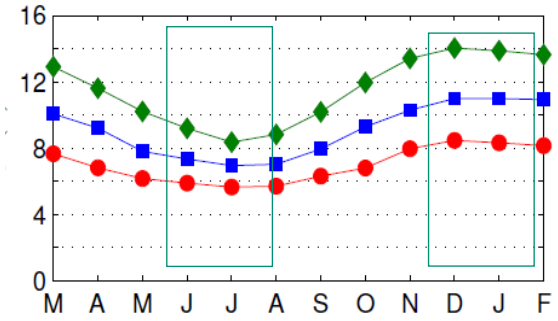
$J\ (kW/m)$



$H_{m0}\ (m)$



$T_e\ (s)$



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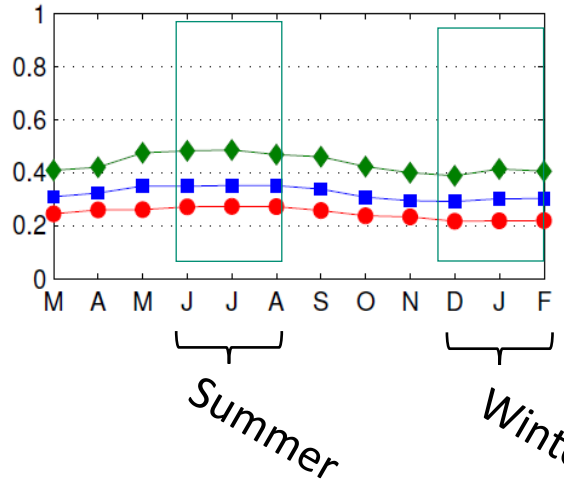
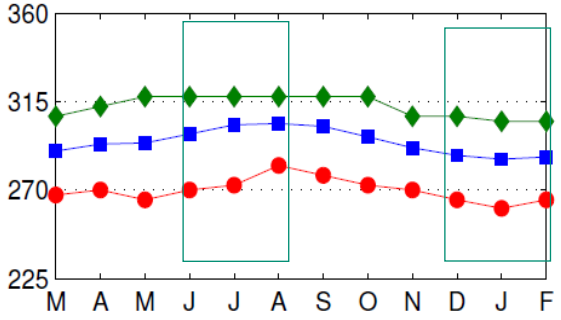


$\theta_{Jmax}\ (deg)$



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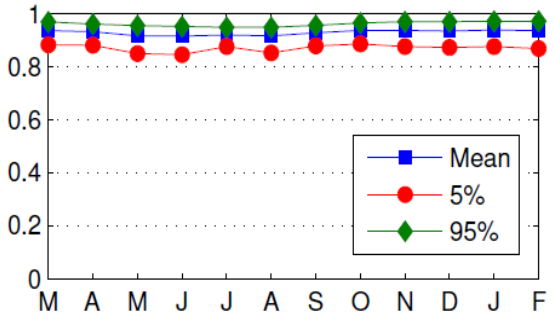
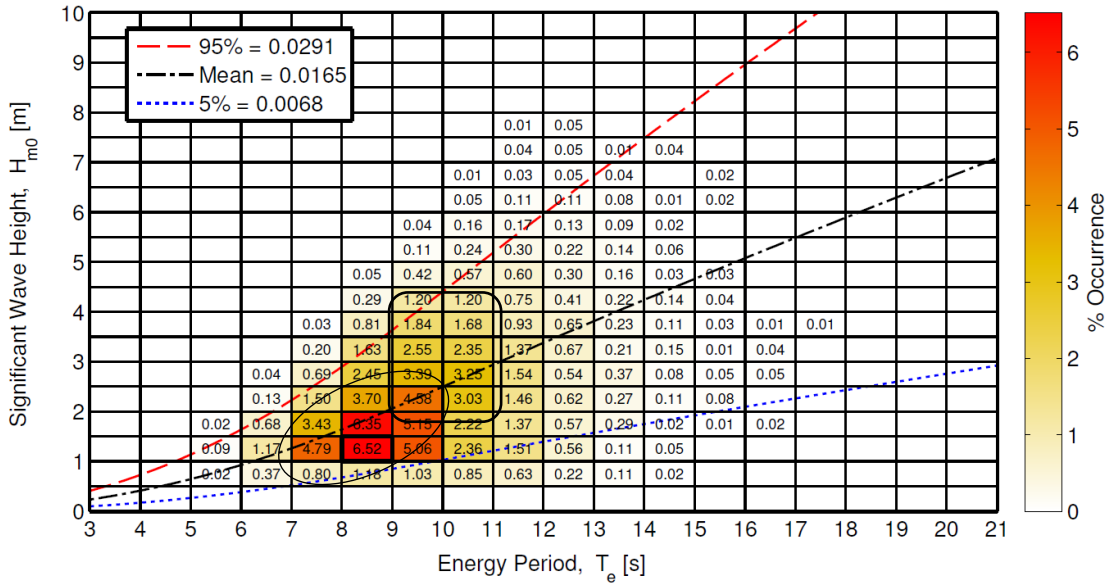




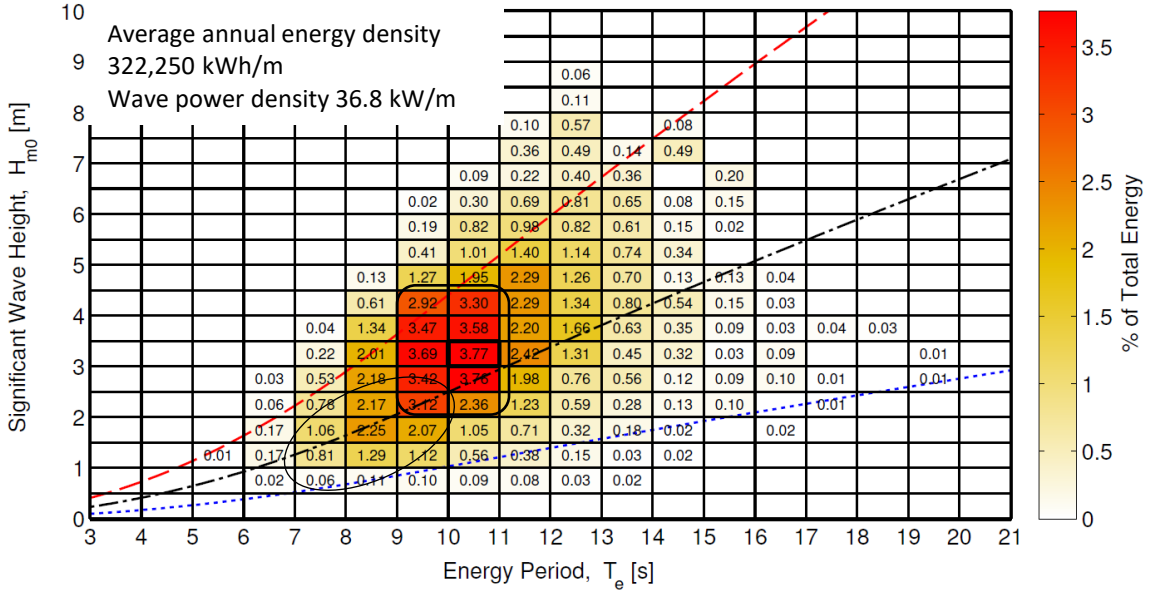
% Occurrence of Sea States

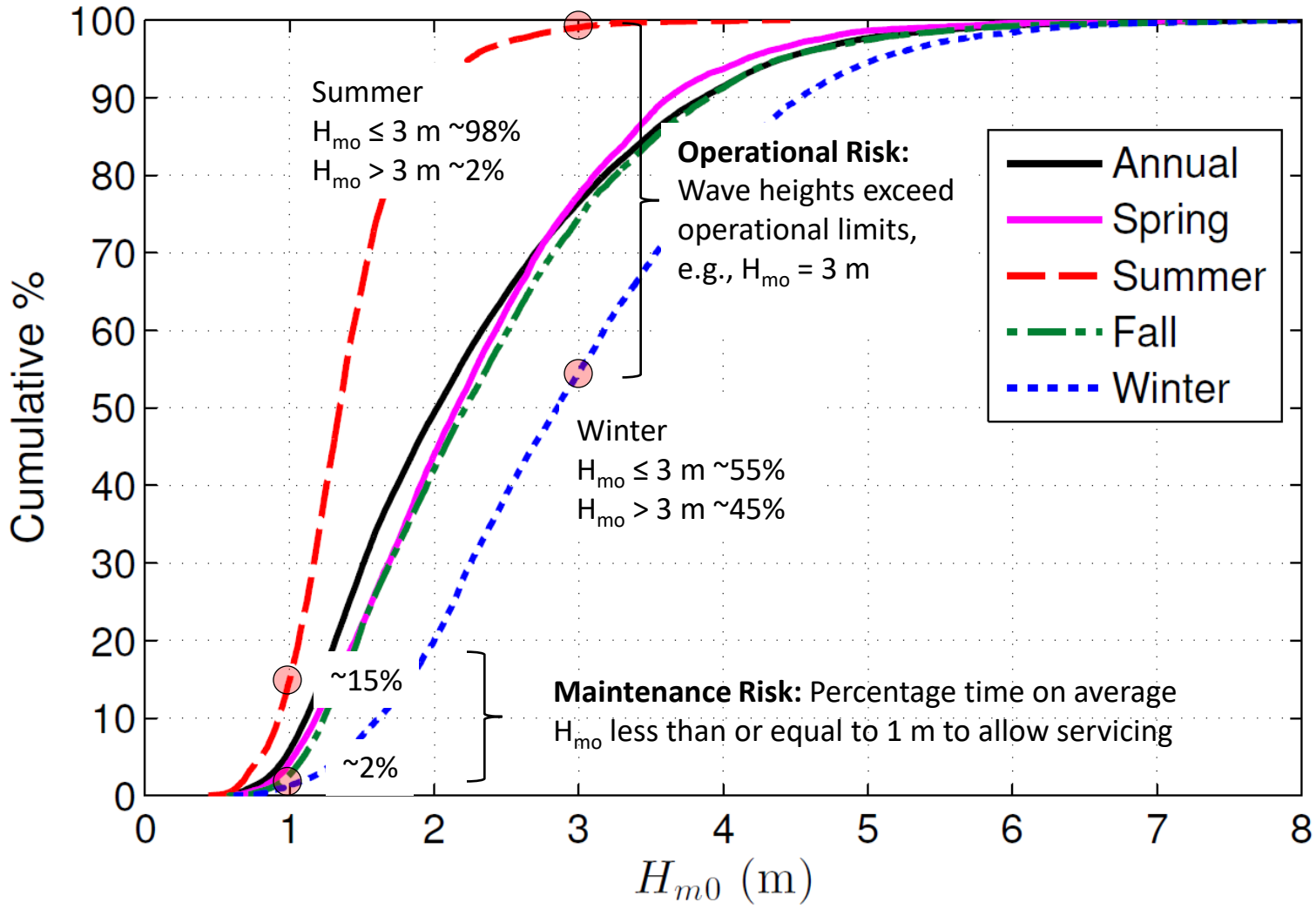
Most sea states have wave heights 1-2 m, with 8-10 second periods

Wave energy distribution

Most energy in sea states 2-4.5 m, and 9-11 seconds

Sea states with most energy (RECTANGLE) not those occurring most often (ELLIPSE)




Cumulative %
H_{m0} (m)
Summer
H_{mo} ≤ 3 m ~98%
H_{mo} > 3 m ~2%
Operational Risk:
Wave heights exceed
operational limits,
e.g., H_{mo} = 3 m
Winter
H_{mo} ≤ 3 m ~55%
H_{mo} > 3 m ~45%
~15%
~2%
Maintenance Risk: Percentage time on average
H_{mo} less than or equal to 1 m to allow servicing
Annual
Spring
Summer
Fall
Winter