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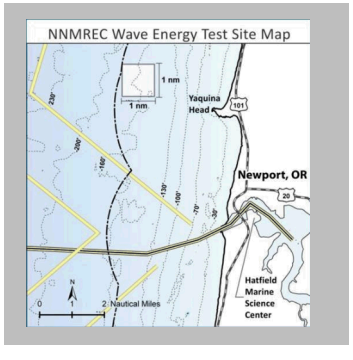

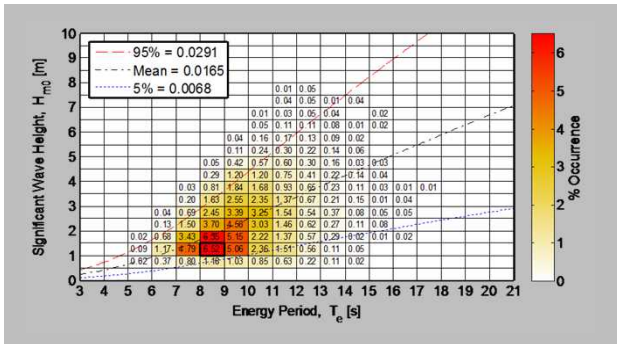

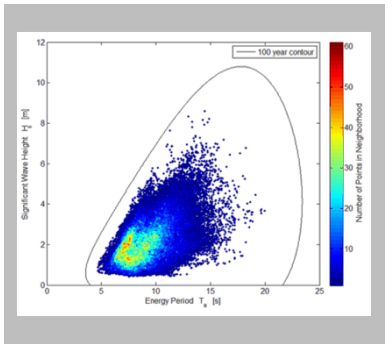

Wave Resource Characterization at US Wave Energy Converter (WEC) Test Sites

Ann Dallman, Vincent Neary

Ocean Sciences Meeting, New Orleans, LA, 26 January 2016

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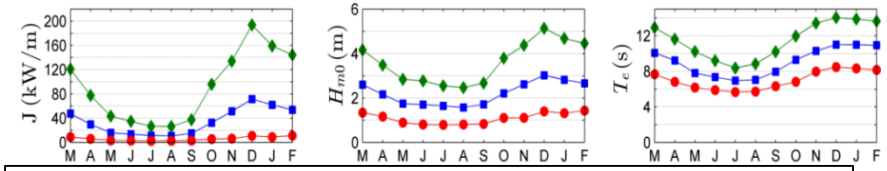
Introduction

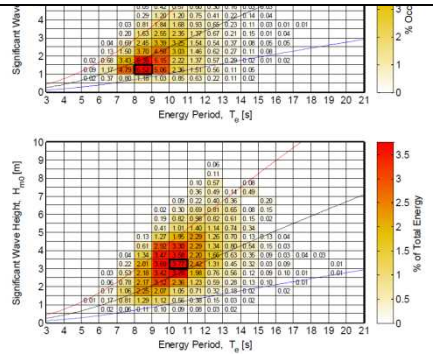
- Resource assessment & characterization critical for WEC development
- (Prior to project) lacking consistent characterization at test sites
- DOE MHK program project: Sandia developed catalogue –
  - 1st edition (2014): 3 high energy U.S. sites
  - 2nd edition (2015): 5 additional sites
- Consistent framework for future site characterizations
- Dataset for initial wave classification system

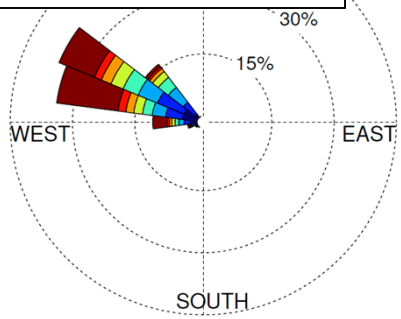
IEC 62600-101 TS: Wave Energy Resource Assessment and Characterization

- Three classes of assessment:
  - Reconnaissance (>300 km),
  - Feasibility (20-500 km),
  - Design (<25 km)
- Minimum 10 years recommended
- Model hindcast data preferred; measure-correlate-predict (MCP) method acceptable
- Quantify six resource parameters
- Monthly mean values & time histories over short period
- JPDs
- Cumulative frequency distributions
- Wave roses



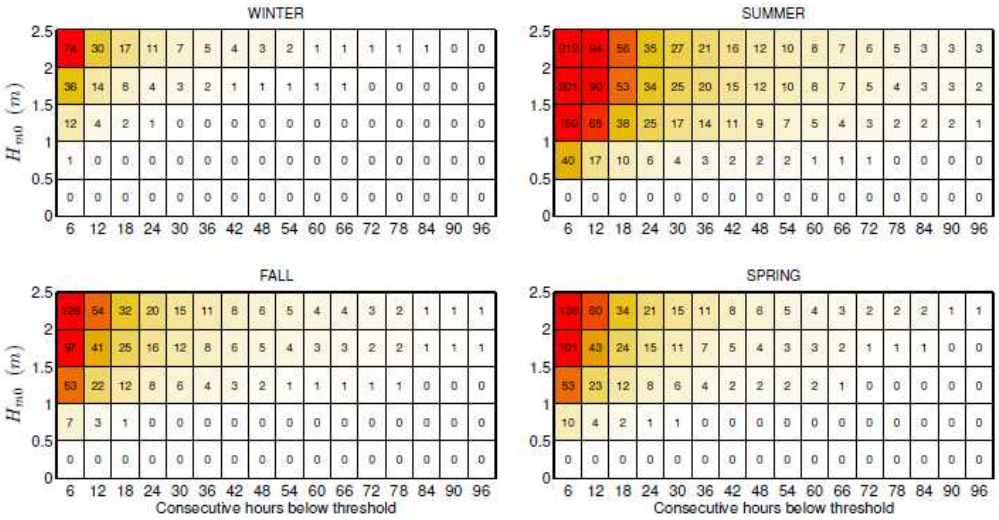
J	Omnidirectional wave power
H_{m0}	Significant wave height
T_e	Energy period
ϵ_0	Spectral width
θ_j	Direction of max directionally resolved wave power
d_θ	Directionality coefficient

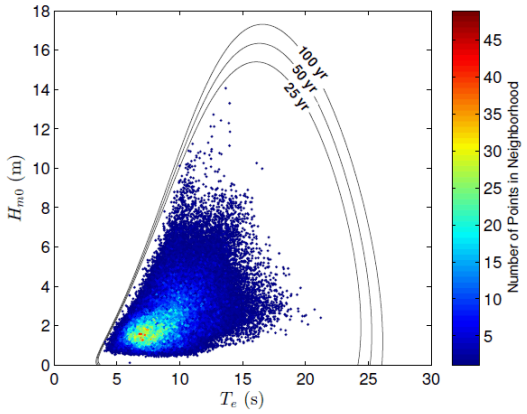


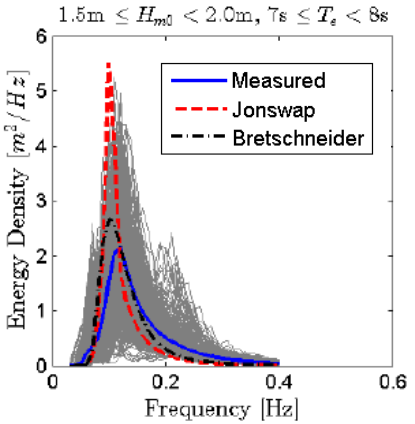


Wave characterization at U.S. test sites

- 8 U.S. test sites
- Description of site, testing infrastructure, available met-ocean measured data
- Simulated hindcast data, ≥ 10 years for most
- Parameters and plots recommended by IEC TS
- Additional data provided:
  - Weather windows
  - Extreme sea states (environmental contour plots)
  - Measured spectra compared to standard forms
  - Wind & ocean current statistics





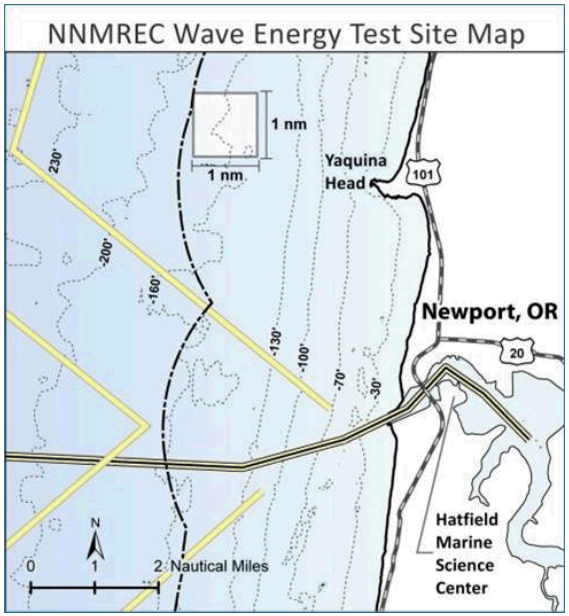


Available at:
http://en.openei.org/wiki/Characterization_of_U.S._Wave_Energy_Converter_(WEC)_Test_Sites

U.S. test sites included

- Existing test sites
  - U.S. Navy Wave Energy Test Site (WETS)
  - Pacific Marine Energy Center (PMEC) North Energy Test Site (NETS)
  - Jennette's Pier Wave Energy Test Center
  - USACE Field Research Facility (FRF)
  - PMEC Lake Washington

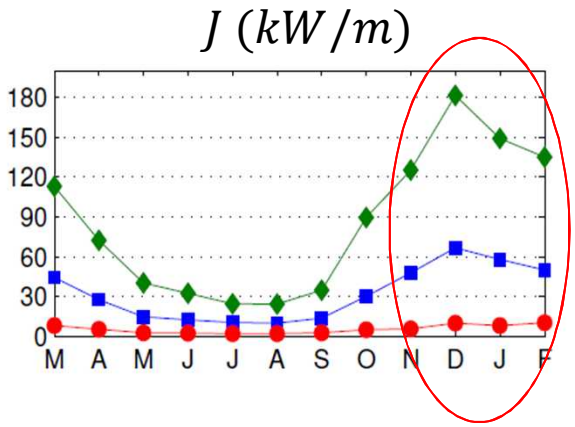
- Potential / planned test sites:
  - PMEC South Energy Test Site (SETS)
  - CalWave Central Coast WEC Test Site at Vandenberg Air Force Base
  - Humboldt Bay, CA

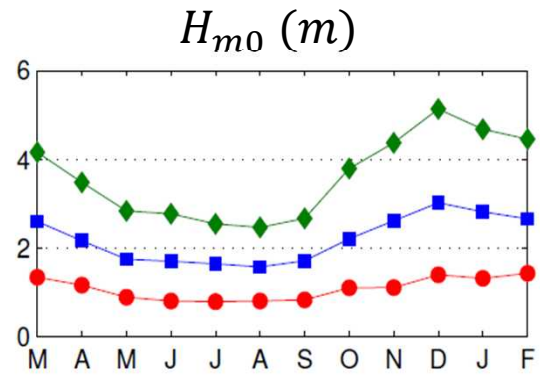


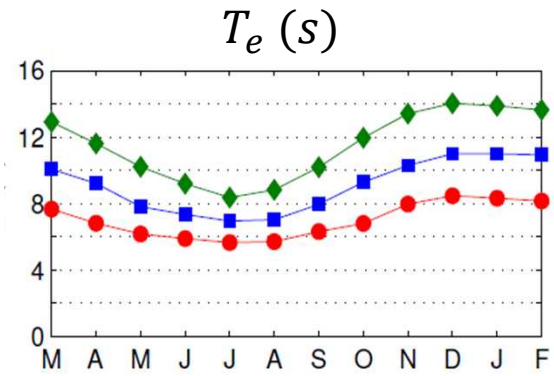
Source: http://nnmrec.oregonstate.edu/pmec-facilities

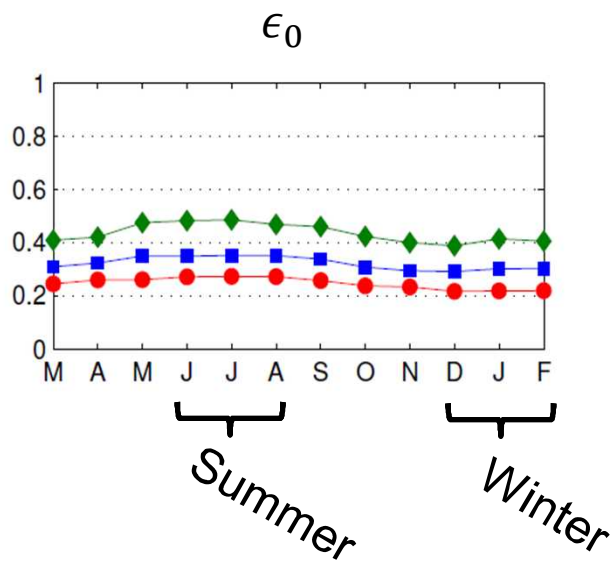
Available at:
http://en.openei.org/wiki/Characterization_of_U.S._Wave_Energy_Converter_(WEC)_Test_Sites

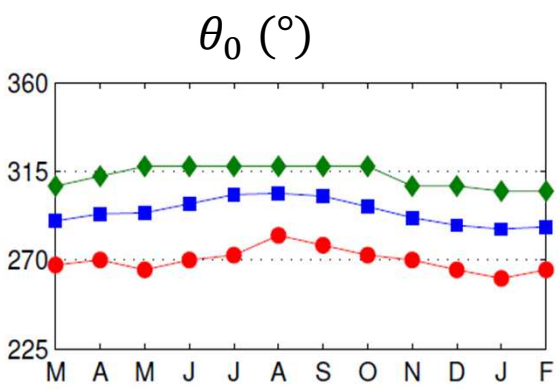
Monthly Means

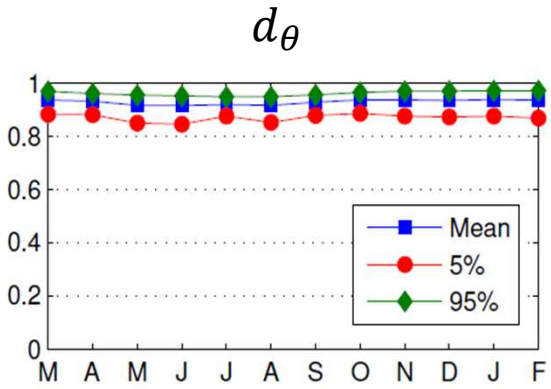












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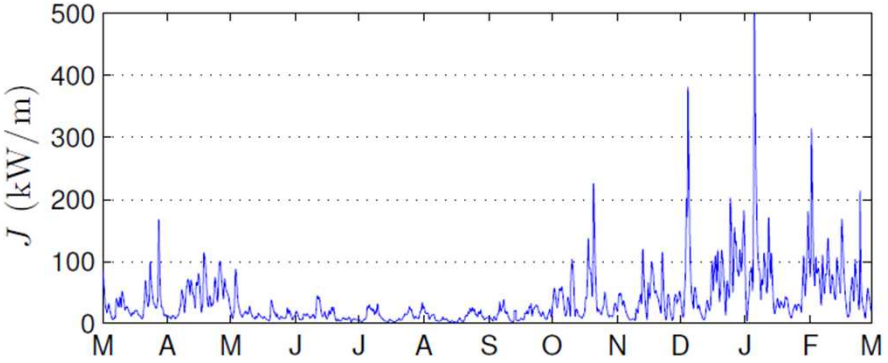
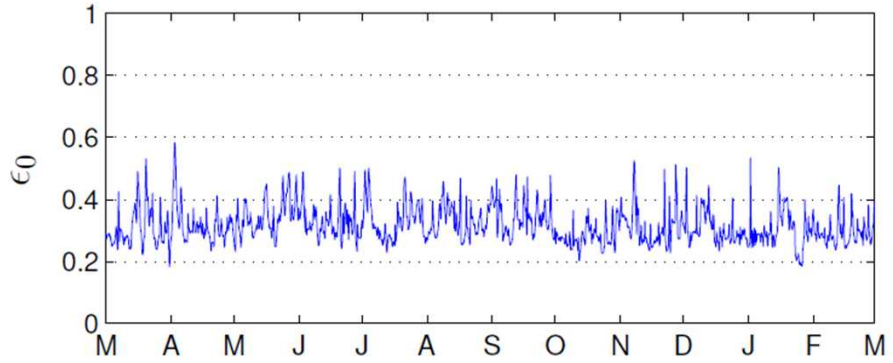
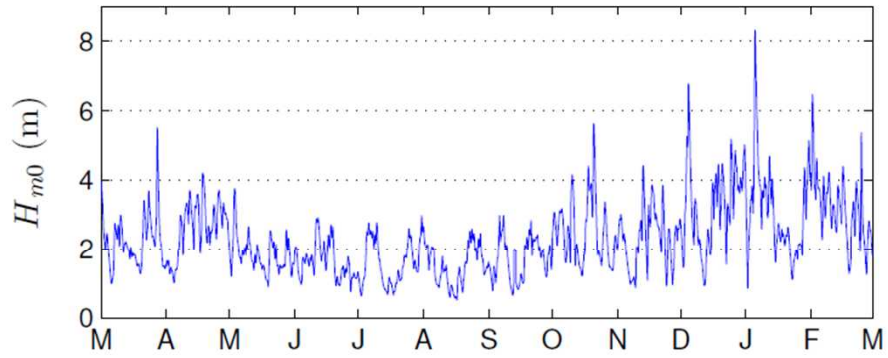
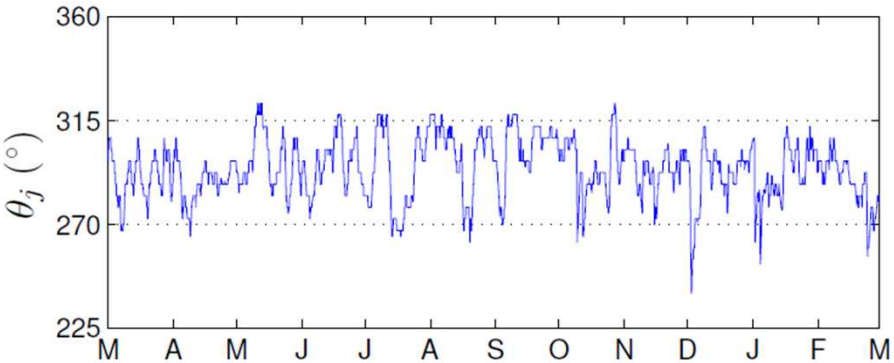
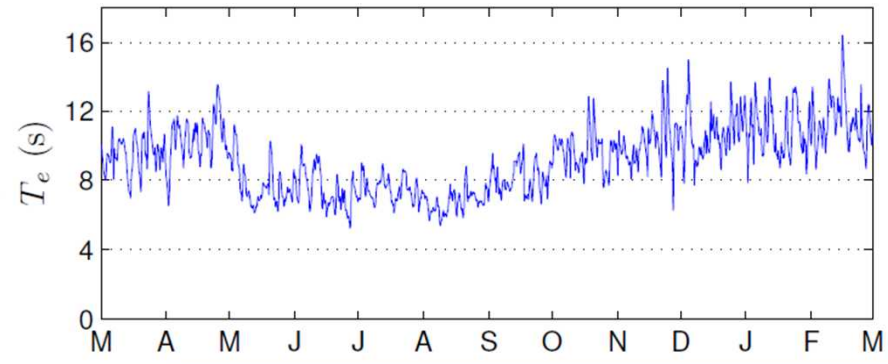
Time series of 6 parameters

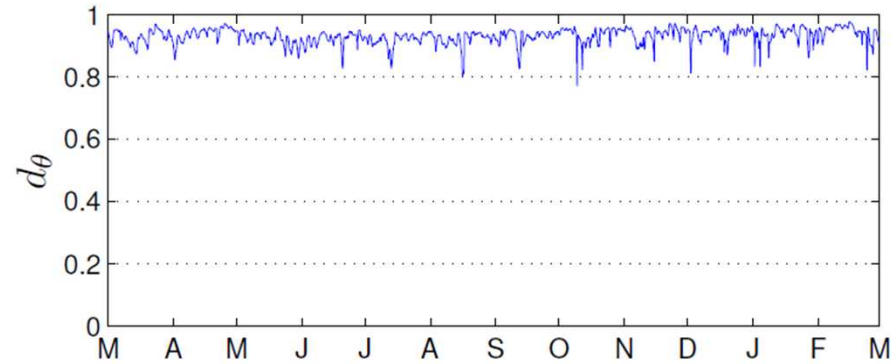




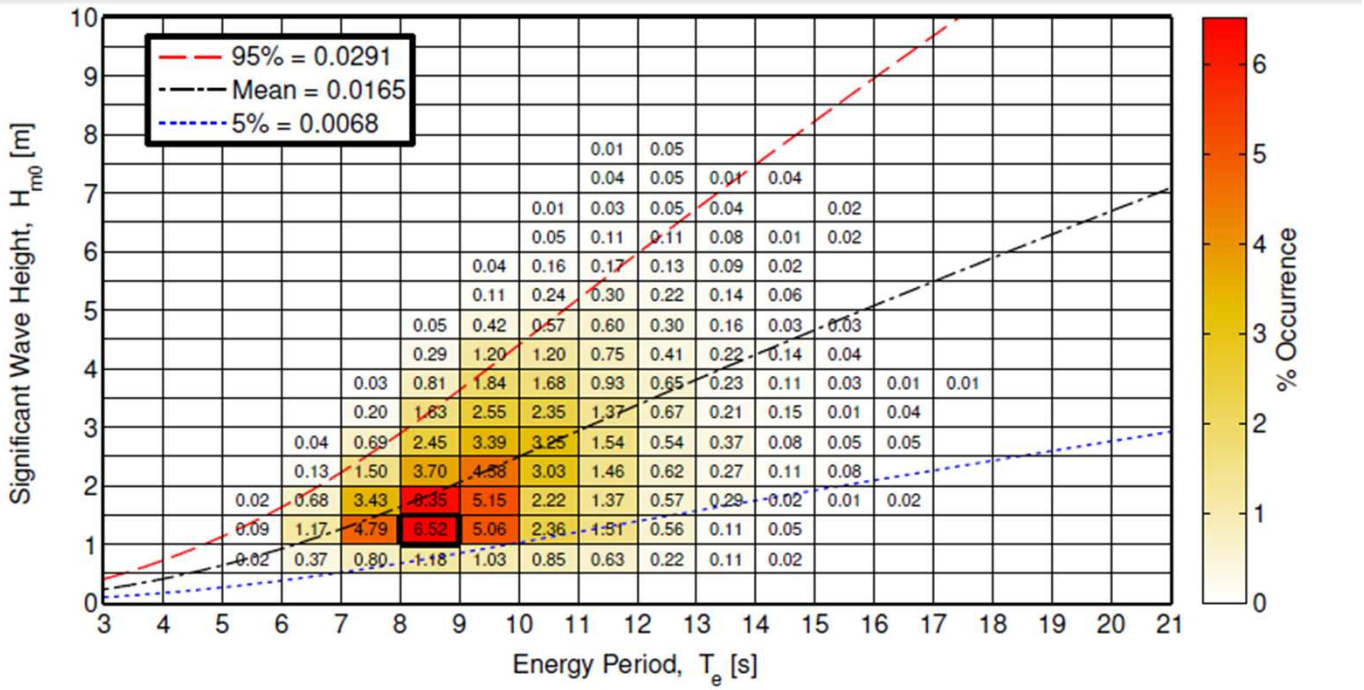


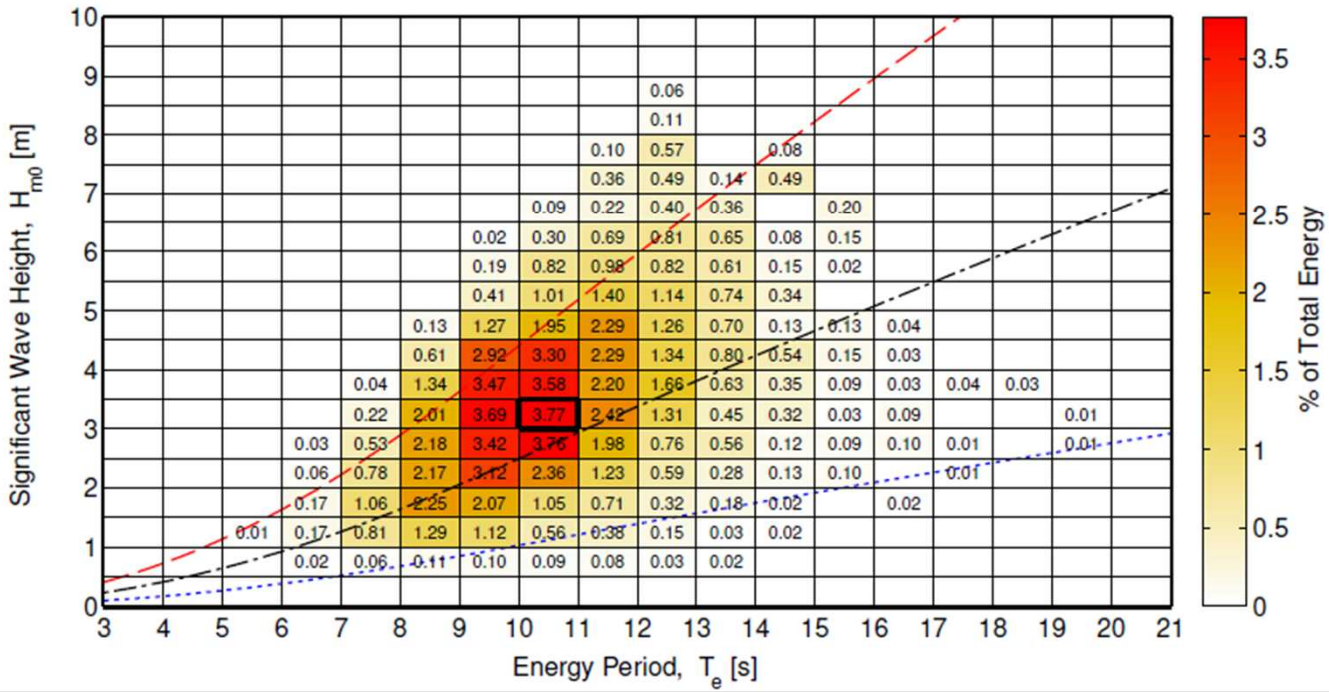






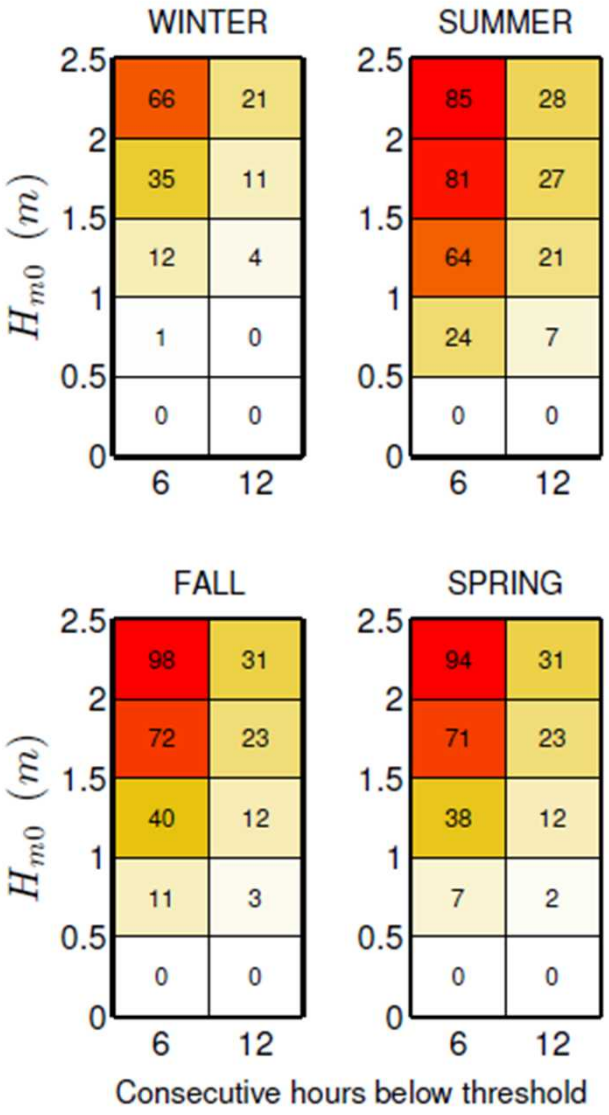
JPDs


95% = 0.0291
Mean = 0.0165
5% = 0.0068
Significant Wave Height, H_{m0} [m]
Energy Period, T_e [s]
% Occurrence

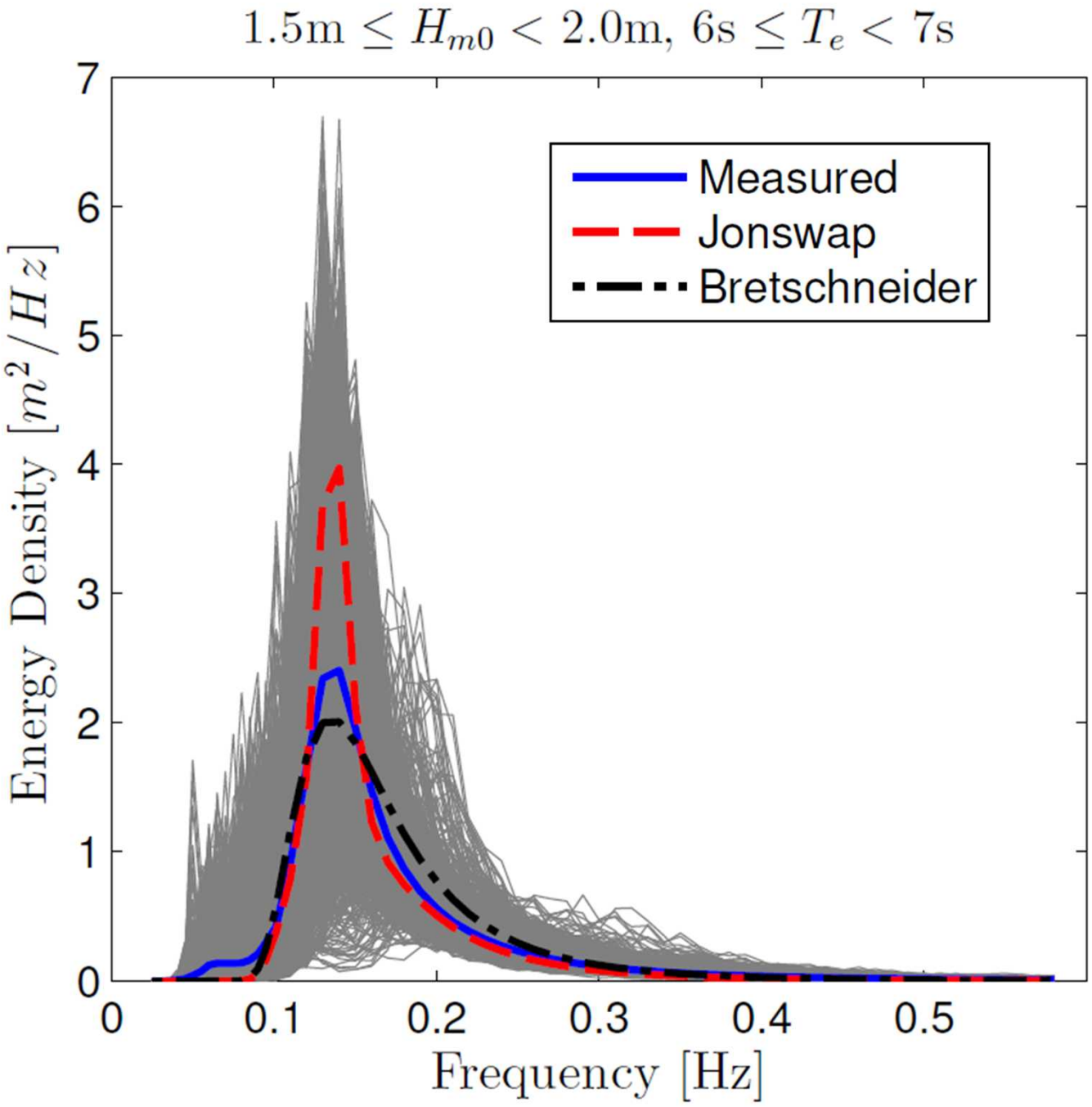

Significant Wave Height, H_{m0} [m]
Energy Period, T_e [s]
% of Total Energy

Weather Windows

- 6 hr windows up to 96 hr (4 days)
- # occurrences of time period below threshold
- Cumulative (one 12-hr window = two 6hr windows)
- Hm0
- Hm0, U<15mph
- Hm0, U<15mph, ~daytime



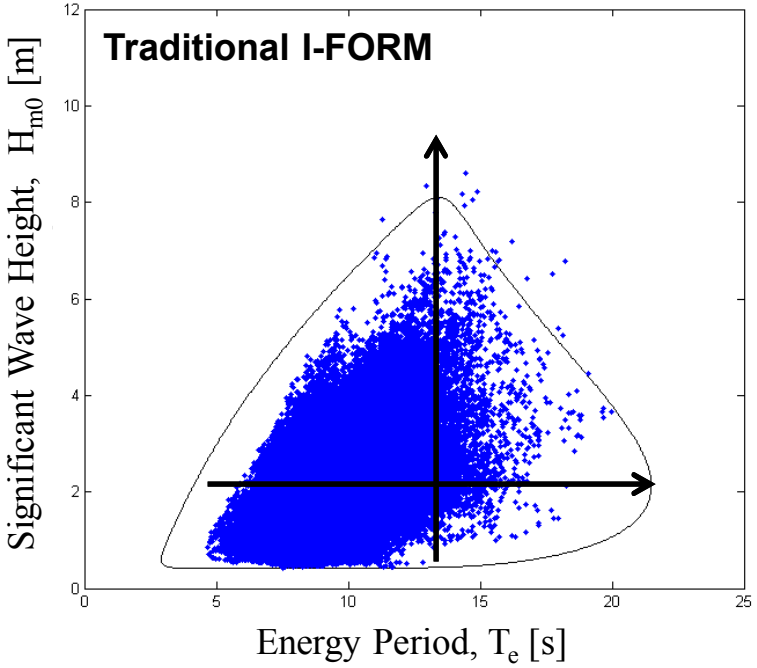
Spectra

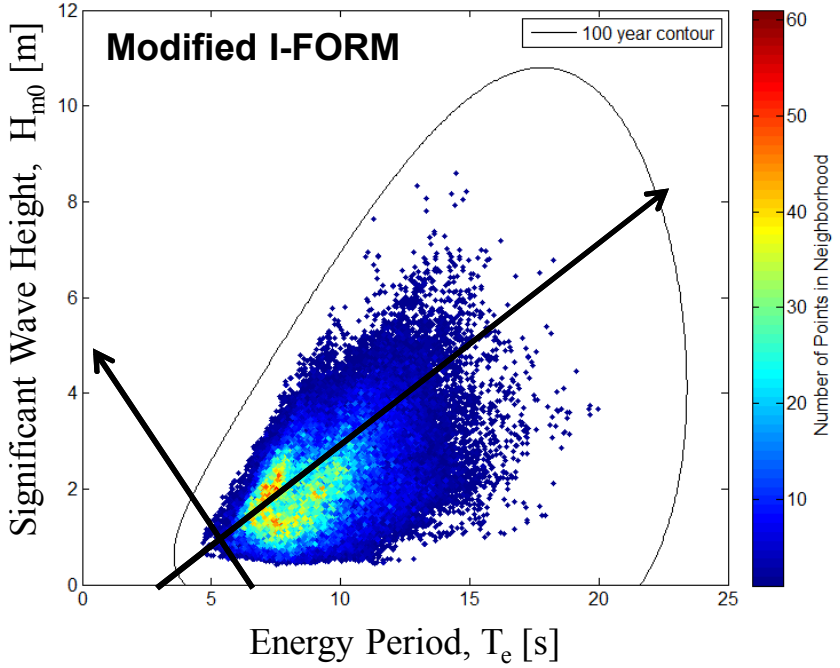

$1.5\text{m} \leq H_{m0} < 2.0\text{m},\ 6\text{s} \leq T_e < 7\text{s}$
Measured
Jonswap
Bretschneider
Energy Density $[m^2/Hz]$
Frequency [Hz]
0
1
2
3
4
5
6
7
0
0.1
0.2
0.3
0.4
0.5

Extreme Sea States

- Variety of methods used in literature
- Most use some type of extreme value analysis to estimate return period of significant wave height
- Inverse FORM technique:
  - Prescribed in DNV standard
  - Includes set of wave height & period combos along #-yr contour (e.g., 50-yr, 100-yr)
- Provides developers with extreme sea states (H_{m0} & T_e) that could affect their device

Extreme Sea States

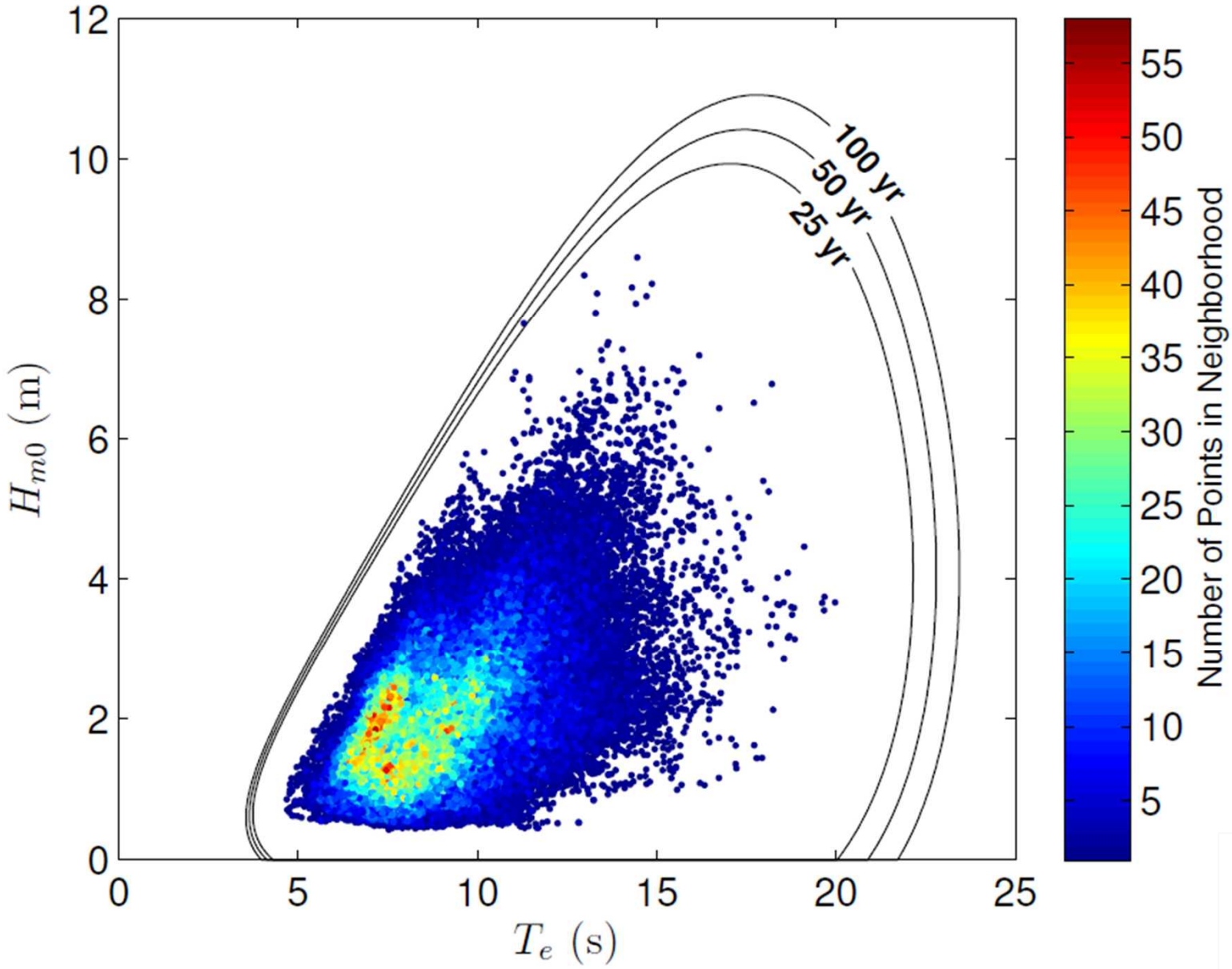




http://energy.sandia.gov/energy/renewable-energy/water-power/resource-characterization/extreme-sea-state-contour/

Aubrey C. Eckert-Gallup, Cédric J. Sallaberry, Ann R. Dallman, Vincent S. Neary, Application of principal component analysis (PCA) and improved joint probability distributions to the inverse first-order reliability method (I-FORM) for predicting extreme sea states, Ocean Engineering, Volume 112, 15 January 2016, Pages 307-319, ISSN 0029-8018, http://dx.doi.org/10.1016/j.oceaneng.2015.12.018.

Extreme Sea States



Conclusions

- Test site catalogue – comprehensive resource
- Water power research & projects aiming to
  - Compress technology and commercial development timelines to reduce levelized cost of energy
  - Reduce risk and uncertainty for emerging wave energy industry
- Available tools / codes for download from SNL
  - Google ‘Sandia Water Power’ for our website
  - SNL-ESSC (SNL - Extreme Sea State Contour)
  - WEC-Sim (Wave Energy Converter SIMulator); joint w/ NREL
  - SNL-SWAN
  - Upcoming – extreme conditions modeling toolbox – TBD

Thank you – Questions?

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- Ann Dallman, ardallm@sandia.gov

- http://energy.sandia.gov/energy/renewable-energy/water-power/
- http://en.openei.org/wiki/Characterization_of_U.S._Wave_Energy_Converter_(WEC)_Test_Sites

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- See 2nd Edition Catalogue for detailed list of acknowledgements