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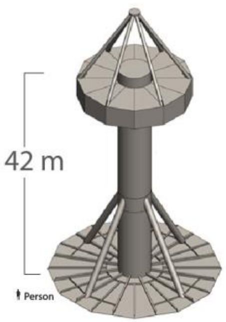

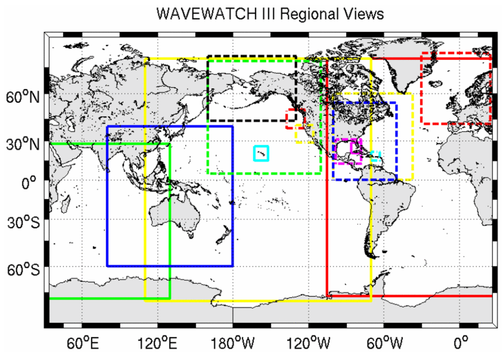

Classification systems for wave energy resources and WEC technologies

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Wave Resource Characterization 4 (#973)

Civil Engineering Building, Room G10

August 29, 2017

12th ewtec 2017 European Wave and Tidal Energy Conference Series

Sandia National Laboratories

cruz atcheson CONSULTING ENGINEERS

Georgia Tech

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Motivation

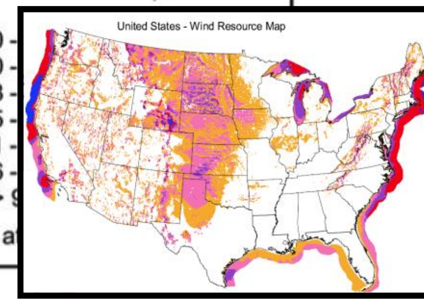
- Resource classification
  - Reduce time and costs for siting, scoping studies and project planning
- Technology classification
  - Reduce design and manufacturing costs

Wind Resource Classification

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m[2]	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
1	Poor	0 - 200	0.0 -	
2	Marginal	200 - 300	6.0 -	
3	Fair	300 - 400	6.8 -	
4	Good	400 - 500	7.5 -	
5	Excellent	500 - 600	8.1 -	
6	Outstanding	600 - 800	8.6 -	
7	Superb	> 800	>	

[a] Wind speeds are based on a Weibull k of 2.4 at



Wind Turbine Classification

Wind turbine class		I	II	III	S
V_{ref}	(m/s)	50	42.5	37.5	Values specified by designer
A	I_{ref}(-)	0.16			
B	I_{ref}(-)	0.14			
C	I_{ref}(-)	0.12			

TC88 Design document, 61400-1 Ed. 3, © IEC:2005

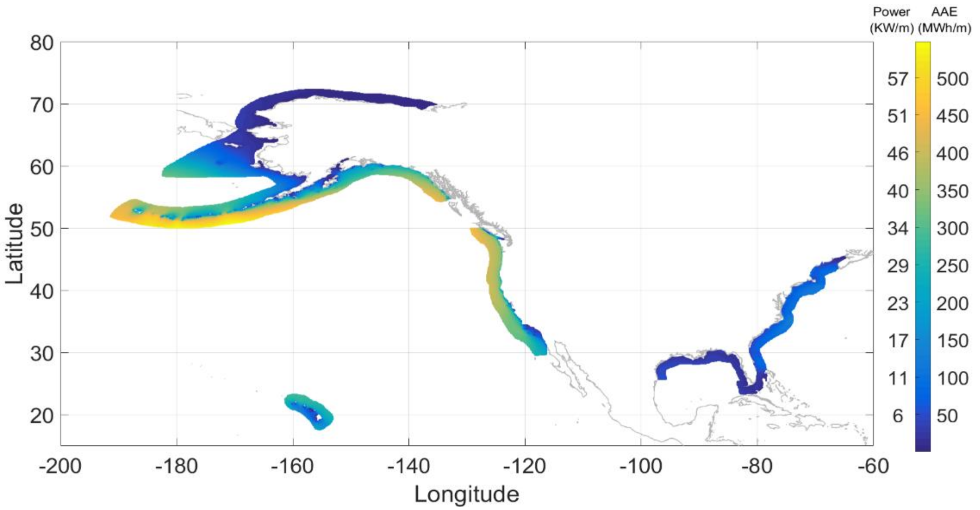
Resource classification: Wave power density

- Omni-directional power density – *opportunity for wave energy extraction*

$$J = \frac{\rho g}{16} H_s^2 C_g(T_e, h) \qquad \text{[KW/m]}$$

- Annual available energy (AAE) density

$$AAE = J(8766h/year) \qquad \text{[KW-h/m]}$$



Geographic distribution of mean omni-directional power density and AAE density in US

Resource classification: Data source

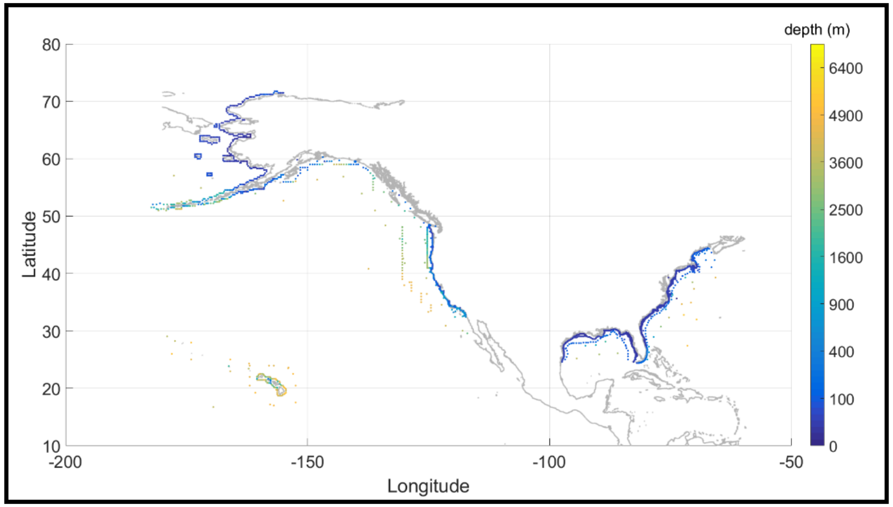
Source : NOAA's 30-year WWIII hindcast (Chawla et al., 2013)

Third generation, spectral wave model providing wave hindcasts

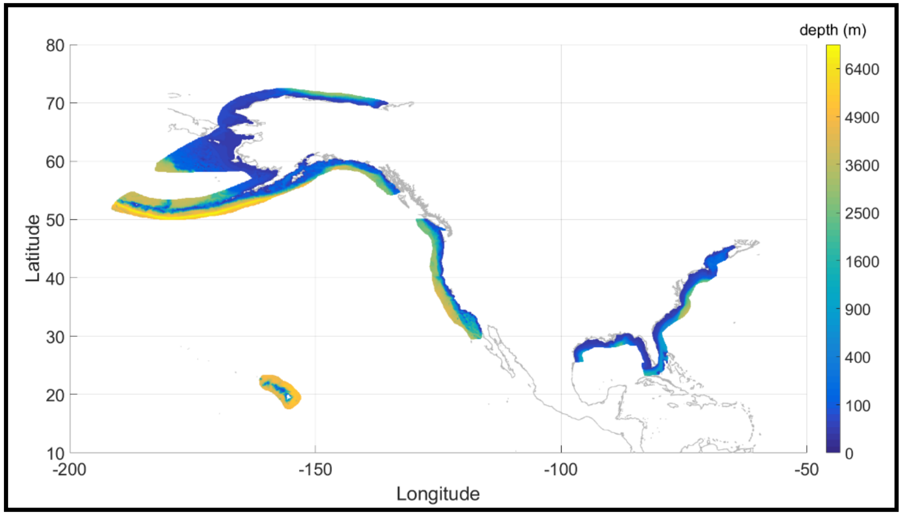
(4min resolution ≈ 7km)

Data :
1. Complete directional wave spectra S(f,θ) at limited grid points
2. Bulk and partition wave parameters (H_s, T_p, θ_m, at each grid point)

Spectra $S(f,\theta)$ - 1,951 locations



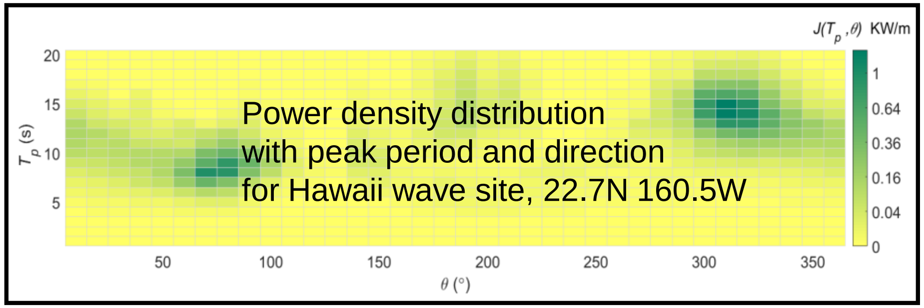
Partition - 70,386 locations



Resource classification: Partitioned J

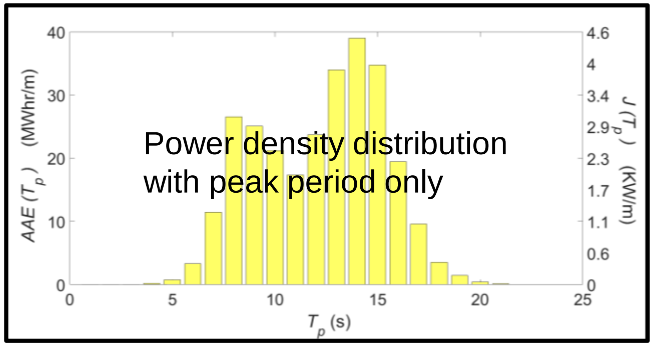
1. Calculate partition wave power densities in peak period and direction bins

$$J(T_p, \theta)$$



2. Sum all direction bins

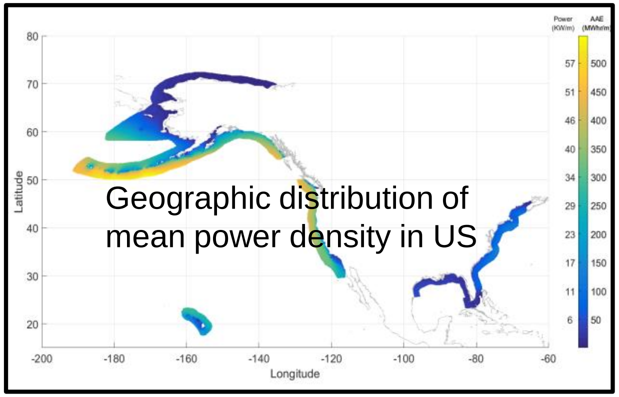
$$J(T_p) = \sum_{\theta} J(T_p, \theta)$$



3. Sum all to get total J and annual available energy (*AAE*) density

$$J = \sum_{T_p} J(T_p) \quad \text{and} \quad AAE = T_{year} * J$$

T_{year}= number of hours in a year (8,766 hrs)

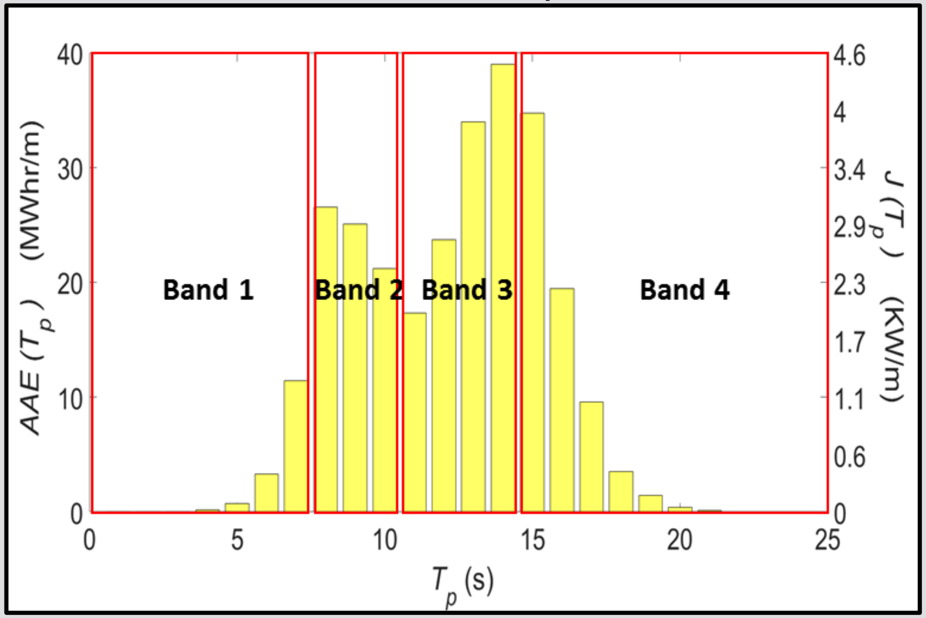


Resource Classification: Class delineation

Frequency/period band classes (4)

Band	Band 1 (local wind sea)	Band 2	Band 3 (short, moderate and long period swell)	Band 4
Period, T_p	$0 < T_p < 7$	$7 < T_p < 10$	$10 < T_p < 14$	$14 < T_p$
Frequency, f	f < 0.14	0.1 <f < 0.14	0.07 < f < 0.1	0 < f < 0.07

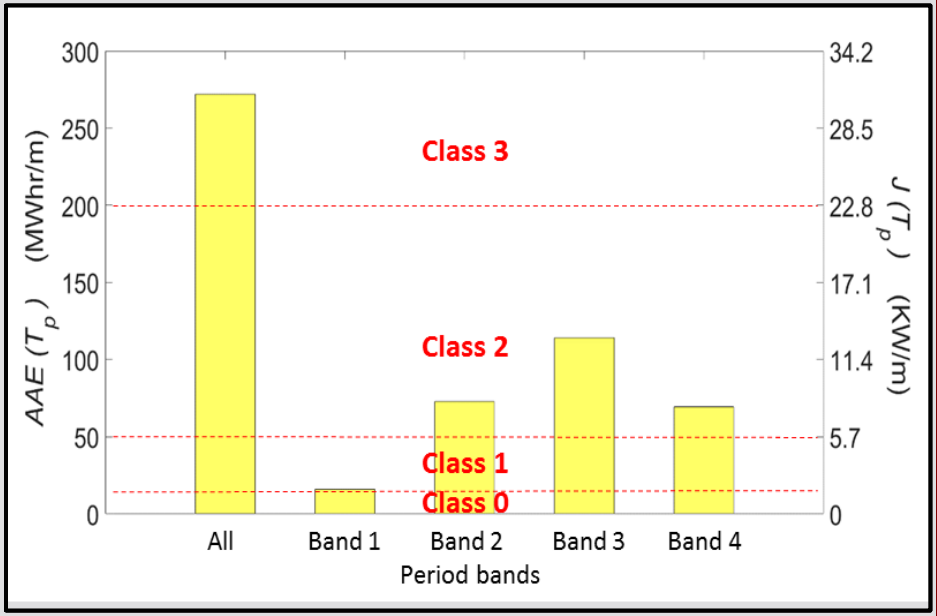
(1) Local wind sea, period ($0 < T_p < 7$)
(2) Swell, short period ($7 < T_p < 10$)
(3) Swell, moderate period ($10 < T_p < 14$)
(4) Swell, long period ($14 < T_p$)



Power classes (4)

Class	0	1	2	3
Power(KW/m)	J<1.14	1.14<J<5.7	5.7<J<22.8	22.8<J
AAE(MWh/m)	AAE<10	10<AAE<50	50<AAE<200	200<AAE

0 – small (P<10 KW), homes, farms, remote
1 – intermediate (10 – 500 KW), village, hybrid systems, distributed
2, 3 – intermediate to large (P>500 KW), commercial, utility scale



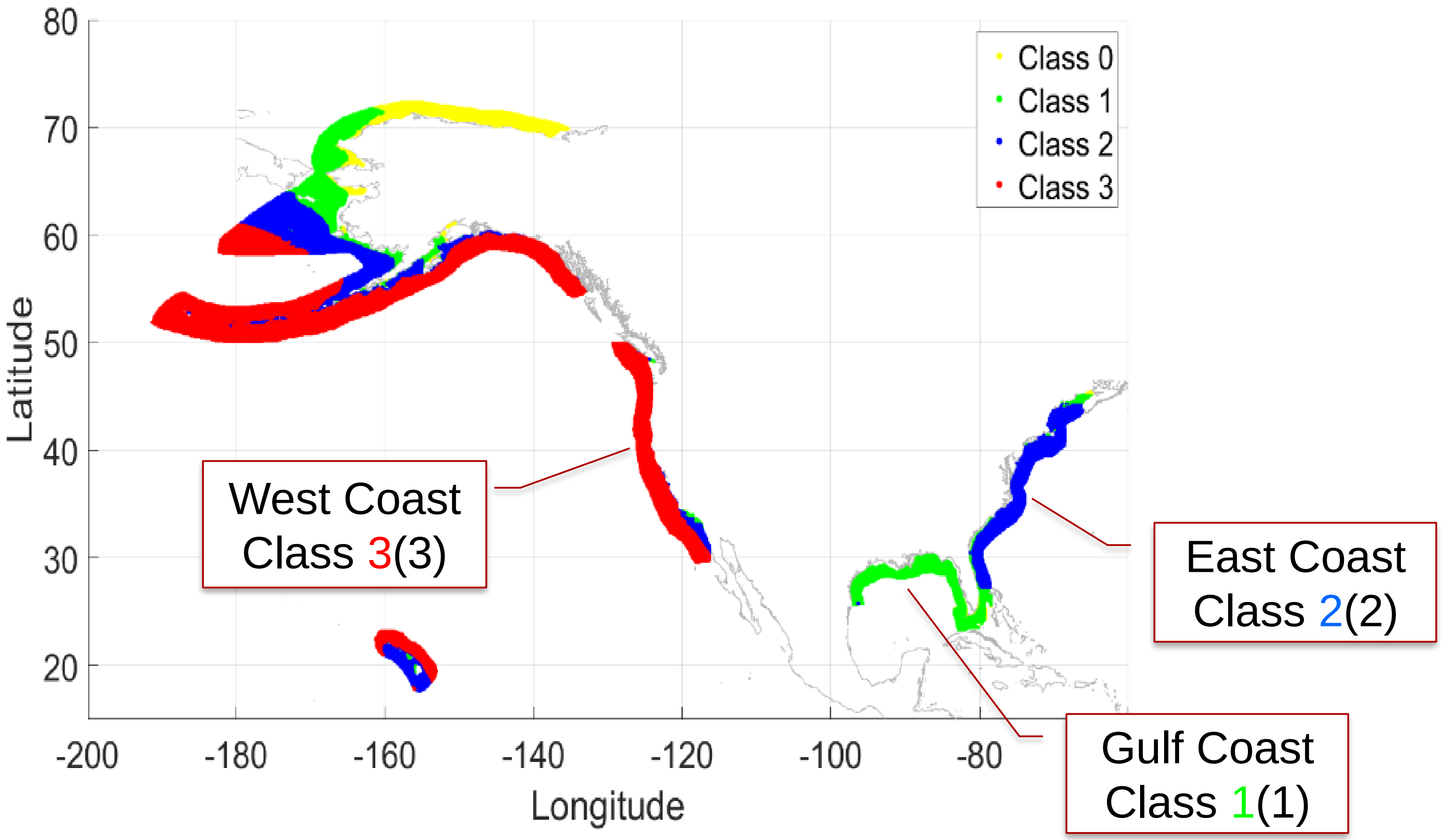
Sample : Hawaii, 22.7N 160.5W

Resource Classification: matrix

Period Band Class		Power Class: 0, J < 1.1	1, 1.1 < J < 5.7	2, 5.7 < J < 22.8	3, 22.8 < J
Period Band Class	1, 0 < T_p <7	0(1)	1(1)	2(1)	3(1)
	2, 7 <T_p<10	0(2)	1(2)	2(2)	3(2)
	3, 10 <T_p<14	0(3)	1(3)	2(3)	3(3)
	4, 14 <T_p	0(4)	1(4)	2(4)	3(4)

- Four power classes
  - 0 – small (P<10 KW), homes, farms, remote
  - 1 – intermediate (10 – 500 KW), village, hybrid systems, distributed
  - 2, 3 – intermediate to large (P>500 KW), commercial, utility scale
- Four period band classes
  - (1) Local wind sea, period (0 < T_p <7)
  - (2-4) Swell, period = (2) short (7 <T_p<10), (3) moderate (10 <T_p<14), (4) long (14 <T_p)

Resource Classification: Regional trends

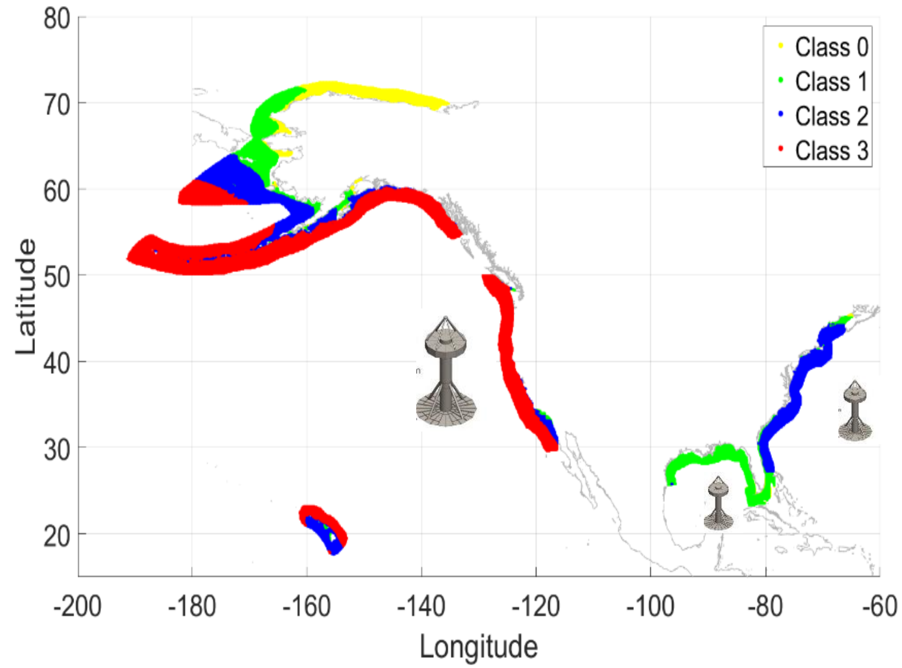


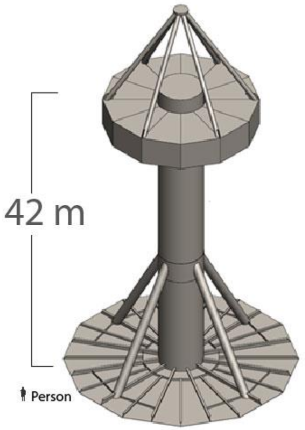
Geographic distribution of wave power classes:

Class 0 (AAE<10 MWh/m)	Class 1 (10<AAE<50 MWh/m)	Class 2 (50<AAE<200 MWh/m)	Class 3 (200<AAE MWh/m)
Class 0 (J<1.14 KWh/m)	Class 1 (1.14<J<5.7 KWh/m)	Class 2 (5.7<J<22.8 KWh/m)	Class 3 (22.8<J KWh/m)

Technology Classification: Feasible?

- Energy capture/cost: Evaluate distribution of optimal designs within each resource class
- Extreme loads: Evaluate the distribution of extreme WEC load responses within each region

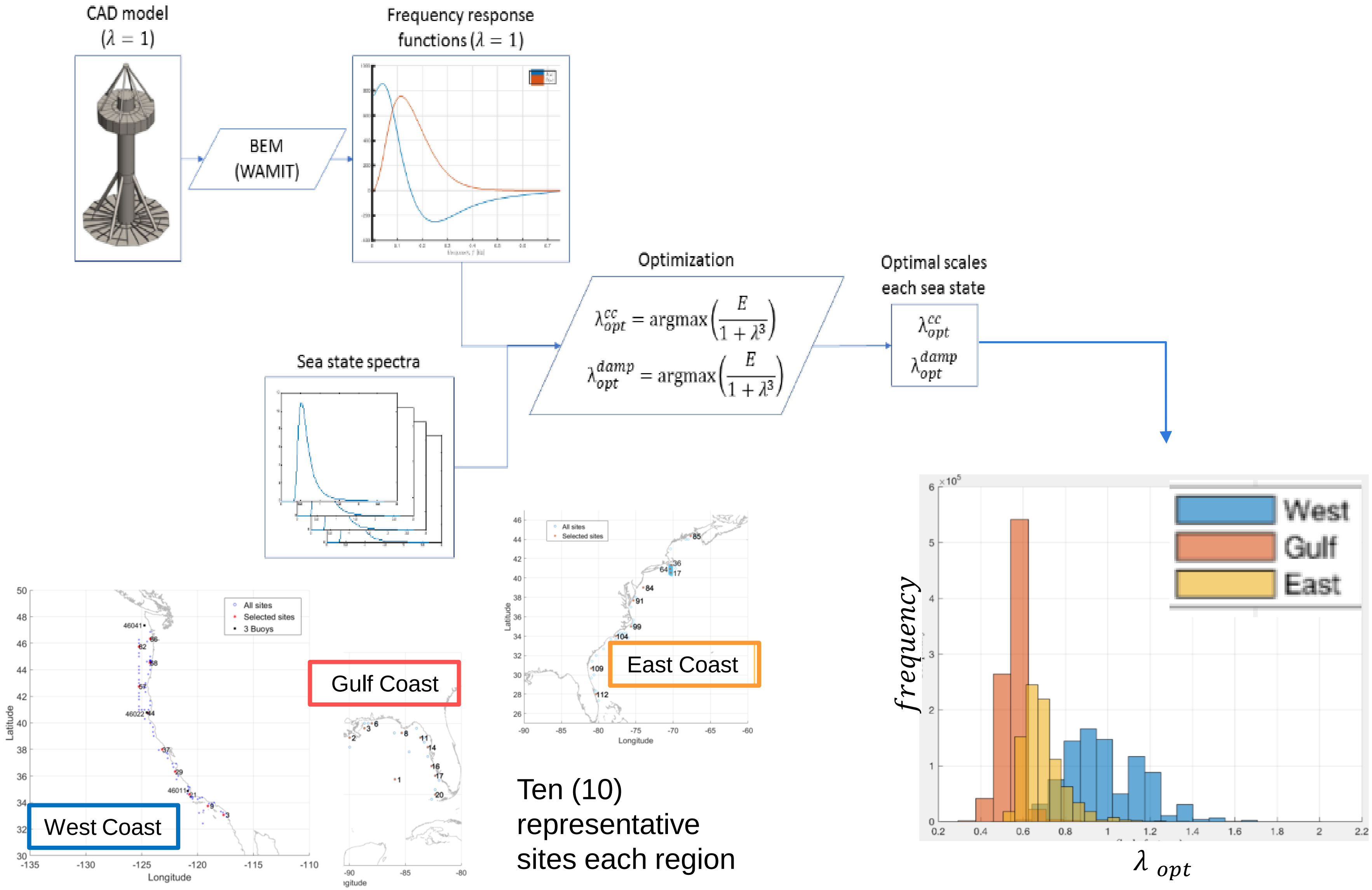




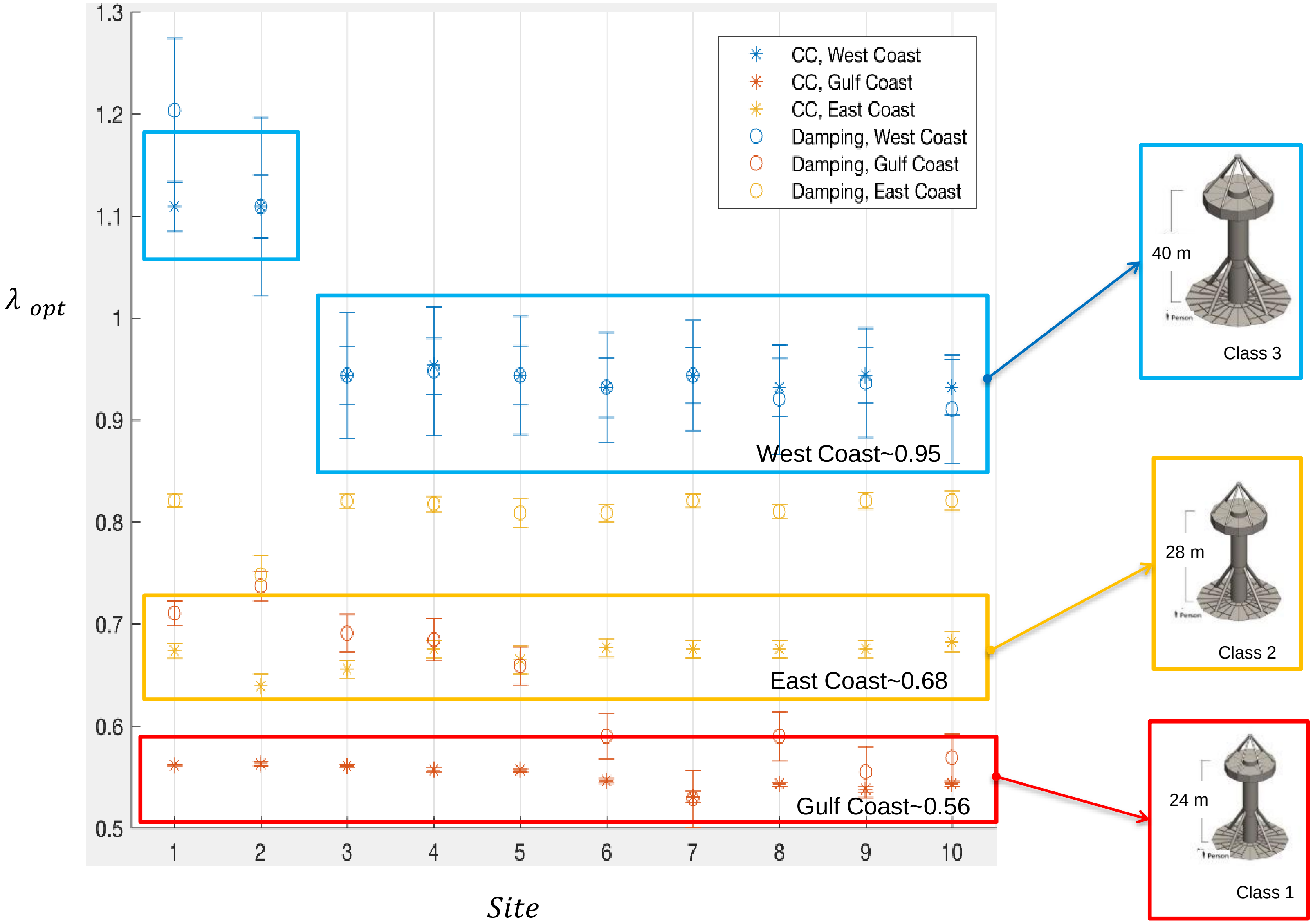
RM3 Point Absorber

$\lambda = 1$

Technology Classification: Design optimization

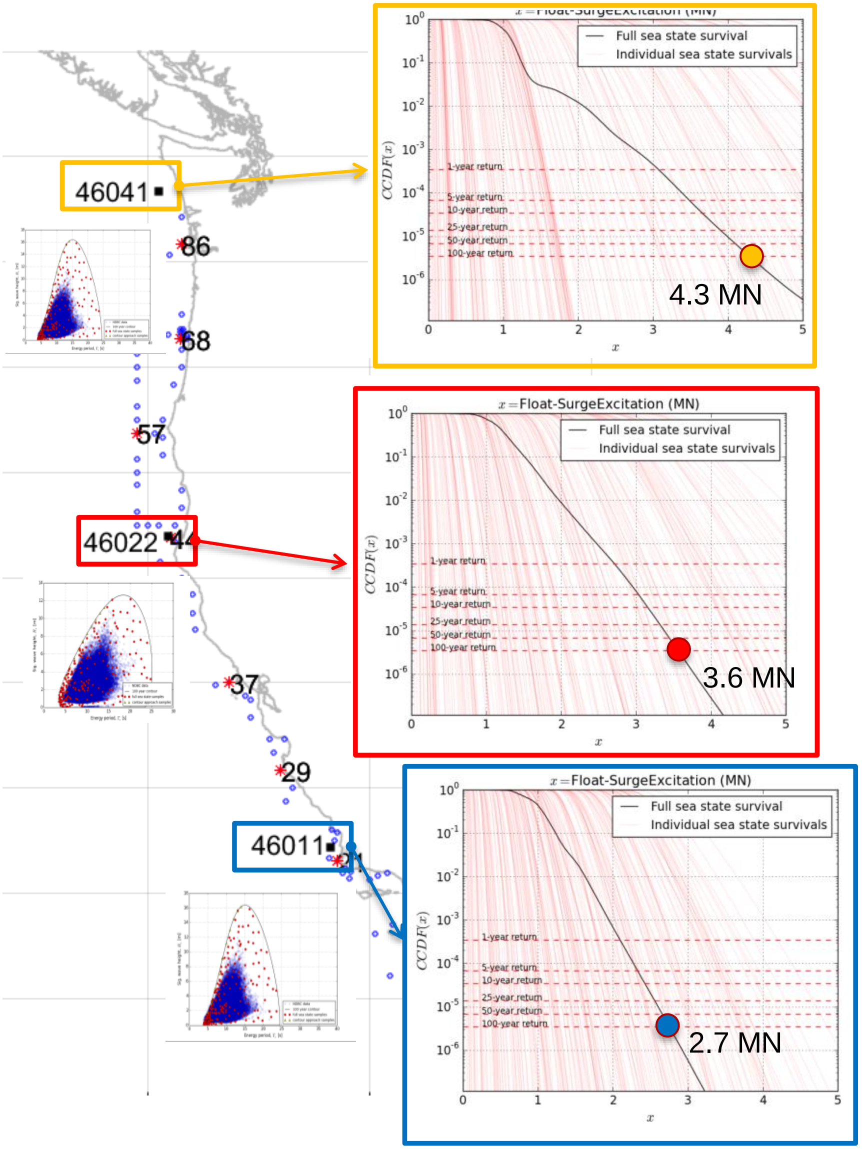


Technology Classification: Design optimization

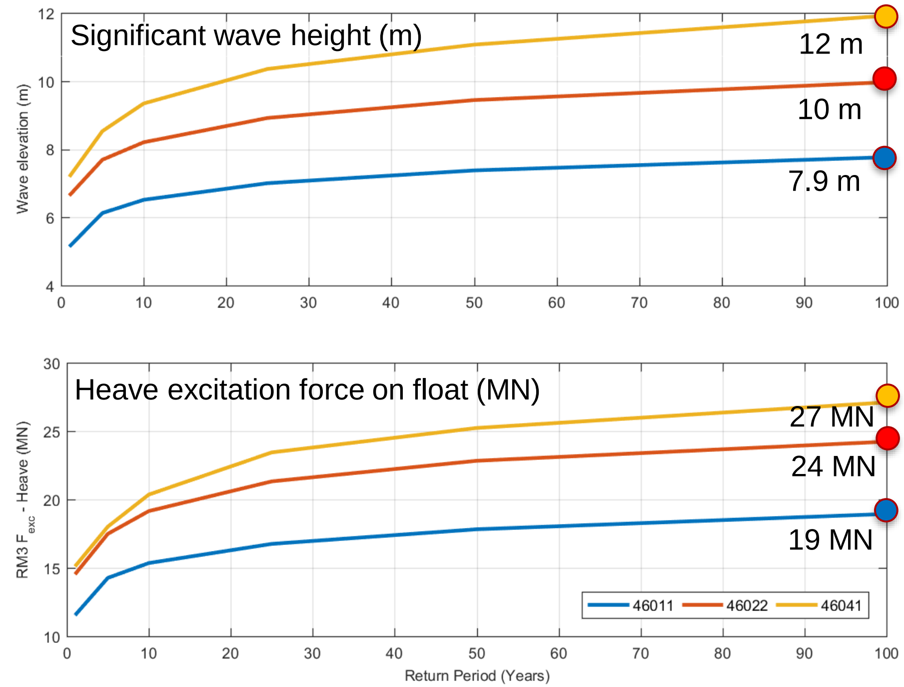


Technology Classification: WEC load response

Surge excitation force on float (MN)



- Inter-regional variation of extreme loads (surge-excitation, *r* = 100-years) 2.7-4.3 MN



Coe et al. 2016. WDRT: A toolbox for design-response analysis of wave energy converters WEC design response toolbox (WDRT), METS 2016.

Conclusions

- Resource classification
  - Distinct regional trends in wave energy characteristics (deep and intermediate depths only)
- Technology classification
  - Energy/cost optimization indicates standard design classes suitable for broad regional wave climates
  - Extreme load response study for only 3 sites, but shows large inter-region variation
  - Limited to point absorber

ACKNOWLEDGEMENTS:

The project presented was supported by the Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), Wind and Water Power Technologies Office (WWPTO). Special thanks to Dr. Joel Cline (DOE) for his continued support as lead for the DOE's marine energy program's resource characterization and assessment work.

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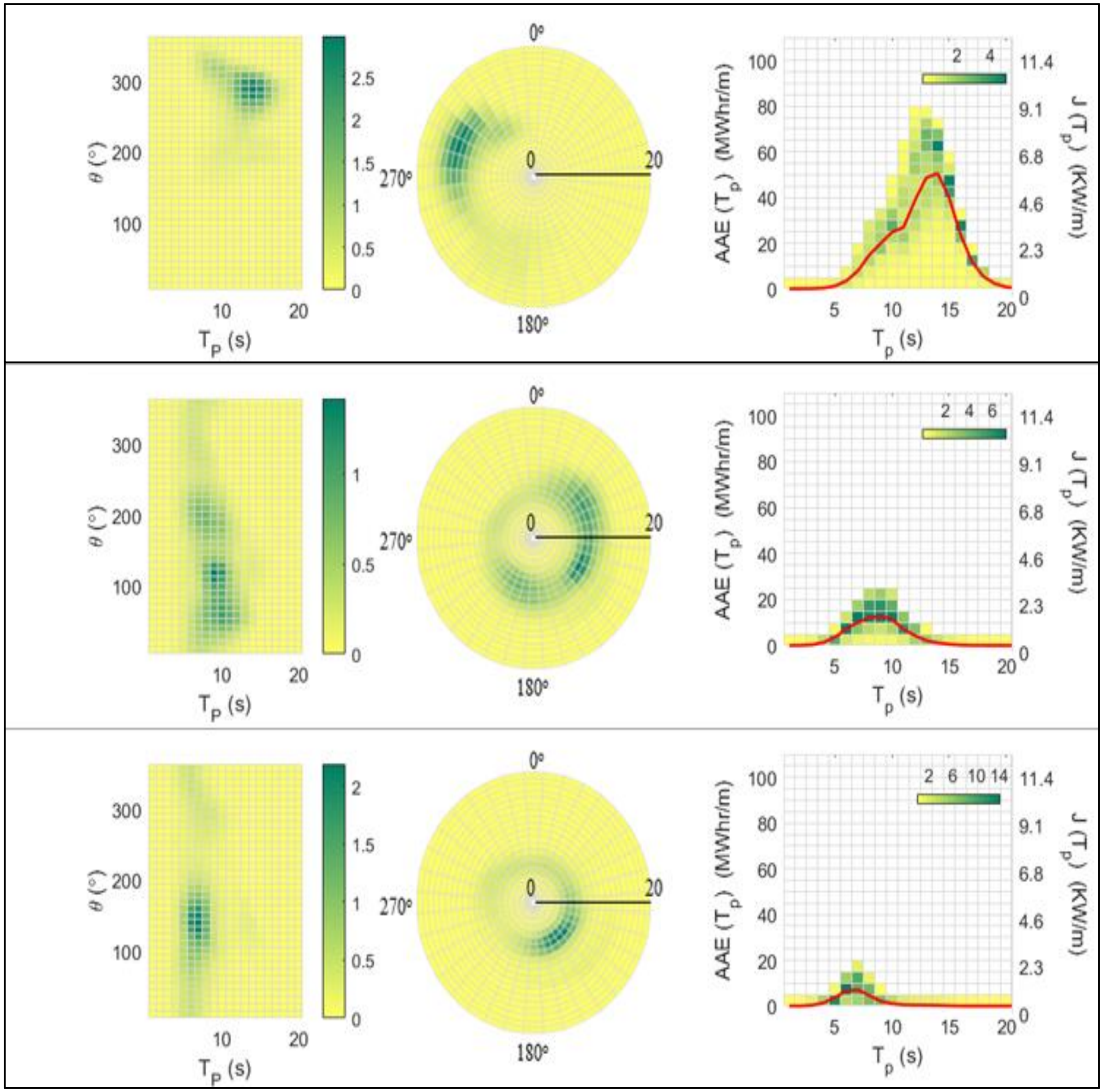
THANK YOU

Contact: vsneary@sandia.gov

EXTRA SLIDES

Resource classification: Regional trends



<u>West Coast</u>
Class 3(3)
High power density
Most energy btw. 10 < T_p < 14
Moderate period swell (band 3)
Directionally focused

<u>East Coast</u>
Class 2(2)
Moderate power density
Most energy btw. 7 < T_p < 10
Short period swell (band 2)
Directionally spread

<u>Gulf Coast</u>
Class 1(1)
Low power density
Most energy btw. 0 < T_p < 7
Local wind sea (band 1)
Directionally spread

Resource: Class delineation

Frequency/period band classes (4)

Band	Band 1 (local wind sea)	Band 2	Band 3	Band 4
		(short, moderate and long period swell)		
Period, T_p	$0 < T_p < 7$	$7 < T_p < 10$	$10 < T_p < 14$	$14 < T_p$
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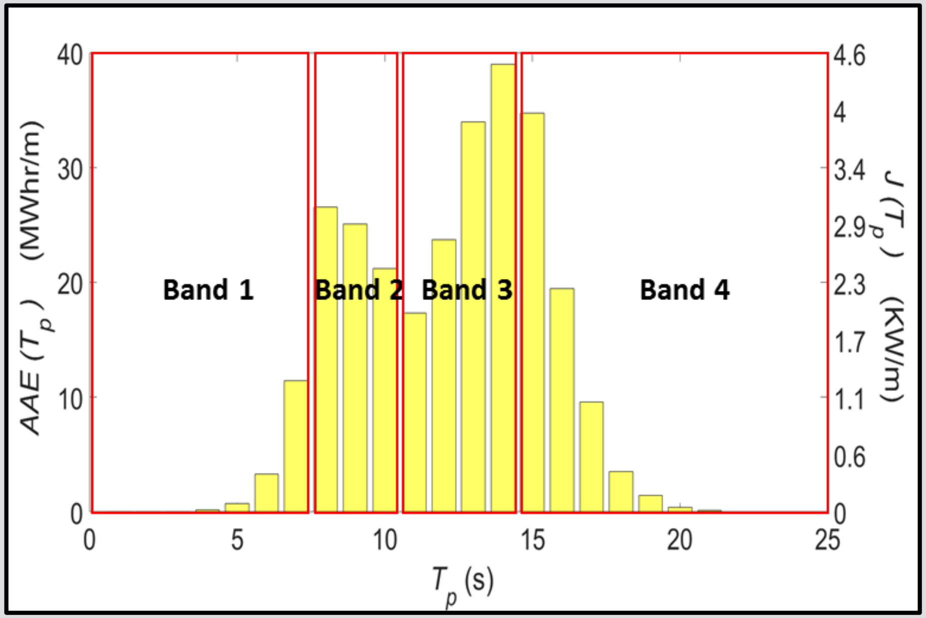

Power classes (4)

Class	0	1	2	3
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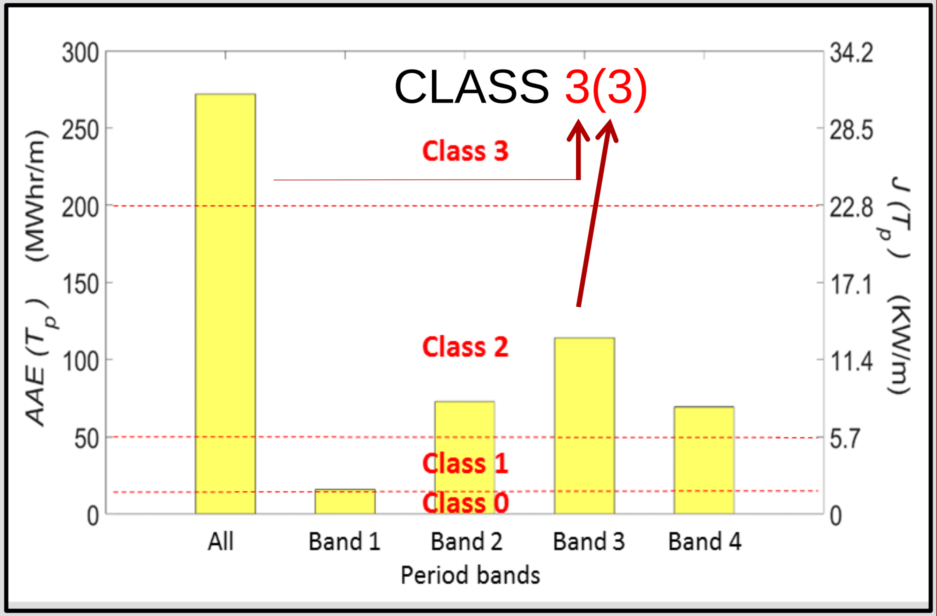
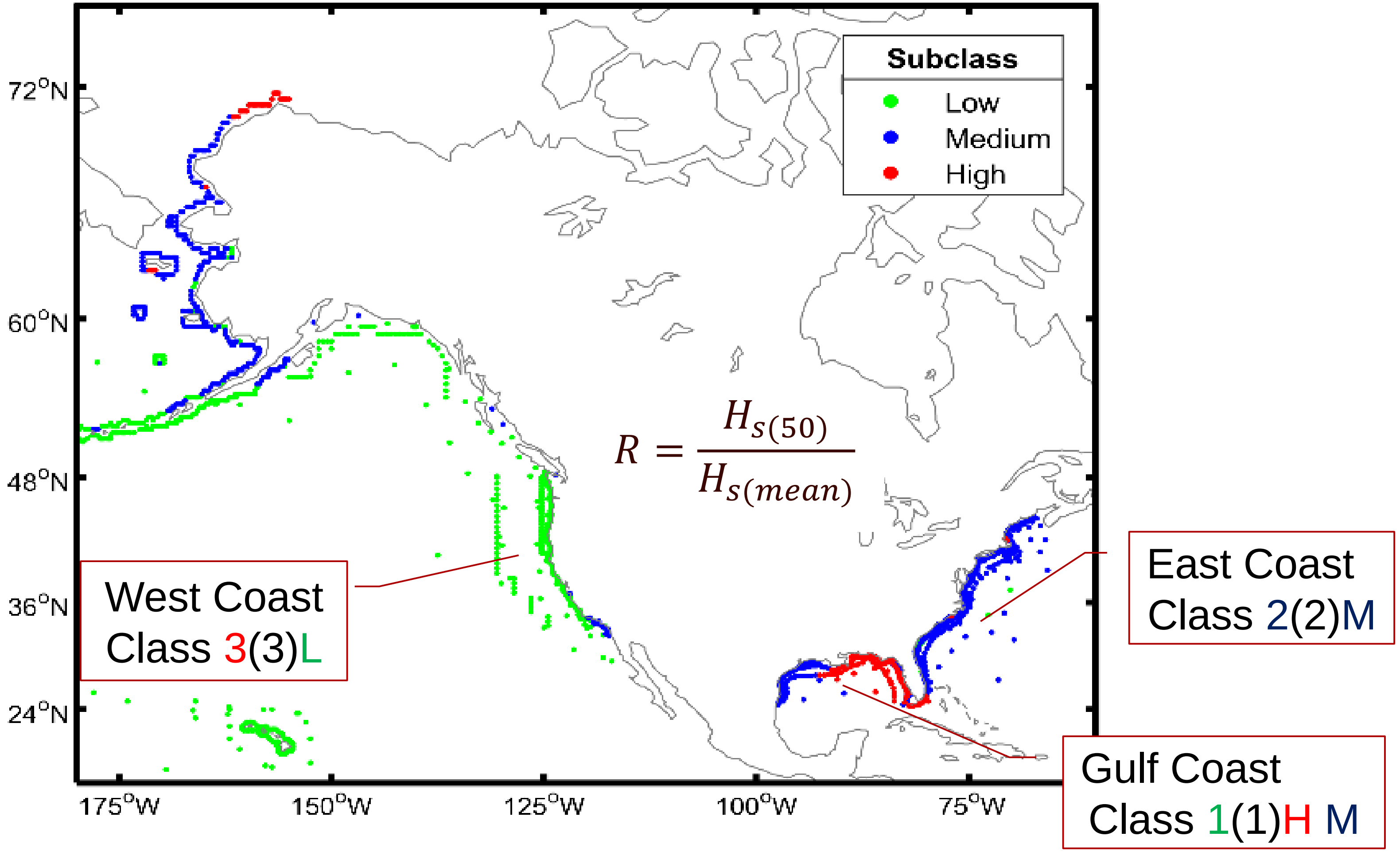


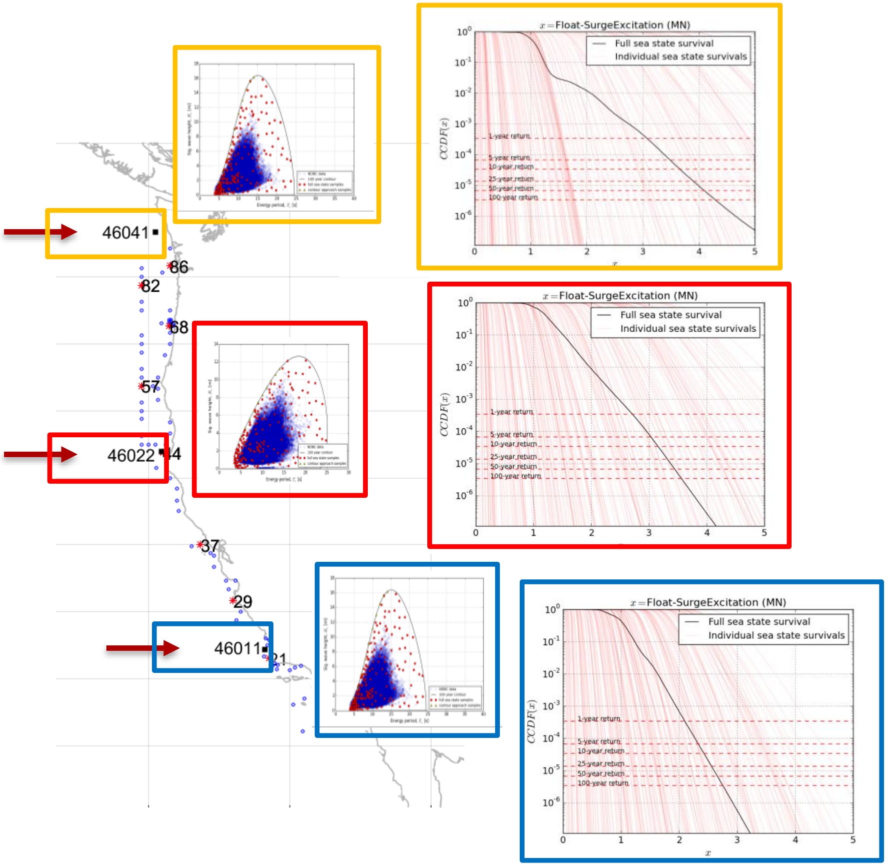
Sample : Hawaii, 22.7N 160.5W

Resource: Regional trends



Geographic distribution of relative risk classes: low ($R \leq 5$), medium ($5 < R < 8$), high ($8 \leq R$).

Technology: Methods, load response



Survival response,
surge excitation force on float

- Selected 3 buoy sites West Coast for inter-region comparison
- Full sea state approach – select 200 sea states to represent design load cases (DLC) for analysis
- WEC-Sim predicts WEC load response
- Generate extreme survival response functions

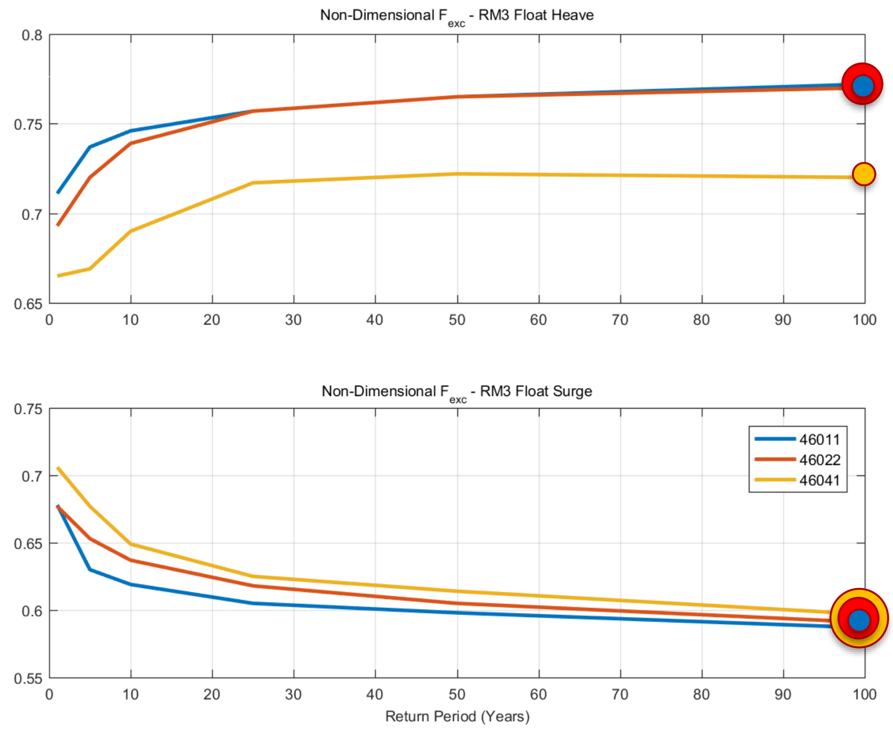
Coe et al. 2016. WDRT: A toolbox for design-response analysis of wave energy converters
WEC design response toolbox (WDRT), METS 2016.

Technology: Results, load response

Non-dimensionalized loads

$$F^* = \frac{F}{\rho g A_c \eta_r}$$

- ρ is the water density
- g is the constant of gravity
- A_c is the characteristic projected area of the device
- η_r is the r-yr return period value of the wave elevation



Next steps

- Resource classification
  - Extend to shallow sites (New DOE high-resolution hindcasts completed in 2019)
  - Review by industry (Marine Energy Council, US TAG: IEC, project steering committee)
- Technology classification
  - Extend the extreme load response study to thirty sites used in optimization study
  - Extend to other WEC archetypes