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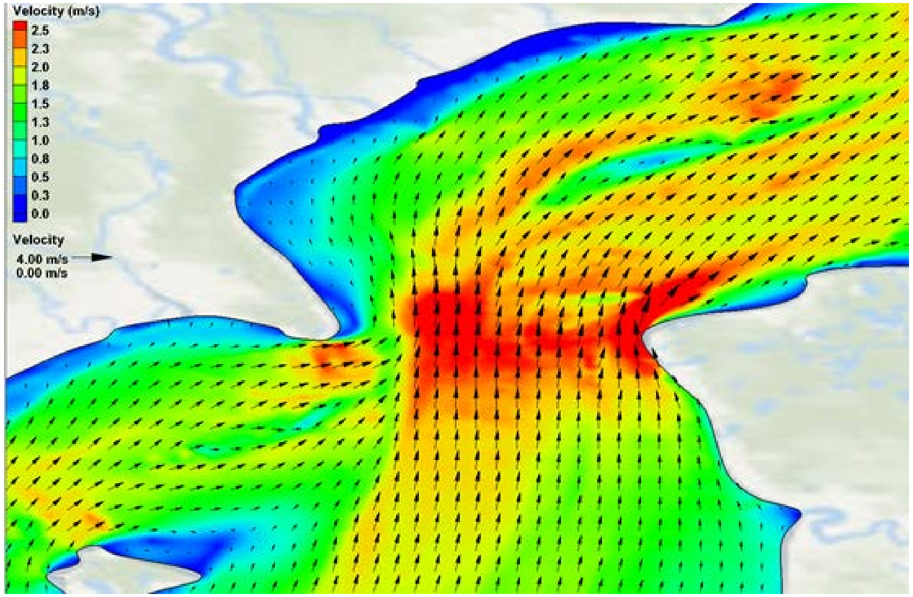

Model Validation and Site Characterization for Early Deployment MHK Sites and Establishment of Wave Classification Scheme

WBS: 2.1.5.401

Marine and Hydrokinetics Program

October 10, 2019

Levi Kilcher (NREL)
Zhaoqing Yang (PNNL)
Vince Neary (Sandia)

Project Overview

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Project Summary

The "Resource Characterization" project delivers the data and tools needed to engineer robust MRE devices and projects. The project measures resource details at commercially promising sites; runs high-resolution models of promising sites and regions; and develops classification schemes that streamline device engineering, improve project development, and increase investor confidence.

Project Objective & Impact

Objectives:

- High-resolution wave resource models that span the entire U.S. Exclusive Economic Zone (EEZ)
- Resource measurements at commercially promising sites
- Develop wave and tidal resource classification schemes

Impact:

- Publicly available data will inform technology and project designs and support more accurate assessments of MRE opportunities and risks, at reduced costs.

Project Information

Project Principal Investigators

Levi Kilcher (NREL)
Zhaoqing Yang (PNNL)
Vince Neary (Sandia)

WPTO Lead

Steve DeWitt

Project Partners/Subs

Ocean Renewable Power Company
Oregon State University
University of Washington
Georgia Tech
Terrasond
University of Hawaii
North Carolina State University
Verdant Power
Ecole Centrale Nantes

Project Duration

- Started: Oct. 2016
- Ends: Sept. 2021

Alignment with the Program

Marine and Hydrokinetics (MHK) Program Strategic Approaches

Data Sharing and Analysis

Foundational and Crosscutting R&D	Technology-Specific Design and Validation	Reducing Barriers to Testing

Alignment with the MHK Program

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Foundational and Crosscutting R&D

- Improve MHK resource assessments and characterizations needed to optimize devices and arrays, and understand extreme conditions
- Develop, improve, and validate numerical and experimental tools and methodologies needed to improve understanding of important fluid-structure interactions

- The primary goal of the resource characterization project is to deliver resource assessment, characterization, and extreme conditions data that aide the engineering, design, and optimization of MRE devices and arrays. These data are publicly disseminated via electronic data portals and through publications.
- The resource characterization project measures and models detailed resource statistics (e.g., turbulence and extreme wave heights) that are important inputs to MRE device simulation tools.

Alignment with the MHK Program

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Data Sharing and Analysis

- Aggregate and analyze data on MHK performance and technology advances, and maintain information sharing platforms to enable dissemination
- Leverage expertise, technology, data, methods, and lessons from the international MHK community and other offshore scientific and industrial sectors

- The project is enhancing the MHK Atlas with new data and functionality that improve accuracy and resolution. This will help identify new project and technology opportunities.
- The project's PIs maintain active communication with international MRE resource characterization experts by participation in international conferences and through active involvement in the International Electrotechnical Commission technical committee on Marine Energy (IEC TC114).

Alignment with the MHK Program

Technology-Specific Design and Validation

- Improve methods for safe and cost efficient installation, grid integration, operations, monitoring, maintenance, and decommissioning of MHK technologies
- Support the development and adoption of international standards for device performance and insurance certification

- Detailed site-specific resource characterization data help quantify project economics (cost); identify grid-integration opportunities and challenges; conduct safe and efficient installation, operations, and decommissioning (e.g., weather windows); and predict maintenance cycles.
- Classification schemes are being proposed to define the “classes” against which devices and projects will be assessed as part of the standards and certification processes. This will improve investor/financier confidence in technologies and projects.

Project Budget

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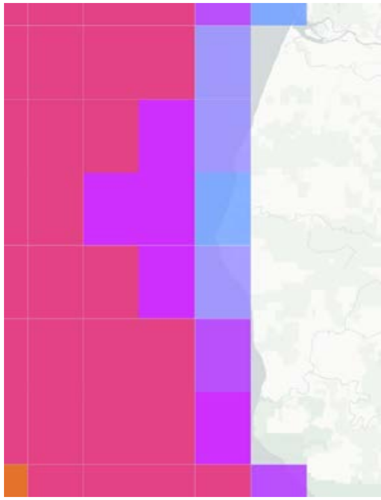
	FY17	FY18	FY19 (Q1 & Q2 Only)	Total Project Budget FY17–FY19 Q1 & Q2 (October 2016–March 2019)	
Lab	Costed	Costed	Costed	Total Costed	Total Authorized
NREL	$902K	$610K	$153K	$1,665K	$2,390K
PNNL	$636K	$907K	$323K	$1,866K	$2,683K
SNL	$865K	$599K	$296K	$1,760K	$2,247K
TOTAL	$2,403K	$2,116K	$772K	$5,291K	$7,320K

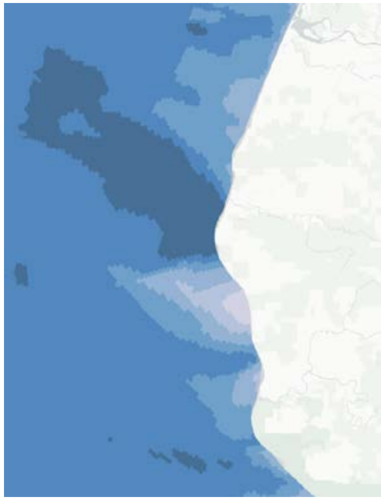
Management and Technical Approach

- Research areas divided between labs:
  - Measurements led by NREL
  - Modeling led by PNNL
  - Classification led by Sandia
- Lab collaboration: delivers consistent results, leverages expertise, and pools resources
- Quarterly steering committee calls inform modeling and measurement approaches
- Measurement sites and model domains are selected based on “early-market” assessments, industry input, and DOE priorities

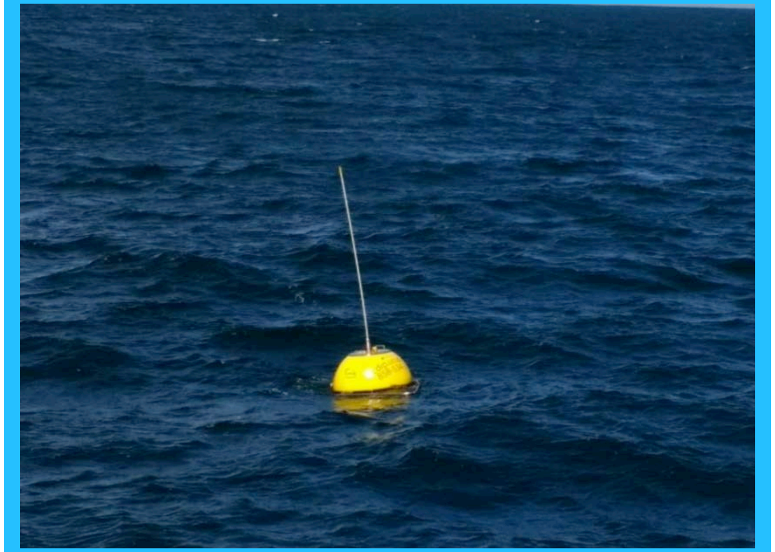
End-User Engagement and Dissemination Strategy

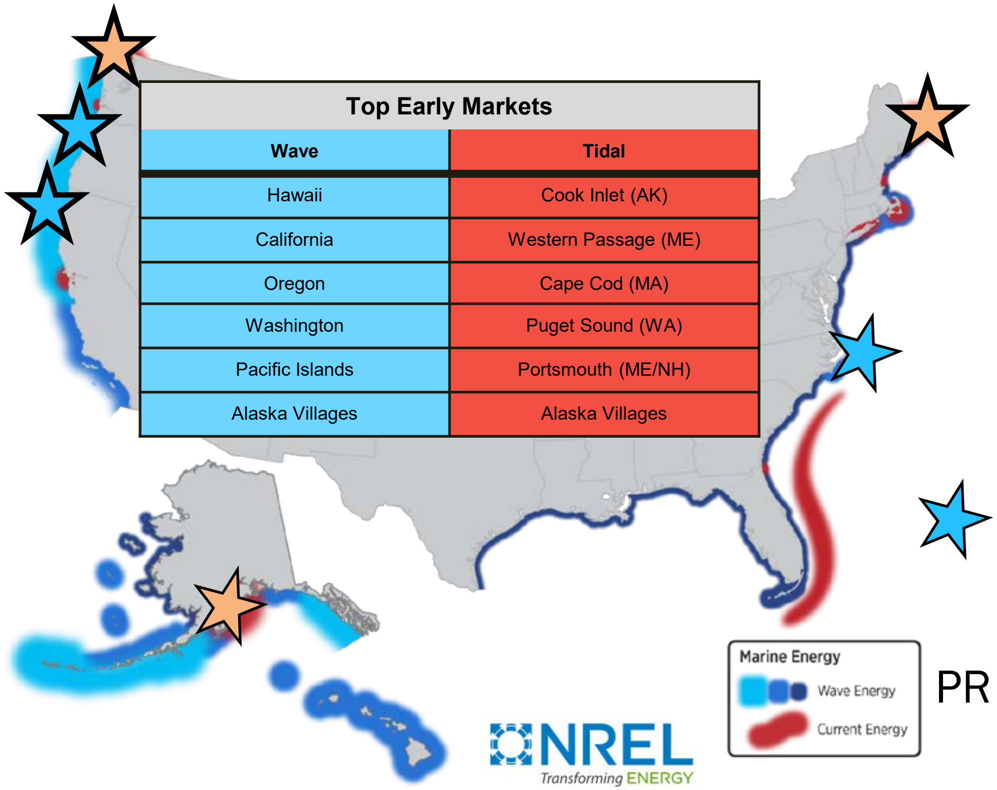
- **Publications**
  - Kilcher et al. 2017. “Turbulence Measurements from Compliant Moorings.” *JTech*
- **MHK Atlas updated with new model results**
- **Full wave hindcast data available soon via Cloud services**
- **Conferences**
  - AGU Ocean Sciences 2018, Portland, Oregon
  - ICOE 2018, Cherbourg, France
  - IMREC/METS 2016–2019
  - AGU Fall Meetings 2016–2019
  - EWTEC Special Session 2019, Naples, Italy





Resource Characterization





Top Early Markets

Wave	Tidal
Hawaii	Cook Inlet (AK)
California	Western Passage (ME)
Oregon	Cape Cod (MA)
Washington	Puget Sound (WA)
Pacific Islands	Portsmouth (ME/NH)
Alaska Villages	Alaska Villages

Ocean Wave
2640 TWh per year

Tidal Current
445 TWh per year

Ocean Current
200 TWh per year

Tidal Modeling

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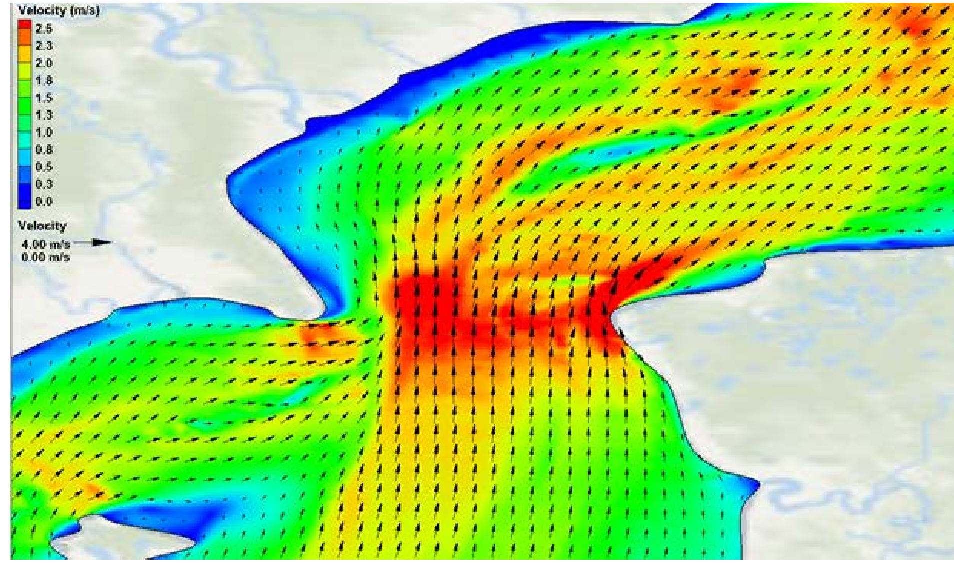
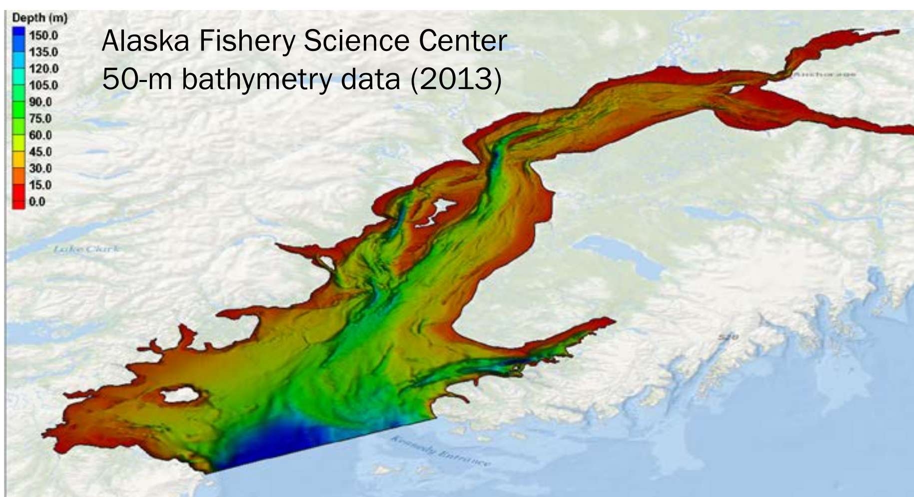
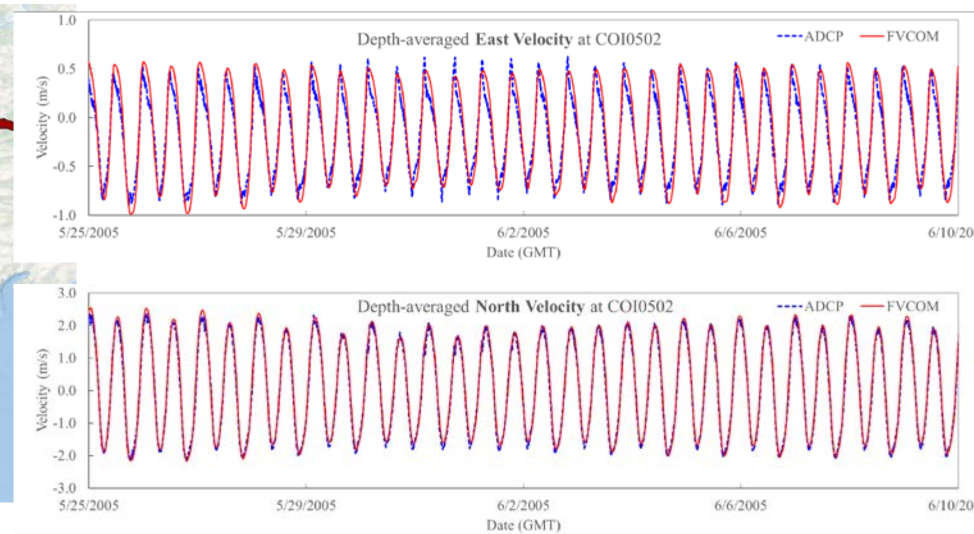
- Western Passage, Maine
- Puget Sound/Salish Sea, Washington
- Cook Inlet, Alaska (shown)





Alaska Fishery Science Center
50-m bathymetry data (2013)



Wave Modeling

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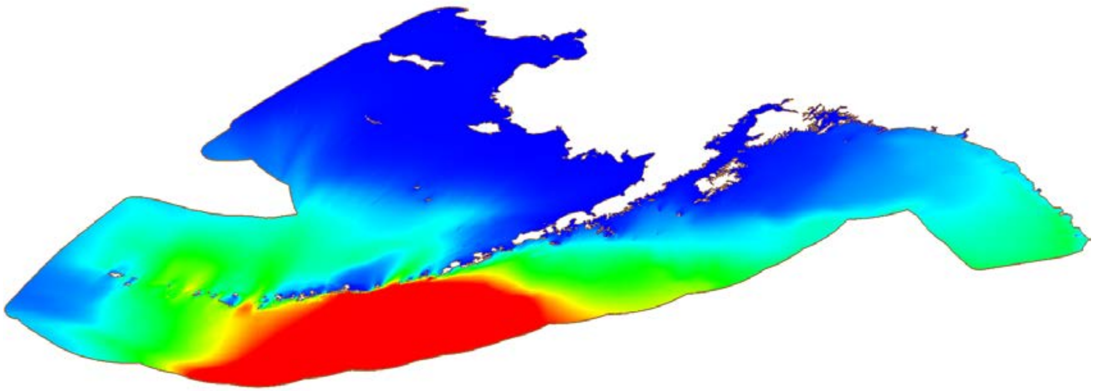


6 Regions

West Coast (complete)

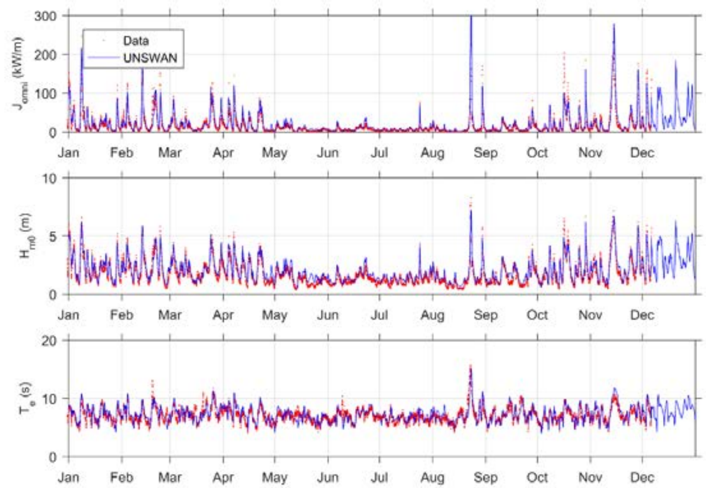
East Coast (complete)

Alaska (complete)

Gulf Coast + Puerto Rico
+ USVI (2020)

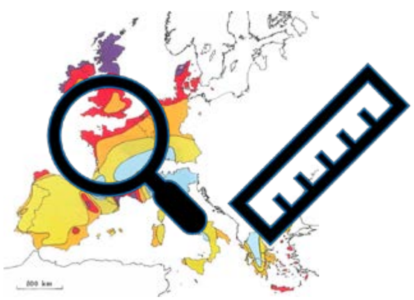
Hawaii (2020)

Pacific Islands (2020)



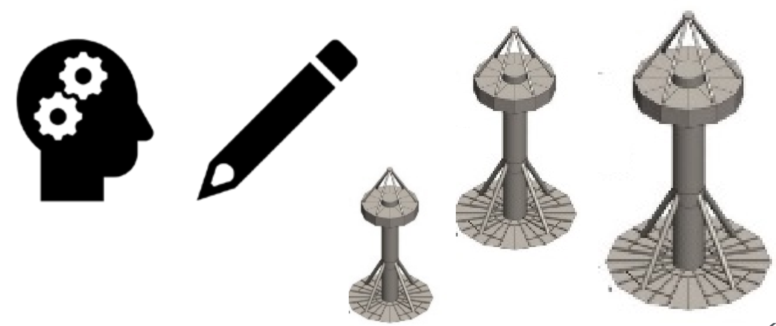
Marine Energy Resource Classification Systems

Following from experience in the wind industry, marine energy classification systems codify and support resource assessment, support device design, and facilitate device-type certification.



Project (resource attributes) classification—support project siting, feasibility, and scoping studies; regional energy planning

Device (resource conditions) classification—codify and streamline device design, device-type certification, product-line development, and manufacturing

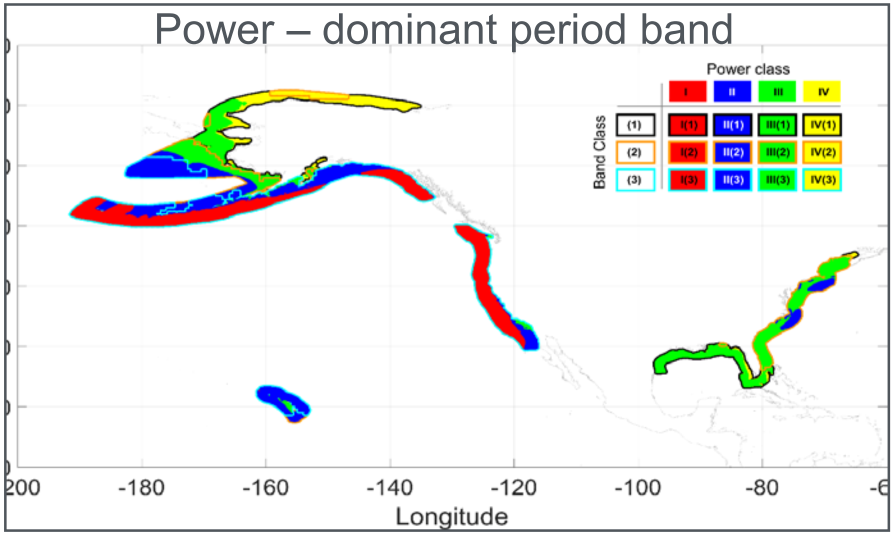


V.S. Neary, K.A. Haas, J. Colby. 2019. “Marine Energy Classification Systems: Tools for resource assessment and design,” European Wave and Tidal Energy Conference (EWTEC), Naples, Italy.

Wave Project (Resource Attributes) Classification

- Main parameter, wave power, *J* (kW/m); Class I, II, III, IV
- Subclass parameter, T_p, peak period bandwidth, delineates three WEC resonant bandwidths
  - 1. Local wind seas, $0<T_P<7$
  - 2. Short-period swell, $7 \le T_P \le 10$
  - 3. Long-period swell, $10<T_P$
- Related standards
  - Wave resource assessment and characterization, IEC TS 62600-101:2015-06
  - WEC power performance assessment, IEC TS 62600-100:2012-08

Power class		I $22.8<J$	II $5.7<J\le 22.8$	III $1.1<J\le 5.7$	IV $J\le 1.1$
1	$0<T_P<7$	I(1)	II(1)	III(1)	IV(1)
2	$7\le T_P\le 10$	I(2)	II(2)	III(2)	IV(2)
3	$10<T_P$	I(3)	II(3)	III(3)	IV(3)

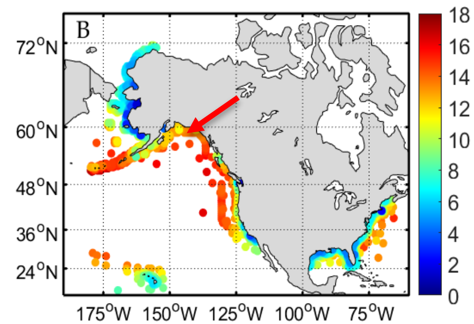


S. Ahn, K.A. Haas, and V.S. Neary. 2019. "Wave energy resource classification system for US coastal waters," *Ren & Sust Energy Rev*, 104, 54-68. https://doi.org/10.1016/j.rser.2019.01.017

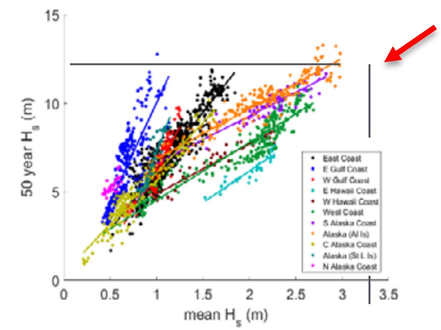
Wave Device (Resource Conditions) Classification: Concept (Strawman)

- Main parameter, $H_{s(ref)} = H_{s(50)}$ (m), 50-year return H_s, Class I, II, III
- Note $H_{s(mean)} = CH_{s(50)}$ for distinct wave climates
- Subclass parameter, T_p, peak period bandwidth, delineates three energy transfer mechanisms (normal operations)
  - 1. Local wind seas, $0<T_P<7$
  - 2. Short-period swell, $7<T_P<10$
  - 3. Long-period swell, $10<T_P$
- Related technical specs, standards
  - Design requirements for marine energy systems, IEC TS 62600-2:2016-08
  - Environmental conditions & environmental loads, DNV-RP-C205:2014

Class		I	II	III	S
H_{ref} (m)		15	10	5	Specified by designer
1	$0<T_P<7$	I(1)	II(1)	III(1)	
2	$7\le T_P\le 10$	I(2)	II(2)	III(2)	
3	$10<T_P$	I(3)	II(3)	III(3)	



Geographical distribution of Hs50 (m) for US Coast [Neary et al. 2019]; Alaska site, $H_{s(50)}$~12 m



Regional correlations extreme and mean wave heights [Neary et al. 2018]; Alaska site, $H_{s(mean)}$~2.8 m T_p band is Class 3

$H_{s(ref)}$(site) ~ 12 m
T_p (site)~Class 3

SITE **CLASS I(3)**

Extreme DLC based on $H_{s(ref)}$ = 15 m

Normal DLC based on $H_{s(mean)}$ = 2.8 m, $10<T_p$

V.S. Neary, K.A. Haas, and J. Colby. 2019. "Marine Energy Classification Systems: Tools for resource assessment and design," European Wave and Tidal Energy Conference (EWTEC), Naples, Italy.

New Wave Resource Methodology

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National Academy Review: "double counting"?

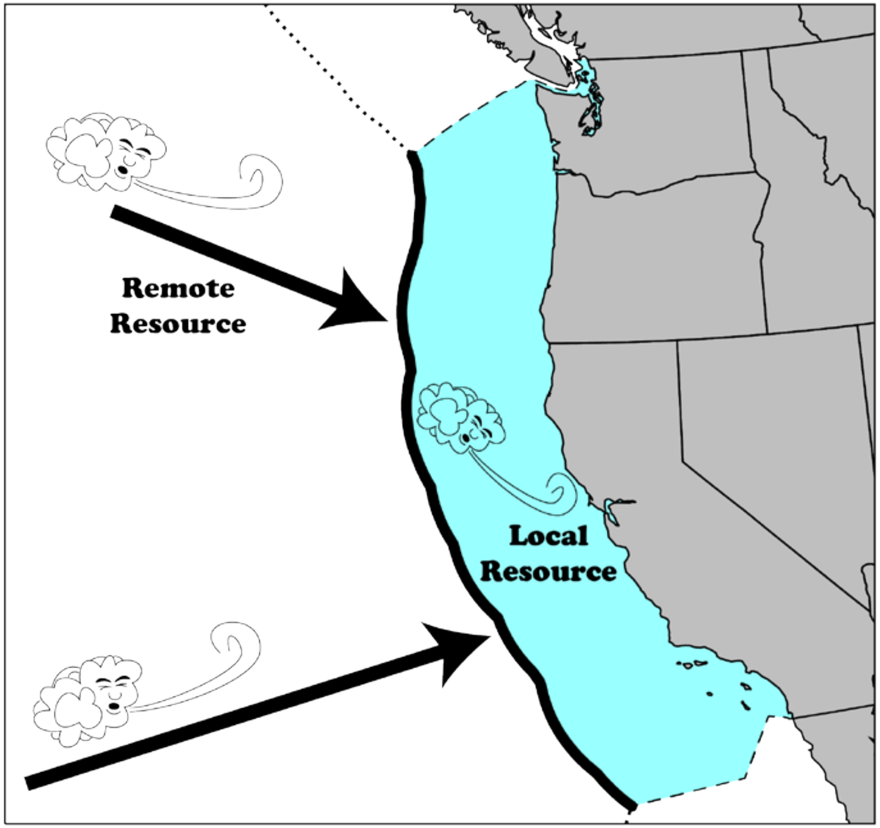
- One-way dot-product to calculate "**remote resource**"

What about winds inshore of WEC array?

- Area integral of source terms gives "**local/potential resource**"

Arbitrary resource area?

- Extend to **full EEZ,** don't count fluxes across "**borders**"



Total = Remote + Local

New Wave Resource Results

Region	EPRI 2011 *Remote Only* TWh/yr	New *Total* TWh/yr	% Change
West Coast	590	510–610	-5 ±10
Hawaii	130	300–380	+160 ±30
East Coast	240	280–320	+25 ±8
Gulf of Mexico	80	63–73	-15 ±7
Alaska (Pacific)	1,570	2,000–2,430	+40 ±15
Puerto Rico	30	17–32	-20 ±25
TOTAL	**2,640**	**3,170–3,845**	**+33 ±13**

Publications

- Ahn, S., K. Haas, and V.S. Neary. 2019. "Wave energy resource classification system for US coastal waters," *Renewable and Sustainable Energy Reviews,* 104, 54-68*.* https://doi.org/10.1016/j.rser.2019.01.017
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- Yang, Z., G. Garcia Medina, W-C Wu, and T. Wang. 2019. "Wave Resource Characterization for the U.S. West Coast, Part II: Characteristics and Variability of the Nearshore Resource." *Renewable Energy*, in review.

Future Work

- Publish new wave resource methodology
- Cook Inlet tidal resource measurements
- North Carolina and Puerto Rico wave measurements
- Full wave hindcast data available to public (via Cloud)
- Wave models: Hawaii, Gulf of Mexico, Puerto Rico, USVI, Pacific Island Territories
- Classification: complete classification schemes for wave and tidal device (resource conditions) and tidal project (resource attributes) classification
- Formal planning through TC 114 for incorporating classification systems into IEC 62600 technical specifications