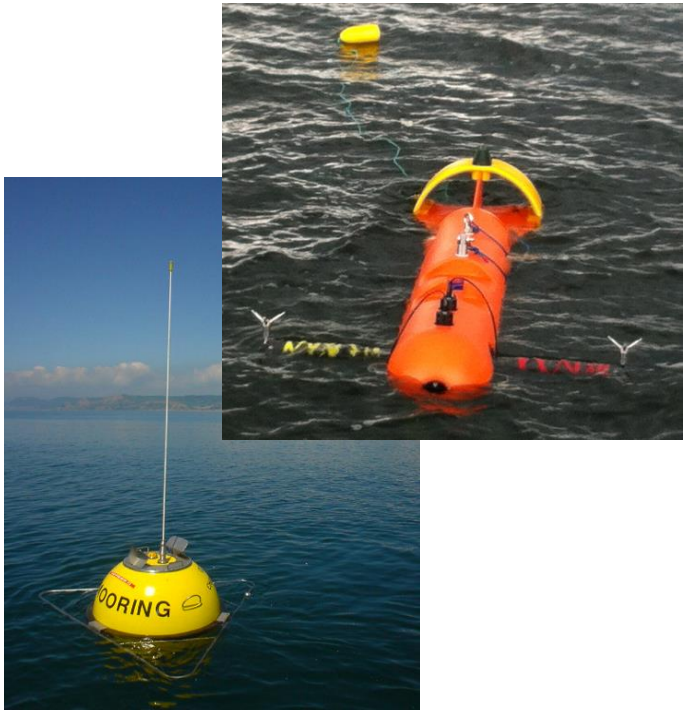
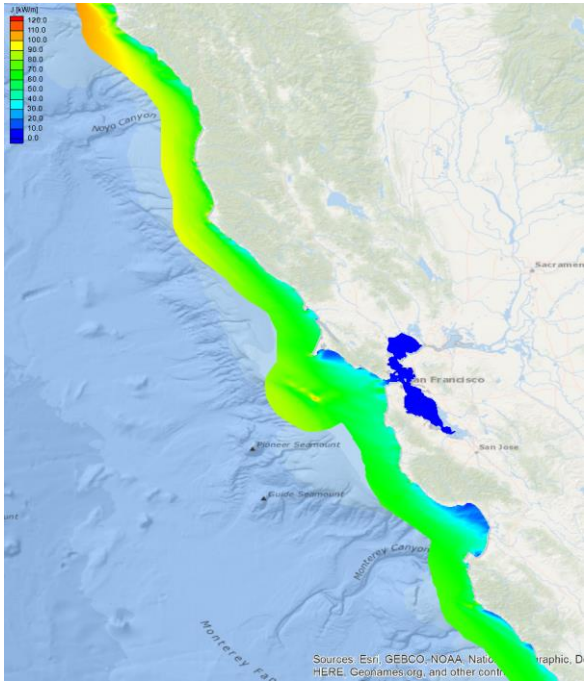
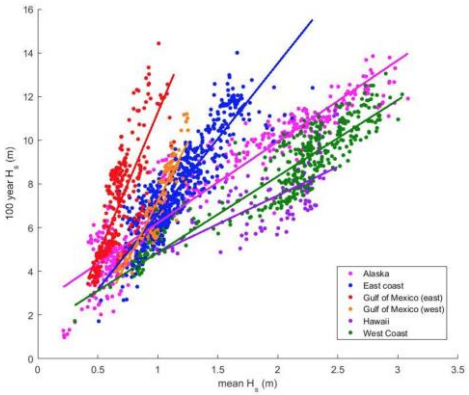
Measurements (NREL)



Resource Modeling (PNNL and SNL)



Wave Classification (SNL)



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

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Model Validation and Site Characterization for Early Deployment MHK Sites and Establishment of Wave Classification Scheme ("Resource Characterization"):

- Provide high-quality site characterization data for early MHK sites that lack this data
- Measure resource details, validate high-resolution models, and provide a wave classification scheme
- This project helps identify opportunities and reduce risks across all stages of MHK project lifecycles

The Challenge:

Limited knowledge of resource characteristics is restricting technology development, siting decisions, marine spatial planning decisions, and classification scheme development.

Multi Lab Collaboration:

National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), Sandia National Laboratories (SNL)

Program Strategic Priorities

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Technology Maturity

- Test and demonstrate prototypes
- Develop cost effective approaches for installation, grid integration, operations and maintenance
- Conduct R&D for Innovative MHK systems & components
- Develop tools to optimize device and array performance and reliability
- **Develop and apply quantitative metrics to advance MHK technologies**

Deployment Barriers

- Identify potential improvements to regulatory processes and requirements
- Support research focused on retiring or mitigating environmental risks and reducing costs
- Build awareness of MHK technologies
- Ensure MHK interests are considered in coastal and marine planning processes
- Evaluate deployment infrastructure needs and possible approaches to bridge gaps

Market Development

- **Support project demonstrations to reduce risk and build investor confidence**
- Assess and communicate potential MHK market opportunities, including off-grid and non-electric
- Inform incentives and policy measures
- Develop, maintain and communicate our national strategy
- **Support development of standards**
- Expand MHK technical and research community

Crosscutting Approaches

- Enable access to testing facilities that help accelerate the pace of technology development
- **Improve resource characterization to optimize technologies, reduce deployment risks and identify promising markets**
- Exchange of data information and expertise

Project Strategic Alignment

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Crosscutting Approaches

Improve resource characterization to optimize technologies, reduce deployment risks and identify promising markets

Market Development

Support project demonstrations to reduce risk and build investor confidence

Support development of standards

Technology Maturity

Develop and apply quantitative metrics to advance MHK technologies

Deliverables and Impact

- Site identification reports identify promising early markets (NREL)
  - Quantitative metrics help guide investment
- Measurement data and measurement best practices at early market sites (NREL)
  - Valuable to early-market site project development
  - Data and knowledge will inform TC114 standards development
- High-resolution, validated models (PNNL, SNL)
  - Improve siting decisions and array designs
  - Provide data for the wave classification scheme
  - Improve understanding of extreme events
- Wave classification scheme (SNL)
  - Streamlines wave energy converter (WEC) design and manufacturing, lowering costs and reducing risks
  - Developing wave classification standards

Technical Approach: Measurement Siting

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Wave

1. Site Identification and Ranking Methodology (http://www.nrel.gov/docs/fy17osti/66038.pdf)
2. Value to Wave Classification Scheme
   a) Currently lacks public measurements
   b) West coast: shallow water measurements for model validation

Wave measurements in new locations and new regimes (e.g. shallow water) will improve model accuracy.

Tidal

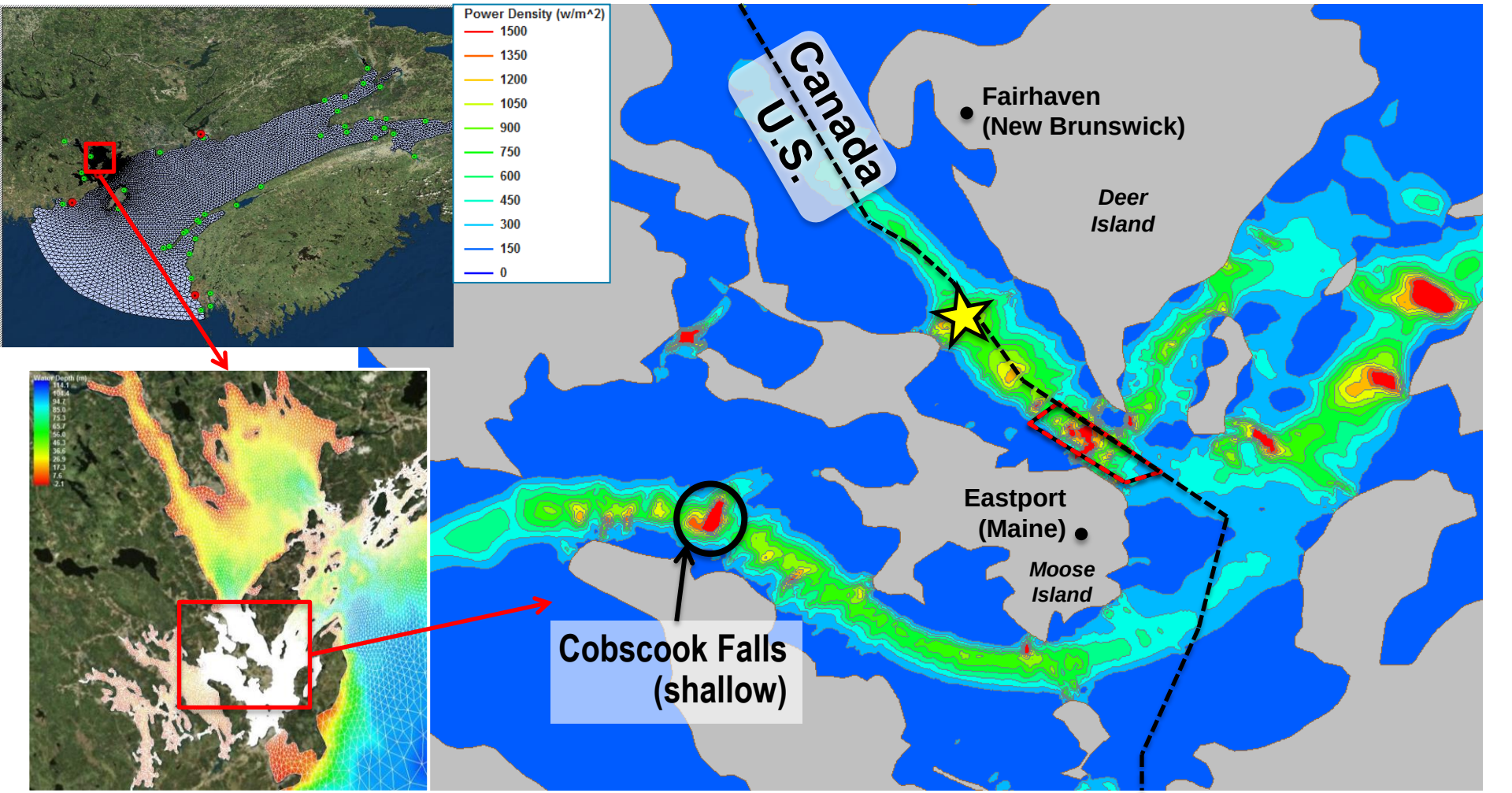
1. Site Identification and Ranking Methodology (http://www.nrel.gov/docs/fy17osti/66079.pdf)
2. Currently lacks public measurements

Velocity and turbulence measurements will be used to validate models, inform siting decisions, and facilitate device loads estimates from device simulation tools.

	State	Site Name	Longitude	Latitude	Depth
2016					
August (Delayed)	Oregon	Lakeside – **WAVE**	43.58N	124.29W	45m, 80m
July (Delayed)	*Maine*	*Western Passage – **TIDAL***	*44.92N*	*66.99W*	*60m*
2017					
June	N. California	Fort Bragg – **WAVE**	39.47N	123.87W	30m
July	Alaska	Kodiak – **WAVE**	57.48N	151.70W	90m
TBD	*Washington*	*Rosario Strait – **TURBULENCE****	*48.56N*	*122.75W*	*60m*
		*Bellingham Channel – **TURBULENCE****	*48.56N*	*122.66W*	*95m*
		*San Juan Channel – **TURBULENCE****	*48.56N*	*123.00W*	*150m*
2018					
July	*Alaska*	*Cook Inlet – **TURBULENCE****	*60.72N*	*151.43W*	*40m*
July	Puerto Rico	San Juan – **WAVE**	18.56N	66.43W	100m
July	N. Carolina	Cape Hatteras – **WAVE**	34.76N	75.35W	150m

***: Tidal resource measurements exist or are planned; turbulence measurements are the focus at these tidal energy sites.**

Accomplishments and Progress: Tidal Modeling (PNNL)

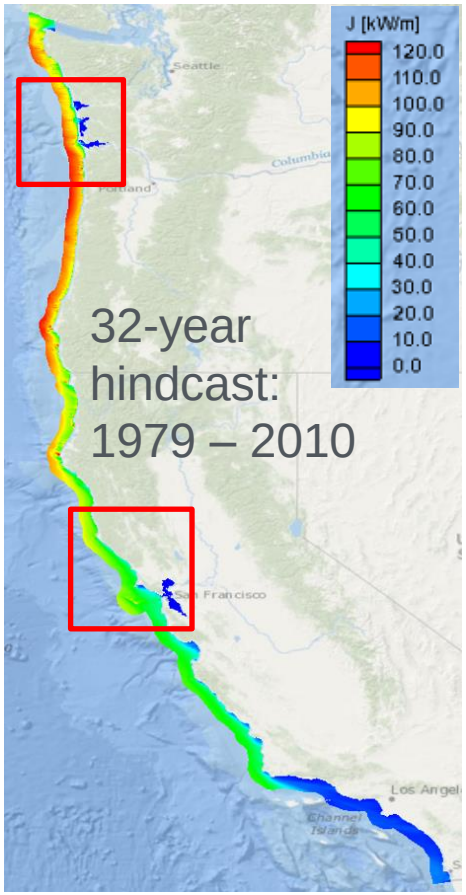


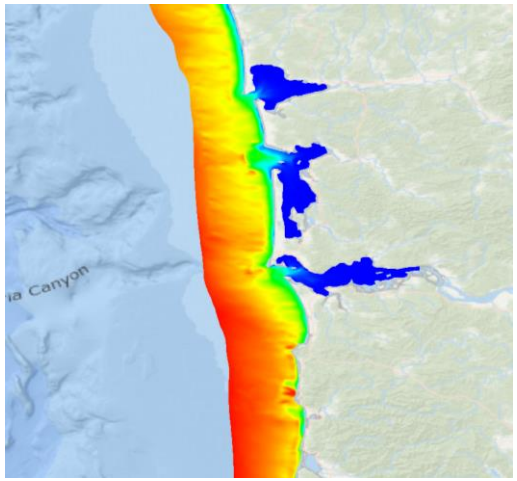
High-resolution tidal models enable detailed feasibility studies and assist with project design.

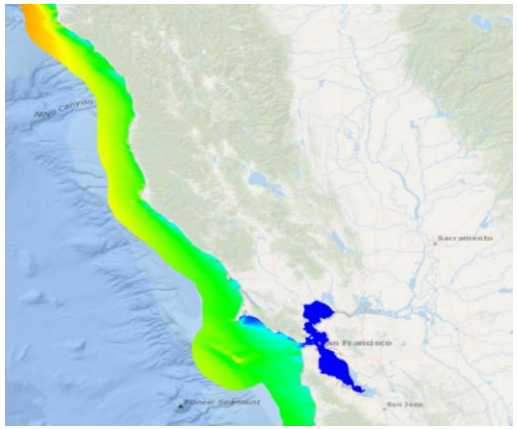
Accomplishments and Progress: West Coast Wave Model (PNNL)

EPRI, 4'x4'

NEW: PNNL, 12"x12"

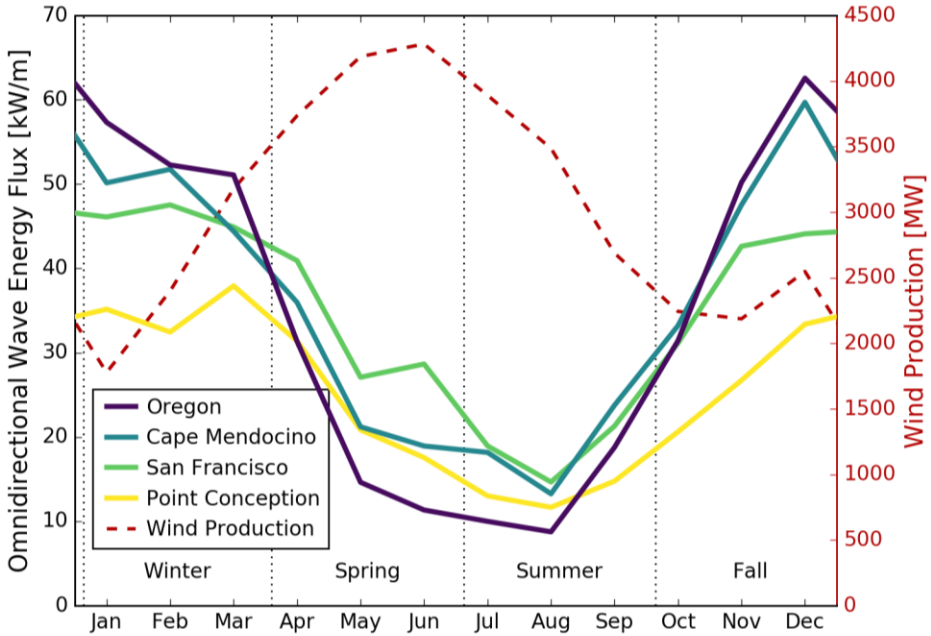


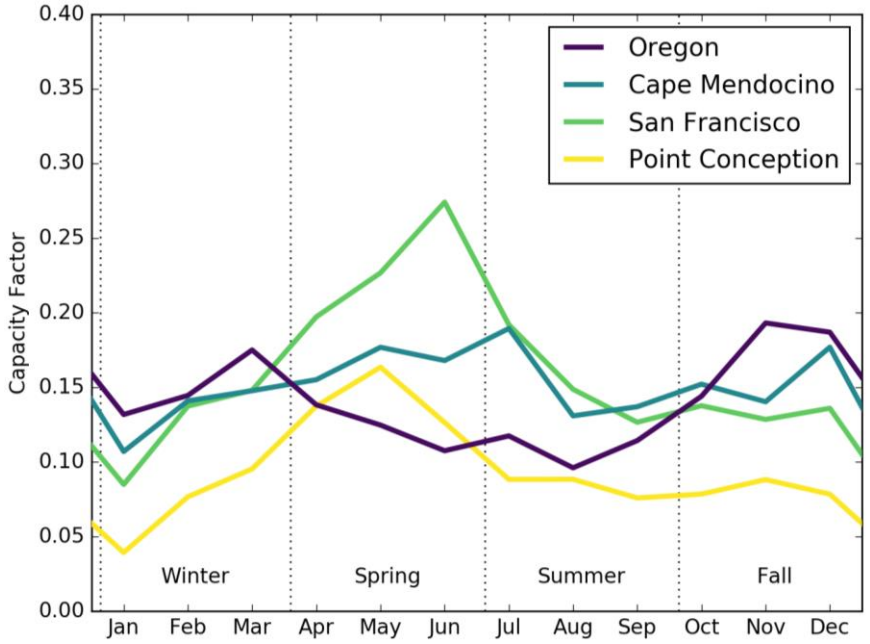




High-resolution wave models help with detailed feasibility studies, marine spatial planning, and project/array design.

Accomplishments and Progress: Resource & Integration Analysis (NREL)



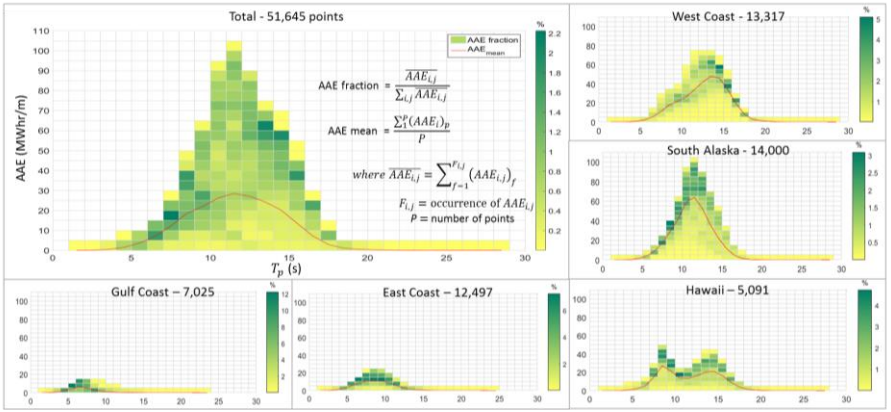


Wave resource complements seasonality of existing wind production ➔ Added value as renewable penetration increases

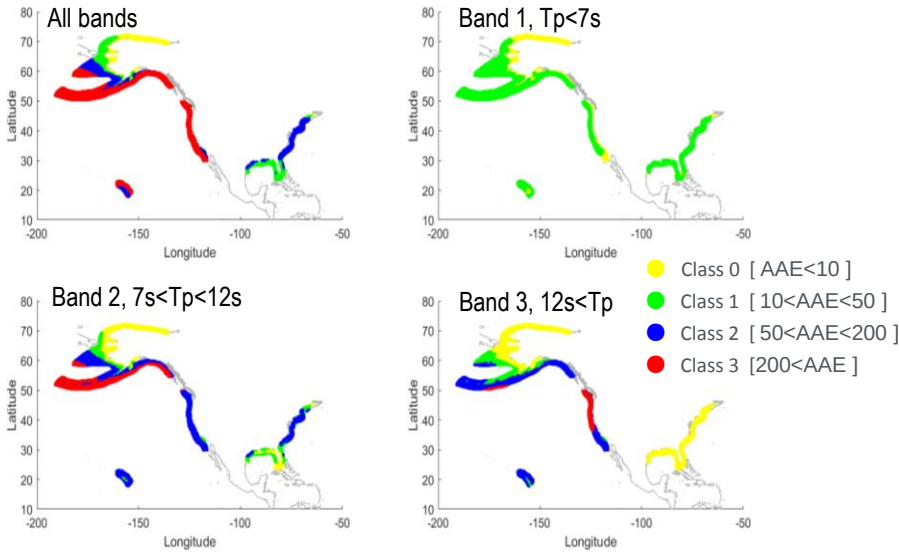
Technology details change production curves ➔ Resource details are important to quantifying project opportunities and risks

Accomplishments and Progress: Wave Energy Resource Classification (SNL)

- Developed wave energy resource classification scheme with two basic parameters – tool developers can use to quickly assess resource opportunities and risks regionally and by site
- Opportunity metric – Annual available energy (AAE) density. Similar to omni-directional power density, AAE density is a measure of opportunity for wave energy conversion. It is distributed over different period bandwidths, and was found to have distinct regional properties.
- Classes 0 (negligible) to Class 3 (high)
- Subclasses based on period bandwidth, Band 1 (low) to Band 3 (high)



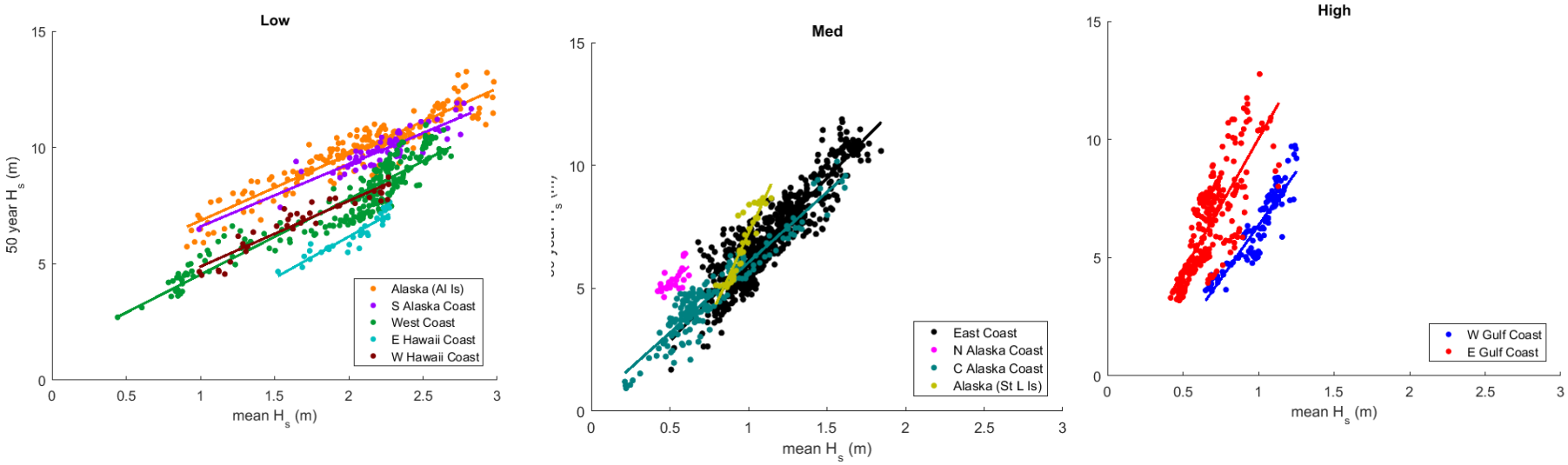
Probability distribution of AAE density as function of peak period.



Geographic distribution of AAE density classes.

Accomplishments and Progress: Wave Energy Resource Classification (SNL)

- Risk/opportunity metric – Ratio of significant wave height with 50-year recurrence interval, Hs(50), to mean value, Hs(mean)
- Three subclasses
  - Hs(50)/Hs(mean) ≤5
  - 5<Hs(50)/Hs(mean)<7
  - 7 ≤ Hs(50)/Hs(mean)



Class	Low	Medium	High
$H_{s_{50}}/H_{s_{mean}}$	$H_{s_{50}}/H_{s_{mean}} \leq 5$	$5 < H_{s_{50}}/H_{s_{mean}} < 7$	$7 \leq H_{s_{50}}/H_{s_{mean}}$
Regions	Hawaii, West Coast	Alaskan Coast, East Coast	Gulf Coast

Accomplishments and Progress: Summary

- **Site Identification reports published**
  October 2016
- **West Coast wave modeling completed**
  September 2016
- **Tidal model for Eastern Passage**
  September 2016
- **Measurement deployments delayed**
  target: Spring 2016
- **Wave classification report draft**
  September 2016

Project Plan & Schedule

- Site Identification 'Hot Spots' project (NREL)

  October 2014–October 2016

- Model Validation and Site Characterization for Early Deployment MHK Sites and Establishment of Wave Classification Scheme project (NREL, PNNL, SNL)

  October 2015–September 2018

  – Instrumentation deployment (NREL)
    - delays due to: site selection, subcontracting, permitting

  – Resource modeling:
    - West Coast wave model complete (PNNL)
    - Tidal models for Maine, Puget Sound, Alaska under development (PNNL)
    - East Coast model under development (SNL, target completion: September 2017)
    - Hawaii, Puerto Rico, and Alaska wave models (SNL and PNNL)

Project Budget

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	Budget History					
	FY2014		FY2015		FY2016	
	DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
Site Identification	$0	$0	$350k (NREL)	$0	$220k (NREL)	$0
Resource Characterization	$0	$0	$0	$0	$920k (NREL) $800k (PNNL) $800k (SNL)	$0

- Site Identification: at request of Marine Energy Council, $220k of FY2016 funding to investigate discrepancies between DOE tidal resource assessment (Haas et al. 2011) and measurements
- Resource Characterization: >$500k in subcontracts so far
- Resource Characterization: planned to continue with flat funding for three years
- Project costs:
  - Site Identification: All funding has been costed
  - Resource Characterization: 55% of total funding has been costed

Research Integration & Collaboration

Partners, Subcontractors, and Collaborators:

North Carolina State University: east coast regional modeling support
Georgia Institute of Technology: wave energy resource classification support
University of Maine: tidal modeling support
Integral Consulting: Oregon wave deployment
Ocean Renewable Power Company (ORPC) Solutions: Maine tidal deployment
University of California San Diego: wave data hosting (cdip.ucsd.edu)
Oregon Wave Energy Trust: Oregon wave deployment stakeholder outreach
Cruz-Atcheson: Wave energy resource classification support
Oceangybe Environmental: steering committee chair

Communications and Technology Transfer:

Oregon Wave Energy Trust Conference Presentation, Portland, OR, September 2016
Marine Energy Technology Symposium Conference Presentation, Washington DC, April 2016 and May 2017
American Geophysical Union Fall Meeting, San Francisco CA, December 2016: wave classification
Marine Energy Council Resource Subcommittee (several teleconferences)
Site Identification Reports:

- Wave: http://www.nrel.gov/docs/fy17osti/66038.pdf
- Tidal: http://www.nrel.gov/docs/fy17osti/66079.pdf
- MHK Data Repository: data and tools for reassessing site ranking

Next Steps and Future Research

FY17/Current research:

- Deploy instrumentation
  - Wave: Oregon, California
  - Tidal: Maine, Washington
- High-resolution wave and tidal models to MHK Atlas
- East coast high-resolution wave modeling
- Continue to refine classification scheme
- Investigate discrepancies between tidal resource estimates (models) and measurements ("tidal gaps analysis")

Proposed future research:

- Device performance testing
- Related project: refine resource model results
- Additional site characterization measurements