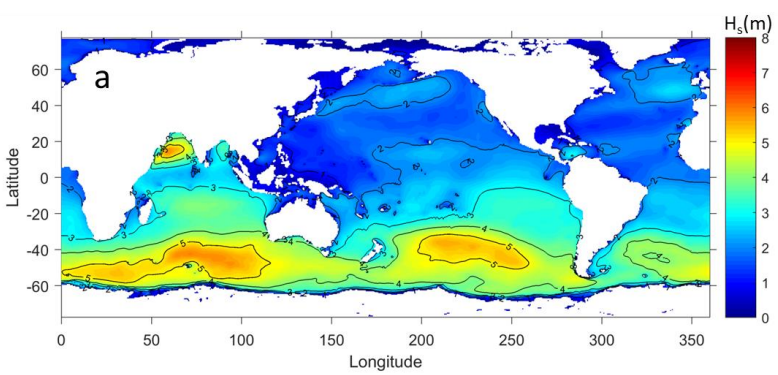

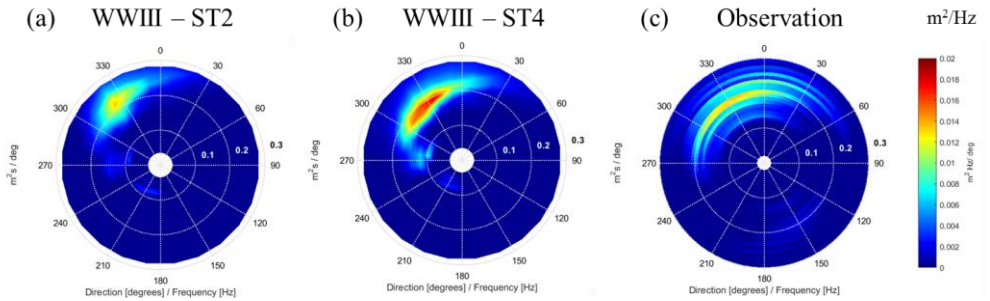

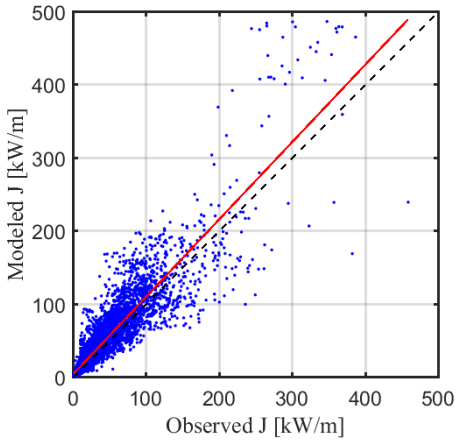

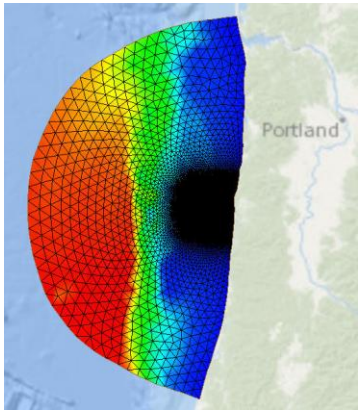

Wave Resource Model Integration

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Project Overview

Wave Resource Model Integration: Accurate resource characterization is a crucial step for wave energy development, which relies primarily on wave model hindcasts for deriving wave energy resource parameters recommended by the IEC Technical Specifications (TS). The overall goal of this study is to establish a wave model test bed at which to benchmark, test, and evaluate modeling methodologies and model skills for wave resource characterization.

The Challenge: Various wave models, methodologies, and forcing products are being used worldwide for wave resource characterization. There is a strong need to identify knowledge gaps, understand the current state of science, and recommend best practices for accurate and consistent wave resource characterization.

Who Benefits: Wave energy conversion (WEC) developers for optimal siting and array deployment; financial investors for best resource and sound investment

Partners and their Roles:

- Sandia National Laboratories (SNL): Co-PI, assessment of wave models and methodologies for resource characterization
- Oregon State University: chairing technical steering committee
- University of Massachusetts-Dartmouth: wave modeling support

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

Program Strategic Alignment

Market Development

- **Support project demonstrations to reduce risk and build investor confidence**

Crosscutting Approaches

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

Target: Bridge the knowledge gaps for wave resource characterization and provide modeling recommendations that will improve model accuracy for wave resource characterization

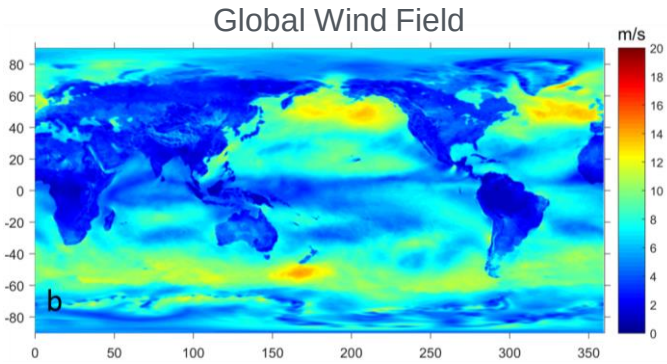
Impact: Improve the accuracy of predicting wave resource parameters recommended by IEC TS using advanced spectral wave models and establish best practice modeling approach for wave resource characterization

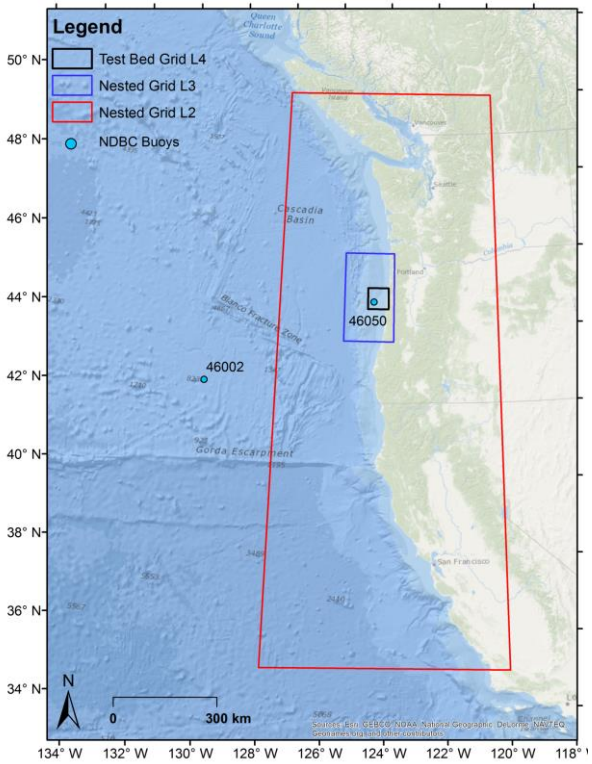
Endpoint: (1) A test bed for testing and benchmarking wave models and methods; (2) to aid the MHK industry in resource characterization and sites selection for WEC deployment; 3) report, and conference and peer-reviewed papers that summarize the methods and findings from the test bed study.

Technical Approach

A wave model test bed study:

- A test bed site with high wave energy was selected off central Oregon Coast to test and benchmark wave models and methodologies
- High-quality long-term measurements are available at the site for model validation
- A technical steering committee that consists of experts from academia, national lab and industry was established to oversee the project and provide technical guidance
- A nested-grid modeling approach— from global scale to local test bed scale—was implemented

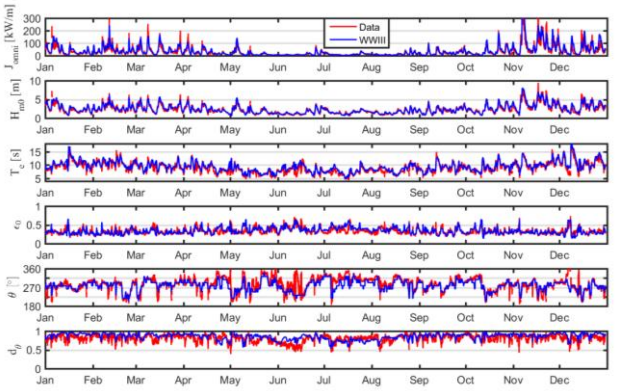


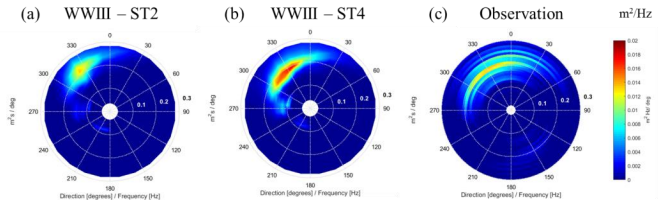


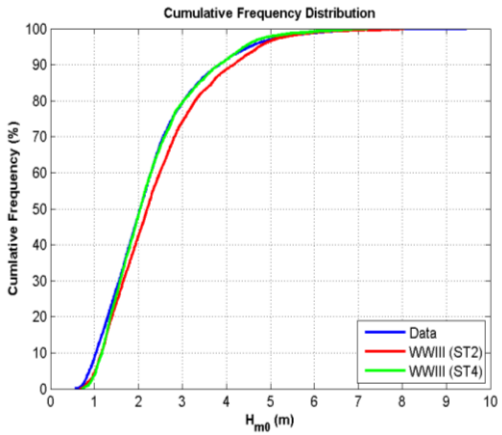
Technical Approach

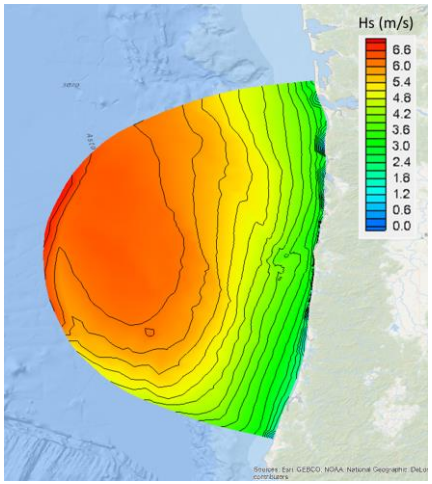
Models and methods evaluation:

- Conducted a comprehensive review of several most popular spectral and phase-resolving models and recommended WAVEWATCH III® and Simulating WAves Nearshore for the study, which was endorsed by Steering Committee
- Quantified model skills for predicting wave resource parameters recommended by IEC TS and computational efficiency
- Conducted sensitivity analysis on different physics packages for wave growth and dissipation and different frequency directional resolutions
- Identified key error sources
- Evaluated the newly developed unstructured-grid wave models for m flexibility and efficiency









Accomplishments and Progress

- Established a consistent nested-grid modeling approach for wave resource characterization at feasibility and design scales to establish best practice for WEC industry
- Identified model source terms that provide most accurate modeling of wave energy resource to support industry
- Summarized and published model test bed study results to encourage further research at test bed
- Submitted a manuscript to the *Journal of Renewable Energy* to socialize results among international researchers

Project Plan & Schedule

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Dates and Schedule	Explanation
Project Initiation Date	October 2013
Project Completion Date	September 2015
Milestone	Project was completed on schedule

Go/No Go Decisions	FY14	FY15	FY16
Decision point	None	Form a steering committee by 1/1/2015	
Outcome	None	Steering committee was formed on schedule	

Project Budget

Budget History					
FY2014		FY2015		FY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$300k (PNNL)	$0	$275k (PNNL) $275k (SNL)	$0	$0	$0

- Project was completed within budget
- No funding modification during the project

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators:

- Sandia National Laboratories: Dr. Vincent S. Neary (Co-PI)
- Oregon State University: Dr. Tuba Ozkan-Haller, Chairman of Steering Committee
- University of Victoria: Dr. Bryson Robertson, Steering Committee member
- Oscilla Power™, Inc.: Dr. Tim Mundon, Steering Committee member
- National Oceanic and Atmospheric Administration/National Center for Environmental Prediction: Dr. Arun Chawla, Steering Committee member
- National Renewable Energy Laboratory: Dr. Levi Kilcher, Steering Committee member
- University of Massachusetts-Dartmouth: Dr. Changsheng Chen, modeling support

Communications and Technology Transfer:

- One study report: PNNL-25385 / SAND2016-8497 R, March 2016
- Three conference presentations: European Wave and Tidal Energy Conference (EWTEC15), AGU-Ocean Sciences (OS) 16 and Marine Energy Technology Symposium (METS16)
- Two conference publications: EWTEC15 and METS16
- One manuscript submitted to the Journal of Renewable Energy
- Methodologies are currently being used in project titled, “Model Validation and Site Characterization for Early Deployment MHK Sites and Establishment of Wave Classification Scheme” for high-resolution wave resource characterization in U.S. coastal waters

Next Steps and Future Research

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FY17/Current research:

- The modeling approach and methodologies developed in this project are currently being applied to conduct the high-resolution wave resource characterization in U.S. coastal waters in the project, “Model validation and site characterization for early deployment MHK sites and establishment of wave classification scheme.”

Proposed future research:

- Evaluate model capability in simulating large waves under extreme event conditions to support project siting
- Validate models with shallow water buoy data and evaluate model capability in simulating shallow process processes
- Invite wave modeling community to participate in the wave test bed study through a cooperated effort