Regional Wave Field Modeling and Array Effects

Presented By: Kelley Ruehl

Wind & Water Power Technologies

Sandia National Laboratories

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Outline

- **Overview of SNL's Large-Scale Wave and WEC Array Modeling Activities**
  - WEC Farm Modeling on Roadmap
  - SNL Current Modeling Capabilities
  - SNL WEC Farm Model Tool Development

WEC Farm Modeling

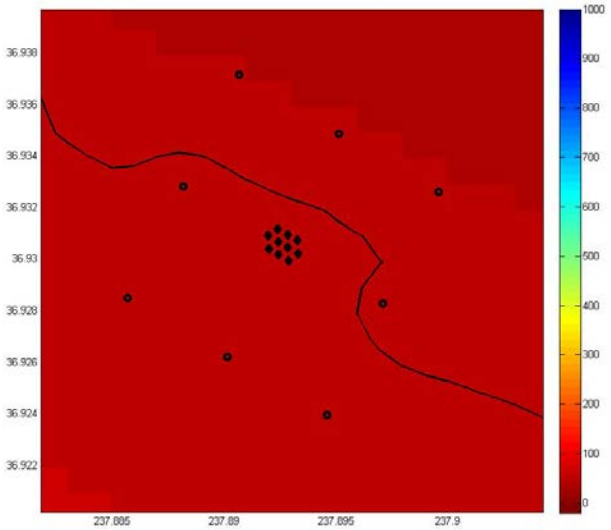
WEC Farm Modeling:
WEC Farms on the Roadmap

WEC Farm TRL 4 & 5/6

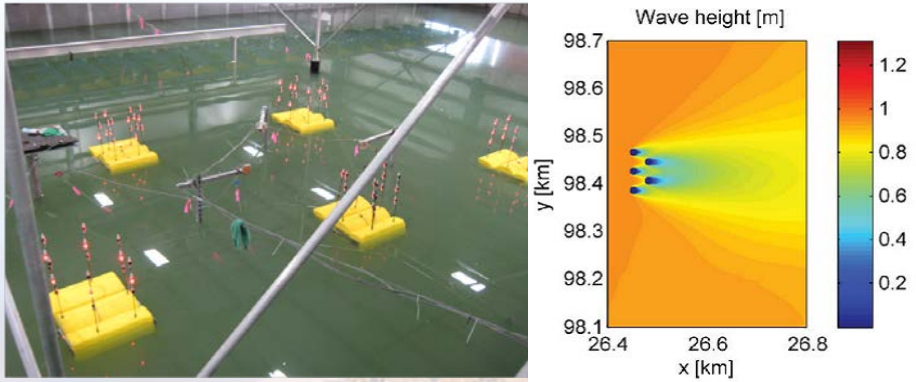
- **WEC Farms**
  - Currently focused on improving large scale wave models for environmental assessments

WEC Modeling

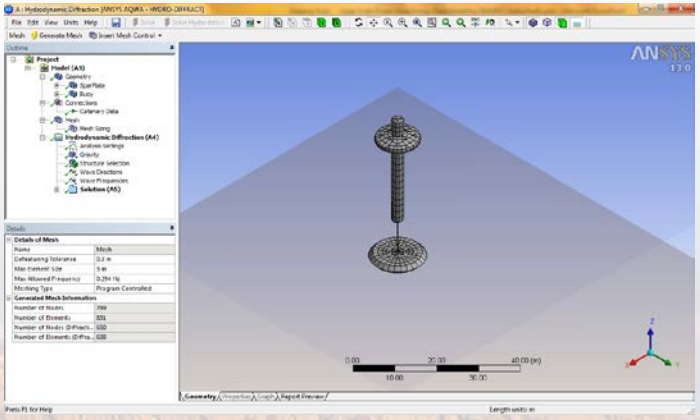
- **SNL uses several WEC modeling tools**
  - ANSYS-AQWA: Device Scale BEM solver
  - WAMIT: Device Scale BEM solver
  - OrcaFlex: Device Scale Morison EQ solver
  - SWAN: Large Scale spectral wave solver
  - SNL-EFDC: Resource Scale Hydrodynamics



SWAN WEC Array Model (SNL model)



Columbia Power WEC array testing at OSU Tsunami Basin (left) and SWAN model for a similar array configuration(right).



ANSYS-AQWA 2-Body Point Absorber WEC Model (SNL model).

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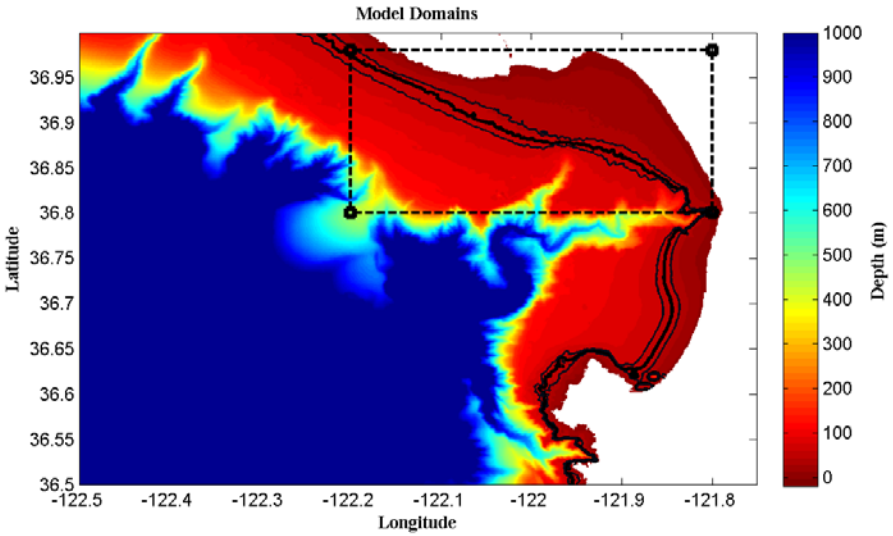
WEC Farm Modeling: SWAN

- **Simulating WAves Nearshore**
  - Spectral action balance equation solver
  - Includes current, wind, and bottom friction
- **Inputs:**
  - Bathymetry (can have nested grids)
  - Wave Spectra at boundary condition
- **Example Outputs:**
  - Wave Spectra
  - Wave Height, Period and Direction
- **Notes:**
  - Typically used for large-scale environmental modeling
  - Wave energy can be extracted by defining obstacles which remove a percentage of the incident wave energy at all frequencies
  - SNL plans to develop energy sinks that can extract wave energy as a function of frequency and direction



SWAN Monterrey Bay Model (SNL model).

WEC Farm Modeling:

Monterrey Bay Sensitivity Analysis

- **WEC Farm Sensitivity Analysis**
  - SWAN Monterrey Bay Model
  - Model WECs with standard SWAN capabilities (T/R coefficients)
  - 10 WEC Farm with 2X, 5X and 10X spacing
  - Varied WEC coefficients and incident wave conditions (117 combinations)
  - Monitored wave height, period, and direction at 15 output locations around and landward of array

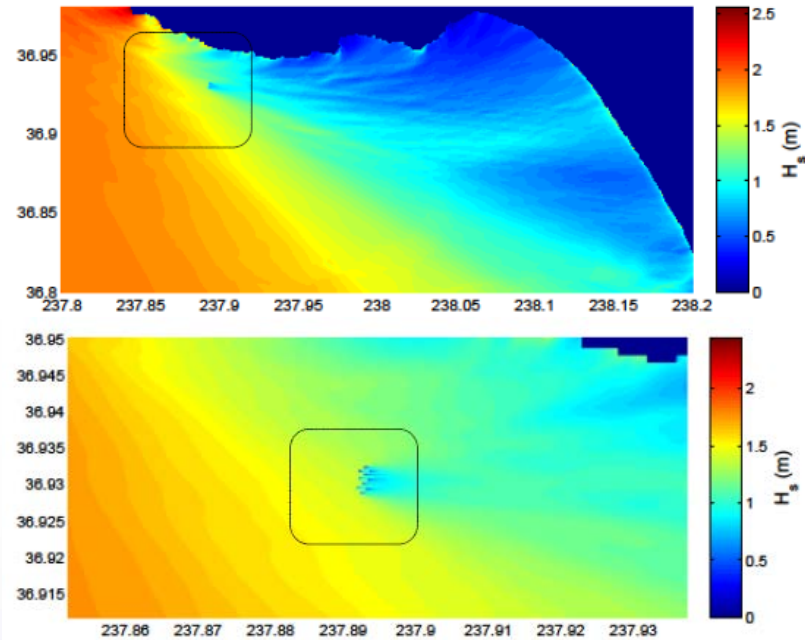
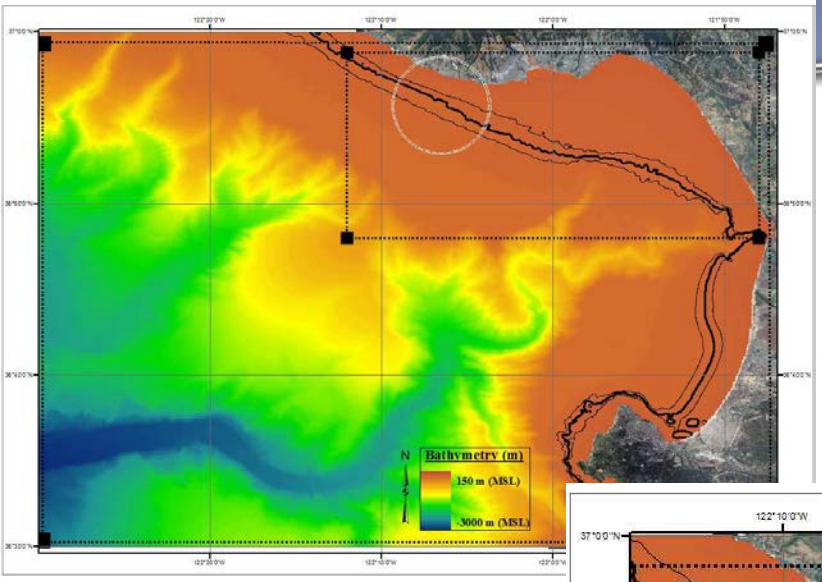


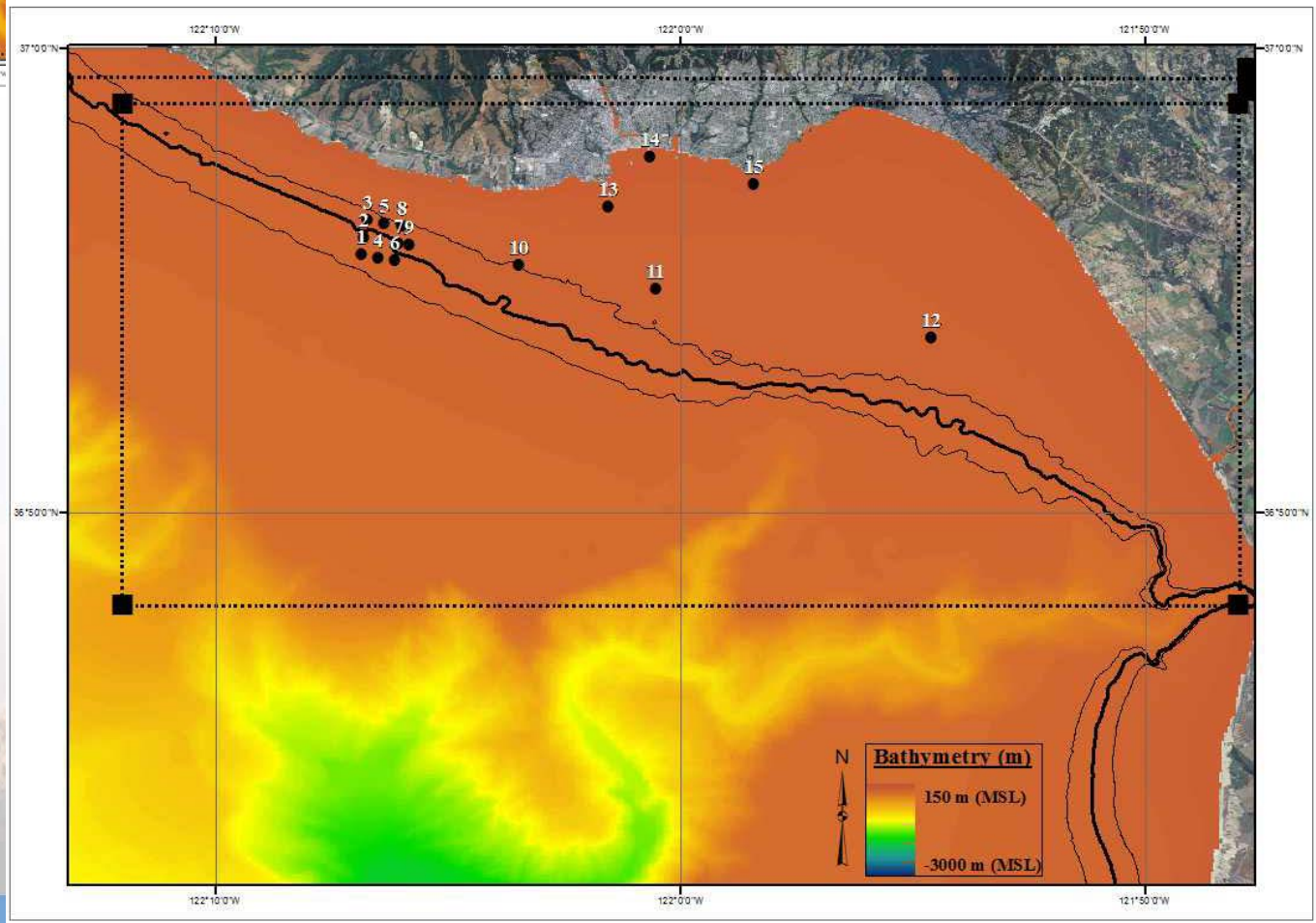
Table 2: Sensitivity analysis parameter values

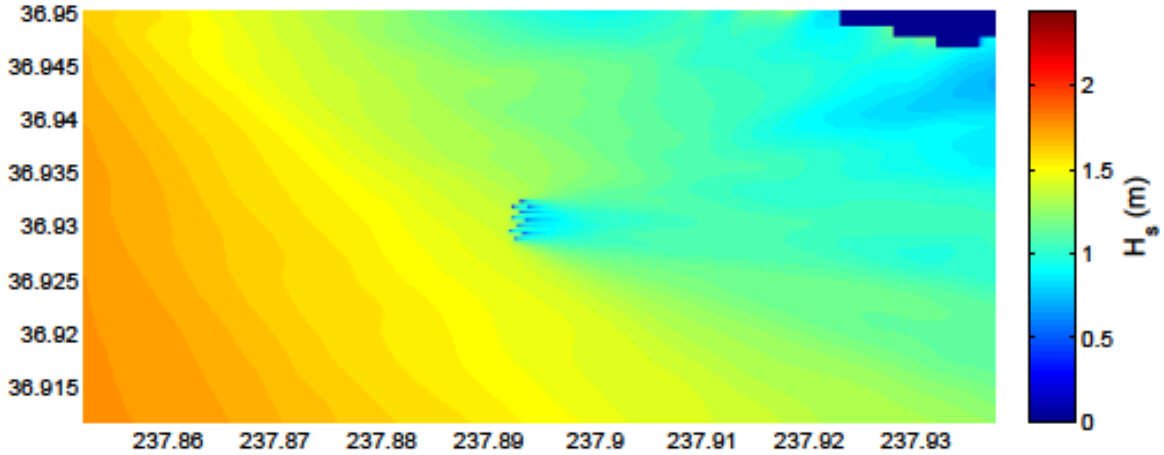
SWAN Coefficient	Value(s)
Transmission (C)	[0, 0.2, 0.4, 0.6, 0.8, 1.0]
Reflection	[0. 0.25]
Frequency Spreading (gamma)	[3.3, 10]
Directional Spreading (m)	[2, 10]

Monterey Bay Wave Model with WECs and output locations



- **Results**
  - Trans. coef. Is most sensitive parameter largely effecting Hs
  - Largest effects landward of array (but not always in-line)
  - Lower DSC enables wave direction changes to penetrate further
  - Tp most affected by DSC
  - Wave direction most affected by DSC

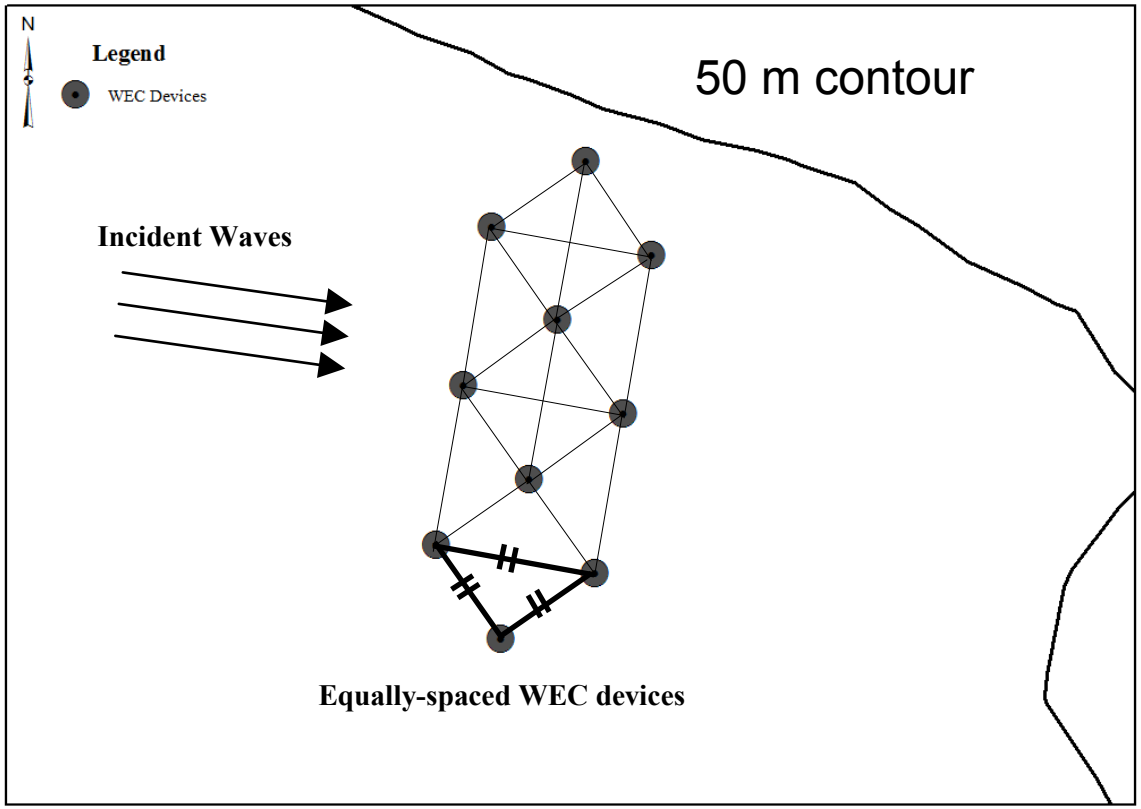




WEC Spacing

2.5X, 5X, 10X

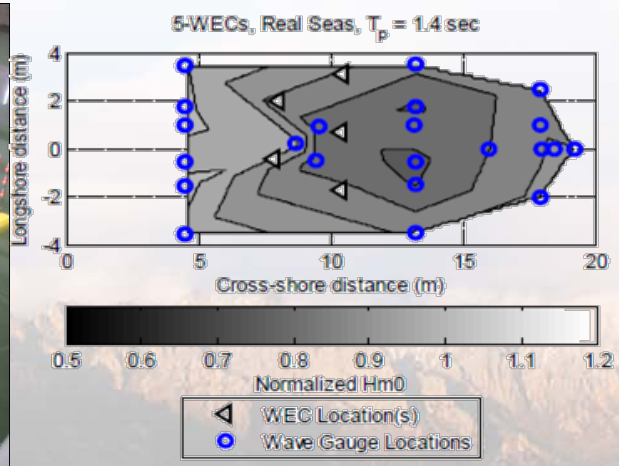
- **Effects of Array spacing**
  - More densely packed arrays have larger effects near the array
  - Less densely packed arrays have larger effects further away from array



WEC Farm Modeling:

Tsunami Basin Sensitivity Analysis

- **WEC Farm Sensitivity Analysis**
  - SWAN OSU Tsunami Basin Model with 5 WEC Farm
  - Model WECs with standard SWAN capabilities (T/R coefficients)
  - Varied WEC coefficients and incident wave conditions (693 combinations)
  - Monitored wave height, period, and direction at wave gage locations



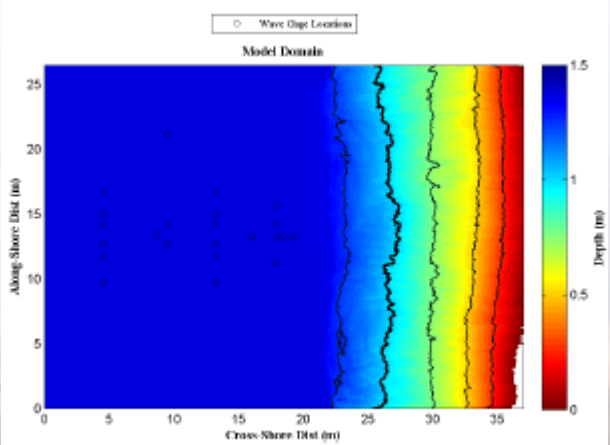
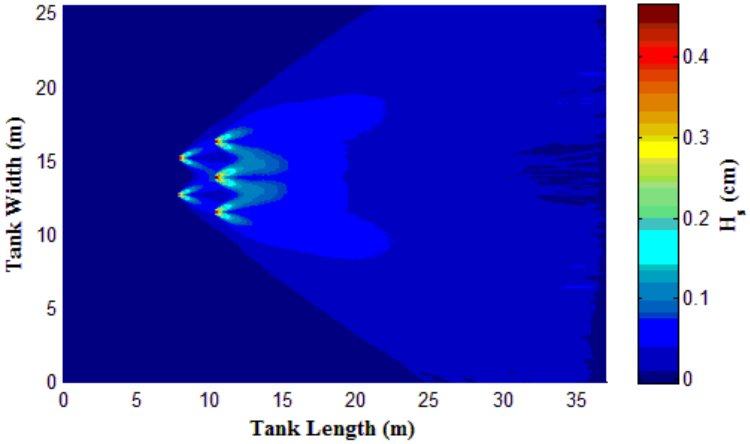


Figure 3 : SWAN Tsunami Basin Model Domain

WEC Farm Modeling:

Tsunami Basin Sensitivity Analysis Results

- **Results**
  - Example output from WEC Farm model compared to baseline case
  - Currently processing the Tsunami Basin sensitivity analysis data



SWAN Tsunami Basin Model Results for 5 WEC Array with Hs = 7.58 [m], Tp = 2.22 [s] and DSPR = 4.

Table 3: OSU Tsunami Basin Sensitivty Analysis Parameters

Test #3 Real Seas (Irregular Waves)								
Sea State	Shape	Hm0 (cm)	Tp (s)	Mean Wave Direction (°)	# of WECs	Transmission Coeff	Reflection Coeff	Spreading Index
7	1			1	3	11	1	3
Oregon - 1	PM	4.54	1.62	0	1, 3, 5	0 : 0.1 : 1.0	0	4, 10, UD
Oregon - 2	PM	7.58	1.42	0	1, 3, 5	0 : 0.1 : 1.0	0	4, 10, UD
Oregon - 3	PM	7.58	1.82	0	1, 3, 5	0 : 0.1 : 1.0	0	4, 10, UD
Oregon - 4	PM	7.58	2.22	0	1, 3, 5	0 : 0.1 : 1.0	0	4, 10, UD
Oregon - 5	PM	13.6	2.22	0	1, 3, 5	0 : 0.1 : 1.0	0	4, 10, UD
HI - Kaneohe	PM	4.54	1.22	0	1, 3, 5	0 : 0.1 : 1.0	0	4, 10, UD
IR - M4 buoy	PM	10.6	1.62	0	1, 3, 5	0 : 0.1 : 1.0	0	4, 10, UD

WEC Farm Modeling:
WEC Energy Sink Definition

- **WEC Energy Sink Definition**
  - Currently WECs modeled in SWAN as constant transmission (absorption) terms
  - Definition of WEC Energy Sinks with Frequency- and Directional-Dependence

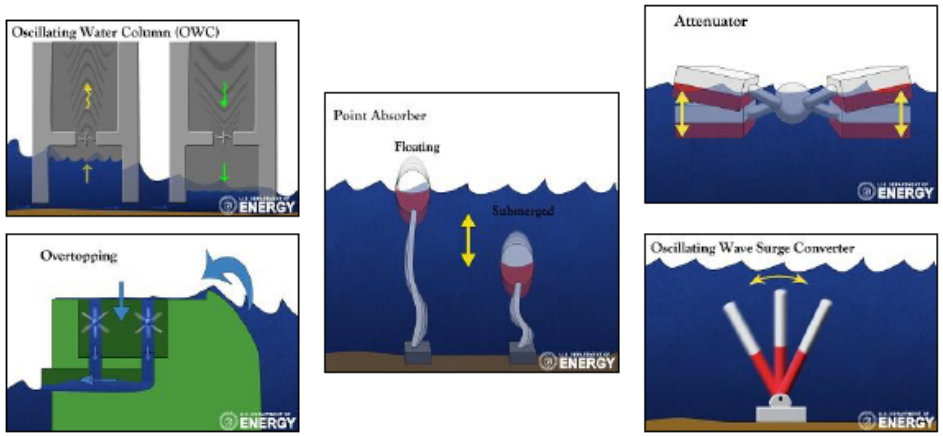
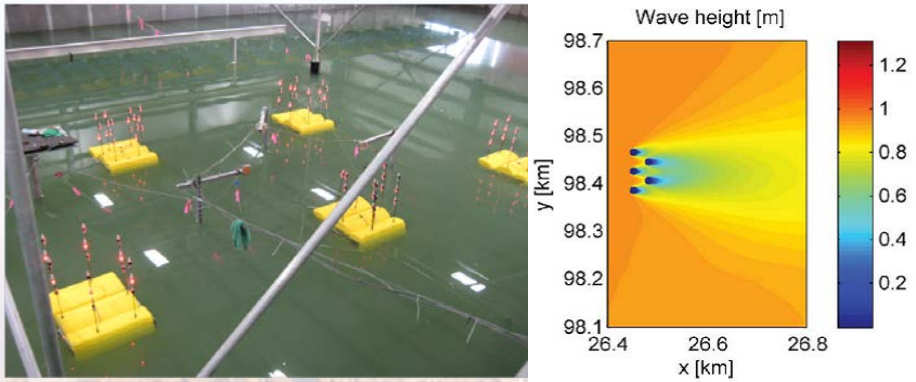


Figure 6: Diversity of Existing Wave Energy Converter Technologies [10]

WEC Farm Modeling:
Future Goals

- **More accurately model WECs in large scale models by modifying the SWAN source code to include Frequency- and Directional-Dependent energy sinks**
  - Modify the SWAN source code to include WEC energy sinks
  - Compare numerical results with experimental data
    - In collaboration with Oregon State University and Columbia Power



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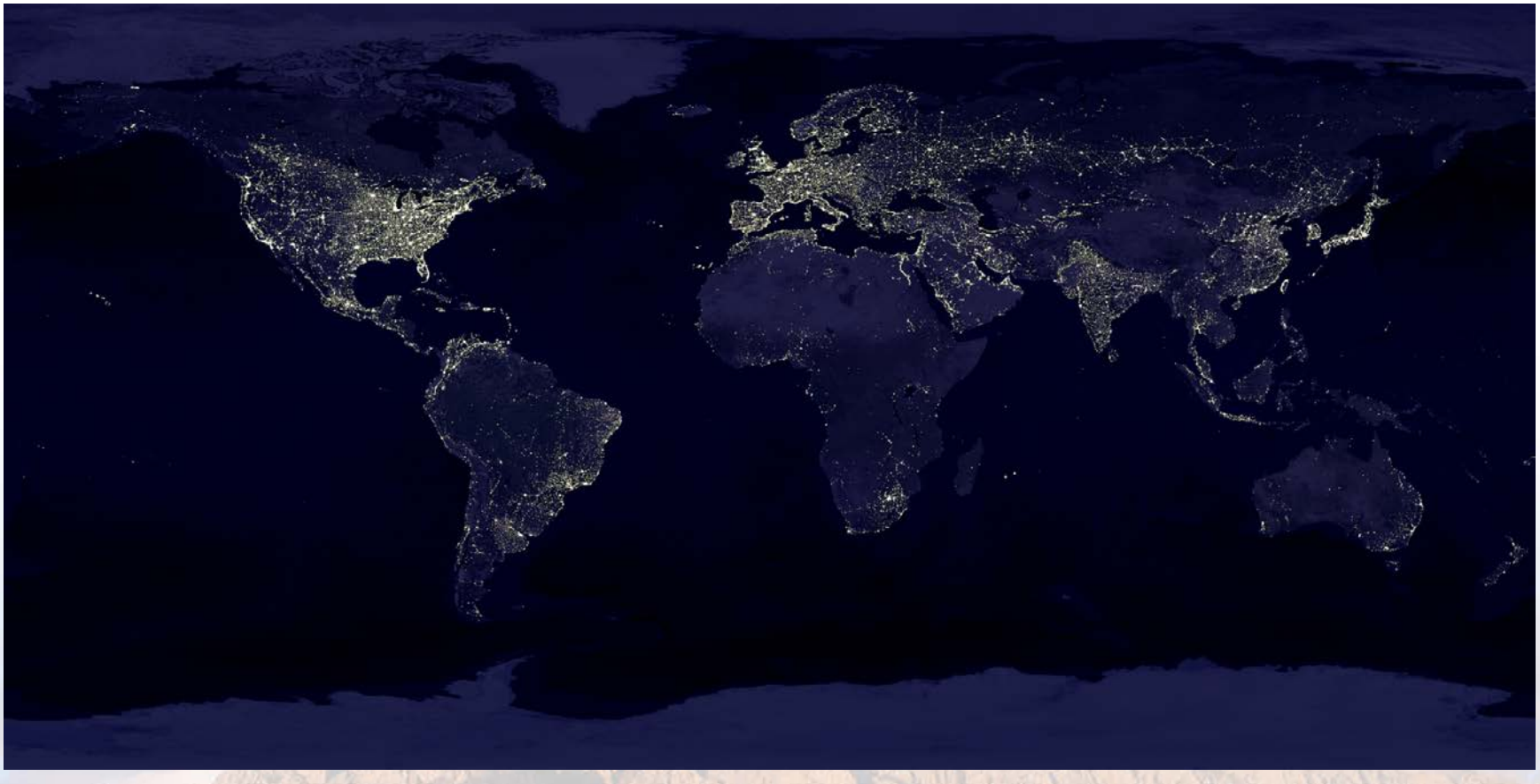
Recap

- **Overview of SNL's Large-Scale Wave and WEC Array Modeling Activities**
  - WEC Farm Modeling on Roadmap
  - SNL Current Modeling Capabilities
  - SNL WEC Farm Model Tool Development

Questions???

Thanks for your time!

kmruehl@sandia.gov



http://visibleearth.nasa.gov/