Water Power Technologies
MHK Market Acceleration and Deployment

SNL-EFDC: A Tool for Predicting Physical Environmental Effects of Current Energy Converters

Jesse Roberts (Principle Investigator)

jdrober@sandia.gov

Daniel Laird (Manager)

dllaird@sandia.gov

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SNL Vision of MHK MA&D Thrust Area

- **Vision: Overcome** environmental and regulatory **challenges** through **technical innovation** and **Outreach**.

  - **Develop MHK-Specific tools** to accurately characterize the influence of MHK-Devices on the environment.

  - Use the tools to **design environmentally friendly MHK developments**, allaying environmental concerns and speeding up the permitting process.

  - Help industry **generate power environmentally responsibly** and be stewards of the next generation of clean energy.

  - SNL key areas of work:
    - CEC **Blade strike** analysis
    - Physical environmental effects of **WEC arrays**
    - Physical environmental effects of **CEC arrays**
    - CEC **acoustic** signature predictions

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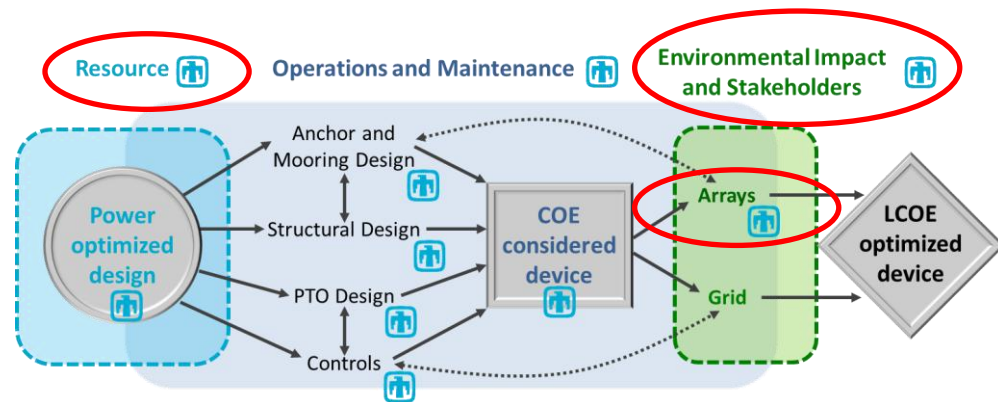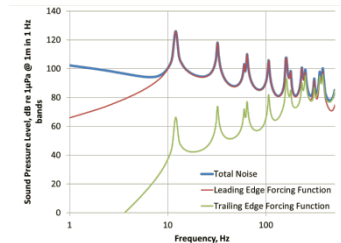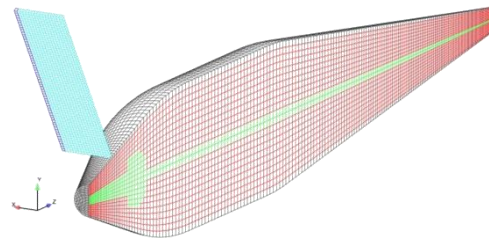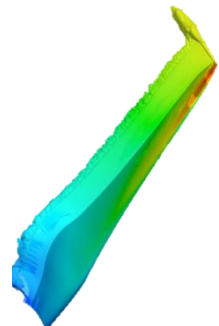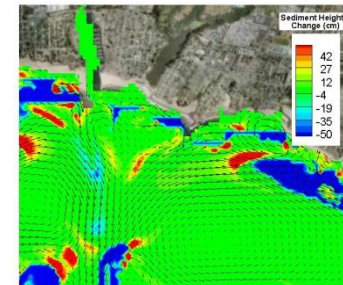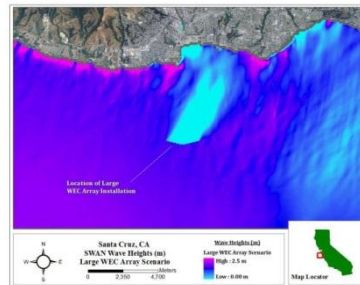
SNL-EFDC Application, Validation, and Tech Transfer
Environmental Evaluations and Array Power Performance

- ## Objectives
  - Develop and demonstrate **SNL-EFDC:** a tool for **balancing** MHK-turbine energy harvest **efficiency and environmental effects.**
    - **Maximize power** and **minimize** potentially harmful **environmental effects**
  - Address **CEC array power performance and environmental concerns** about large-scale development.
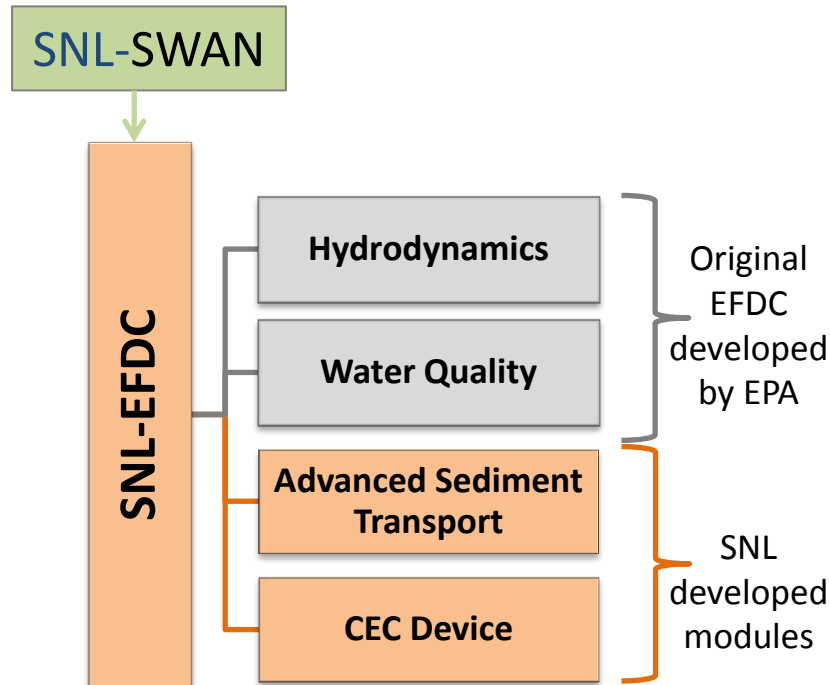
- ## Background
  - **High fidelity CFD codes** (LES or URANS) are **computationally expensive** for large domains.
  - Some **Lower fidelity CFD-RANS codes** incorporated vegetation losses but were **not MHK specific**.
  - SNL developed **'MHK-friendly' SNL-EFDC** through DOE-FOA award.

- ## Tool (Leverage Well-Respected EPA Code)
  - EFDC – Environmental Fluid Dynamics Code (RANS)
    - Originally Developed by the EPA for Clean Water Act
    - Rectangular or curvilinear orthogonal grid
    - Coupled-equation solution (mass, momentum, TKE…)
  - **SNL-EFDC** – adds **CEC module** and advanced **sediment transport routines**.

EFDC Extensively Validated

SNL-SWAN

SNL-EFDC

- Hydrodynamics
- Water Quality

Original EFDC developed by EPA

- Advanced Sediment Transport
- CEC Device

SNL developed modules

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CEC Energy Extraction Module

- MHK device energy extraction is manifest as
  - Decreased momentum
  - Altered (usually increased) turbulent kinetic energy
  - Increased turbulence dissipation rate (turbulent length scale)
- Momentum and K-ε are advected and dispersed downstream

$$P_{\text{MHK}} = \frac{1}{2} C_{\text{T}} A_{\text{MHK}} \rho U^3$$

$$S_Q = -\frac{1}{2} C_{\text{T}} A_{\text{MHK}} U^2$$

Momentum Sink

◯ **- Empirical constants**

$$S_K = \frac{1}{2} C_{\text{T}} A_{\text{MHK}} \left(\beta_p U^3 - \beta_d UK \right)$$

$$S_\varepsilon = C_{\varepsilon 4} \frac{\varepsilon}{K} S_K$$

$K - \varepsilon$ Modifications

Katul, G. G., L. Mahrt, D. Poggi, and C. Sanz (2004), One- and two-equation models for canopy turbulence, *Boundary-Layer Meteorology, 113, 81-109.*

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CEC Module Porous Approximation

- CEC can be represented by multiple cells or a single cell
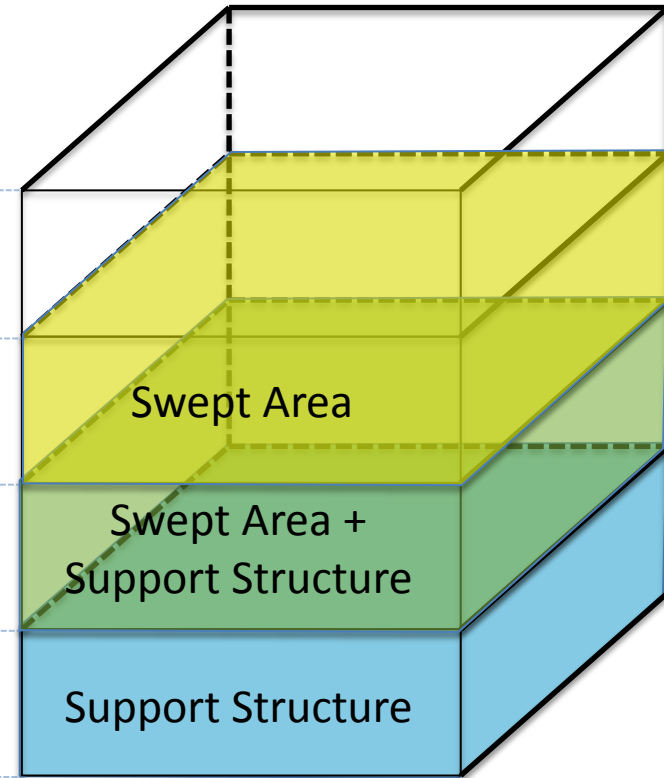- CEC can occupy an entire cell or a fraction of a cell
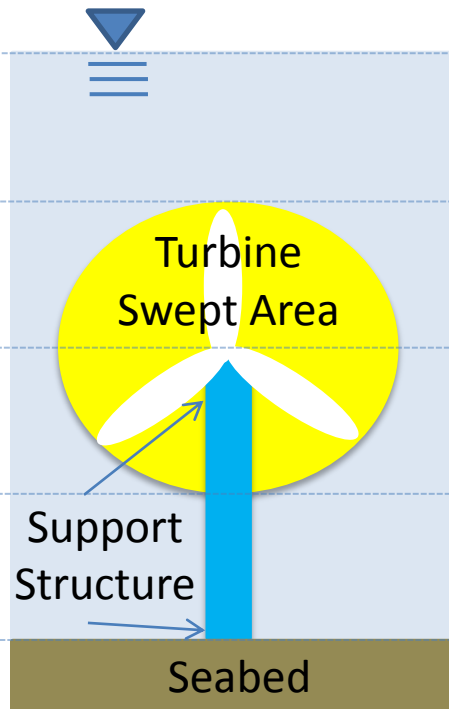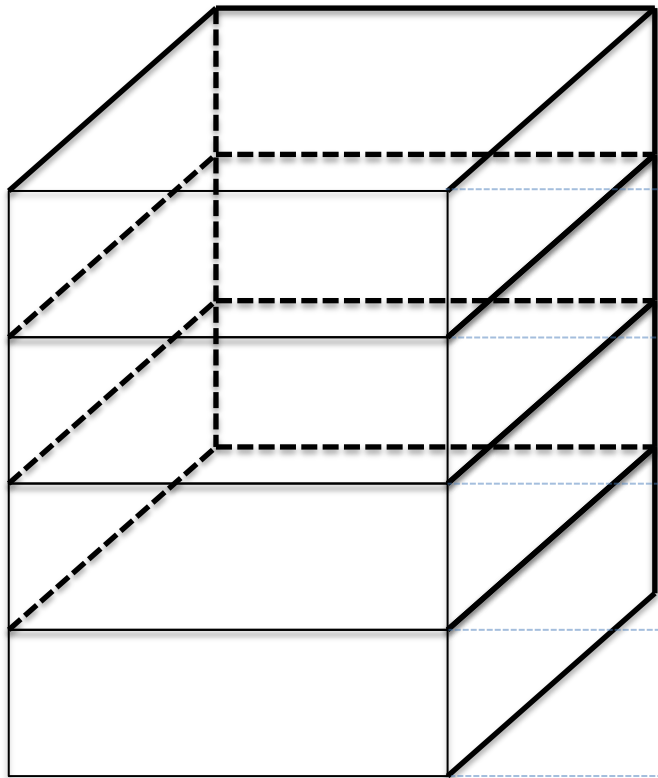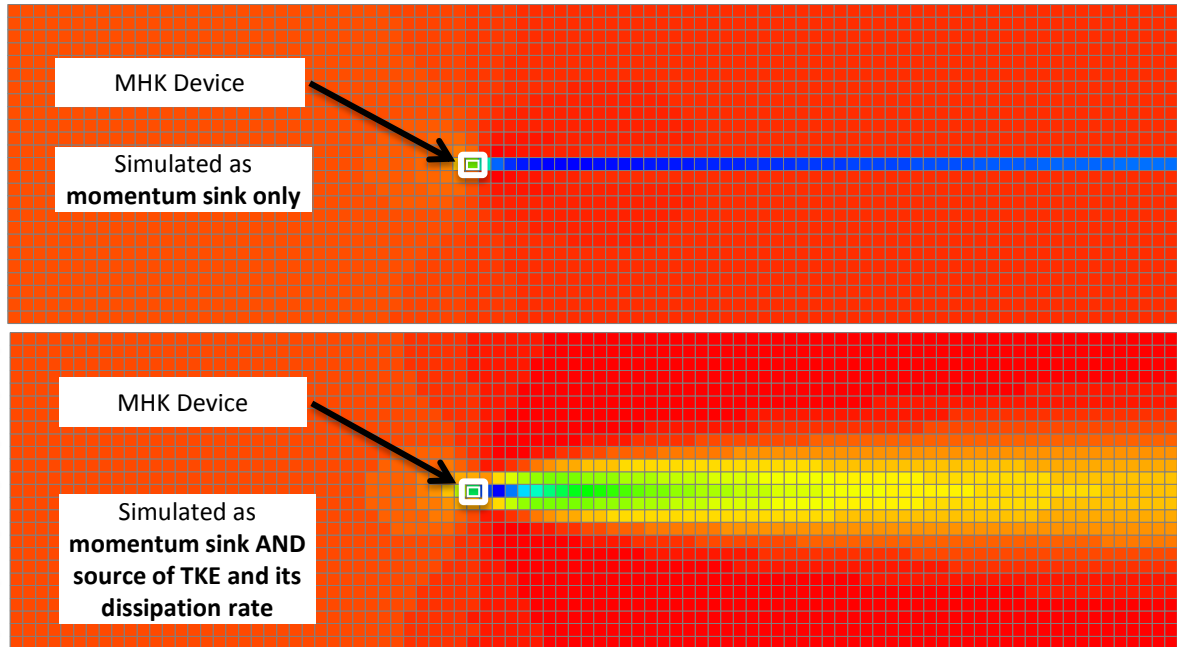
Hydrodynamic Model Grid
+
SNL-EFDC Turbine Representation

Hydrodynamic Model Grid

Turbine Swept Area

Support Structure

Seabed

Swept Area

Swept Area + Support Structure

Support Structure

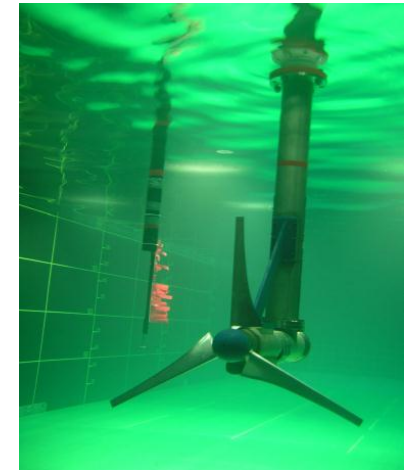Sandia National Laboratories

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SNL-EFDC – MHK Module Validation

- SNL-EFDC enhanced to represent CEC-devices (MHK-Friendly)
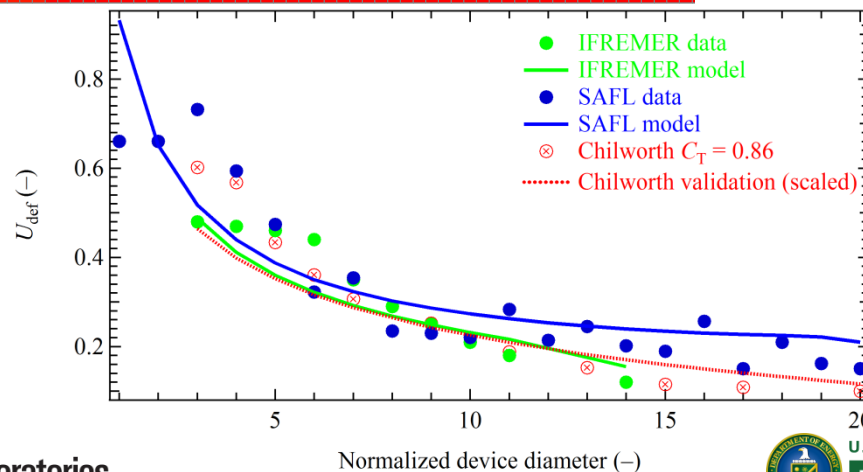- Three distinct laboratory data sets (single device or actuator disk)

MHK Device

Simulated as **momentum sink only**

MHK Device

Simulated as **momentum sink AND source of TKE and its dissipation rate**

SAFL

IFREMER

	SAFL	IFREMER	Average
β_p	0.05	0.08	**0.065**
β_d	2.9	2.1	**2.5**
$C_{\varepsilon 4}$	9.8	10.4	**10.1**

- IFREMER data
- IFREMER model
- SAFL data
- SAFL model
- Chilworth $C_T = 0.86$
- Chilworth validation (scaled)

U_{def} (−) vs Normalized device diameter (−)

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SNL-EFDC – Array Validation

- 1-array data set (Meyers, 2012) using actuator disks
- Shear and wake interactions required increase in eddy diffusivity (relative to single device)
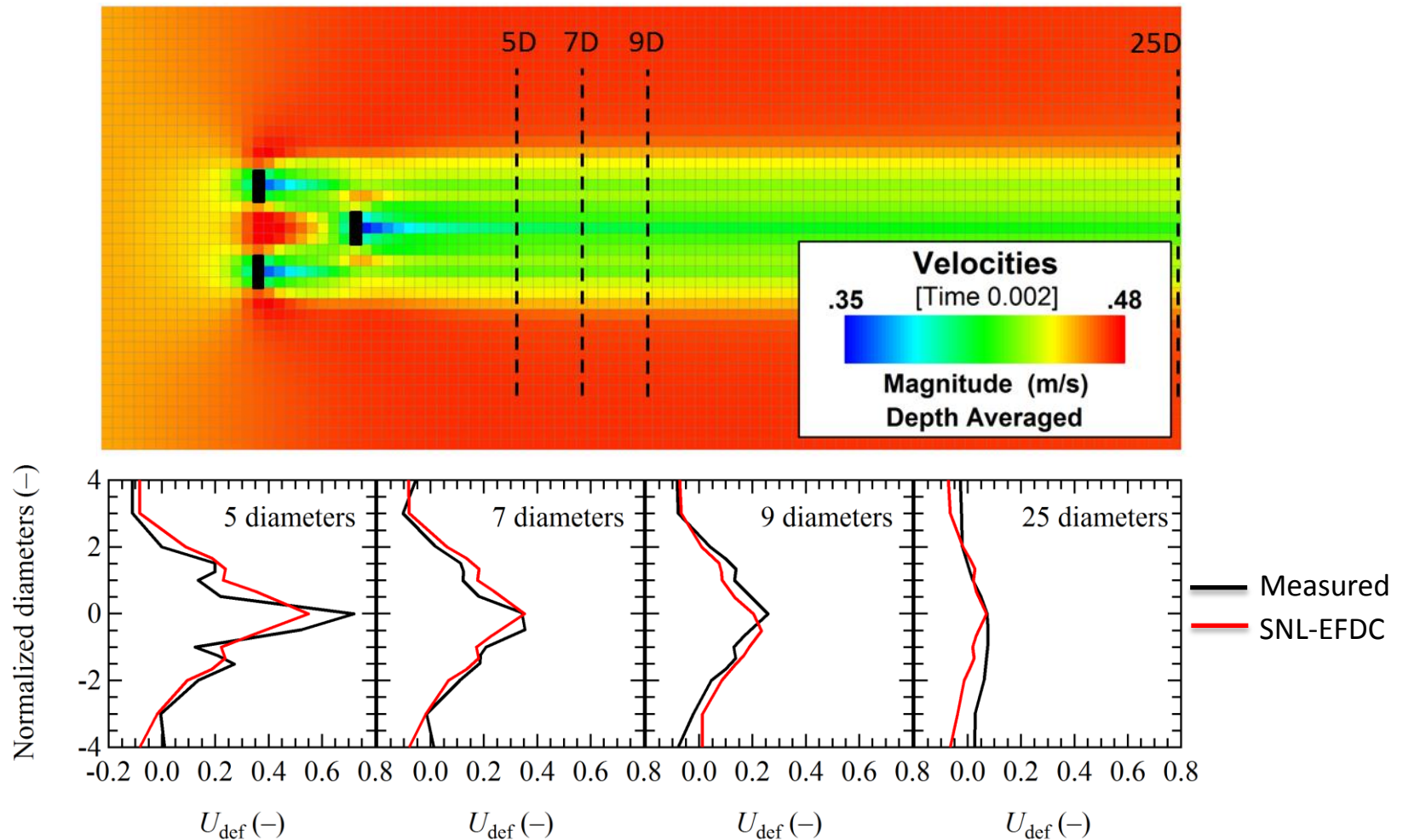
SNL-EFDC – Array Optimization

- Spanwise and Streamwise CEC spacing critical to array power performance
- Flow naturally moves around and under/over CEC devices (path of least resistance)
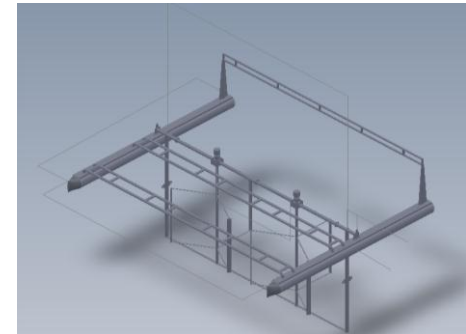- Array spacing effects both power generation, the flow field, and therefore the environment

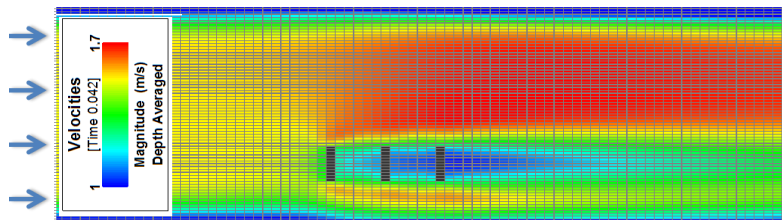### CEC Spacing Options
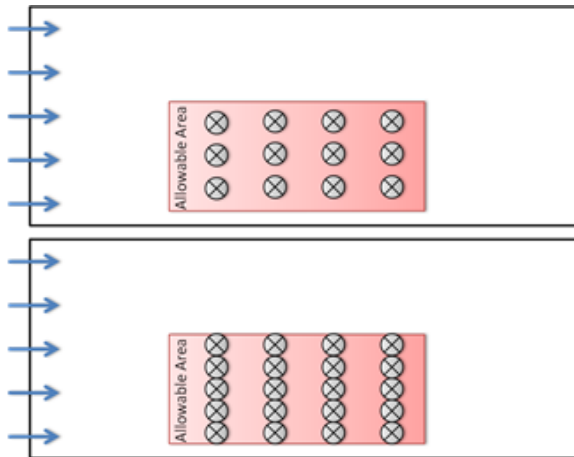
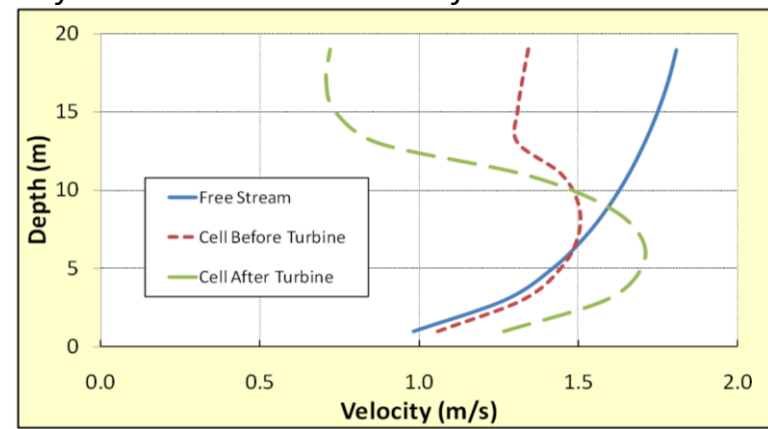### Array Power vs. Spacing
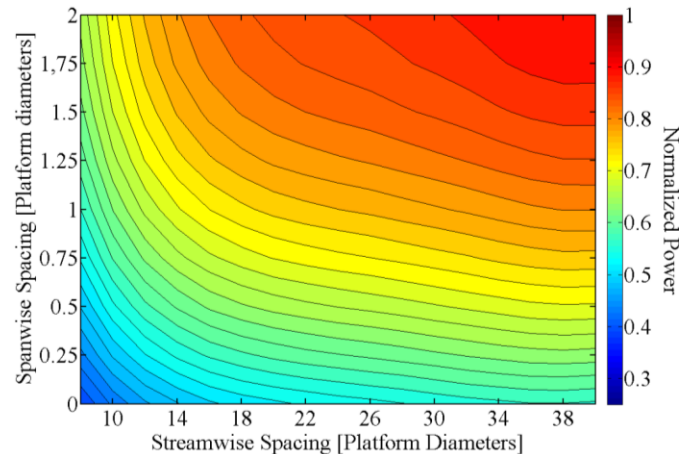
Surface Mounted CEC

Un-Optimized CEC Array
flow accelerates around array

Vertical Velocity Profiles
flow accelerates under surface mounted CECs


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SNL-EFDC Demonstration, Validation, and Tech Transfer
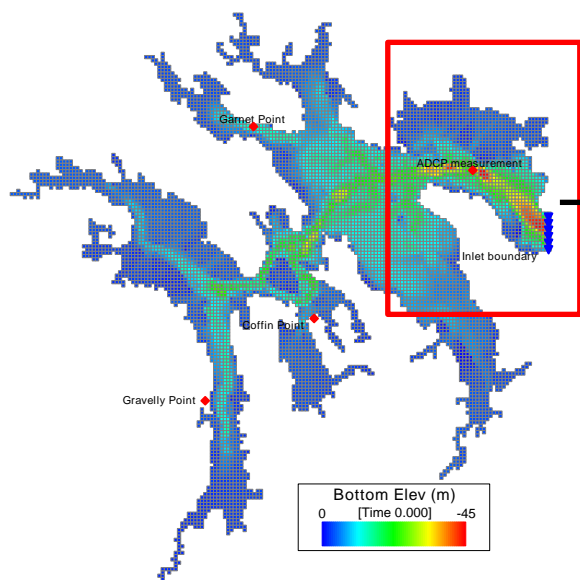## *Environmental and Array Power Performance Assessments*

- ## SNL-EFDC Demonstration Activities
  - Goal = Determine relationship between number of CECs deployed vs. environmental response
  - SNL-EFDC application – San Francisco Bay
    - Investigated **tidal flushing and range** for 30, 150, & 300 20-m diameter generic CEC arrays.
  - SNL-EFDC application – Mississippi River, LA
    - Investigated **performance, flood hazard, and sedimentation** concerns for 12, 132, 534 CEC arrays (FFP).
  - SNL-EFDC application – Cobscook Bay
    - Investigated **tidal flushing and range** for 5 CEC array (ORPC) Almost **no discernible effects**.
    - Investigating near-field hydrodynamics and sediment transport for influence on **array power generation, fish behavior, and benthic habitat.**
    - **ORPC included SNL report in FERC documents**
  - Peer Review of SNL-EFDC, CEC module
    - By former **E**nvironmental **P**rotection **A**gency **expert**
  - SNL-EFDC technical transfer
    - Completed two training courses
    - 2-3 more courses for FY13 (Verdant, ORPC-ME/AK)
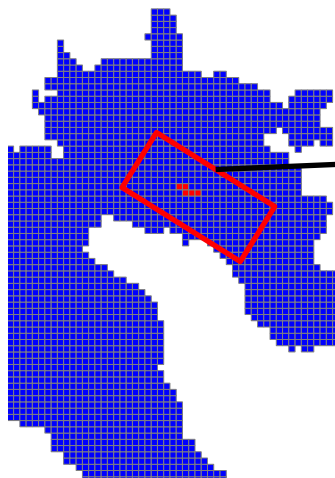   - **Willing to schedule training course for regulatory community upon request**

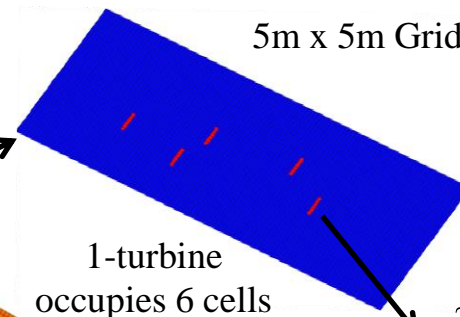U.S. DEPARTMENT OF ENERGY
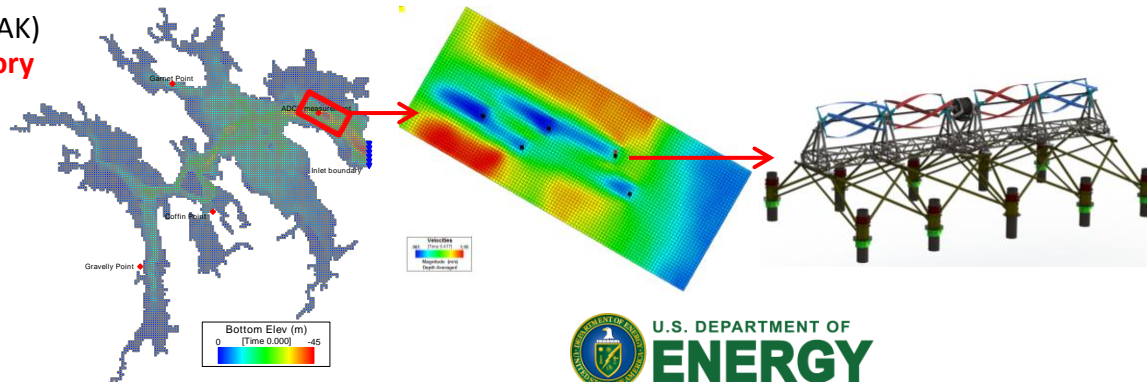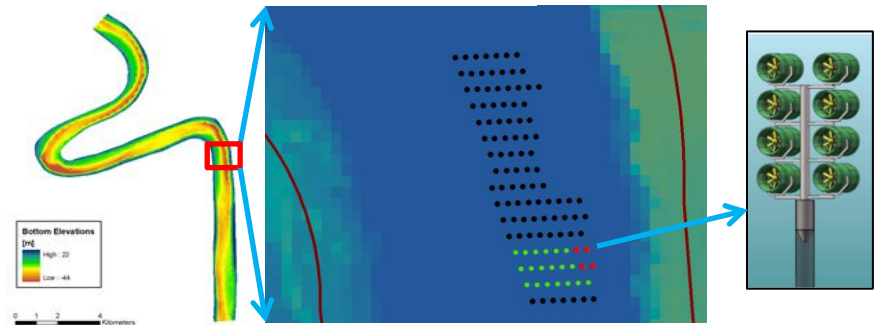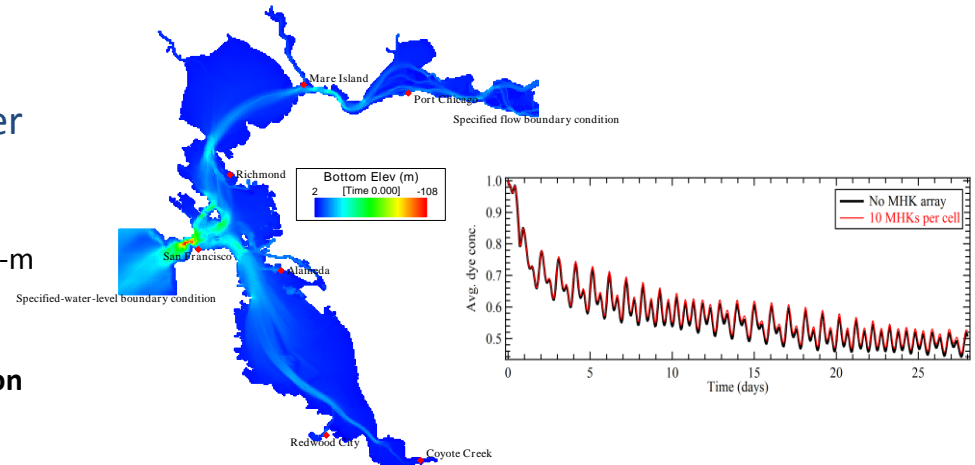
SNL-EFDC Demonstration – Cobscook Bay
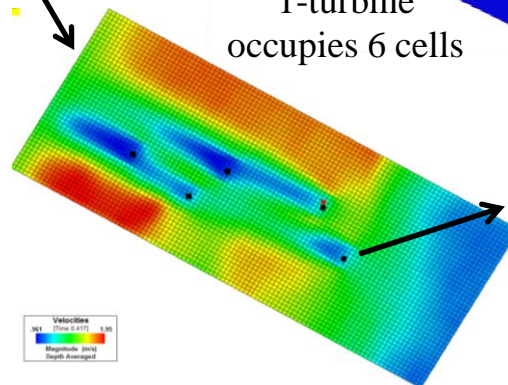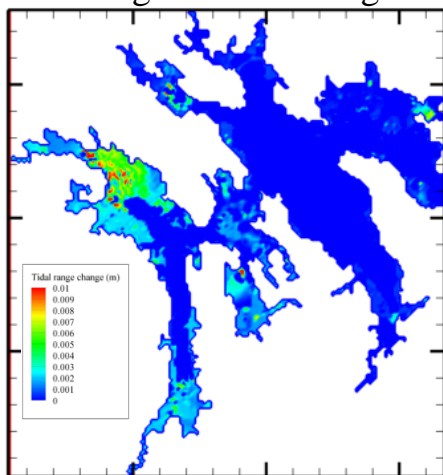

100m x 100m Grid

5 Turbines (1/cell)

5m x 5m Grid

1-turbine occupies 6 cells

~30m

Bottom Elev (m)
0   [Time 0.000]   -45

Velocities
[Time 0.417]
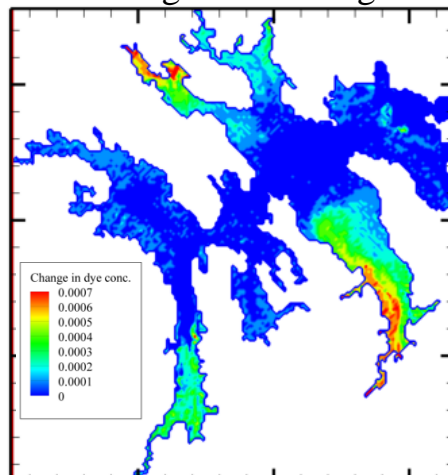Magnitude (m/s)
Depth Averaged
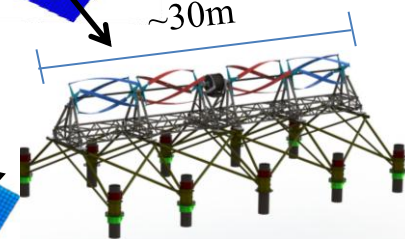
Effects of 5 Turbines is Negligible

Change in Tidal Range

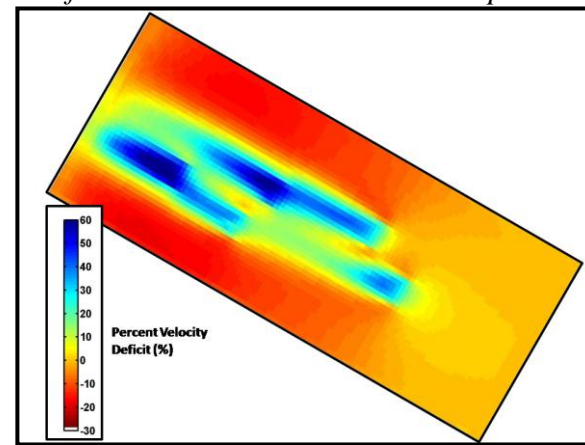Change in Flushing

Velocity Change Map (without – with turbines)
Informs fish behavior and sediment transport modeling

Tidal range change (m)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0

Change in dye conc.
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0

Percent Velocity Deficit (%)
60
50
40
30
20
10
0
-10
-20
-30

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