

SNL Water Power Program

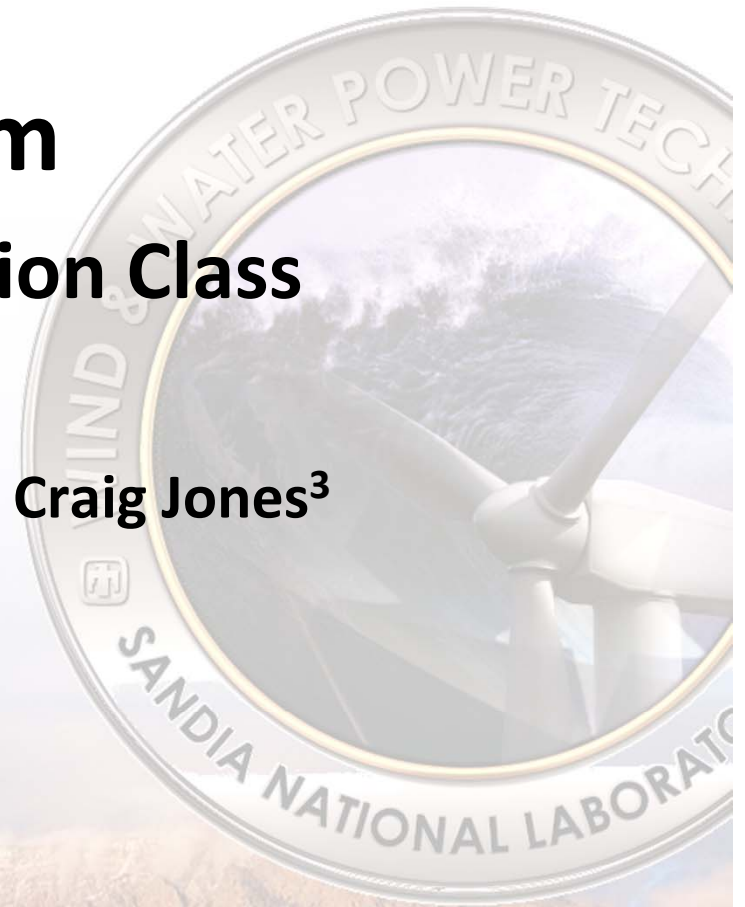
SNL-EFDC Array Optimization Class

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³Sea Engineering Inc.



Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.



Goals for the Class

- Familiarize participants with the Environmental Fluid Dynamics Code (EFDC) and SNL enhancements (SNL-EFDC)
 - **MHK turbine representation**
 - Sediment dynamics
 - Water-quality kinetics
- Develop hands on experience with SNL-EFDC with example models using EFDC Explorer (graphical user interface)
 - Straight channel, SF Bay, site examples
- Identify gaps/challenges for meeting MHK application/research goals
- Feedback on class structure and tools



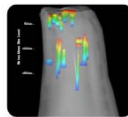
History of Sandia Energy Programs



Sandia was born as a nuclear weapons engineering laboratory with deep science and engineering competencies

Energy crisis of the 1970s spawned the beginning of significant energy work

Strategic Petroleum Reserve -geologically characterizing salt domes to host oil storage caverns



DOE's Tech Transfer Initiative was established by Congress in 1991



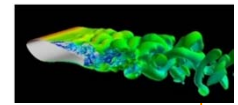
Advent Solar

CRF & Cummins partner on their newest diesel engine



Joint BioEnergy Institute

Energy Policy Act of 2005



Water Power Program



Our core NW competencies enabled us to take on additional large national security challenges



Vertical-axis Wind Turbine

NRC cask certification studies & core melt studies



Solar Tower opens

Combustion Research Facility (CRF) opens to researchers



Power grid reliability study

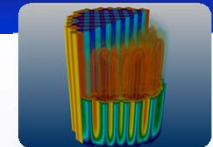


SunCatcher™ partnership with Stirling Energy Systems



Sunshine to Petrol Pilot Test

Large-scale pool fire tests of liquefied natural gas (LNG) on water



Consortium for Advanced Simulation of Light Water Reactors (CASL)

Climate study uncertainties to economies




Combustion Research Computation and Visualization (CRCV) opens



Distributed Energy Technology Laboratory (DETL) to integrate emerging energy technologies into new and existing electricity infrastructures



 Sandia National Laboratories

Sandia

Sandia's Water Power Research

SNL Water Power Research Focus Areas

MHK Technology Development (TD)

Develop tools to assist the industry in the design, development, and optimization of MHK devices and arrays.

Provide resources, expertise, and locations to facilitate testing of a wide variety of MHK systems and components.

Generate relevant and reliable data on cost, performance, and reliability.

Develop baseline cost of energy (COE)

Identify and evaluate key cost-reduction pathways.

MHK Market Acceleration and Deployment (MA&D)

Develop tools and evaluate the effects of MHK technologies on the surrounding environment and ecosystem.

Support project planning and permitting.

Conventional Hydropower (CH)

Develop an integrated tool set for optimizing the operational efficiency and environmental performance of hydroelectric power plants.

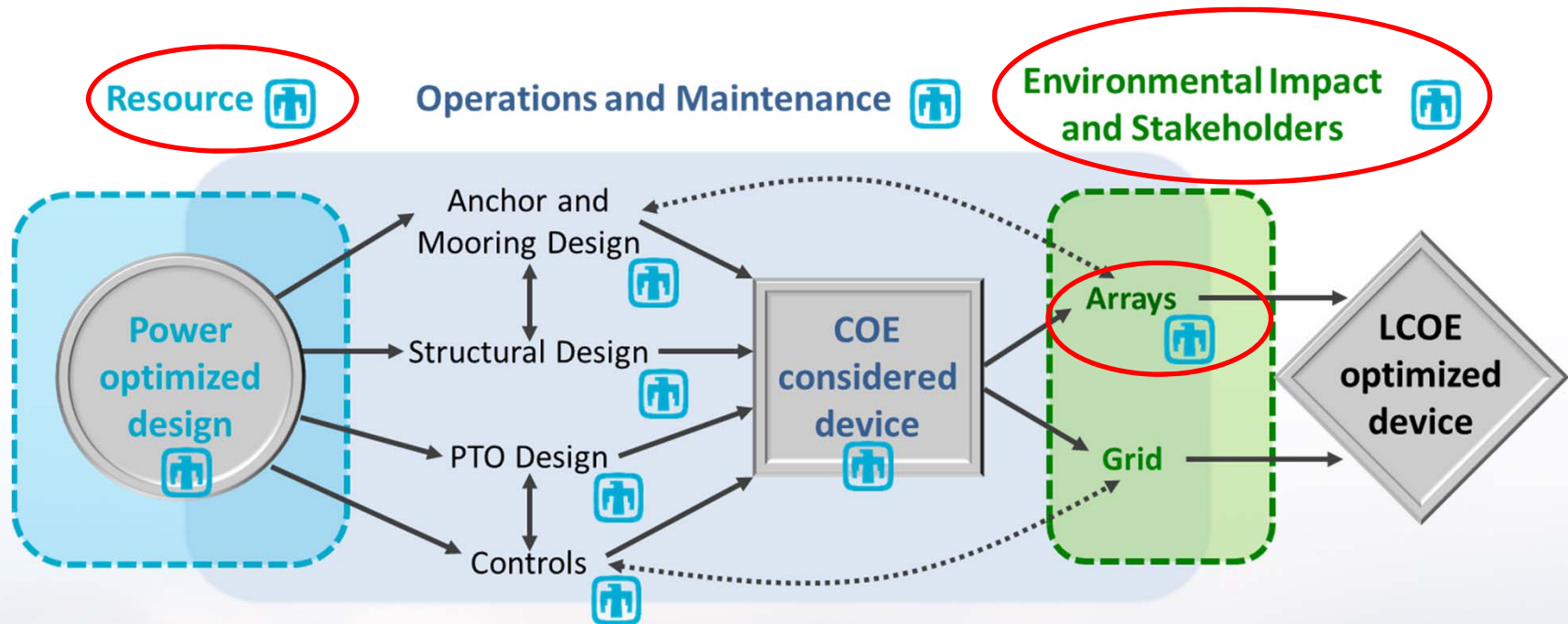


Sandia MHK Research Program

- Unofficial start: 2008 support to Verdant Power
- New U.S. DOE water power program in 2009
- Leveraged existing Sandia capabilities



Sandia's Water Power Research



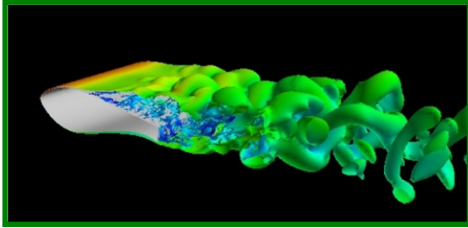
WEC TRL 1

WEC TRL 9

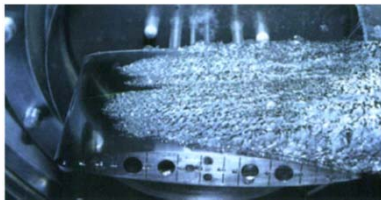


Device Modeling/Testing

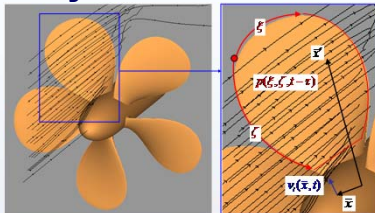
Hydrofoil Design/Analysis



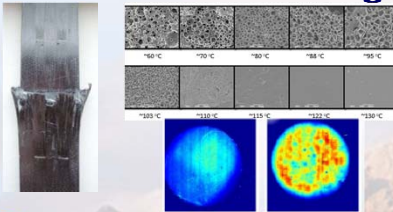
Cavitation



Hydro-Acoustics



Materials & Coatings



Performance Modeling

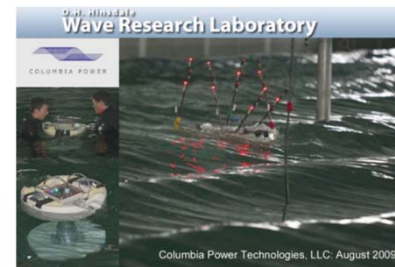


Rotor Design & Testing



Power Takeoff Testing

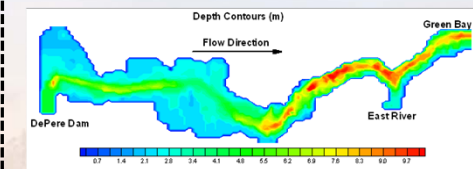
Columbia Power 1/15th Scale Test (OSU)



Water Tunnel (PSU/ARL)



Coupled Device-Array and Environmental Analysis



SNL EFDC

Components

Sub-systems

System Testing

Deployment

Environmental Evaluations and Array Power Performance

Objectives

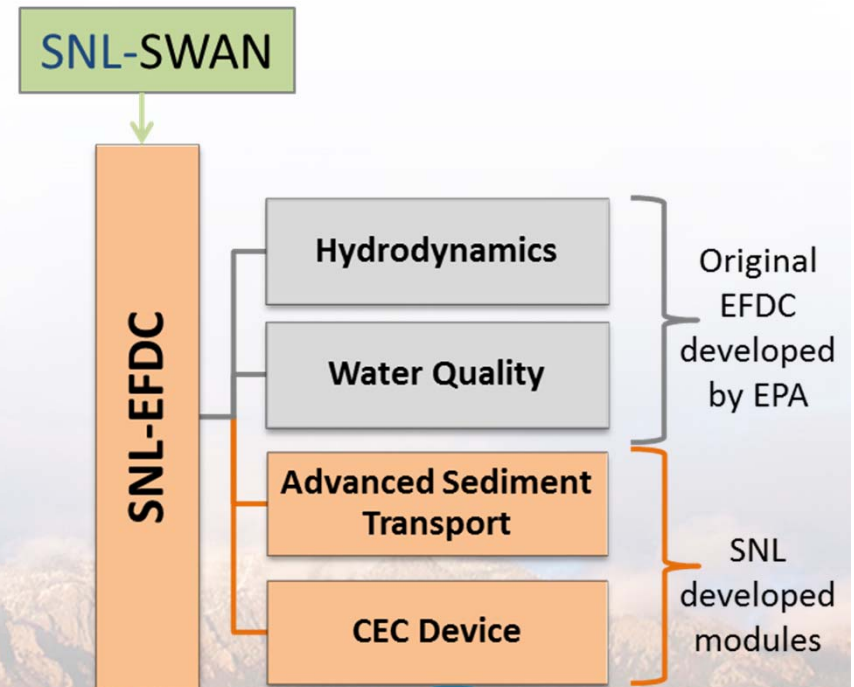
- Develop and demonstrate **SNL-EFDC**: a tool for **balancing** MHK-turbine energy harvest **efficiency and environmental effects**.
 - ◆ **Maximize power** and **minimize** potentially harmful **environmental effects**
- Address **CEC array power performance and environmental concerns** about large-scale 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**.



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 - e are advected and dispersed downstream

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

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

} Momentum Sink

○ - Empirical constants

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

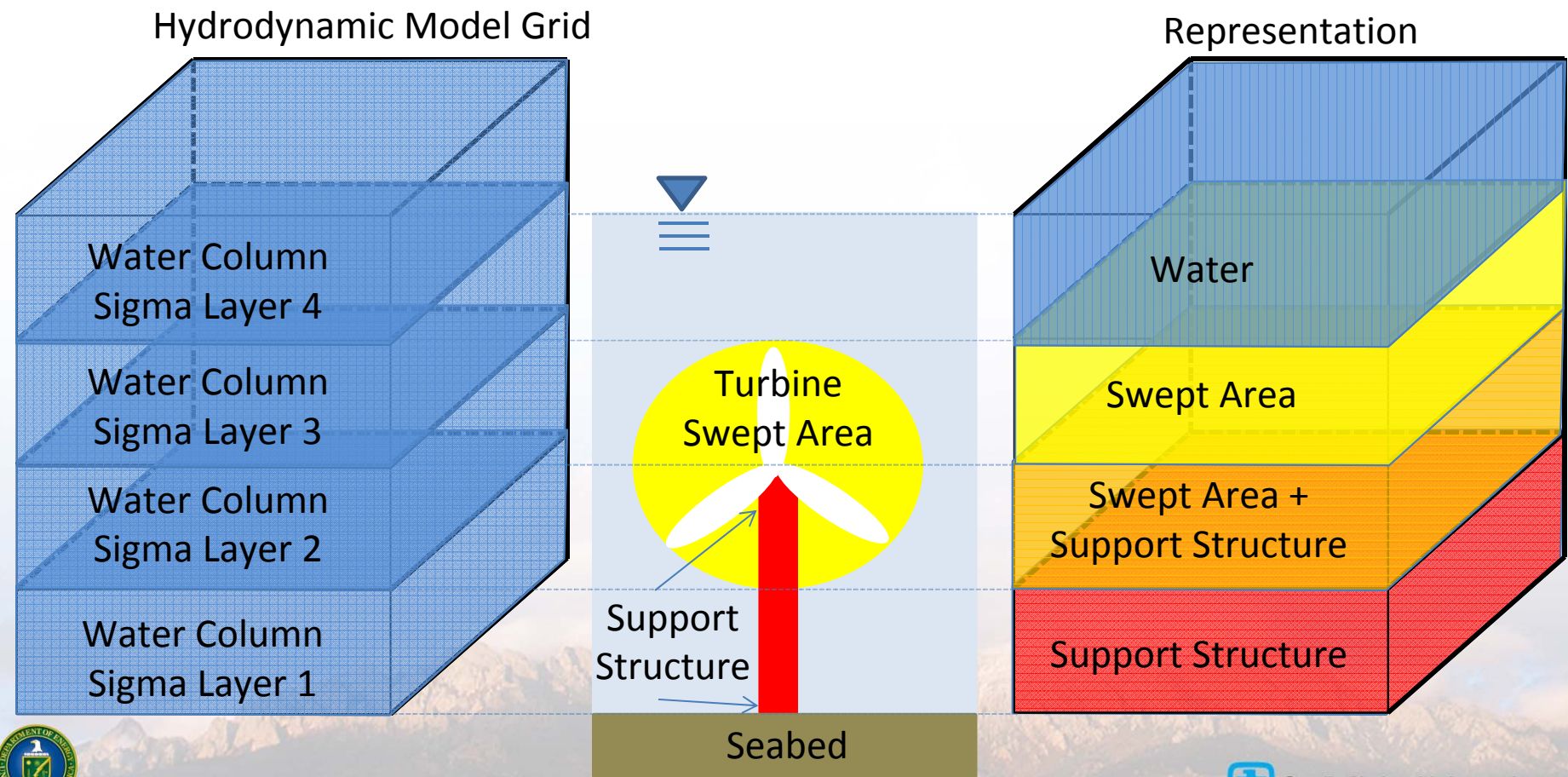
$$S_\varepsilon = C_{\varepsilon 4} \frac{\varepsilon}{K} S_K$$

} K - e Modifications



CEC Module: Porous Approximation

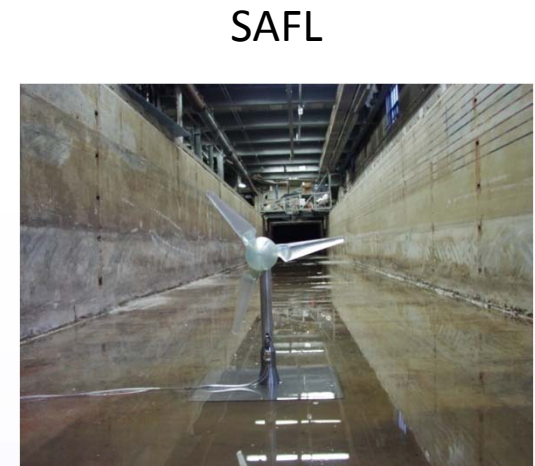
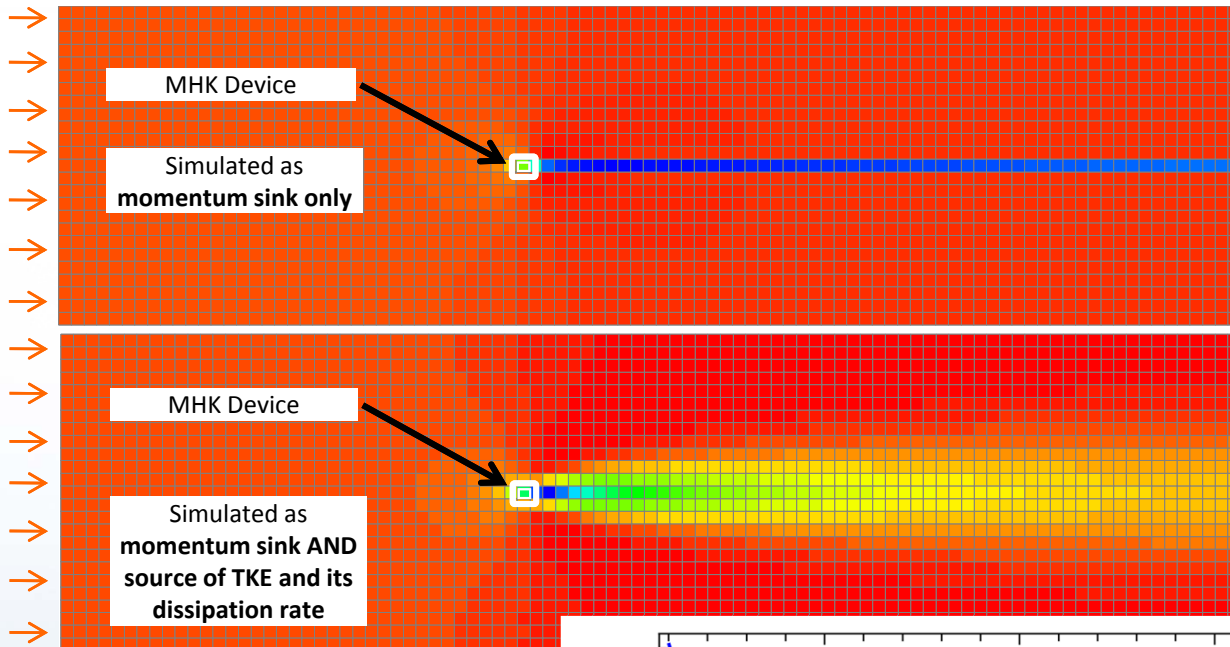
- CEC can be represented by multiple cells or a single cell
- CEC can occupy an entire cell or a fraction of a cell



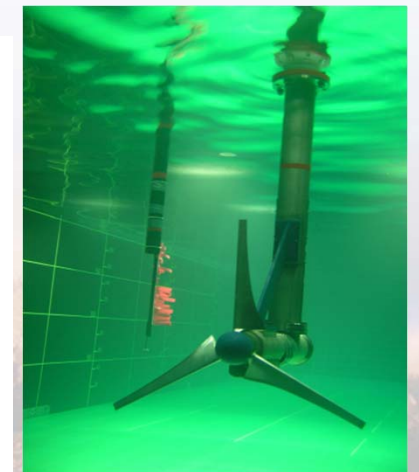
SNL-EFDC: CEC Module Validation

Singe Device

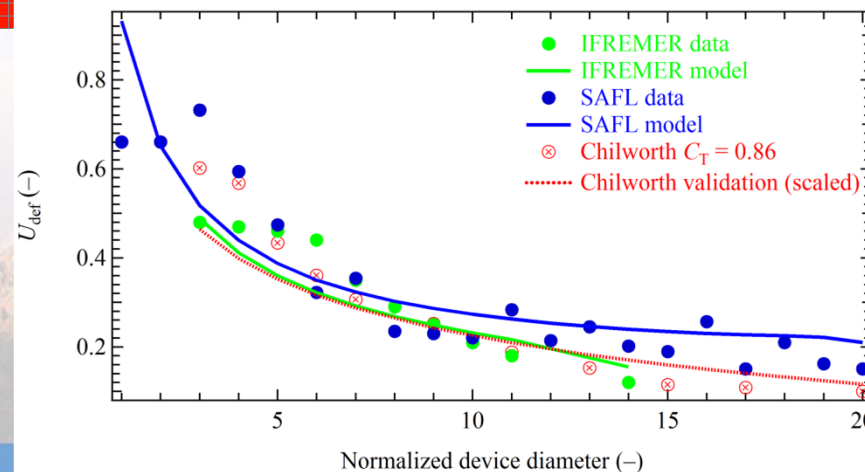
- SNL-EFDC enhanced to represent CEC-devices (MHK-Friendly)
- Three distinct laboratory data sets (single device or actuator disk)



IFREMER



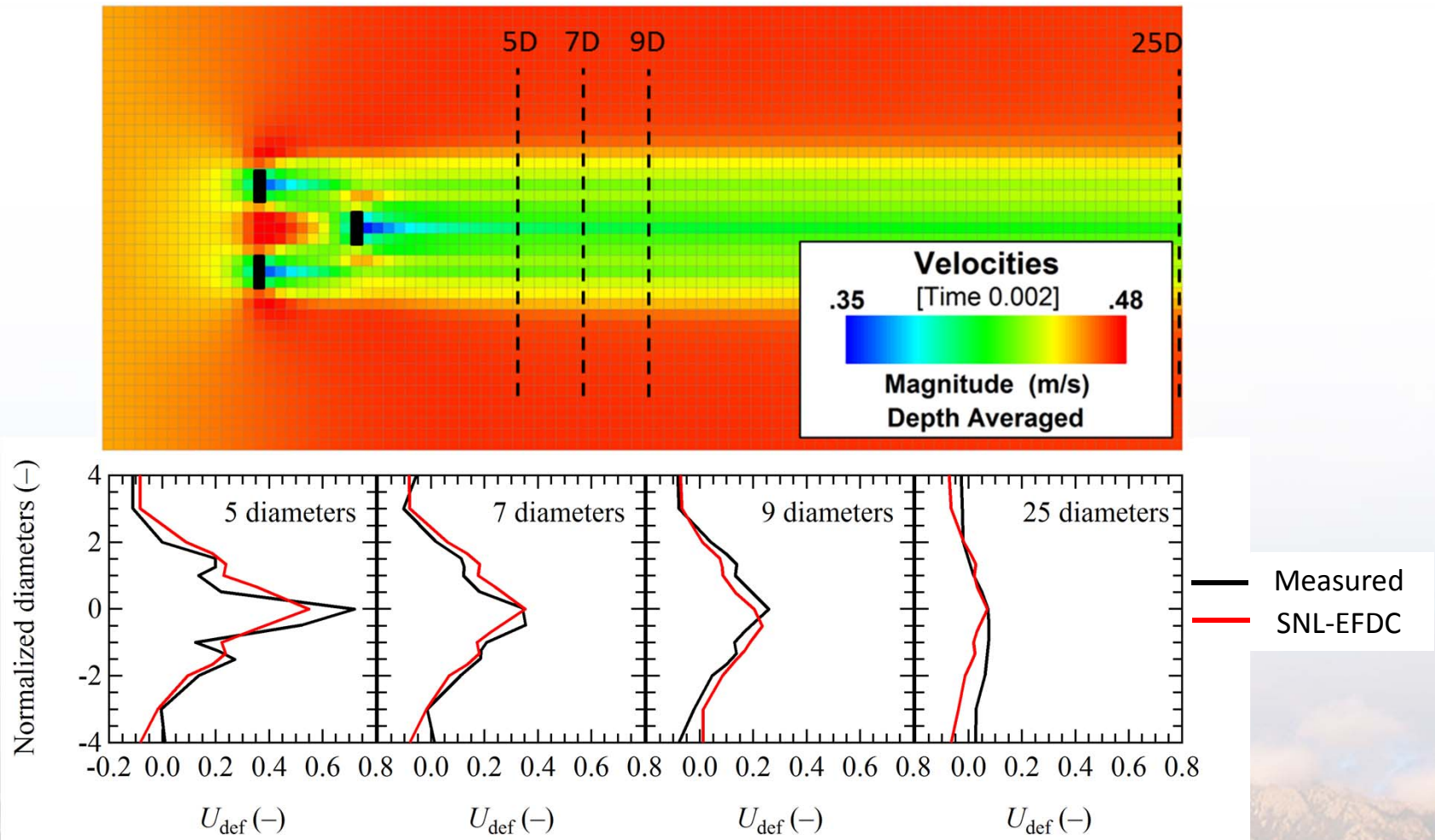
	SAFL	IFREMER	Average
β_p	0.05	0.08	0.065
β_d	2.9	2.1	2.5
$C_{\epsilon 4}$	9.8	10.4	10.1



SNL-EFDC: CEC Module Validation

Array

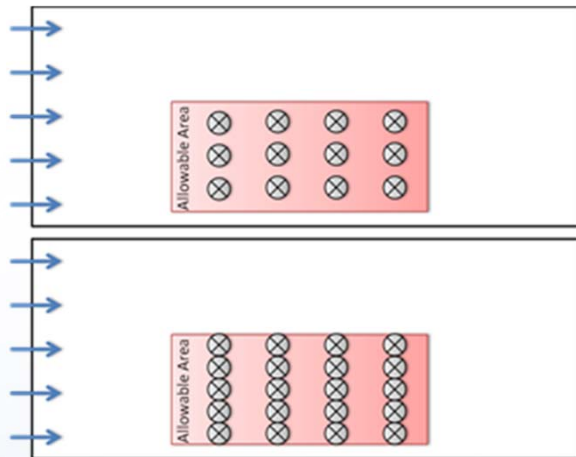
- 1-array data set (Meyers, 2012) using actuator disks
- Shear and wake interactions required increase in eddy diffusivity (relative to single device)



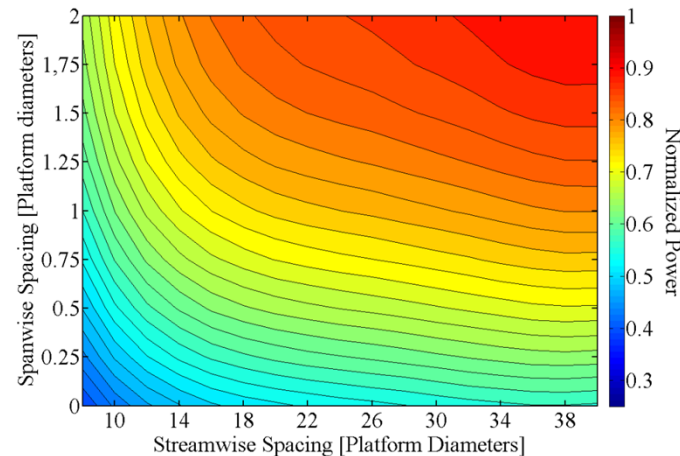
SNL-EFDC: Array Optimization

- 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 power generation, the flow field, & therefore the environment

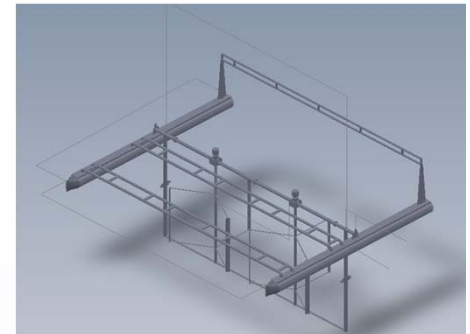
CEC Spacing Options



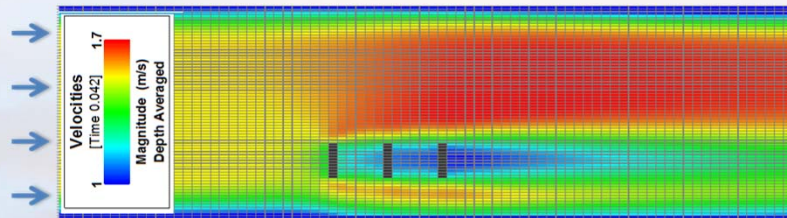
Array Power vs. Spacing



Surface Mounted CEC

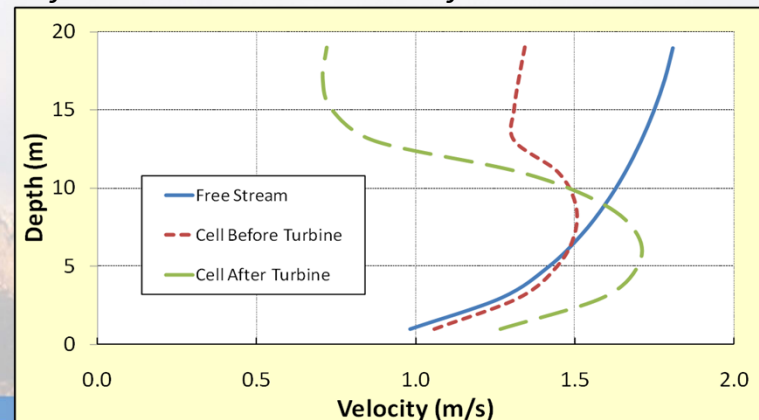


Un-Optimized CEC Array *flow accelerates around array*



Vertical Velocity Profiles

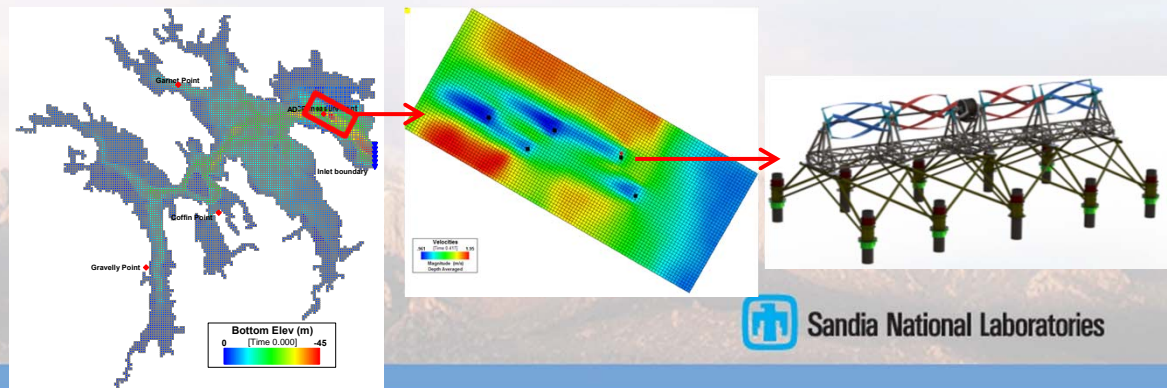
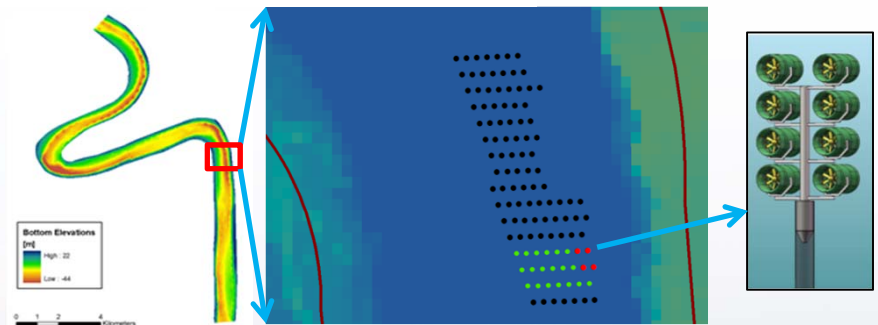
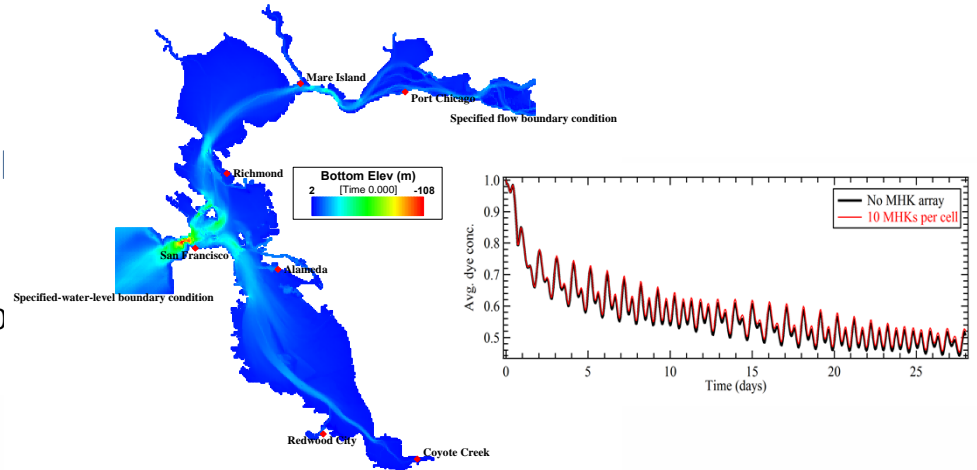
flow accelerates under surface mounted CECs



SNL-EFDC: Demonstrations

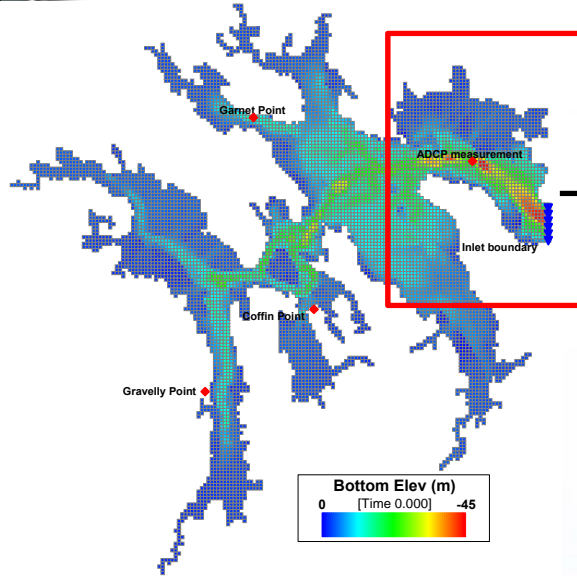
• SNL-EFDC Demonstration Activities

- 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**.
- Peer Review of SNL-EFDC, CEC module
 - ◆ By former Environmental Protection Agency **expert**
- SNL-EFDC technical transfer
 - ◆ Completed two training courses
 - ◆ 2 more courses for FY13 (Verdant, ORPC)

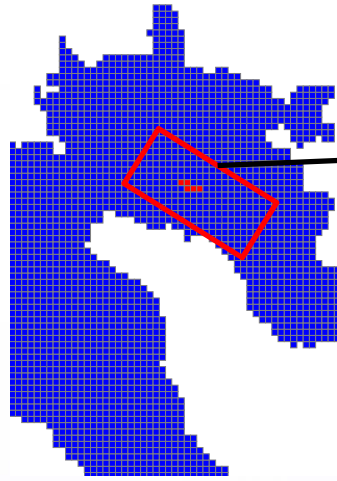


SNL-EFDC: Demonstration – Cobscook Bay

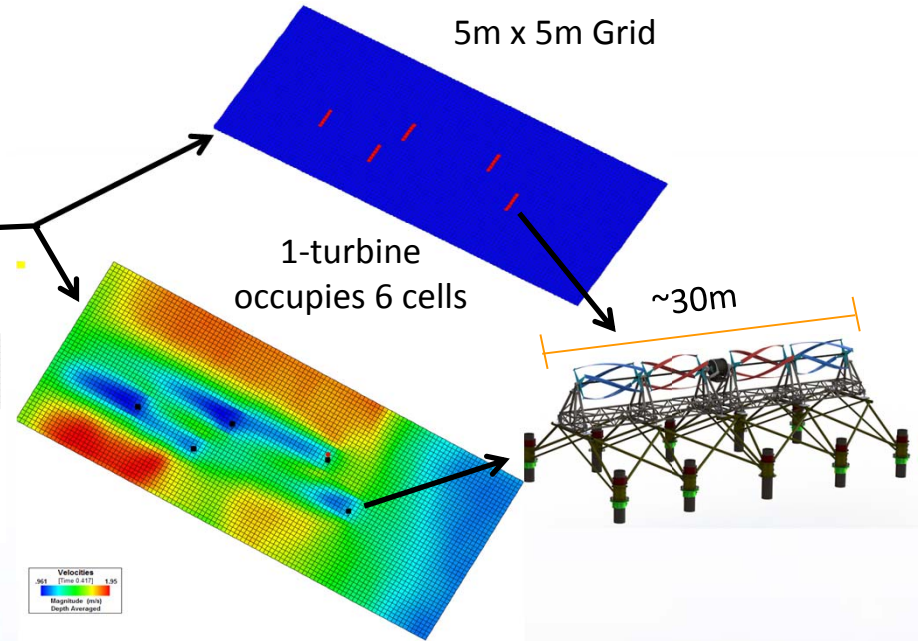
100m x 100m Grid



5 Turbines (1/cell)

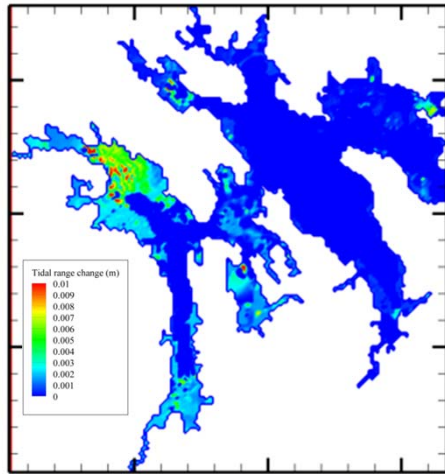


5m x 5m Grid

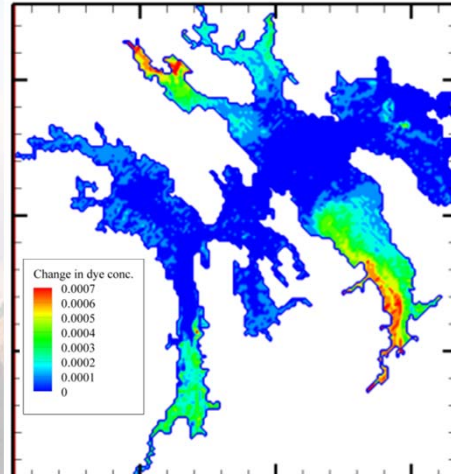


Effects of 5 Turbines is Negligible

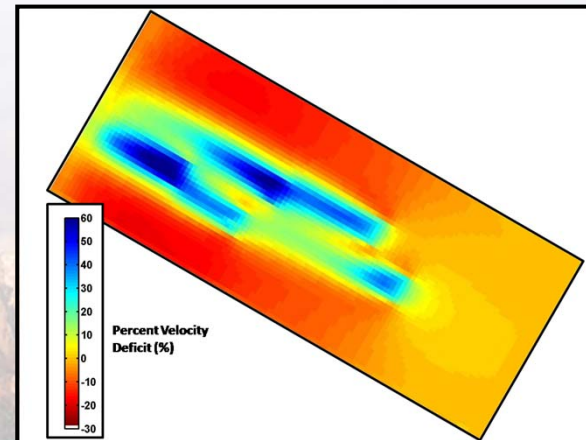
Change in Tidal Range



Change in Flushing

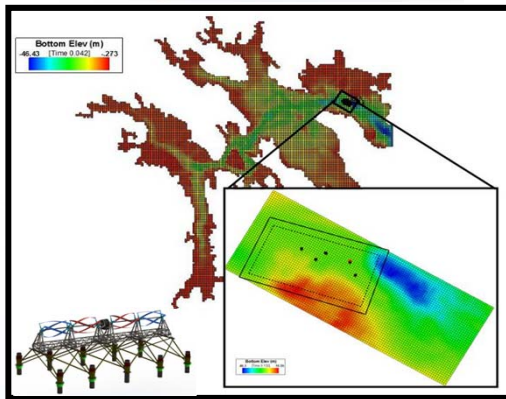


Velocity Change Map (without – with turbines)
Informs fish behavior and sediment transport modeling

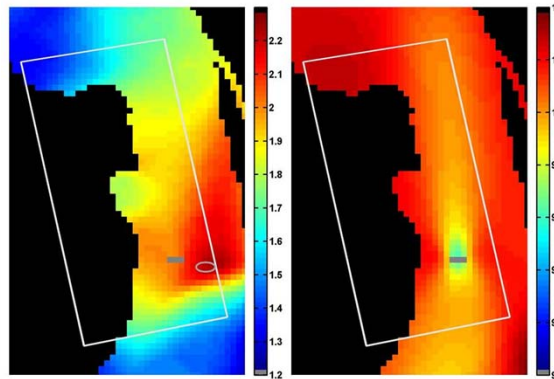


SNL-EFDC Optimization Framework

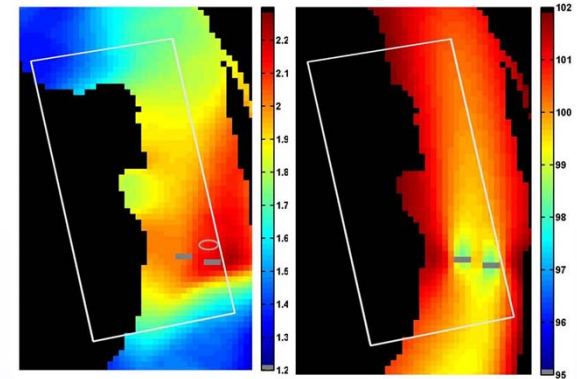
Application to Cobscook Bay



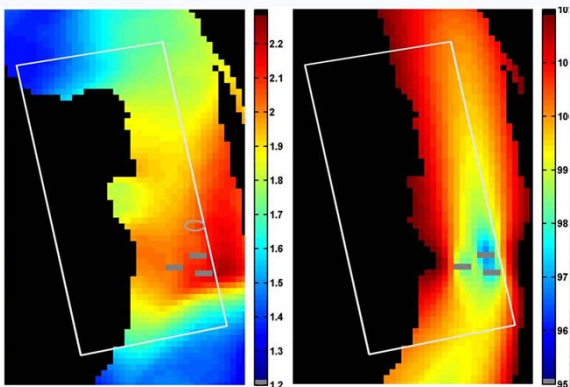
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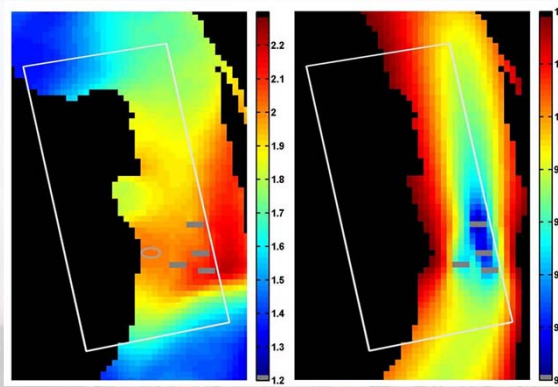
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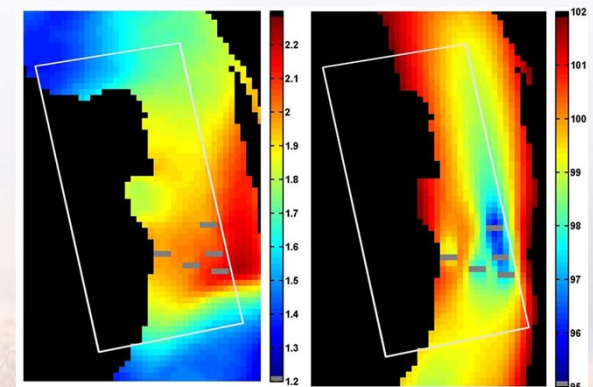
3



4



5





Additional Slides



Sandia National Laboratories

MHK Sediment Testing

Field Measurements & Data Analysis: Existing Capabilities

Sediment Transport Measurement:

■ Tools for measuring sediment transport

- Adjustable Shear Stress Erosion & Transport (ASSET) Flume (Patented, 2002): Simulates river environments (unidirectional flow)
- Sediment Erosion Actuated by Wave Oscillations & Linear Flow (SEAWOLF) Flume (patented, 2004): Simulates ocean/estuarine environments (combined wave and current action)

■ Unique Features:

- Mobile facility allows on-site measurements of erosion rate, critical shear stress, and transport mode
- Can apply large shear stresses (to simulate extreme storm events)
- Measure erosion with depth to account for sediment consolidation and stratification
- Can measure transport properties for non-cohesive and cohesive sediments

■ Both devices used in field and laboratory settings to quantify and understand erosion rate/transport mode

