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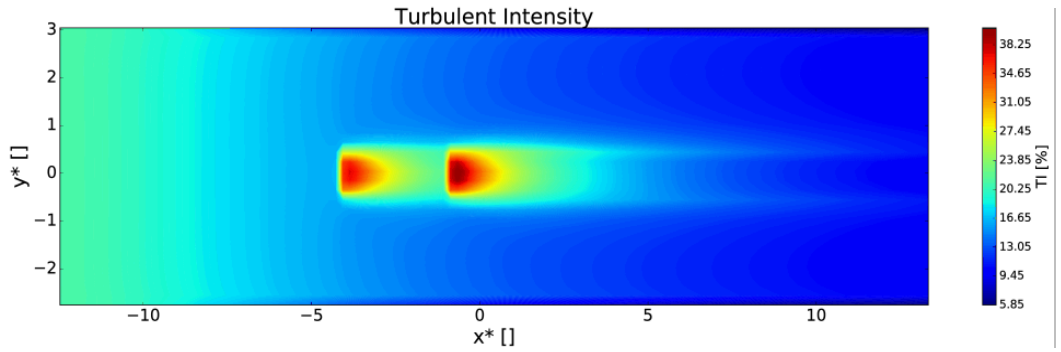

Simulating current-energy converters: SNL-EFDC model development, verification, and parameter estimation

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Motivation: Research for Marine Renewable Energy

- Resource assessment
- Environmental-effects assessment
- Array-layout optimization
- Licensing

New Modeling Tool to Support the Marine Hydrokinetic Energy Industry

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- Leverages decades of model development by using the US EPA's Environmental Fluid Dynamics Code (EFDC).
- Sandia has upgraded this code with improved water-quality, sediment-dynamics, and marine-hydrokinetic subroutines.
- In particular, this research outlines the development, application, and calibration of the current-energy-capture (CEC) module, which simulates the effects of these devices on the flow field (i.e., accurately represents their wake characteristics).

New Current-Energy Capture Module

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- Estimate the amount of energy extracted from the flow.
- Represent CEC wakes and their recovery accurately.
- Simplified 2D model compares favorably to an analytical solution.
- Turbulence parameters have been estimated through calibration to flume experiments.

Current Energy Capture

- CEC effects manifest as:
  - Decreased momentum
  - Increased turbulent kinetic energy, k
  - Increased turbulence length scale, ℓ
- Sinks and sources are added to the appropriate momentum and k-ℓ turbulence transport equations

Momentum Sink

$$P_{\mathrm{CEC}} = \frac{1}{2} C_T' A \rho U^3$$

$$S_Q = -\frac{1}{2} C_T' A U^2$$

$$C_T' = 4 \frac{1 - \sqrt{1 - C_T}}{1 + \sqrt{1 - C_T}}$$

Power Potential in a Channel

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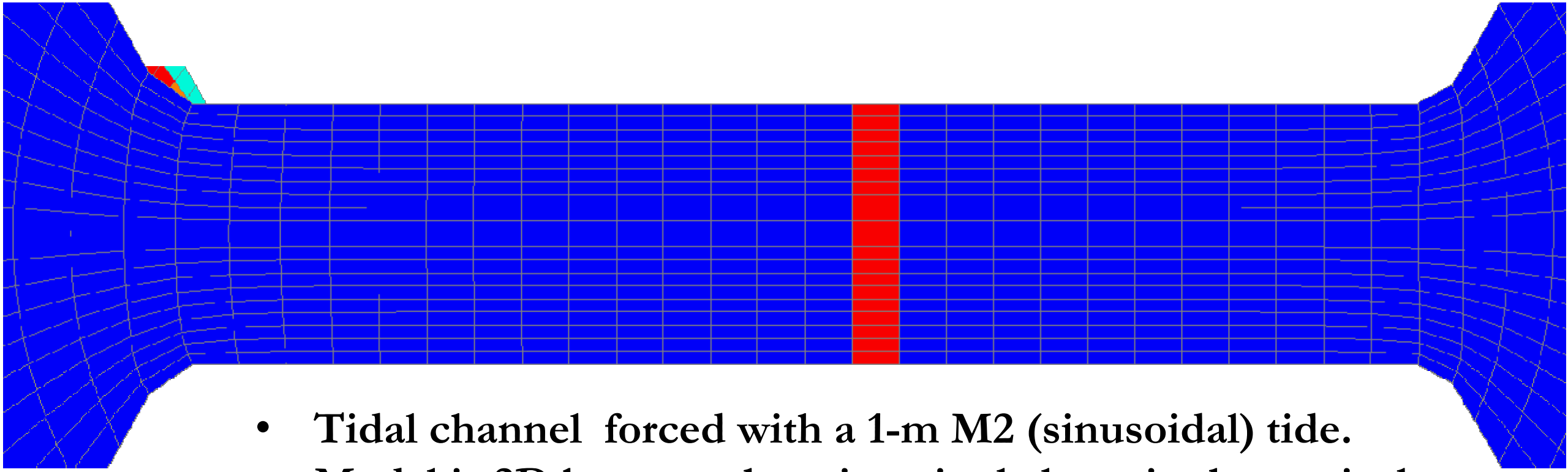
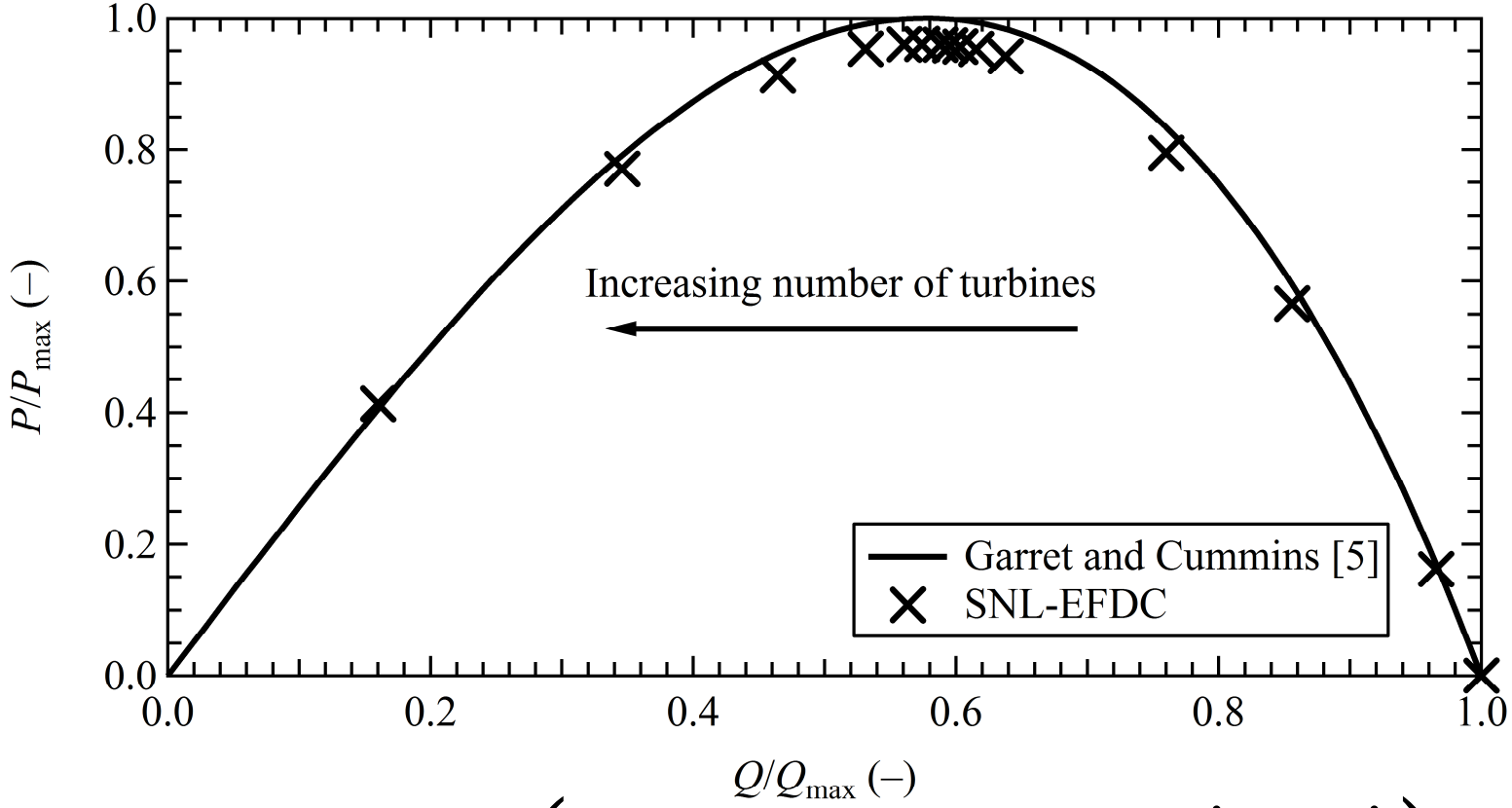


- Tidal channel forced with a 1-m M2 (sinusoidal) tide.
- Model is 2D because there is a single layer in the vertical.
- A “tidal fence” is installed across the channel throat.

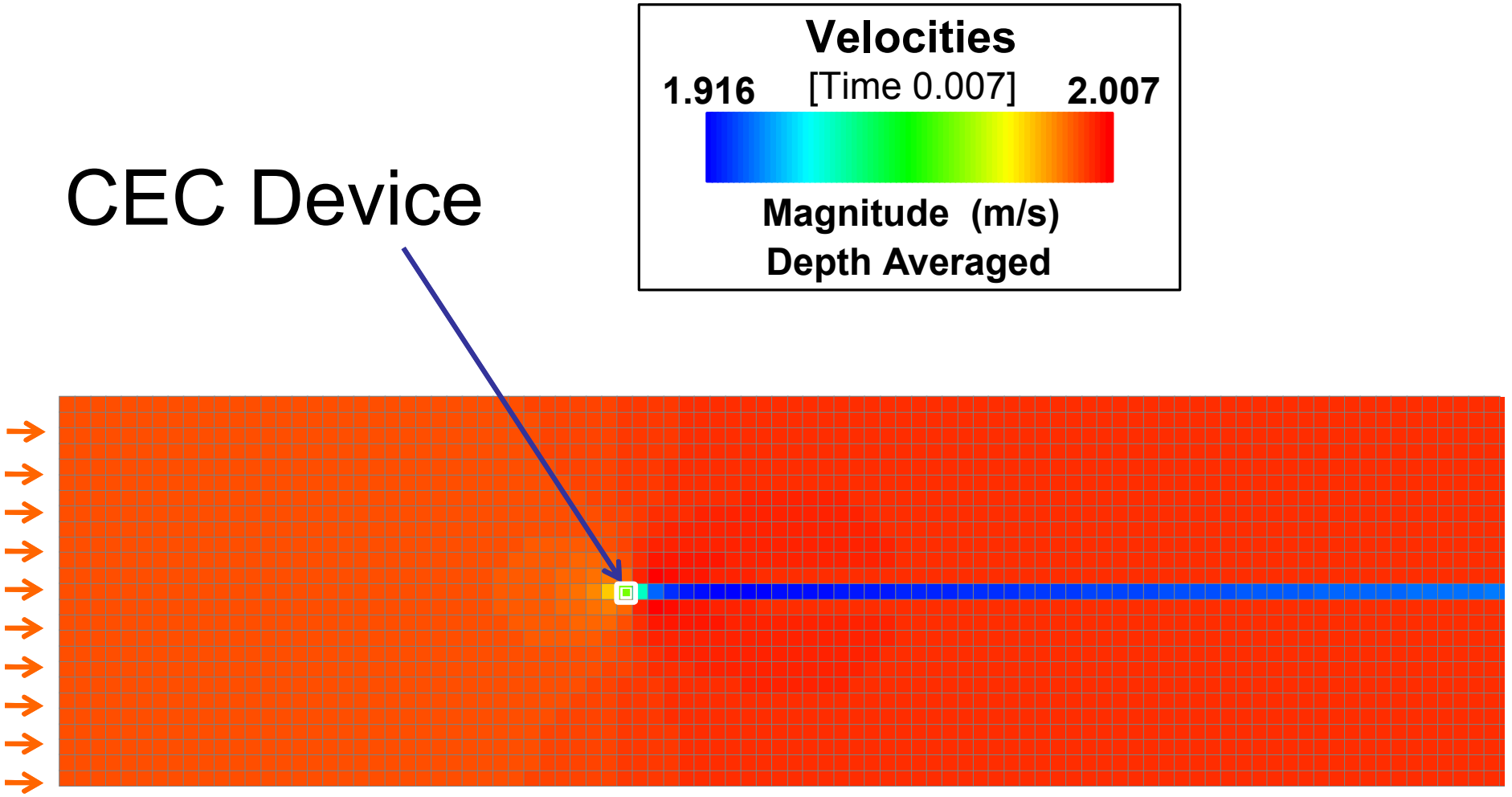
Verification against an Analytical Solution



$$P = \rho Q\left(g\zeta - \alpha Q|Q|\right)$$

Garrett, C. and P. Cummins (2005), The power potential of tidal currents in channels, *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 461, 2563-2572.

Single-Device Model – Momentum Sink Only



Overly persistent velocity deficit

k-ℓ Modifications

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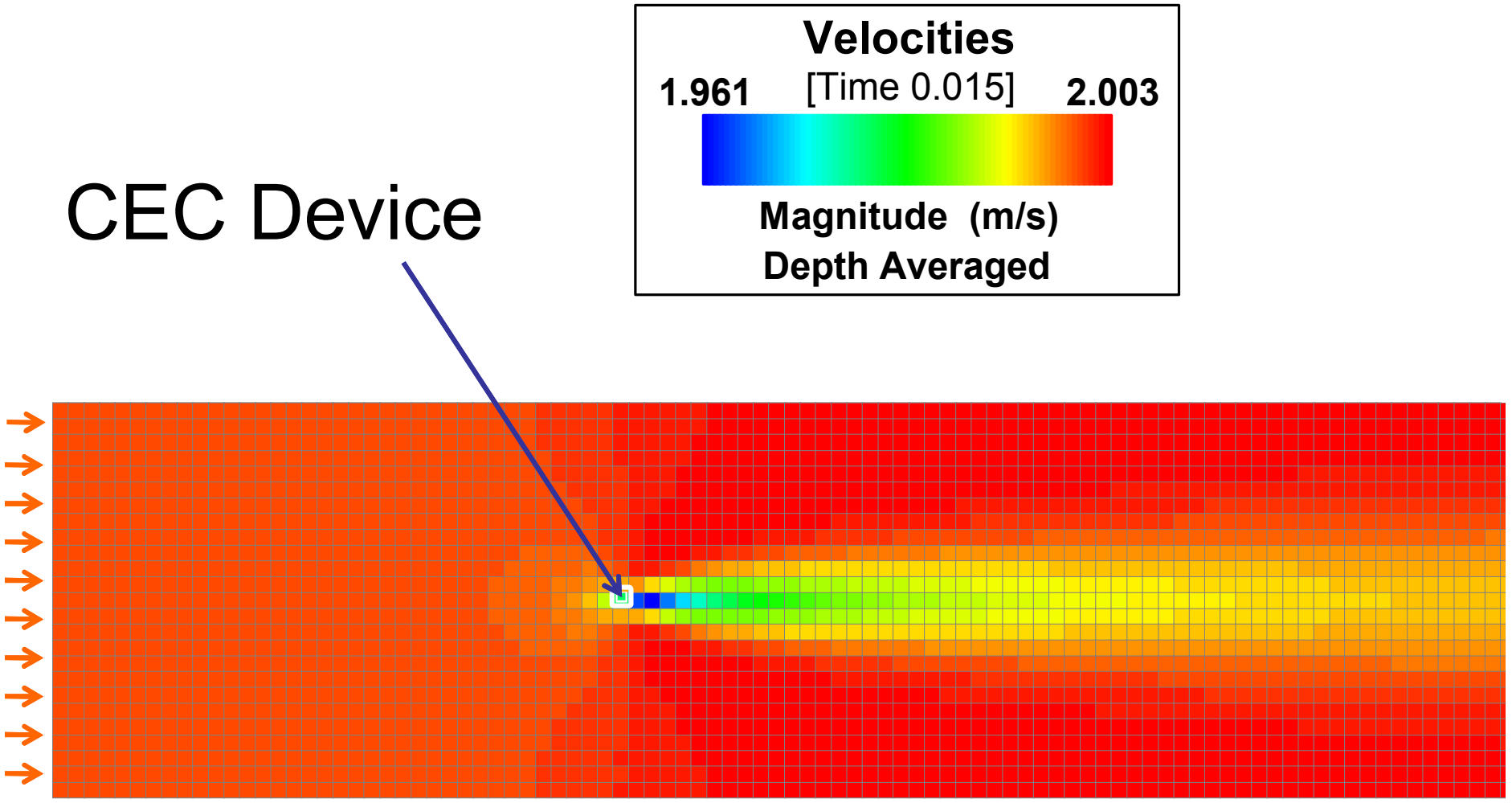
Empirical constants
(identified through calibration)

$$S_k = \frac{1}{2} C_T' A \left(\beta_p U^3 - \beta_d U k \right)$$

$$S_\ell = C_{\ell 4} \ell S_k$$

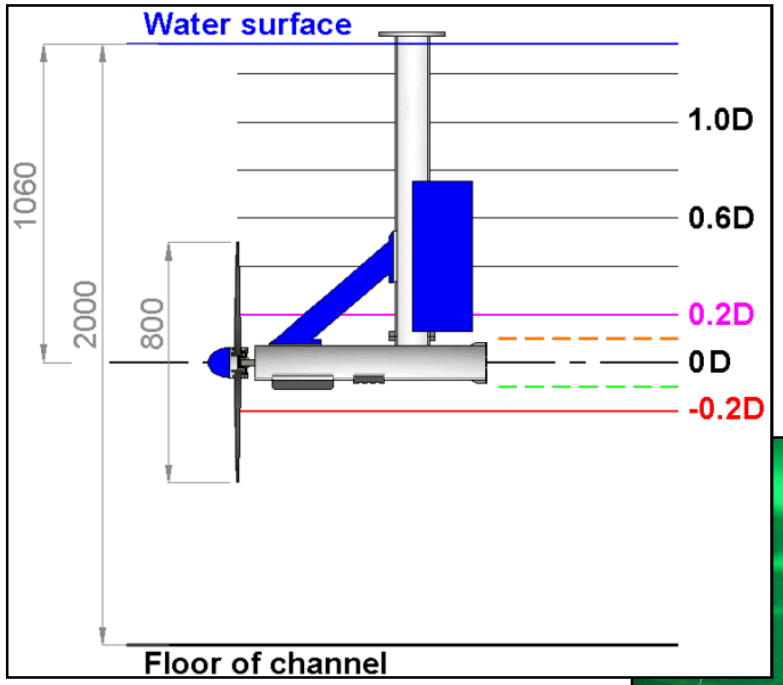
Katul, G. G., L. Mahrt, D. Poggi, and C. Sanz (2004), One- and two-equation models for canopy turbulence, *Boundary-Layer Meteorology*, 113, 81-109.

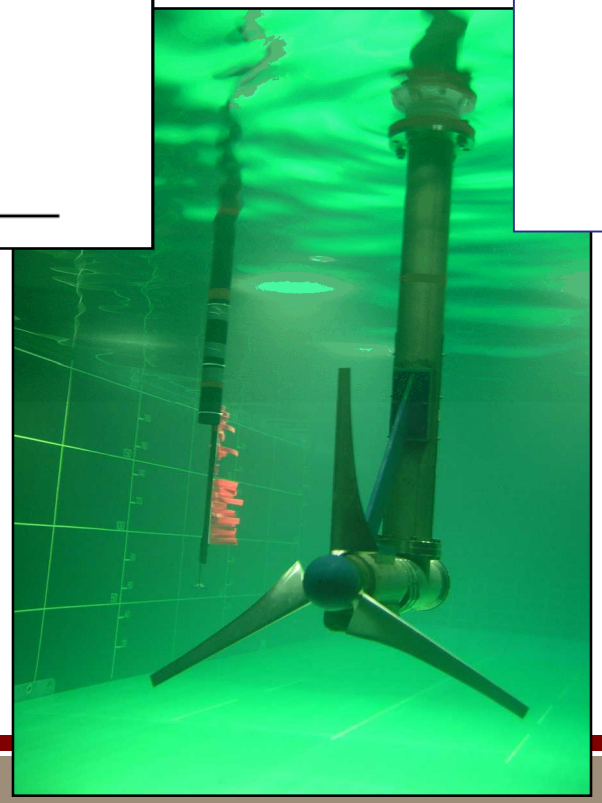
Single-Device Model – k-ℓ Sources Included



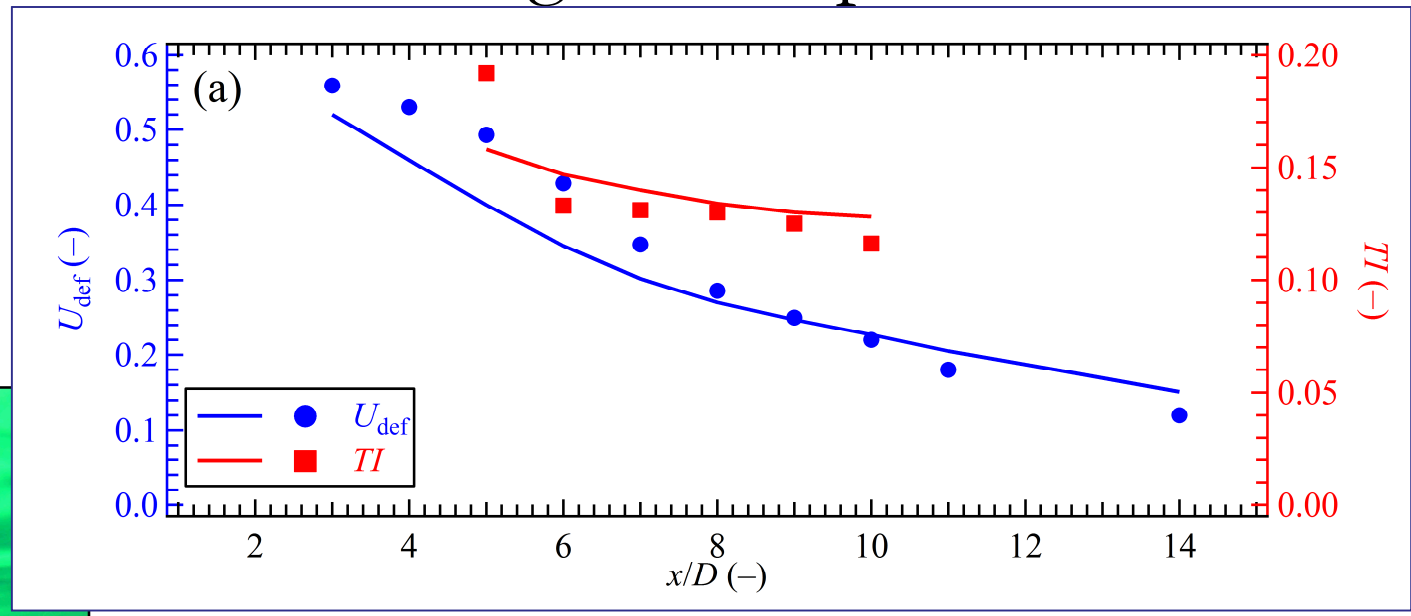
Realistic fluid energy loss/wake behavior

Model Verification





Longitudinal profiles



Parameter	Value
β_p	0.96
β_d	1.38
$C_{\varepsilon 4}$	3.87

Ongoing Research Efforts

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- Department of Energy continues to support “CEC-friendly” model development:
  - SNL-Delft3D-CEC: Simulate the effects of current-energy converters on flow
    - Structured-grid version is available
    - Flexible-mesh version to be released soon
  - SNL-SWAN: Simulate the effects of wave-energy converters on wave fields (SNL-SWAN is easily integrated into Delft3D)
- All software and codes are open source and freely available at:
  - http://energy.sandia.gov/energy/renewable-energy/water-power/
  - http://energy.sandia.gov/snl-delft3d-cec/
  - http://energy.sandia.gov/snl-swan/
  - Training available as:
    - Manuals
    - Tutorials
    - Short courses