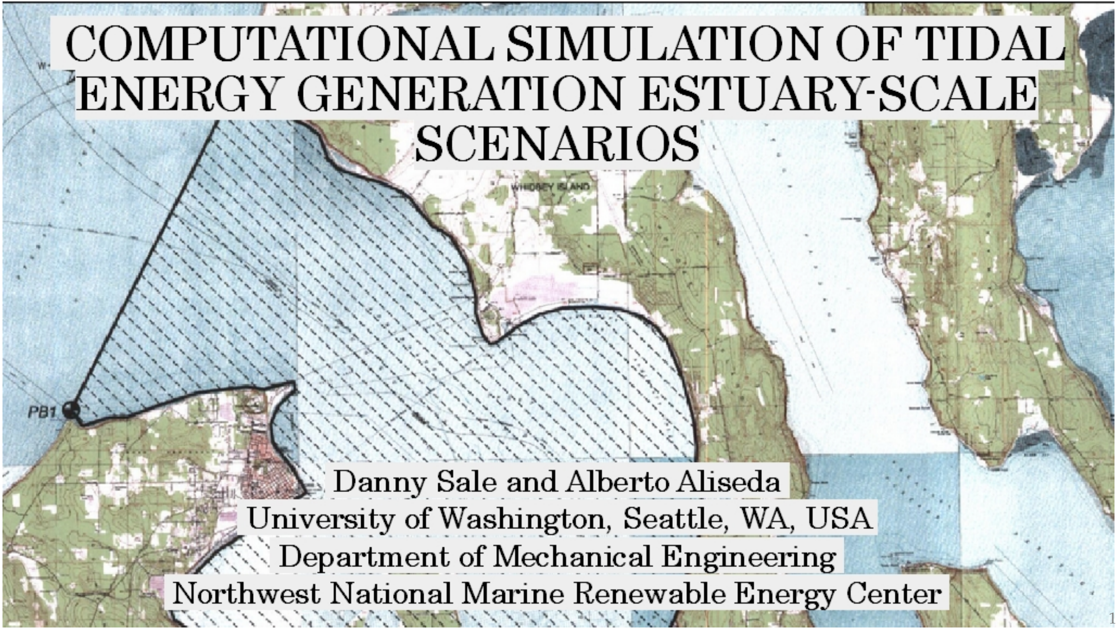
COMPUTATIONAL SIMULATION OF TIDAL ENERGY GENERATION ESTUARY-SCALE SCENARIOS



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Marine Hydro-Kinetic (MHK) Energy

Motivating Questions:

- What is the interaction of a tidal power plant with large-scale estuary dynamics? Are possible changes measurable, and under what conditions?

- Is it possible to balance energy capture with favorable control of estuary flow dynamics?

- What are the right computational tools to study efficiently the contrasting spatio-temporal scales? Are turbulence closure models adequate?

Overview of Estuary-scale case studies

Idealized Tidal Channel

- Approximate size of Admiralty Inlet
  - Compare 2 farm layouts and effect upon lengths larger than turbine farm

Admiralty Inlet

- Shallower site compared to PUD project
  - Study effect of complex bathymetry

Nested in Ocean Circulation Model

- A nested model around Admiralty Headland
  - ROMS provides boundary conditions to nested domain

Methods in Computational Fluid Dynamics (CFD)

STAR-CCM+

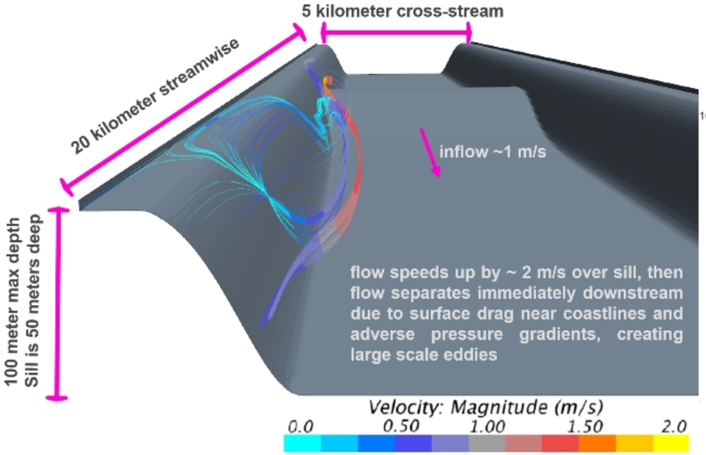
- 3D Reynolds Averaged Navier Stokes, **steady** (RANS)
- Turbine Model via "**Virtual Disk Method**", variant on "**Actuator Disk**"
- Turbulence models: SST K-Omega, **Elliptic-Blending Realizable K-Epsilon**, Reynolds Stress Transport
- Meshing: polyhedral meshes with **Adaptive Mesh Refinement (AMR)** upon the turbulent kinetic energy (TKE) generation
- High-Performance-Computing **(HPC)**: minimum of **3 compute nodes**, **~3 to 10 million cells**, **~200 GiB RAM**, solve time **~2 hours**

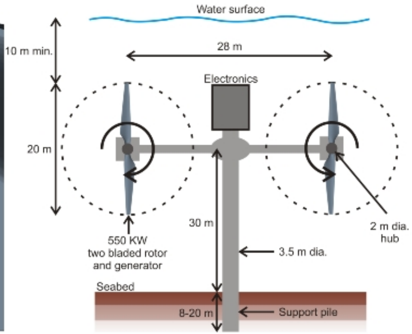
Regional Ocean Modeling System (ROMS)

- **3D RANS** formulation, **Generic Length Scale (GLS)** turbulence closure, **Bathymetry** at 183 to 9 meter resolution, **mesh dx**~20 meters **dz**~5 meters
- **Estuary Scale dynamics**: tracks temperature, salinity, nutrients.
- **1-way coupling** to STAR-CCM+ via **nested domain**
- **Matlab** for data exchange and **mapping boundary conditions** to STAR-CCM+

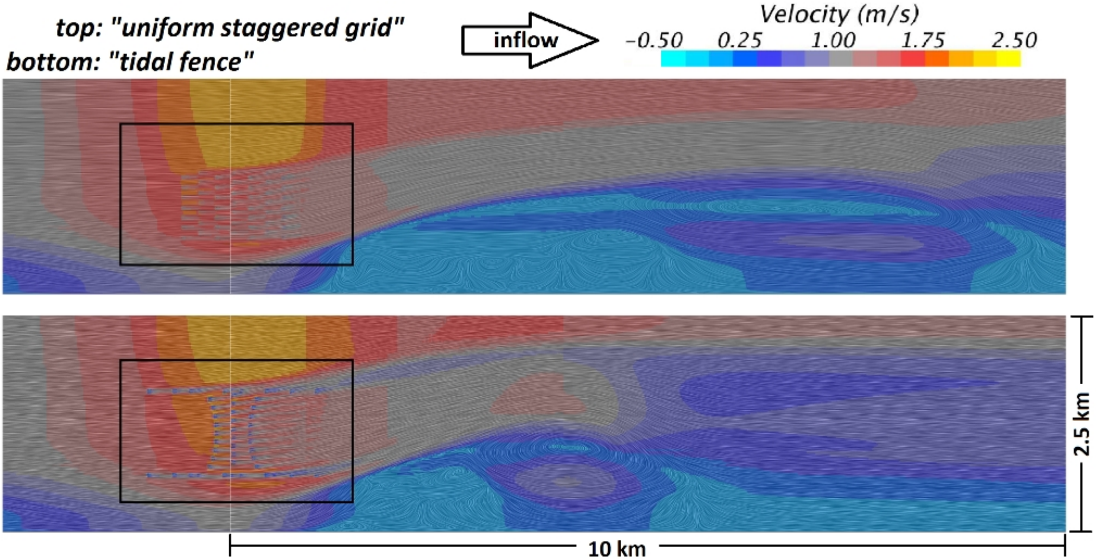
Tidal Channel

An idealized model of a narrow tidal channel with a sill, representative of the conditions in Admiralty Inlet, can reproduce similar flow features. This provides a testbed for studying different layouts of tidal power plants. A hypothetical power plant with 49 turbines (total 53.9 MegaWatt capacity) is tested in two layouts: a uniform staggered grid and a "tidal fence".

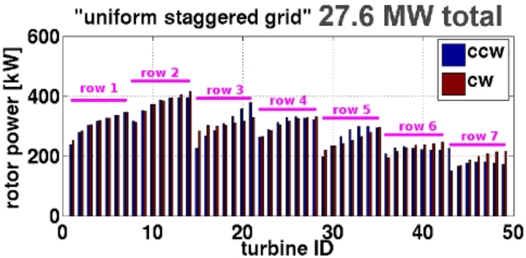


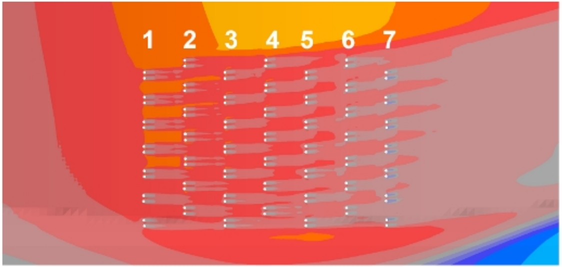


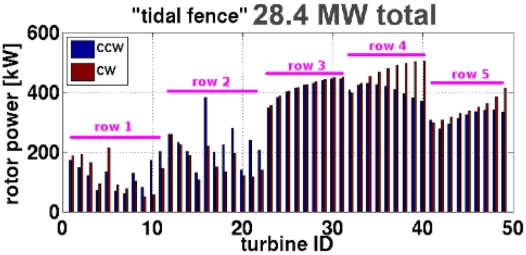
Tidal Channel

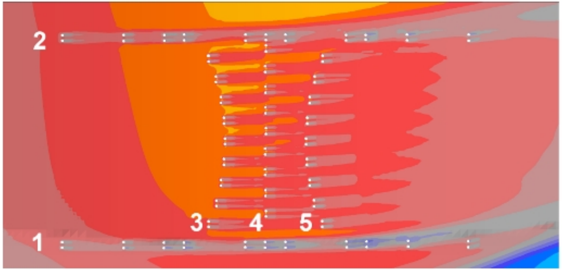


Tidal Channel

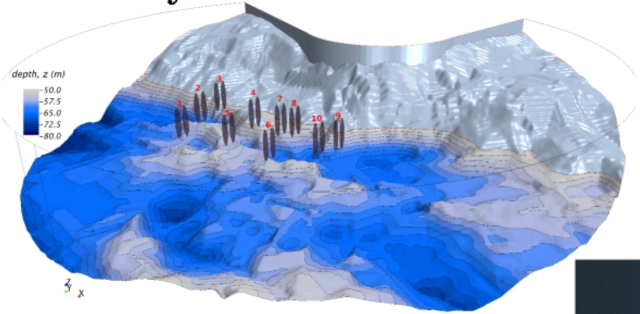




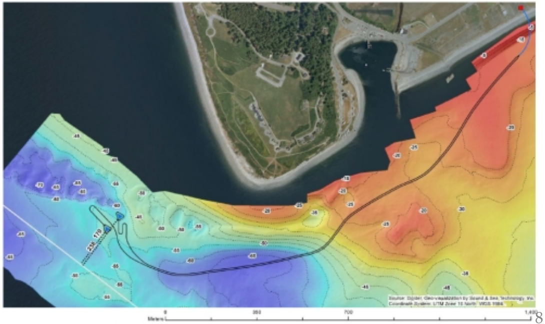




Admiralty Inlet



A hypothetical 11 MegaWatt tidal power plant composed of 10 DOE RM1 turbines is deployed in Admiralty Inlet. To study the effect of complex bathymetry the turbines are deployed in a site with shallower water compared to the Snohomish Public Utility project.



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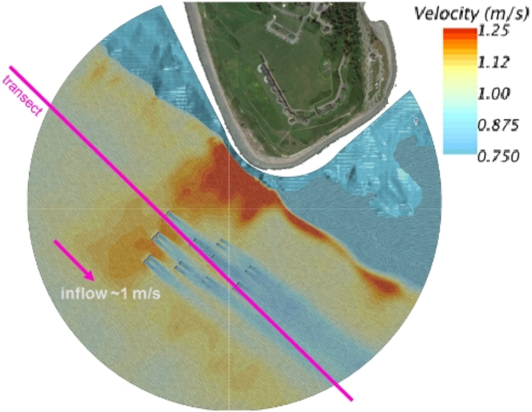
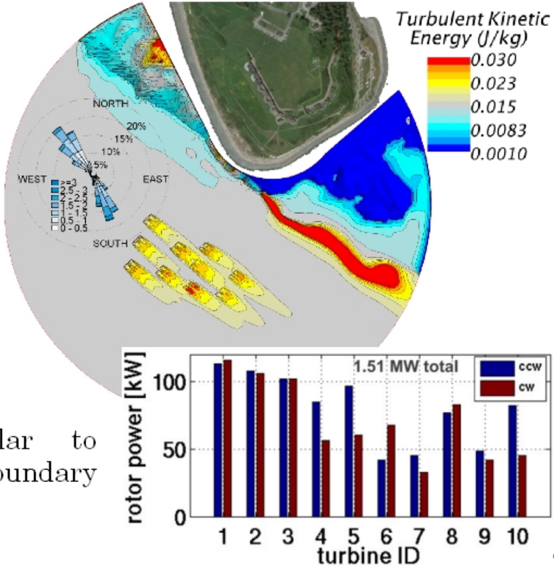
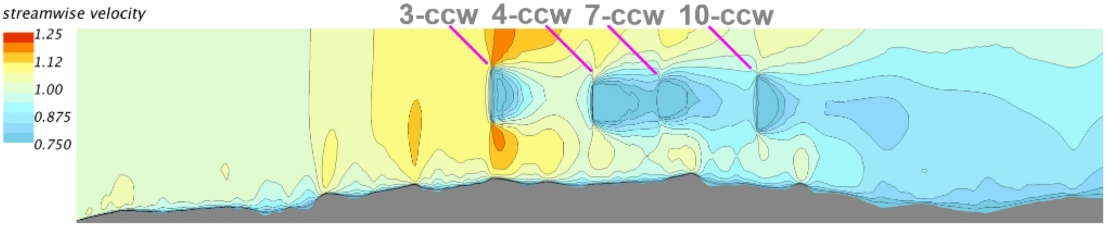




Boundary conditions applied similar to logarithmic law for Atmospheric Boundary Layers

Admiralty Inlet

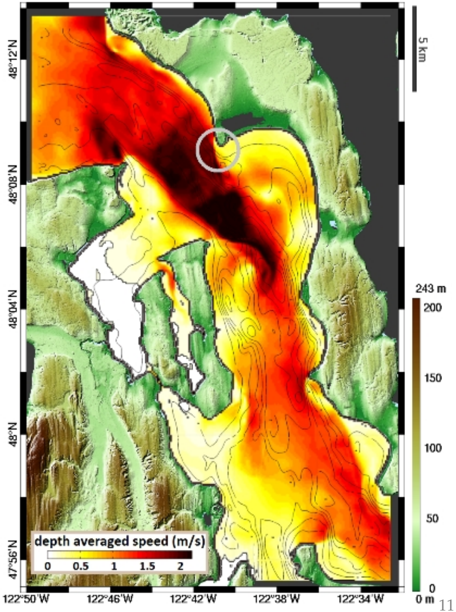
In these transects, notice the speedups caused by bathymetric features and interaction of wakes upon seabed and sea surface. The velocity field and turbulent kinetic energy suggest how proximity to headlands, sills and basins could affect turbine performance & fatigue.



Nesting in Regional Ocean Modeling System (ROMS)

Using the ROMS dataset developed by "D. Sutherland and P. MacCready (2011) "A Model Study of the Salish Sea Estuarine Circulation" to serve as "parent domain" for the "nested domain"

- bathymetry resolution is 183 to 9 meters, forecast for ~2 weeks, "30 minute" snapshots were saved
- STAR-CCM+ has sub-meter resolution, and more appropriate turbulence models for wake flows
- Initialize by mapping ROMS solution (and Sea-Spider observations) to STAR-CCM+ domain
- 1-way coupling is planned, and developing a "point-and-click" interface to automate nested meshing/simulation "anywhere" in ROMS domain



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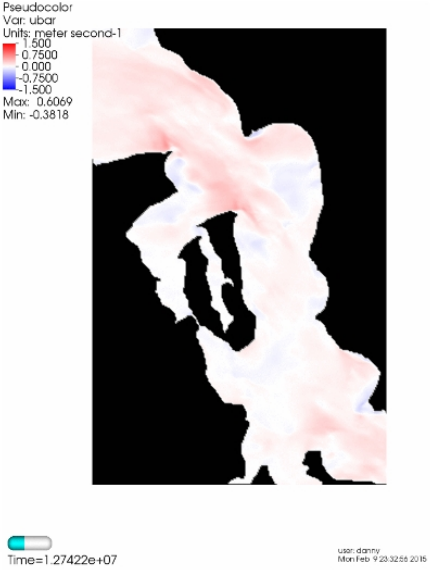
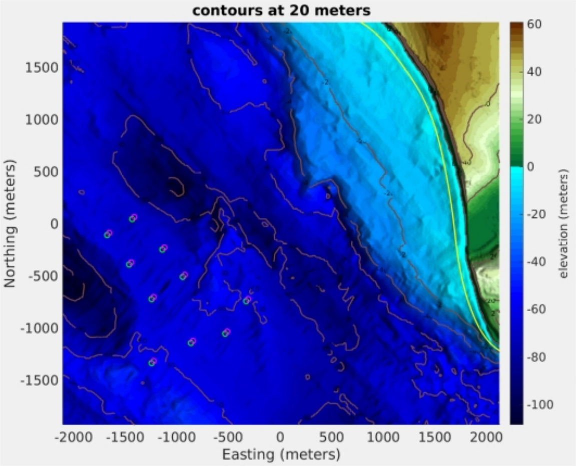
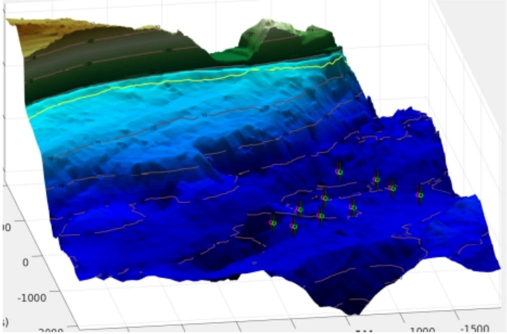


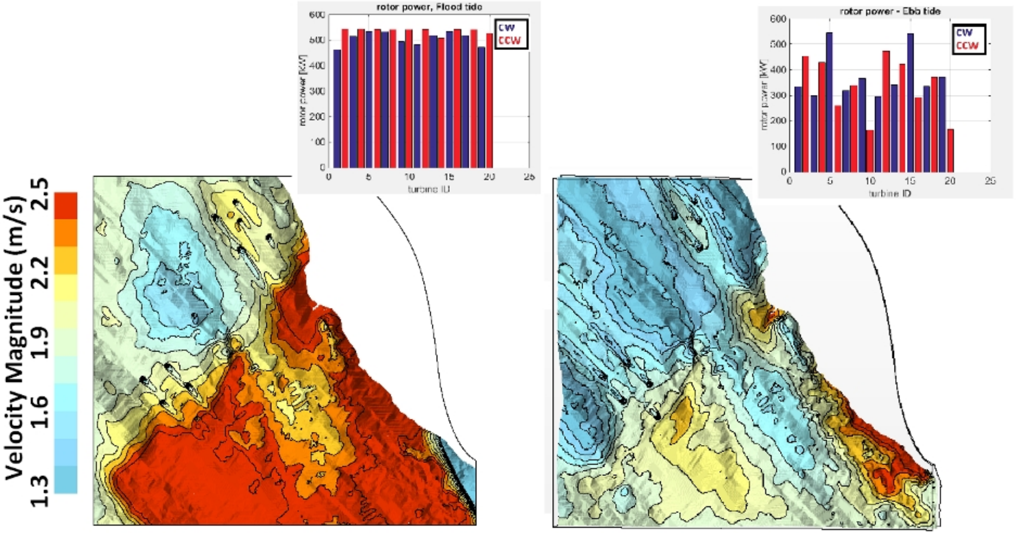
Nesting in Ocean (Regional) Circulation Model

Estuary scale flow features are simulated with the Regional Ocean Modeling System (ROMS) code. ROMS simulations provide boundary conditions to the nested STAR-CCM+ meso-scale simulations.





compare flood and ebb tides



flood tide

ebb tide

findings from Estuary Scale scenarios

- "dual rotor" turbine design will experience **large asymmetry on rotors**, possibly exciting multiple failure modes
- Layout of MHK turbine farms did not strongly effect total power generation, but exhibit notable differences in the downstream "far-field" flow ... plenty of "design space" to explore with an **"optimum" somewhere between the two extremes**
- Bathymetric features can produce highly energetic "turbulent structures" compared to the turbine wakes, need to run several key points in the tidal cycle (wind-rose) to evaluate extreme conditions
- Concerns regarding the "far-field": *possible* large up-wellings may "move the food around", redirection of currents, erosion, change to estuary mixing

Future work:

Computational Fluids:

- "grid dependence" study is ongoing, trying to automate high-quality mesh generation suitable for the "adjoint flow solver" to run accurately.

Coupling RANS models within the ROMS:

- Post-processing of ROMS is going well, ongoing "Matlab-ing" for mapping mesh/turbulence models and B.C.s
- We now have supercomputer ("Hyak"), so can run the "full wind rose" scenarios, and incorporate optimization into farm layout/control

Thank you! Questions? Suggestions?