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Evaluating the tidal energy resource for smooth power output and grid integration in the United States

October 29, 2019

Danielle Preziuso
Associate Energy Scientist

Gabriel García Medina, Rebecca O'Neil, Zhaoqing Yang

U.S. DEPARTMENT OF ENERGY BATTELLE

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PNNL-SA-148706

Overview

- Background – Tides
- Why is this important?
- Context
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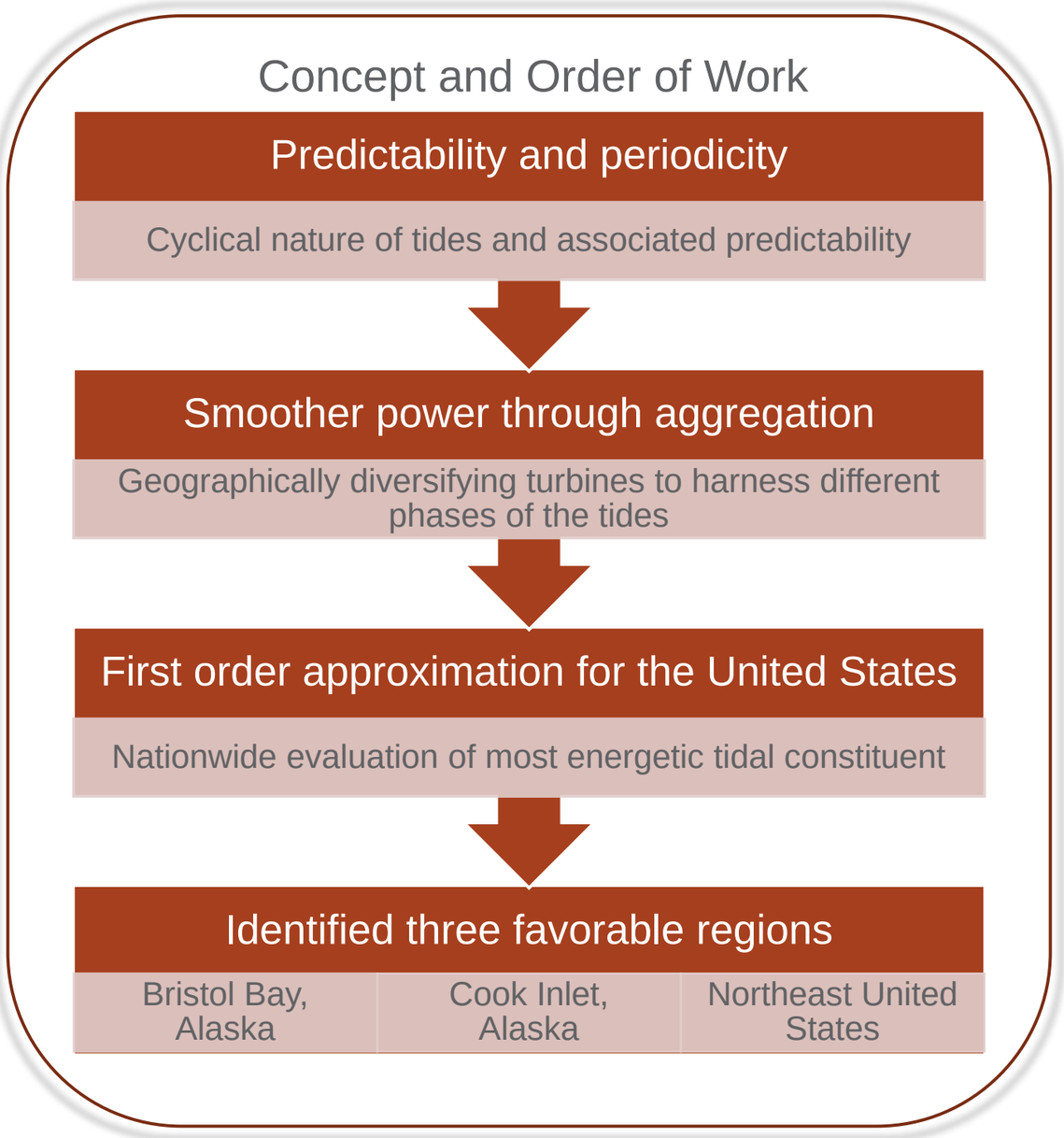
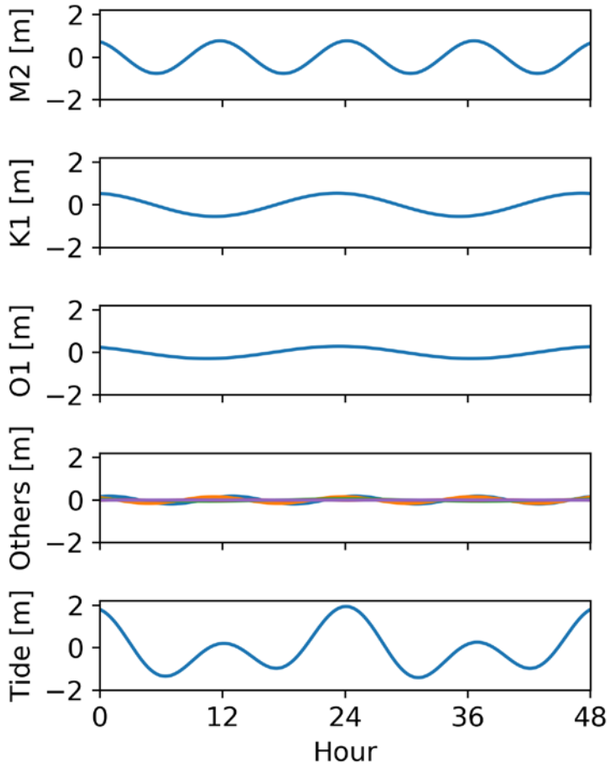
- Results
- Summary
- Future Work

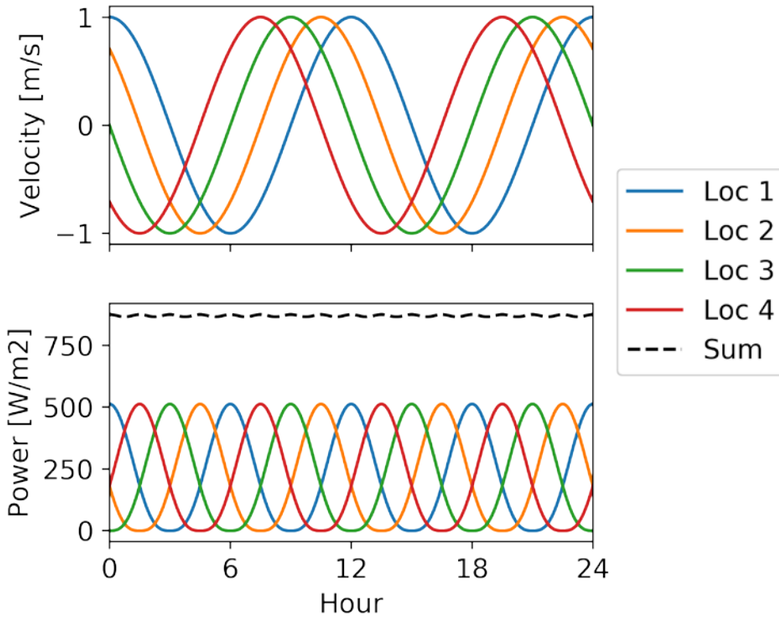


Background - Tides

- Tides can be represented by the sum of sine waves
  - One per tidal constituent, specified by amplitude, period, and phase
- In theory, the sum of opposite fluctuating resources can produce smoother power



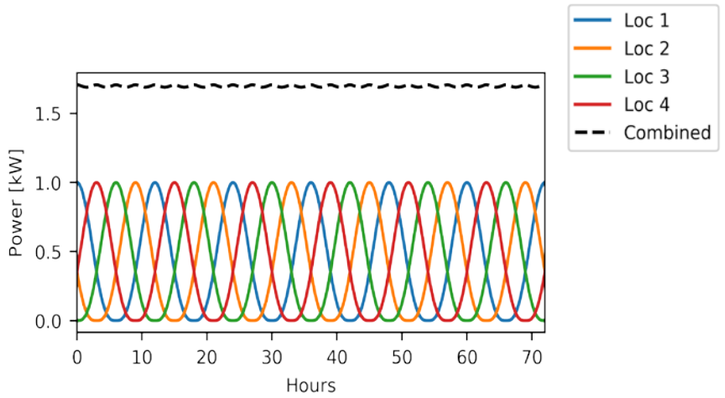
Surface Tidal Constituents



Theoretical Power Output

Why is this important?

Amount of renewables on the grid continues to increase



Smooth power output is of fundamental importance to the grid

Unique benefit supplied to the grid compared to other renewables

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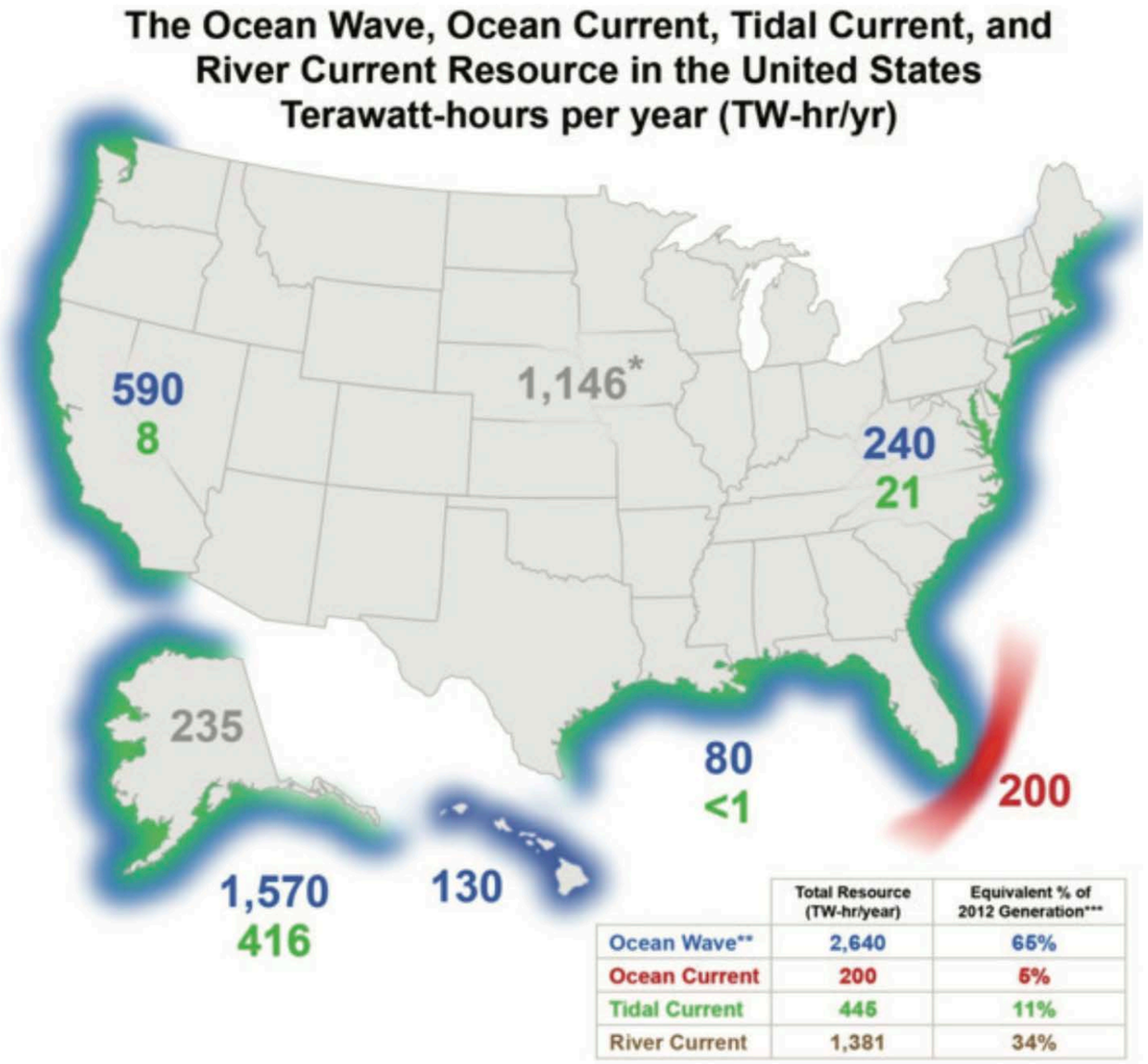
Context

- Work has been done to look at the extent of tidal resources in the United States
  - Not as much with the interface to the grid
- Some European countries have looked into phase diversity of tides for the purposes of baseload
  - United Kingdom, Ireland

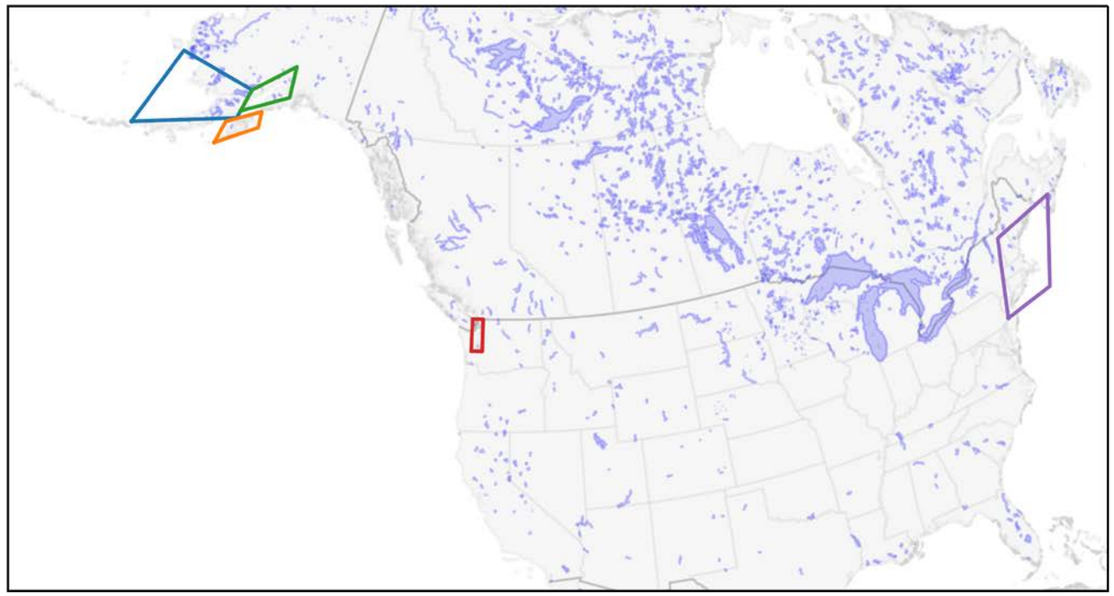


	Total Resource (TW-hr/year)	Equivalent % of 2012 Generation***
Ocean Wave**	2,640	65%
Ocean Current	200	5%
Tidal Current	445	11%
River Current	1,381	34%

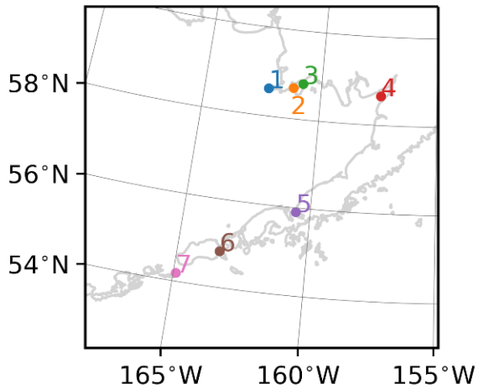
DOE (U.S. Department of Energy). 2015a. "Advancing Clean Electric Power Technologies: Technology Assessments." Chapter 4 in *Quadrennial Technology Review 2015.*

Analysis

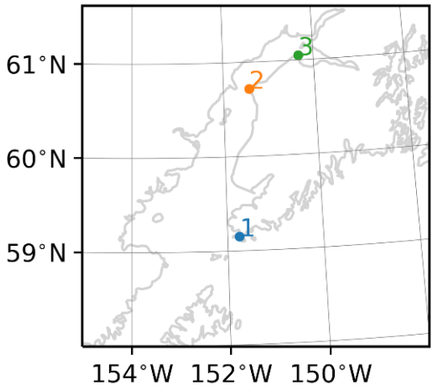
- Goal: Perform a first order analysis
  - Data: Haas et al. (2011)
    - ✓ Mainland U.S., the Pacific coast of Alaska, Puerto Rico, and the U.S. Virgin Islands
  - Estimate power output from the most energetic tidal constituent
  - Enabling assumptions:
    - ✓ Minimum water depth of 20m
    - ✓ Minimum tidal stream velocity of 50 cm/s
  - Identifying regions of interest
    - ✓ Selecting representative sites for cross correlation calculations
- Limitations:
  - Greater diversity might be achieved with more relaxed assumptions
  - Limited by the power profile generated by the most energetic constituent



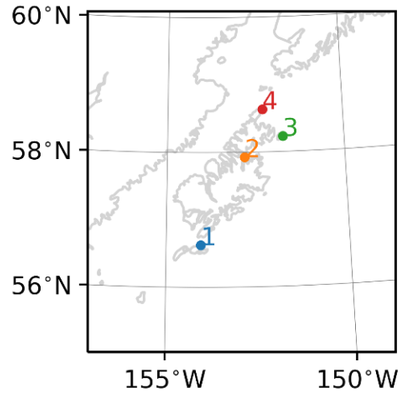
Identified Regions



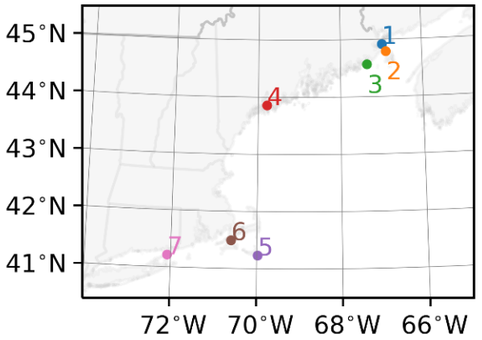
Bristol Bay, Alaska



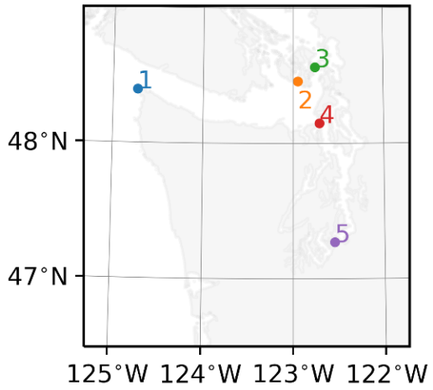
Cook Inlet, Alaska



Kodiak Island, Alaska

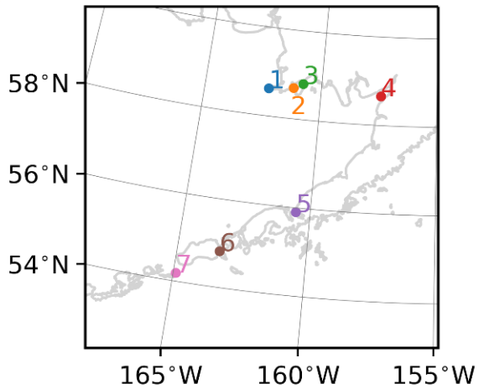


Northeast

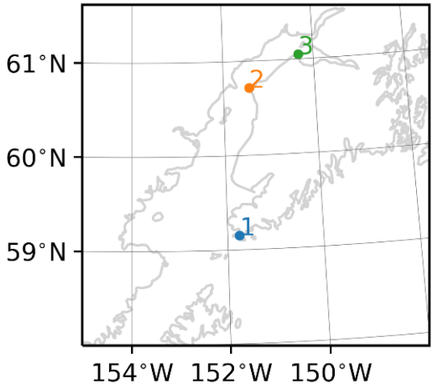


Salish Sea, Washington

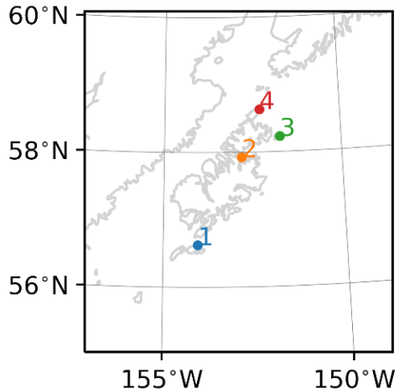
Identified Regions



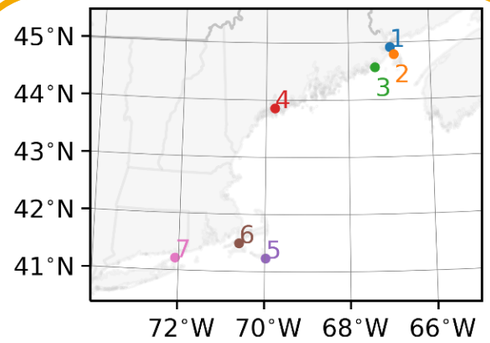
Bristol Bay, Alaska



Cook Inlet, Alaska



Kodiak Island, Alaska



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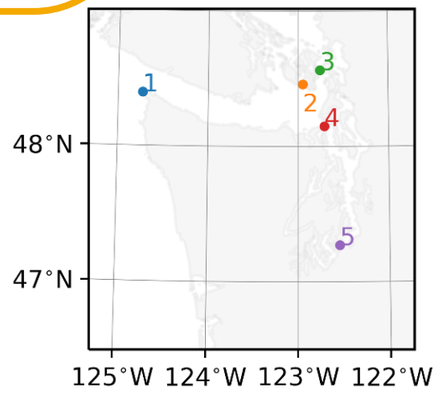
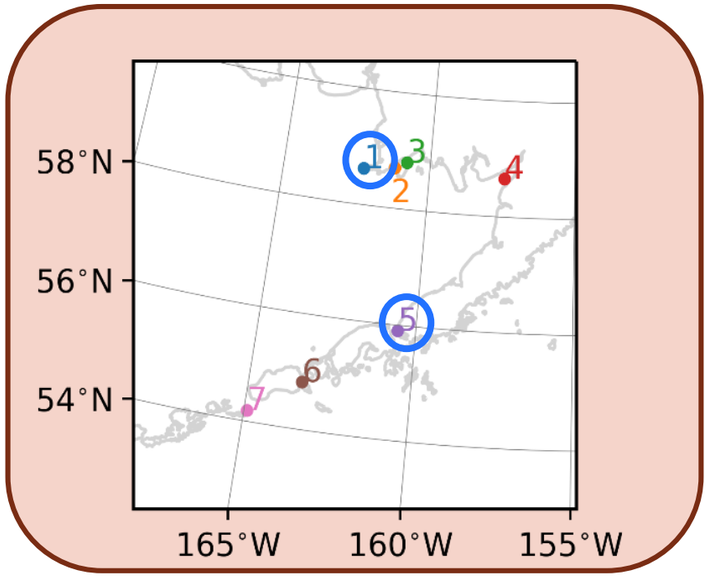


Salish Sea, Washington

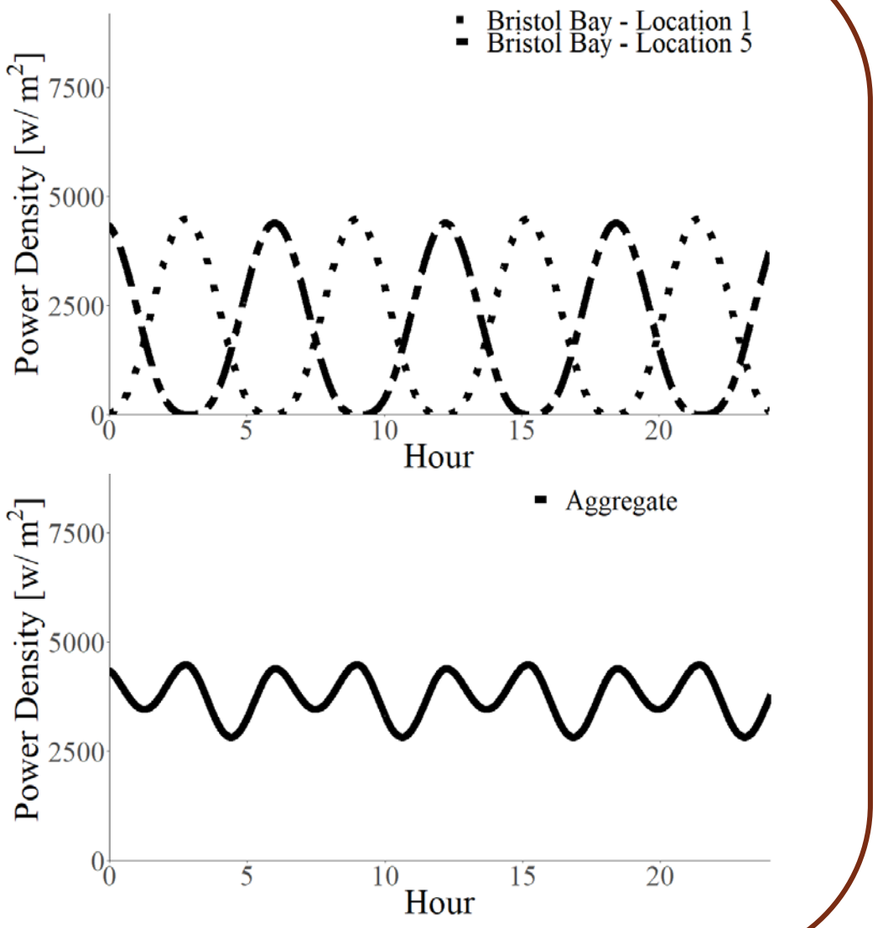
Bristol Bay, Alaska



Location

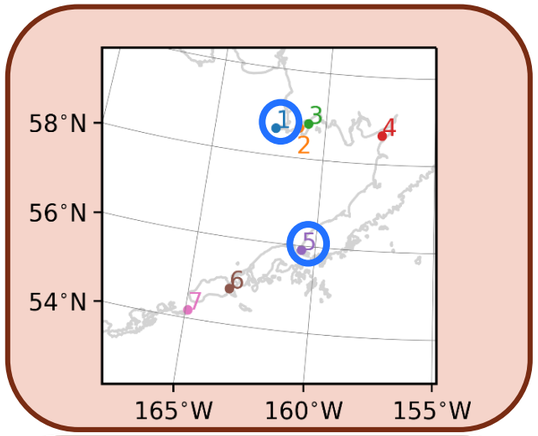
Location	1	2	3	4	5	6	7
1	1.00	0.90	-0.05	0.63	***-0.91***	-0.31	-0.07
2	0.90	1.00	0.32	0.27	***-0.79***	0.06	0.31
3	-0.05	0.32	1.00	***-0.70***	0.10	0.95	1.00
4	0.63	0.27	***-0.70***	1.00	***-0.72***	***-0.84***	***-0.71***
5	***-0.91***	***-0.79***	0.10	***-0.72***	1.00	0.37	0.12
6	-0.31	0.06	0.95	***-0.84***	0.37	1.00	0.95
7	-0.07	0.31	1.00	***-0.71***	0.12	0.95	1.00

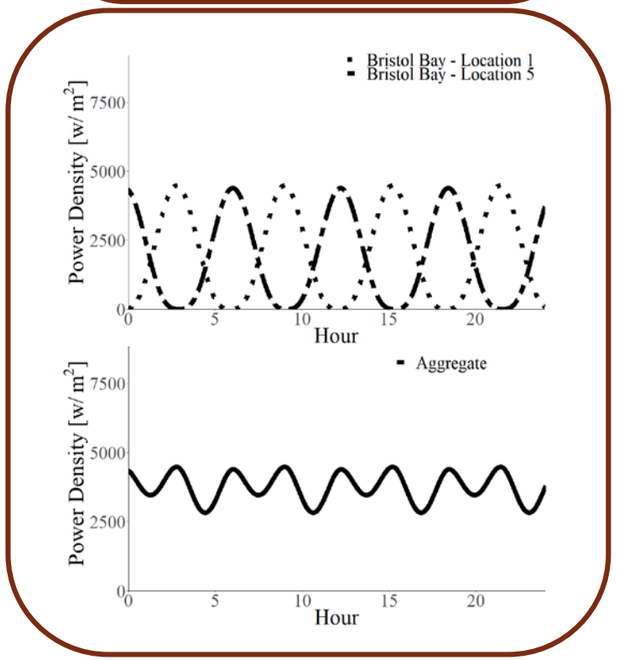
Cross Correlation Results



Power Density at Pair with Strongest Anti-correlation

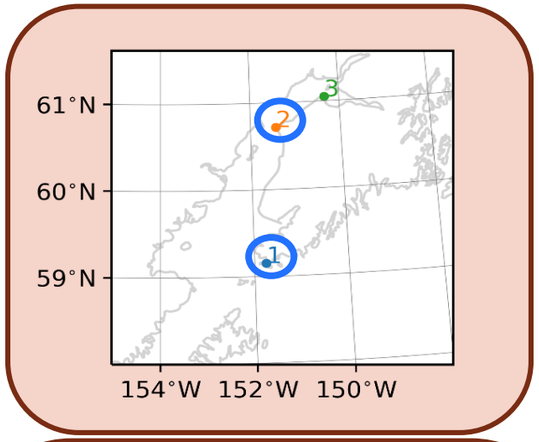
Favorable Correlations

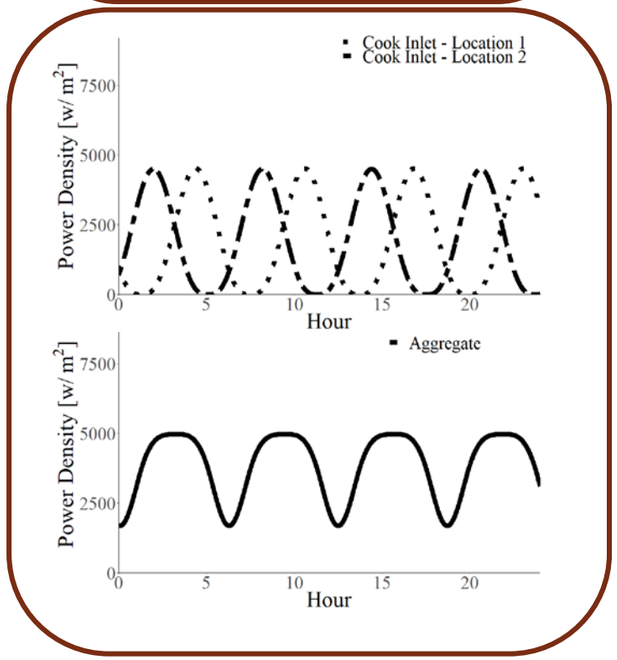




Bristol Bay, Alaska

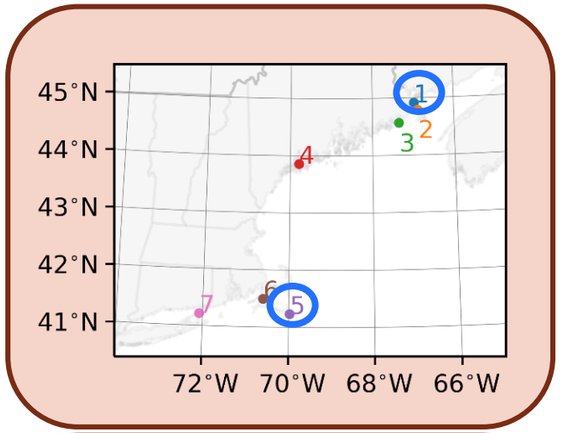
-0.91

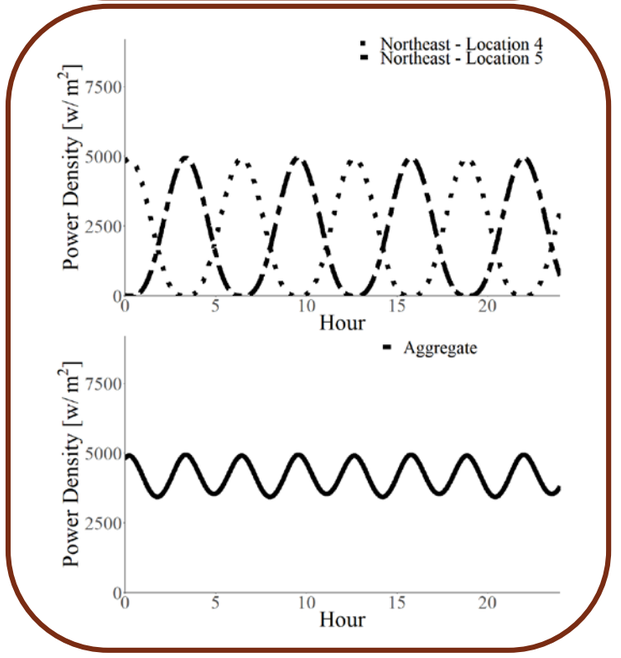




Cook Inlet, Alaska

-0.71

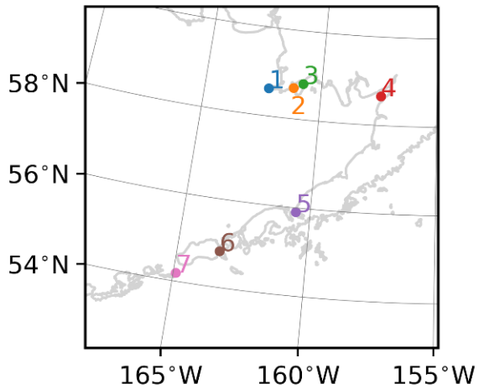




Northeast

-0.91

Identified Regions



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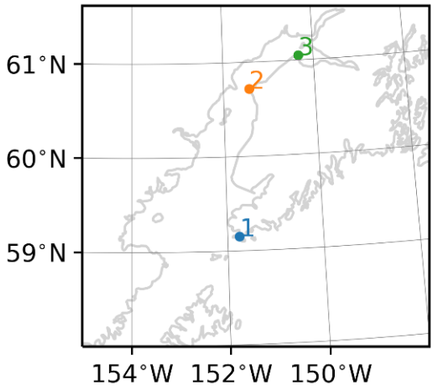

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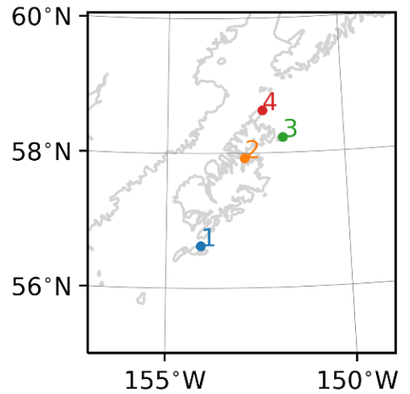

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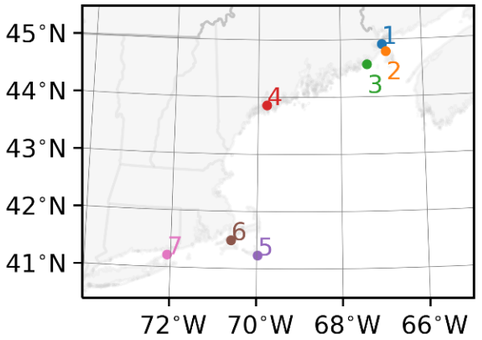

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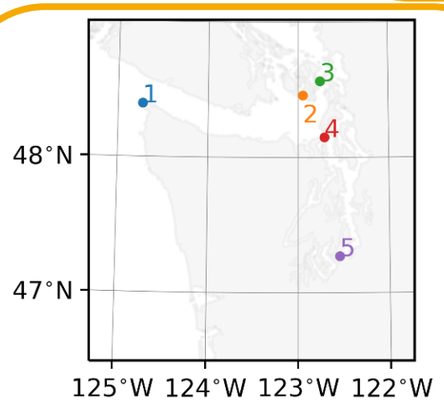
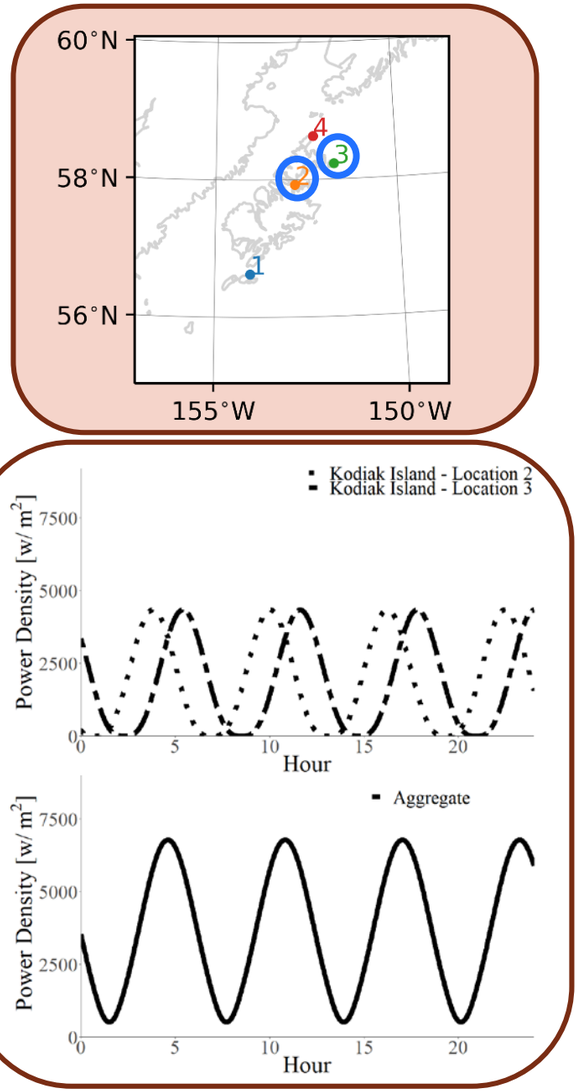
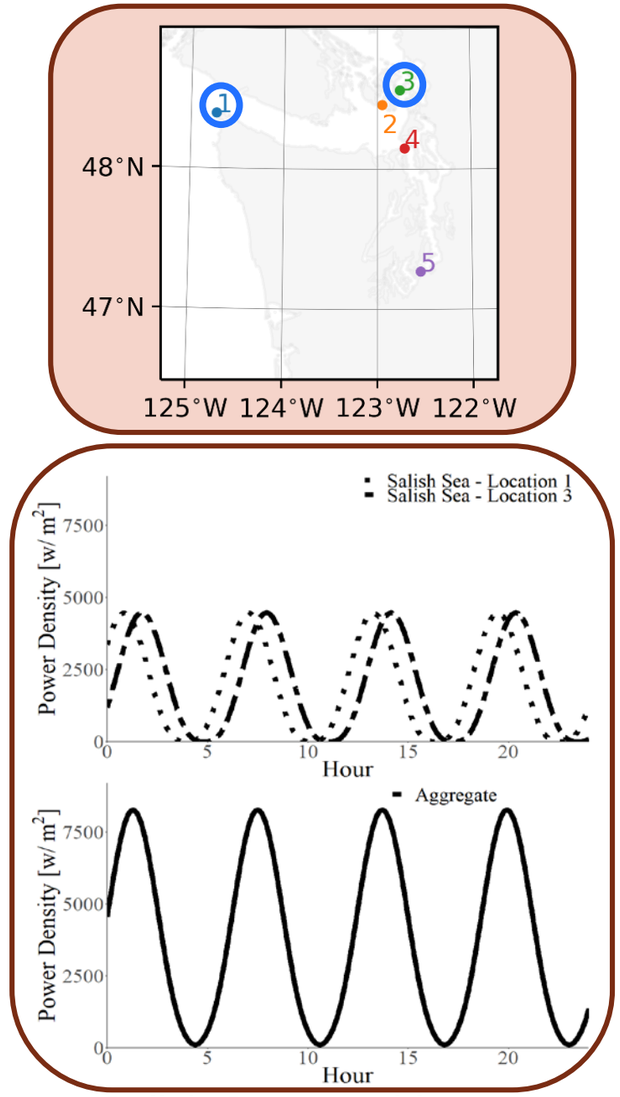


Salish Sea, Washington

Unfavorable Correlations



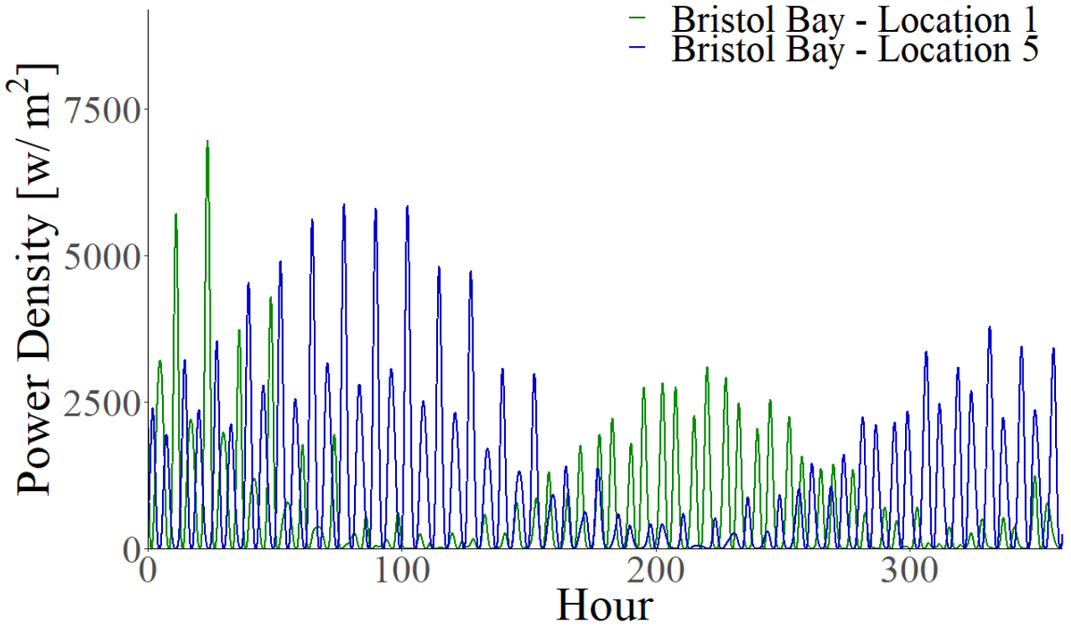
Kodiak Island, Alaska
-0.06

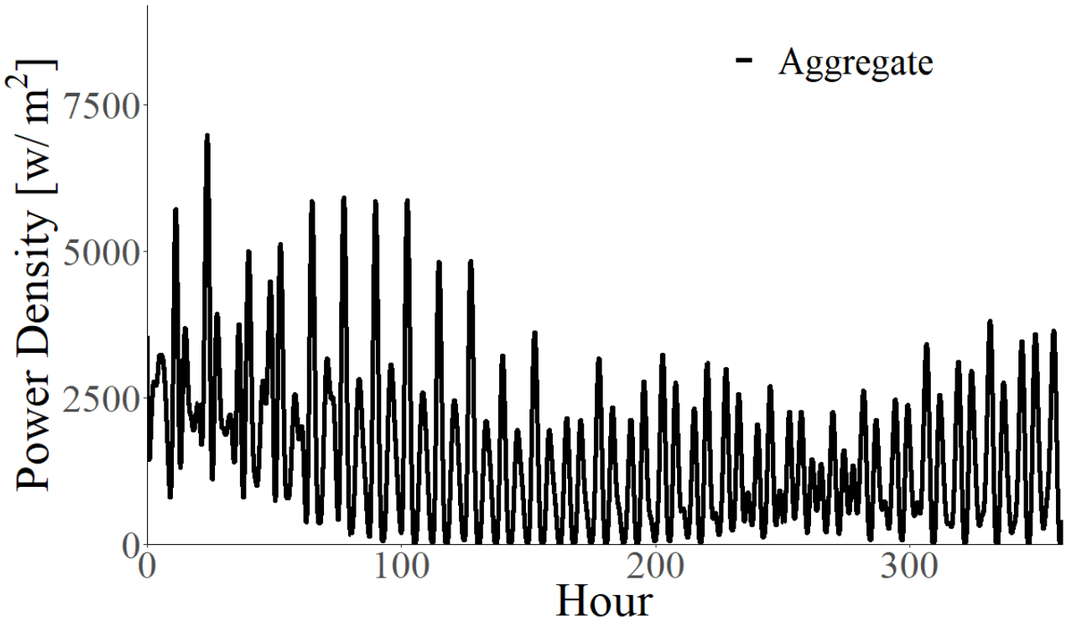


Salish Sea, Washington
0.38

Summary and Future Work

- Three favorable regions for smoother power output were identified:
  - Bristol Bay, Alaska
  - Cook Inlet, Alaska
  - Northeast
- Higher resolution and more accurate hindcast data are needed to refine the analysis
- Evaluating power from the full time series, including all tidal constituents
- Developing locational bounds where smoother power could be realized in practice





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Thank you

Danielle Preziuso

danielle.preziuso@pnnl.gov

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