In-Situ Performance and Load Measurements for a Grid Connected Tidal Energy Conversion System

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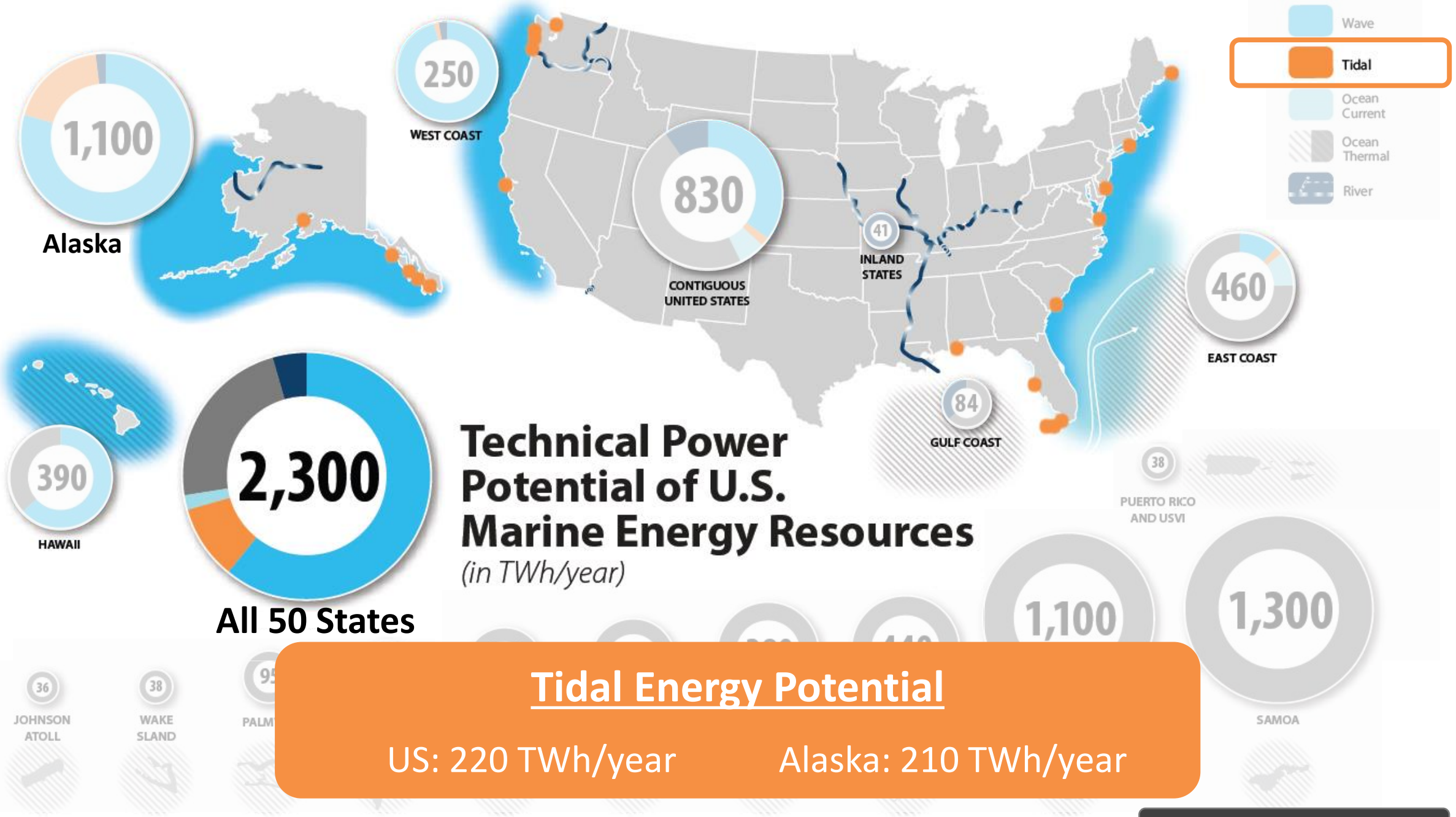


Tidal Energy Potential

US: 220 TWh/year Alaska: 210 TWh/year

Kilcher et al 2021 NREL

Why Tidal Energy?

- Tidal currents are highly predictable
- Tidal energy is the closest to commercialization
- A distributed tidal energy network could potentially provide constant baseload power in some locations
- Remote Communities & Blue Economy applications

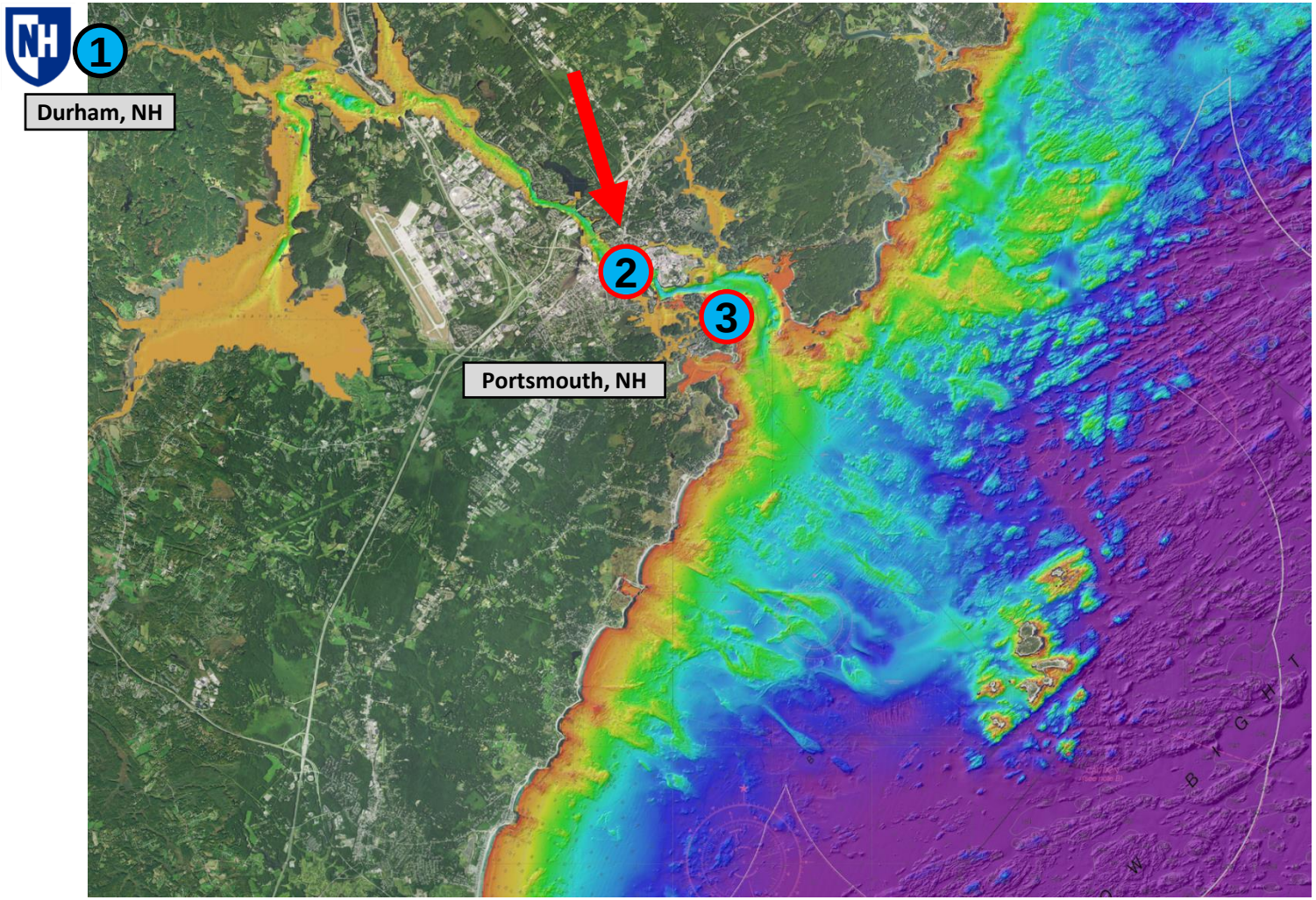
Figure 2 – 2 MW Orbital O2 Axial Flow Turbine (CNBC)

Continued Research

- Development of standardized testing procedures by International Electrotechnical Commission (IEC)
  - IEC TC 114 - Marine Energy Converters
- Operational experience to improve reliability
- Quantify and potentially retire environmental risks
- Structural loading case studies to reduce component costs

Figure 3 – 85 kW OPRC TideGen 1.0 Cross Flow Turbine (ORBC)

UNH Tidal Energy Test Site at Memorial Bridge in Portsmouth, NH



1 UNH campus: Jere A. Chase Ocean Engineering Laboratory

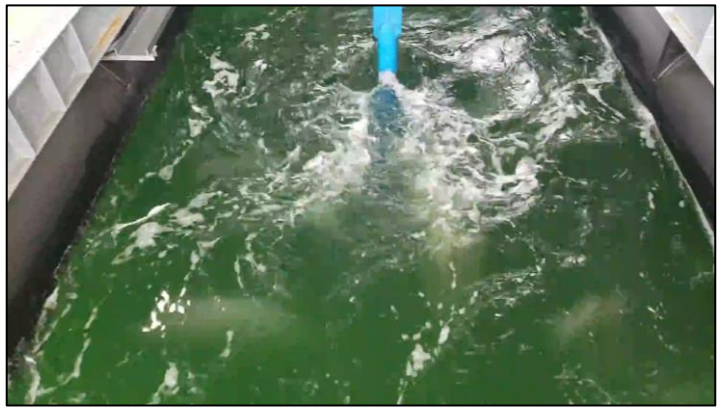
2 Tidal Energy Test Site at Memorial Bridge (NSF Living Bridge Project)

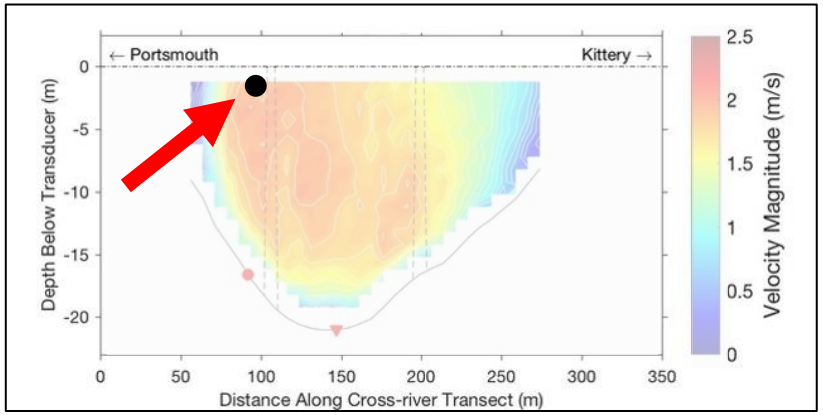
3 **UNH Pier & Judd Gregg Marine Research Complex**

(~1 hour north of Boston, MA)

Tidal Energy Conversion System (TECS) at the Memorial Bridge

- Tidal Energy Test and Demonstration Site
- Deployment off 15m x 6m floating test platform, turbines up to D~3m (cross flow/axial flow)
- Maximum currents >2.5 m/s during ebb tide
  - Stronger ebb than flood at site
- Nominal depth ~18m, tidal range ~3.7m, platform attached to bridge pier via vertical guide posts
- ***Grid-connected, easy access***
- New Energy model EVG-025 deployed since June 2018





(spring ebb, 42 minute average)

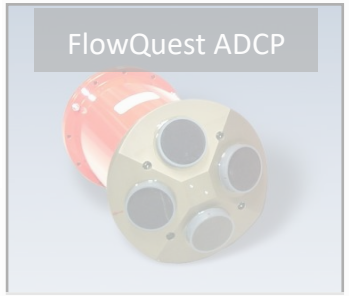
Research Project Objectives

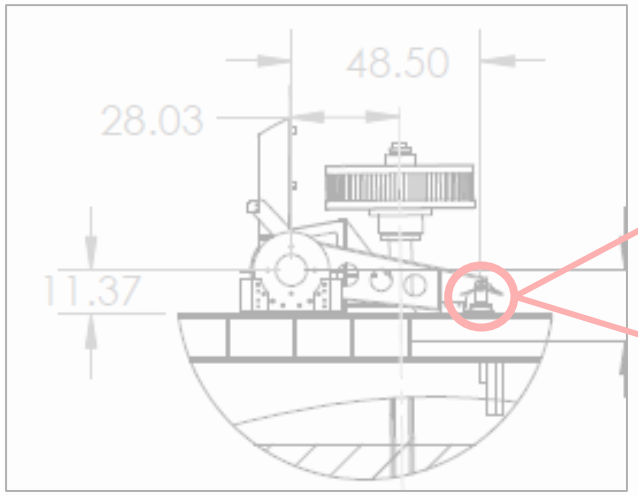
Goal: Collect concurrent **tidal resource**, **power performance** and **thrust load** measurements, while the turbine was in **grid-synchronous operation**.

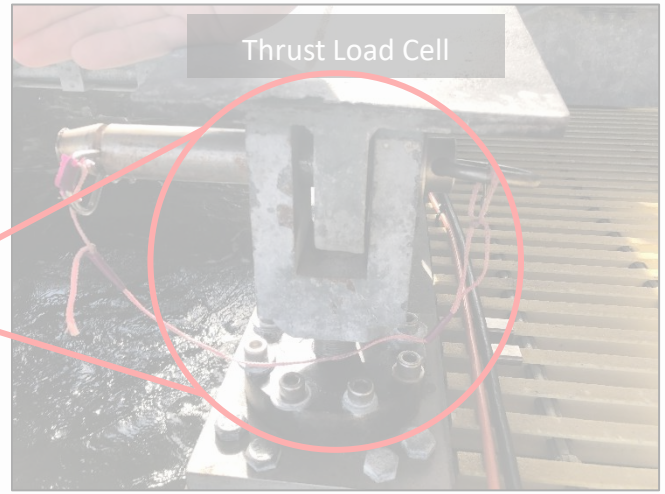
1. **Tidal resource** estimates for ebb and flood tide directions
   - Q.2 LinkQuest FlowQuest 1000kHz ADCP (2min Ensemble)
   - Q.2 Nortek Vector ADV (16 Hz)

2. **Power performance** data in grid connected mode
   - Voltsys records turbine rpm and rectifier power output
   - Shark meter records grid synchronous power

3. **Thrust load** measurements
   - Using Q.2 100kN tension and compression load cells estimate the transmit thrust load through turbine deployment structure







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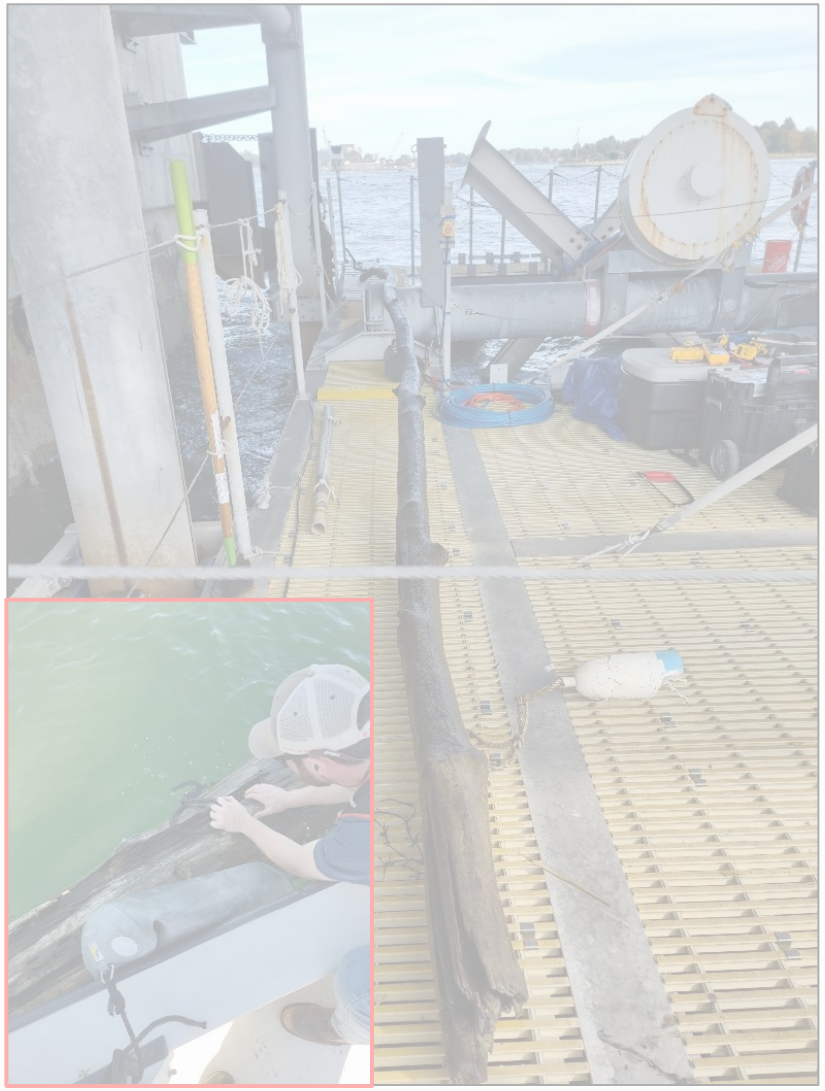
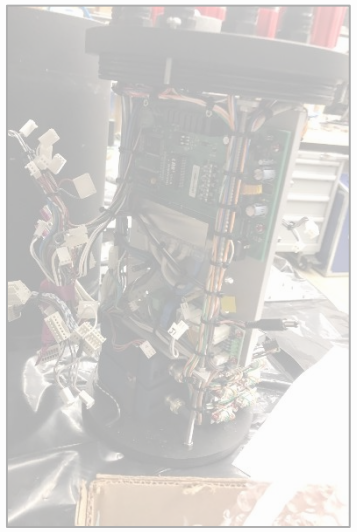
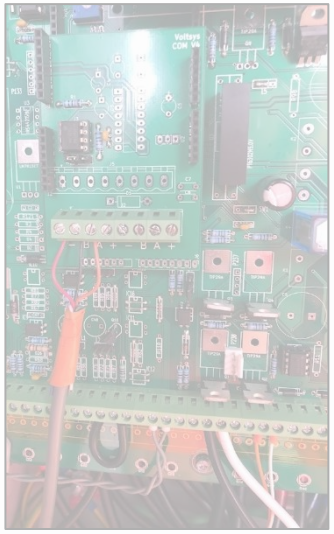
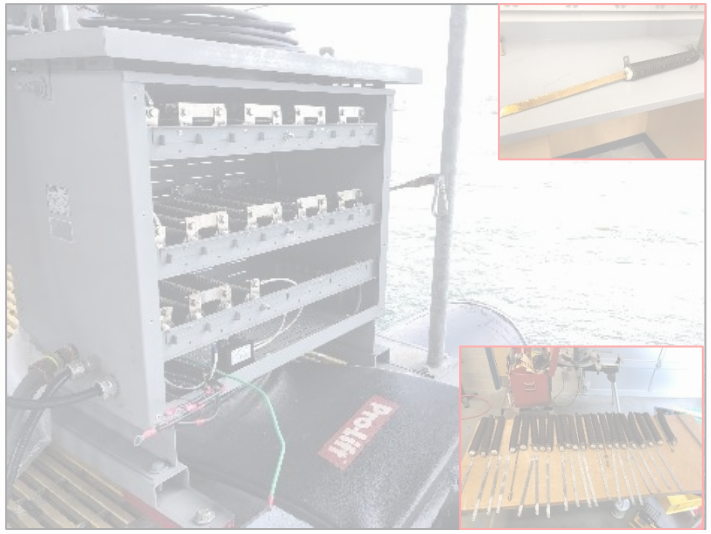
How do we get to Measurements?

Operations and Maintenance





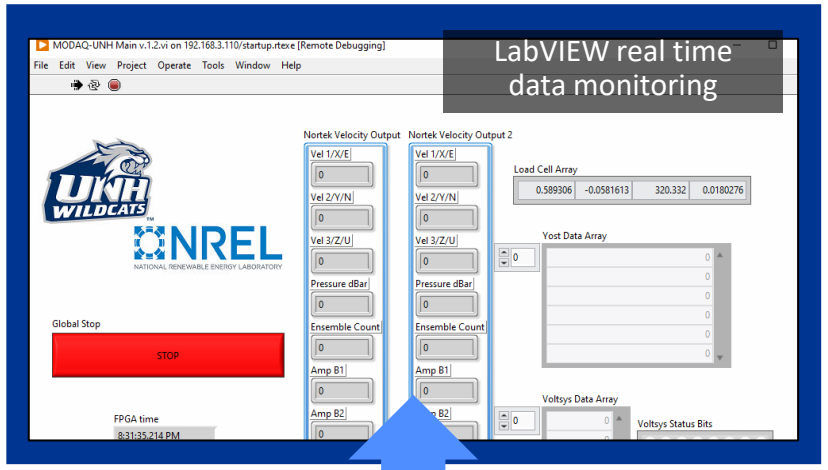




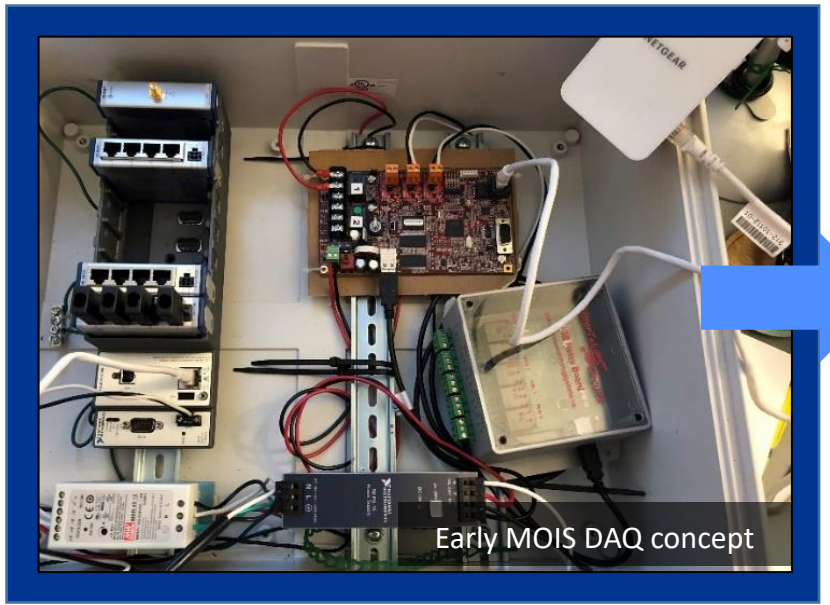
How do we get to Measurements?

DAQ Design and Integration

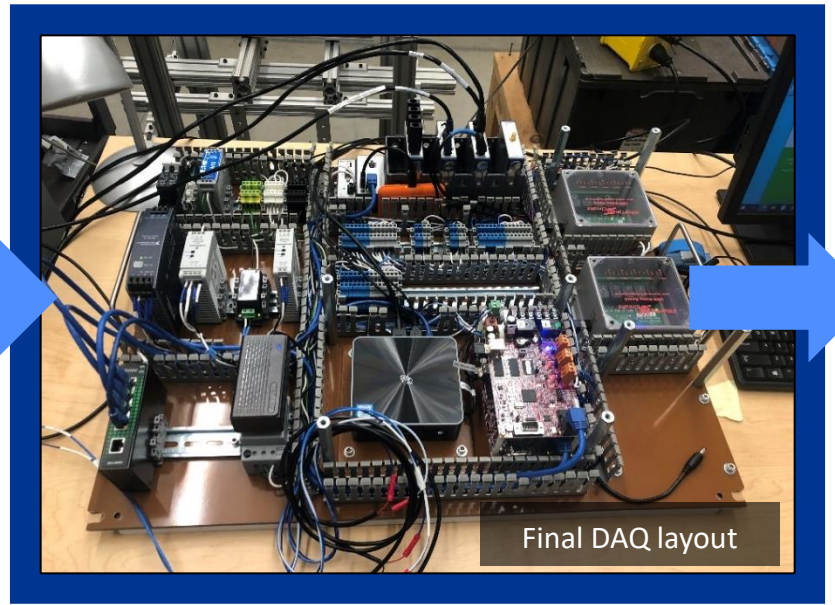
- Developed in partnership with NREL, on their MODAQ platform
- Integration of ADV, Power Performance, and Thrust Load data streams
- GPS time reference
- Easily switch between DAQ and instrument software with common cable
- Remote data viewing and downloading while DAQ is deployed



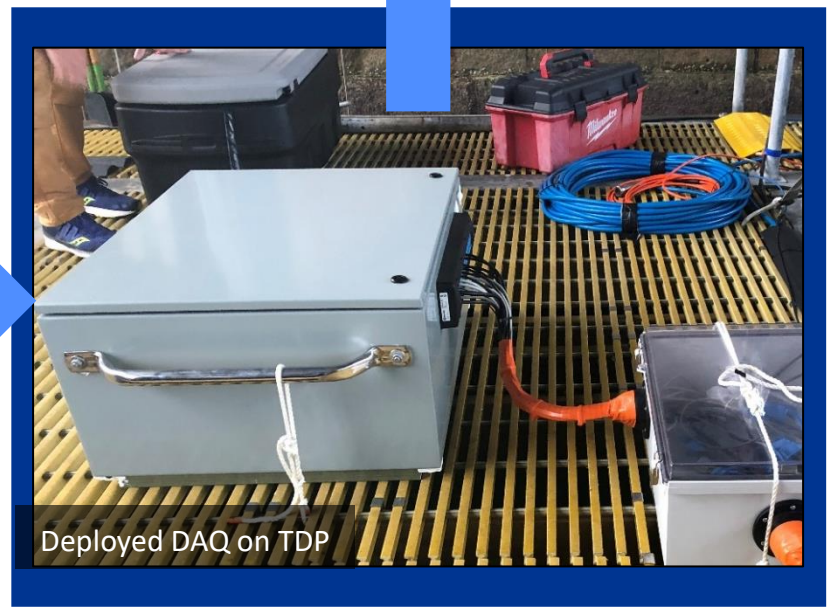
LabVIEW real time data monitoring



Early MOIS DAQ concept



Final DAQ layout



Deployed DAQ on TDP

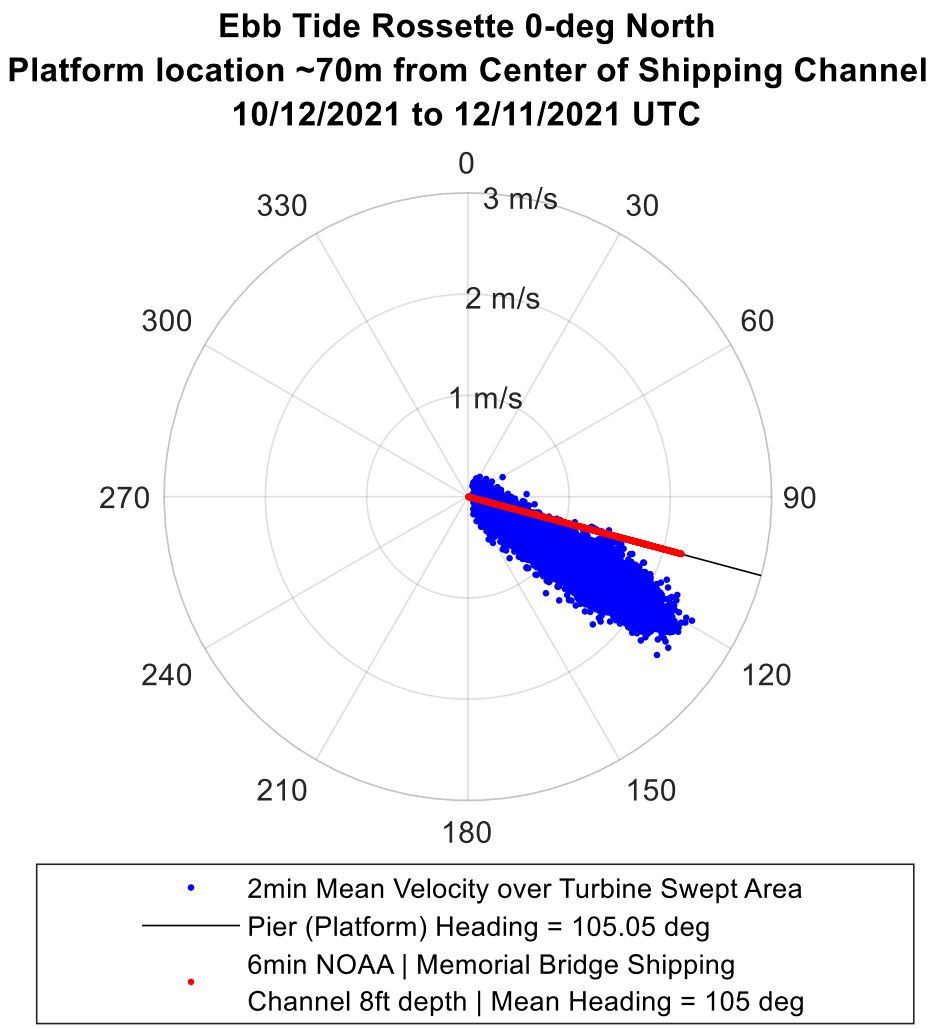
Measurement Campaign Data Timeline

| Turbine/Instrument Operation Status | 10/12/21 | 10/13/21 | 10/14/21 | 10/15/21 | 10/16/21 | 10/17/21 | 10/18/21 | 10/19/21 | 10/20/21 | 10/21/21 | 10/22/21 | 10/23/21 | 10/24/21 | 10/25/21 | 10/26/21 | 10/27/21 | 10/28/21 | 10/29/21 | 10/30/21 | 10/31/21 | 11/01/21 | 11/02/21 | 11/03/21 | 11/04/21 | 11/05/21 | 11/06/21 | 11/07/21 | 11/08/21 | 11/09/21 | 11/10/21 | 11/11/21 | 11/12/21 | 11/13/21 | 11/14/21 | 11/15/21 | 11/16/21 | 11/17/21 | 11/18/21 | 11/19/21 | 11/20/21 | 11/21/21 | 11/22/21 | 11/23/21 | 11/24/21 | 11/25/21 | 11/26/21 | 11/27/21 | 11/28/21 | 11/29/21 | 11/30/21 | 12/01/21 | 12/02/21 | 12/03/21 | 12/04/21 | 12/05/21 | 12/06/21 | 12/07/21 | 12/08/21 | 12/09/21 | 12/10/21 | 12/11/21 | 12/12/21 | 12/13/21 | 12/14/21 | 12/15/21 |
|---|---|---

Data Quality Control (QC)

- ADCP and ADV records were QC'd for erroneous data points by adapting the Integrated Ocean Observing System (IOOS) guide to our deployment
  - *The Manual For Real-Time Quality Control Of In-Situ Current Observations: A Guide To Quality Control And Quality Assurance Of Acoustic Doppler Current Profiler Observations*
- Thrust load cells: the data logger only recorded the magnitude load levels but not the direction (tension or compression)
  - A custom algorithm was designed and implemented to determine when a data point should be negative corresponding with a tensile load
- Missing time points in the ADCP and Shark 100 Power meter time series were identified and added to each data set

Results
Tidal Current Resource



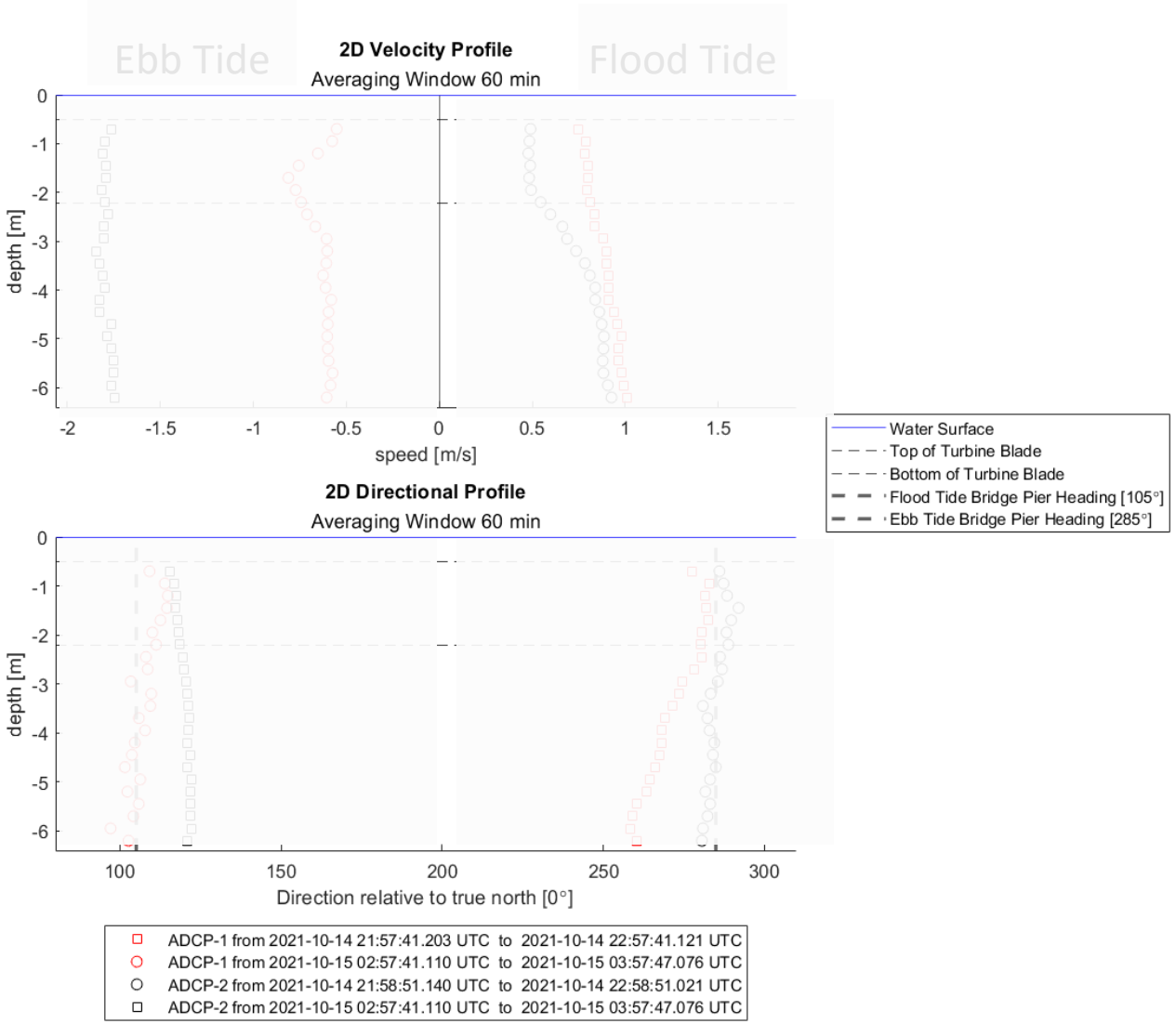
$$P \propto U^3$$
$$P = Power$$
$$U = Water\ Velocity$$

Results

Tidal Current Velocity Inflow and Turbine Wake Profile

1 hour time averaged ADCP horizontal velocity at each 0.25m depth bin during peak tidal current in an Ebb tide (-) and subsequent Flood tide (+)

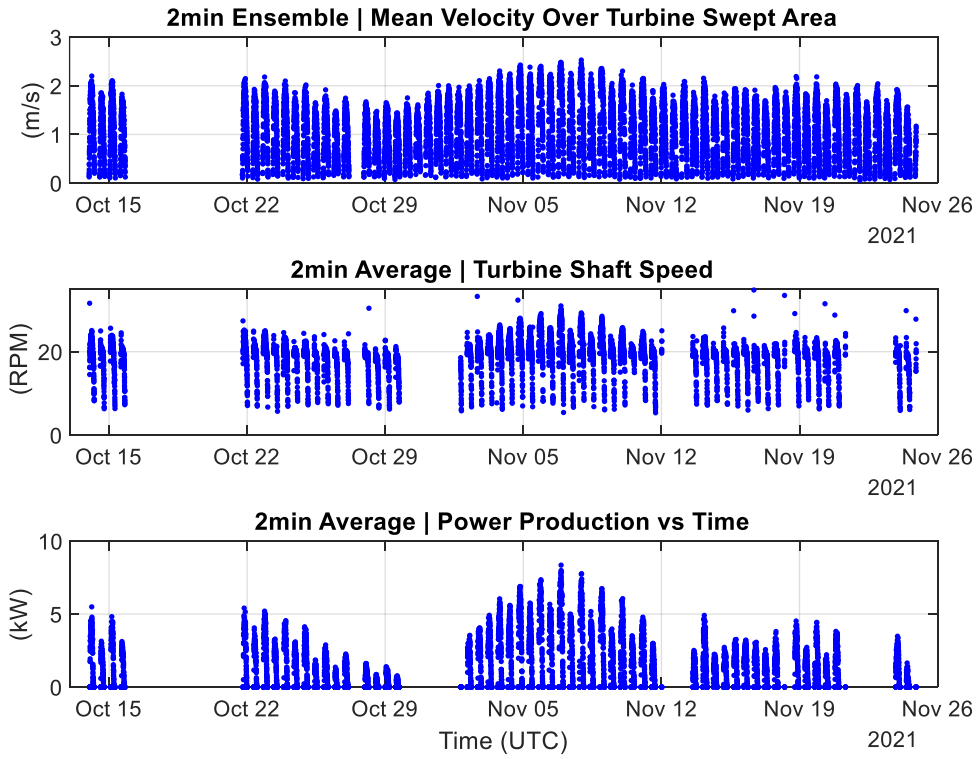
- Squares = inflow velocity
- Circles = wake velocity
- Red = Stern ADCP 1 (tidal resource on Flood tide)
- Black = Bow ADCP 2 (tidal resource on Ebb tide)
- -------- = turbine swept area in water column

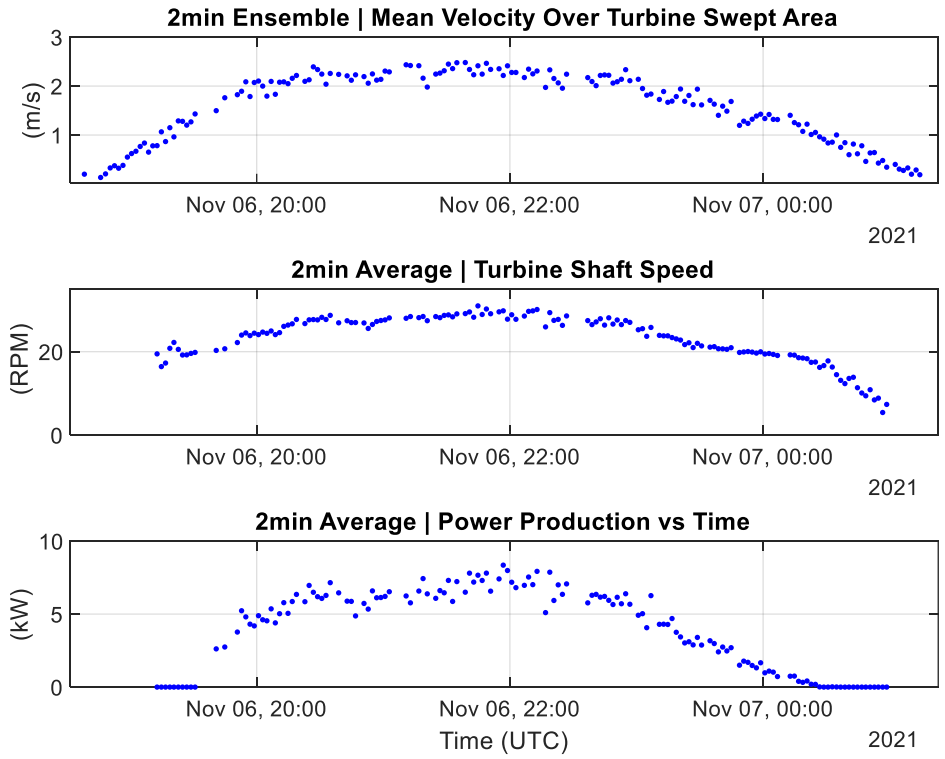


Results

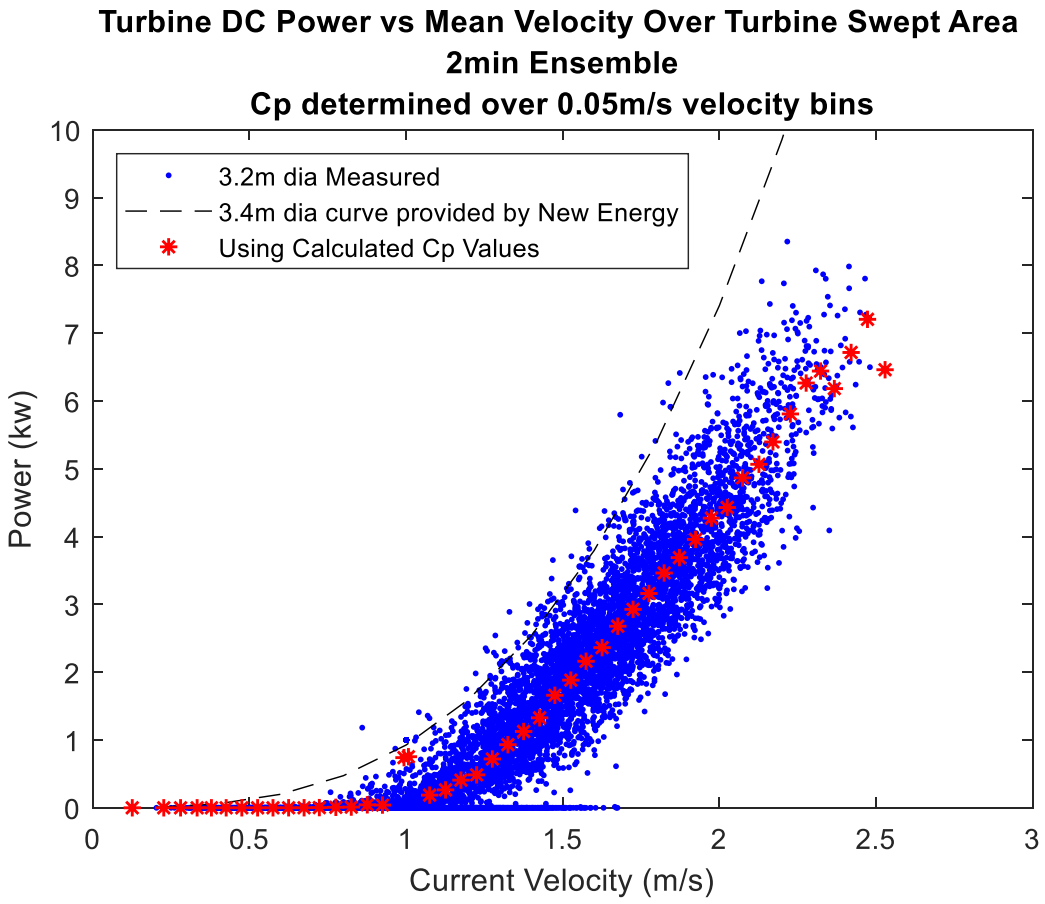
Operation and Power Delivery Experience

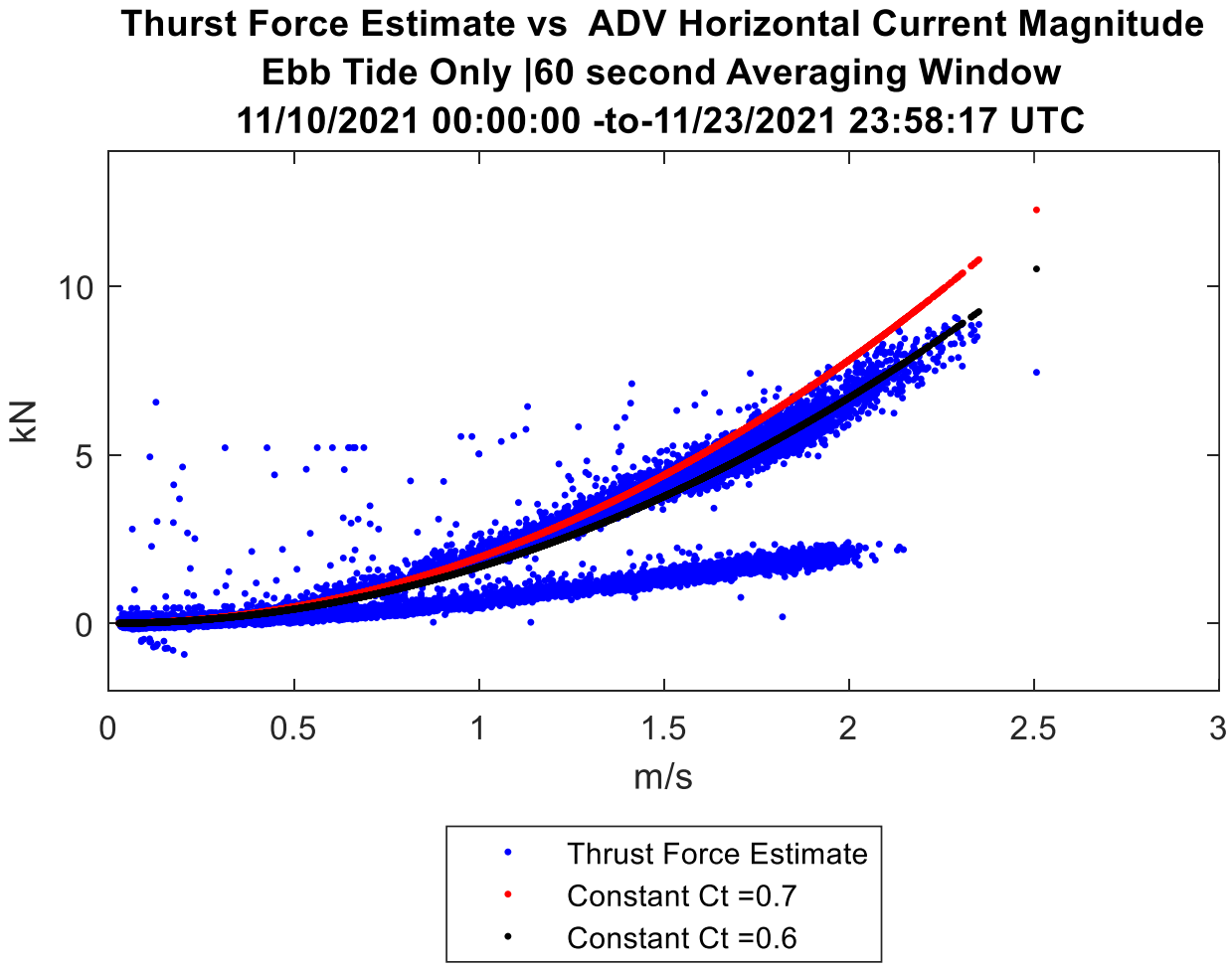
- Produced 767kWh of grid connected power
- ~ monthly energy demand of 1 NH home
- Gaps in power output correspond with power inverter operational issues





Results
Turbine Power Performance

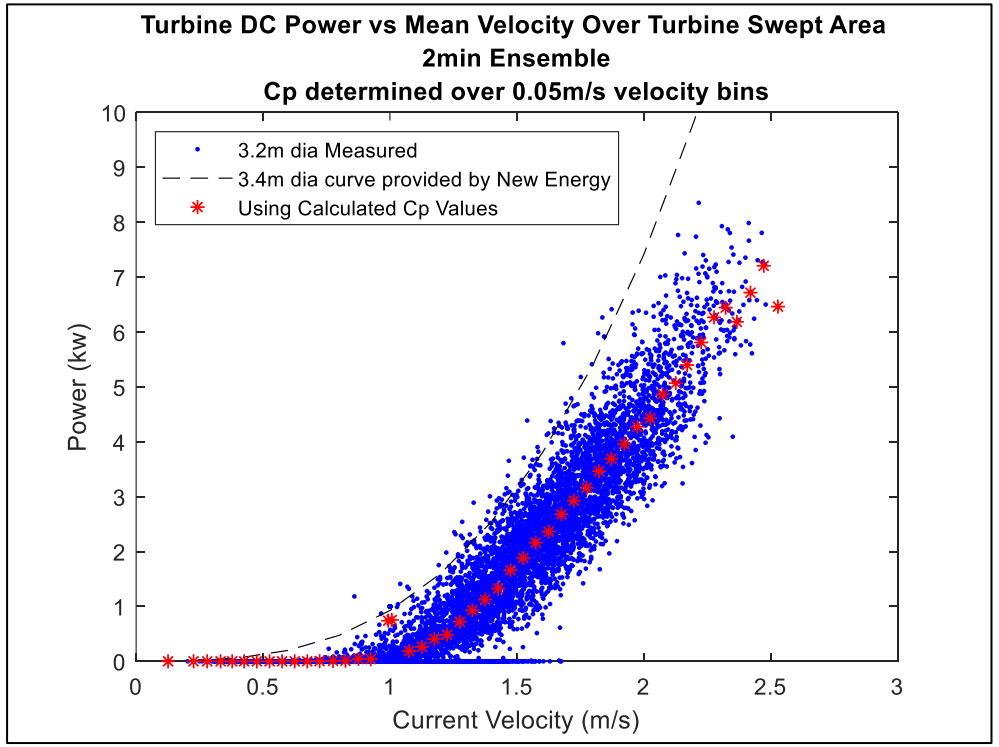


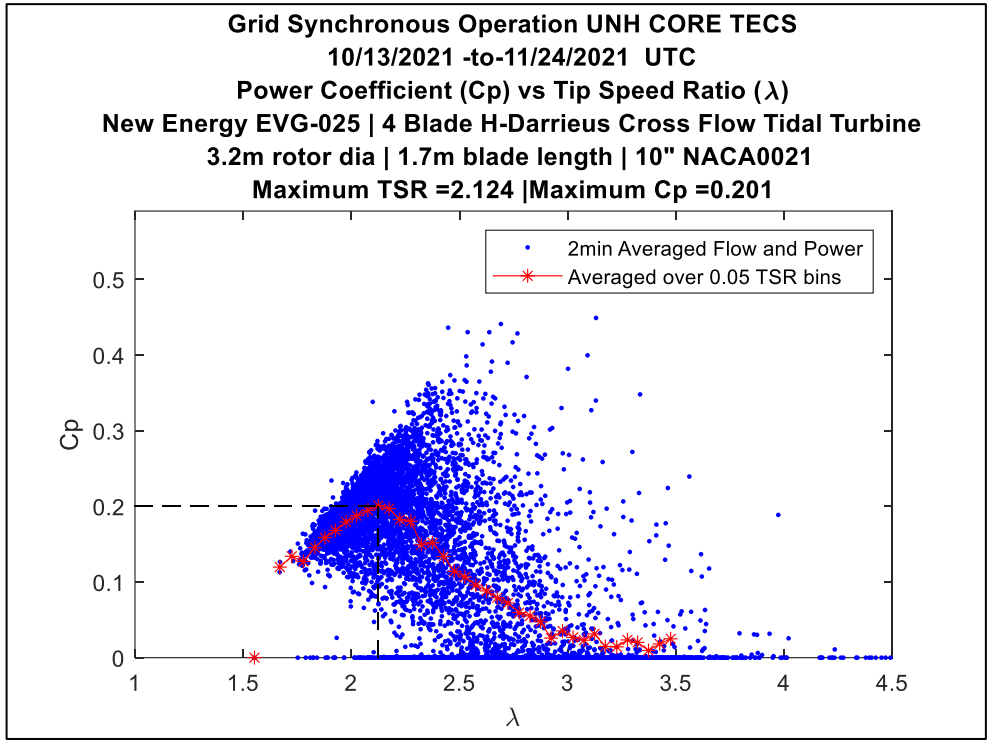


Results

Performance Metrics in a Real Tidal Flow

- Generate turbine power performance results which provide confidence for future investment in industry
- Compare against expected performance from the manufacturer (left)
- Non dimensional results to compare against theoretical and laboratory performance results (right)





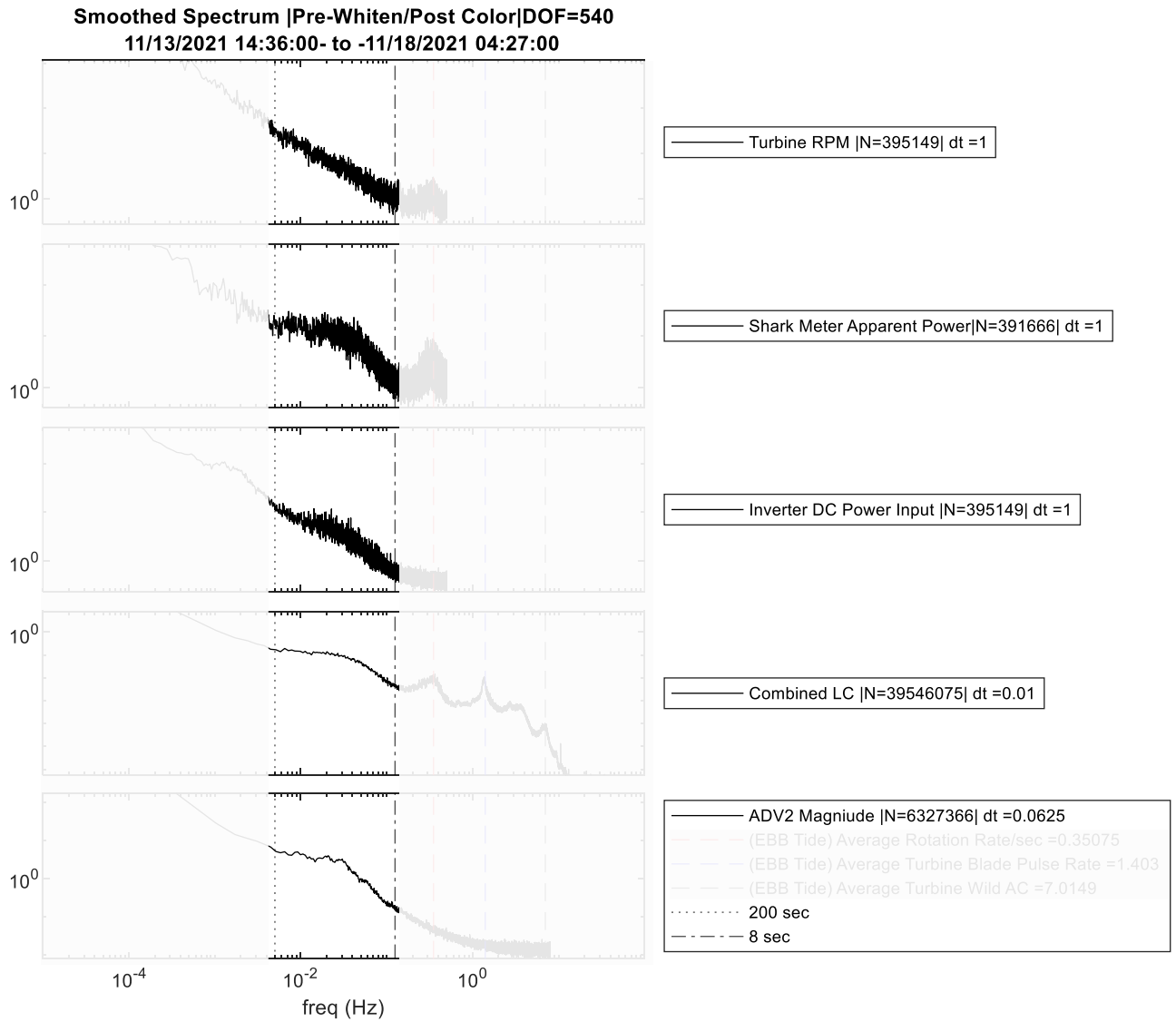
$$Cp = \frac{P}{P_o}$$

$C_P = Power\ Coefficent$
$P = Actual\ Power\ Produced$
$P_o = Theoretical\ Power\ Available$

$$\lambda = \frac{\omega * R}{V}$$

$Tip\ Speed\ Ratio = \lambda$
$Blade\ Angular\ Velocity = \omega$
$Turbine\ Radius = R$
$Free\ Stream\ Velocity = V$

Results
Frequency Analysis



Data will be made available through PRIMRE/MHKDR

Characterizing Environmental Impact

Fish Strike Simulation Using Lures an Active Acoustic Camera

Passive Acoustic Drifters to Quantify Underwater Noise - IEC TS 62600-40 under IEC TC 114 Marine Energy Converters

- Haxel J, Zang X, Martinez J, Polagye B, Staines G, Deng ZD, Wosnik M, O'Byrne P. (2022) Underwater Noise Measurements around a Tidal Turbine in a Busy Port Setting. Journal of Marine Science and Engineering. 2022; 10(5):632. https://doi.org/10.3390/jmse10050632
- Staines GJ, Mueller RP, Seitz AC, Evans MD, O'Byrne PW, Wosnik M. (2022) Capabilities of an Acoustic Camera to Inform Fish Collision Risk with Current Energy Converter Turbines. Journal of Marine Science and Engineering. 2022; 10(4):483. https://doi.org/10.3390/jmse10040483

University of New Hampshire

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- Atlantic Marine Energy Center
- NREL Marine Energy Research Team
- New Energy Corporation Inc. (Calgary, CA)
- Northeast Integration (North Hampton, NH)
- SMSOE Marine Facilities and Operations

UNH Turbine Deployment Platform being moved back to UNH Pier on 17 Dec 2021 after **3 years and 2 months of continuous deployment (!)**

- Floating platform, using small boats, cost-effective
- Re-deployment in ~3-4 weeks with instrumented blade, continued collaboration with NREL.

This work was based upon funding from the Alliance for Sustainable Energy, LLC, Managing and Operating Contractor for the National Renewable Energy Laboratory for the U.S. Department of Energy

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U.S. DEPARTMENT OF ENERGY

New Energy CORPORATION

Northeast Integration, LLC

AMEC Atlantic Marine Energy Center

References

Figure 1: Kilcher et al 2021 *Marine Energy in the United States: An Overview of Opportunities*

Figure 2: 2 Megawatt Axial Flow Tidal Turbine, Adapted from: “This image shows Orbital Marine Power’s 2 megawatt turbine, the Orbital O2”, CNBC, May 25, 2021, From powerful tidal turbines to huge wave machines, Scotland is becoming a hub for marine energy, URL: https://www.cnbc.com/2021/05/25/tidal-power-wave-machines-scotland-becoming-a-hub-for-marine-energy.html, Accessed: 5.2.2022, © 2022 CNBC LLC. All Rights Reserved. A Division of NBCUniversal

Figure 3: ORPC TidGen® Cross-Flow Tidal Turbine, Adapted from TETHYS Engineering, “Cross Flow Turbines”, Ocean Renewables Power Company, https://tethys-engineering.pnnl.gov/technology/cross-flow-turbine, Accessed: 5.2.2022

Figure 4: Generation Sources, Adapted from, “Our #GridWeek infographic shows how electricity is generated, transmitted and distributed for use in our homes”, S. Gerrity, 2014, DOE INFOGRAPHIC: Understanding the Grid, https://www.energy.gov/articles/infographic-understanding-grid, Accessed 5.2.2022