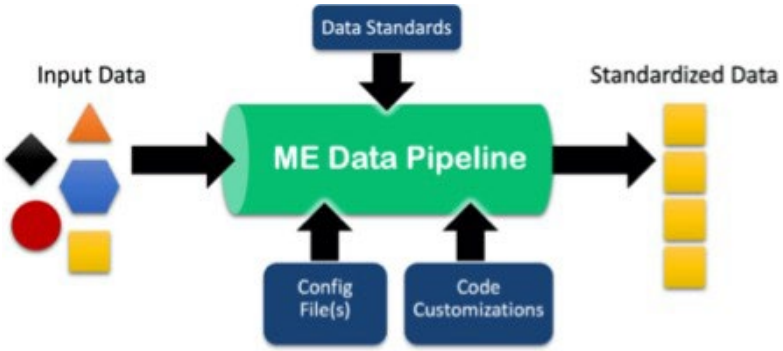
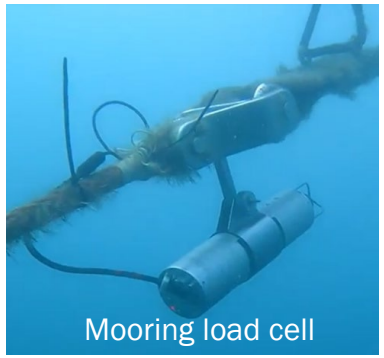
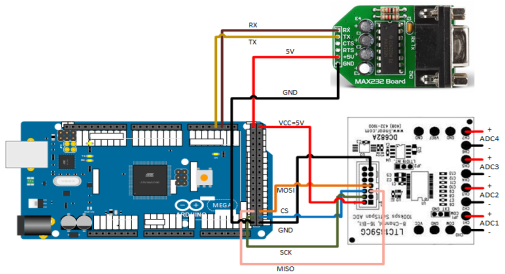
# 2.3.3.404 – NATIONAL LAB AND UNIVERSITY COLLABORATION FOR MHK INSTRUMENTATION AND DATA PROCESSING TOOLS





Mooring load cell


MiniDAQ

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July 20, 2022

Photo: Scripps Institution of Oceanography/CalWave Power Technologies
Screen shots: Budi Gunawan, SNL

NREL/PR-5700-83326

This work was authored in part by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Water Power Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

# Project Overview

## Project Summary

In partnership with industry and academia, this multilab project is developing **software tools, instrumentation**, and **guidelines** that empower the marine energy (ME) community to **reliably** and **efficiently collect, curate, process, manage, and share quality test data**. These products fill gaps to enable high-quality field and laboratory validation, testing, demonstration, operation, and real-time data analysis that **provide critical information** used to feed all aspects of technology development and help **increase** the **technology readiness level** of ME converters.

## Intended Outcomes

- **Increased** level of **data processing and analysis** at a **lower cost**
- Higher-quality **data products and reporting** that provide the **foundation** for **design, evaluation, and certification** of ME systems
- **Increased** data **accessibility, reuse**, and sharing
- Better ability to perform cross-project and **cross-data analysis** and **comparisons**
- **Increased measurement success** and higher-quality data produced in laboratory and field testing
- **Increased** submission of **high-quality data sets** to the **Marine and Hydrokinetic (MHK) Data Repository** in standardized formats
- **Higher quality** and breadth of **loads measurements** in field deployments
- **Increased understanding** of **ME loads**, resulting in **high reliability** of ocean deployed systems

## Project Information

| Principal Investigator(s) |
|---|
| • Rebecca Fao, Chitra Sivaraman, and Budi Gunawan |
| **Project Partners/Subs** |
| • Oregon State University<br>• Florida Atlantic University<br>• CalWave<br>• AquaHarmonics |
| **Project Status** |
| Ongoing |
| **Project Duration** |
| • Aug. 1, 2018–Present |
| **Total Costed (Fiscal Year [FY] 2019–FY 2021)** |
| $2,415,000 |

# Project Overview

To increase the value and success of the project testing/validation, the ME community needs:

- Access to experts
- Availability of proven hardware/software solutions
- Reduced cost of measurement and data processing
- Established practices that leverage existing knowledge, standards, and guidelines
- Shared experience and lessons learned.

# Project Overview

## 2017: 3rd MHK Instrumentation Workshop

### Gap 1: ME test data processing and analysis software

Solution: MHK Toolkit (MHKiT), Marine Renewable Energy (MRE) Code Hub/Catalog, and ME Data Pipeline

- IEC compliant metric calculations
- Real-time data quality control and analysis
- Cloud processing
- Easy access to standardized code

### Gap 2: Micro Data Acquisition (DAQ) for small scale tank testing

Solution: MiniDAQ

- Open-source design
- Customizable
- Low cost
- Low mass

### Gap 3: Mechanical and PTO load sensors for larger scale field testing

Solutions: Instrumentation and guidance

- Mechanical and power take-off load guidance manual
- Remote and wireless mooring load sensor
- Fiber optic hull strain monitoring
- Structural health monitoring

### Gap 4: Guidelines for instrumentation and measurement systems

Solution: Telesto knowledge base in Portal and Repository for Information on MRE (PRIMRE)

- MRE testing
- MRE measurement
- Regulations, standards, guidelines, and certification

# Project Objectives: Relevance

## Multi-Year Program Plan (MYPP) ME Program Activity 2 – Technology-Specific System Design and Validation

- Improves device response and signal quality for small-scale lab testing (MiniDAQ)
- Increases the understanding of ME loads resulting in high reliability of ocean-deployed systems (load sensor design and field validation)

## MYPP ME Program Activity 3 – Reducing Barriers to Testing

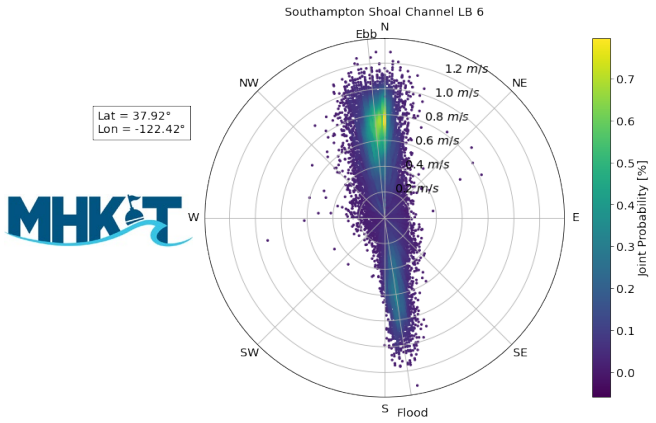
- Produces software tools, instrumentation, and guidelines that enable successful testing by capturing and disseminating testing knowledge, ensuring high-quality data, enabling data analysis, reducing testing costs, and accelerating testing timelines

## MYPP ME Program Activity 4 – Data Access, Analytics, and Workforce Development

- Enables quicker, cheaper, and consistent data processing, eliminating duplication of code development and reducing the risk of errors
- Aids device certification through turnkey IEC-standards-compliant data processing
- Enable near-real-time data processing and analysis to assist operator in making critical decisions
- Enables submission of high-quality data sets to the MHK Data Repository in standardized formats, leading to improved data preservation and knowledge capture

# Project Objectives: Approach

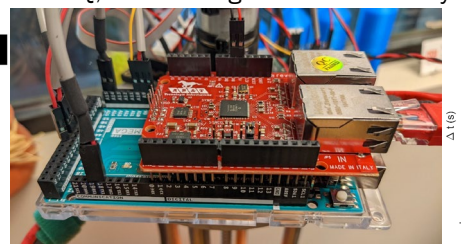
1) Develop, disseminate, and maintain open-source software tools and repositories for data ingestion, reduction, conditioning, quality control, transformation, calculation, and visualization, bringing validated ME data processing code together for ease of discovery and utilization
2) Design and construct a small and low-cost DAQ system, providing a standard small DAQ solution that developers and researchers can easily leverage
3) Develop and demonstrate reliable mechanical load measurement instrumentation that meets the needs of ME field testing, standardizing loads measurements
4) Develop and disseminate experience-based guidelines for laboratory and field measurement and testing, reducing the loss of knowledge over time and allowing the industry to build on previous work



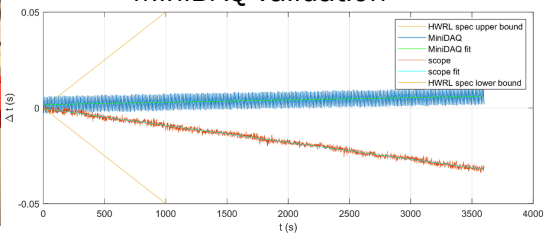

Screen Shots: Budi Gunawan, SNL

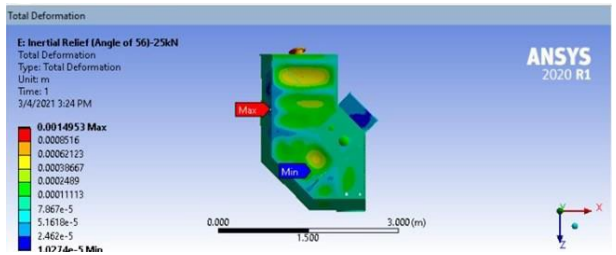
MHKiT tidal resource assessment module

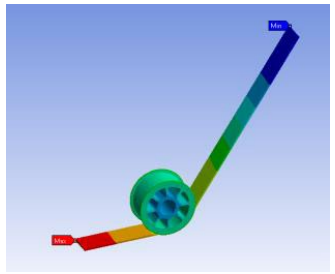

MiniDAQ, Credit: Oregon State University



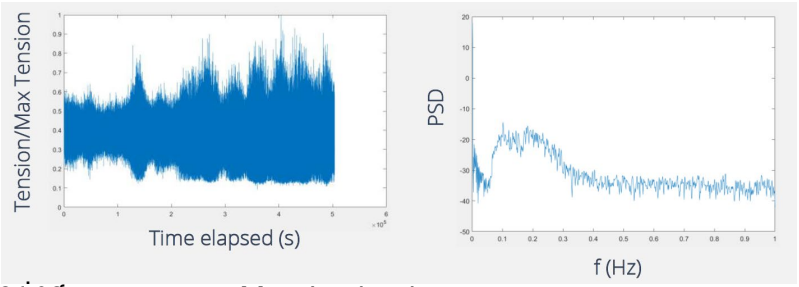
MiniDAQ validation



Finite element analysis of wave energy converter and power take-off belt mooring




Mooring load measurements

# Project Objectives: Expected Outputs and Intended Outcomes

## Outputs:

- **Software/tool/model**: MHKiT-Python and MATLAB, structural model of wave energy converter power take-off mooring lines, ME Code Hub, PRIMRE Code Catalog, ME Data Pipeline
- **Hardware**: Open-source low cost, small, and lightweight DAQ system for small-scale testing and underwater wireless telemetry system for load measurements
- **Publications**: Scientific papers (10+), best-practices guidance, conference presentations
- **Training**: Manuals, documentation, tutorial videos, webinars
- **Data sets**: Mooring load data from ocean wave energy converter deployment
- **Standards:** Improvement to IEC -3 Mechanical Load Measurements Technical Standard

## Outcomes:

- Increased level of data processing and analysis at a lower cost with easy access to standardized data processing and analysis tools
- Better ability to perform cross-project and cross-data analysis and comparisons
- Ability to standardize and process data in real time on the cloud, allowing for real-time operational decision making
- Increased measurement success and higher-quality data produced in laboratory and field testing, leading to improved knowledge capture and pathways to commercialization
- Increased understanding of ME loads, resulting in high reliability of ocean-deployed systems
- Further development, increased use, and broader acceptance of IEC standards

# Project Timeline

## FY 2019

Completed IEC functions for wave, river, and tidal

Populated Code Catalog and Code Hub integration with PRIMRE

MiniDAQ design requirements

Load **sensor** system design

## FY 2020

Released MHKiT v0.1.0

Completed Code Catalog and Code Hub integration with PRIMRE

Guidelines **document** for mechanical and **power take-off** load sensors for **larger-scale** field testing

Completed load sensor system dry testing with CalWave

Completed MiniDAQ bench testing

## FY 2021

Released MHKiT v0.4.0

# Project Budget

| FY 2019 | FY 2020 | FY 2021 | Total Actual Costs FY 2019–FY 2021 |
|---|---|---|---|
| Costed | Costed | Costed | Total Costed |
| NREL: $218,000<br>PNNL: $102,000<br>Sandia: $390,000<br>Total: $710,000 | NREL: $219,000<br>PNNL: $151,000<br>Sandia: $523,000<br>Total: $893,000 | NREL: $195,000<br>PNNL: $189,000<br>Sandia: $428,000<br>Total: $812,000 | NREL: $632,000<br>PNNL: $442,000<br>Sandia: $1,341,000<br>Total: $2,415,000 |

# End-User Engagement and Dissemination

**Online Repositories:** Open source tools and designs are hosted at online repository, e.g., MHKiT, ME Data Pipeline, and MiniDAQ on GitHub. End users: ME developers and researchers.

**Knowledge Hubs:** Open-source wikis and databases provide guidance for MRE testing, measurement, and data processing based on experience, lessons learned, standards, and best practices.

**Webinars and Workshops:** Conducted for industry, academia, and focus groups throughout the ME space, webinars have been recorded and posted to YouTube for future reference.

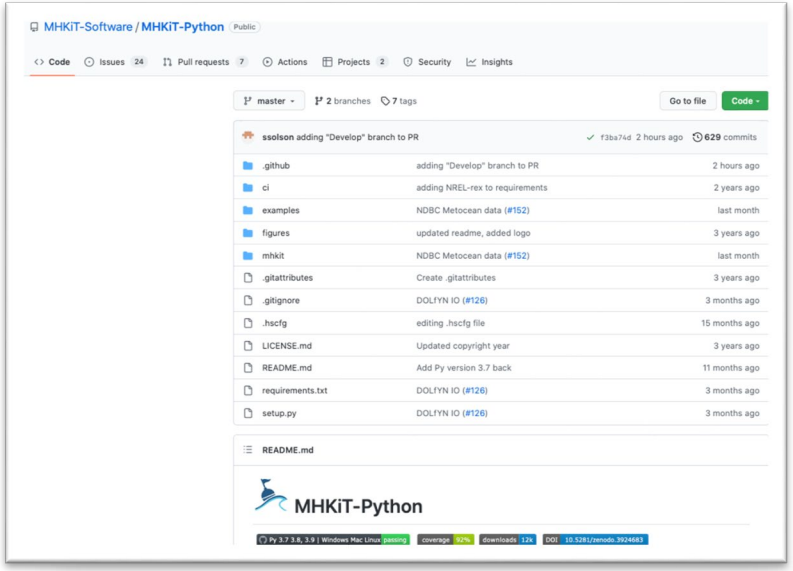
**Scientific Articles:** Journal and conference articles and presentations targeting industry and academia have been published.

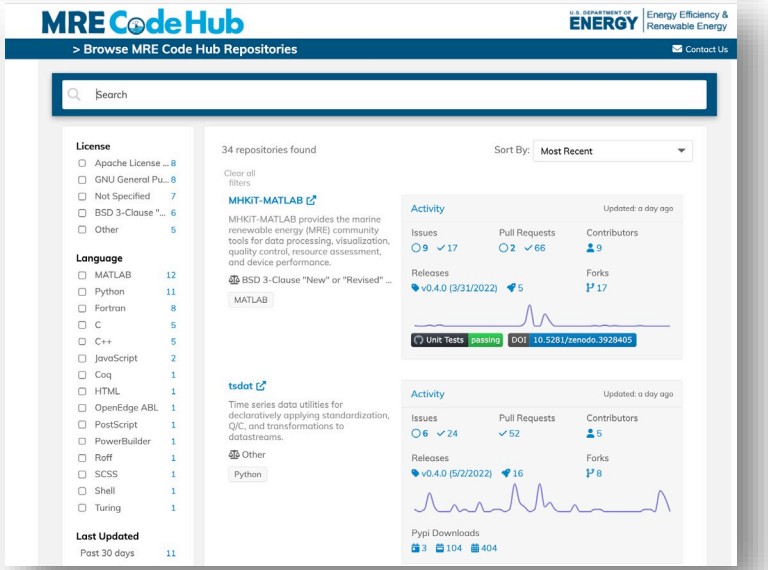
**Cross-Project Integration:** We have leveraged contributions from other WPTO- and non-WPTO-funded projects in other domains to strengthen the core framework.

**Industry and University Partnerships:** We leveraged developers' ocean testing projects (e.g., CalWave's and AquaHarmonics' WPTO FOA 1663 projects) and knowledge at university partners (Oregon State, Florida Atlantic).

**Feedback:** We seek feedback to improve tools through industry surveys.

**News Articles:** We email news through Tethys Engineering, WPTO News, and Lab News.




*Screenshots by Chitra Sivaraman - PNNL*

# Performance: Accomplishments and Progress

## Enabled standardized data processing through verified, open-source tools – leading to rapid, consistent data analysis and knowledge capture when we:

- Released MHKiT Python and MATLAB (MHKiT- Python had over 11,000 all time downloads [in 3 years]) and twice-yearly updates, bringing major function improvements to users.
- Released the initial version of the ME data pipeline (16,000 all-time downloads [in 1 year]) with 33 public repositories using tsdat.

## Simplified discovery of ME relevant code and guidelines - saving time and money needed to create new code and research best practices when we:

- Released the MRE Code Catalog, PRIMRE Code Hub, and Telesto.
- Published a guidelines document for mechanical and power take-off load sensors for larger-scale field testing.
- Released a data quality control standards document.

## Improved data collection capabilities for small scale testing, increasing knowledge capture, when we:

- Released MiniDAQ design and performance validation.

## Developed and demonstrated new loads measurement capabilities, easing the ability to collect critical loads data, when we:

- Completed ocean testing for mooring load system with Calwave.

# Future Work

## Expand software tools to include additional capabilities as the ME industry evolves and grows:

- Release a new MHKiT to include met-ocean, Powering the Blue Economy, mooring, noise, and other processing capabilities based on user feedback.
- Develop new capabilities for ME Data Pipeline: Transformation pipelines, built-in quality checks and controls, and built-in support for a common data format.

## Continue user engagement and training:

- Develop training and guidance materials for user-developed MHKiT functionality.
- Develop ME Data Pipeline end-user support and dissemination.

## Complete the first phase of knowledge dissemination:

- Continue to populate Telesto with additional guidance (under the PRIMRE project).

## Demonstrate and validate field and laboratory hardware:

- Load measurement sensor design and field testing in conjunction with AquaHarmonics' ocean deployment in FY 2023/2024.
- Demonstration of MiniDAQ on a wave energy converter laboratory testing (wave basin).

# Project Links and Publications – Reference

**MHKiT and MiniDAQ Dissemination**

- https://mhkit-software.github.io/MHKiT/
- https://github.com/ME-Data-Pipeline-Software
- https://github.com/tsdat
- https://github.com/bretbosma/Mini-DAQ
- https://doi.org/10.5281/zenodo.5042211

**Scientific Articles**


- Bosma, B., R. Coe, G. Bacelli, T. Brekken, and B. Gunawan. 2022. "Mini-DAQ: A lightweight low-cost data acquisition system for wave energy converter testing." *HardwareX Journal* (under review).
- Beaujean, Pierre-Philippe, Nigel Kojimoto, Budi Gunawan, Frederick Driscoll. 2022. "A Self-Synchronizing Underwater Acoustic Network for Mooring Load Monitoring of a Wave Energy Converter." *Oceans' 2022* (in review).
- Abdellatef, M., J. Clark, N. Kojimoto, and B. Gunawan. 2022. "Finite element analysis and wear prediction of polyurethane-steel tension member belt for wave energy." To be presented at UMERC/METS 2022, Portland, Oregon, September 2022 (in review).
- Bosma, Bret, Ryan Coe, Giorgio Bacelli, Ted Brekken, Budi Gunawan. 2022. "Mini-DAQ: A lightweight, low-cost, high resolution, data acquisition system for wave energy converter testing." To be presented at UMERC/METS 2022, Portland, Oregon, September 2022 (in review).
- Sterling Olson, Rebecca Fao, Kelley Ruehl, Frederick Driscoll, Budi Gunawan, Chitra Sivaraman, Carina, Lansing, and Hristo Ivanov. 2021. "The Marine and Hydrokinetic ToolKit (MHKiT) for Data Quality Control and Analysis." Presented at European Wave and Tidal Energy Conference 2021, Plymouth, United Kingdom, Sept. 5–9, 2021.
- Beaujean, Pierre-Philippe, Bryan Murray, Budi Gunawan, Frederick Driscoll. 2021. "A Self-Synchronizing Underwater Acoustic Network for Mooring Load Monitoring of a Wave Energy Converter." Presented at European Wave and Tidal Energy Conference 2021, Plymouth, United Kingdom, Sept. 5–9, 2021.
- Bosma, Bret, Ryan Coe, Giorgio Bacelli, Ted Brekken, Budi Gunawan. 2021. "A lightweight low-cost data acquisition system for device testing." Poster presented at the 8th International Conference on Ocean Energy 2021, virtual, April 28–30, 2021.
- Pauly, R., F. Driscoll, J. Weers, C. Sivaraman, C. Lansing, M. Macduff, T. Shippert, T. Martin, K. Klise, B. Gunawan, K.M. Ruehl, S. Olson, and Z. Morrel. 2021. "Marine Hydrokinetic Tools (MHKiT)." Presented at the International Conference on Ocean Energy, Washington D.C., April 2021.
- Driscoll, F., C. Sivaraman, K. Klise, R. Pauly, B. Gunawan, C. Lansing, K.M. Ruehl, M. Macduff, T. Martin, and J. Weers. 2020. "Marine HydroKinetic Tools – MHKiT." Presented at the PAN American Marine Energy Conference, San Jose, Costa Rica, January 26–28, 2020. To be presented.

# Q&A