From Design to Ocean Deployment: Lessons Learned from the SURF-WEC Project in Hawaii

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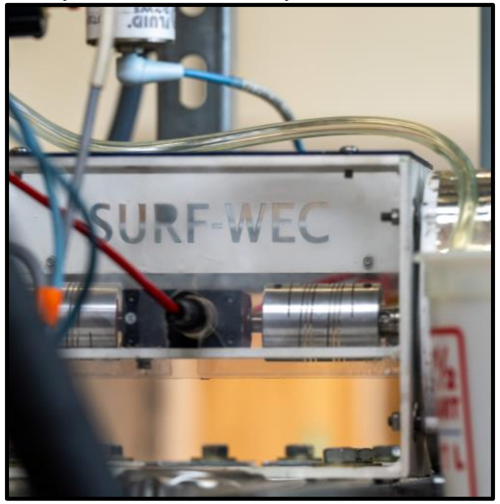
The Story of the SURF-WEC

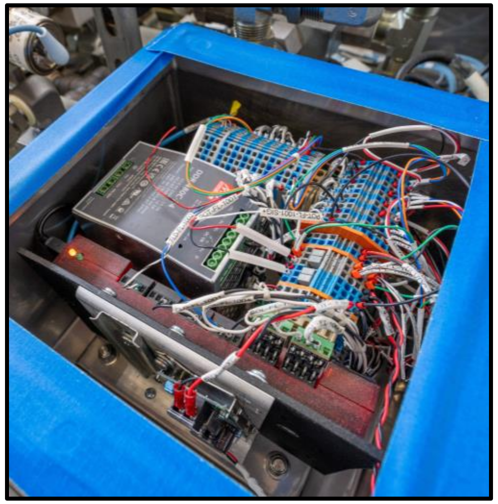
- 3 years
- 1 ocean deployment
- Over 70 Lessons Learned
  - 30 shared throughout presentation
  - Full list at end of PowerPoint

Not a standard. Not a recipe.

Lessoned learned (LL) or practice worth repeating (PR)
A little context into the SURF-WEC experience

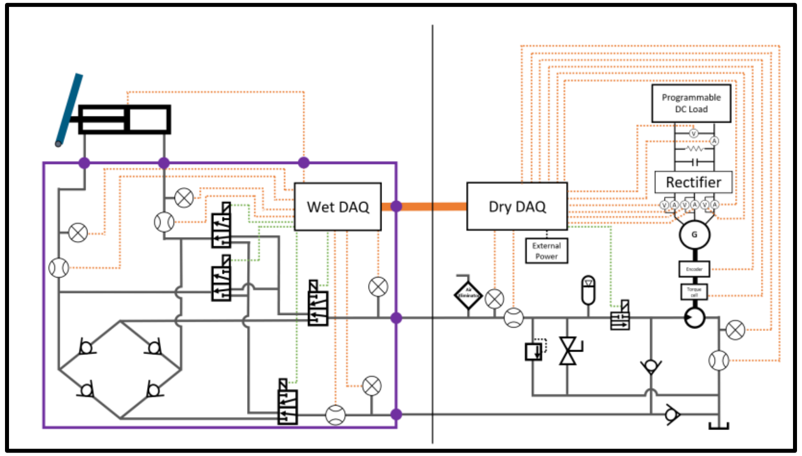
Photos taken by Josh Bauer and Taylor Mankle / NLR





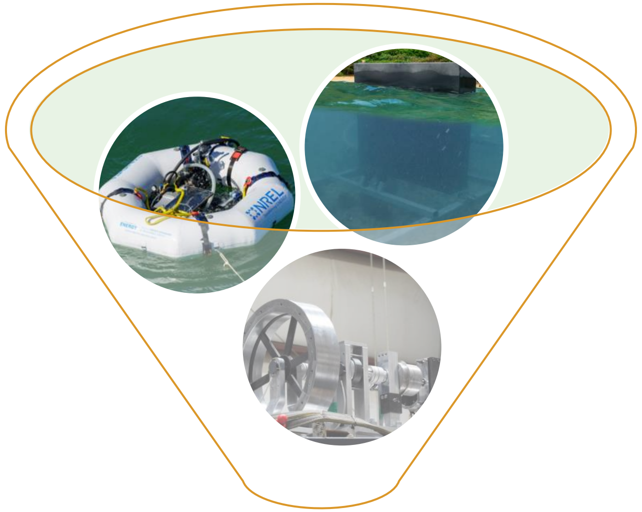
SURF-WEC: Small Underwater Research Flap Wave Energy Converter

HMEC 1m x 1m oscillating surge wave energy converter (OSWEC)



NLR design, build, test power take off (PTO)

SURF-WEC
Integrate OSWEC and PTO
Up to 1 year deployment



Open-Source Data and Lessons Learned for the Marine Energy Community

Why deploy a small WEC?

- Less than 100ft from pier
- Water depth 3-5ft
- Component bundles less than 1,000 lbs

Kilowatt Deployment

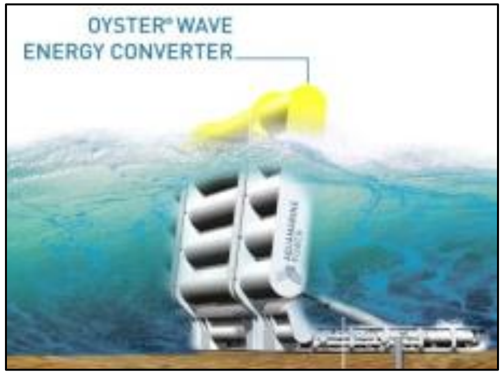
Watt Deployment

Modeling

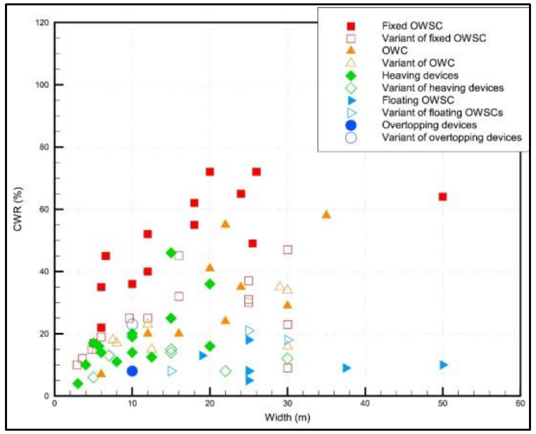
Risk, Cost, Time

12m x 18m

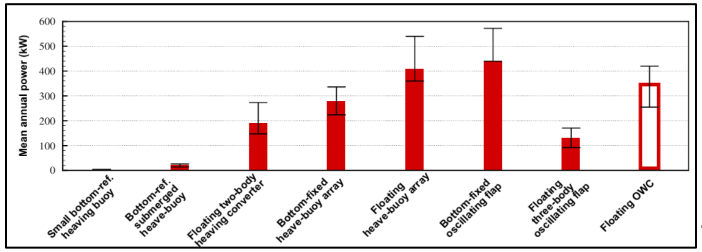
300-600KW



Renzi, Doherty, Henery, and Dias (2014)



Babarit (2015)



Babarit, Hals, Muliawan, et al. (2012)

Three goals guided decisions throughout the project

Deployment

Learn what is required for the deployment, operation & maintenance, and retrieval of a small-scale OSWEC with PTO

PTO

Evaluate a PTO providing another data point for tuning simulations

Report

Provide useful open-source **data** and **lessons learned** for the marine energy community

Know your goals (PR)
Having three very clear goals reduced scope creep and answered critical crossroad questions

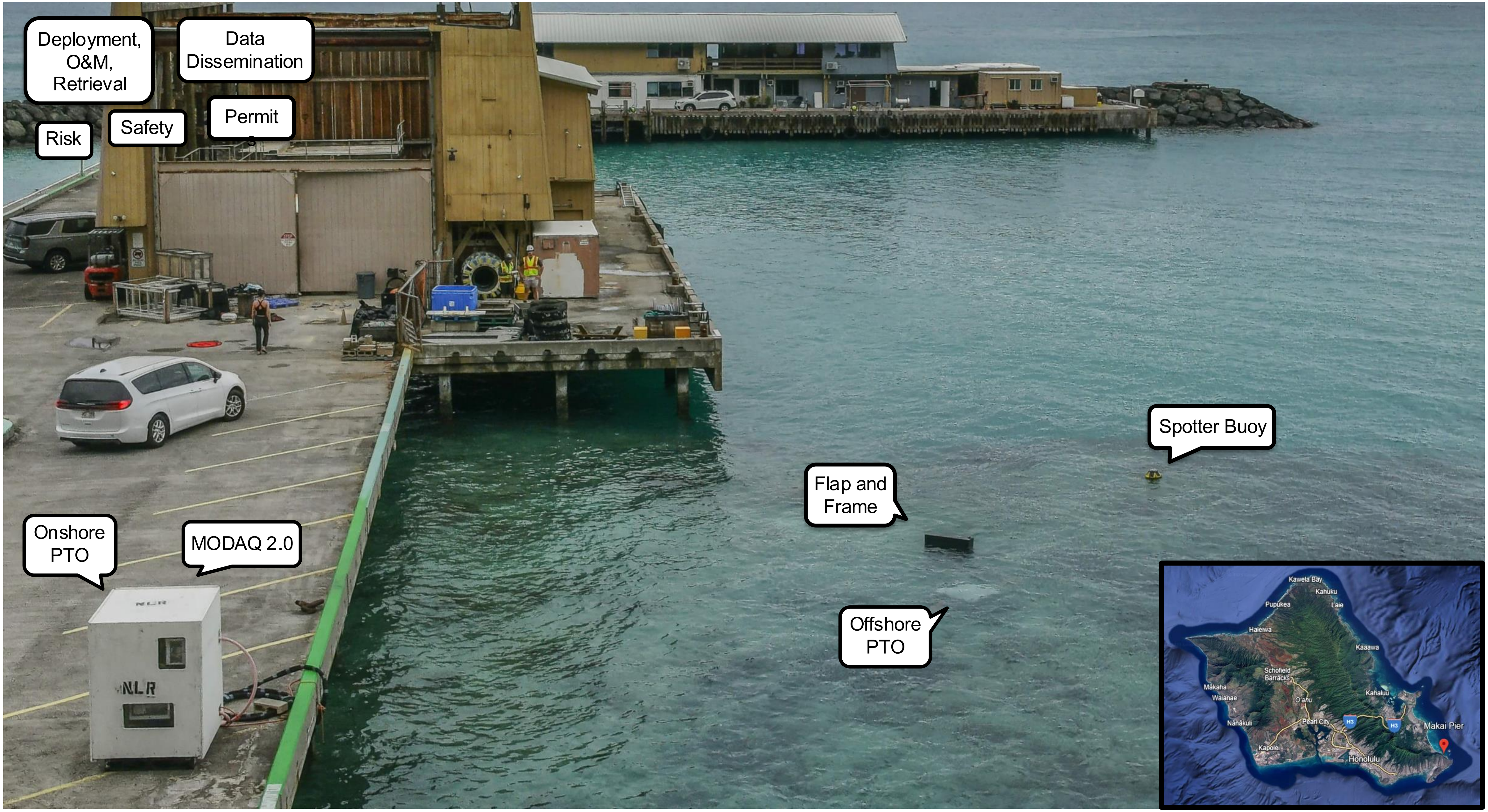


Photo taken by Josh Bauer / NLR

Permits

Agency	Permit
Essential Fish Habitat - NOAA	NEPA Consultation
National Marine Fisheries Service - NOAA	NEPA Consultation
US Army Corps of Engineers, Honolulu District	USACE NWP5 – Spotter Buoys
	USACE NWP5 – SURFWEC Frame
US Coast Guard	USCG PATON
Hawaii Department of Land and Natural Resources	Right of Entry
Bureau of Ocean Energy Management	Not Required- Not deploying in federal waters

Make permits as broad and all-inclusive as possible (PR)
When possible, lengthen dates, and include optional equipment that you think you may want to deploy
LL- include drone flights for taking pictures during deployment if wanted

Permits will take longer than you think
Permitting took about 2 years for this small-scale project

Determine which permits are required as soon as possible and start pursing all permits (LL)
You never know how long a permit will take, pursue ALL permits early

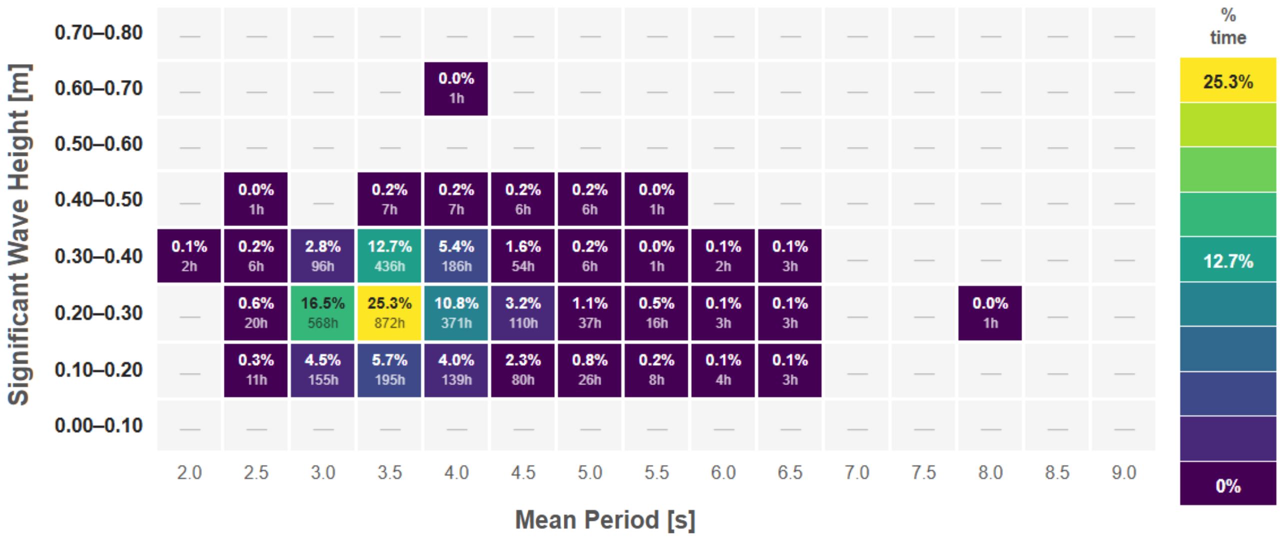
2-year process to acquire all required permits

Wave Characterization

- 3 Spotters deployed
- 1 spotter sits ~20ft in front of the WEC

Wave Resource - Joint Probability Distribution

Mar 18, 2026 – Aug 11, 2026



* % of total hours per sea state bin | Hm0 bin = 0.1 m | Tm bin = 0.5 s | grey cells = no data

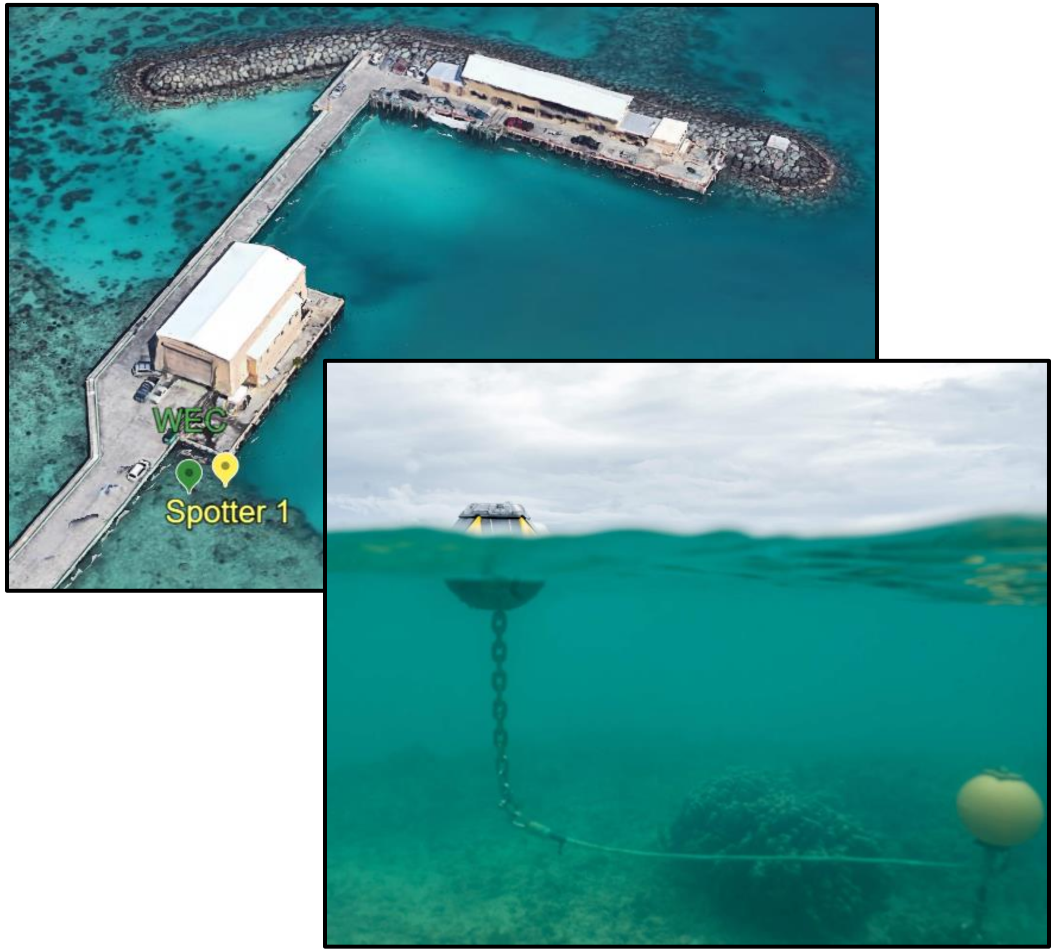


Photo taken by Josh Bauer / NLR

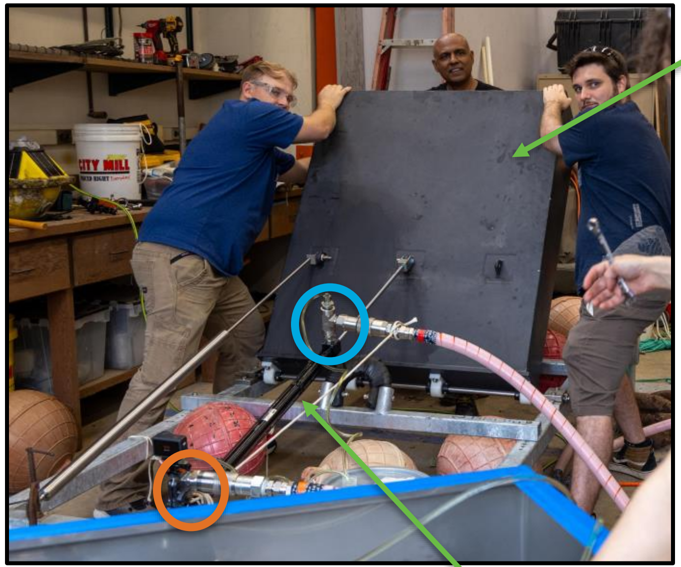
Hydraulic PTO

Off the Shelf Components

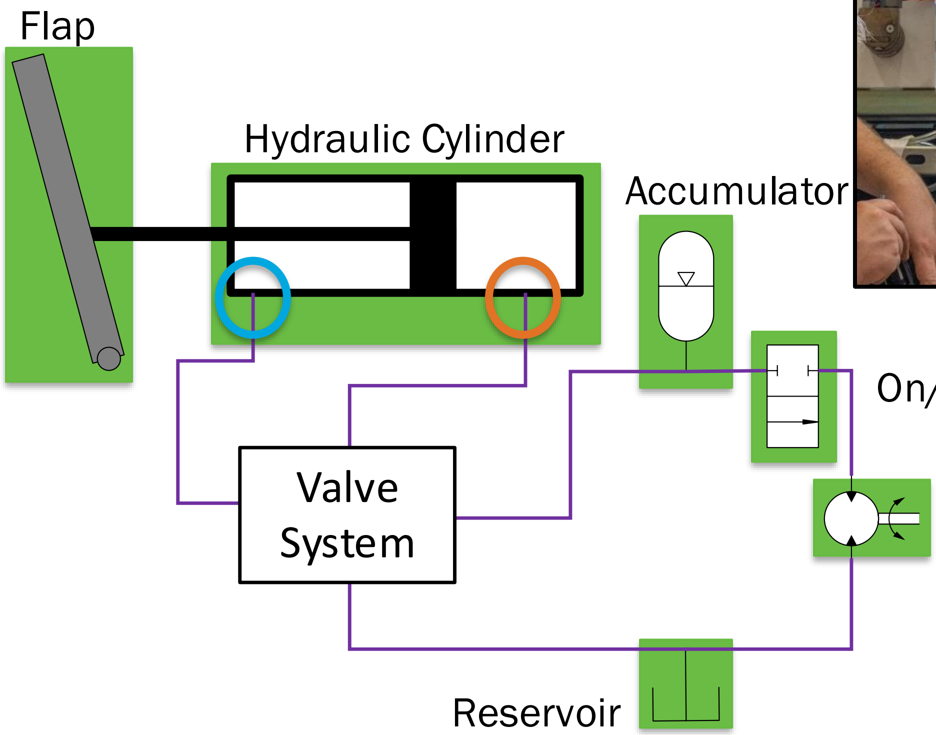
Scalable

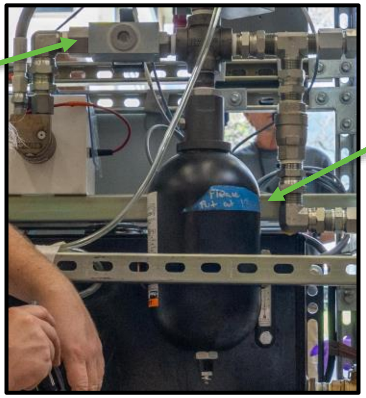
Easier to Marinize

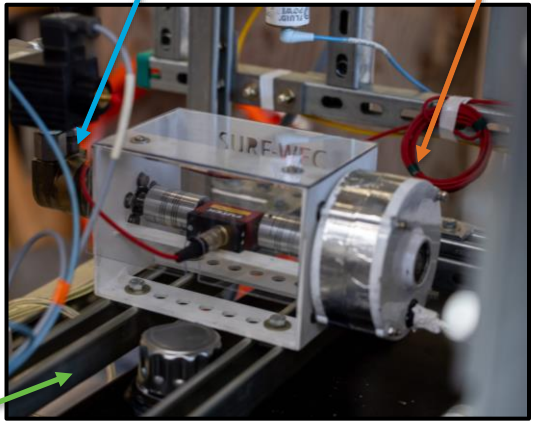
Minimal Effect from Line Length (distance from pier)



Photos taken by Taylor Mankle / NLR



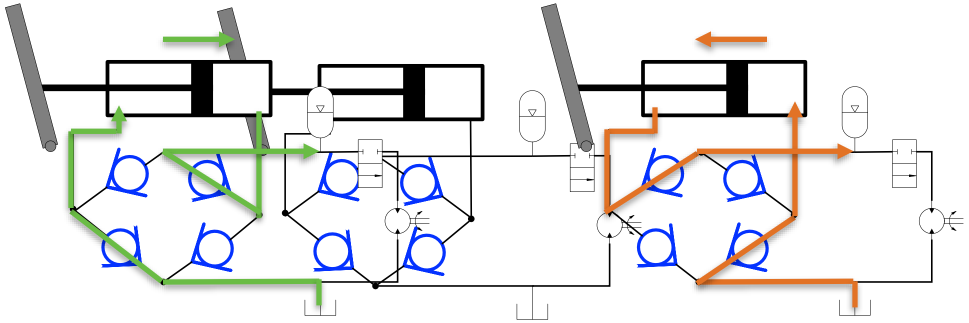




Power Take-Off

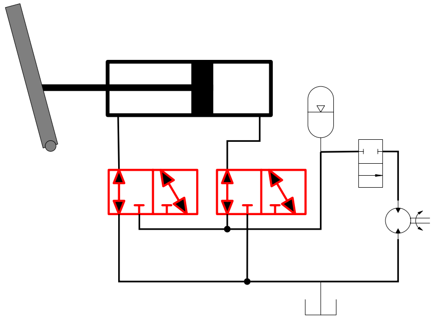
Passive Valving System

- Rectifying Circuit
- Energy always from flap to accumulator
- High pressure → Accumulator
- Low pressure ← Tank



Active Valving System

- Energy can be put into flap to be closer to resonance
- 4 discrete pressure options
  - High Pressure to either Accumulator or Tank
  - Low Pressure to either Accumulator or Tank



Valve connection is independent of flow direction

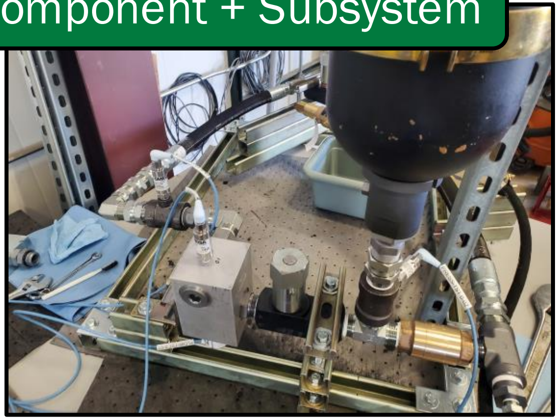
Theoretical ideas and practical systems do not align (PR)
Increase time and budget for unexpected experiences

Clearly define what you are using your model for (LL)
Do components need to be easily scalable? What accuracy do you require?

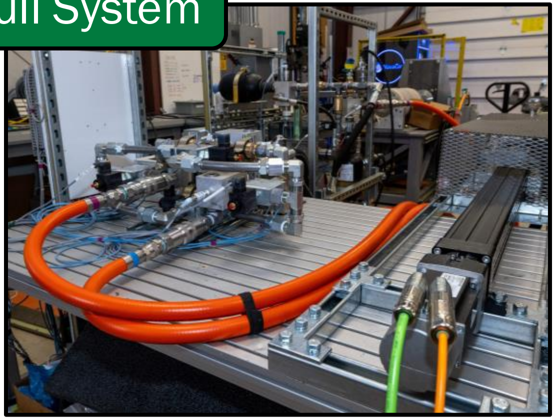
Testing

Photos taken by Taylor Mankle, Josh Bauer and Gregory Cooper / NLR

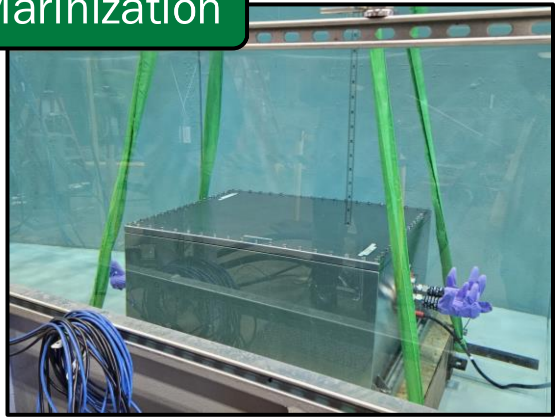
Component + Subsystem



Full System



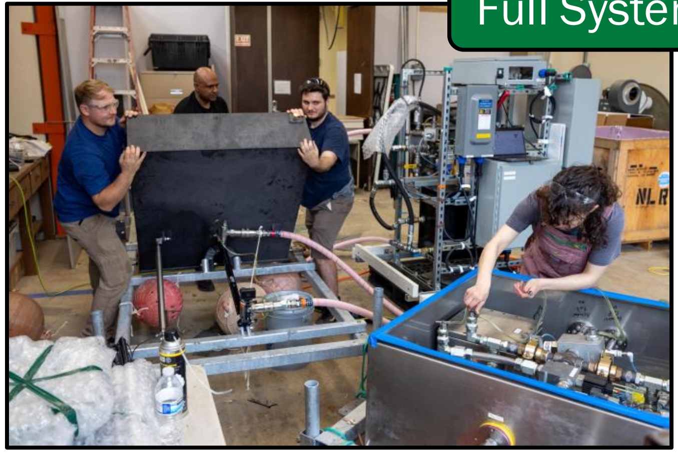
Marinization



Full System

Ship

Full System



Component testing before full system (PR)
Subcomponent testing reduces total test time

Plan for testing at every stage
If it doesn't work in the lab, it won't work at sea

Prioritize function over performance (PR)
If it works is more critical than how well it works

Post Marinization Testing

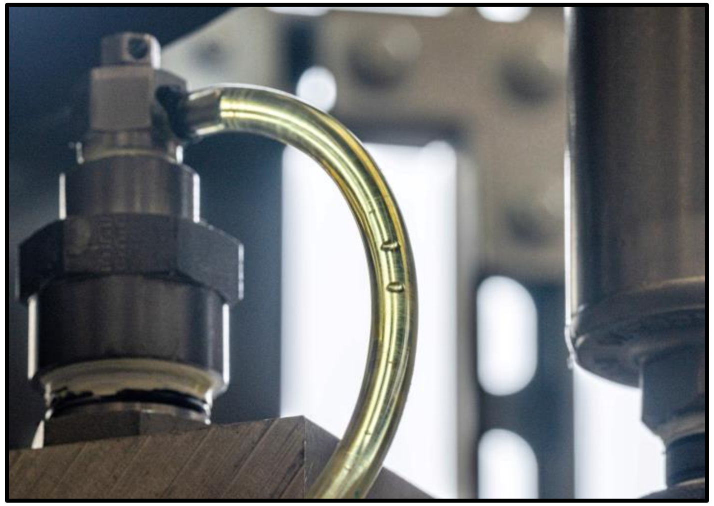
- **Expectations:**
  - System will perform as in pre-marinization
  - Should be a simple test
  - Little time required
- **Reality:**
  - System initially didn't work
  - Tracked air bubble issue without checking the rest of the system
  - Took multiple weeks of troubleshooting to find and fix the issues

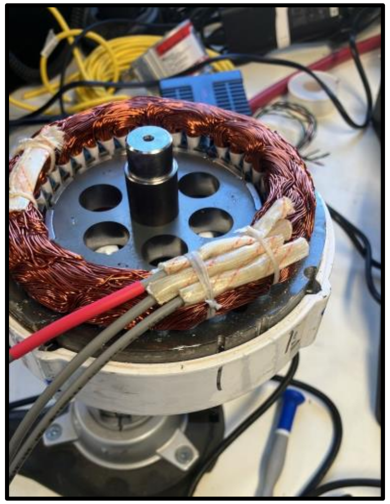
Design for easy flushing and purging of hydraulics (LL)
Think about where air will get trapped and design for ways to get it out

Evaluate the system before focusing on individual issues (LL)
When possible do not immediately focus on the first problem you see, instead find all the problems first

Test applicable procedures before deployment (PR)
Oil flushing procedures were changed based on learnings from testing

Photos taken bv Josh Bauer and Mark Murphy / NLR





Dry Commissioning

- **First time integrating the flap with the PTO**
- **Test system after shipping before deployment**
- **Expectations and reality matched**

Emphasize how systems from different teams will integrate (PR)
Test integration early on or at least make sure all teams are on the same page

Script out very detailed procedures (PR)
Everyone being on the same page prior to deployment is critical

In water personnel should be apart of setting up the system prior to deployment (PR)
Water makes everything more difficult, learn it out of water first

Photo taken by Josh Bauer / NLR

Weather Contingency

- **Expectation**
  - "let's have a 3-day weather contingency, we will never need it though" –Local Team Member
- **Reality**
  - O'ahu experienced historic Kona low storm
  - The entire weather window was required

Include a weather contingency even if you expect to never use it (PR)
Assume a bad storm will come through during your deployment

Trust the weather judgement of local team (PR)
The local team knows how weather translates to ocean conditions

Prepare on and offshore equipment for the worst weather (LL)
Forecasts can be wrong, prepare for the worst

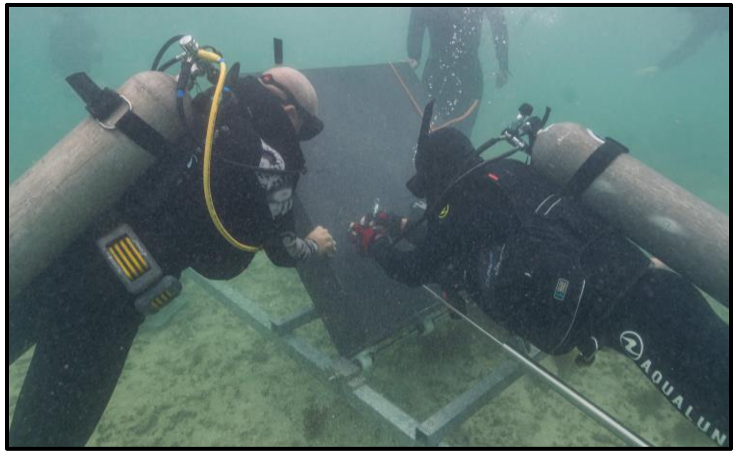
Photo taken by Josh Bauer / NLR

Deployment

- Deployed in sections with a forklift
- 2 divers and 2-3 swimmers
- System was stable immediately after deployment
- Expectations and reality matched

Have one clear deployment lead and hold daily "Plan of the Day" meetings (PR)
This ensures everyone is on the same page and one person is aware of everything going on in and out of the water

When designing components design for the high impact from deployment activities, not just longevity (LL)
Many times, the highest loads will be seen during deployment or retrieval activities



Photos taken by Taylor Mankle and Josh Bauer / NLR

Flap Deployment

- **Expectation**
  - Fully flooding the flap would take 6 minutes
  - Flap would be “easy” to maneuver once fully flooded
- **Reality**
  - Time in water feels different than time in lab
  - Flap was buoyant through all of deployment
  - Difficulty in aligning the flap with the flap anchor

Choose your tide intentionally (LL)
The more the flap is surface piercing, the less divers are fighting the buoyancy of the flap

Deploy flap anchor before flap (PR)
Flap can be difficult to manage underwater, deploying flap anchor alone allows for more precise positioning

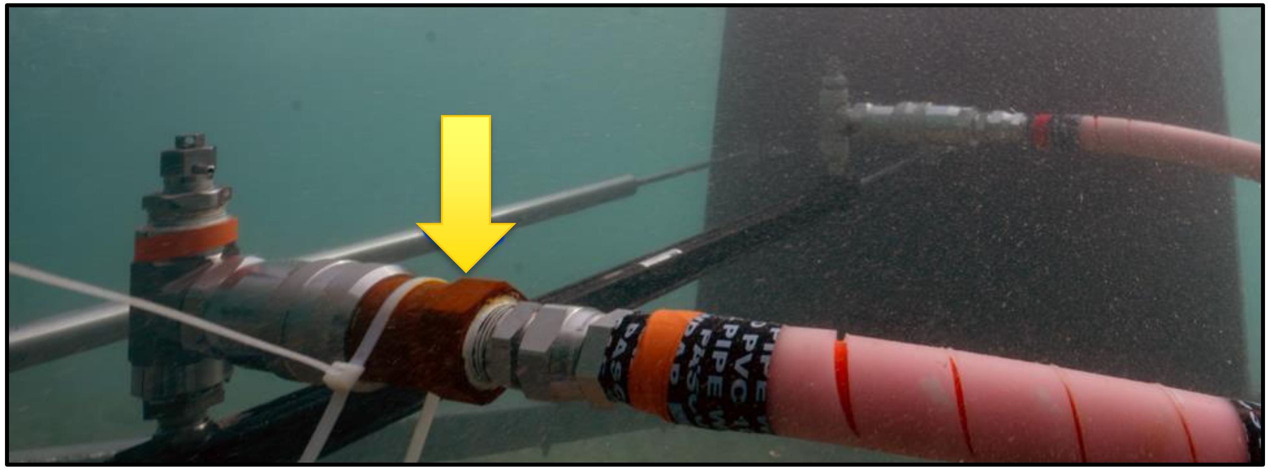
Consider large guides for mounting flap to anchor (LL)
Difficult to align the flap with its anchor connection points

Photos taken by Josh Bauer / NLR

24-Hours into Deployment

- System fully operational
- Found a fitting to be rusty
- Fitting was sold as 316 SS
- 5 other units of the same part sit under water, all looked fine
- Part number looked correct
- Bought from a reputable supplier

Consider testing components with a magnet or in salt water (LL)
Extra check on materials before deployment



Photos taken by Josh Bauer / NLR

Remote Monitoring – MODAQ 2.0

Significant Wave Height: 0.42m	Mean Period: 4s	Average Power: 6.4W

Automatically re-start MODAQ after failure (PR)
Even if equipment is accessible (on the pier), it still takes time to get there, make it as hands-off as possible

Email alerts/text messages are useful for operation team (PR)
Receiving text messages about system issues allows for the issue to be dealt with sooner

Current Status – 8/11/2026

System continues to operate properly, producing power and collecting data

Days in Water	146
Data Collected	3.3 TB
Energy Produced	5.9 kWh
Average Power	1.7 W

Have a "first in line" sensor (PR)
A sensor that can be considered the first input in the system is helpful for debugging

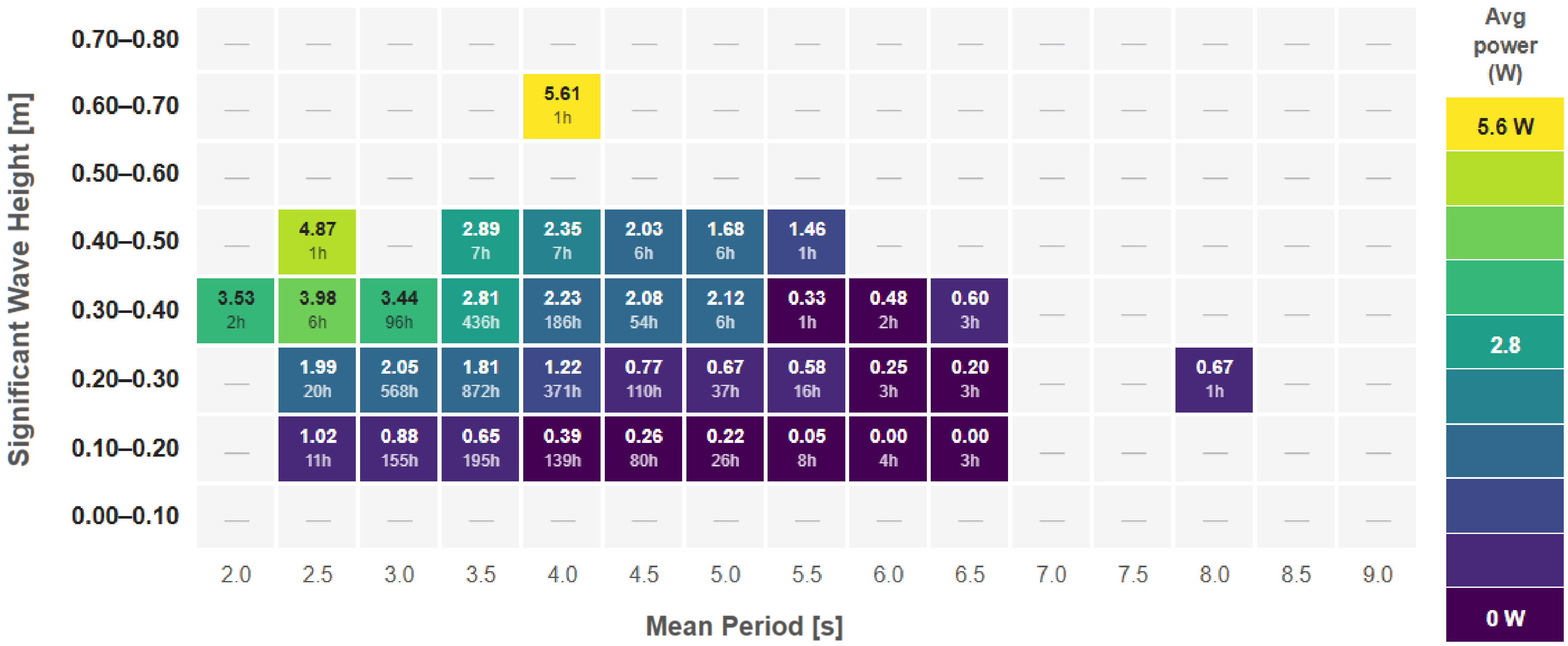
Test failsafe conditions (LL)
Physically going through failsafe situations in the lab may flag new issues

Video taken by Kimball Millikan / HMEC

Current Status – 8/11/2026

SURF-WEC Power Matrix

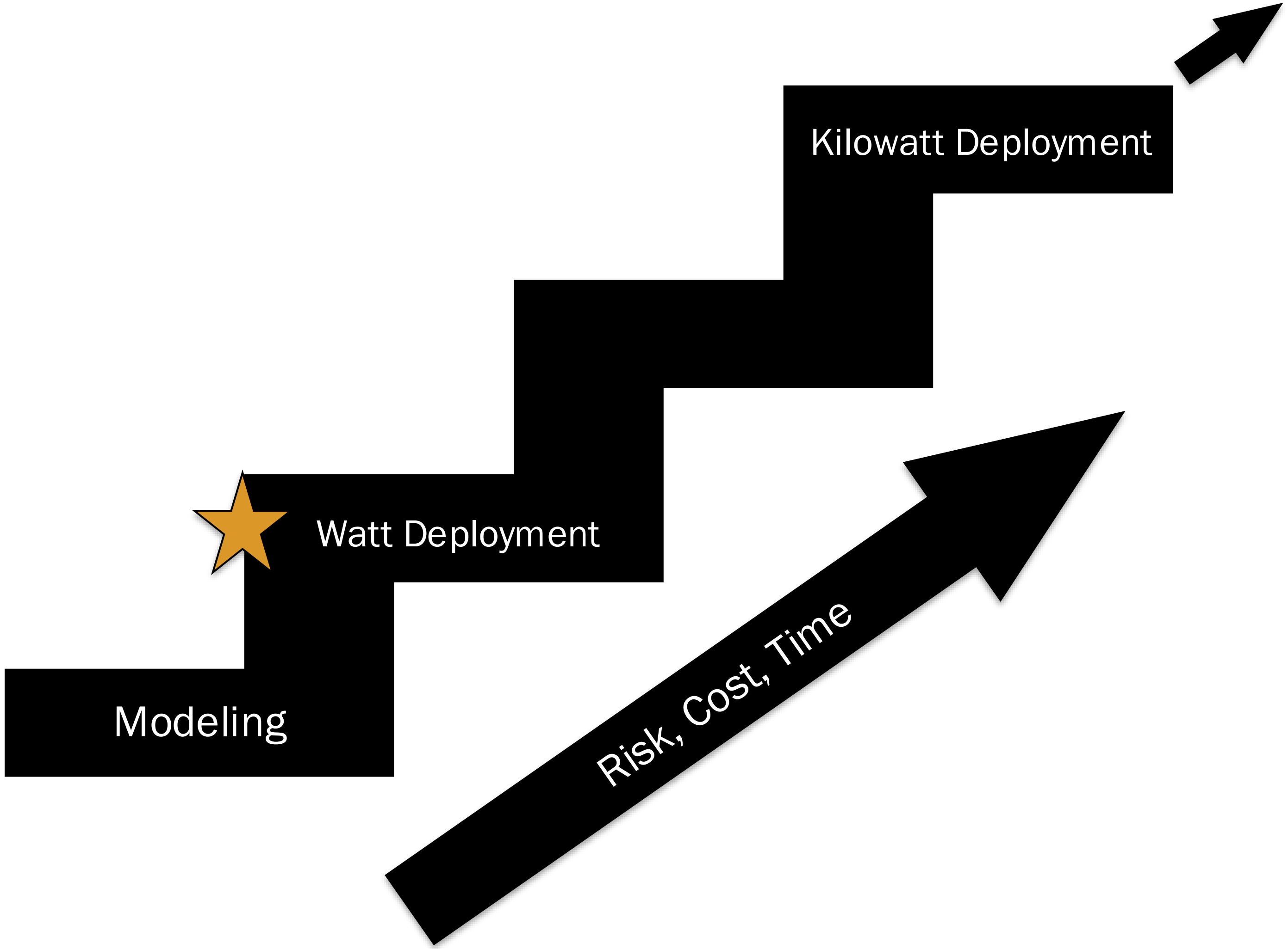
Mar 18, 2026 – Aug 11, 2026



* Average power (W) per hourly sea state bin | Hm0 bin = 0.1 m | Tm bin = 0.5 s | grey cells = no data

Impact

- Theoretical knowledge ≠ practical knowledge
- Small deployments generate useful lessons learned and data for larger systems

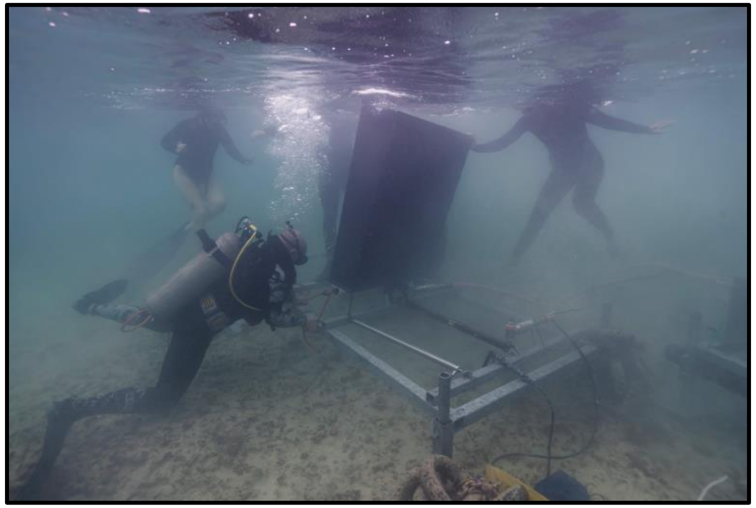


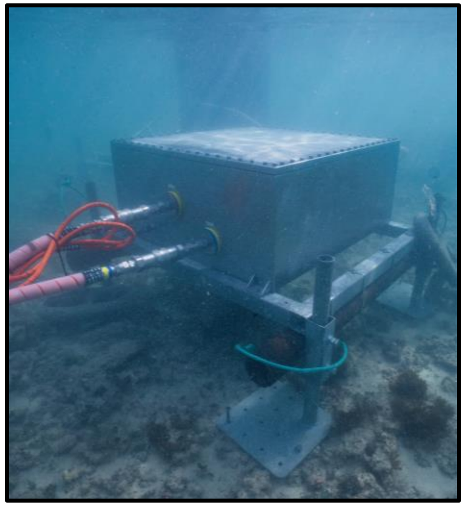
Update documents regularly
The more documentation, the more the project can be learned from

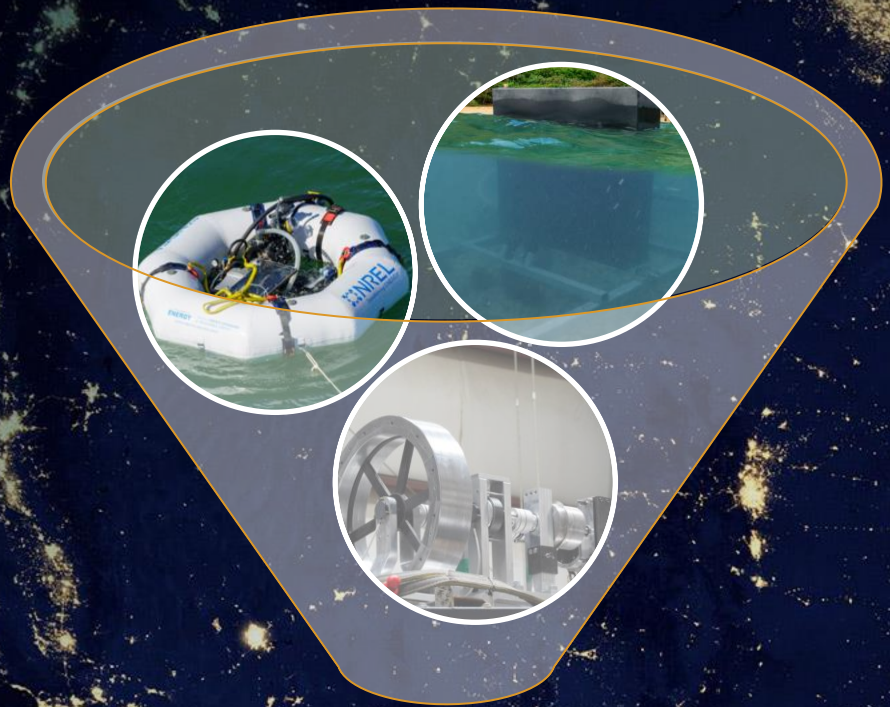
Future Work

- Monitor system for up to 1 year
- Test tunable parameters
- Maintenance and Retrieval
- Analyze raw data
- Upload lessons learned and data to MHKDR
- Continue to update lessons learned

Photos taken by Josh Bauer and Taylor Mankle / NLR







MHK

Open-Source Data and Lessons Learned for the Marine Energy Community

Questions

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National Laboratory of the Rockies

HMEC
HAWAI'I MARINE ENERGY CENTER

Photo from Getty Images 181828180

SURF WEC Lessons Learned – June 2026

Overall

- **Know your goals (PR)** – Have very clear goals that the whole team can use as a guide to what is being worked towards. This prevents scope creep and helps answer critical crossroad questions. *This project had three very clear goals and continued to return to them during critical discussions.*
- **Whenever possible emphasize making something that works, even if timelines or budgets need to shift (PR)** –Whenever possible work with stakeholders to shift budget, timeline and/or scope as needed so the project has a chance at being successful under rapidly changing conditions. Choose what makes sense for the project based on risk and resources. *The project continued to push back timelines to confirm that the system worked. If the timeline had not been pushed back multiple times, the WEC would not have been successfully deployed and would not have made power for so long.*
- **Sponsors emphasis on success and not timeline was critical for success (PR)** – Know how "real" the timeline is. *This project had "made-up" timelines, not having pressure from sponsor to stick to "made-up" timelines enabled this project to be successful.*
- **Theoretical ideas and practical systems do not align, plan mitigations (budget, timeline, personnel)** – Increase time and budget for things to go very differently than a model.
- **Evaluate as much of the system (or component(s)) as you can before starting to solve any issues (LL)** – If possible do not immediately start solving a problem once you see it. Evaluate everything you can and understand as many issues as possible before starting to solve one, this can save time in the long-run. *The system did not work due to air bubbles during post marinization bench testing, before focusing on solving the air bubble issue, everything else in the system (i.e. all sensors) should have been checked.*
- **Hold regular tactical meetings (if desired) (PR)** – Having senior personnel hear regular updates on the project provided regular feedback and guidance to an early career led team.
- **Complete TQAF Reviews (PR)** – TQAF reviews (including the design review, test readiness review and deployment readiness review) are helpful for forcing documentation are receiving feedback at critical points in the project. *For example, to prepare for the deployment readiness review our team was forced to talk in very specific detail about deployment procedures and then communicate that with the review team. This enabled us to see potential issues and determine solutions before deployment started. These reviews also provide great documentation for the team to look at later on.*
- **Evaluate if it works and can survive, before evaluating how well it works (PR)** – Do not focus on performance until you have confidence in the system working, producing power inefficiently is better than the system breaking shortly into deployment.
- **Have one document with all critical design numbers-** This is especially important for multiple people who need to complete design off of these numbers, it is crucial that everyone is working off of the same numbers.

Model

- **A model that is easy to change but less accurate may be preferred (LL)** – This is research, things always need to be changed. Consider building models for easy tuning and scaling, even if this comes with a loss of accuracy. *The initial model was built for accuracy but not tunability. The team later switched to a model that could more easily be tuned to understand how different components would perform.*

Permitting

- **Make permits as broad and all-inclusive as possible (PR)** – Lengthened the dates for timeline slipping and included a camera as optional equipment. **(LL)** – Include drone flights for comms.
- **Permits will take longer than you think** – Allow time for permits to take a while. *Permitting took about 2 years for this project.*
- **Find out what permits you need as soon as possible and start pursing all permits immediately (LL)** – Permits you think are simple may take a while. *We didn't pursue the state permit till the very end of our process and this caused a delay in spotter buoy deployment.*

SURF WEC Lessons Learned – June 2026 Continued

Design, Build and Test

- **Complete sub-component testing before building a new system (PR)** – Sub-component testing requires time and budget but will likely save time and budget over the course of the project. Subcomponent testing supports better models and allows for a better understanding of individual components. Issues can also be caught before the system is fully built. *During Test 0 the team evaluated individual and sub-components using a simple hydraulic circuit. Test 0 saved the project a significant amount of time and supported producing better results.*
- **Be intentional when sizing components (LL)** – Know if a component has a minimum or maximum required specification. In research it can be nice to oversize components for extra play. *The accumulator was sized for what was needed, there would have been more room to play if it was oversized.*
- **Don't make last minute changes unless necessary (LL)** – Are you making the system ever so slightly better or are you making a critical change? Things do not go to plan; a simple change like tightening a fitting can lead to a broken fitting of a critical component or a broken O-ring.
- **Have spare parts when you can** – Cheap critical components or long lead time parts should have spares if possible. If other projects use similar parts (i.e. MODAQ components) it is even easier to have spares on hand.
- **Select robust components** – Cheaper in the short term does not always mean cheaper in the long term. Select robust equipment based on required service life.
- **Test failsafe conditions (LL)** – Physically going through failsafe situations in the lab (when possible) may flag new issues. The p*rogrammable DC load needing to be manually turned back on every time power is lost has been a large lift for local personnel. Requiring about 3 hours (transit to and from pier plus opening box to turn on system) every time the system loses power. This issue would have been known (and maybe mitigated) before deployment if the team had gone through a lost power scenario.*
- **Allocate more time for shipping preparation (LL)** – NLR shipping and receiving does not build crates in house, they contract it out. *NLR shipping and receiving made an exception for us; it would have taken longer if they didn't.*
- **Minimize bending sheet metal (LL)** – Equipment is less likely to align when bent. *This still needs to be validated (a mistake may have been made prior to the bends done for this project).*
- **Be intentional with your material selection** – Confirm material compatibility and select the material best for the job (including risk and cost).
- **Plan for a testing at every stage** – If it doesn't work in the lab, it is not going to work in the ocean. Schedule and plan for enough time to fully bench test the system.
- **Consider testing components with a magnet (LL)** – Parts are not always what you think they are. If they are magnetic, they are not 316 SS. *24 hours after initial deployment a supposably 316 Stainless Steel part was fully rusted. After further investigation it is unclear why this part was not stainless steel. The part has since been confirmed to be magnetic. The part number engraved in the part is correct (although in a different location than others of the same part), and the manufacture does not make an equivalent steel version. The same part number has a total of 6 units underwater and 4 units above water, 11 of them have not rusted. It would have been nearly impossible to know this part was not 316 stainless without some sort of material testing (with a magnet, or pre-seawater submersion).*
- **Consider testing components in a saltwater tank (LL)** – Parts are not always what you think they are. This is a test to see if they rust in a few days prior to deployment. Note this test could be time consuming, costly and difficult, only do this if it makes sense for the project. *Same experience as "Consider testing components with a magnet (LL)"*
- **Record serial numbers of components that have them in BOM (LL)** – Parts are not always what you think they are. Confirm you got what you purchased by looking at serial numbers on the parts and comparing them to receipt and quote. *Same experience as "Consider testing components with a magnet (LL)" though the serial number was still correct on the part, so although this is a good practice it would not have caught this issue.*
- **When designing components design for the high impact from deployment activities not just longevity (LL)** – Many times the highest loads will be seen during deployment or retrieval activities, design for these loads just as much as normal operation and longevity. *Less emphasis was placed on designing strain relief for "high-impact" deployment activities, during design the bigger focus was long-term sitting in the water. In-water personnel was concerned about hitting some of the connections during deployment.*
- **Put emphasis on how systems or components from two different teams integrate** – A critical part of a system can't always be tested beforehand if the integration between components of two different teams is required. Put a lot of emphasis, making sure there are no communication errors between the teams. If possible, send components between teams before deployment for initial integration and time for fabrication or changes as needed. Another consideration is to purchase multiple units of the critical components for both teams to test. *Our team was unable to send components early (flap and frame could have come to CO, or cylinder and position sensor could have been sent to HMEC) but could have built this into our schedule and budget. Instead, we spent a few meetings discussing the integration between the two teams components. If the integration was more complex something could have been easily overlooked.*

SURF WEC Lessons Learned – June 2026 Continued

MODAQ

- **Control Rules can be complex and require tuning and refining time** – Lots of iterations are required, build this into the schedule and budget.
- **If possible, test the quality of the cell network in the area (PR)** – Knowing the quality of the cell network before using it allows the team to plan. If comparing the network to your phone, make sure you turn off 5G if the system won't be using 5G.
- **Use Github (or similar) to track code changes (PR)** – You will want to know when or why specific code changes happened, track the changes and make notes on who made the change and why.
- **Have clear dates on code freezes (LL)** – Make sure everyone is aware of when code or design freezes are in-place. If any changes have to happen after a design/code freeze (this is research so they 100% will happen) make sure everyone is aware immediately that changes have occurred. Consider having the list of all relevant parties and send an email to all parties whenever a change is known to be needed and again when the change has happened. Consider having a formal Management of Change process.
- **Have multiple people who know the system (PR)** – Having multiple people to reach out to when an issue arose was incredibly helpful. Valuable testing time was not lost because one person was unavailable.
- **Consider a UPS or back-up battery system for barebones MODAQ (LL)** – Consider a minimal power mode that uploads a few sensors of data or even just provides a ping to let remote users know the system is still functioning and there is just no power. *When the pier loses power there is no way to know what is going on with the system, is the system broken or is there just no power.*
- **Have MODAQ automatically re-start in failure mode (PR)** – MODAQ restarting automatically after losing and then regaining power reduces the need for personnel to go to the equipment and quickens the time that remote personnel can check the health of the system.
- **Email alerts and text messages are useful for development team (PR)** – When the system has been rebooted (intentionally or unintentionally), it is useful for the development team to know something happened to the system to investigate the cause if unintentional.
- **VPN connection is critical to system monitoring (PR)** – Unless personnel can physically go to the system, a VPN/remote access is required to ensure health of the system and DAQ and perform maintenance or apply updates if needed.
- **A flexible IO subsystem is useful in the event of having to switch the type of sensor used for a measurement (PR)** – This is research, things will change plan for change of measurements ahead of time as much as possible. *Towards the end of marinization, the torque sensor was found to be broken, and the same torque sensor had a 14 week lead time. The new torque sensor was a +/-5V output rather than the previous 2mV/V output. The flexible IO subsystem made this a relatively low lift to change on the hardware and software side.*

Hydraulic

- **Design the system for easy flushing/purging, think about local and global low and high points, minimize horizontal runs (LL)** – Hydraulic systems rely on purging the system of air, when designing the system think about where air will get trapped and design for ways to get it out. Horizontal runs and local high points are two places air is easily trapped. *Due to poor air purging design, it took multiple weeks to learn that air was the issue and find a solution to purge the system of air.*
- **Place reservoir at an intentional height relative to the rest of the system (LL)** – If you are using gravity to "pull" from the reservoir place the reservoir high, if you are using a pump to "pull" from the reservoir place the reservoir low. *The system was designed to "pull" from the reservoir using gravity, but the reservoir was not at the very top of the system. When the reservoir was sitting at ground level in the lab, gravity was not being used and instead suction was relied on which was likely not strong enough. The onshore system was then moved to sit on top of a table so the reservoir would be higher.*
- **Know all possible flow paths (PR)** – Knowing all possible flow paths makes debugging the system much easier. If changing the flow path is possible, issues can be narrowed down to more specific sections of the system. This is also critically important to understand where pressure can build and be stored in the system. *By testing different flow paths when an issue (i.e. air bubbles) was seen, we could pinpoint where the issue was in the hydraulic system, allowing us to solve the issue faster.*
- **Include easily cleanable filters (LL)** – Teflon (among other debris) will get into the system, if possible include accessible filters so that the debris can be removed from the system. *While testing a failure state, Teflon got stuck in the pressure relief valve which made the pressure relief valve leak hydraulic oil to the reservoir at any pressure, therefore the relief valve had to be replaced.*
- **Confirm compatibility between hydraulic fittings (LL)** – *Swivel fittings were NPSM not NPT, and an NPSM male fitting was required for connection to minimize leakage.*

SURF WEC Lessons Learned – June 2026 Continued

Deployment

- **Test as many procedures as possible prior to deployment (PR)** – Any procedures that can be tested before deployment should be tested and re-written as needed. *Oil flushing was tested before shipping the equipment and found to be difficult, because of this bleeder ports were added and the system was shipped filled with oil.*
- **Write (and draw) very detailed procedures (PR)** – Going into as much detail as possible will ensure the team is on the same page and find and solve issues prior to deployment. Budget for this to be done.
- **Have a daily "Plan of the Day" meeting (PR)** – Go over plans for the day, safety notes, and lessons learned from the previous day. *Having daily meetings kept everyone on the same page, allowing for everyone to know their individual roles/tasks for the day and the teams' overall goals.*
- **Have one person as the lead (PR)** – Have a clear lead and sub-leads, having sub-leads both in and out of water, this ensures everyone is on the same page and ensure that one person was aware of all major decisions.
- **Consider a UPS, or battery/generator system to be less reliant on grid power for data collection (LL)**
- **For a multi-day deployment consider first day in water having less tasks, allowing for time to make changes** – Plan for a larger learning curve during the first deployment task. *Deployment of the flap frame before pausing outdoor operations for the storm allowed the team to evaluate how the flap frame deployment went and make changes to improve the rest of deployment. This would not be applicable for many projects and is a "nice to have." During the flap frame deployment the hard floats started to float away because there was not an easy way to secure them. During later deployment activities more lines were dropped from the pier with carabiners connected for easy gear attachment.*
- **When there are multiple components, the head diver (and preferably any in-water personnel) should be a part of setting up system out of water (PR)** – This will make setting the system up in-water much smoother, it is critical that the in-water personnel are comfortable setting up the system without input from pier personnel. *The head diver and 1 swimmer were a part of HMEC dry commissioning, they saw how the system was set-up when fully put together. For example, they knew where the two frames needed to sit relative to each other so the hydraulic cables could reach between the two.*
- **Ask local personnel about power outages if the system is reliant on grid power (LL)** – Understand the situation as much as possible before making decisions. *Knowing power outages are common on the pier may have led to a different power supply decision.*
- **In-water personnel should not be required for pier operations (LL)** – *The fork-lift operator was also the diver, requiring them to run from forklift operations to water operations. Procedures would have gone more seamlessly if the fork-lift operator was not a diver or swimmer.*
- **Calculate expected weights of components and then verify by weighing shortly before putting into the water** – Knowing the weights of all equipment is critical to be able to plan properly for buoyancy. Put all this information in one place, have expected weight and volumes of equipment and then add measured weights.
- **Test system after shipping before deployment (PR)** – Testing just before deployment (after shipping) provides piece of mind that the equipment is fully functional before being deployed. If there was any issue once deployed, the team would know it was not an issue from shipping.
- **Include a weather contingency even if you think you will never use it (PR)** – Allow sufficient buffer time for unexpected weather conditions (e.g., severe thunderstorms, tropical or subtropical storms, heavy rainfall, and flash flooding). *Prior to deployment, we experienced a severe Kona storm that led to an emergency proclamation by the state governor and a statewide suspension of non-essential services. Although we never expected to use our weather window, we used the entire contingency.*
- **Include contingency for things to take longer than expected (PR)** – Planning with a contingency allows safer and smarter decisions to be made in the moment.
- **Minimize tools required underwater** – The less tools needed underwater the better, divers have enough to deal with, and tools are easily misplaced. *Bolt sizes were minimized, so only two different wrenches were required.*
- **Ensure the spaces being used have the amenities required (PR)** – Talk about the space to be used for setting up and what amenities are needed. Think through what will be done, do you need power, garage doors, a forklift, nitrogen tank, bathroom, water access, etc.
- **Be intentional with number of personnel in water (PR)** – To many people in the water will clutter the work, have just enough people to get the job done safely and efficiently. Think through everyone's individual tasks.
- **Prepare the equipment for the worst storm, even if you don't think it is coming (LL)** – Prepare both the in-water and onshore systems to withstand severe weather and natural hazards, including tropical and subtropical storms, earthquakes, tsunamis, and flash flooding. Given the inherent uncertainty in weather forecasts, ensure that onshore and offshore systems are always fully secured—even when major events are not anticipated. *The onshore system was not tied down immediately because major weather wasn't forecasted. The forecast was wrong and although this did not damage the system it could have.*
- **Confirm 24/7 access to the deployment site is possible for the length of the deployment (LL)** – Even if you don't think you will use it, try to have the option of 24/7 access to the device. *We lost power the first weekend the device was deployed, it would have been very nice to be able to reset the gfci during the weekend so MODAQ could be powered on.*

SURF WEC Lessons Learned – June 2026 Continued

Deployment Cont.

- **Trust the weather judgements of local team** – Balance the forecasted weather with the local teams site experience.
- **If you know how long something should take consider setting a timer when it starts, time feels different in the ocean (LL)** – There's an eagerness and haste that can come when working in the water. Anything that can be done to reduce time in-water should likely be done. Things that require an expected amount of time consider setting a timer. *The flap took a while to flood, this was timed during a test in a tank pre-deployment, but should have been timed during deployment. If timed during deployment, the team would have known when they could expect the flap to be fully flooded.*
- **Note lifetime your equipment is rated for** – *The flap was not designed with 1 year deployment in mind, concerned about the wear on the aluminum pad-eye.*
- **Have the proper tools for the job** – Invest in tools that help the job get done right. *Having the forklift extension made lifts easier and safer for both personnel and equipment.*

Flap Deployment

- **Choose your tide intentionally (LL)** – Deployment of the flap would have been easier if the flap was piercing more of the surface. *The flap was deployed during high tide and barely pierced the surface. The more of the flap sticking out of the water, the less divers will be fighting buoyancy.*
- **The method of making the flap less buoyant should be as easy as possible (LL)** – Consider larger plug/vent holes on the flap. *Not all the air was removed from the flap causing the flap to stay positively buoyant and made it difficult to connect one side of the flap to the frame.*
- **Deploy flap anchor before flap (PR)** – The flap is more "unwieldly" than the flap anchor (flap frame), deploying the flap frame before the flap allows for more careful/ and controlled placement of the flap frame, allowing for more control on where the flap will end up sitting
- **Consider large guides for mounting flap to anchor (LL)** – It was difficult to align the flap with the flap frame while in the water. One idea (which could be applicable to larger flaps) is to have a mounting "plate" connected to the bottom of the flap which can be used as both a guide and later securement to the flap anchor.

Forklift

- **Have a lead for forklift operations who is communicating with the forklift operator (LL)** – Have only one person talking to the forklift operator for much smoother and safer lifts. Anyone can call STOP if something is unsafe.
- **Use taglines when needed for forklift operations (PR)** – Using tag lines keeps personnel further from the lifted equipment allowing personnel to be safer while still moving the equipment in a control manner.

Data

- **Have a "first in line" sensor (PR)** – Having a sensor that can be used as the first input is incredibly useful for debugging when any sensor throughout the system is providing unexpected results. *For this project that sensor is the position sensor. Knowing the movement of the flap is incredibly useful in making a guess of how the rest of the system should be responding. When the systems power output has been incredibly low, it is useful to be able to look at the position sensor and evaluate if the flap is moving more than expected based on the power being produced.*
- **Use the same time zone for everything (PR)** – If different time zones are used it would be very easy to misalign data. *We chose to use UTC time for everything, this makes looking at data a lot easier, with no question about what time zone was used.*
- **There is no replacement to actually looking at the data (PR)** – Quality control is very useful and a great tool, but it cannot replace actually looking at the data.

Project Management

- **Prepare (budget and timeline) for colleagues to leave the project (LL)** – People are likely to leave the project or the organization over a multi-year project. This can increase the timeline and budget of the project due to the learning curve of whoever is taking over the work of the colleague leaving.
- **Have regular documentation practices** – Regularly document what is being done for the project. This is especially critical when a colleague is leaving the project. Immediately when a colleague knows they are leaving the project (whether a year before or a day before) have them document all the work they have done that is not yet documented.
- **Allocate budget for TQAF preparation and review (LL)** – Preparing the level of detail requires for a TQAF review took a significant amount of time, this time should be allocated in the budget specifically for TQAF work. *Our team received positive feedback on the level of detail we went into (specifically for the deployment readiness review), but this took a lot of time to prepare. This detail supported our success, but should be specifically budgeted for.*