- U.S. Marine Corps Base Hawaii, Kaneohe
- 30m, 60m, 80m berths in place, grid-connected
- First 2 devices deployed, more coming
- HNEI role
  - Acoustic, EMF, ecological, sediment transport measurements
  - Independent device durability and performance analysis
  - Site-dedicated support vessel/maintenance protocol development

NAVFAC Naval Facilities Engineering Command

APPLIED RESEARCH LABORATORY
UNIVERSITY OF HAWAI'I

U.S. Navy Wave Energy Test Site – Project Overview and Early Research

Patrick Cross, Hawaii Natural Energy Institute (HNEI)

Hawaii Natural Energy Institute

Alternative Fuels: Biomass and biofuels; methane hydrates

Electrochemical Power Systems

Fuel Cells, Batteries

Renewable Power Generation

Ocean Energy

Photovoltaics

Energy Efficiency

Building technology

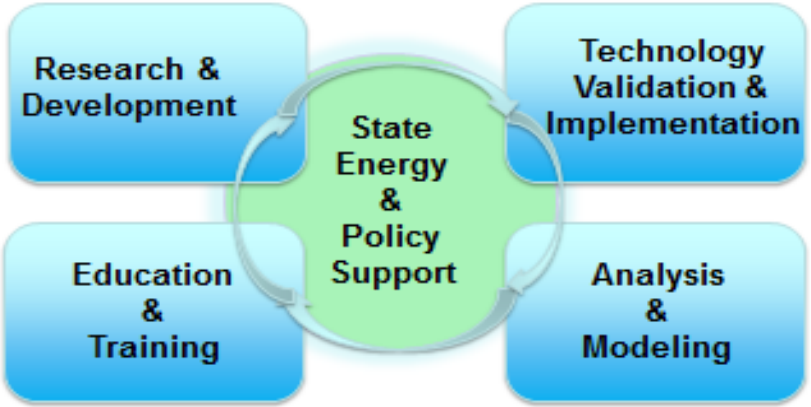
Sea Water Air Conditioning

Systems Integration

Grid modeling and analysis

Smart grid development

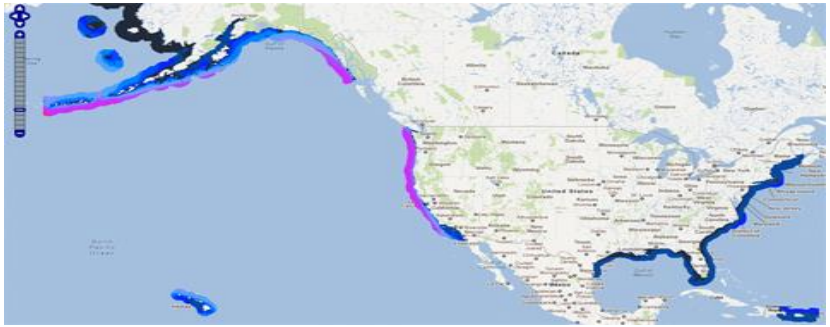
Grid-scale storage



Funding Sources for WETS Support

- US Department of Energy
- US Navy – Naval Facilities Engineering Command
- Office of Naval Research

Wave Energy Intro

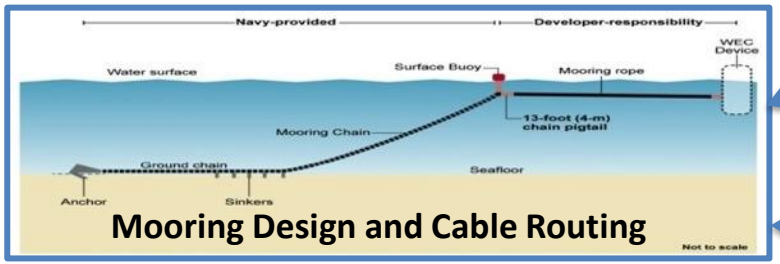


- "Recoverable" resource is vast
  - 1170 TWh/year nationally*
  - 80 TWh/year in Hawaii*
- Challenges abound
  - Large devices/deployment challenges
  - Marine environment/survivability/serviceability
  - Cabling to shore
  - Cost of energy (LCOE) numbers remain daunting
- At-sea testing is essential, but costly, with limited permitted, grid-connected venues in the world
  - European Marine Energy Center in Orkney Islands, Scotland
  - Wavehub in Cornwall, England
  - Navy's Wave Energy Test Site (WETS) in Hawaii
- Not yet close to commercialization
  - ➢ Efforts at WETS of high interest globally

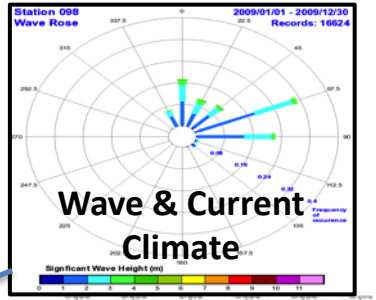
* EPRI Report

Progress to Date

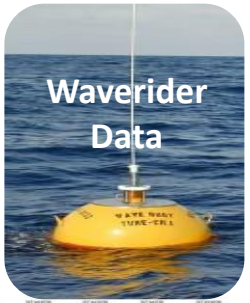
- Site Design and Environmental Assessment(60m and 80m berths)
  - Design by Sound and Sea Technology for NAVFAC
  - HNEI Support
    - Wave/current analysis
    - Bathymetry and sediment survey
    - Participation in design planning discussions/meetings

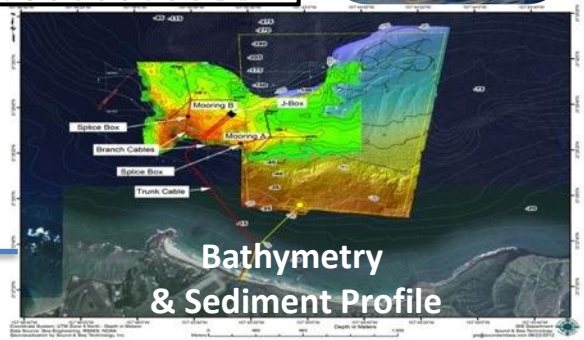


Mooring Design and Cable Routing



Wave & Current Climate





Bathymetry & Sediment Profile

- Navy EA Complete, Finding of No Significant Impact
  - HNEI served in advisory role with NAVFAC, NOAA, DOE, Marine Corps for over 2 years
  - Authorizes point absorber and OWC devices, subject to CATEX
- Nearly 2 Years of Environmental Measurements
- First WEC (Northwest Energy Innovations Azura) deployed May 2015, Second (Fred.Olsen (Norway) Lifesaver) Mar 2016
  - Devices coming from Ocean Energy (Ireland), Columbia Power, Oscilla, Northwest Energy Innovations

WETS Layout

80m

Waverider

Waverider

60m

30m

Bunker

Cable Capacity
30m Berth – 250kW
60/80m Berths – 1MW

Legend
- Splice Box
- Mooring Anchor
- WEC Device Mooring Point
- Waverider Buoy
- Surface Buoy (with WEC deployed)
- Surface Buoy (vacant berth)
- Work Boat Mooring
- WET Existing Buoy

SubSeaCables
- SubSeaCable_80mSite
- SubSeaCable_60mSiite
- Existing Cable (30m site)
- MooringLegs
- Terestial Cable Route
- Contour 5m

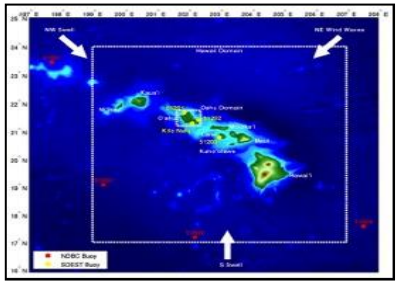
Coordinate System: UTM Zone 4 North - Depth/Elevation in Meters
Data Source: UofH, RSIMS, NOAA
Geovisualization by Sound & Sea Technology, Inc.

0 250 500 1,000
Meters

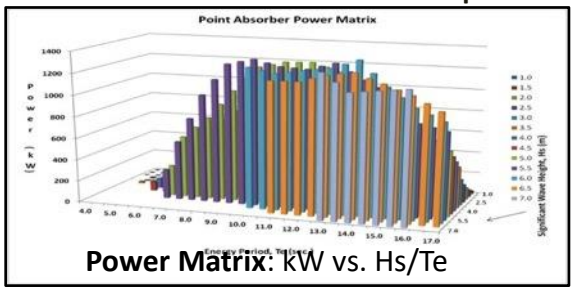
Isolines in Meters Depths

GIS Department
Sound & Sea Technology
gis@soundandsea.com 4/4/2014

HNEI WEC Device Performance Studies

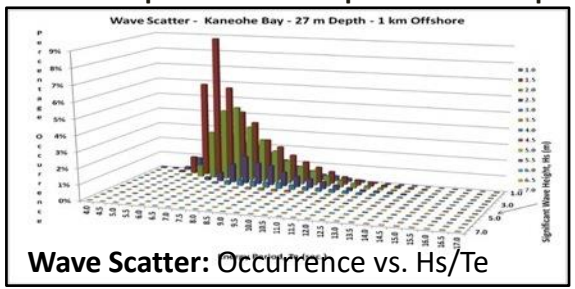


- Wave Measurements with Waverider Buoys and ADCP
  - WETS Waverider #1 deployed Oct 2012, #2 Aug 2016
- Daily 7.5-day Wave Forecasts with High-res Model
  - Calibrated w/Waverider data
- Wave 34-year Hindcast Database Developed
- Regular ROV and diver-based device and mooring inspections to analyze durability and develop operational and maintenance protocols
- Power matrix development – wave input versus power output



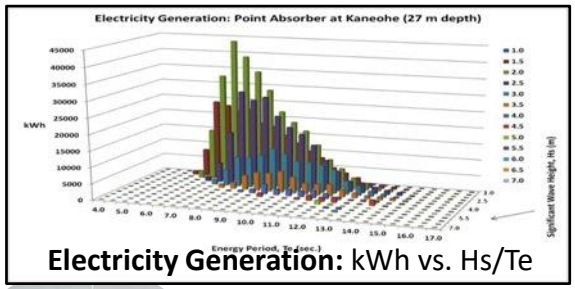
Power Matrix: kW vs. Hs/Te

X



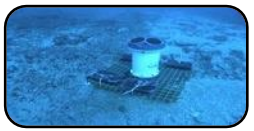
Wave Scatter: Occurrence vs. Hs/Te

=



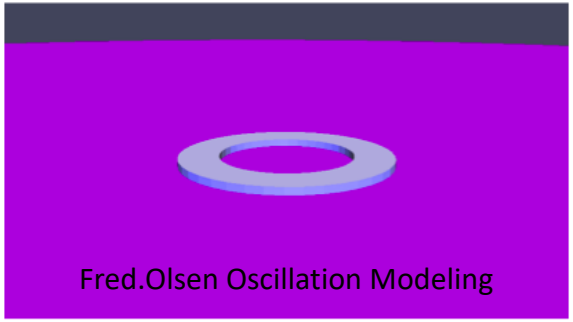
Electricity Generation: kWh vs. Hs/Te

- Numerical Modeling
  - Device (CFD, non-linear physics)
  - Array (predict power extraction/area requirements)

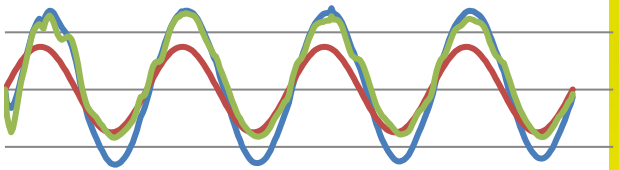


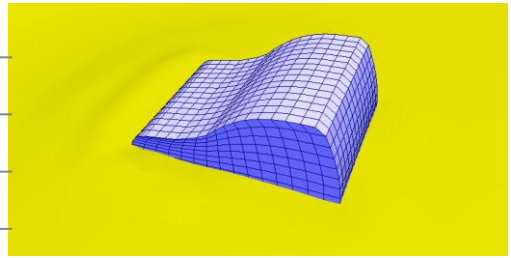
WEC Numerical Modeling

- Provide state-of-the-art numerical modeling assistance to WEC developers planning/conducting tests at WETS, as desired
  - Prediction of power performance matrix
  - Validation of predicted power matrix versus measured
- ➢ Provide insights into device modifications for performance enhancement
- Modeling tools employed by HNEI:
  - Mid-fidelity: WECSIM, WAVEDYN, WAMIT
  - High-fidelity: FLOW-3D, OpenFOAM

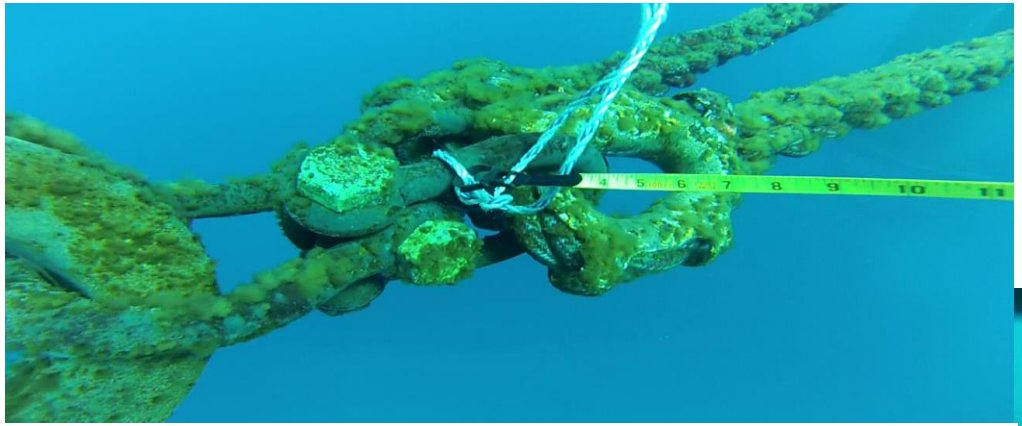

Fred.Olsen Oscillation Modeling

Azura Heave Oscillation Tests from OpenFOAM

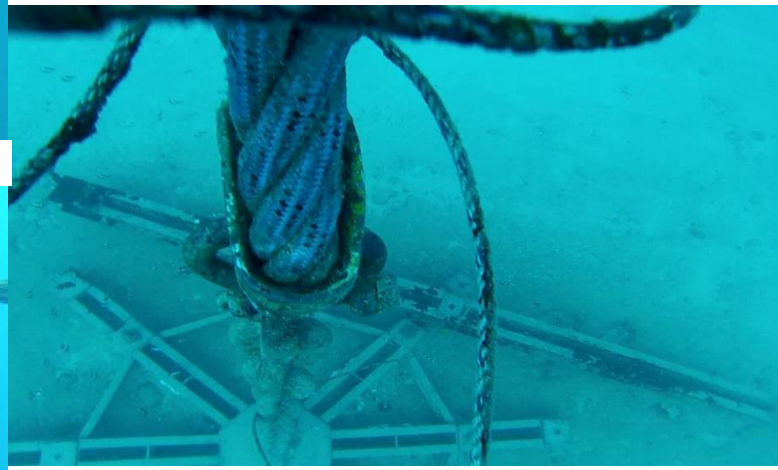




Device and Mooring Durability Assessment



- Quarterly surface and diver/ROV inspections of WEC devices and mooring infrastructure
- Document maintenance issues and develop protocols



Environmental Data Collection

- Measurements to support regulatory and stakeholder databases
- Device acoustic signatures
  - Bottom-mounted and drifting hydrophone systems
  - Regular deployments to build database
  - Assess device signatures and ambient noise
- Electromagnetic fields
  - Partner with OSU to periodically deploy system for measurement of EMF
- Sediment transport
  - Baseline and periodic measurements to detect changes
- Ecological surveys and water chemistries
  - Regular diver and ROV surveys of marine ecosystems, including water samples
- Protected marine species monitoring
  - During WEC device deployments, at-sea operations, and periodically from shore

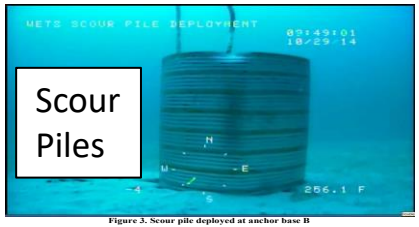


Figure 3. Scour pile deployed at anchor base B

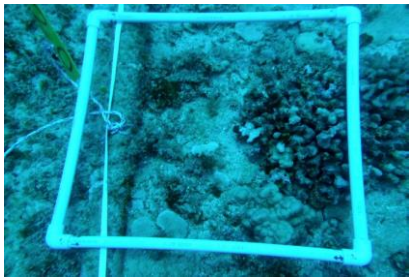
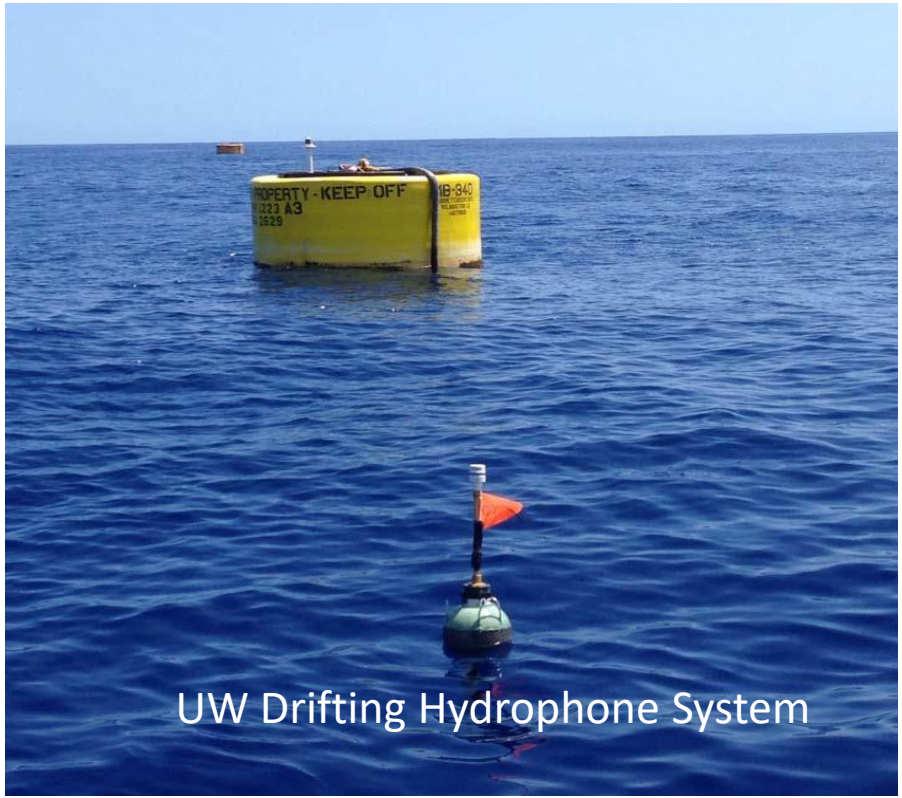


Figure 12. Deep Transect: 20m Location

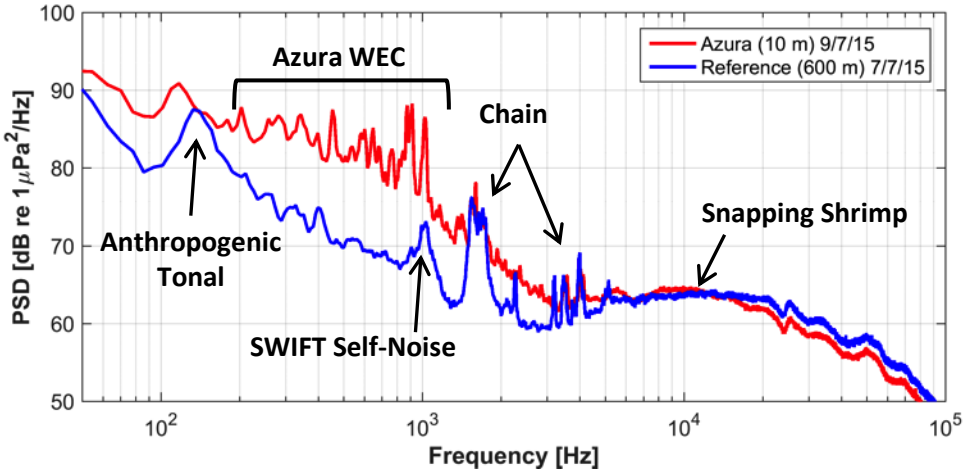
Acoustic Instrumentation Systems

UW/UH Bottom-Mounted
3-hydrophone Station

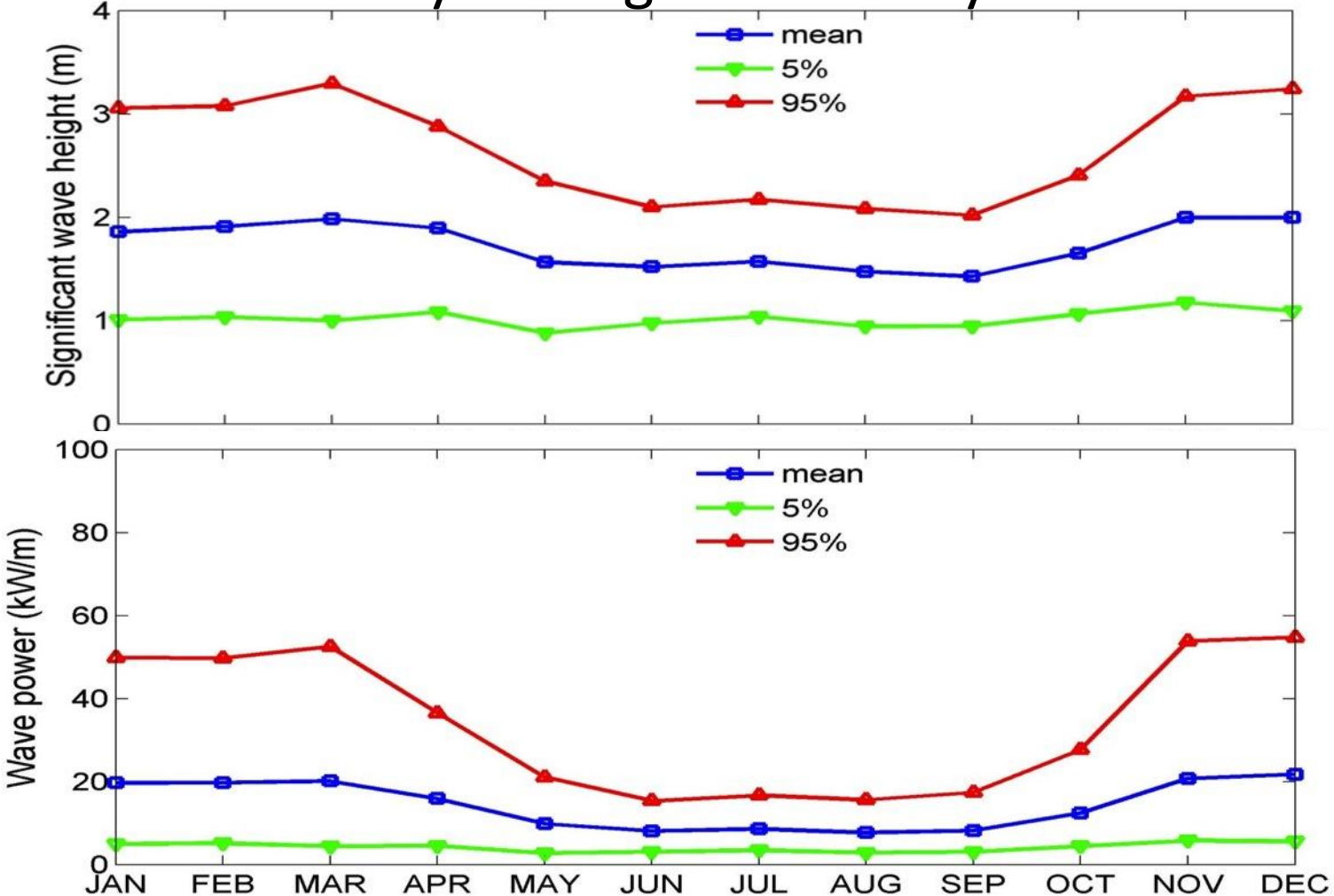


UW Drifting Hydrophone System

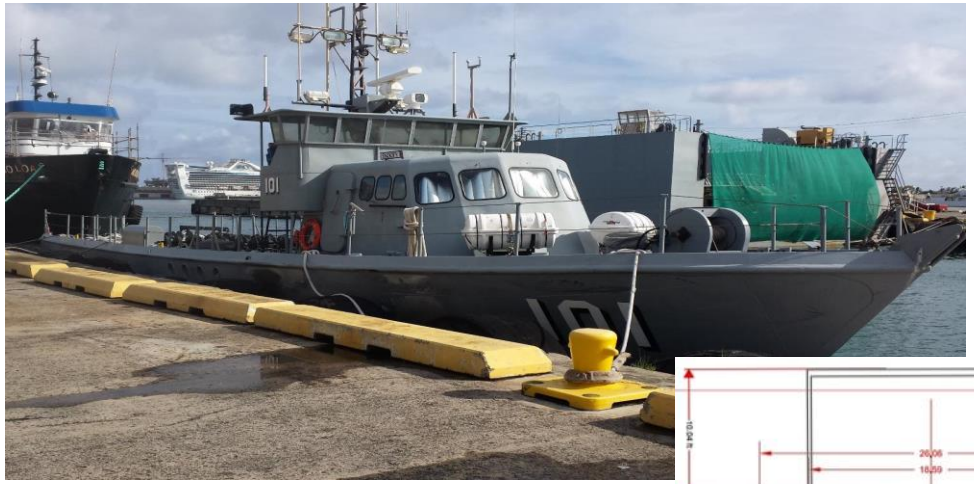
Acoustic Data Collection

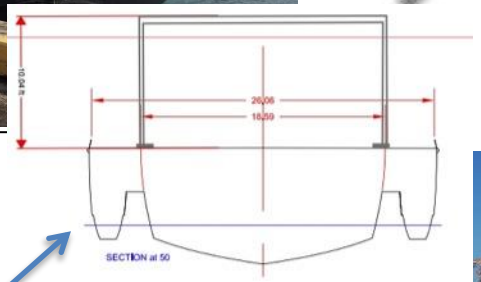


WETS Monthly Averages from 34-year Hindcast



WETS Site-Dedicated Support Vessel – Sea Engineering, Inc.





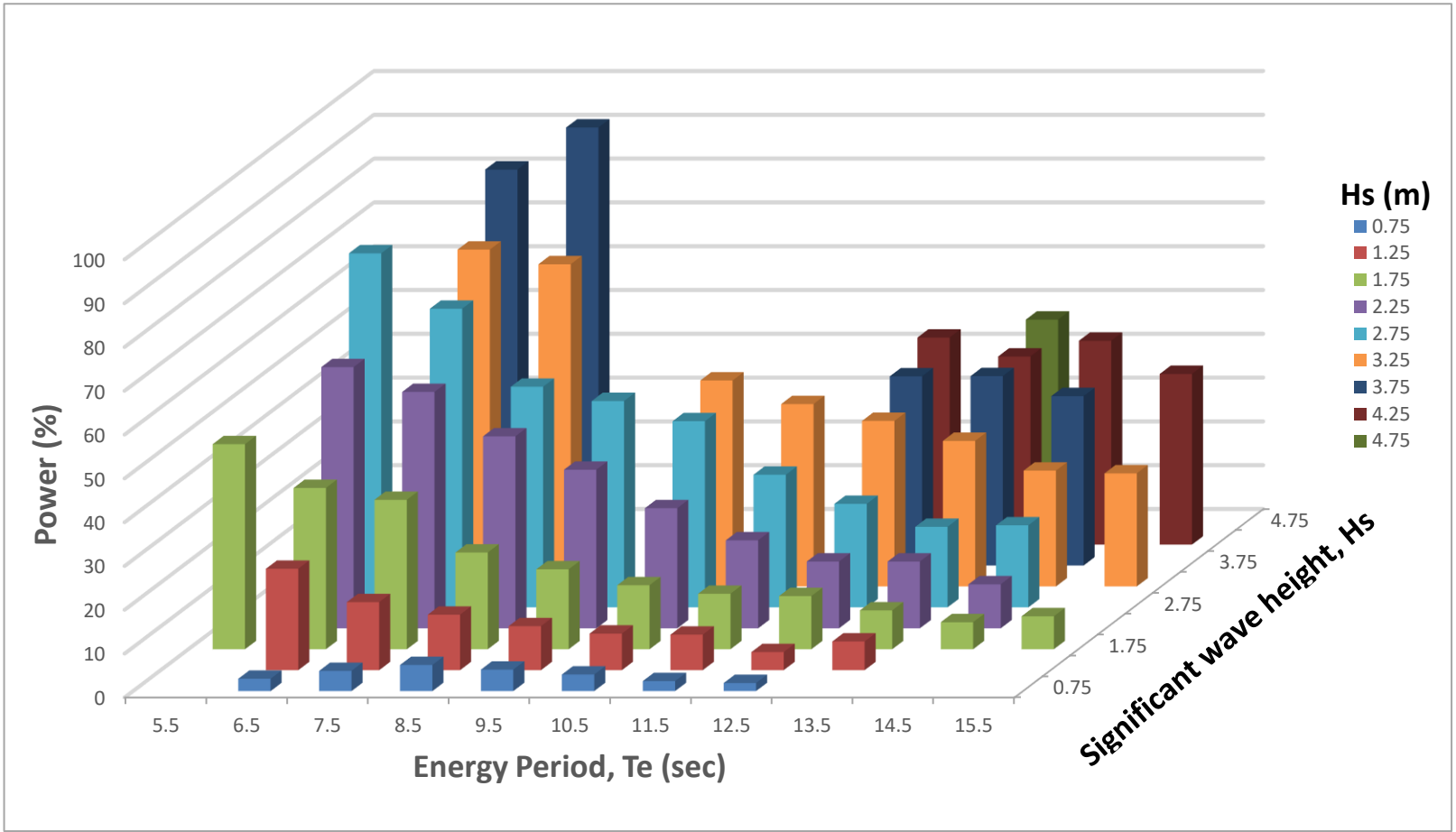
- 85 foot LOA
- 4-point mooring capability
- 10-ton lift capacity
- Deepwater dive spread
- ROV enclosure
- Reconfiguring w/added beam
- To be kept at boat harbor ~ 1hr away

NWEI Azura at Pier 26 (Sea Engineering) in Honolulu

Deployment of Azura – 28 May 2015


HUKI PAU

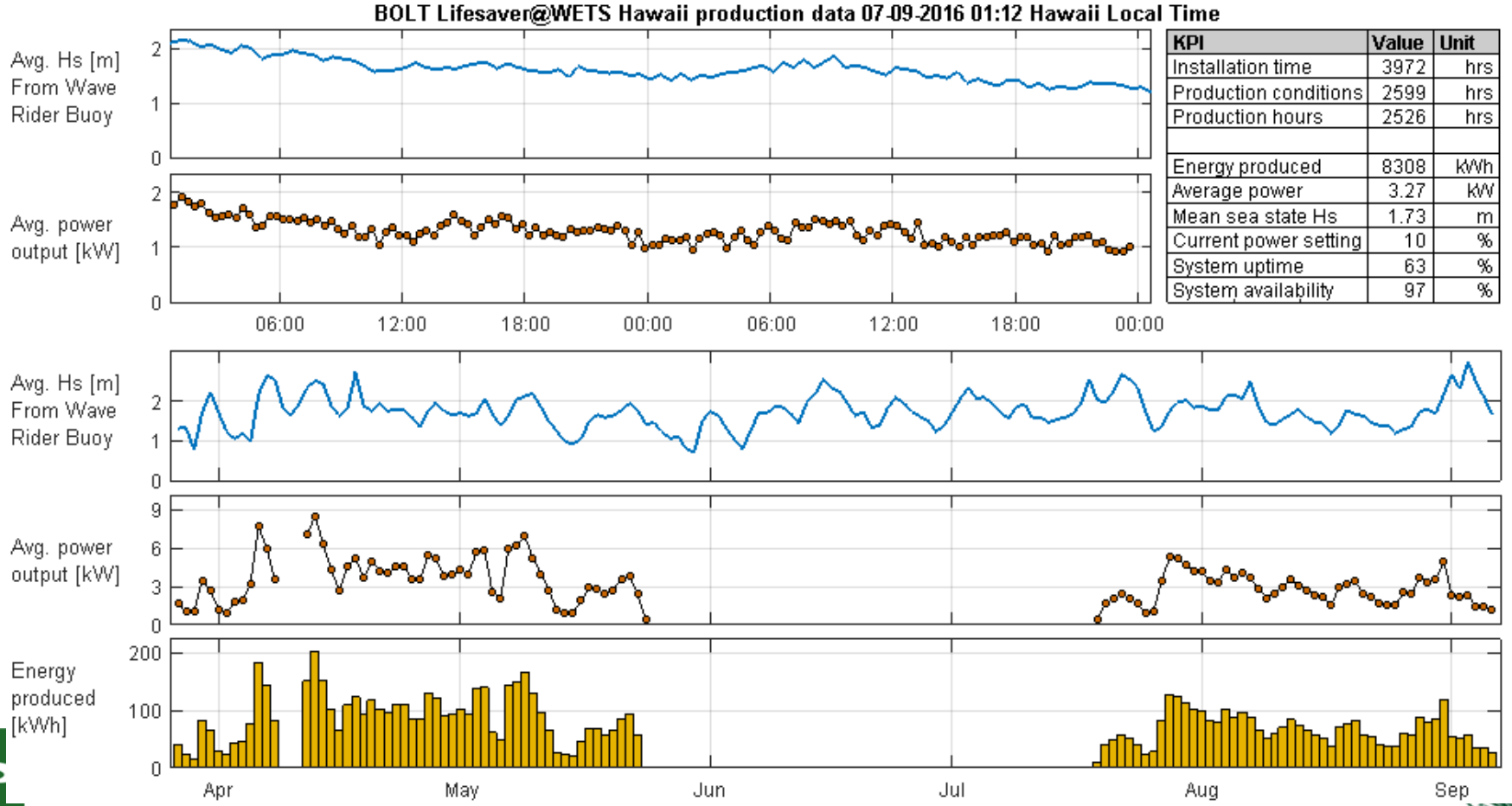
Azura Power Matrix at WETS



Launch of Lifesaver
28 August 2015


DANGER - KEEP AWAY - NO MOORING

Fred.Olsen Lifesaver Performance at WETS



KPI	Value	Unit
Installation time	3972	hrs
Production conditions	2599	hrs
Production hours	2526	hrs
Energy produced	8308	kWh
Average power	3.27	kW
Mean sea state Hs	1.73	m
Current power setting	10	%
System uptime	63	%
System availability	97	%

Questions