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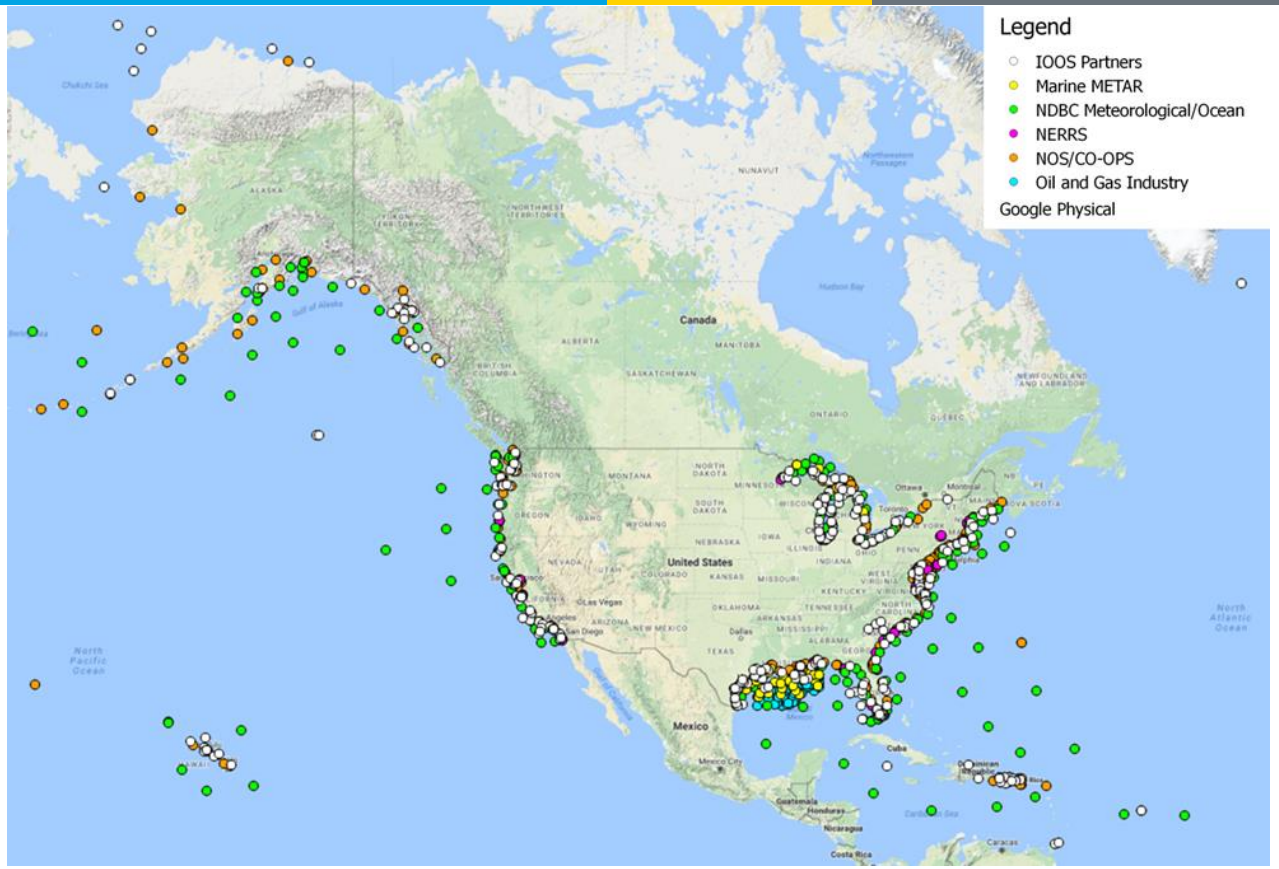


# Marine and Hydrokinetic Energy Metocean Data-use, Sources, and Instrumentation

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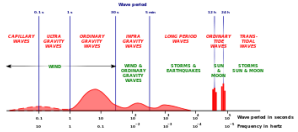
# Metocean Data Flow Throughout Project Lifecycle

**MEASUREMENT**

Instruments

**MEASURED DATA**

Public and Private



**METOCEAN DATA**

Wave, Current, Wind, and Soil

**USERS**

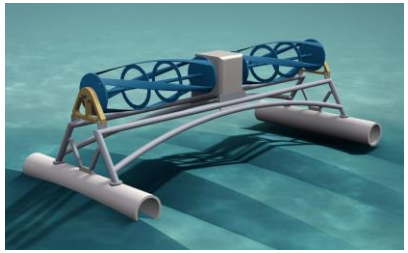
Developers, Original Equipment Manufacturers, (OEMs) Regulators, Installers, Operations & Maintenance (O&M) , Investors, Insurers, Grid Operators, and Public Utility Commissions (PUC)

**PROJECT PHASES**

I-Feasibility, II-Engineering, III-Installation, IV-Operations, and V-Decommissioning


**RULES**

Regulations, Standards, Guidelines



**DESIGN & ANALYSIS**

**MHK ENERGY FARM**

Deployment and Operations

# Project Overview



- This project aims to accelerate deployment of marine and hydrokinetic (MHK) technology by establishing:
  - relevant existing and evolving standards and guidelines
  - meteorological and oceanic (metocean) data use
  - data sources
  - instrumentation guidance

  for siting, design, and operation of MHK devices along the U.S coastline

- The purpose is to improve the process of exploration of potential development sites, which involves design, deployment, operation, decommissioning, and cost and revenue studies

- Draft report under review prior to publication

# Program Strategic Priorities

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## Technology Maturity

- Test and demonstrate prototypes
- Develop cost-effective approaches for installation, grid integration, and operations and maintenance
- Conduct R&D for innovative MHK systems & components
- Develop tools to optimize device and array performance and reliability
- Develop and apply quantitative metrics to advance MHK technologies

## Deployment Barriers

- Identify potential improvements to regulatory processes and requirements
- Support research focused on retiring or mitigating environmental risks and reducing costs
- Build awareness of MHK technologies
- Ensure MHK interests are considered in coastal and marine planning processes
- Evaluate deployment infrastructure needs and possible approaches to bridge gaps

## Market Development

- Support project demonstrations to reduce risk and build investor confidence
- Assess and communicate potential MHK market opportunities, including off-grid and non-electric
- Inform incentives and policy measures
- Develop, maintain, and communicate our national strategy
- Support development of standards
- Expand MHK technical and research community

## Crosscutting Approaches

- Enable access to testing facilities that help accelerate the pace of technology development
- Improve resource characterization to optimize technologies, reduce deployment risks, and identify promising markets
- **Exchange of data information and expertise**

# Project Strategic Alignment

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## Crosscutting Approaches

- Exchange of data information and expertise

## The Impact

- De-risk projects for stakeholders by:
  1. Providing data for guidance to applicable regulations, standards, guidelines, and certification processes
  2. Providing guidance and outlining the required metocean data for evaluating project feasibility
  3. Providing metocean data sets available by state and gaps in areas of coverage
  4. Gathering the required metocean data for instrumentation requirements
- Draft report under review prior to publication

# Technical Approach



- Leverage existing knowledge from:
  - MHK industry
  - Offshore wind industry
  - Offshore oil and gas industry
  - Instrumentation experts
  - Universities
  - Resource centers
- Regulations, standards, guidelines, and certification
  - Investigate gaps existing for MHK development and supplement the gaps from other offshore-related industries
- Metocean users
  - Identify MHK project life cycle data users and data needs
- Metocean data
  - Identify metocean parameters needed for MHK project life cycle and relevant instrumentation to measure such data
  - Identify sources for instrumentation
- Metocean data sets (private and public)
  - Mine sites with metocean data (not clearing houses) relevant for MHK development
  - Provide a list filtered by states
- Metocean data set gaps
  - Identify stations collecting some kind of metocean data to highlight the areas that are not being covered
  - Bridge gaps in metocean data sets

## Regulations, standards, guidelines, and certification applicable to the MHK industry:

### Regulations

- Code of Federal Regulations (CFR)
- Federal Aviation Administration (FAA)
- U.S. Coast Guard (USCG)

### Standards

- American Institute of Steel Construction (AISC)
- American National Standards Institute (ANSI)
- American Petroleum Institute (API)
- International Electrotechnical Commission (IEC)
- International Standards Organization (ISO)

### Guidelines

- American Bureau of Shipping (ABS)
- Det Norske Veritas - Germanischer Lloyd (DNVGL)

### Certification

- Type Certification Modules (adapted from IEC 61400-22 type certification)
- Project Certification Modules (adapted from IEC 61400-22 type certification)

## Project life cycle users of metocean data and the level of data uncertainty:

| Entity | Phase I Feasibility | Phase II Engineering | Phase III Installation | Phase IV Operations | Phase V Decommissioning |
|---|---|---|---|---|---|
| Developer | ✓ | ✓ | ✓ | ✓ | ✓ |
| OEM | ✓ | ✓ | ✓ | ✓ | ✓ |
| Regulators | | ✓ | ✓ | ✓ | ✓ |
| Installers | | ✓ | ✓ | | ✓ |
| O&M | | ✓ | | ✓ | |
| Certified Verification Agent | | ✓ | | | |
| Investors | ✓ | ✓ | | | |
| Insurers | | ✓ | | | |
| Grid Operators | | ✓ | | ✓ | |
| PUC | | ✓ | | ✓ | |
| **Metocean Data** | **Measured or Modeled** | **Measured (1-year min)** | **Measured** | **Continued Measurement (3-year min)** | **Measured** |
| Uncertainty | Medium to High | Low | Low | Low | Low |

# Accomplishments and Progress

## Metocean data needed for both wave and current devices:

| WAVE DEVICE | Phase I Feasibility | Phase II Engineering | Phase III Installation | Phase IV Operation | Phase V Decommissioning |
|---|---|---|---|---|---|
| **WAVE** | | | | | |
| Significant Height [ Hs ] | ✓ | ✓ | ✓ | ✓ | ✓ |
| Peak Period [ Tp ] | ✓ | ✓ | ✓ | ✓ | ✓ |
| Direction | ✓ | ✓ | ✓ | ✓ | ✓ |
| Annual Hs/Tp Occurrence Probability | ✓ | ✓ | | | |
| Directional Spectrum | ✓ | ✓ | | | |
| **CURRENT** | | | | | |
| Speed [ U ] | ✓ | ✓ | ✓ | ✓ | ✓ |
| Direction | ✓ | ✓ | ✓ | ✓ | ✓ |
| Depth | | ✓ | ✓ | ✓ | ✓ |
| Annual Speed Occurrence Probability | | ✓ | | | |
| **OCEAN/RIVER** | | | | | |
| Depth (MWL) | ✓ | ✓ | ✓ | ✓ | ✓ |
| Salinity | | ✓ | | | |
| **WIND** | | | | | |
| Speed | | ✓ | ✓ | ✓ | ✓ |
| Direction | | ✓ | ✓ | ✓ | ✓ |
| **SOIL** | | | | | |
| Bathymetry | | ✓ | ✓ | | ✓ |
| Soil Type | ✓ | ✓ | ✓ | | ✓ |

| CURRENT DEVICE | Phase I Feasibility | Phase II Engineering | Phase III Installation | Phase IV Operation | Phase V Decommissioning |
|---|---|---|---|---|---|
| **WAVE** | | | | | |
| Significant Height [ Hs ] | | ✓ | ✓ | ✓ | ✓ |
| Peak Period [ Tp ] | | ✓ | ✓ | ✓ | ✓ |
| Direction | | ✓ | ✓ | ✓ | ✓ |
| **CURRENT** | | | | | |
| Speed [ U ] | ✓ | ✓ | ✓ | ✓ | ✓ |
| Direction | ✓ | ✓ | ✓ | ✓ | ✓ |
| Depth | ✓ | ✓ | ✓ | ✓ | ✓ |
| Annual Speed Occurrence Probability | ✓ | ✓ | | | |
| Turbulence | ✓ | ✓ | | | |
| **OCEAN/RIVER** | | | | | |
| Depth (MWL) | ✓ | ✓ | ✓ | ✓ | ✓ |
| Density | ✓ | ✓ | | | |
| Salinity | | ✓ | | | |
| **WIND** | | | | | |
| Speed | | | ✓ | ✓ | ✓ |
| Direction | | | ✓ | ✓ | ✓ |
| **SOIL** | | | | | |
| Bathymetry | | ✓ | ✓ | | ✓ |
| Soil Type | ✓ | ✓ | ✓ | | ✓ |

# Accomplishments and Progress

## Instrumentation needed to measure metocean data:

| | ATMOSPHERIC | | | | | | WIND | | OCEAN & RIVERS | | | | | | | WAVE | | | | | | | CURRENT | | | SOIL | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AT-D | AT-P | AT-T | AT-L | AT-PR | AT-I | WN-S | WN-DR | WA-D | WA-SL | WA-MG | WA-I | WA-T | WA-MWL | WA-SS | WV-H | WV-DR | WV-HS | WV-TP | WV-DS | WV-FS | CR-S | CR-DR | CR-DP | SL-BY | SL-TY | SL-SC |
| Air Properties | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Air temperature, pressure, and relative humidity sensors | X | X | X | | | | | | | | | | | | | | | | | | | | | | | | |
| Lightning detector | | | | X | | | | | | | | | | | | | | | | | | | | | | | |
| Pressure | | | | | X | | | | | | | | | | | | | | | | | | | | | | |
| Freezing rain and ice detectors | | | | | | X | | | | | | | | | | | | | | | | | | | | | |
| Wind Speed and Direction | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cup and vane anemometers | | | | | | | X | X | | | | | | | | | | | | | | | | | | | |
| Ultrasonic anemometers | | | | | | | X | X | | | | | | | | | | | | | | | | | | | |
| Acoustic resonance anemometers | | | | | | | X | X | | | | | | | | | | | | | | | | | | | |
| Acoustic Current and Wave | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Doppler current meter – Single point | | | | | | | | | | | | | | | | | | | | | | X | X | X | | | |
| Doppler current profilers | | | | | | | | | | | | X | X | X | X | X | X | X | X | X | X | X | X | X | | | |
| Velocimeters | | | | | | | | | | | | | | | | | | | | | | | X | X | | | |
| Single beam (vertical) | | | | | | | | | | | | | | X | X | X | | X | X | | X | | | | | | |
| Mechanical/Other Current | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Vane current meters | | | | | | | | | | | | | | | | | | | | | | X | X | X | | | |
| Electromagnetic | | | | | | | | | | | | | | | | | | | | | | X | X | X | | | |
| Laser Doppler velocimeters | | | | | | | | | | | | | | | | | | | | | | X | X | X | | | |
| Radar | | | | | | | | | | | | | | | | | | | | | | X | X | | | | |
| Mechanical/Other Wave | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Wave-following buoys | | | | | | | | | | | | | | | | X | X | X | X | X | X | | | | | | |
| Pressure/tide gauge | | | | | | | | | | | | | | | | X | | X | X | | X | | | | | | |
| Radar | | | | | | | | | | | | | | | | | | X | X | X | | | | | | | |
| Water Properties | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Stationary conductivity and temperature (CT) | | | | | | | | | X | X | | | X | | | | | | | | | X | | | | | |
| Profiling conductivity, temperature, and depth (CTD) | | | | | | | | | X | X | | | X | | | | | | | | | | | | | | |
| Sampling rosette | | | | | | | | | | X | | | | | | | | | | | | | | | | | |

# Accomplishments and Progress

## Instrumentation inventory based on 3 of 15 outreach responses:

| Organization | Department | Acoustic Doppler Profilers | | | | | | | | | | | | | | | | | | | | Current Meters | | | Surface Current/ Wave Radar | | Wave Buoys | | Water Properties (CT/CTD) | | Wind | | | | | | Air Properties | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Current Profile Only | | | | | Current Profiler with Waves, No Surface Tracking | | | | | Current Profiler with Waves and Surface Tracking | | | | | Horizontal | | | | | | | | | | | | | | Anemometers | | | Area and Profilers | | | | Point | | Profiling | |
| | | 0 - 30 | 0 – 60 | 0 – 120 | 0 – 500 | 0 - > 500 | 0 - 30 | 0 – 60 | 0 – 120 | 0 – 500 | 0 - > 500 | 0 - 30 | 0 – 60 | 0 – 120 | 0 – 500 | 0 - > 500 | 0 - 30 | 0 – 60 | 0 – 120 | 0 – 500 | 0 - > 500 | Acoustic Velocimeters | Fixed Vane | Electromagnetic | Single Antenna Stations | Multiple Antenna Stations | Standalone | Integrated into Larger Buoy Suite | Profiling | Stationary | Cup and Vane | Ultrasonic | Acoustic Resonance | SODAR | Stationary Lidar | Floating Lidar | Radar | Temperature | Relative Humidity | Microwave Profiling Radiometer | Raman Lidar |
| Sandia National Labs for U.S. DOE/Office of Science/BER | Atmospheric Sciences Dept. (Mark Ivey, mdivey@sandia.gov) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 8 | | | 4 | | 8 | 8 | 8 | 2 | |
| National Renewable Energy Lab | National Wind Technology Center (eric.nelson@nrel.gov) | | | | | | | | | | | 1 | 3 | | | | | | | | | 4 | | | | | 3 | | | | > 10 | > 10 | | 2 | | | | > 10 | > 10 | | |
| University of Washington | Mechanical Engineering/Marine Renewable Energy Laboratory + Andy Stewart/APL (Brian Polagye) | | | | | | | | | | | | 1 | | | | | | | | | 4 | | | | | | | | | | | 5 | | | | | 5 | | | |

The continued effort collecting instrumentation source information will be added to the MHK instrumentation and sensor database.

- The source will be able to update the database
- Benefits the MHK community and availability of the instrument

# Examples of Metocean Data Set (report includes world, United States, and U.S. states)

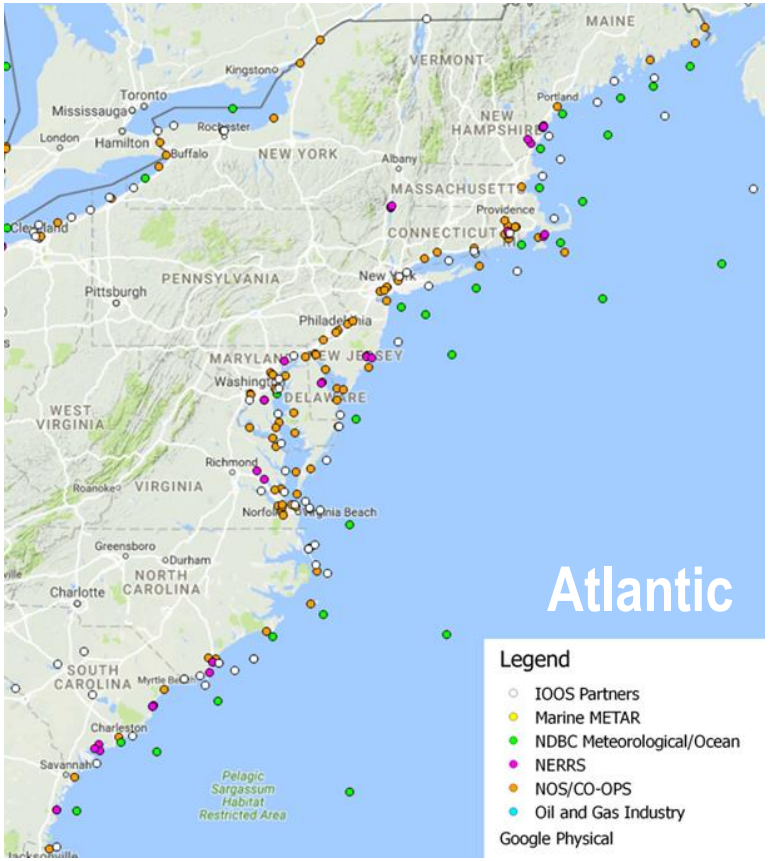
## United States

| Entity | Link | Air | Water | Soil |
|---|---|---|---|---|
| **Public** | | | | |
| National Oceanic & Atmospheric Administration, National Data Buoy Center (NOAA-NDBC) | http://www.ndbc.noaa.gov/ | WN-S, WN-SD (AT-P, AT-T) | WV-DR, WV-HS, WV-TP, WV-DS (OR-T, WV-H, WV-FS) | |
| National Oceanic & Atmospheric Administration (NOAA-TC) | http://tidesandcurrents.noaa.gov/products.html | | CR-S, CR-DP, CR-DR, CR-PO (OR-T, OR-MWL, OR-SS, OR-TD) | |
| U.S. Army Corps of Engineers (WIS) | http://wis.usace.army.mil/ | WN-S, WN-SD | WV-DR, WV-HS, WV-TP, WV-DS (WV-H, WV-FS) | |
| NOAA Integrated Ocean Observing System (NOAA-IOOS) | http://www.ioos.noaa.gov/catalog/welcome.html | WN-S, WN-SD (AT-P, AT-T) | OR-SL, WV-DR, WV-HS, WV-TP, CR-S (OR-T, WV-H) | |
| Physical Oceanographic Real-Time System (NOAA-PORTS) | http://tidesandcurrents.noaa.gov/ports.html | WN-S (AT-P, AT-T) | (OR-T, OR-MWL, OR-TD) | |
| Coastal Data Information Program (CDIP) | http://cdip.ucsd.edu/themes/cdip | WN-S | OR-SL, WV-DR, WV-HS, WV-TP, WV-DS, WV-PO, CR-S (OR-T, WV-H, WV-FS, WV-SM) | |
| **Private** | | | | |
| AWS Truepower: Mesoscale Modeling and Wind Trends Database (AWS) | http://www.awstruepower.com/ | WN-S, WN-SD, WN-DR (WN-DD) | | |

## California

| Entity | Link | Air | Water | Soil |
|---|---|---|---|---|
| **Public** | | | | |
| Central & Northern California Ocean Observing System (CenCOOS) | http://www.cencoos.org/ | WN-S, WN-SD (AT-P, AT-T) | OR-SL, WV-HS, WV-TP (OR-T, OR-MWL, WV-H) | |
| Southern California Coastal Ocean Observing System (SCCOOS) | http://www.sccoos.org/ | (AT-P) | OR-SL (OR-T) | |
| Bodega Marine Laboratory Bodega Ocean Observing Node, UC Davis (BOON) | http://bml.ucdavis.edu/boon/index.html | WN-S, WN-SD (AT-P, AT-T, AT-PR) | OR-SL, WV-DR, CR-S, CR-DP (OR-T, WV-H) | |
| Monterey Bay Research Institute Ocean Observatories (MBARI) | http://www.mbari.org/ | (AT-T) | CR-S, CR-DP, CR-DR (OR-TD) | (SL-BY) |
| Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) | http://www.piscoweb.org/ | | CR-S, CR-DP, CR-DR (OR-T, OR-MWL) | |
| Shore Station Program (SCRIPPS-SSP) | http://shorestations.ucsd.edu/shore-stations-data/ | WN-S | OR-SL, CR-S (OR-T) | |

# Examples of Metocean Data Collection Stations to Identify Lack of Coverage (Report includes the United States, Alaska, Atlantic Coast, Great Lakes, Gulf of Mexico, Hawaii, and Pacific Coast

# Example of NDBC and Partner Stations with Applicable Metocean Data for MHK Development

| Station | Site | Barometric Pressure (AT-P) | Atmospheric Temperature (AT-T) | Wind Direction (WN-DR) | Wind Speed (WN-S) | Wave Height (WV-H) | Dominant Wave Period (WV-DP) | Water Temperature (OR-T) | Water Tide (OR-TD) | Water Salinity (OR-SL) | Current Speed (CR-S) | Current Direction (CR-DR) | Current Depth (CR-DP) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 41001 | 2.3D04 (SC) East Hatteras | x | x | x | x | x | x | x | | | | | |
| 41002 | 3D50 (AR) South Hatteras | x | x | x | x | x | x | x | | | | | |
| 41004 | 3D58 (AR) Edisto | x | x | x | x | x | x | x | | | | | |
| 41008 | 3D36 (AM) Grays Reef | x | x | x | x | x | x | x | | | | | |
| 41009 | 3D86 (AM) Canaveral | x | x | x | x | x | x | x | | | | | |
| 41010 | 3D26 (AR) Canaveral East | x | x | x | x | x | x | x | | | | | |
| 41013 | 2.3D01 (SC) Frying Pan Shoals, NC (buoy) | x | x | x | x | x | x | x | | | | | |
| 41025 | 3DV09 (AR) Diamond Shoals | x | x | x | x | x | x | x | | | | | |
| 41040 | 3D56 (AR) North Equatorial One | x | x | x | x | x | x | x | | | | | |
| 41041 | 3D72 (AM) North Equatorial Two | x | x | x | x | x | x | x | | | | | |
| 41043 | 2.3D08 (SC) NE Puerto Rico | x | x | x | x | x | x | x | | | | | |
| 41044 | 3DV49 (SC) NE St. Martin | x | x | x | x | x | x | x | | | | | |
| 41046 | 2.3D07 (SC) East Bahamas | x | x | x | x | x | x | x | | | | | |
| 41047 | 3DV42 (SC) NE Bahamas | x | x | x | x | x | x | x | | | | | |
| 41048 | 3DV02 (AR) West Bermuda | x | x | x | x | x | x | x | | | | | |
| 41049 | 3DV31 (AR) South Bermuda | x | x | x | x | x | x | x | | | | | |
| 42001 | 3D30 (AR) Mid Gulf | x | x | x | x | x | x | x | | | | | |
| 42002 | 3D74 (AR) West Gulf | x | x | x | x | x | x | x | | | | | |
| 42003 | 3D20 (AR) East Gulf | x | x | x | x | x | x | x | | | | | |
| 42012 | 3DV11 (AR) Orange Beach, AL | x | x | x | x | x | x | x | | | | | |
| 42019 | 3DV14 (AR) Freeport, TX | x | x | x | x | x | x | x | | | | | |
| 42020 | 3DV26 (AR) Corpus Christi, TX | x | x | x | x | x | x | x | | | | | |
| 42035 | 3DV17 (AR) Galveston, TX | x | x | x | x | x | x | x | | | | | |
| 42036 | 3D37 (AR) West Tampa | x | x | x | x | x | x | x | | | | | |
| 42039 | 3D55 (SM) Pensacola | x | x | x | x | x | x | x | | | | | |
| 42040 | 2.4D05 (SC) Luke Offshore Test Platform | x | x | x | x | x | x | x | | | | | |
| 42055 | 3D49 (AR) Bay Of Campeche | x | x | x | x | x | x | x | | | | | |
| 42056 | 3DV46 (SC) Yucatan Basin | x | x | x | x | x | x | x | | | | | |
| 42057 | 3D57 (AR) Western Caribbean | x | x | x | x | x | x | x | | | | | |
| 42058 | 3DV27 (AR) Central Caribbean | x | x | x | x | x | x | x | | | | | |
| 42059 | 3DV38 (SC) Eastern Caribbean Sea | x | x | x | x | x | x | x | | | | | |
| 42060 | 2.3D10 (SC) Caribbean Valley | x | x | x | x | x | x | x | | | | | |
| 44005 | 3DV16 (AM) Gulf Of Maine | x | x | x | x | x | x | x | | | | | |

# Project Plan and Schedule



- Project schedule
  - October 2015 initiation date
  - September 2016 completion date

- Milestones

| FY16 | Milestone | Percent Complete |
|---|---|---|
| Q1 | Compile list of existing MHK metocean measurement data sets identified (both public and private) | 100% |
| Q2 | Establish list of MHK metocean data needs from site identification through decommissioning | 100% |
| Q3 | Complete draft MHK metocean gaps analysis (geographic, data types, data attributes) | 100% |
| Q4 | Provide summary of MHK metocean data use guidelines to DOE HQ and schedule call to walk through | 100% |

- Go/No-Go decision
  - None

# Project Budget



| Budget History | | | | | |
|---|---|---|---|---|---|
| FY2014 | | FY2015 | | FY2016 | |
| DOE | Cost Share | DOE | Cost Share | DOE | Cost Share |
| $0 | $0 | $200k | $0 | $0 | $0 |

- There has been no variance from planned budget or project plan
- Project was executed as budgeted and fully costed
- Additional funding necessary for publication and dissemination of the work's usefulness for the MHK industry at MHK conferences

# Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

## Partners, Subcontractors, and Collaborators

- None

## Communications and Technology Transfer

- The report will be distributed to the Marine Energy Council Resource Assessment Subcommittee for comments.
- Additional funds are needed to get the report ready for public distribution.

# Next Steps and Future Research



## FY17/Current Research

- Project completed

## Proposed Future Research

- There is a need for joint probability distributions (JPDFs) of wave height, wave period, and wind speed to provide design parameters for MHK devices, as well as give better estimates of the expected energy production at a site
- Include hourly values of significant wave height, wave period, and 10-m wind speed on a 4-ft (1/15-degree) grid for the U.S. coastal waters which will be available from the 30 years of hind-cast data from NOAA's WaveWatch III model
- The hind-cast data can be processed to create JPDFs of wave and wind conditions at each point to be displayed on NREL's MHK Atlas

## MHK Atlas