# Development of a Metocean Reference Site near the Massachusetts and Rhode Island Wind Energy Areas

***Final Report***

Prepared for:

**National Offshore Wind Research and Development Consortium**

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# Notice

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# Abstract

This project developed the first long-term U.S.-based offshore MetOcean Reference Site (MORS-1) by capitalizing on a unique combination of one of the few existing publicly available offshore wind energy metocean observational campaigns in the United States and the only existing research-grade offshore fixed tower. Data collected at MORS-1 has facilitated improved wind resource assessments, improved short-term power production estimates, and reduced costs for sensor validation and calibration efforts, which translate into reduced overall wind energy project risk and cost for developers. Now operational, MORS-1 serves the needs of both industry and researchers using a nonprofit, joint industry-academic partnership model. Led by the Woods Hole Oceanographic Institution, the MORS-1 development effort focused on creating both a recognized organizational structure that will ensure support of the MORS-1 by the wider wind energy industry and research community, and a highly validated data collection and sensor validation facility that will serve as the premier location for cost- and uncertainty-reducing resource characterization and research efforts.

# Keywords

MetOcean, Reference Station, Offshore Wind Energy, Site Characterization, Instrument Validations, Lidar Buoy, Wind Resource Assessment

# Acknowledgments

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# Acronyms and Abbreviations

| | |
|---|---|
| AEP | annual energy production |
| amsl | above mean sea level |
| ASIT | Air-Sea Interaction Tower |
| DOE | U.S. Department of Energy |
| MassCEC | Massachusetts Clean Energy Center |
| MORS-1 | MetOcean Reference Site |
| MVCO | Martha's Vineyard Coastal Observatory |
| NOWRDC | National Offshore Wind Research and Development Consortium |
| NM | nautical miles |
| NREL | National Renewable Energy Laboratory |
| NTS | Nantucket Test Site |
| PATON | Private Aids to Navigation (U.S. Coast Guard) |
| SLCOE | simple levelized cost of energy |
| WHOI | Woods Hole Oceanographic Institution |
| WRF | Weather Research and Forecasting model |

# Executive Summary

This effort developed the first long-term U.S.-based offshore MetOcean Reference Site (MORS-1) by capitalizing on a unique combination of one of the few existing publicly available offshore wind energy metocean observational campaigns in the United States and the only existing research-grade offshore fixed tower. Data collected at MORS-1 have shown that metocean conditions along the east coast of the U.S. are distinctly different from those recorded at the publicly available FINO tower stations in Europe. These data have facilitated improved model assessments of the wind resource in the United States, improved short-term power production estimates in comparison to numerical models of regional winds, and, due to the unique nature of the metocean reference site, reduced costs for sensor validation and calibration efforts. All these efforts translate into reduced overall project risk and cost. Now operational, MORS-1 serves the needs of both industry and researchers using a nonprofit, joint industry-academic partnership model. Led by Woods Hole Oceanographic Institution, the MORS-1 development effort focused on creating both a recognized organizational structure that will ensure support of the MORS-1 by the wider wind energy industry and research community, and a highly validated data collection and sensor validation facility that will serve as the premier location for cost- and uncertainty-reducing resource characterization and research efforts. MORS-1 will rely on lidar buoy validation service fees to fund reference site observations, which will be made publicly available for both industry and research users in perpetuity.

# 1 Background

Utilizing atmospheric winds to produce electricity and integrating the produced power at large scale into existing electricity grids is a rapidly growing sector of the energy industry with the potential to offset or eliminate the detrimental effects of fossil-fuel-based electricity production on the global climate. Utility-scale wind farms, which harness near-surface winds to produce electricity, are becoming more common on land in the United States, and efforts to expand production into oceanic environments have been underway in Europe for the past 20 years. Offshore wind energy production is a rapidly emerging industry in the United States and is initially focused on the East Coast, particularly the Mid-Atlantic Bight, due to the combined presence of relatively strong winds, shallow bottom depths, and nearby population centers. With more than 15 offshore wind energy lease areas in differing stages of development, the offshore wind energy industry is poised for rapid growth along the U.S. East Coast.

Wind energy developers require accurate estimates of the wind resource as a first step in the long process of developing a lease area for power production. Wind resource estimates are critical for understanding both how much wind is present to fuel a potential turbine and how the wind might affect the turbine's operations. Collecting data to understand the wind as a fuel and as a design criterion is uniquely more challenging over the ocean as opposed to over land because of the harsh ocean environments. While efforts to collect these data offshore in Europe were done via the construction of large meteorological masts placed on purpose-built offshore structures, the cost and impact of these structures is significant. Additionally, growth in technology over the past two decades has produced remote sensing instruments capable of collecting the required data without the installation of a large structure. These systems—laser-based vertical profilers or lidars—probe the bottom 200 m of the atmosphere remotely to measure the horizontal surface winds with high accuracy. Lidars have a small spatial footprint and require minimal power. As a result, lidar buoys—a lidar system located on a surface buoy moored on site—are now a critical part of offshore wind energy resource characterization and monitoring campaigns. Following the *Carbon Trust Offshore Wind Accelerator Roadmap for the Commercial Acceptance of LiDAR Technology* (DNV GL et al., 2018), buoy-based lidar systems can be utilized for resource characterization and project data collection. However, long-term reference stations are required in combination with shorter-term buoy deployments of wind sensors in a lease area to collect the observations needed to constrain and validate numerical models simulating the wind resource over both long and short time periods.

## 1.1 Industry Needs for Validated Lidar Observations

Using buoy-based systems to collect resource characterization data is highly advantageous to wind energy developers, as it can dramatically decrease the cost of an individual data campaign compared to using meteorological towers. However, the lidar's estimates of the wind field still need to be highly accurate to ensure the data collection is robust and adheres to industry standards. Thus, sensor validations are required before each data collection campaign to document that each sensor (with a specific serial number) meets industry standards for accuracy. Additionally, buoys are not fixed in space but move as a result of oceanic waves, surface currents, and the winds themselves. Thus, the motion of the buoy and its effect on the lidar's data collection must be included in the lidar validation activity. As a result, proper pre-deployment validation of the lidar AND the buoy system against a primary or secondary reference standard is needed to certify the lidar wind observations for use in energy-related data uses (DNV 2018; IEA Wind, 2017; Fig. 1).

A validation activity consists of a user and a wind energy developer or their service provider anchoring their functioning buoy system in proximity to a fixed platform or location where meteorological data with a known validation history is being collected at the same heights above the sea surface as the buoy-based lidar will be observing. The fixed sensor suite could be a meteorological mast with industry-standard, validated cup anemometers and wind vanes. However, a second functioning lidar system located on a fixed structure could also serve as the reference standard, provided that it was previously validated against a tall tower of anemometers and wind vanes. In either case, data from the buoy-based system and the fixed system are compared over a data collection period that spans 6–10 weeks (International Electrotechnical Commission, 2017), depending on the variability of the wind field, to document the capabilities of the buoy-based system before it is deployed for its data collection campaign.

## 1.2 Public Needs for Long-Term Datasets

Somewhat independent of the developer's needs to validate lidar buoys prior to their deployment offshore within their lease areas, the wider wind industry as well as the scientific community require more information about the wind resource present both near the lease areas as well as over a wide region around the wind farm. High-quality, multiyear observations of the wind resource at hub height in areas relevant to offshore wind energy are required to reduce uncertainties in regional wind resource assessments and improve wind energy estimates. These data must be well documented and publicly available to have maximum impact. Thus, a long-term, publicly available dataset provides a point of reference for both regional and lease-area specific efforts and improves the fidelity of numerical model hindcasts and forecasts of wind energy power production. These activities would have a direct impact that benefits the energy consumer, the ratepayer.

## 1.3 The Need for Reference Stations

The need for metocean reference sites for energy and climate are threefold: (1) Wind energy developers are currently required to validate buoy systems prior to data collection campaigns per international standards. (2) Wind energy developers, grid operators, and installers as well as operations and maintenance service providers need regionwide robust data collection at sites proximate to U.S.-based lease areas that have conditions representative of wind energy development areas to provide accurate regional site characterization and inform estimates of interannual variability in the wind resource and metocean conditions at a given lease area. (3) Long-term monitoring and data collection of the atmosphere and ocean is a critically required component for informing long-term climate assessments and improving model parameterizations of wind,  transfers of heat, moisture, and gases between the ocean and atmosphere in order to accurately understand the global climate system. Regional “super sites” for metocean data collection are needed to provide climate-relevant datasets that can be maintained and utilized over the long term.

Such sites would aid developers, turbine manufacturers, and utility operators as well as researchers and forecasters. Such sites should be representative of the types of meteorological and oceanographic conditions in the wind energy lease areas and provide a lower cost of development efforts compared to the present practice of shipping buoys to validation facilities in Europe. Shipping buoys to Europe would have the disadvantage of validating sensors in a different climate than where they would be deployed after validation in the United States.  Additionally, if operated with continuous data collection between validation activities, such a site could provide a long-term reference dataset that would serve as a point of reference for both regional and lease-area specific efforts, thereby improving the fidelity of numerical model hindcasts and forecasts of wind energy power production.

Few such facilities exist within or near active U.S. offshore wind energy lease areas that can provide both a long-term reference dataset to aid developers, turbine manufacturers, and utility operators and a location for the in situ validation of wind resource assessment sensors and buoys. The creation of a metocean reference site proximate to the Massachusetts and Rhode Island wind energy lease areas is used here as an example of a successful, valuable reference station for both energy and climate.

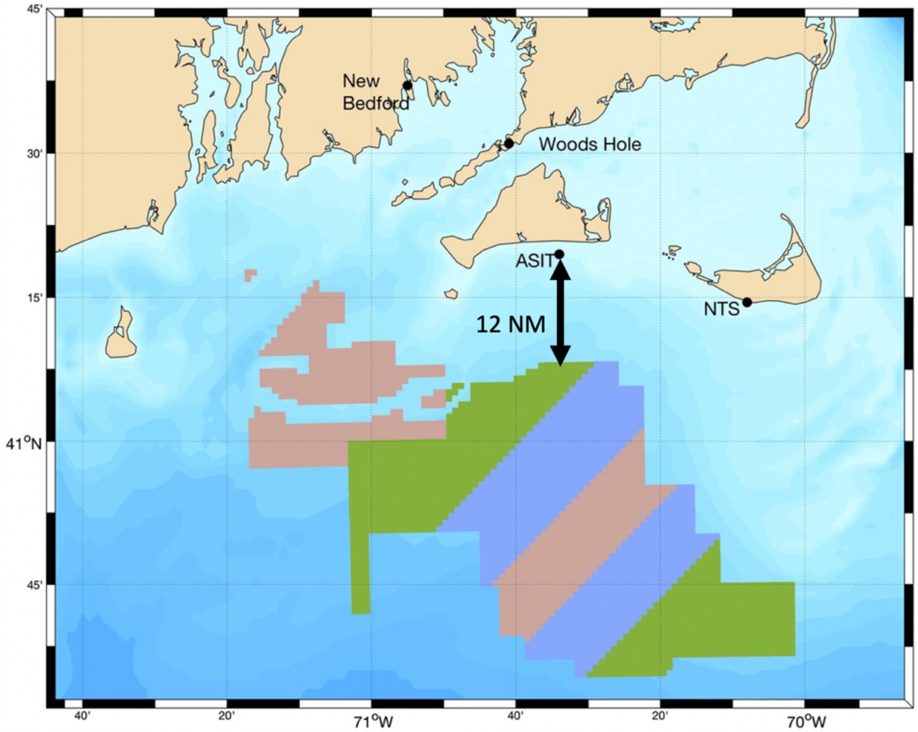
# 2 Project Goals and Tasks

## 2.1 MORS-1 Project Goal

The goal of this project was to develop the first long-term U.S.-based offshore metocean reference site by capitalizing on a unique combination of one of the few existing publicly available offshore wind energy metocean observational campaigns in the United States and the only existing research-grade offshore fixed tower. Now operational with a 6-year-long data record, MORS-1 has facilitated improved wind resource assessments, improved short-term power production estimates, and reduced costs for sensor validation and calibration efforts. All of these have translated into reduced overall project risk and cost. MORS-1 serves the needs of both industry and researchers using a nonprofit, joint industry-academic partnership model. Led by the Woods Hole Oceanographic Institution (WHOI), the MORS-1 development effort focused on creating both a recognized organizational structure that will ensure support of the MORS-1 by the wider wind energy industry and research community, and a highly validated data collection and sensor validation facility that will serve as a premier location for cost- and uncertainty-reducing resource characterization and research efforts.

MORS-1 builds on an initial metocean observation campaign that started in 2016 at the Air-Sea Interaction Tower (ASIT), located offshore of Martha's Vineyard, Massachusetts, in 17 m of water. Located 12 nautical miles (NM) away from the Rhode Island and Massachusetts wind energy lease areas, the ASIT is a facility of the Woods Hole Oceanographic Institution (WHOI) and is maintained by WHOI to support basic and applied science research. The initial metocean observations were funded by the Massachusetts Clean Energy Center (MassCEC) to support Massachusetts lease holder bids for the 2018 and 2019 state competitions, but support for the initial effort ended in December 2019. In developing MORS-1, our goal was to extend the multiyear record of metocean observations located at the ASIT in perpetuity as well as facilitate the regular validation of lidar buoys in the United States. MORS-1 uses the observations supported at ASIT as well as those from a nearby land-based site.

**Figure 1.** The Rhode Island and Massachusetts offshore wind energy lease areas are shown south of New Bedford, MA. WHOI's Air-Sea Interaction Tower (ASIT) is shown, located 1 NM south of the island of Martha's Vineyard and 12 NM north of the nearest federal lease areas.




## 2.2 MORS-1 Project Tasks

The MORS-1 project had the following development tasks, to be completed between January 2020 and August 2023:

1. Establish an advisory board consisting of a representative set of industry users and partners (including the NOWRDC) to provide guidance and feedback to the MORS-1 activities and structure.

2. Expand publicly available reference datasets on metocean offshore observations to establish MORS-1 as a long-term reference site. Additionally, a temporary expansion of metocean sensing to a nearby land-based site was used to add critical spatial context to the MORS-1 dataset.

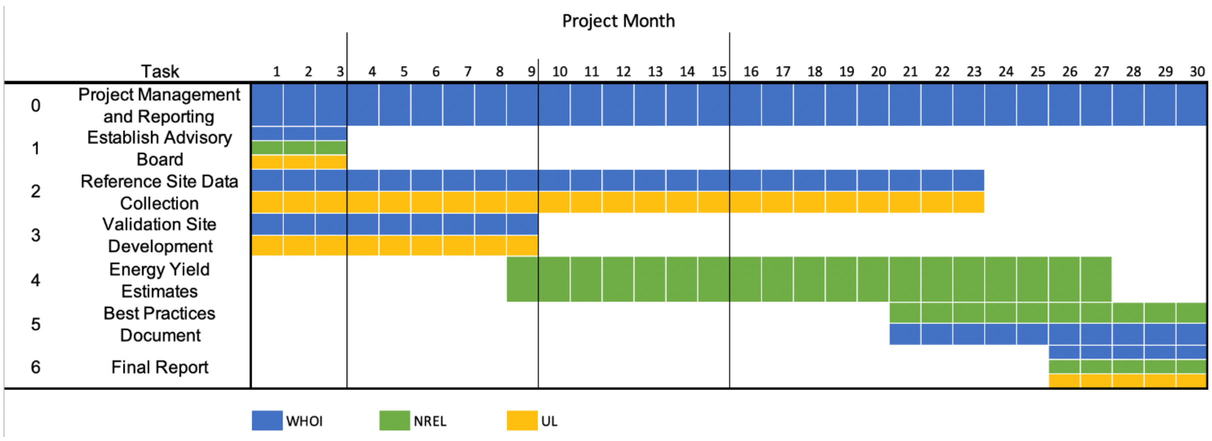
3. Remove barriers to U.S.-based in situ validation activities by developing a pre-permitted lidar buoy validation site at MORS-1 that leverages the ongoing reference data collection.

4. Demonstrate the ability of the MORS-1 data to reduce uncertainty in energy yield assessments for wind energy areas and assess possible differences/similarities with northern European baseline records such as those collected at the FINO towers.

5. Develop a best practices document relating to the testing, validation, and calibration of measurement systems against reference site measurements that will link with the ongoing Metocean Standards process organized by the American Clean Power Association.

The execution of these tasks over the lifespan of the project are illustrated in both the project Gantt chart and milestones and deliverables table (Figure 2, Table 1).

**Figure 2.** MORS-1 tasks and timeline




As described below, the WHOI-led project team completed all specified project tasks and milestones; however, the most significant testament to the successful completion of the overall project is the fact that, at this time, MORS-1 is operating as a stand-alone, user-supported data reference site with high-quality, long-term datasets being archived and shared publicly as well as an active validation center with a wait list for its use as a validation facility.

**Table 1.** Milestone, deliverable, and payment schedule for the MORS-1 development project

| Task | Milestone Number | Milestone Description | Budget Period (1-4)* | Deliverable Number | Associated Deliverable(s) | Forecasted Due Date (month) |
|---|---|---|---|---|---|---|
| 2 | 2.1.1 | All metocean sensors deployed, monitored, and validated for budget period 2 | 2 | 2.1.1 | Aggregates of monthly observation and validation reporting products for budget period 2 | M3 |
| | 2.1.2 | All metocean sensors deployed, monitored, and validated for budget period 3. | 3 | 2.1.2 | Aggregates of monthly observation and validation reporting products for budget period 3 | M15 |
| | 2.1.3 | All metocean sensors deployed, monitored, and validated for budget period 4 | 4 | 2.1.3 | Aggregates of monthly observation and validation reporting products for budget period 4 | M27 |
| | 2.2 | Backup lidar purchased | 2 | 2.2 | Proof of Backup Lidar purchase | M3 |
| | 2.3 | Metocean Validation Data Analysis and Reporting | 3 | 2.3 | Backup Lidar met-mast validation report | M9 |
| | 2.4 | Backup lidar deployed at NTS for spatial context observations | 4 | 2.4 | NTS deployment data and report | M20 |
| | | **Task 2 Total** | | | | |
| 3 | 3.1 | Develop business plan and lidar buoy validation center description. | 3 | 3.1 | MORS-1 lidar buoy validation center business plan and informational documents. | M9 |
| | 3.2 | Complete permitting roadmap or agreement for streamlined buoy validation activities | 3 | 3.2 | Buoy validation permit roadmap or agreement | M9 |
| | | **Task 3 Total** | | | | |
| **GO/NO-GO EVALUATION** | | | | | | |
| 4 | 4.1 | Characterize the wind climate in the Mid-Atlantic Bight and compare the wind climate observed to European baseline records. | 3 | 4.1 | Report on the quantitative characterization of the wind climate in the Mid-Atlantic Bight and the similarities and differences in the conditions wind plants will encounter in the northeast wind energy areas when compared to offshore wind plants in northern Europe. | M15 |
| | 4.2 | Quantify the impact of the reference site measurements on energy yield estimates and the impact of vertical extrapolation as a source of energy yield uncertainty. | 4 | 4.2 | Report that quantifies to what extent the reference site data can improve simulations and reduce uncertainty of the offshore wind climate in the U.S. northeast and the impact of vertical extrapolation as a source of energy yield uncertainty. | M27 |
| | | **Task 4 Total** | | | | |
| 5 | 5.1 | Develop a best practices document for U.S.-based wind energy resource characterization sensor validations. | 4 | 5.1 | A final report of Reference Site Best Practices | M30 |

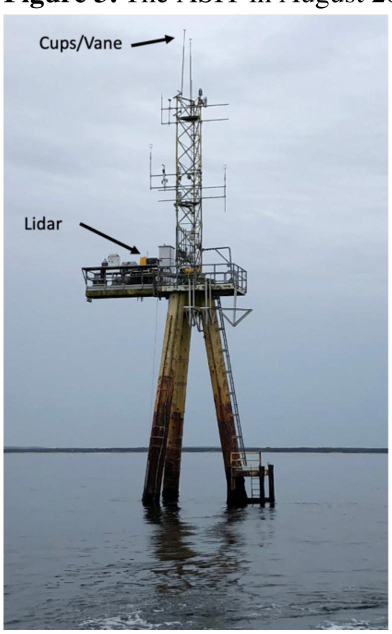
# 3 Results

Results of the project's activities are captured here in the context of the milestones and deliverables required for the project plan, starting with the operation and maintenance of the required instrumentation on the ASIT, the development of the site as a buoy validation location, and the team's work to document the value of the site as a facility to be utilized by industry and researchers alike.

## 3.1 Operation and Maintenance of MORS-1

WHOI and UL worked throughout the project period to maintain and expand the publicly available reference datasets of wind energy specific metocean observations established during the 2016–2019 MassCEC-supported metocean program (Filippelli et al., 2015; Kirincich 2020) in order to establish MORS-1 as a long-term reference site. This effort utilized the research facilities of WHOI's Martha's Vineyard Coastal Observatory (MVCO) for atmospheric and oceanic research. Created in 2001, MVCO has hosted critical experiments on the coupled air-sea boundary layer (e.g., Edson, 2007), underwater noise, autonomous underwater vehicle testing and development, and atmospheric research (Bodini et al. 2019). Central to the MVCO, the ASIT is a cabled, fixed platform located approximately 3 km south of Martha's Vineyard in 17 m of water. An upgrade to the power and communications systems in 2019 provides up to 5 kW of power and enhanced data transfer speeds to support testing and validation of new atmospheric and oceanographic sensors.

**Figure 3.** The ASIT in August 2021 with two lidars and the standard MORS-1 sensor suite deployed.



### 3.1.1 ASIT

The MORS-1 effort augments the ASIT's core sensors (WHOI, 2019) with a suite of wind resource-specific monitoring equipment, including a pair of cup anemometers above the top of the tower at 26 m above mean sea level (amsl), a wind vane at 23 m amsl, and a vertically profiling lidar on the main platform at 13 m amsl. During the project period, WHOI worked to extend the described time series for 2 years (Month 1–Month 24 from project initialization) to culminate in a 5-year record of sustained observations that can provide critical information on the interannual variations of the wind resource. These observations included:

1. A Leosphere WindCube or ZX 300 vertical profiler to measure horizontal winds in the bottom 200 m of the atmosphere at 13 m amsl.

2. MEASNET-calibrated cup anemometers (i.e., RNRG P2546-OPR and RNRG #40C) for measuring estimates of wind speed at 26 m amsl.

3. Wind vane (RNRG 200P or equivalent) based wind direction at 26 m amsl.

4. Temperature and conductivity sensor (SBE37) on the ASIT underwater beam to provide complementary oceanographic observations not available at the ASIT otherwise.

An additional lidar system was purchased by WHOI and tower-validated by UL to serve as a backup system, allowing WHOI to cycle through lidars on the ASIT to ensure the highest level of data quality and system redundancy.

For all tower operations, a regular servicing and maintenance schedule was developed and instituted following the sensor protocols and maintenance schedules described in "Metocean Data Needs Assessment and Data Collection Strategy Development for the Massachusetts Wind Energy Area" by Filippelli et al. (2015) to establish MORS-1 as a dependable reference site that can ensure sustained data collection. Tower validations of each of the lidars are scheduled to occur every 1.5 to 2 years to maintain maximum traceability of the data collection effort. Monthly reports of all datasets and measurements collected were created and are available via all data distribution pathways (see Section 3.1.4).

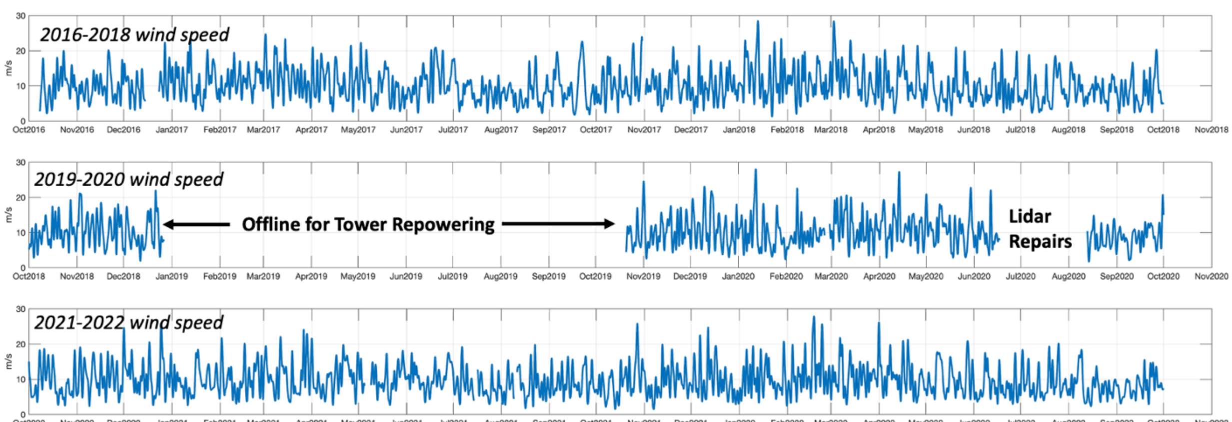
**Figure 4.** The MORS-1 sensor suite, including self-sustained and ancillary data collection efforts.

## MORS-1 Full Sensor Suite

| Parameter | Sensor | Description | |
|---|---|---|---|
| Vertical profiles of horizontal winds | Leosphere Windcube v2 Lidar Wind profiler | 13 m amsl[a] | MORS-1 supported |
| Wind speed | rNRG 40c, P2546c-OPR cup anemometers | 26 m amsl | MORS-1 supported |
| Wind direction | rNRG 200P wind vane | 24 m amsl | MORS-1 supported |
| Air temperature, pressure, and relative humidity | Vaisala HMP45A-P | 20 m amsl | Ancillary |
| Sea surface temperature and salinity | Seabird 37 CT | 4 m bmsl[b] | Ancillary |
| Ocean waves currents | 1200 kHz RDI ADCP | at the MVCO 12-m underwater node | Ancillary |

[a]above mean sea level
[b]below mean sea level

**Figure 5.** The full record of 150-m wind speeds, from inception of MORS-1 in October 2016 to October 2022. Additional data have been collected to present.



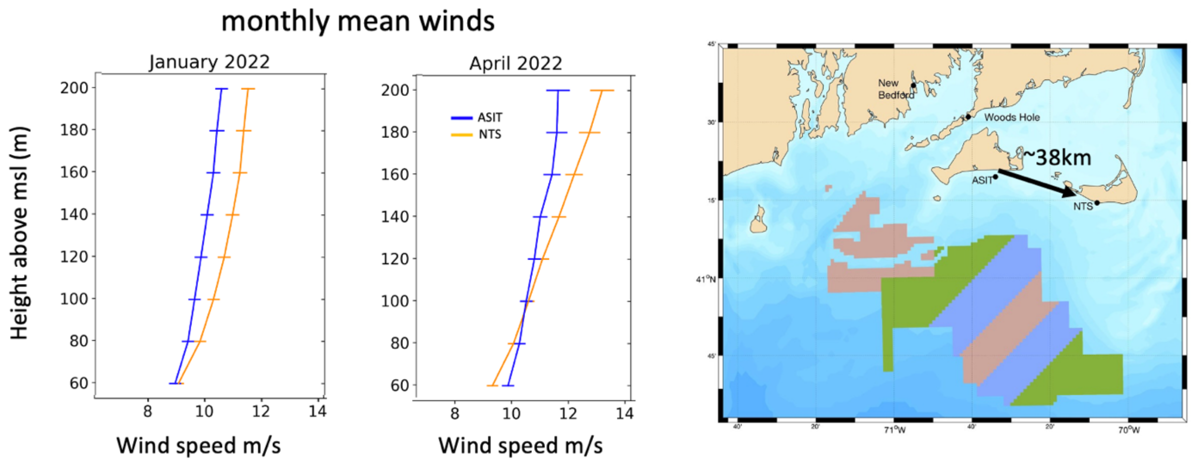

### 3.1.2 Nantucket Test Site

WHOI and UL utilized the Nantucket Test Site (NTS), a facility operated cooperatively by WHOI and the Town of Nantucket, to conduct complementary land-based lidar observations during a portion of the project period. Located 20 NM to the southeast of ASIT and a similar 10 NM from active lease areas, the NTS has powered, secure sensor locations 100 m from the ocean along the low-relief south coast of Nantucket. Data collection at the NTS using a freshly validated Windcube v2.0 lidar at the Nantucket site started Nov. 6, 2021, and was removed on Nov. 10, 2022, achieving the project goal of providing one year of observations to help characterize spatial scales of winds in the region.

**Figure 6.** The WHOI Windcube v2.0 lidar stationed at the Nantucket test site, maintained between November 2021 and November 2022.


Comparing winds from the ASIT and NTS sites during the year that NTS was occupied showed clear trends in the differences between local hub-height winds at the two sites. Hub-height (~150 m above mean sea level) winds were consistently stronger at Nantucket, compared to ASIT, during all times of the year. Shown in Figure 7, monthly mean wind speeds at NTS were 1–2 m/s larger at Nantucket compared to ASIT. Both data sets from this period have been documented appropriately and made available via the data distribution pathways described in Section 3.1.4.

**Figure 7.** Nantucket vs ASIT mean wind speeds in January and April, 2022, along with the relative locations of the two sensor locations, shown at right.




### 3.1.3 Third-Party Validation

For all months of the 2-year data collection period as well as the periods before and since, subcontractor UL has provided validation services for the ASIT deployed sensors as well as the lidar deployment at the Nantucket Test Site. A copy of all validation reports has been submitted to the NYSERDA data portal for this project, and copies have been uploaded to the data repositories listed above. Validation activity since the NOWRDC funding period for observations was funded by validation user fees as per the design and goal of the MORS-1.

### 3.1.4 Data Availability

Data from the MORS-1 dataset have been archived in a number of ways to maximize both awareness and use of the dataset by industry and the research community. A citable DOI is regularly updated with new data via the WHOI data library that can be used by academic researchers that seek to use MORS-1 data in published works. These data are updated by WHOI personnel yearly with additions or corrections to the data archive. Secondly, an ftp site, maintained by UL, exists to enable developers and their agents to access data from the full MORS-1 record in wind energy consultant-specific formats in order to aid ingestion into resource characterization efforts. Finally, data from all available sensors can be viewed in real time via the MVCO website (Figure 8).

**Figure 8.** MORS-1 Public Data Repository locations.

**MORS-1 Public Data Repositories**

https://hdl.handle.net/1912/27014
*citable for research and publication use*

https://ftp.awstruepower.com
*for industry real-time data viewing*

https://mvco.whoi.edu/projects/vertical-wind-profile/
*for real-time data viewing*

## 3.2 Lidar Buoy Validations

The need for metocean reference sites within the industry are both for regional resource characterization as well as in situ validation. At the start of the project period, few lidar buoy validations had been performed in the United States. Most agents used European centers to validate lidar buoys prior to use in the United States. These steps required additional time and expense, and included shipping instruments and buoys back and forth between Europe and the United States. To remove barriers to the U.S.-based in situ validation activities, WHOI sought to establish a pre-permitted lidar buoy validation site at MORS-1 that leverages the ongoing reference data collection described above.

### 3.2.1 Formal Permitting by Epsilon

WHOI worked with project team member Epsilon to identify and approach state and federal agencies with jurisdiction over non-development permitting ocean activities at the location of the ASIT. Our goal was to find the best, most consistent way to reduce the timeframe and burden of a permitting action by an individual vendor or developer for the purpose of validation while also maintaining the highest level of environmental protection. Because the ASIT is in state waters, the primary authorizations required were local permits from the town and the harbormaster for the site. However, given the activity and the national interest in wind energy in the region, the consistency of this determination and permitting pathway for the project required review by both state and federal agencies (USCG and Mass Chap. 91).

WHOI and Epsilon carried out the review by local, state, and federal regulators, which resulted in a single proposal for a 3-year, renewable permit to host up to five buoys per year at two specific sites 500 m away from the ASIT. This proposal was seen as a holistic way to account for the full impact of the validation site in the permitting process as opposed to having each effort apply separately. The permitting process took 9 months, starting with an application to the Edgartown Conservation Commission for a Negative Determination of Applicability, which was granted. A permit issued from the harbormaster followed, along with consistency review by Massachusetts Coastal Zone Management. The final required permit from the U.S. Army Corps of Engineers was issued in April 2022 (Fig. 9) and allows the use of the ASIT as a validation site for buoys from different vendors under the direction of WHOI as long as they (1) have mooring designs that do not exceed the largest permitted mooring design, (2) display the USACE permit number on their buoy during the deployment, and (3) separately apply for a U.S. Coast Guard Private Aids to Navigation (PATON) designation directly within 14 days of deployment.

**Figure 9.** MORS-1 USACE permit cover letter.

**DEPARTMENT OF THE ARMY**
US ARMY CORPS OF ENGINEERS
NEW ENGLAND DISTRICT
696 VIRGINIA ROAD
CONCORD MA 01742-2751

April 19, 2022

Regulatory Division
File No. NAE-2022-00270

Woods Hole Oceanographic Institution
Attn: Anthony Kirincich
569 Woods Hole Road
Falmouth, Massachusetts 02543
akirincich@whoi.edu

Dear Mr. Kirincich:

This is in response to a recent request dated April 13, 2022 to modify a project authorized by the Department of the Army permit number NAE-2022-00270. The authorization was for the placement of structures below the mean high water mark of waters of the United States as part of a temporary deployment of two wind validation buoys.

This work is located in the Atlantic Ocean south of Martha's Vineyard, Massachusetts at site coordinates 41.325003, -70.571439 and 41.322542, -70.560056. The work is shown on the enclosed plans titled "Figure 1 Locus Map" and "PNNL 15m Mooring Diagram", on two sheets, and undated.

The project is hereby modified to clarify that two buoys will be periodically deployed for up to 90-day periods for the duration of the authorization. In addition, the following special condition has been modified:

As a result of WHOI's actions to host the permit for buoy deployments in the area for validations, the time scale for an individual developer to apply for and be granted a permit for this activity has decreased from 4–6 months to a matter of days. Additionally, by coordinating the use of a single permit rather than a large group of individual permits, WHOI has reduced the number of reviews required from regulators and enabled the single review to be a holistic assessment of the full set of activities.

### 3.2.2 Documentation of Validation Activities for Users

WHOI and Epsilon created a set of reference documents that would be needed by vendors to plan and prepare for a MORS-1-based validation. These documents include all the requirements of the validation site, instructions for how to use and adhere to the requirements of WHOI's site permit, and PATON application directions. These documents are included as an appendix in the final report for completeness. As of summer 2023, two validation actions have been carried out or are in progress for 2023, with one additional validation being planned for the calendar year.

## 3.3 Reference Station Assessments

Project team member National Renewable Energy Laboratory (NREL) worked with WHOI team members to utilize the data from the MORS-1 to (1) examine the characteristics of the wind field at the ASIT in comparison to that of the European FINO towers, which were more familiar to the industry at the time of the inception of the U.S.-based industry, and (2) estimate energy yield assessments with and without the MORS-1 data to provide a clear assessment of the value of the MORS-1 value and assess possible differences/similarities with northern European baseline records such as those collected at the FINO towers. Results of work toward these tasks are described here.

### 3.3.1 Comparison of ASIT Conditions to the FINO Tower Datasets

The MORS-1 dataset allows a quantitative characterization of the interannual variability of the wind climate in the Mid-Atlantic Bight and a comparison against European baseline records to assess similarities and differences in the conditions that wind plants will encounter in the northeast wind energy areas when compared to offshore wind plants in northern Europe. NREL used these long-term measurements from MORS-1 to quantitatively characterize the wind climate in the Mid-Atlantic Bight (NREL Task 1) and compared those data on the wind climate observed to European baseline records to assess similarities and differences in the conditions wind plants will encounter in the northeast wind energy areas when compared to offshore wind plants in northern Europe (NREL Task 2). The main results are summarized in the following points:

- There is a statistically significant higher percentage of stronger hub-height wind speeds at ASIT stations than at the FINO stations.
- Extreme high-wind conditions (>20 m/s) were shown to occur on 2–3 % of days during winter and spring seasons at the ASIT station, indicating that extreme weather events such as strong winter storms might occur.

- Wind speeds at the ASIT tower are generally more variable than those from FINO stations, suggesting that the U.S. northeast coastline is more subject to meteorological disturbances than European areas.
- The wind directions at both ASIT and FINO stations exhibit similar patterns, where the most dominant wind direction at hub height is from the southwest. However, the seasonal variation of wind direction from both stations exhibits significant differences, especially during the winter months.
- The maritime atmospheric boundary layer of the U.S. northeast coast has a significantly higher risk of experiencing highly unstable conditions compared to northern Europe, particularly during the winter months. This poses a challenge when planning and constructing offshore wind plants in these regions.

**Figure 10.** Geographical locations of the ASIT (black), FINO1 (green), FINO2 (blue), and FINO3 (red) stations.

**Figure 11.** Histogram of hub-height wind speed (m/s) between ASIT and FINO (FINO1, 2, and 3 combined) stations from 2017 to 2020.

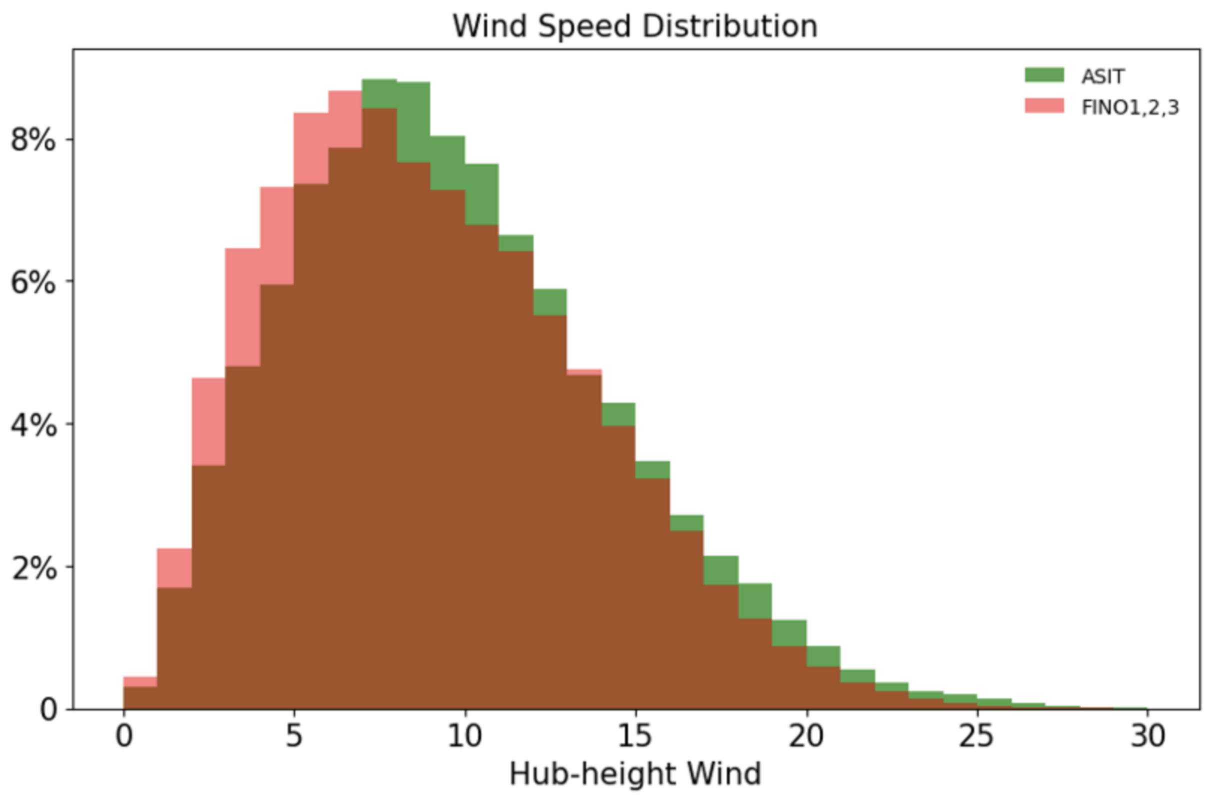
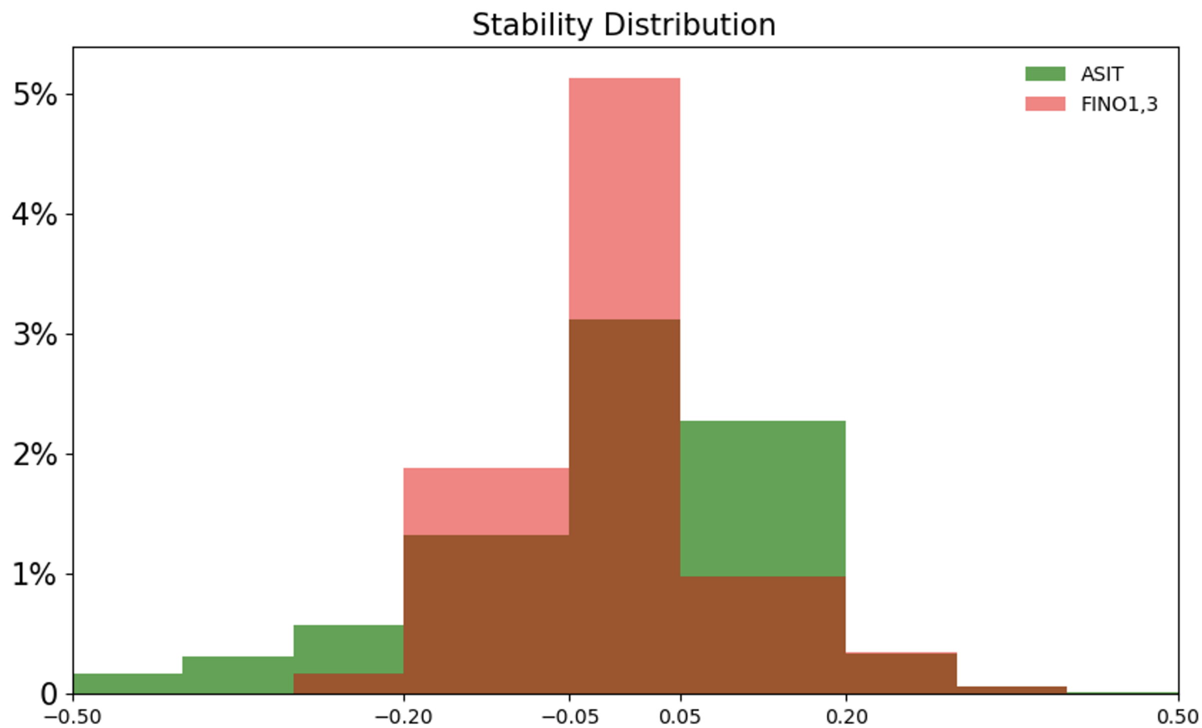


**Figure 12.** Histogram of near-surface atmospheric stability (1/m) at ASIT and FINO (FINO 1 and FINO 3 combined) stations from 2017 to 2020.




### 3.3.2 Assessment of the Impact of MORS-1 Observations on LCOE Estimates

NREL also worked to quantify the impact of the reference site measurements on energy yield estimates, based on the annual energy production at a hypothetical wind farm. This work was done using two approaches: using MORS-1 data to bias-correct the output of mesoscale atmospheric simulations of wind conditions in the wind energy area, and using MORS-1 data to tune or train vertical extrapolation techniques to predict hub-height winds based on surface wind observations. The impact of vertical extrapolation as a source of energy yield uncertainty in this area was quantified by NREL by comparing two datasets: vertical wind speed profiles derived from the lidar measurements and vertical wind speed profiles obtained via vertical extrapolation of ASIT tower measurements (NREL Task 3). NREL then sought to quantify to what extent the reference site data can improve simulations and reduce uncertainty of the offshore wind climate in the northeast U.S. and to couch that reduction in terms of a reduction in levelized cost of energy (NREL Task 4).

For these tasks, NREL leveraged two different models in comparison to ASIT: a numerical weather prediction approach using the Weather Research and Forecasting model (WRF), and a machine learning model capable of vertically extrapolating wind speeds. Bias correction of these models was also performed to help eliminate any potential bias in the modeled wind speeds. The general climate conditions for 2017–2020 were analyzed, along with the conversion of wind speed to power using an IEA offshore reference turbine. Energy metrics such as annual energy production (AEP) and simple levelized cost of energy (SLCOE) were calculated to get an idea of how much energy a hypothetical turbine would produce and cost over the period of interest.

Overall, the models performed well compared to observations at ASIT (Fig. 12). Wind speed biases before bias correction were less than 0.2 m/s and agreed well on monthly and diurnal time scales. AEP and SLCOE values never deviated by more than 3% against ASIT, with the unbiased WRF coming within 0.5% of observed values. Ultimately, the bias correction did not improve performance of the models much, if at all, and in some instances performance degraded.

While the models used in this study excelled in capturing the general wind and hypothetical energy conditions at ASIT, wind resource estimation techniques are often not enough to correctly characterize the metocean environment in which offshore turbines will be installed. Additionally, without reference observations such as ASIT, data-driven models such as the random forest would not be possible. Reference metocean sites are critical not only for the validation and verification of models, but also for the development of new models.

**Figure 13.** NREL results showing the change in the mean hourly wind speed error (in m/s) for the NREL 20-year hindcast simulation with and without bias correction using the MORS-1 dataset at the ASIT. Here, "WRF" stands for the Weather Research and Forecasting model, "RF" the random forest model, and "BC" bias-corrected.

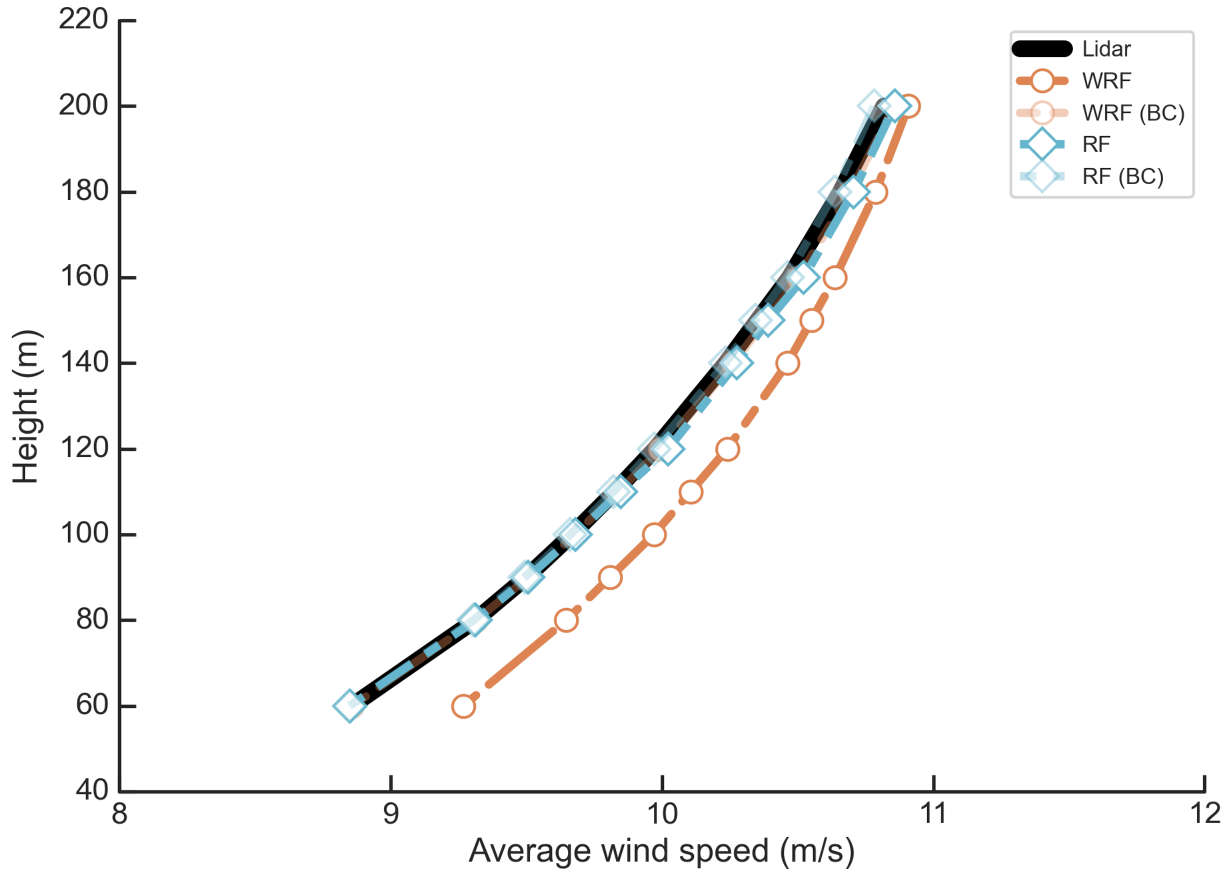


**Table 2.** Basic statistics for the wind resource estimation techniques at 150 m before and after being bias corrected.

| Model | Pearson $r^2$ | MBE[1] (m/s) | cRMSE[2] (m/s) | EMD[3] (m/s) |
|---|---|---|---|---|
| WRF | 0.865 | 0.195 | 1.987 | 0.286 |
| WRF (BC) | 0.864 | 0.031 | 1.910 | 0.100 |
| RF | 0.860 | 0.022 | 1.902 | 0.351 |
| RF (BC) | 0.860 | -0.029 | 1.934 | 0.160 |

[1]MBE: mean bias error
[2]cRMSE: centered root mean square error
[3]EMD: error mean difference

**Table 3.** Average annual energy production (AEP) values for all models, before and after bias correction, for 2017–2020 (most of 2019 excluded).

| Data source | AEP (GWh) | % diff. from lidar |
|---|---|---|
| Lidar | 79.40 | --- |
| WRF | 79.80 | 0.50 |
| WRF (BC) | 80.41 | 1.26 |
| RF | 81.58 | 2.67 |
| RF (BC) | 78.07 | 1.70 |

**Table 4.** Parameters used in the simple levelized cost of energy (SLCOE) calculation, along with results using two different financing rates. For all cases in the table, the project life of the turbine is assumed to be 30 years.

| Data source | OCC[1] ($/kW) | Finance rate (%) | OMC[2] ($/kW-yr) | Average CF[3] (%) | SLCOE ($/MWh) | % diff. from lidar |
|---|---|---|---|---|---|---|
| Lidar | 4000 | 10 | 80 | 60.37 | 95.28 | --- |
| WRF | 4000 | 10 | 80 | 60.68 | 94.80 | 0.50 |
| WRF (BC) | 4000 | 10 | 80 | 61.14 | 94.08 | 1.26 |
| RF | 4000 | 10 | 80 | 62.03 | 92.72 | 2.68 |
| RF (BC) | 4000 | 10 | 80 | 59.36 | 96.90 | 1.70 |
| Lidar | 4000 | 7.5 | 80 | 60.37 | 79.10 | --- |
| WRF | 4000 | 7.5 | 80 | 60.68 | 78.70 | 0.51 |
| WRF (BC) | 4000 | 7.5 | 80 | 61.14 | 78.10 | 1.26 |
| RF | 4000 | 7.5 | 80 | 62.03 | 76.98 | 2.68 |
| RF (BC) | 4000 | 7.5 | 80 | 59.36 | 80.45 | 1.71 |

[1]OCC: overnight capital cost
[2]OMC: operations and maintenance cost
[3]CF: capacity factor

# 4 Conclusions and Future Outlook

Building and/or maintaining offshore fixed towers for the sole purpose of collecting metocean observations specific to the offshore wind energy industry is exceedingly expensive. This project worked to develop the first long-term U.S.-based offshore metocean reference site, MORS-1, by capitalizing on a unique combination of one of the few existing publicly available offshore wind energy metocean observational campaigns in the United States and the only existing research-grade offshore fixed tower. Via a public-private partnership model, a potential reference site can be uniquely capable of providing the reference observations that are critically needed by developers, grid operators, and researchers alike.

Data collected at MORS-1 has facilitated improved model assessments of the wind resource, improved short-term power production estimates, and reduced costs for sensor validation and calibration efforts, which translate into reduced overall project risk and cost. Now operational, MORS-1 serves the needs of both industry and researchers using a nonprofit, joint industry-academic partnership model. Led by WHOI, the MORS-1 development effort focused on creating both a recognized organizational structure that will ensure support of the MORS-1 by the wider wind energy industry and research community, and a highly validated data collection and sensor validation facility that will serve as the premier location for cost- and uncertainty-reducing resource characterization and research efforts.

### 4.1.1 Reference Site Best Practices

The goal of a reference site is to provide long-term sampling of critical parameters in areas of interest to the industry and the scientific community. This data collection effort allows benchmarked testing of sensors and sensing systems and the ability to validate and constrain numerical models and forecasts of the wind resource available for power production. The best long-term metocean reference stations for energy and climate research have:

1. Multiple-use datasets that are easily accessible
2. Stable, self-generating funding sources
3. Clear and attainable measurement objectives
4. Open and transparent adherence to international data and measurement standards.

Each of these qualities has been met at the MORS-1, and its successful development effort has led to a self-sustaining reference site with a long record of observations that provide context for lease area measurements in many of the active lease areas. The MORS-1 site, located at WHOI's Air-Sea Interaction Tower, provides a model for the development of other reference sites at coastal, pier, or jetty sites in the United States to be developed to serve the needs of the energy and the climate communities with valuable, cost-effective monitoring and reference datasets.

### 4.1.2 Future Outlook

As a result of this project, the data collection effort at MORS-1 is a trusted source of regional environmental conditions for both industry and the research community. The MORS-1 data are regularly used by developers to augment their in-area observations for their site characterization studies. Numerous scientific studies are also utilizing the dataset in their research. As an example of the dataset's reach within the science community, a recent session at the January 2023 American Meteorological Society's annual meeting on wind energy had eight podium presentations, six of which used data from the MORS-1 repository in their research efforts. As these researchers will be able to cite the DOI repository in their publications, use of the MORS-1 in the science community will soon be trackable via literature searches. Finally, as soon as the validation site permitting was complete, individual users were seeking to use the facility. The facility will run validations at capacity this year (2023) and is expected to remain at capacity for the next 5 years at minimum.

# 5 References

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# Appendix A. Sample of MORS-1 Validation Site Informational Packet

A sample of the validation site informational packet that is distributed to users is attached as Appendix A in the pages that follow.

## Martha's Vineyard Coastal Observatory

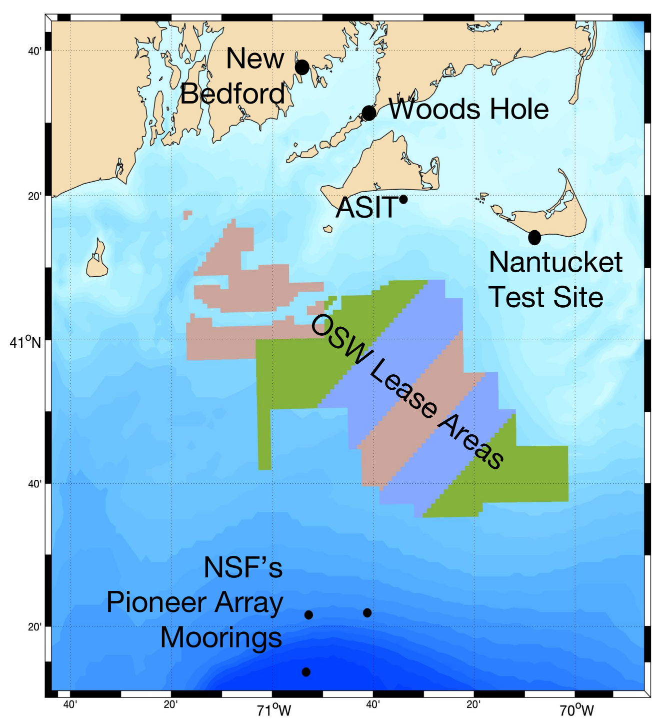
### MetOcean Reference Site (MORS-1)
### Offshore Wind Energy LIDAR Buoy Validations

**Facility Coordinator and Data Provider:** Woods Hole Oceanographic Institution
**Data Validator:** AWSTruepower/UL
**Permitting Consultant:** Epsilon Associates
**Point of Contact:** Anthony Kirincich (akirincich@whoi.edu)

**Summary:** The Woods Hole Oceanographic Institution seeks to assist the offshore wind energy industry in the local calibration of wind resource characterization buoys. WHOI will coordinate the use of its existing research facility, the Martha's Vineyard Coastal Observatory's Air Sea Interaction Tower for validation efforts, both maintaining a suite of validation sensors and assisting user-led permitting for buoy installations in up to two specific pre-identified anchor locations adjacent to the tower. Interested users should contact WHOI for additional information on potential deployments.

**Background:** LIDAR buoys are now a critical part of offshore wind energy resource characterization and monitoring campaigns. Following the Carbon Trust Offshore Wind Energy Roadmap for LIDAR technology[1], buoy systems can be utilized for resource characterization and project data collection. However, proper pre-deployment validation of the LIDAR and buoy system against a primary or secondary reference standard is needed to certify the LIDAR wind observations for use in energy related data uses[2]. With no purpose-built validation facility in the U.S., developers are currently required to validate buoy systems overseas prior to domestic data collection campaigns.

The Martha's Vineyard Coastal Observatory's Air Sea Interaction Tower (ASIT) is uniquely capable of providing domestic validation activities. This effort capitalizes on an initial investment by the Commonwealth of Massachusetts and

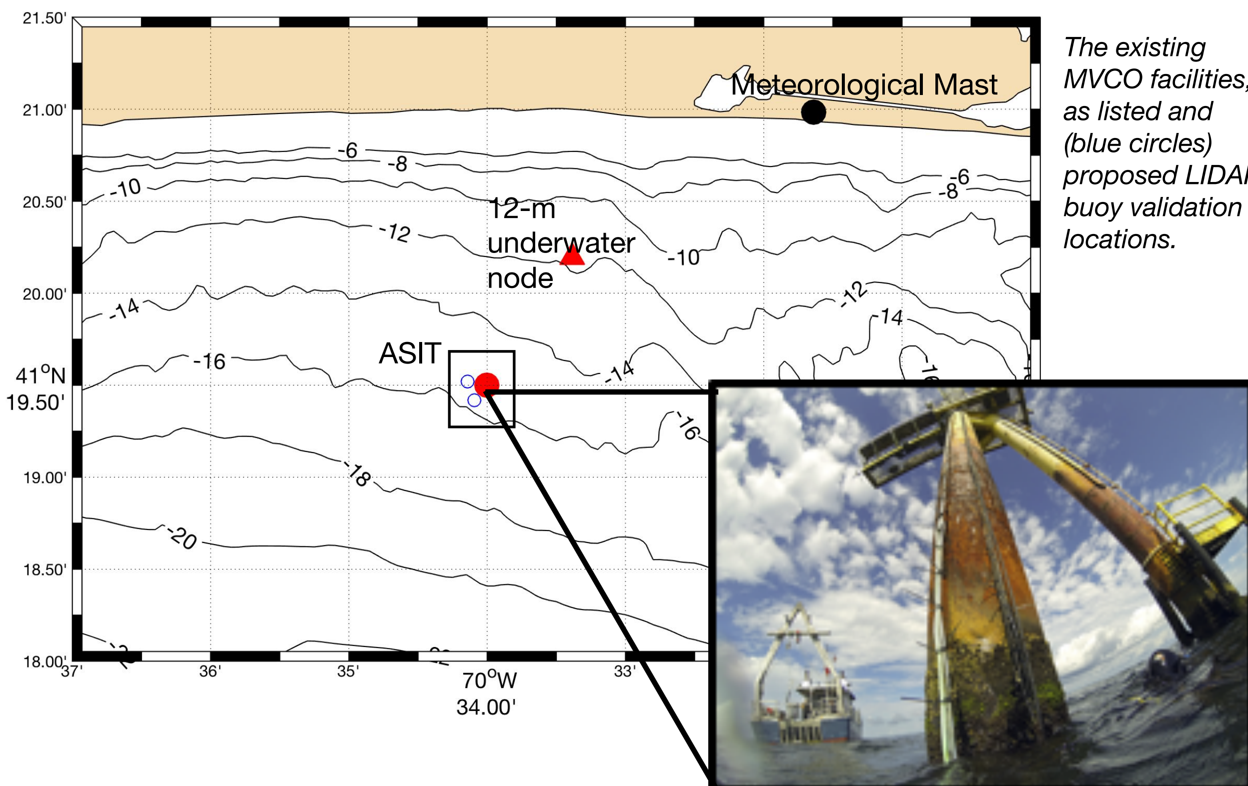



*The Rhode Island and Massachusetts Outer Continental Shelf (OCS) with the locations of: existing OSW lease areas, WHOI's Air-Sea Interaction Tower (ASIT), and the National Science Foundation's Ocean Observing Initiative Pioneer Array Moorings relative to Woods Hole and New Bedford.*

transitional funding by the National Offshore Wind Research and Development Consortium (NOWRDC).

As WHOI owns and operates the ASIT tower for research purposes, use of this existing asset will minimize the impact of validation activities on the local coastal ocean and its existing stakeholders, provide a validation location that has wind and wave conditions representative of much of the Mid-Atlantic Bight OCS, as well as streamline user efforts to prepare and carry out site characterization activities in the U.S.

**About the Observatory:** Created in 2001, the Martha’s Vineyard Coastal Observatory (MVCO) is a purpose-built facility for conducting detailed atmospheric and oceanic research. Numerous researchers have utilized the facility[3], including critical experiments focusing on the coupled air-sea boundary layer[4]. Central to the research activities of the MVCO, the Air-Sea Interaction Tower (ASIT) is a cabled, fixed platform located approximately 3 km south of Martha's Vineyard in 15 m of water (see below). The ASIT has a maximum height of 23 m above mean sea level, and a platform at 13 m suitable for larger instruments. An upgrade to




*The existing MVCO facilities, as listed and (blue circles) proposed LIDAR buoy validation locations.*

the power and communications systems of the tower in 2018-2019 provides up to 5 kW of power and enhanced data transfer speeds to support testing and validation of new atmospheric and oceanographic sensors.

Since 2016, a MetOcean initiative[5] has collected continuous observations of the atmospheric boundary layer at the ASIT. At the site, a suite of specific wind resource monitoring equipment is being used to augment the existing sensors deployed by MVCO, including a pair of cup anemometers above the top of the tower at 26-m above mean sea level (msl), a wind vane at 23-m above msl, and a vertically profiling lidar on the main platform, at 13-m above msl. All metocean data collected by WHOI is validated by AWS Truepower, a UL company. The ASIT is located 10 NM onshore of the RI/Mass wind energy areas and convenient to WHOI's Iselin dock facilities, for research activities, and the New Bedford Marine Commerce Terminal, for commercial activities.

**WHOI owns two vertically profiling lidar systems: a Leosphere WindCube v2, purchased in 2016 and a ZX300m, purchased in April 2021. The ZX was tall-tower validated in August 2021 and installed on the ASIT in September 2021. All validation activities were overseen by AWSTruepower/UL.**

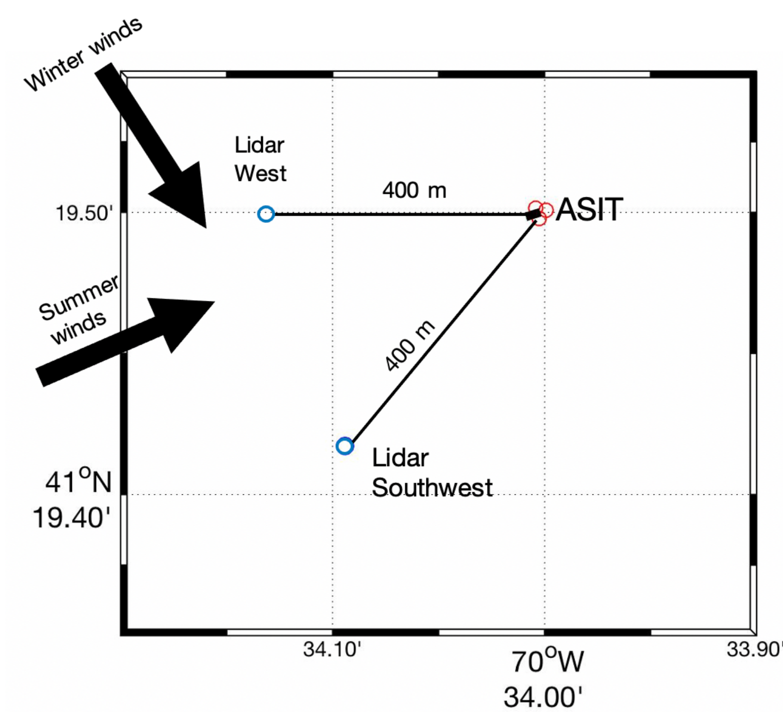
**Using the Facility for Metocean Buoy Validations:** WHOI is a non-profit research institution and has used funding from MassCEC and NOWRDC to start up the facility and maintain initial data collection at the reference site. User fees are required for each validation activity at the ASIT to cover the cost of sensor maintenance during the validation, validation planning or assistance by WHOI and UL, and supporting this data collection activity at ASIT.

Validation activities will be organized as follows:

- WHOI maintains the suite of MetOcean sensors on the ASIT including fixed cup anemometers, vanes, air and sea temperature, pressure, relative humidity, and waves, as well as a platform-based fixed LIDAR wind vertical profiler (see ASIT schematic) on a year-round basis.

- Independent validation of the key WHOI-deployed instruments is provided by AWSTruepower /UL to ensure all MetOcean sensors are deployed and maintained following industry standards.

- Potential facility users would contract directly with WHOI to coordinate a buoy deployment location for a set block of time, at one of




*Detailed site map of an approximately 700m x 700m area near the ASIT. The tower legs and platform extension directed towards a bearing of 253° are shown at approximately true scale. Proposed LIDAR buoy anchor locations (blue circles), should be more than 200-m from the tower, are shown at bearings of 220° and 280° from the tower. With predominant summer winds from ~250° and winter winds from ~320°, this configuration would minimize wind wakes on the buoys from the tower.*

two pre-permitted validation locations, both approximately 400 m away from the ASIT at:

- ***Lidar West:*** ***41°19'30.01"N 70°34'17.18"W***
- ***Lidar Southwest:*** ***41°19'21.15"N 70°34'12.20"W***

- Prior to and during the validation activity, users would again access to:
  - Curated data from the Lidar, cup anemometers, and wind vane sensors.
  - Raw data from the Lidar, cup anemometers, and wind vane sensors.
  - Curated data from ancillary sensors on and near the tower including:
    - Air temperature, air pressure, and relative humidity
    - Sea surface temperature and salinity
    - Local ocean currents and waves.

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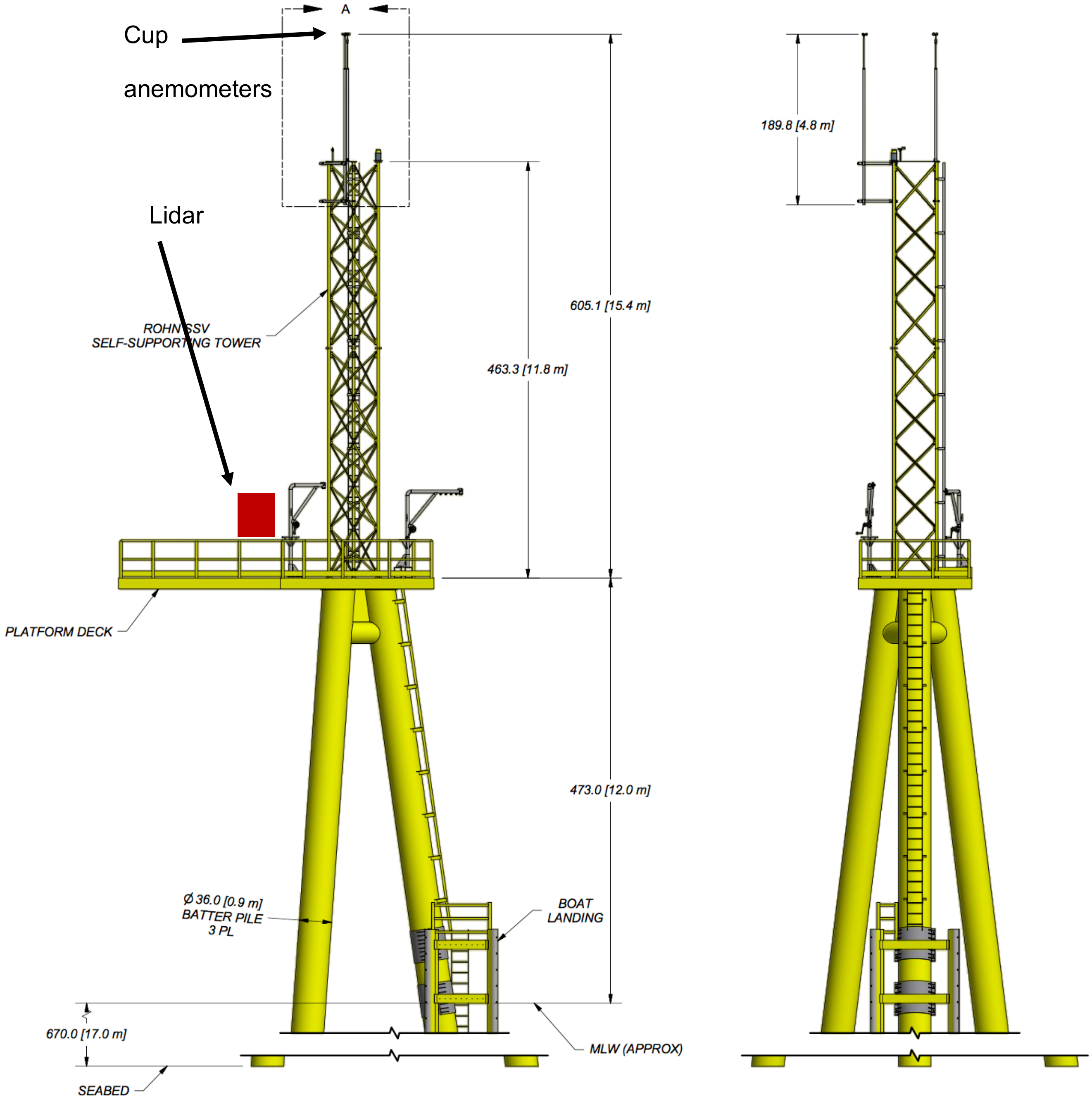


*Detailed schematics of WHOI's existing Air Sea Interaction Tower (ASIT) including all pertinent elevations and dimensions of the tower structure and fixed MetOcean sensors. The locations and heights of the cup anemometers and vane are shown at the top of the tower. The lidar system is located outboard on the platform deck, which is oriented to point into the direction of the prevailing summer winds, or ~ 250° True.*