Metocean Reference Station Best Practices:

MORS-1 case study

Final Report

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Acronyms and Abbreviations

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
WHOI	Woods Hole Oceanographic Institution

Executive Summary

The goal of a Metocean Reference Station should be to aid both near-term development of the offshore wind energy industry as well as long-term climate and energy research. Capitalizing on existing shared-use facilities wherever possible, reference stations should provide data valued by industry users as well as research users in a cost-effective way. Cost-effectiveness is a critical component of developing a reference site, as the real value of the site's data collection efforts is the length of the time series it is able to sustain.

This report seeks to lay out the best practices toward developing and maintaining metocean reference stations in the United States. The best practices described here focus on suitable platforms, sensor integration, and long-term operations of the reference station itself, as best practices of operations for individual sensors for the research community or validation enterprises focused on industrial use of metocean data are well described in the literature. This work focuses on potential stations in the United States because the market for reference data and validation facilities is less well defined in the United States, given the young age of the rapidly emerging offshore wind energy industry here.

Best practices for reference stations in the U.S. are described based on the successful creation of the first U.S.-based station along the East Coast. This station, located at the Woods Hole Oceanographic Institution's Air-Sea Interaction Tower, capitalizes on a unique combination of the only publicly available wind-energy-specific metocean observational campaign in the U.S. and a research-grade, offshore fixed tower. With 6 years of continuous operations, the facility is now self-sustaining, and serves the rapidly emerging U.S. industry by providing a locally relevant, highly validated, easy-to-use validation site option at lower total costs than presently available sites, which are based primarily in Europe. Based on these experiences, the best long-term metocean reference stations for energy and climate research will have stable, self-generating funding sources; clear measurement objectives that are simply defined and followed; multiple-use datasets and dual-use platforms; robust recordkeeping; and open communications to all potential users.

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.

Figure 1: A lidar buoy owned by the U.S. Department of Energy on validation at Woods Hole Oceanographic Institution's Air-Sea Interaction Tower in January 2020.

Photo credit, Jay Sisson, WHOI

2 The MORS-1 Facility

This first facility, named the offshore MetOcean Reference Site (MORS-1), builds on a metocean observation campaign started in 2016 at the Air-Sea Interaction Tower (ASIT), 10 nautical miles (NM) away from the Rhode Island and Massachusetts wind energy lease areas located in 17 m of water south of Martha's Vineyard, Massachusetts. The ASIT is a facility of the Woods Hole Oceanographic Institution (WHOI) and maintained by WHOI for general and applied science use. The data collection effort at MORS-1 has become a trusted source of regional environmental conditions and has been used by many developers to augment their in-area observations within their site characterization studies.

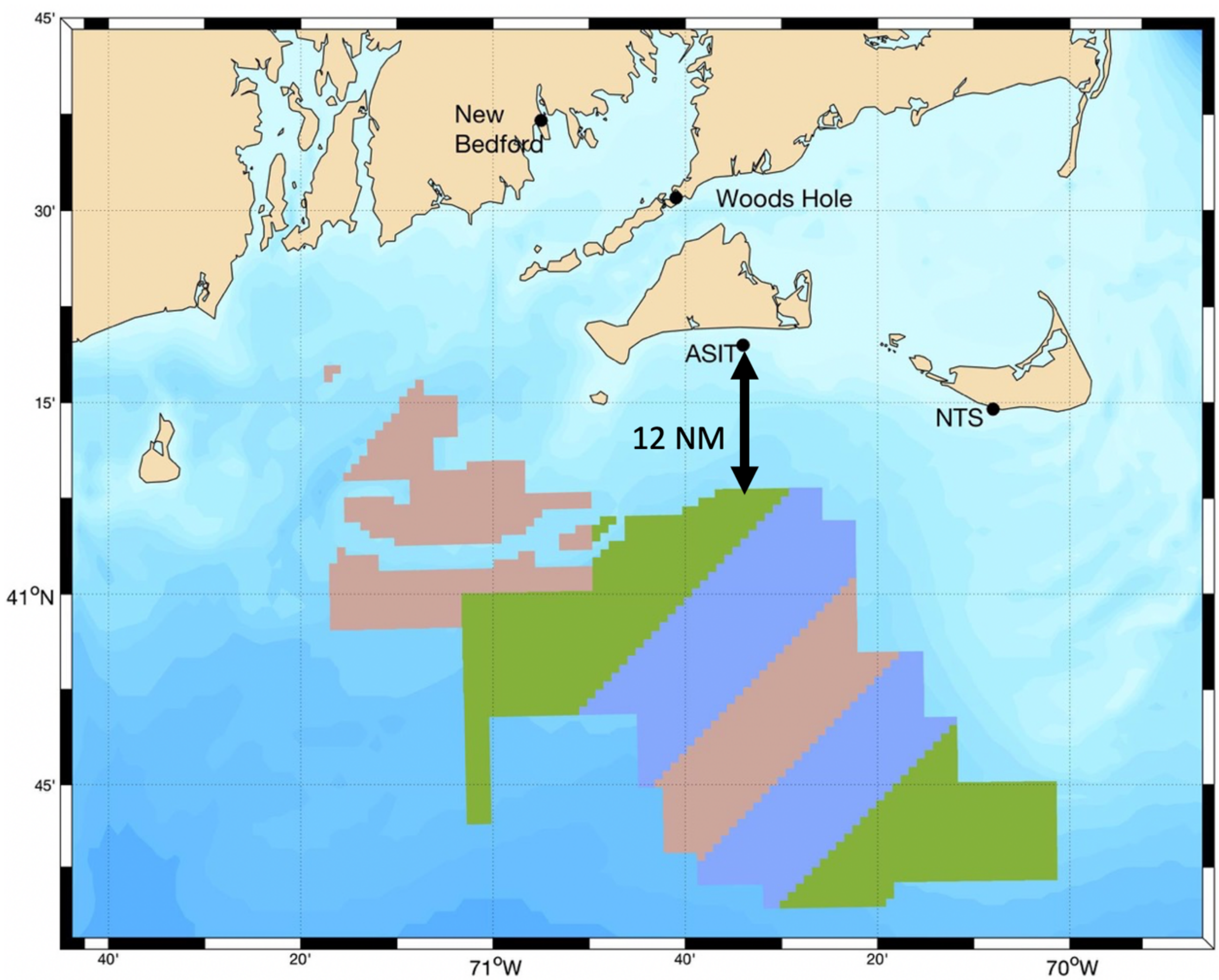
MORS-1 serves the needs of both industry and researchers using a nonprofit, joint industry-academic partnership model (Kirincich, 2020). With 6 years of continuous operations, the MORS-1 facility is now self-sustaining, and serves the rapidly emerging U.S. industry by providing a locally relevant, highly validated, easy-to-use validation site option at lower total costs than presently available sites, which are based primarily in Europe. This solution couples the validation site data collection effort with a long-term metocean reference site to leverage the short-term data needs of the industry to produce a long-term record of wind-energy-specific conditions at a highly relevant location. This coupled goal will benefit the industry, the research and forecast communities, and the general public.

Two areas for validation near the tower are pre-permitted for use by the energy community, meaning that delays related to the cost and time to validation are minimized for the site users. In practice, 3–5 buoy validations can take place per year. The user fees collected for validation activities are designed to balance the ongoing maintenance and sensor costs of the data collection effort, making MORS-1 a self-sustaining operation over a 3-year time period.

MORS-1 exploits the research facilities of WHOI's Martha's Vineyard Coastal Observatory (MVCO). Created in 2001, the MVCO is a purpose-built facility for conducting detailed atmospheric and oceanic research. Numerous researchers have utilized the facility (MVCO, 2023) for critical experiments focusing on the coupled air-sea boundary layer (Edson et al., 2007) as well as wind energy research (Bodini et al, 2019). Central to the research activities of the MVCO, the ASIT is a cabled, fixed platform located south of Martha's Vineyard. The ASIT is located proximate to all of the Rhode Island/Massachusetts wind energy areas and is convenient to WHOI's Iselin dock facilities for research activities and the New Bedford Marine Commerce Terminal for commercial activities (Fig. 2).

The ASIT has a maximum height of 23 m above mean sea level (msl) and a platform at 13 m suitable for larger instruments (Fig. 3). An upgrade to 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.

Figure 2. 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.



Since 2016, a metocean initiative (Filippelli et al., 2015) 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 msl, a wind vane at 23 m above msl, and a vertically profiling lidar on the main platform at 13 m above msl (Table 1). All metocean data collected by WHOI on the ASIT have been validated by AWS Truepower, a UL company.

Figure 3. The ASIT in August 2021 with two lidars deployed.

Via the initial Massachusetts Clean Energy Center (MassCEC) funding, which ended in 2019, and the current NOWRDC support, WHOI owns two vertically profiling lidar systems: a Leosphere WindCube v2, purchased in 2016, and a ZX300m, purchased in 2021. Most recently, a second lidar wind profiler was purchased from Zephir. The unit, a ZX300M, was tall-tower validated in July 2021 and installed on the ASIT in August 2021. All validation activities were overseen by AWS Truepower/UL to document that the facility is adhering to IEC standards (IEC, 2017) for the industry. In developing MORS-1 to facilitate the validation of lidar buoys on-site, this work extends and augments the multiyear record of metocean observations located at the ASIT. Additionally, all lidar sensors used at MORS-1 have been tall-tower validated to ensure they can serve as a transferable standard for compatibility with industry needs.

Figure 4. The ZX 300M Lidar being lifted to the ASIT in August 2021.

Table 1. ASIT MetOcean Sensor Suite 2016–2023

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

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

It is important to note that the metocean reference site located at the ASIT does not directly fund all the observations it is able to use to characterize the atmospheric and oceanic conditions present. A number of the sensors whose data are reported with the MORS-1 results are ancillary to the project and supported by other users of the ASIT or by WHOI itself. In this way, locating the MORS-1 at a shared-use facility has been advantageous to constraining costs of the reference site.

Figure 5. 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 Best Practices for a Reference Station

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 would allow benchmarked testing of sensors and sensing systems and 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 will have clear measurement objectives; multiple-use datasets; and stable, self-generating funding sources and will follow international standards with open communication and availability of the results. Each of these important qualities are addressed in detail below.

3.1 Clear Measurement Objectives

Clear measurement objectives that are simply defined and easy to follow represent a critical first component of the best practices of a reference station. To obtain the most consistent sampling of the reference site's dataset, a clear, thoughtful analysis is needed that summarizes what measurements are required to be maintained by the program itself and what other observations represent ancillary, or "nice-to-have," data. The MORS-1 site has used a needs assessment and strategy document (Filippelli et al., 2015) as the foundational and guiding document for the observatory. This initial assessment provides the sampling strategy, the justification for which sensors to support with site funds and which should be considered ancillary, and the maintenance and operational protocols to be followed throughout.

All funding for the reference site should focus on the required sensors at the expense of the consistency of the ancillary data streams. Ancillary datasets can and should be integrated into the site's datastream, if and when they are available, but not specifically created and maintained by the reference station funding itself. For example, the MORS-1 site seeks to directly support the lidar, cup, and vane data collection only, but collects ancillary data from other users or MVCO itself. These include air temperature, pressure, and relative humidity; the sea surface temperature and salinity; and the ocean currents. Each of these datastreams are published into the MORS-1 record as available, and generally have less reliability than core data. The goal of making them available is to allow MORS-1 users to benefit from these additional results without risking or degrading the ability of MORS-1 to carry out the support of the prime sensors.

Maintenance protocols for the site-supported sensors should be written down with justifications that link back to the measurement objectives. Again, the foundational document of Filippelli et al. (2015) provides the justification for the monthly to bimonthly site visits to the tower required for MORS-1, the sensor refresh plans, and the requirements for third-party validation of all sensors by UL. Backup plans and procedures should also be in place and written down. Critical lidar observations should be validated every 2–3 years, and a fresh, validated unit should be on standby in case the primary sensor on the tower has a failure that requires its removal or replacement. Given the timelines to plan and carry out visits to the tower, MORS-1 strives for a 90% sensor uptime averaged over a year. This would allow a reasonable 3-week time period for remote identification of a sensor issue, an initial visit to diagnose the issue further, and a follow-up visit with repair materials or a replacement sensor. That said, maintenance visits to the ASIT regularly carry spare sensors and supplies to fix small issues on the spot.

While a particular reference site data set might vary in the types of observations it contains, depending on the measurement objectives established at the outset of the individual site; the providence of the individual sensors used are of the utmost importance. Each sensor should have a calibration record against factory calibrations or third-party validations (International Electrotechnical Commission, 2017). A fixed, vertically profiling lidar, if used to serve as a transferable standard for a buoy based lidar, should be tower validated offsite by a third party and all validation reports freely available. With use of a lidar, additional fixed sensors, including industry standard cup anemometers and wind vanes, should be present at some measurement height at or above 10 m above sea level to link the lidar observations to traditional meteorological mast observations. Finally, observations that provide a metric of atmospheric stability, including temperature, pressure, and relative humidity at a minimum, should be collected near the sea surface at any reference site.

For a lidar buoy validation activity, data from the buoy-based system and the fixed system are generally compared over a data collection period that allows enough data in each wind direction and wind speed bin (generally 30 degrees and 1-2 m/s in size) to obtain statistical significance for each comparison (DNV et al, 2018). This can require up to 8-10 weeks depending on the variability of the wind field at the validation site. The reference site data collection must be maintained carefully during this period to minimize the validation period.

3.2 Multiple-Use Datasets

Multiple-use datasets and dual-use platforms represent a robust way to attract and maintain multiple user groups for the site that will lead to sustained interest in the site and industry-wide acceptance of the validation activities as useful and beneficial over both single project and multi-project time scales. The development effort of a reference site should focus on creating both a recognized organizational structure that will ensure the use and support of the site by the wider wind energy industry and research community, and a highly validated data collection and sensor validation facility. Creating datasets that are valued by multiple user groups will increase the utilization of the facility, and by extension, the support of the facility. MORS-1 data are used both by the industry for power generation estimates and validations and by the research community for energy-related research needs as well as climate-focused studies. This dual-use dataset aspect of MORS-1 and the wide availability of the data are critical components of its initial success. The idea of multiple-use datasets also extends to the ancillary data, as these data are purpose-collected by others and used by the reference site as ancillary data.

3.3 Stable Self-Generating Funding Sources

Funding a reference station by pairing the site with a high-quality buoy validation facility provides a responsive, and potentially stable, funding source to support the observations over the long term. This pairing requires the ability to host sensor validations at the site using the same sensors as used for the long-term data collection. It also requires a site that is easy to use and access for moored systems and that is representative of the meteorological and oceanic environments of the lease areas where buoys would be located post-validation. Additional sensor data on the wave climate, surface currents, ocean temperatures and salinities, and ancillary meteorological data (humidity, radiation, rainfall) add value to the validation activity but are not required for it. Stable and highly-regarded data from these sensors are required to ensure the validation activity will be successful. In addition:

- Data should be available from a meteorological mast or a fixed lidar system measuring at the same heights as the buoy-based sensor.
- If using a fixed lidar, additional industry-standard cup anemometers and wind vanes should be deployed to allow comparisons of cup-specific quantities such as turbulence intensity.
- All sensors should have recent validation documentation.
- Redundancy of observations, power, and communications are required to lower the potential risk to individual validations of a failure of the fixed platform affecting the validation timeline. This might have a different time scale than that required for the maintenance of a long-term data collection effort.
- A plan to minimize maintenance and downtime of the sensor suite during validation should be in place.
- The validation site should have user-friendly access to the site via a documented site plan and a permitting pathway for user mooring systems.
- The validation site should be easily accessible for the user from neighboring ports.
- The validation site should have broad industry acceptance and adhere to IEC guidance on data collection and validation standards.

3.4 Follow International Data Standards

Finally, the reference station should follow international standards for data collection and sensor validation whenever possible (DNV et al, 2018; International Electrotechnical Commission, 2017). The MORS-1 site has done this via third-party validation of all critical sensors throughout the measurement history, robust recordkeeping of commissionings, maintenance trip reporting, data quality control, etc. Coupling WHOI's observational and scientific expertise with the validation expertise of AWS Truepower/UL, the MORS-1 effort has achieved the development of a fully functional and highly utilized validation and reference site. As a result, the data collection effort at MORS-1 is a trusted source of regional environmental conditions for both industry and the research community. Its data is regularly used by developers to augment their in-area observations for their site characterization studies.

4 Analysis of Funding Models

Since 2016, a highly validated suite of wind-energy-specific observations (Fig. 5) has been collected at the MORS-1 site, and it has become an internationally recognized site for long-term data collection for the growing U.S.-based sector of the offshore wind energy industry. Different models for funding the observations and carrying out the reference site activities were evaluated to understand the preferred models of financing and operations. An analysis of these different models is presented here to provide a complete picture of the best practices developed above.

4.1 Business Model

The MORS-1 reference site depends on the willingness of others to want to conduct buoy validations to fund the historical records that have been collected at the ASIT. However, because the measurement parameters required to support a buoy validation—validated data from a wind profiler, point sensors of turbulence, and surface meteorology—are the same observations required by the community for a reference site, a successful implementation of a validation facility will, by default, be able to extend and maintain the long-term collection of reference data for the benefit of multiple groups.

Other business models, or methods of funding the reference site observations over the long term, have been explored, including direct developer support and continuous public funding. Our exploration of both is described here. Early on in the process of setting up this reference station, WHOI engaged a group of wind energy developers on their willingness to support the observations as a group, as they would all directly benefit. The model discussed at the time was a monthly payment for a data service, because the developers did not wish to own any equipment or hardware. The implementation of this type of a model was limited by (1) the startup costs of the site and (2) developer concerns about fairness regarding who would pay in to make the observations possible, given the desire to make the observations publicly available.

Taking in the lessons learned from our European colleagues, publicly available resource data were considered to be a key difference that we could pursue to drive costs down and advance the U.S.-based industry quickly. Developers generally agreed with this but were also unwilling to fund data that others would have unfunded access to. Alternatively, if the site was controlled by any single developer, they argued, the developer would be highly likely to move to privatize the data. Trust among the developers was an issue. For this and other reasons, WHOI worked with MassCEC to fund the startup costs of the first years of data collection to ensure the data were publicly available to benefit the public in the state's initial power purchase agreement competition. Use of the site for validations was quickly seen to be a way to enable the now-started effort to continue, with additional benefits.

Secondly, despite the desire to make all the data publicly available, continuous public funding for the site was also rejected as a potential model. Federal and state agencies, while seeing the high value of the site's data to the public good, were less willing to sign on for long-term data collection that the industry was not willing to pay for (see above) but would benefit tremendously from. Thus, the joint public-private model described here was adopted, where public funding was utilized to establish the site, and private funding, via the service of individual validations, will be used to fund its long-term existence.

4.2 Financial Model

MORS-1 was developed to carefully serve the needs of both industry and researchers using a nonprofit, joint industry-academic partnership model. In this model, the host (WHOI, a nonprofit research institution) serves as the fiscal agent for the MORS-1, and users of the buoy validation service will pay a fee to WHOI to reserve space for a validation activity. In exchange for the use fee, the user receives the site permit for the buoy validation activity as well as access to all of the MORS-1 collected data, including the lidar raw data products for use in completing their validation. The cumulative fees paid by users for validations will support the expenses of MORS-1 in maintaining high-quality data collection at the ASIT on the industry's behalf. In this way, MORS-1 can exist as a self-sustaining reference site, with an open framework for user input, and a documented value to the industry.

It is critical to note that MORS-1 does not pay a facilities cost to WHOI for the use of the ASIT for its data collection effort, nor does it fund the maintenance of the tower itself. However, as it is a project run by WHOI, using WHOI technical staff to prepare and service sensors, the costs associated with MORS-1 are subject to WHOI overhead or indirect fees.

Potential users for MORS-1 data span multiple user groups. Within industry, wind energy developers, their consultants, and original equipment manufacturers all desire access to metocean datasets that can reduce uncertainty of their business plans focused on offshore wind energy extraction. Previous experience has shown that in the present operational climate and with traditional data use policies in the United States, industry groups are unlikely to fund a reference site explicitly for long-term data collection. However, industry groups are likely to support essentially the same datasets as those required for long-term reference site observations via discrete activities that require proximate use of the data such as lidar buoy validations or the testing of advanced sensors.

The long-term goal of MORS-1 is to operate "at cost" to continue to provide critical metocean observations and a platform for value-added research for industry and researchers alike. Initial research suggests that 3–5 buoy validation activities per year will likely be required by industry users for each of the next 7–10 years, given current market trends.

Validation site costs should be flexible, as a majority of the data collection costs are fixed and do not vary from year to year. Thus, the more the site is used by industry, the lower the per-use cost should be. MORS-1 validation costs are set yearly with the goal of balancing the costs of the data collection effort over a running 3-year period. Initial results indicate that (1) industry use of the data, (2) project support for instrument tests or validation activities at the site, and (3) lidar buoy pre-deployment validation activities at market rates will be able to support the sensor maintenance and use of the ASIT as a self-contained, nonprofit cost center inside WHOI. Note that this status would likely be preferred by industry and agency users alike due to the significant benefits of coupling this activity to the ongoing use of the ASIT by science users.

4.3 Public-Private Partnership Model

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. 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. With few long-term reference stations, MORS-1 provides measurement and validation locations with wind and wave conditions representative of much of the U.S. East Coast Outer Continental Shelf.

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. The DOE's own unsuccessful effort to rehabilitate the Chesapeake Light Tower is evidence of this fact. The validation activities at an existing site can occur at a reduced cost and with greater public benefits by coupling the observational needs of the offshore wind energy community with the observational and experimental needs of basic science researchers for the atmospheric and oceanic sciences. A combined-use platform, such as the ASIT, with a long track record of success, will enable both the wind industry's needs to be met in a cost-effective manner, and the industry to benefit from a facility maintained for ongoing science and technical research.

Additionally, this can be the case in other areas using exposed, shore-based locations (jetties, lighthouses, etc.) that will streamline user efforts to carry out site characterization studies in regions of interest for offshore wind energy. Oceanographic field stations at exposed island sites, or coastal areas where a background interest in creating and maintaining a long-term record of the ocean and atmosphere exist from other ocean users, could provide successful non-tower locations for additional reference sites that would benefit the wind energy industry.

4.4 Reference Site Risks

Potential risks to a reference site funded and maintained using the model of MORS-1 include:

Lack of validations: Less than the minimum number of validations per year should be paired with a reduction in the project's yearly budget to reduce costs, including the sensor maintenance, management, and sensor replacement.

Equipment failures and sensor costs: Contingency plans must be in place for potential failures of the power or communications at the site. Each should be able to be implemented within a period of 10–14 days from the failure assessment. At MORS-1, additional funds are included in the yearly expense estimate to pay for lidar upgrades and repairs, as well as to accumulate for the purchase of additional sensors.

Permitting timelines: Having the site control the mooring permit with the state and federal regulators represents an effective way to shrink the permitting timeline for an individual user and to have a single request that captures the true scope and scale of the impact of the activities on the local environment. This serves a direct benefit for both the industry and the regulatory agencies. For MORS-1, this process took 6–8 months using an outside permitting contractor.

Run as a not-for-profit: While potentially considered to be a risk by some, the ability to be supported by a local not-for-profit organization, both for the maintenance and operation of the site as well as the fiscal agent for accepting funding from developer to pay for the observations, should be seen as a net gain for a reference site, lowering the overall cost of validation and the reference station.

5 Summary

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. Via a public-private partnership model, a potential reference site at an exposed coastal area or research structure that already exists can be uniquely capable of providing the reference observations that are critically needed by developers, grid operators, and researchers alike. As an example of this, the MORS-1 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, jetty, or other exposed sites in the United States to be developed to serve both the needs of the energy and the climate communities with valuable, cost-effective monitoring and reference datasets.

6 References

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Appendix A. Validation Informational Package

A group of documents that describe the MORS-1 validation site and includes the technical details of the site and what a potential user should know about the site is attached here.

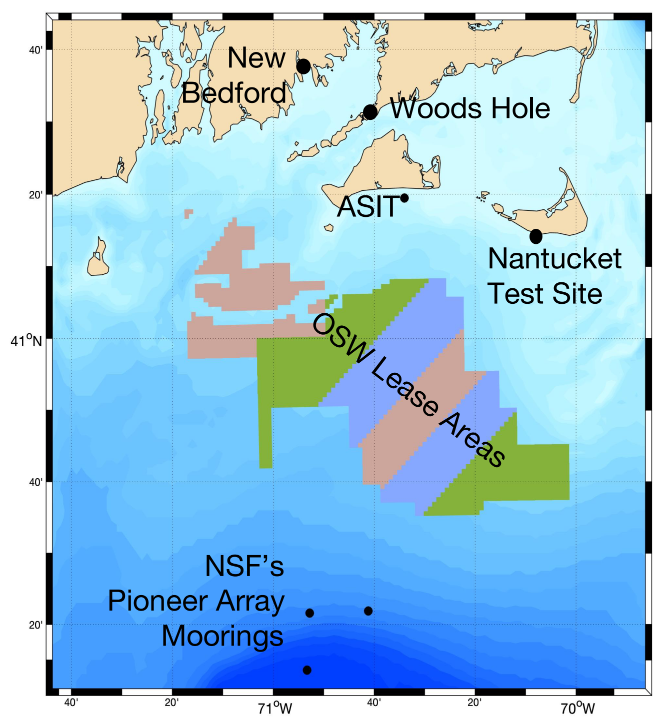
Martha's Vineyard Coastal Observatory
MetOcean Reference Site (MORS-1)
Offshore Wind Energy LIDAR Buoy Validations

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.

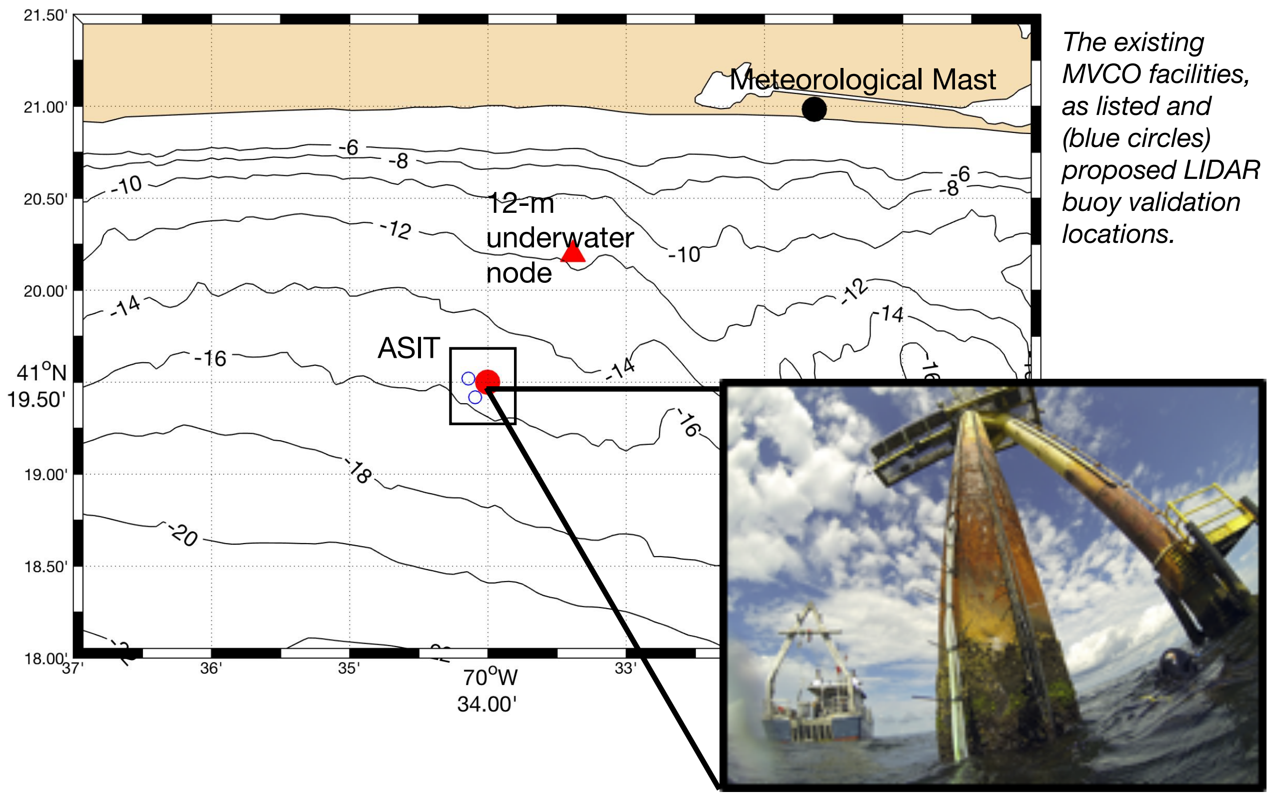
The Martha's Vineyard Coastal Observatory's Air Sea Interaction Tower (ASIT) is uniquely capable of providing domestic validation activities. This effort capitalizes on an initial investment by the Commonwealth of Massachusetts and transitional funding by the National Offshore Wind Research and Development Consortium (NOWRDC).



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.

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 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.



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

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.

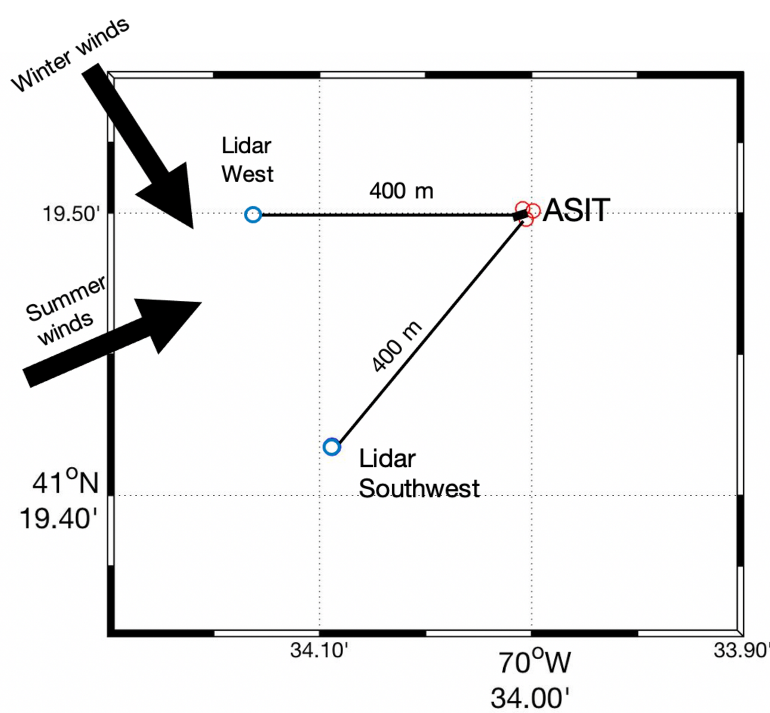
Using the Facility for Metocean Buoy Validations: WHOI is a non-profit research institution and has used funding from MassCEC and NOWRDC to start up the facility and maintain initial data collection at the reference site. User fees are required for each validation activity at the ASIT to cover the cost 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 two pre-permitted validation locations, both approximately 400 m away from the ASIT at:



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.

- ***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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1. Carbon Trust, Offshore Wind Accelerator Roadmap for the Commercial Acceptance of Floating LiDAR Technology, V2, Oct. 2018

2. IEA Wind, Expert Group Report on Recommended Practices, 18. Floating LiDAR Systems, First Edition 2017. O. Bischoff, I. Würth, J. Gottschall, B. Gribben, J. Hughes, D. Stein, H. Verhoef. https://community.ieawind.org/publications/rp

3. http://www.whoi.edu/mvco/publications

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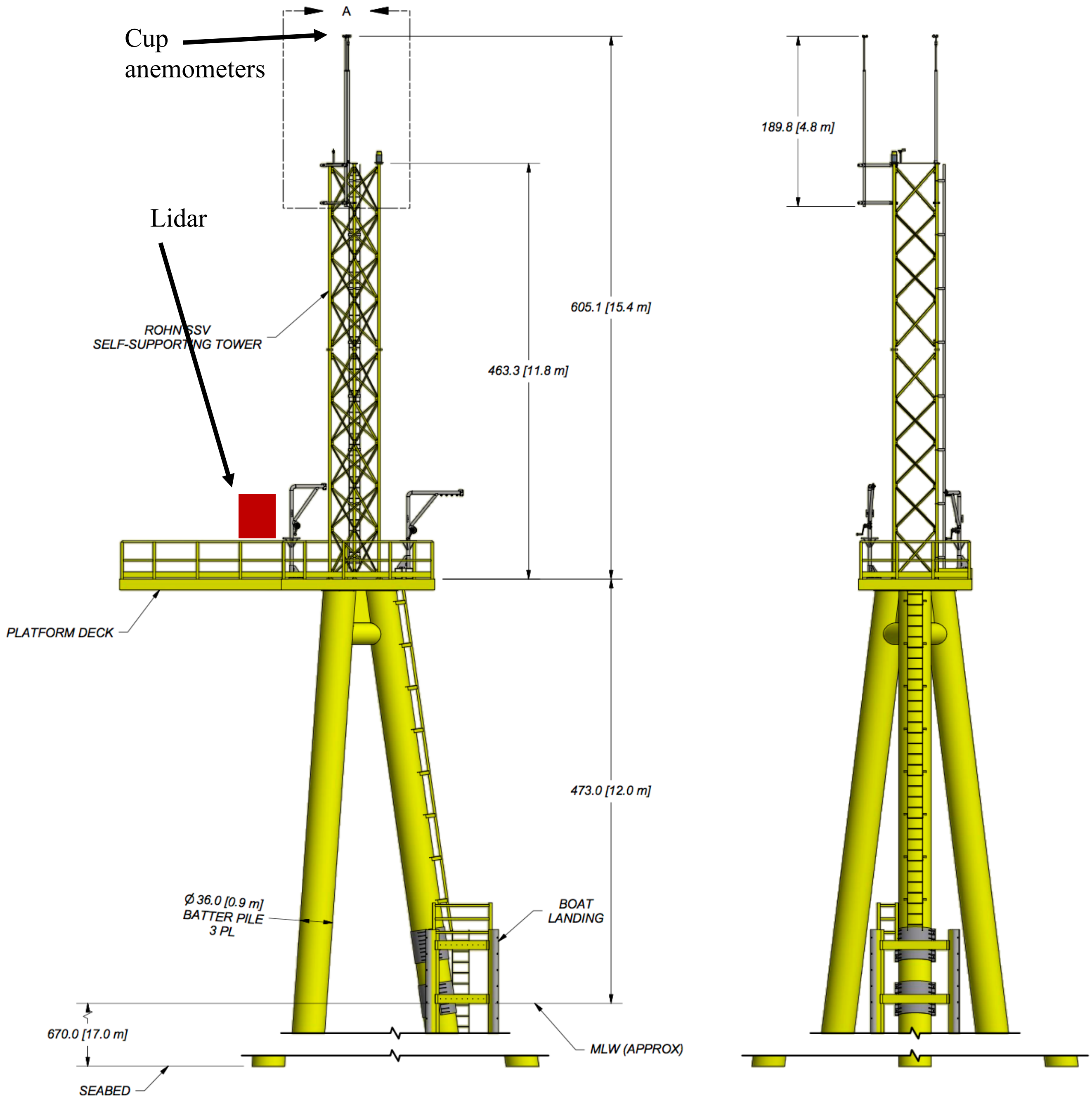
5. Filippelli, M. V., Markus, M., Eberhard, M., Bailey, B. H., & Dubois, L., 2015, Metocean data needs assessment and data collection strategy development for the massachusetts wind energy area (Tech. Rep.). Retrieved from http://files.masscec.com/research/wind/MassCECMetoceanDataReport.pdf



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.