A Metocean Reference Station for Offshore Wind Energy Research in the U.S.

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Abstract. There is an acute need for a long-term metocean reference site that will aid the near-term development of the offshore wind energy industry in the United States. High quality, multi-year observations of the wind resource at hub height in areas relevant to offshore wind energy are a requirement for reducing uncertainties in wind resource assessment, improving the fidelity of numerical models, assimilated products of the resource, and forecasts of near-term operational conditions and wind energy power production. Yet, few long-term data sets exist over the U.S. outer continental shelf that can provide accurate guidance for developers, turbine manufacturers, and utility operators. Thus, there is a critical need for robust, long-term data collection at a site having conditions representative of wind energy development areas. Additionally, an efficient and effective location for validating existing measurement systems and testing and verifying the accuracy of new sensors will play a key role in reducing uncertainty of estimates of the wind resource and reducing the cost and risk associated with offshore development.

1. Introduction
High quality, multi-year observations of the wind resource at hub height in areas relevant to offshore wind energy are a requirement for reducing uncertainties in wind resource assessment as well as improving the fidelity of numerical models, assimilated products of the resource, and forecasts of near-term operational conditions and wind energy power production. A fixed offshore station is the only feasible way to make long-term observations of wind speed and direction throughout the plane of a wind turbine’s rotor, either via fixed or remote-sensing observational systems. Ancillary observations – i.e. temperature, pressure, humidity, and heat flux – of the atmospheric boundary layer that such a structure could acquire over the coastal ocean in addition to the wind observations themselves, are critical to effective model simulations and forecasts as well as only possible in bulk from a fixed offshore station.

European entities such as ORE Catapult, the Carbon Trust, or the Fraunhofer IWEA have shown the utility and need for long term observations from fixed structures similar to the FINO towers in the German North Sea [1]. These platforms have been used to: constrain historical wind conditions in the region around the tower site, develop and validate remote sensing solutions for campaign-based observations of the wind resource, and monitor atmospheric properties that can’t yet be done via floating or mobile systems. Such observations are critically important to the long-term growth of the emerging offshore wind energy industry [2]. However, given the new popularity of lidar buoys for wind resource campaigns [3], individual developers are unlikely to
build and maintain fixed towers themselves expressly for the purpose of long-term monitoring activities that would aid the industry as a whole once the wind farm is completed.

Thus, there is a critical need in the U.S. for robust data collection at a long-term reference site, having conditions representative of wind energy development areas. Yet, few long-term data sets exist over the U.S. outer continental shelf (OCS) that can provide accurate guidance for developers, turbine manufacturers, and utility operators. Additionally, an efficient and effective location for validating existing measurement systems and testing and verifying the accuracy of new sensors will play a key role in reducing uncertainty of the wind resource and reducing the cost and risk associated with development.

This paper seeks to further the development of a long-term Metocean reference site that will aid the near-term development of the offshore wind energy industry in the U.S. using the Air-Sea Interaction Tower (ASIT). The ASIT is located offshore of Martha’s Vineyard, Massachusetts in 17 m of water and 10 NM away from the Rhode Island and Massachusetts wind energy lease areas (Fig. 1). An organized, maintained reference site would capitalize on a unique combination of one of the few existing public metocean observation campaigns in the Mid-Atlantic Bight and an existing research-grade, offshore fixed tower, and create a catalyzing opportunity for wind energy research in the U.S.

This paper is organized as follows. The state of U.S. research assets is presented first, followed by additional details about the ASIT and nearby land-based observational facilities. Historical and recent efforts at the ASIT are then described along with future plans, developments, and a summary of the effort. Combined with regional land-based observations, an ASIT-based reference station will facilitate improved model assessments of the wind resource, improved short-term power production estimates, as well as streamline sensor validation and calibration efforts.
2. U.S. Metocean Research Needs
Within the U.S. OCS, buoy-based, non-profileing wind sensing by federal and state funded research and monitoring initiatives compose the majority of in situ observations being made of the marine atmospheric boundary layer. Previously, fixed structures operated by the U.S. military or the Coast Guard have been used to collect metocean observations. However few operating structures still exist, and none are in areas relevant to offshore wind energy production. Additionally, none of these structures were designed for metocean data collection and research within the U.S. OCS, and as a result, most have significant flow distortion issues. While one wind energy developer, U.S. Wind, has been working to install a metocean-specific offshore tower within the Maryland lease area, this location is highly specific to the lease area in question. Long term research structures are needed in the vicinity of multiple lease areas to best service the widest and most diverse swath of industry needs. Ironically, the best long-term fixed structures would be those proximate to, but outside of individual lease areas, which would be free from the potential wake effects of any future wind turbines or proprietary data issues.

Potential users for metocean reference site data span multiple user groups. Within industry, wind energy developers, consultants, and manufacturers all desire access to metocean datasets that can reduce uncertainty of their business plans focused on offshore wind. Previous experience has shown that in the present operational climate and with traditional data use policies in the U.S., industry groups are unlikely to fund a reference site explicitly for long term data collection. Within academia, researchers focused on understanding the climatological wind resource or working to improve forecast or hindcast resource assessments have a critical need for the observations that a reference station could provide. The most valuable observations to the academic researcher is likely to be the historical record of wind profiles together with atmospheric stability and oceanographic boundary observations.

Government agencies and laboratories have equal interest in the use of the data products for historical or hindcast analyses as well as use for realtime application and model ingestion. Inclusion of observations from a the reference site, and temporary expansions of it, would dramatically aid potential future government supported research efforts such as wind forecast improvement project (WFIP)-type large scale experiments.

3. The Air-Sea Interaction Tower
The Air-Sea Interaction Tower (ASIT: Fig. 2) is the only fixed structure within the U.S. OCS suitable for a long term reference station. Installed in 2002 by the Woods Hole Oceanographic Institution (WHOI), the ASIT is a purpose-built facility for conducting detailed atmospheric and oceanic research. The ASIT is a cabled, fixed platform located 3 km south of Martha’s Vineyard in 17-m of water (Fig. 1 and 4). The ASIT currently extends to 23 m above mean sea level (amsl), with a platform at 13 m suitable for larger instruments (Fig. 3). However, plans exist

![Figure 2. The Air Sea Interaction Tower (ASIT).](image)
to extend the tower height to 46-m amsl. The ASIT is a unique offshore platform in the U.S., exposed to predominantly open ocean wind and wave conditions and \(\sim 10\) NM from the Rhode Island and Massachusetts wind energy lease areas. WHOI maintains a suite of atmospheric sensors on the ASIT including fixed sonic anemometers and air temperature, air pressure, and relative humidity sensors that are considered core measurements of the observatory. In the ocean, detailed observations of water column velocity, density, and surface gravity waves are commonly deployed as part of the observatories core sensor suite.

Since its inception, the ASIT has been continuously occupied, making observations for both short term, intensive oceanic and atmospheric studies as well as long-term monitoring of the marine environment for general scientific use. Data from the core sensors deployed on the ASIT are routinely ingested into NOAA National Weather Service real-time datasets. The ASIT has served as a national test site for a wide swath of advanced oceanic and atmospheric sensors and sensing platforms since its commissioning. As an example, the ASIT hosted the first successful implementation of high frequency (HF) radar sensing of oceanic surface currents from a fixed, metal, offshore structure [4], which is now being replicated on oil and gas platforms of opportunity in the Gulf of Mexico. Numerous researchers have utilized the facility for scientific studies or experiments [5], from critical experiments focusing on the coupled air-sea boundary layer [6] to more recent efforts relevant to offshore wind energy itself [7]. An upgrade to the power and communications systems of the tower in 2018-2019 allows the ASIT to now provide up to 6 kW of power and enhanced fiber optic data transfer speeds to support testing and validation of new atmospheric and oceanographic sensors and platforms.

4. Metocean Efforts to Date

The area around the ASIT has a long history of oceanic and atmospheric research, which the establishment of a long term metocean reference site would complement and extend. The ASIT site, as well as the coastal waters around it, have been the subject of individual research efforts focused on the circulation of the inner part of the continental shelf [8, 9, 4, 10], the marine atmospheric boundary layer [6], as well as acoustics and autonomous vehicle research. Additionally, a number of larger observational and research programs are being conducted in the region. WHOI has recently partnered with the state of Massachusetts to develop an autonomous underwater vehicle (AUV) and acoustic test site at the ASIT that will increase the abilities of robotics developers to build, test, and validate new autonomous systems for use in the ocean. Further offshore, the Ocean Observing Initiative’s (OOI) Pioneer Mooring Array is centered 150 km south of the ASIT. This multi-year program supported by NSF seeks to observe the structure and the variability of the shelf break front that separates the waters of the continental shelf from the global ocean offshore. Finally, the Northeast U.S. Shelf Long Term Ecological Research (NES-LTER), which spans the shelf between the ASIT and the Pioneer Array with quarterly shipboard interdisciplinary sampling is also supported by NSF. The goals of the LTER are to understand and predict how planktonic food webs change through space and time, and how those changes impact the productivity of higher trophic levels. All of these programs have collected, or are collecting, detailed information on the surface meteorological characteristics of the atmosphere that forces the ocean.

Locally at the ASIT, a metocean initiative [11] funded by the Massachusetts Clean Energy Center (MassCEC), has collected continuous observations of the atmospheric boundary layer since 2016. This initiative has augmented the ASIT’s core sensors [5] with a suite of wind resource specific monitoring equipment, including: a pair of cup anemometers placed above the top of the tower at 26-m amsl, a wind vane at 23-m amsl, and a Leosphere WindCube V2 vertically profiling LIDAR on the main platform, at 13-m amsl (Fig. 3 and Tab. 1). All metocean data collected by WHOI for the project was validated by AWS Truepower. More information on this initiative, results of the first-year analysis as well as data access can be found
Figure 3. 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. Drawing by J. Sisson.

at https://www.masscec.com/masscec-metocean-data-initiative [12]. To date, the initiative has collected 2.5 years of lidar wind profiles and 3 years of cup and vane observations of the marine atmospheric boundary layer (MABL) at the ASIT, resulting in a full characterization of offshore flow and Lidar-based turbulence over the annual cycle [7].

Other regional initiatives have the potential to expand the data collected by an ASIT reference station. Via a partnership with the Town of Nantucket, WHOI maintains a powered and instrumented coastal station on the island of Nantucket on the open, low relief, southwest coast of the island. This site, the Nantucket Test Site (NTS), is located 40 km southeast of the ASIT, but a similar ~10-15 NM away from the nearby lease areas. With data collection areas located less than 100 m from the ocean along the southwest side of the island, ample power, a secure
Table 1. ASIT MetOcean Sensor Suite

| Parameter                              | Sensor Description                  | Description       |
|----------------------------------------|-------------------------------------|-------------------|
| Vertical profiles of horizontal winds  | Leosphere Windcube v2               | 13 m amsl<sup>a</sup> |
|                                        | Lidar Wind profiler                 |                   |
| 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<sup>b</sup> |
| Ocean waves currents                   | 1200 kHz RDI ADCP                   | at the MVCO       |
|                                        |                                     | 12-m underwater node |

<sup>a</sup>above mean sea level  
<sup>b</sup>below mean sea level

facility and available lab space, the area is well suited for collecting lidar-based wind profiles at an exposed, but land-based area, as well as supporting shorter term testing and validation of advanced sensors. A nearby radio tower, reaching 80 m height and located ∼1 km from the coastline exists that could support additional instrumentation.

5. Future plans and developments

WHOI plans to continue the existing metocean monitoring campaign at the ASIT. This would provide the backbone of a long-term reference site that could be sustainably supported by both commercial and research users for the coming decades. At the ASIT, the existing, 3-year long, data collection effort should be maintained for the near future. Additional, integrated observations of local waves and/or currents at the tower or nearby would add value to the metocean data campaign, providing sea-state information that would assist both planning and real-time operations over the coming years. However, the effort should also be expanded to include a distributed network of monitoring locations to provide spatial context about the atmospheric boundary layer structure, specifically the wind fields, observed at the ASIT. Expanding the regional observations to include lidar and temperature profile observations at nearby locations would also add context to those data collected inside lease areas by direct developer activities. The NTS would be an ideal location for this effort, given the prevailing winds from the southwest in summer and northwest in winter, the location is effectively ‘downwind’ of the lease areas and experiences ‘onshore’ wind conditions over most of the year. The nearby, 80-m tall tower could be instrumented with fixed point sensors to augment lidar-based observations made at the main NTS location. Thus, the NTS is would be ideal for hosting an expanded metocean data collection effort that could provide critical information on the regional variability of the wind field.

Additional research efforts at the ASIT or NTS can pay dividends to the emerging offshore wind energy industry by capitalizing on the existing metocean data collection program at the
ASIT as well as the infrastructure of the ASIT and NTS. As an example, the abilities of lidar systems and floating lidar systems more specifically to measure the turbulent properties of the wind field is an unresolved question in the community [13]. The characteristics of turbulence, the small-scale motions not represented in the temporally or spatially averaged mean winds, are critical for a range of wind energy issues, including wind farm spatial planning, turbine selection and controls, maintenance and operations, wake mitigation, and power forecasts [7, 14]. IEC standards for turbine selection traditionally use Turbulence Intensity (TI), the ratio of the standard deviation and the mean horizontal velocity over a 10-minute time interval, as measured by a cup anemometer, to both report observations of turbulence and gauge their impact on critical aspects of wind farm planning [15]. In contrast, atmospheric and oceanic scientists typically define turbulence using turbulent kinetic energy (TKE) [16] or Reynolds stresses [17], which consider the vertical as well as the horizontal components of the flow. Vertically-profiling lidars do not provide measurements directly comparable to TI, as it is defined, in part due to the lidar’s volume-averaged measurement [13, 3].

A short extension to the existing mast atop the ASIT would allow detailed point measurements of winds and TI from standard cup anemometers from a range of heights within a range bin of both a fixed and a potential floating lidar system deployed nearby. Plans exist to replace the existing 30’ tower on the ASIT with a similar 100’ tall tower, which could host a series of cup and sonic anemometers, wind vanes, and temperature and humidity sensors at the heights needed to make direct comparisons. This potential effort would provide both new insights into turbulence in the MABL and a rigorous quantification of the differences between turbulence characteristics observed by floating lidars, fixed lidars, and fixed-point measurements by cup and sonic anemometers.

As a second example, via the ASIT and NTS, WHOI has both land-based and in situ fixed platform based test facilities that could be used to assist companies or researchers seeking to validate instruments or sensors for use in the emerging offshore wind energy industry in the U.S.. Both the ASIT and the NTS are capable of providing space, power, and communications links for sensors requiring in situ validation or testing for new sensors. At the NTS, WHOI maintains a facility located at the seaward edge of the fenced in, secure facility, with power and space for additional sensors. At the ASIT, the recent power and communications upgrade, combined with the suite of metocean sensors WHOI maintains on site (Tab. 1) would allow for nimble deployments of new instruments that require at sea testing in a controlled, supported environment.

These types of datasets are acutely needed by atmospheric modelers working to refine both mesoscale and higher resolution numerical models of the marine atmospheric boundary layer, the coastal ocean, and the air-sea interactions that occur between them. The transfer heat, freshwater, and momentum across this dynamic regime are challenging to accurately simulate, and the inclusive, combined datasets that would result from the metocean monitoring effort described here would allow both data assimilative products to be produced as well as advance research on new, updated parameterizations for the unresolved fluxes that are at the heart of atmospheric and oceanic exchanges. Complementary observations at a coastal site on Nantucket will add regional context to the ASIT observations and allow for the validation of and improvements in mesoscale modeling solutions of the regional wind resource and the energy available.

Finally, a long term reference site for metocean observations is the ideal location to conduct the required final validation efforts for lidar buoys. A pre-permitted lidar buoy validation site, via comparisons between buoy lidars and the fixed lidar on the ASIT [18, 1, 3, 14], could be developed proximate to the ASIT (Fig. 4) that could provide this service to the emerging U.S. offshore wind energy community. This type of activity is in line with the goals of a metocean data collection campaign, and would allow for potential multiple uses of the reference station
Figure 4. Detailed site map of an approximately 400m × 400m 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), both 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.

data, contributing to its support and operation. At ASIT, two ideal locations exist for hosting lidar buoys, both within 400 m of the tower (Fig. 4). With predominant summer winds from 250° and winter winds from 320°, placing buoys at bearings of 220° and 280° from the tower would minimize wind wakes on the buoys from the tower. Additional efforts would be required to finalize the organization of the site as a facility for lidar buoy validation, set up appropriate data handling structures and ensure the reliability of the data collection effort for the long term.

6. Summary
The ASIT and NTS are uniquely capable of providing the metocean reference data sets that are critically needed by developers, grid operators, and researchers alike. A successful reference site development effort would triple the amount of publicly available hub height lidar-based observations of the wind resource proximate to the Rhode Island and Massachusetts-based lease areas within the next three years. The ASIT location can provide measurement and validation locations with 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. Complementary observations at a coastal site on Nantucket will add regional context to the ASIT observations and allow for the validation of and improvements in mesoscale modeling solutions of the regional wind resource and the energy available. Use of these existing assets will minimize the long-term cost to the industry for validation activities as well as provide a trusted source of data and analysis for advanced sensor testing. Finally, the overall coordination of these observations, buoy validation, and sensor testing efforts will result in an established center of research for the offshore wind energy industry that will accelerate developments in metocean monitoring and advances in site characterization.

Acknowledgments
This manuscript was supported by internal funds from the Woods Hole Oceanographic Institution. The author would also like to thank Jim Edson, Julie Lundquist, and Nicola Bodini for helpful conversations.
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