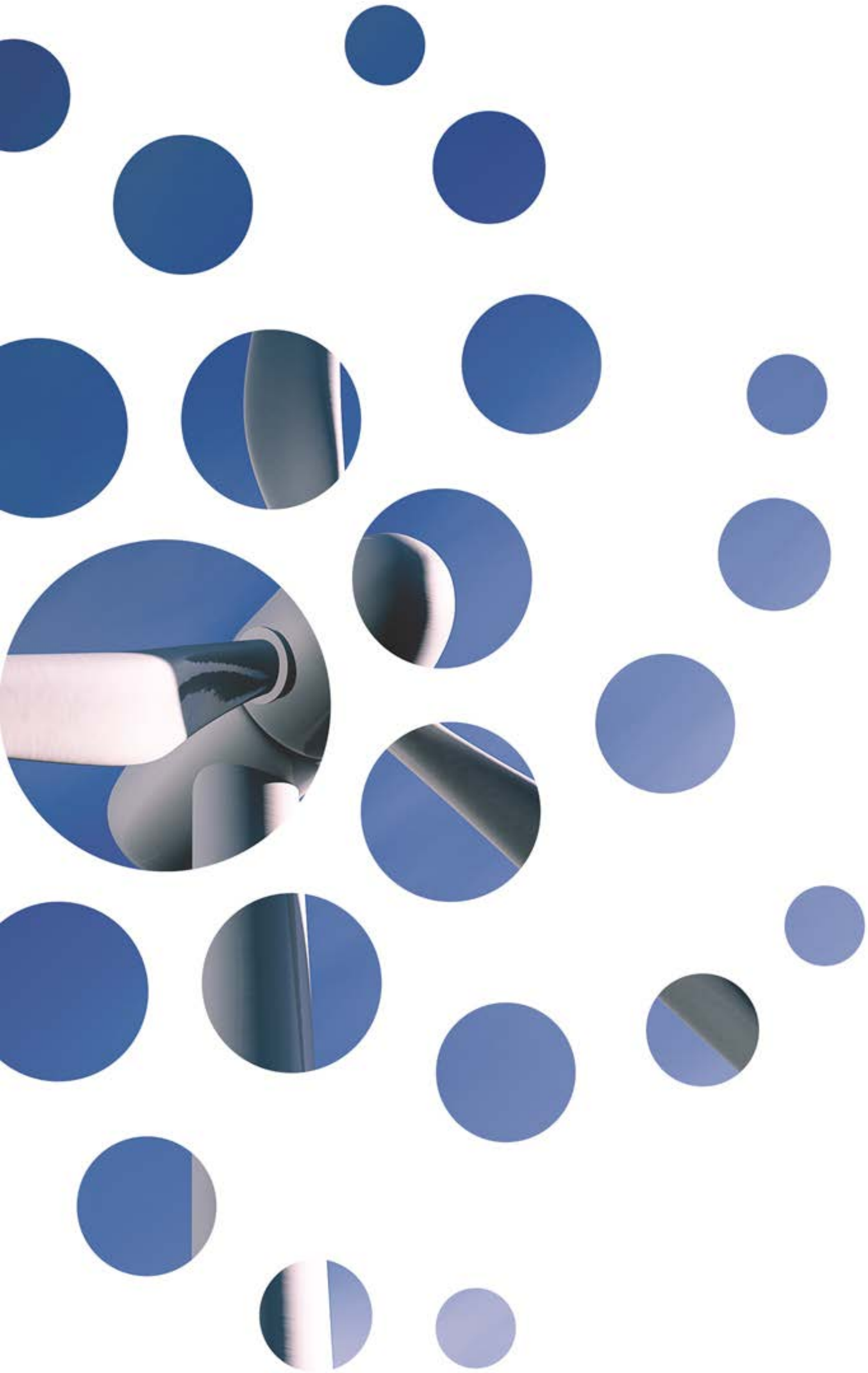

PREPARED FOR
MASSACHUSETTS CLEAN ENERGY CENTER

METOCEAN MONITORING PLAN

Ref. No.: 16-00974

METOCEAN DATA INITIATIVE SUPPORT

Woods Hole Oceanographic Institution
Air-Sea Interaction Tower
Offshore Massachusetts

21 October 2016

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DOCUMENT HISTORY

Issue	Date	Summary
A	21 October 2016	Initial Report

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1. INTRODUCTION

1.1 Background

AWS Truepower (AWST) has been engaged by the Massachusetts Clean Energy Center (MassCEC) to develop monitoring campaign guidance in support of MassCEC's "Metocean Initiative". The goal of the Initiative is to "advance planning and permitting and reduce the costs of offshore wind energy in the Bureau of Ocean Energy Management's (BOEM) designated Massachusetts Wind Energy Area (MAWEA) and the Rhode Island/Massachusetts (RI/MA) Wind Energy Area (together, the 'WEAs')."[1] The data collected and developed during this campaign are planned to support characterization of the WEAs' long-term wind resource and metocean design conditions.

The body of this report presents a recommended monitoring campaign framework.. The content of this document is based upon the information presented in the MassCEC Metocean Data Needs Assessment report [1], the MassCEC Metocean Initiative RFP [2], and subsequent discussions with the campaign team. The metocean campaign described here is expected to form the cornerstone of new observed public data sets developed specifically to support regional offshore wind energy development.

1.2 Campaign Overview and Objectives

The metocean monitoring campaign is designed around the observation of key atmospheric and ocean parameters at an existing offshore platform in the proximity of the WEAs. The campaign is comprised of the following basic activities:

- Deployment of an accepted, validated, industry-standard profiling light detection and ranging (lidar) remote wind sensor at the Air Sea Interaction Tower (ASIT) offshore of Martha's Vineyard;
- Deployment of new industry-standard wind speed and direction sensors (two cup anemometers and a wind vane) at the ASIT, mounted on industry-standard hardware above the top of the existing lattice tower structure;
- Deployment of supporting atmospheric and ocean sensors at the ASIT to capture the balance of relevant metocean parameters;
- Concurrent operations and maintenance of this sensor suite according to wind and measurement community norms for the duration of at least one (1) year;
- Concurrent data collection, transmission, archiving, and processing for the sensor suite for the duration of at least one year;
- Development of standard data products and reports from the collected measurements, including but not limited to:
  - Raw time series,
  - Validated time series, and
  - Regular (e.g. monthly) observed statistics summaries;
- Optional development of standard analytical products from the observed data, regional historical data sets and new modeling efforts;
- Posting and/or distributing the data and data products to regional offshore wind stakeholders and the general public; and
- Decommissioning of the new equipment from ASIT upon conclusion of the campaign.

The objective of the campaign is to develop observed data sets and analysis products that support the metocean characterization of the Massachusetts WEAs. The new data and associated analyses may supplement but are not intended to replace site-specific evaluations of the WEAs by the individual developers for wind resource assessment, energy yield calculation or design condition determination. Rather, the data are intended to improve the quality and quantity of the regional public metocean information. By targeting the specific offshore wind needs and applications, this information in turn is anticipated to reduce development risks in the WEAs and accelerate project deployment timeframes.

In addition to the primary objectives described above, the station may also serve several supplementary purposes for the regional offshore wind industry. Specifically, the lidar and ancillary sensors may serve as a reference system for floating lidar system validation. Further, the profiling lidar and newly deployed sensors may support additional metocean research in the region. The scope of supplementary objectives achievable by the station is dependent upon the duration of the campaign and future industry and research projects.

The objectives of this report are to identify clear expectations with regard to data outputs and quality, to provide a technical outline of the campaign configuration, to clarify roles and responsibilities throughout the campaign, and to provide guidance for the measurement plan implementation.

1.3 Stakeholders and Roles

This section identifies key participants in the campaign and stakeholders in process. Anticipated roles and responsibilities are presented for the monitoring team, and candidate engagement activities for the other stakeholders are also presented.

1.3.1 Campaign Team

The campaign team is comprised of MassCEC, AWST and the Woods Hole Oceanographic Institution (WHOI). These entities will be directly sponsoring, executing and overseeing the monitoring campaign, data and analytical products. The roles and responsibilities for each team member are summarized below. These are subject to revision and refinement campaign based upon campaign progress and goals.

MassCEC (Sponsor): In addition to sponsoring the campaign, it is anticipated that MassCEC will provide strategic guidance on campaign goals, work plans, program assumptions and methodologies. MassCEC is also anticipated to support high-level interactions with other peer organizations and stakeholders (e.g. DOE, NYSERDA, utilities, etc.). As the ultimate data owner, MassCEC is also anticipated to provide guidance and support on data distribution, campaign scope and duration.

AWST (Technical Advisor): AWST will provide oversight, guidance and support of the monitoring campaign for its entire duration. It will also provide over-arching technical advisory services to MassCEC in support of achieving the goals of their Metocean Data Initiative. This role includes, but is not necessarily limited to, the following tasks:

- Engagement and cooperation with the deployment partner (WHOI),
- Preparation, review, and/or comment on program reports,

- Deployment verification, confirmation of data transmission and installation documentation,
- Programmatic data QA/QC, analyses and official reporting,
    - e.g., industry-facing monthly reports and data products
- Supplementary data analyses including modeling and related data products,
- Collaborative presentation of the campaign, observed data, and related analyses in various venues and publication (industry fora),
- Campaign operations oversight and support as required,
- Stakeholder identification and engagement, and
- Technical advisory services as requested by MassCEC.

The Technical Advisor is accountable to the Sponsor.

WHOI (Deployment Partner): WHOI, as the Deployment Partner, will provide turn-key campaign deployment, operations, and data transmission support. This includes, but is not necessarily limited to:

- Access to the ASIT facility and the associated power, data, and communications infrastructure,
- Deployment logistics, including vessel and technician provision,
- All system operations and maintenance services,
- Remote communications, control and data transfer from the measurement equipment suite,
- Serve as raw data repository, including raw data hosting, archiving, and regular delivery to AWST,
    - This may also include provision of supplementary raw data products, and scientific- and community-facing data files,
- Collaborative presentation of the campaign, observed data, and related analyses in various venues and publications (scientific fora),
- Monitoring and O&M services as requested by MassCEC.

The Deployment Partner is accountable to the Sponsor.

1.3.2 Stakeholders

Through MassCEC's and related state-level efforts, Massachusetts is taking a leadership role in offshore wind development and deployment. As such, the range of stakeholders in this data initiative is broad. Key stakeholders and their anticipated roles are summarized below. A more complete descriptive listing and is presented in Section 5 of [1].

WEA Leaseholders: The WEA leaseholders (and other developers interested in MA) are anticipated to be the primary end-users and beneficiaries of the new data sets and associated analytical products. While these stakeholders are not providing sponsorship under the program's current configuration, their input will be considered throughout the campaign. Specifically, they will be asked to provide input on campaign configuration, data collection and analytical products, and end use applications.

Government Peers: State peer groups, such as the Massachusetts Office of Coastal Zone Management, Massachusetts Department of Energy Resources, New York State Energy Research and Development Authority (NYSERDA) and the Rhode Island office of Energy Resources, may be engaged to coordinate and share experience on offshore monitoring in the region. Relevant Federal entities, specifically the Department of Energy (DOE), the Bureau of Ocean Energy Management

(BOEM) the National Renewable Energy Laboratory (NREL), and other research institutions labs active in offshore wind,[1.1] may be engaged to ensure visibility into and coordination within the national offshore wind efforts.

Scientific Community: Relevant scientific branches of government, local institutions and related organizations such as the National Oceanic and Atmospheric Administration (NOAA), universities and research institutions, the Northeastern Regional Association of Coastal Ocean Observation Systems (NERACOOS), and the American Meteorological Society (AMS) all have a vested interest in such a campaign and the resulting data and products. They may also support data distribution and sharing across many diverse end users.

2. MONITORING EQUIPMENT AND CONFIGURATION

This section summarizes AWST's recommended sensor models, monitoring elevations, boom orientations, and related station configuration details. It also presents recommendations for the use of vertically profiling remote sensing on the offshore platform. Some flexibility is available in the configuration and sensor recommendations based upon the platforms pre-existing configuration and the available ancillary sensors.

2.1 Air-Sea Interaction Tower (ASIT)

The Air-Sea Interaction Tower (ASIT), deployed and operated by WHOI, will be the primary monitoring platform for this campaign.

The ASIT is a bottom-founded offshore platform deployed for the study of ocean-atmosphere interaction. It is situated approximately 2.8 km south of Martha's Vineyard in approximately 16.8 m deep water. The station's coordinates are provided below in Table 4.1. A map of the Station's location relative to the WEAs and other related regional monitoring stations is presented in Figure 4.1. High-precision GPS coordinates will be provided as part of the commissioning documentation.

The platform is comprised of a main deck, located at approximately 12 m elevation above the water line, and a lattice tower section that extends from the main deck to an elevation of approximately 22 m above the water line. The main deck includes a "diving board" extension oriented to the southwest (into the prevailing wind direction). The tower has various mounting hardware and equipment installation options to support sensors deployed from the sea bed (e.g. acoustic Doppler current profiler – ADCP), to above the top of the tower. The platform will host the lidar on the deck, the balance of the atmospheric sensors on the tower section, and the ocean sensors at various locations on or adjacent to the structure under the water line. The tower's structure is illustrated in Figure 4.2.

[1.1] Other national research institutions engaged in offshore wind activities include, but are not limited to, the Pacific Northwest National Lab (PNNL), the Savannah River National Lab (SRNL), Sandia National Laboratories, and Lawrence Berkley National Lab (LBL)

Table 2.1: WHOI Air-Sea Interaction Tower (ASIT) Location

WHOI Air-Sea Interaction Tower (ASIT) Location		
	Latitude	Longitude
ASIT Coordinates – WGS84	41° 19.5' N	70° 34.0'

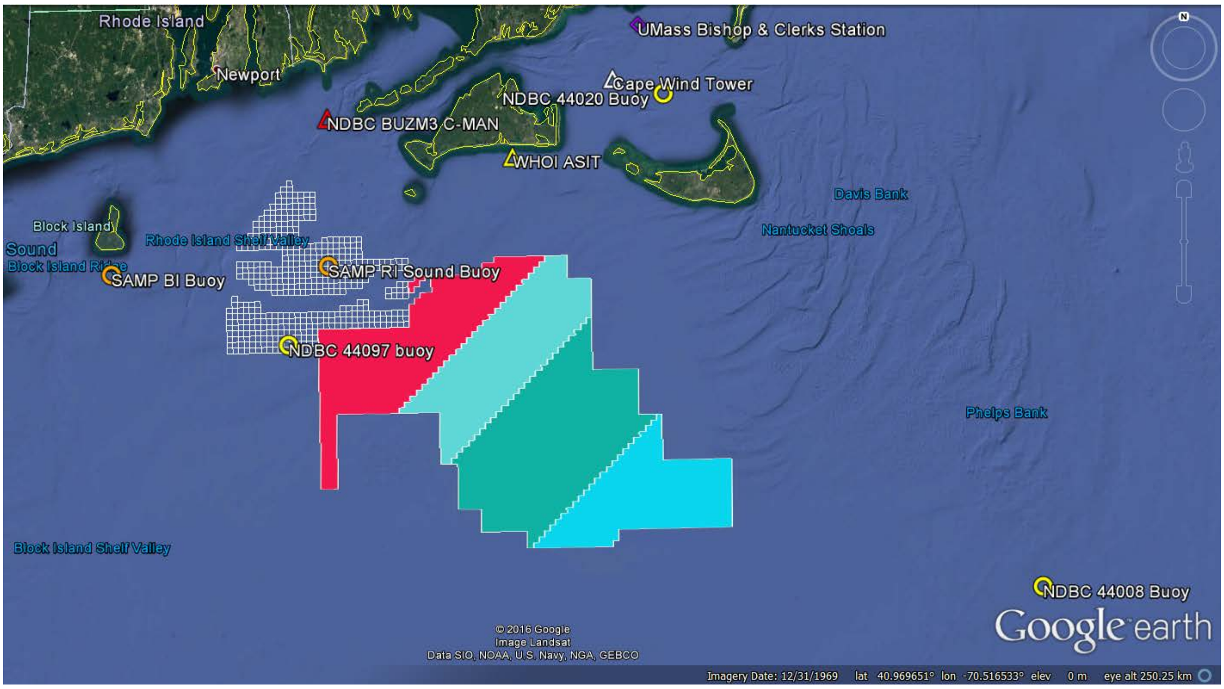


Figure 2.1: Regional Map of the ASIT Location, WEAs, and Regional Monitoring Stations

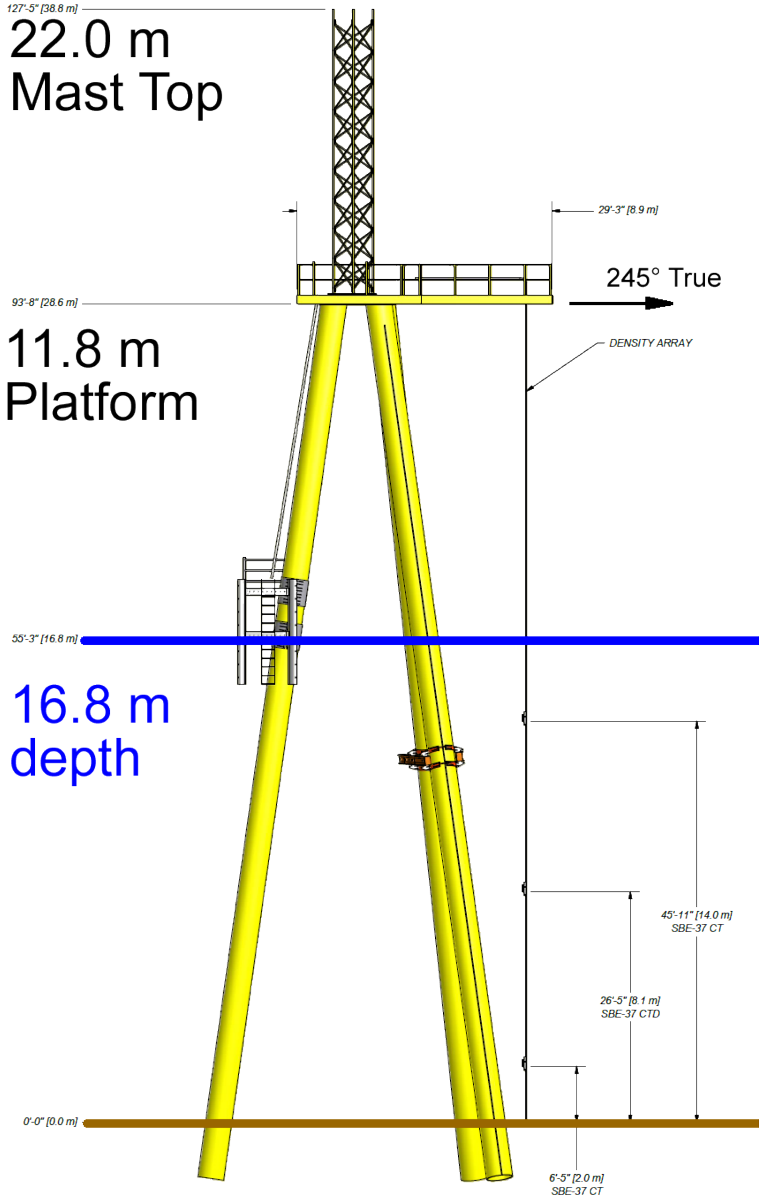


Figure 2.2: ASIT Structure

2.2 Metocean Sensors

Two new, industry-standard cup anemometers and a wind vane will be deployed on the ASIT. These sensors serve several purposes. At an expected monitoring height of between 24 and 26 m MSL,[2.2] they provide an important measurement point in the wind profile between the first lidar reporting level – 40 m above the lens, or roughly 53 m above the water – and the surface. These sensors will also provide industry-standard measurements of turbulence intensity and wind gusts, which are key turbine suitability inputs. Since interpretation of these parameters from lidar data is still an open area of industry development, the observations from the cup anemometers limit uncertainty in

[2.2] Final monitoring height to be determined based upon WHOI boom design. Anticipated to be between 2 and 3 m in height from the top of the ASIT lattice mast assessing them. Additionally, observations from these sensors, which are to be logged and stored separately from the lidar data (as further detailed below), will provide a level of redundancy for wind measurements. While not completely independent of the lidar – they are expected to share a power supply – they will provide a level of data coverage if the lidar unit has operational issues. Once data analyses begin, the anemometers and vane may also have value in extending the onsite period of record in time through correlations with the on-site sonic anemometer or regional reference stations.

The balance of atmospheric and ocean sensors will be deployed from WHOI's stock of high-quality instrumentation. This section provides guidance on the primary wind sensor (cup anemometers and wind vanes) characteristics and configuration. The balance of the atmospheric sensors will be sourced from WHOI and configured accordingly to accommodate existing ASIT mounting hardware and industry monitoring practices.

A high-level summary of the primary sensors and their characteristics is provided In Table 4.2 below; final sensor configuration, model numbers and detailed characteristics will be documented in site commissioning forms. All metocean sensor data detailed above and in table 2.2 will be collected in a Campbell Scientific CR1000 data logger fully integrated in the ASIT communication network.

Table 2.2: Metocean Sensory Summary

Instrument	Accuracy	Vendor / model	Boom Direction (° True)	Mounting Guidance
Cup Anemometers	IEC Class I [3]	RNRG / P2546-OPR And RNRG / #40C	337.5 157.5	Two sensors mounted above top of mast per IEC 61400-12 ed. 1 mounting requirements [3]
Wind Vane		RNRG / 200P	N/A[2.3]	Mounted above top of mast per IEC 61400-12 ed. 1 mounting requirements [3]
Air Temp	+/-0.5°C	WHOI stock	0	Mounted in naturally aspirated shield at deck level or higher
RH	+/-2% RH[2.4] +/-4% RH[2.5]			
Water Temp	+/- 0.5°C	WHOI stock	155	ASIT underwater boom
Air Pressure Sensor	+/- 1.0mb [2.6]	WHOI stock	0	Mounted at or near deck level
ADCP		WHOI Stock	N/A	Sea floor, adjacent to ASIT

It is required that all wind speed sensors are calibrated prior to deployment, preferably according to MEASNET procedures.[4] For the recommended wind speed sensors, this is typically available upon purchase as an option from the vendor and is included in the new sensor price. Wind speed sensor post-calibration (wind tunnel testing after in-field operation to verify stability of transfer function),

[2.3] If not mounted in the goalpost configuration, boom should be oriented on a side-mount boom, approximately towards North

[2.4] from 10% to 90% RH @ 25°C

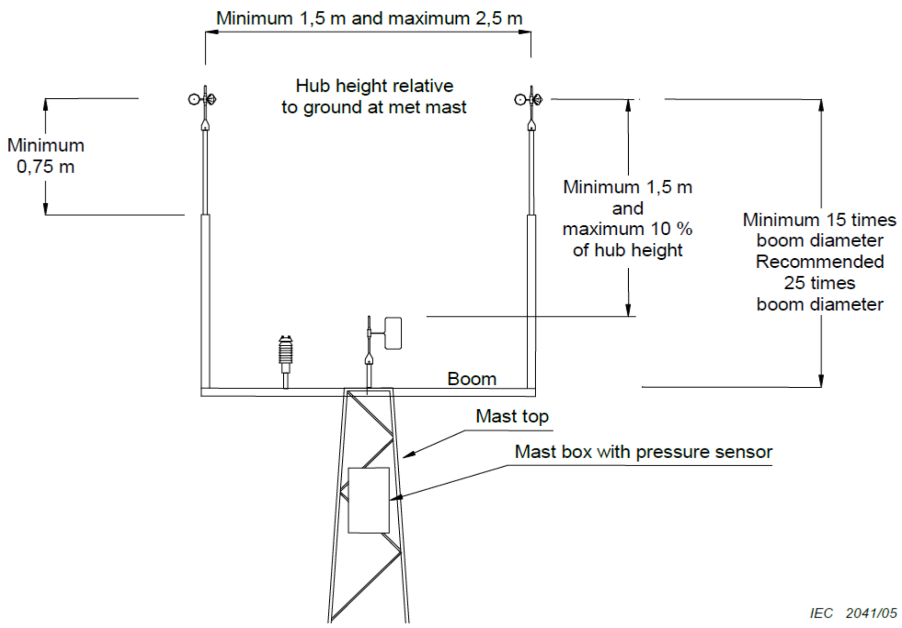
[2.5] from 0% to 100% RH @ 25°C

[2.6] from -20° to +45°C

refurbishment and re-calibration are typically separate costs, along with return shipping, that may be incurred during the O&M phase of operations. Those topics are addressed further in the following section. Pre-deployment calibration of other sensors, e.g. air temperature, is strongly recommended to help ensure functionality and inform confidence in the resulting data sets. As the Deployment Partner, and the manager of campaign operations, these calibration tasks and associated costs are assumed to be managed by WHOI.

Instrument stand-offs from the tower structure, mounting booms, and adjacent instruments are strongly recommended to meet IEC 61400-12 ed. 1 guidance.[3] Specifically, AWST recommends the tower-top “goal post” mounting configuration for the two cup anemometers and vane. This is illustrated in Figure 4.3 below. Given the cost and design challenges of meeting IEC requirements for all monitoring elevations and sensor types, AWST recognizes that some mounting compromises may be necessary. Specifically, some sensors may be required to share booms or accommodate existing mounting points on the tower, and some booms may not provide the recommended stand-off from the structure. AWST and WHOI have initiated engagement on tower-top boom design. It is expected to be an iterative process coordinating between monitoring requirements, structural design constraints and costs. Final boom designs, mounting heights and orientations will be coordinated with WHOI and documented as part of the commissioning process.

The primary anemometer boom orientations are recommended to be 157.5° and 337.5° relative to True North. This allows the majority of the expected wind conditions to be measured by both sensors with minimal obstruction. This reduces the influence of flow distortions caused by the tower structure and the other sensors on the wind measurements. It further helps reduce uncertainty. Candidate boom orientations are presented relative to the tower orientation and a regional wind direction frequency distribution (wind rose) in Figure 2.3:



Source: IEC 61400-12-1 ed. 1[3]

Figure 2.3: IEC-recommended Anemometer and Vane Mounting Guidelines

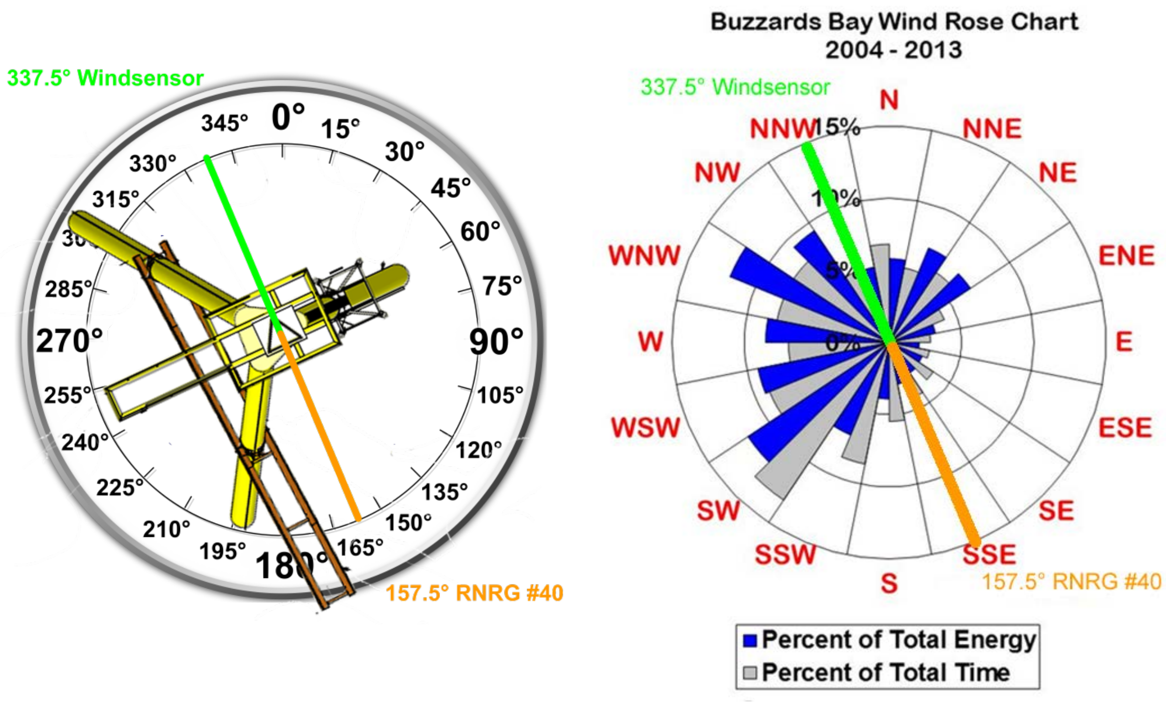


Figure 2.4: Recommended Anemometer Boom Orientations Relative to ASIT Structure (Left) and Regional Wind Rose (Right)

2.3 Lidar

A vertical profiling lidar system is an integral part of this measurement campaign as the atmospheric sensor heights are far below potential offshore wind turbine hub heights. The lidar selected for this deployment is a refurbished, validated Windcube V2 manufactured by Leosphere in France, and supported by Renewable NRG Systems of Hinesburg, Vermont. The system, which is capable of collecting wind measurements up to heights of 200 m above its lens, will serve as the primary source of wind measurements above the met tower. Use of an industry-standard and accepted system is vital to the third-party use and acceptance of the resulting data sets.

Based upon vendor feedback, system availability, and pricing, a standard onshore Windcube V2 was secured for the project. While this system does not include some of the features of Leosphere's offshore version of the V2, the benefits were determined to be too modest to justify the costs and timing implications. Instead, rigorous O&M protocol is understood to be in place for the system to help facilitate high system reliability and data recovery.

The lidar unit is planned for deployment near the outboard (southwest) end of the ASIT "diving board" deck, on the station's work table. The work table is elevated above the deck and runs along the diving board's south railing. That location is expected to allow easier access to the unit for installation and operations, and to facilitate adequate exposure. The work table location is expected to result in a deployed lens height of approximately 13 m above the waterline; the as-built height will be verified upon commissioning. Installation recommendations and requirements for the lidar are bulleted below. A graphical representation of the system's proposed orientation is presented in Figure 4.5.

- The lidar unit and its washer fluid reservoir should be mounted securely to the platform such that the components don't move.
- The unit should be mounted such that it is level (verifiable within the systems software), and the wiper is unobstructed.
- The unit should be oriented such that all of the beams are unobstructed by the tower or other equipment.
- The unit's chassis and North beam should be oriented as close to True North (0°) as possible.
    - The system's orientation relative to True North may be adjusted to accommodate fitment on the work table and/or to avoid laser impingement on the tower-mounted sensors

The final deployment configuration should also follow vendor guidance and warranty/O&M requirements.

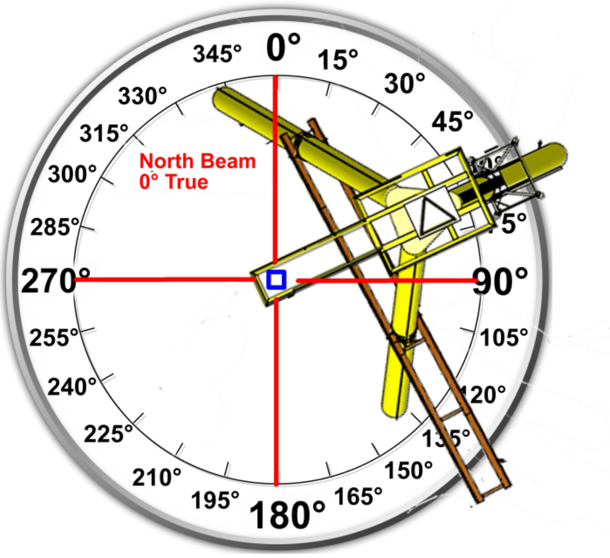


Figure 2.5: Recommended Windcube V2 Orientation on the ASIT, relative to True North

The Windcube V2 allows the user to configure up to twelve measurements heights or range gates between 40 and 200+ m. At a minimum, 10 range gates should be used and set to represent relevant heights across typical offshore wind turbine rotor spans. Table 4.3 below presents recommended range gates for the Windcube V2 on the ASIT tower assuming a deployed lens height of 13 m MSL. These monitoring elevations are based upon current and near-term offshore wind turbine physical dimensions, and the goals of measuring at expected hub heights and across the majority of the expected rotor swept areas. For example, a currently available 6 MW turbine with a 150 m rotor diameter deployed at a 100 m MSL hub height[2.7] would have eight measurements distributed across its rotor span (25 m – 175 m MSL). Similarly, an 8 MW turbine with a 180 m rotor diameter deployed at a 120 m hub height[2.8] would have all ten measurements distributed across its rotor span (30 m – 210 m MSL). If all 12 measurement heights are employed, additional resolution around hub height is recommended, e.g., a 90 m monitoring height, and at or above tip height, e.g. 220 m MSL. Final measurement heights will be determined based upon the as-built lens height and system performance.

[2.7] Current dimensions of the GE Haliade wind turbine-
[2.8] Current dimensions of the Adwen AD 8-180 wind turbine

Table 2.3: Basic Range Gate Recommendations for Windcube V2 at ASIT

Range Gate	Height* (m V2 lens)	Height (m MSL)	Comments
Level 10	187	200	
Level 9	167	180	
Level 8	147	160	
Level 7	127	140	
Level 6	107	120	Expected near-term hub height
Level 5	97	110	Expected near-term hub height
Level 4	87	100	Expected near-term hub height
Level 3	67	80	
Level 2	47	60	
Level 1	40	53*	Lowest available monitoring height

Note (*) Lidar heights subject to revision based upon actual as-deployed lens elevation

3. DATA MANAGEMENT AND REPORTING

Once the measurement systems are commissioned, the process of collecting, validating, and reporting on the recorded data begins and continues for the duration of the monitoring campaign. It is imperative that the data be properly handled so that they are transmitted intact and protected from loss. A high-level graphical overview of the data management processes and industry-related data flow[3.9] is presented in Figure 4.1 below. The general philosophy of the program's data management should adhere to simplicity and transparency. Clear delineation of tasks and thorough documentation of actions within each process (including O&M) will help ensure data fidelity and a clear chain of custody.

WHOI has primary responsibility for raw data collection, transmission, storage and distribution. Once delivered by WHOI, AWST has primary responsibility for the campaign's data validation and reporting. AWST will manage the data according to industry standard practices, which are summarized at a high level in this section. Specific recommendations on each of these tasks and responsibilities are presented in this section.

[3.9] WHOI has existing infrastructure, and may establish additional processes, to support raw and processed data distribution to the scientific and research communities. Specific discussions of these data management processes are outside the scope of this document; however, they are understood not to interfere with the primary objectives of this study.

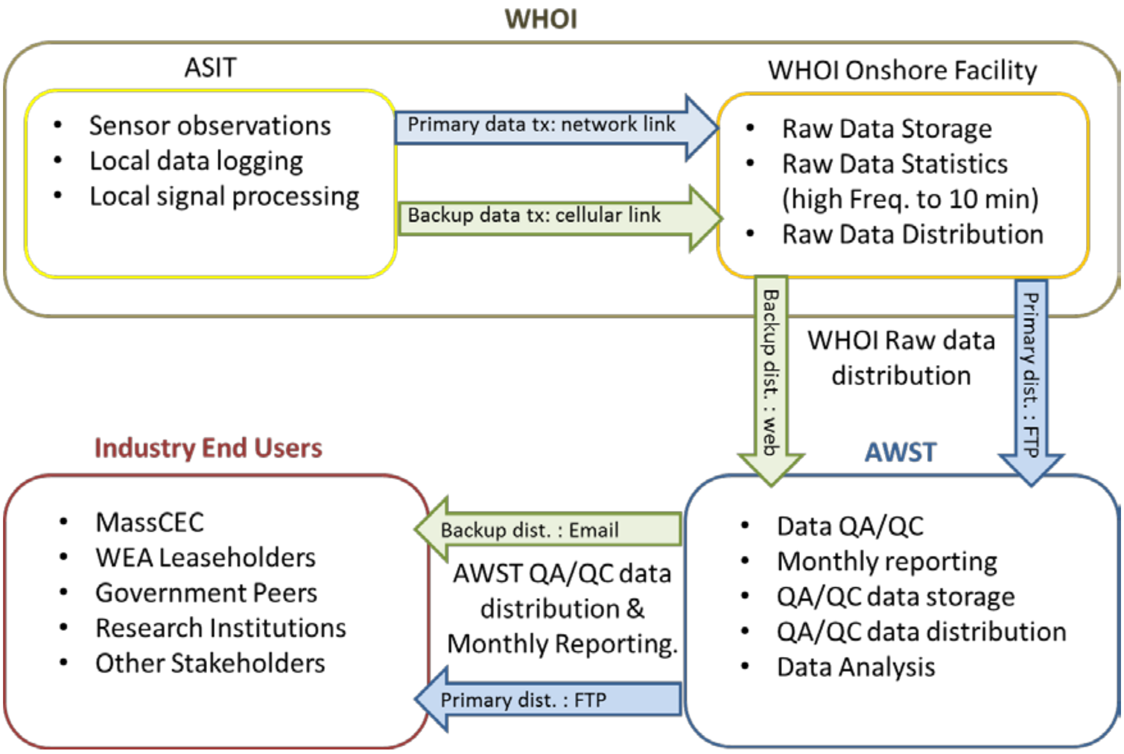


Figure 3.1: Summary Overview of Data Management Process and Data Flow

3.1 Data Management

Data management, which generally includes collection of sensor observations, signal processing, data logging, data transmission, data storage, quality assurance and quality control (QA/QC), data and processing, will be managed by both WHOI and AWST, with the former having the bulk of the responsibility. This section provides recommendation on the structure of data retrieval and data validation tasks.

3.1.1 Data Retrieval and Distribution

WHOI has primary responsibility for data retrieval and distribution, with support from AWST, as required. The general data delivery and distribution tasks comprise the initial portions of the data management processes, from collection of observation to distribution of the raw data files, up to, but not including data, QA/QC and processing. Specific action items and processes for each project participant are summarized in the following tables. Table 4.1 addresses the ASIT tower instrumentation suite, and Table 4.2 addresses the Lidar data retrieval and distribution.

MassCEC does not have any specific, direct responsibilities in the Data Retrieval outside of program guidance and direction.

Table 3.1: Data Retrieval and Distribution Tasks – ASIT Tower Suite

Task Topic	WHOI Responsibilities	AWST Responsibilities
Sensor Observations	Acquire new calibrated wind sensors. Recalibrate and refurbish previously deployed sensors as required. Deploy and Configure atmosphere and ocean sensor suite (sensors, booms, cables, logger, enclosures, communication equipment, etc.) on ASIT structure: • Employ recommended monitoring heights, configurations and orientations for the atmosphere sensors (described in Section 2.2) • Time Synchronization (NTP if available, Clock set to UTC) • Program the CR1000 to meet sensor sampling, signal processing, data averaging, and data storage recommendations (described in this table) • Set sampling period for new wind sensors (1.0 Hz, continuous) • Set averaging period for all sensors (10 minutes)[3.10] • provide logger program and wiring diagram, as well as station configuration drawings as part of documentation package • configure output files to be test files, with comma or tab delimiters Review and supplement commissioning form as required Define specific components and configuration of data flow from sensor to onshore data storage and processing Carry out and document station O&M	Verify tower and sensor as-built configurations, logger wiring and program, communication configurations, data output formats and document in site verification form Incorporate WHOI documentation – logger program, wiring diagrams, station measurement and communication configurations into verification form Provide CR1000 logger programming support as required or requested. Support station O&M and documentation as required
Local Data Logging	New wind sensors (2 anemometers and vane) planned to be integrated into ASIT data logging and communication network through a Campbell Scientific CR1000 data logger • Logger should be programmed to store high frequency observations at sampling rate • Logger may also be configured to process raw sample observations into standard 10 minute averaged data files No other local data logging assumed for ancillary atmosphere or ocean sensors; WHOI to verify and/or describe	Support and feedback on data logger configuration and programming, as required

[3.10] Averaging period for ocean data from the ADCP to be based upon WHOI's standard configuration. Averaging period requested to be no longer than 60 minutes; preferably 30 minutes or less.

Table 3.1: Data Retrieval and Distribution Tasks – ASIT Tower Suite

Task Topic	WHOI Responsibilities	AWST Responsibilities
Local Signal Processing	Within the CR1000, the anemometer and wind vane signals may be logged in their raw output – pulse counts and DC voltages – or with the calibrated slopes and offsets applied. • AWST's recommends that the calibrated slopes and offsets are programmed into the logger to support data review and processing • The output values should be configured to retain sufficient significant resolution to allow accurate re-processing of the results back to the original signal (e.g., IEEE4 four byte floating point data type) Also within the CR1000, the high-frequency data records may be locally processed into standard 10 minute average data files. If this is employed, each 10 minute record should contain the following parameters: • Average: average over the 10 minute interval • Minimum: value of minimum sample • Maximum: Highest value of a 3-second rolling average within the interval (to represent a 3-second gust) • Standard Deviation: standard deviation of the samples over the interval WHOI to describe and document the local signal processing employed for the balance of the ASIT sensor suite, e.g. sampling rate, A to D conversion, auto-screens, sensor slope and offset programming, etc. AWST recommends no local QA/QC on any data stream	Review of WHOI's local signal processing methods; integration of that info into the commissioning form. Support and feedback on data logger configuration and programming, as required
Raw Data transmission (ASIT to shore)	Maintain primary and secondary remote data communication protocols • Primary: sensor communication through ASIT node to shore laboratory on Martha's Vineyard, and on to WHOI • Backup: directional microwave and cellular communication options are understood to be available at ASIT; WHOI to confirm AWST understands WHOI's current ASIT communication and data logging configuration allows near real-time data collection shore. WHOI to verify and describe data logging and transmission configuration in detail. • At a minimum, complete raw data files need to be transmitted from ASIT to the onshore facility at least once daily	None, all data transmission at this stage is within WHOI's scope

Table 3.1: Data Retrieval and Distribution Tasks – ASIT Tower Suite

Task Topic	WHOI Responsibilities	AWST Responsibilities
Raw Data Storage (Onshore Facility)	Archive all raw high frequency data from ASIT suite	Archive all received 10 minute data files and requested high-frequency data files
Raw Data Statistics	If not already processed locally (at ASIT or shore station), derive 10 minute average data records for the balance of the ASIT sensor suite. Required parameters described above under "Local Signal Processing"	None
Raw Data Distribution	Primary distribution of 10 minute average data files from ASIT sensor suite daily, via FTP. Candidate account provided below. May be replaced with WHOI FTP account to facilitate transfer: • link: ftp.awstruepower.com • user: WHOI • pass: MVCO4now (MIKE VICTOR CHARLIE OSCAR 4 november oscar whiskey) Backup / alternative distribution through WHOI's MVCO web server - http://mvcodata.whoi.edu/jg/dir/mvco/ Distribution of high-frequency (1 Hz) data files conducted upon request from AWST, MassCEC or authorized stakeholder, via FTP transfer or webserver.	Retrieve daily posts of 10 minute raw data files from FTP (Primary) or WHOI webserver (Backup) Request and receive FTP delivery of high-frequency data files as required: • Unscheduled data transfers may be appropriate in the event of perceived sensor irregularities or following severe weather to determine if the sensors are working properly. • Should problems be suspected, AWST will coordinate with WHOI to determine if action required Archive all raw data files received from ASIT instrumentation suite Develop automated data delivery and system function check protocol compatible with data file format and delivery mechanism. • daily data delivery checks • weekly functional checks and flags AWST to notify WHOI and MassCEC if any flags are raised during data collection and functional checks

Table 3.2: Data Retrieval and Distribution Tasks – Windcube Lidar

Task Topic	WHOI Responsibilities	AWST Responsibilities

Sensor Observations	Deploy and Configure lidar:
	• Appropriate monitoring heights, (described in Table 2.3)
	• Direction offset (Per deployment setup)
	• Averaging period (10 minutes)
	• Time Synchronization (GPS, Clock set to UTC)
	• Site description (per deployment set-up)
	• Email alert and data delivery addresses:
	  o logger@awstruepower.com
	  o mfilippelli@awstruepower.com
	• WHOI recipient
	• MassCEC recipient, if requested
	
	Deploy ancillary components – aluminum shield, bird spikes and water reservoir
		Verify lidar configuration and deployment, document in verification form
		
		Support station O&M and documentation as required
		
		Periodic system login and check-up

Table 3.2: Data Retrieval and Distribution Tasks – Windcube Lidar

Task Topic	WHOI Responsibilities	AWST Responsibilities
	Review and supplement commissioning form as required Provide lidar WindWeb credentials to team • Link: http://windcubeanywhere.leosphere.com/windweb/ • user: WHOI • pass: MVCO4now (MIKE VICTOR CHARLIE OSCAR 4 november oscar whiskey) Carry out and document station O&M	
Local Data Logging	Lidar is automatically configured to locally store(onboard hard drive) two sets of data files: • Real Time Data (*.RTD files): These are the high-frequency observations recorded at ~1 Hz • Statistical Data Files (*.STA files): These are the 10 minute averaged data files created once daily with standard statistics for each monitoring elevation	None
Local Signal Processing	None required for lidar	None
Raw Data transmission (ASIT to shore)	Setup and maintain primary and secondary remote data communication protocols: • Primary: ASIT LAN connection – This is the existing primary hub at the station, providing the lidar both a fixed IP address on the WJHOI network and internet access for the WindWeb server • Secondary (planned): Digital cellular modem to support WindWeb access Setup regular, primary data collection protocol (from ASIT to onshore facility) for all data files: • *.RTD: Collect via Leosphere FTP over ASIT LAN; recommended collection frequency – once daily • *.STA - Primary: set up WindWeb server to automatically send *.STA files daily to AWST and WHOI (noted above) • *.STA – Backup: manual collection via WindWeb interface (over LAN or cell connection)	Receive daily email delivery of *.STA files
Raw Data Storage (Onshore Facility)	Archive all *.RTD and *.STA files	Archive all received *.STA files
Raw Data Statistics	None required; Lidar automatically creates RAW 10 minute averaged data files	None

Table 3.2: Data Retrieval and Distribution Tasks – Windcube Lidar

Task Topic	WHOI Responsibilities	AWST Responsibilities
Raw Data Distribution	Required daily delivery of statistical files is satisfied with WindWeb email distribution Distribution of *.RTD or backup delivery of *.STA, conducted upon request from AWST, MassCEC or authorized stakeholder, via FTP transfer. Candidate account provided below. May be replaced with WHOI account to facilitate transfer: • link: ftp.awstruepower.com • user: WHOI • pass: MVCO4now (MIKE VICTOR CHARLIE OSCAR 4 november oscar whiskey)	Receive daily email delivery of *.STA files Request and receive FTP delivery of *.STA and/or *.RTD data files as required: • Unscheduled data transfers may be appropriate in the event of perceived sensor irregularities or following severe weather to determine if the sensors are working properly. • Should problems be suspected, AWST will coordinate with WHOI to determine if action required Archive all raw data files received from lidar Incorporate ASIT lidar data into Data Transmission Reporting (DTR) protocol – this is AWST's standard data delivery check and initial value review: • Data files are automatically extracted from delivery emails on a daily basis and stored on AWST's server. System flags if data are not delivered • Data files are manually reviewed for reasonableness and data recovery on a once- or twice-weekly schedule; Stations with anomalous data recovery or values out of bounds are flagged AWST to notify WHOI and MassCEC if any flags are raised during DTR for lidar

3.1.2 Data Validation

AWST will carry out standard validation procedures on the raw data files delivered by WHOI. As part of this process a master validated data file will be created for each system. Additional details on the wind parameter validation procedures are discussed here.

The objective of the data validation process is to identify and flag invalid or suspect values in the data record. Once complete, the resulting validated data set will provide as accurate a representation of the observed wind conditions as possible. The data validation process will be accomplished in two steps: 1) automated data screening, and 2) manual screening. Automated screening uses a set of algorithms, including as range tests, relational tests, and trend tests, to flag suspect data records. The follow-up manual screening step relies upon an analyst to review the flagged data and determine whether to retain or reject the suspect values.

Table 5.1 provides example range test criteria used in the validation process. Measurements are compared to allowable upper and lower limiting values. The limits of each range test will be set so that they span nearly the full range of plausible values for the site. For example, a reasonable range for 10-minute average wind speeds is from the anemometer offset to 30 m/s. Any values that fall below the offset should be flagged as either missing or invalid; speeds above 30 m/s are possible, such as during severe weather, but should be verified.

Table 3.3: Example Wind Measurement Validation - Range Criteria

Parameter	Validation Criteria
Horizontal Wind Speed	
Average	Offset < Avg. < 30 m/s
Standard Deviation	0 < Std. Dev. < 3 m/s
Maximum Gust	Offset < Max < 35 m/s
Wind Direction	
Average	0° < Avg. < 360°
Standard Deviation	3° < Std. Dev. < 75°
Temperature	Varies seasonally
Typical Range	-35° < Avg. < 35°C
Solar Radiation	Varies seasonally
Typical Range	Offset < Avg. < 1200 W/m^2

Relational tests rely on comparisons between various measured parameters to identify potentially spurious data. For example, wind speeds recorded at the same height should be very similar to each other (except when one anemometer is in the wind shadow of the tower). Table 5.2 gives examples of several relational test criteria used in routine data validation. These tests are designed to ensure that physically improbable situations are subject to scrutiny.

Table 3.4: Example Wind Measurement Validation - Relational Test Criteria

Parameter	Validation Criteria
Wind Speed	
Max Gust vs. Average	Max Gust ≤ 2.5 * Avg.
60 m/40 m Average Difference	≤ 3 m/s
60 m/40 m Daily Max Difference	≤ 5 m/s
Wind Speed: Same Height	
Average Difference	≤ 0.5 m/s
Maximum Difference	≤ 3.0 m/s
Wind Direction	
60 m/40 m Average Difference	≤ 15°
Wind Shear	Varies with terrain
60 m/40 m Average	-0.05 < α* < 0.45
* α = wind shear exponent	

The last of the three automated screening tests are based on the rate of change in a value over time. Table 5.3 lists sample trend test criteria. The thresholds actually used will be adjusted as necessary to suit the site conditions.

Table 3.5: Example Wind Measurement Validation - Trend Test Criteria

Parameter	Validation Criteria
Wind Speed Average	All sensor types
1 Hour Change	< 5.0 m/s
Temperature Average	
1 Hour Change	≤ 5°C

After the raw data are subjected to the automated validation checks, a reviewer will decide what to do about the suspect data records. Some suspect values may represent real (albeit unusual) weather occurrences and will not be excluded from the data record; others may reflect sensor or logger problems and will be flagged. Once a particular data record is deemed to be invalid, it is assigned a code to indicate the reason for its rejection. Table 6.4 gives examples of codes that can be used in the validation process. Note that code "-998" would apply to data recorded while a sensor is being serviced (which should be noted in the site activity documentation).

Table 3.6: Example Wind Measurement Validation - Validation Codes

Code	Rejection Criteria
-990	Unknown Event
-991	Icing or wet snow event
-992	Static voltage discharge
-993	Wind shading from tower
-995	Wind vane deadband
-996	Operator error
-997	Equipment malfunction
-998	Equipment service
-999	Missing data (no value possible)

3.2 Data Products and Statistics

AWST will provide regular monthly reports of metocean observations and statistics from the validated data.. Table 5.5 lists some of the parameters addressed in monthly wind parameter reports. Ocean parameter reports carry similar parameter statistics. The design and length of the reports will initially be set based upon AWST's standard formats, but must be configured to this project's exact data set and end-user input. A mix of tables, charts, and graphs are typically used to communicate the results. These stats will include, but are not limited to, a summary table of average statistics, a wind and wave rose, a graph of the diurnal wind speeds, a speed frequency distribution table, wave height frequency distribution, and others. A notes section will be provided to describe special events such as a maintenance trip or strong storm. Example monthly lidar and met buoy summary reports are attached as Appendices A and B, respectively. These formats will be integrated with ocean condition summaries for the final Program report format.

Table 3.7: Example Wind Measurement Reporting – Stats Summary

Report Products	Units
Data Recovery Fraction	%
Mean and Annualized Mean Wind Speed	m/s
Wind Shear	Non-dimensional exponent
Turbulence Intensity	%
Mean Air Temperature	ºC
Mean Air Density	Kg/m3
Speed Frequency Distribution	Graph
Weibull A and k parameters	m/s (A) non-dimensional (k)
Wind Rose	Graph
Daily and Hourly Speed Distributions	Graph

4. MAINTENANCE PROTOCOLS

Throughout the metocean campaign, data confidence will be managed through a well-designed and executed maintenance plan. The goal of operations and maintenance (O&M) is to ensure that high levels of data recovery are maintained throughout the campaign, and that the quality of the data itself is preserved. A program-wide O&M plan should be developed and followed for the key measurement systems, as well as for the data and communications systems.

As the Deployment Partner, and the owner of the deployed equipment and ASIT, WHOI has primary responsibility for O&M. WHOI will be providing an O&M program for the campaign under contract to MassCEC. To supplement the WHOI O&M program, and ensure alignment with standard wind industry practices, this section presents AWST's recommendations on campaign O&M. Bulleted below is a summary of general O&M approaches; the subsequent section present additional narrative around each subset of sensors.

General O&M recommendation:

- Site visit planning:
  - Minimum: one (1) site visit per quarter scheduled, and two (2) additional, unscheduled visit;
  - Preferred: one (1) scheduled site visit every 30 to 60 days for the first several months of the campaign
- As part of O&M plan, create an O&M log to complement system commissioning information to track equipment functionality and repairs
  - AWST will provide a candidate O&M tracking sheet that can be used for this purpose
- Document all site visit work and remote troubleshooting activities and actions in the O&M Log
  - AWST will provide candidate site activity forms that can be used for this purpose
- Follow the respective manufacturers' recommendations for sensor and system O&M
- Have back-up communications and data transfer available to connect to the site for troubleshooting purposes.
- Assess the station's and equipment suite's risks under potential hurricane conditions; develop an action plan to secure or evacuate equipment if required[4.11].

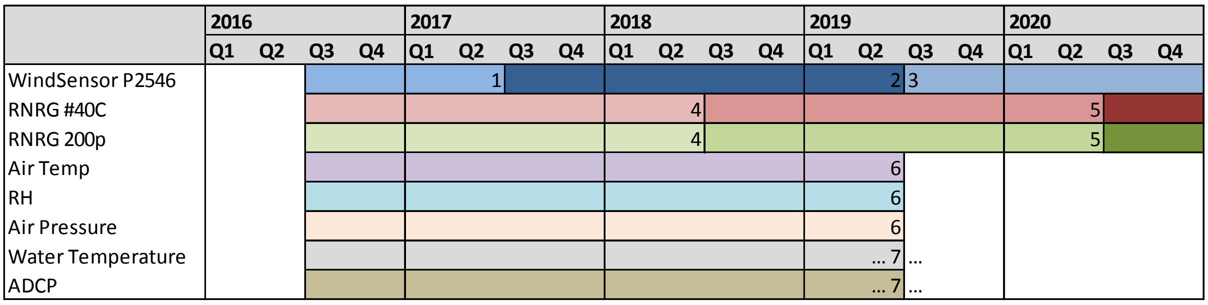
4.1 Metocean Sensors

During operation, it will be important to monitor the performance of the tower-based sensors by analyzing the raw data on a regular basis. There are well-established quality checks and screening procedures for anemometer, wind vane, and ancillary met sensor data that can be used to identify malfunctioning or failed instruments. This data quality monitoring and validation is a key component of station data collection, monitoring and reporting. A high level summary of wind sensor-specific recommendations is presented in the following bulleted list:

- Prior to a site visit get an update on the system functionality and go prepared with appropriate troubleshooting and repair equipment.
- An appropriate stock of spares should be secured prior to deployment
  - In the case of primary wind sensors – one (1) spare for each of the anemometers and vane is recommended
- The primary wind sensors should be decommissioned and replaced after no more than 24 months of operation.

[4.11] The lidar and support equipment may be able to weather in place; however, a specific response plan for hurricanes should still be considered.

- The supplemental ASIT sensors – air temperature, RH, air pressure, water temperature, ADCP, etc. – should be serviced and/or replaced on a schedule based upon their expected operational lifetime or anticipated calibration stability period, whichever is shorter.
    - At a minimum, the supplemental atmosphere sensors should be replaced, recalibrated or have their performance verified every 24 to 36 months.
    - Subsurface sensor – water temperature and ADCP – service and maintenance schedules should follow industry norms and manufacturer recommendations.
- A replacement schedule that minimizes discontinuities in the data record is recommended, and a complete simultaneous refit of the tower's sensors should be avoided for campaigns over 24 months in duration.
    - The sensors on at least one side of the tower should be retained each year on a rotating basis during multi-year campaigns.
    - A candidate maintenance schedule is presented in Figure 3.1
- Both pre- and post-deployment calibrations (prior to reconditioning and re-calibration) of sensors are recommended (required for anemometers) to verify and document consistent instrument performance.
    - Post-calibration is recommended for all wind sensors. Reconditioning, recalibration, and re-deployment may only be worthwhile for high-cost anemometers.
- Inspect sensors, booms, cables, and data logger, communications, and ancillary equipment when onsite.
    - Sensor cables should follow the same replacement schedule as their respective sensors.
    - Replace or repair other components as appropriate.
- Replace any sensors that analysis indicates to be suspect or failing.



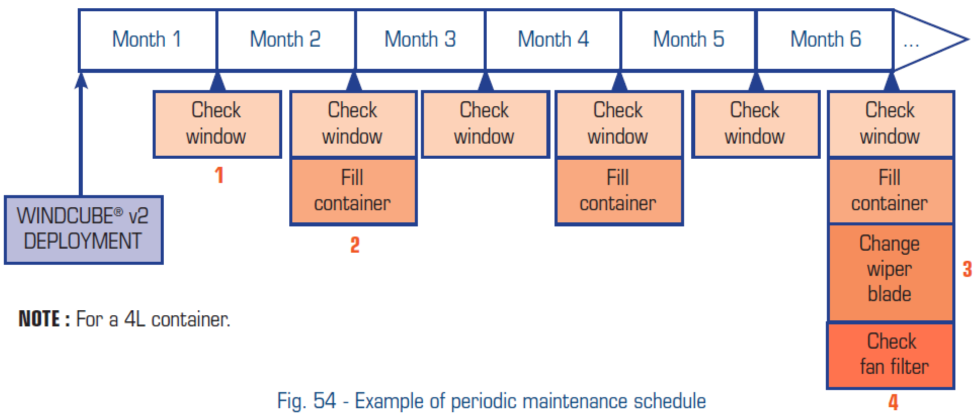
1 Initial WindSensor replaced at 12 months, post-calibrated, refurbished & recalibrated; New sensor deployed
2 Second WindSensor replaced at 36 months, post-calibrated, refurbished and recalibrated
3 Refurbished and recalibrated initial WindSensor re-deployed at month 36
4 Initial RNRG sensors (#40, 200P) replaced at 24 months, anemometer post-calibrated; new sensors deployed
5 Second RNRG sensors (#40, 200P) replaced at 48 months, anemometer post-calibrated; new sensors deployed
6 Supplemental atmosphere sensors serviced, replaced, or calibration checked between 24 and 36 months
7 Supplemental ocean sensors serviced, replaced, or calibration checked according to industry standard

Figure 4.1: Recommended ASIT Sensor Suite Service and Maintenance Schedule

4.2 Lidar

Similar to the tower-based instrumentation, the raw data from the lidar unit should be screened routinely to determine if the device is operating as intended. AWST has protocols planned for lidar data delivery verification, system functional screens, and more advanced data review and processing to help identify any operational issues.. The Windcube is a reliable remote sensing system. However, the deployment of the standard system in an offshore environment may necessitate more frequent maintenance than a typical onshore installation. Consequently, WHOI plans to visit the site on at least a monthly basis for the first year of operation and AWST will closely scrutinize both the reasonableness of the data and its trends in time. Such a program is significantly more robust than a typical V2 onshore deployment and is expected to help detect development of any operational issues and mitigate their impacts. Terrestrial deployments are rarely visited more than once per quarter unless the washer fluid runs out or the power supply fails. The Windcube utilizes notification systems to alert the user of operational issues. However, in some instances these alerts may be limited by the modes of communication available onsite. Once the planned back-up communication system for the lidar – a WHOI-designed cellular modem kit – the risk of communication issues are expected to be mitigated significantly.

Lidar maintenance is planned more frequently than most of the other devices being deployed for the early part of the campaign. Scheduled visits on at least a monthly or two-month basis should be expected for the first few months of operation. The lidar possesses a glass window through which the laser is emitted, and therefore this window needs to remain clear in order for the unit to operate properly. When the window becomes soiled, or during periods of precipitation, the lidar unit will spray washer fluid on the lens and use a small mechanical wiper to wipe clean its window. The washer fluid is stored in an external reservoir that needs to be replenished regularly; usage will be dependent upon the operating conditions. The wiper blades wear during operation, and will need to be replaced every few months. Bird guano is particularly hard on wiper operations and fluid usage. The system's aluminum cover plate and bird spikes are anticipated to reduce the potential impacts of birds and guano on the system's physical operation (wiper) and data quality. However, no bird deterrent system is expected to 100% effective. Special attention should be paid to signal quality in the summer when more birds are present and precipitation is less frequent. Figure 4.1 presents a Leosphere-recommended maintenance cycle for the first few months of operations.



Source: Leosphere Windcube V2 Manual

Figure 4.2: Leosphere-recommended Maintenance Cycle for Initial Deployment Period

Standard lidar maintenance typically stabilizes after the first few months of operations once the system's performance in the offshore environment is understood. WHOI secured a three-year extended warranty on the system which included a factory service visit. This extra coverage provides additional piece of mind when operating the system offshore. The maintenance package included is a robust system check-up and overhaul. It provides not only an operational check and system clean-up, but an opportunity to benchmark measurement performance stability against the Golden Lidar.[4.12]

However, since that maintenance work is necessarily conducted at the RNRG facility, the system will have to be decommissioned and removed from the tower for a period of several weeks. The timing of this work should be carefully planned based upon campaign progress and anticipated weather conditions. The service visit can be planned any time between month 12 and 36; it typically is carried out between month 18 and 30. A rental unit may be considered for the interim period if sufficient budget is available.

Outside of the heavy maintenance the increased frequency of site visits, regular data scrutiny and standard O&M tasks are expected to support reliable lidar operation.

General O&M recommendations:

- Upon delivery of the unit, request guidance on any campaign-specific maintenance requirements, and abide by them.
- Observe the manufacturer's recommendations on low temperature washer fluid.
- Ensure bird spikes and the aluminum cover are deployed on the unit, and inspected regularly.
- Have back-up communications available for the system to support data transmission and remote control during ASIT communication outages.
- If cycling the grid power (e.g. when divers are in the water) causes voltage or current spikes at the tower, ensure surge protection is provided for the lidar.
- If possible, deploy a back-up power supply for the lidar system to help minimize planned and unplanned power-related downtime.

5. SUMMARY

AWS Truepower has been engaged by MassCEC to provide a metocean monitoring plan in support of their Metocean Data Initiative for WEAs offshore Massachusetts. MassCEC has separately engaged WHOI to deploy and operate a Windcube V2 profiling lidar and a suite of metocean sensors on the ASIT platform, an offshore meteorological tower 2.8 km south of Martha's Vineyard. This report presented AWST's commentary and guidance on meteorological and ocean measurements with that tower.

AWST's measurement guidance is based upon industry best practices, extensive experience in US offshore monitoring, and applicable international standards and guidelines. The report presented relevant measurement and analysis parameters, preferred sensors to monitor those conditions, tower configuration recommendation, and campaign management procedures. Implementation of these recommendations is expected to result in the Campaign Team conducting a robust, scientifically rigorous and commercially valuable assessment of metocean conditions near the WEAs.

AWST looks forward to working with MassCEC and WHOI further on this campaign.

[4.12] A Golden Lidar is a reference lidar system that remains att he vendor's facility to be used for field system verification. The performance of the Golden Lidar is traceable back to a known reference mast in Europe.

REFERENCES

[1] AWST, "MassCEC Metocean Data Needs Assessment", Issue A, 13 April 2016

[2] MassCEC, "Request for Proposals: Offshore Wind Metocean Initiative Technical and Deployment Support Services", 23 February 2016, MassCECMetoceanInitiativeRFP2016.pdf

[3] IEC, "Wind turbines – Part 12-1: Power performance measurements of electricity producing wind turbines." Edition 1, Ref. No. IEC 61400-12-1:2005, December 2005,

[4] MEASNET, "ANEMOMETER CALIBRATION PROCEDURE", Version 2, October 2009, http://www.measnet.com/wp-content/uploads/2011/06/measnet_anemometer_calibration_v2_oct_2009.pdf

[5] AWST, "Wind Resource Assessment – A Practical Guide to Developing a Wind Project", Wiley, 2012

[6] IEA, "Expert Group Study on Recommended Practices – 15. Ground-based Vertically-profiling Remote Sensing for Wind Resource Assessment," Edition 1, January 2013 http://www.ieawind.org/index_page_postings/RP/RP%2015_RemoteSensing_1stEd_8March2013.pdf

APPENDIX A: EXAMPLE LIDAR MONTHLY REPORT

Memorandum

To:

CC:

From:

Date:

Re: Redacted Lidar report – Metocean Monitoring site, Two Profiling Lidars & Metocean Buoy

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Introduction

This memorandum report is an update on the analyses for the [Project Name] monitoring program. It covers the deployment period from Month DD, YYYY through Month DD, YYYY – system deployment through the end of the first calendar month. Basic statistics on observed conditions are presented, along with discussion of data transfer, data recovery, and preliminary correlations. This update presents further analysis of observed conditions by direction sector and data availability.

[REDACTED]

Results presented should be considered preliminary until report format, period of record, and data processing protocols are finalized.

Data Delivery and Data Recovery

Data delivered during the reporting period included [LIDAR 01] data from the [Deployment Site 01] and [LIDAR 02] data from the [Deployment Site 02]. Both data sets are provided by [Client] via FTP. The period of record for the [LIDAR 01] was affected by [REDACTED]. Data records for the balance of the program's systems were truncated to the [LIDAR 01] for the analyses presented in this report. Table 1 below summarizes the data delivery for the project. Table 2 summarizes the data recovery by height for [LIDAR 01].

Table 1. Data Delivery Summary for Reporting Period

Data Set	Period Of Record	Delivery Method	Comments
[LIDAR 02]	[Dates]	AWS Truepower FTP & email delivery	Period of record presented here truncated to match [LIDAR 01]
[LIDAR 01]	[Dates]	AWS Truepower FTP	None
Buoy wave	[Dates]	AWS Truepower FTP	None
Buoy met	[Dates]	AWS Truepower FTP	
Buoy motion	[Dates]	AWS Truepower FTP	

Table 2. Data Recovery for [LIDAR 01] by Monitoring Height

Monitoring Elevation (m AMSL)	Valid Records / Number of Records (10 Min)	Cumulative Data Recovery (%)	Comments
40	2591 / 2750	94.2	Data recovery statistics through [Dates] Value represents calculated data recovery at all monitoring levels with equal to or greater than [Data Filter].
60	2591 / 2750	94.2	
80	2591 / 2750	94.2	
100	2591 / 2750	94.2	
120	2591 / 2750	94.2	
140	2591 / 2750	93.6	
160	2591 / 2750	91.5	
180	2447 / 2750	89.0	
200	2354 / 2750	85.6	

Observed Statistics - All data

Summary statistics of observed conditions are provided below for [LIDAR 01] and [LIDAR 02]. Plots and summary tables represent only concurrent measurements between the two systems for all direction sectors and no data filters. Table 3 provides a summary of average speeds at each of the concurrent monitoring heights for all speeds with a breakdown by direction sector. Figure 1 illustrates the wind direction frequency distribution (wind rose) weighted by both frequency and energy for both lidars at the 100 m observation level.

Table 3. Summary of Concurrent Average Wind Speeds by Monitoring Height and Direction Sector, No Data Filtering – [LIDAR 02] and [LIDAR 01]

		Average Speed (m/s) by Direction Sector All Speeds									
Height (m above surface)		All	190-350	N	NE	E	SE	S	SW	W	NW
LIDAR 02	40	4.0	4.1	3.8	2.7	3.7	3.1	4.9	4.2	2.9	3.7
	60	4.5	4.6	4.4	3.4	4.9	3.5	5.4	4.6	3.4	4.1
	80	4.9	4.9	4.8	3.9	5.7	3.8	5.6	4.8	3.9	4.4
	100	5.2	5.2	5.2	4.4	6.2	4.0	5.6	4.9	4.5	4.8
	120	5.4	5.4	5.6	4.8	6.5	4.2	5.7	5.1	5.2	5.1
	140	5.6	5.5	6.0	5.1	6.9	4.3	5.5	5.1	5.8	5.5
	160	5.7	5.7	6.3	5.4	7.1	4.4	5.3	5.3	6.4	5.7
	180	6.0	6.1	6.7	5.6	7.4	4.6	5.3	5.6	7.0	6.2
	200	6.3	6.4	7.2	6.0	7.7	4.6	5.3	5.9	7.7	6.5
LIDAR 01	40	4.5	4.3	4.1	3.5	3.5	3.3	5.8	4.4	2.7	3.4
	60	4.8	4.5	4.5	3.8	4.1	3.5	5.9	4.5	3.0	3.8
	80	5.0	4.8	4.9	4.1	4.7	3.7	5.9	4.6	3.4	4.2
	100	5.3	5.0	5.2	4.4	5.4	3.8	5.9	4.8	3.9	4.5
	120	5.5	5.2	5.5	4.8	5.9	4.0	6.0	4.9	4.5	4.8
	140	5.8	5.5	5.9	5.0	6.3	4.2	6.0	5.1	5.2	5.2
	160	6.0	5.8	6.3	5.3	6.7	4.4	6.0	5.1	5.9	5.6
	180	6.3	6.0	6.7	5.5	7.1	4.7	6.0	5.3	6.7	6.0
	200	6.6	6.4	7.0	5.7	7.4	4.9	6.0	5.6	7.4	6.4
Counts (10 min)		2392	1216	367	100	228	168	714	313	243	259

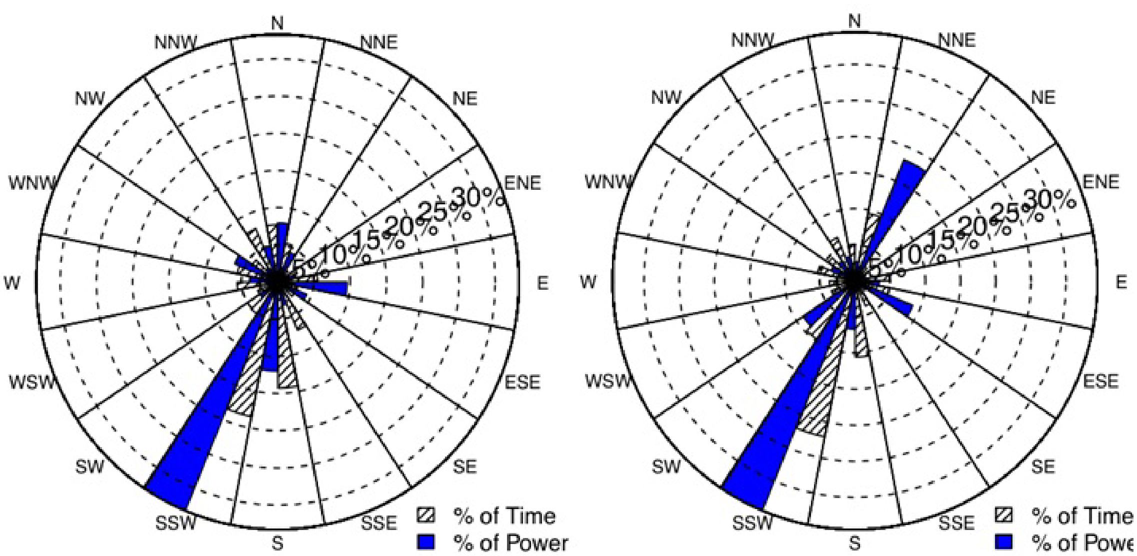


Figure 1. Wind Rose at 100 m, No Filtering – [LIDAR 02] (left) and [LIDAR 01] (right)

Observed Statistics – [Data Filters]

[REDACTED]

Summary statistics of observed conditions are provided below for [LIDAR 01] and [LIDAR 02]. Plots and summary tables represent only concurrent measurements between the two systems with [Data Filter] Table 4 provides a summary of average speeds at each of the concurrent monitoring heights with a breakdown by direction sector. Figure 2 illustrates the wind direction frequency distribution (wind rose) weighted by both frequency and energy for both lidars at the 100 m observation level. Figure 3 provides an illustration of the shear profiles observed by [LIDAR 02] and [LIDAR 01] for all speeds and speeds greater than 5 m/s. Figure 4 provides a time series of wind speeds observed by [LIDAR 02] and [LIDAR 01] at 60 m, 80 m, and 100 m observation levels between the [Dates] of the campaign.

Table 4. Summary of Concurrent Average Wind Speeds by Monitoring Height and Direction Sector for [Data Filters] – [LIDAR 02] **and** [LIDAR 01]

		Average Speed (m/s) by Direction Sector All Speeds [Data Filter]									
Height (m above surface)		**All**	**190-350**	**N**	**NE**	**E**	**SE**	**S**	**SW**	**W**	**NW**
LIDAR 02	40	3.8	4.0	3.8	2.7	3.6	2.8	4.5	4.3	2.9	3.8
	60	4.3	4.5	4.4	3.3	4.7	3.2	5.0	4.7	3.4	4.2
	80	4.7	4.8	4.8	3.8	5.5	3.3	5.1	4.8	3.9	4.6
	100	4.9	5.0	5.2	4.3	6.0	3.5	5.1	5.0	4.5	4.9
	120	5.2	5.3	5.6	4.7	6.4	3.8	5.1	5.1	5.2	5.3
	140	5.5	5.5	6.0	5.0	6.7	4.0	5.1	5.2	5.9	5.6
	160	5.7	5.8	6.4	5.2	7.0	4.3	5.1	5.3	6.5	5.9
	180	6.0	6.1	6.7	5.5	7.3	4.5	5.2	5.6	7.0	6.3
	200	6.3	6.4	7.2	5.8	7.5	4.7	5.1	6.0	7.7	6.7
LIDAR 01	40	4.5	4.2	4.3	3.4	3.4	3.1	5.5	4.5	2.7	3.6
	60	4.8	4.4	4.7	3.7	4.0	3.2	5.5	4.6	3.0	3.9
	80	5.0	4.7	5.1	4.0	4.6	3.4	5.4	4.7	3.5	4.3
	100	5.3	4.9	5.4	4.3	5.2	3.5	5.4	4.8	4.0	4.6
	120	5.5	5.1	5.6	4.6	5.7	3.6	5.4	5.0	4.6	5.0
	140	5.8	5.4	6.0	4.9	6.2	3.8	5.4	5.1	5.3	5.4
	160	6.0	5.6	6.3	5.1	6.6	4.1	5.4	5.2	6.0	5.7
	180	6.3	5.9	6.6	5.3	6.9	4.3	5.4	5.4	6.7	6.1
	200	6.6	6.3	7.0	5.5	7.2	4.7	5.5	5.7	7.4	6.5
Counts (10 min)		1905	1051	279	96	156	119	519	283	239	214

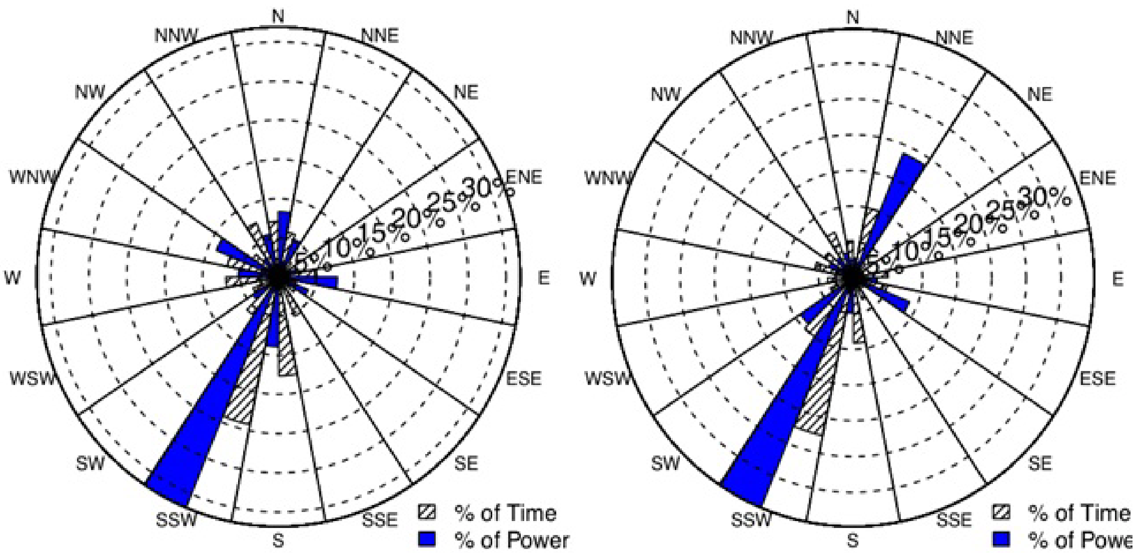


Figure 2. Wind Roses at 100 m, [Data Filter] – [LIAR 02] (left) and [LIDAR 01] (right)

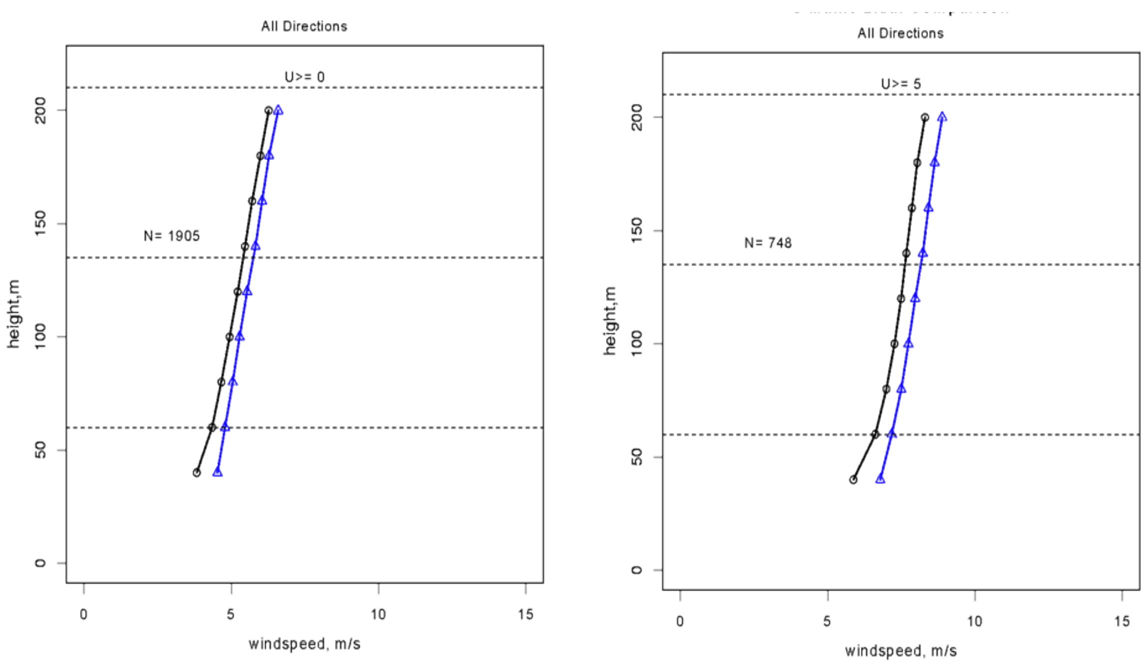


Figure 3. [LIDAR 02] (Black Circles) and [LIDAR 01] (Blue Triangles) Shear Profiles for All Speeds (left) and Speeds Greater than 5 m/s (right), [Data Filter]

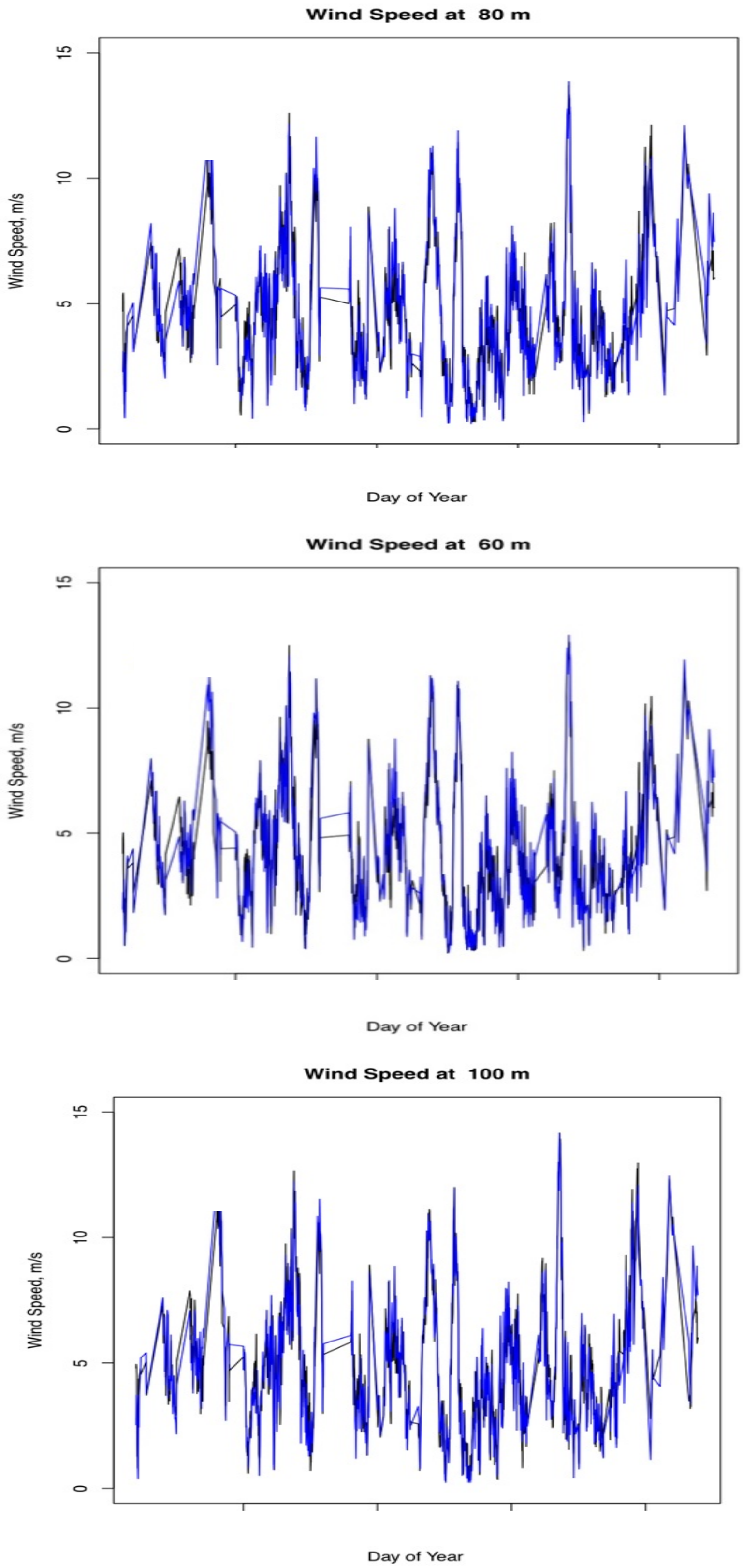


Figure 4. Time Series of [LIDAR 02] (Black) and [LIDAR 01] (blue) Wind Speeds with [Data Filter] at 60 m (Top), 80 m (Center), and 100 m (Bottom) Monitoring Levels

Preliminary Correlations - Filtered Data

[REDACTED]

[REDACTED]

Wind speed correlations were created for concurrent [LIDAR 02] and [LIDAR 01] observations between [Data Filters]. Table 5 provides a summary of wind speed correlation coefficients between comparable monitoring levels for all speeds at 10 Minute and Hourly intervals. Figure 3 provides an illustration of the shear profiles observed [LIDAR 02] and [LIDAR 01] in the valid directions sectors for all speeds and speeds greater than 5 m/s.

Table 5. Summary of Wind Speed Correlation Coefficients for [Data Filters] – [LIDAR 01] compared to [LIDAR 02]

Height (m above surface)	All Speeds [Data Filters]			
	Slope (10 min)	R^2 (10 min)	Slope (hour)	R^2 (hour)
40	1.098	0.972	1.109	0.977
60	1.022	0.983	1.032	0.988
80	1.001	0.985	1.013	0.989
100	0.990	0.986	1.001	0.990
120	0.984	0.986	0.994	0.989
140	0.983	0.986	0.990	0.989
160	0.980	0.988	0.986	0.992
180	0.985	0.989	0.992	0.994
200	0.995	0.989	0.998	0.993

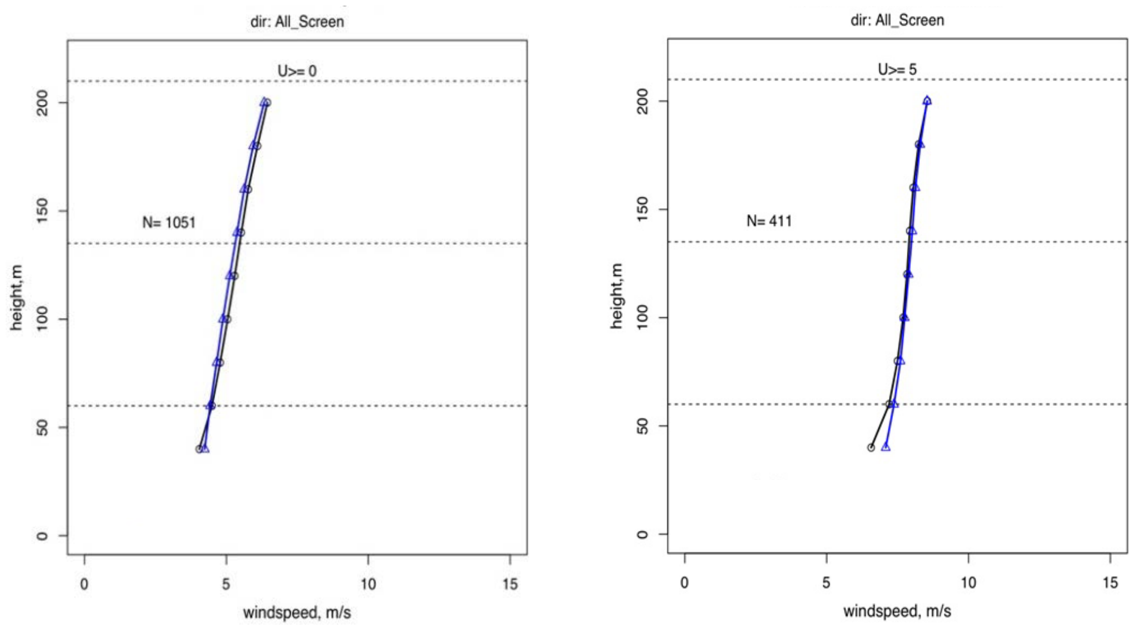


Figure 6. [LIDAR 02] (Black Circles) and [LIDAR 01] (Blue Triangles) Shear Profiles All Speeds (left) and Speeds Greater than 5 m/s (right), [Data Filters]

The wind speed and direction scatter plots between the target and reference systems' 100 m reporting level are presented in Figure 7. The speed correlation illustrates only data for valid direction sectors, while the direction scatter plot highlights the valid sectors [Data Filters].

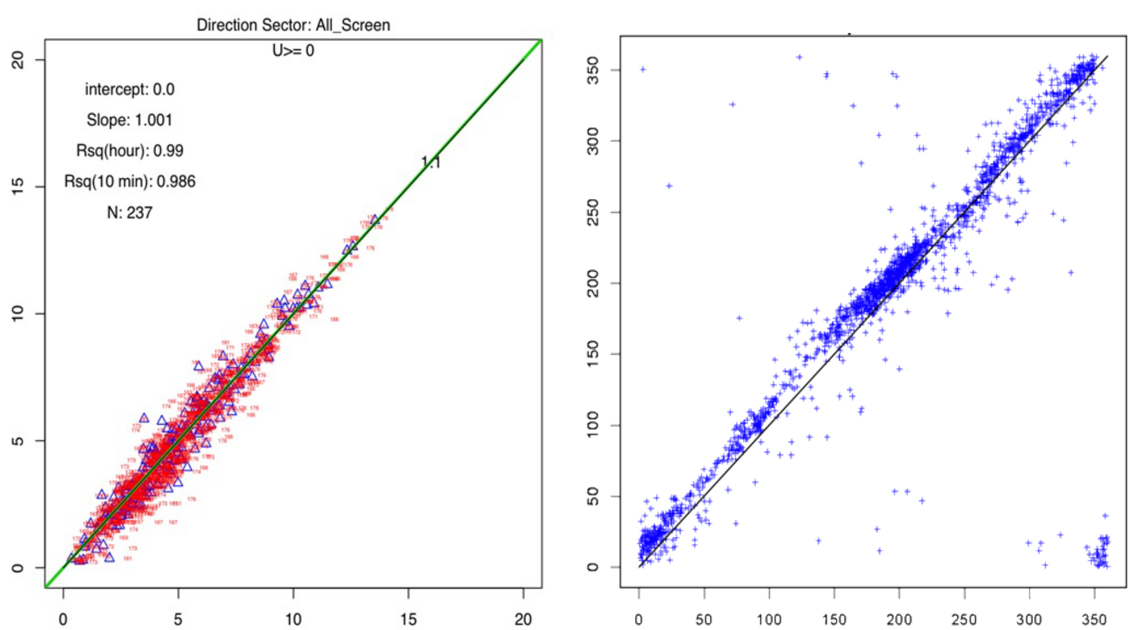


Figure 7. Wind Speed (Left) and Direction (Right) Scatter-plots at 100 m Monitoring Level for All Speeds and [Data Filters]

Summary

[REDACTED]

APPENDIX B: EXAMPLE MET BUOY MONTHLY REPORT

Confidential
Offshore Met Buoy XXXX
Summary of Wind Statistics
Month YYYY

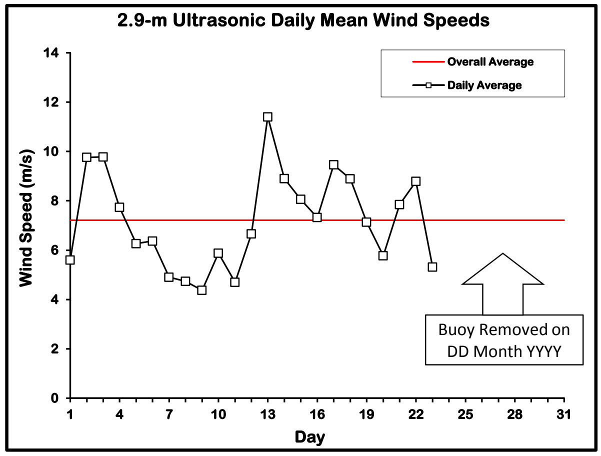
Site Information
Project: Monthly Assessment of Offshore Met Buoy XXXX for Wind Power Applications
Site: Offshore Met Buoy XXXX, Confidential
Location: Confidential
UTM Site Coordinates: Confidential / Confidential (Zone , WGS 84)
Site Elevation: Sea Level
Wind Speed Monitoring Heights: 2.9 m
Data Averaging Interval: 10 Minutes
Data Sampling Interval: 1 Second

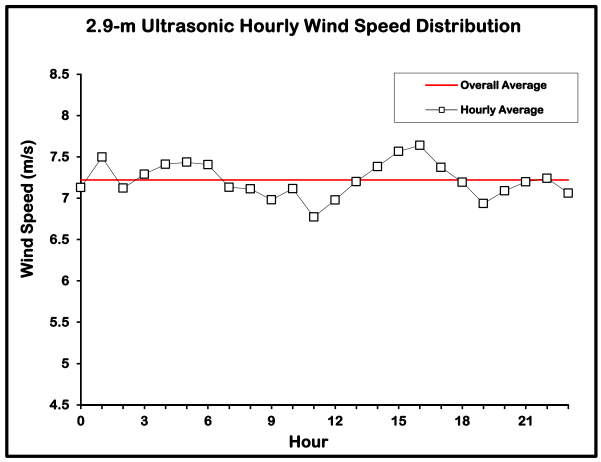
2.9-m [ANEMOMETER A] Ultrasonic Anemometer Wind Statistics	
Mean Wind Speed (m/s):	7.22
10-minute Standard Deviation (m/s):	1.25
*Mean Turbulence Intensity:	0.17
Maximum 10-minute Wind Speed (m/s):	15.82
**90-m Projected Wind Speed (m/s):	10.9
**100-m Projected Wind Speed (m/s):	11.0

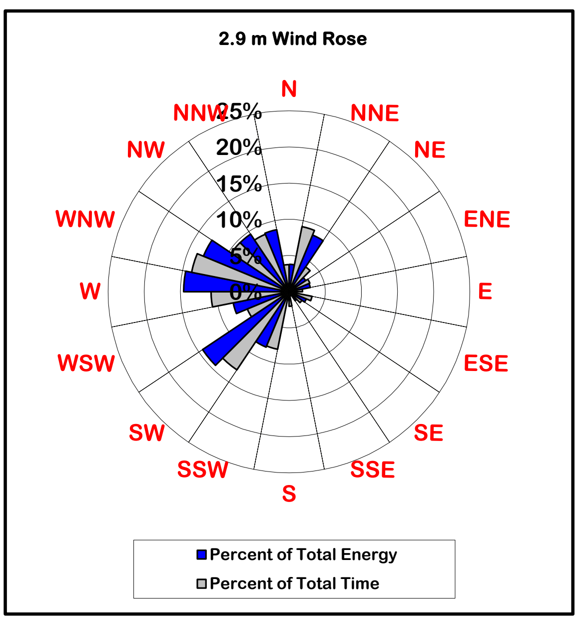
2.9-m [ANEMOMETER B] Wind Statistics	
Mean Wind Speed (m/s):	6.79
10-minute Standard Deviation (m/s):	0.89
*Mean Turbulence Intensity:	0.13
Maximum 10-minute Wind Speed (m/s):	14.22

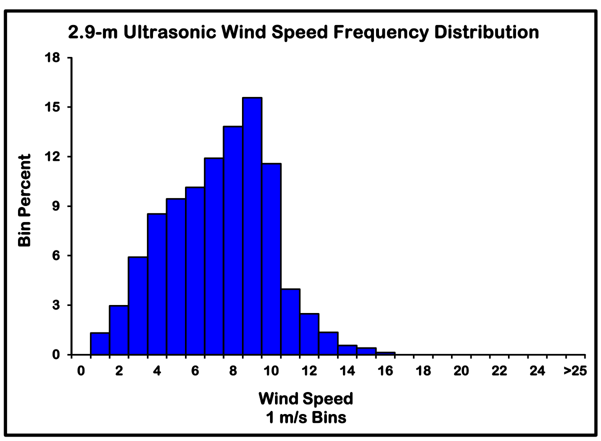
Other Measurements	
Prevailing Wind Direction:	WNW
Prevailing Energy Direction:	W
Wind Speed Data Recovery (%):	76.0
2.9 m Air Temperature (°C):	3.9
-0.6 m Water Temperature (°C):	6.3
2.9 m Station Pressure (mb):	1016.5

*Wind speeds below 4 m/s excluded.
**10% uncertainty due to the large extrapolation distance and lack of onsite shear measurements.









Sensor Status (through [DATE])	
2.9 m [ANEMOMETER A]	Buoy Out of Water
2.9 m [ANEMOMETER B]	Buoy Out of Water
2.9 m Air Temperature	Buoy Out of Water
-0.6 m Water Temperature	Buoy Out of Water
2.9 m Air Pressure	Buoy Out of Water

Confidential
Offshore Met Buoy XXXX
2.9-m Ultrasonic Anemometer Mean Wind Speed (m/s)
Month YYYY

Day	Hour (LST)																								Daily Avg
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
1	4.3	4.3	4.3	4.7	5.9	4.8	4.3	4.1	2.8	3.0	3.1	3.9	4.9	6.1	6.3	7.1	7.4	8.3	8.7	7.2	7.3	8.0	7.2	6.5	5.6
2	8.2	10.1	9.7	9.9	9.2	11.5	12.4	9.2	9.9	11.0	10.7	9.9	9.7	10.2	10.4	10.0	9.5	9.3	9.0	8.5	8.0	8.5	9.7	9.9	9.8
3	9.4	9.3	8.9	8.4	8.5	9.0	9.5	9.3	10.1	10.5	11.7	10.6	9.9	10.8	11.8	11.4	11.3	10.3	9.4	10.0	9.3	8.8	8.6	8.1	9.8
4	8.8	8.8	9.0	8.9	9.0	8.3	8.1	8.2	8.7	7.3	5.8	5.3	4.3	4.3	5.5	5.8	7.4	6.6	7.4	8.7	9.3	9.6	11.0	9.7	7.7
5	8.1	7.6	6.7	6.5	5.9	7.2	7.3	7.8	7.5	7.3	6.9	6.7	7.5	9.3	9.6	9.3	7.4	5.6	4.7	3.2	3.1	2.7	1.1	1.5	6.3
6	3.1	3.6	4.8	6.2	6.8	7.9	7.7	8.2	7.9	7.4	6.7	5.9	7.8	7.7	6.9	6.6	7.5	7.2	7.0	5.8	5.9	5.2	4.7	4.3	6.4
7	5.6	4.9	3.1	3.6	4.5	5.1	5.2	5.2	5.2	4.6	5.0	6.0	5.8	6.0	5.7	6.3	5.7	6.2	5.1	4.4	4.6	3.4	2.9	3.8	4.9
8	5.4	5.4	5.1	6.1	4.5	3.6	3.8	4.3	5.3	4.8	4.2	2.5	2.2	2.7	4.3	5.6	5.5	4.5	3.7	4.6	5.9	6.8	5.8	7.0	4.7
9	7.9	8.0	7.2	6.9	6.4	6.3	5.6	4.5	4.4	3.3	3.8	3.3	2.3	1.3	1.1	2.2	3.1	4.4	5.2	5.5	3.2	2.6	3.5	3.1	4.4
10	2.7	4.7	5.0	6.4	7.3	6.8	7.4	8.0	7.2	6.6	6.9	8.2	9.4	8.2	7.6	6.9	6.3	6.0	5.1	3.0	3.1	2.3	2.7	3.6	5.9
11	3.3	2.9	2.5	1.8	1.8	1.6	1.5	2.0	2.7	2.8	3.3	3.2	3.7	3.9	4.8	5.8	6.9	7.5	7.2	7.8	8.7	9.1	9.6	8.5	4.7
12	8.1	10.7	9.5	9.1	9.0	6.9	5.4	5.7	6.4	6.2	8.2	9.1	9.0	6.7	6.1	5.3	3.9	4.2	3.8	3.5	3.4	5.3	6.5	8.0	6.7
13	9.0	9.8	8.8	9.1	10.7	12.0	11.7	11.9	13.0	13.9	14.8	13.6	15.0	14.6	14.7	13.4	12.6	10.1	9.5	8.9	9.3	9.5	8.8	8.8	11.4
14	9.9	10.0	9.9	9.1	8.7	8.6	8.7	9.4	9.6	9.9	9.3	9.1	9.9	10.0	9.6	9.4	9.5	7.7	6.9	7.1	7.9	7.9	7.8	7.7	8.9
15	7.5	7.7	7.6	7.4	7.7	7.5	9.2	9.9	9.1	9.8	9.2	8.8	8.1	8.1	8.0	7.7	8.0	7.9	7.1	7.0	6.7	7.2	8.2	8.2	8.1
16	8.4	6.9	7.1	6.9	5.8	4.8	4.3	3.0	2.1	1.1	1.0	1.5	5.2	6.6	7.9	9.8	10.8	11.4	11.9	11.9	11.4	12.2	12.2	11.5	7.3
17	11.2	12.3	12.4	12.4	11.8	10.9	9.6	9.8	8.7	8.1	8.6	7.4	7.1	8.1	8.2	7.9	7.5	7.6	9.4	8.3	9.8	10.5	10.3	9.5	9.5
18	8.4	8.1	6.3	8.2	11.2	9.5	10.8	8.8	10.3	10.1	10.3	9.6	9.7	9.4	9.5	9.2	9.1	8.4	7.9	6.9	8.9	7.6	8.0	7.6	8.9
19	8.1	9.1	9.3	10.0	8.7	8.9	8.7	7.5	6.2	4.8	4.4	3.2	1.9	1.5	2.2	3.1	4.3	6.0	7.6	10.3	12.5	12.1	11.5	9.6	7.1
20	8.6	8.2	6.0	5.3	5.6	7.0	7.7	7.5	8.5	9.0	7.5	5.7	5.5	5.7	4.7	4.6	4.3	4.8	4.0	4.1	3.0	4.1	4.1	3.4	5.8
21	3.8	4.7	5.8	6.6	7.6	8.4	8.3	6.6	4.4	5.2	7.8	7.6	7.1	8.7	9.5	9.6	10.3	10.2	9.6	9.1	9.0	9.1	9.6	9.5	7.8
22	9.1	9.8	9.3	9.5	8.9	9.2	9.2	9.5	10.1	10.0	9.8	9.4	8.8	9.8	10.0	10.4	10.0	9.1	8.9	7.2	5.7	5.9	5.8	5.6	8.8
23	5.1	5.6	5.7	4.8	5.1	5.1	4.4	3.7	3.4	3.9	5.0	5.2	5.6	5.8	5.3	6.8	7.6	6.6	6.5	**	**	**	**	**	5.3
24	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
25	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
26	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
27	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
28	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
29	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
30	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
31	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
																									Overall
Hourly Avg	7.1	7.5	7.1	7.3	7.4	7.4	7.4	7.1	7.1	7.0	7.1	6.8	7.0	7.2	7.4	7.6	7.6	7.4	7.2	6.9	7.1	7.2	7.2	7.1	7.2