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Date: March 10, 2017
Re: Wind Direction Offset Adjustments for the Metocean Initiative

1. INTRODUCTION

AWS Truepower (AWST) has been engaged by the Massachusetts Clean Energy Center (MassCEC) to provide monthly observed data summary reports for the wind resource monitoring equipment deployed on the Woods Hole Oceanographic Institutions Air-Sea Interaction Tower (ASIT) in support of MassCEC's "Metocean Initiative" (the "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')." 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 equipment selected for the Initiative is comprised of a factory-validated Windcube V2 profiling lidar (WLS7 436, or "the lidar") and a suite of standard wind, atmosphere and sea surface temperature instrumentation. Installation and operation of the sensors at the ASIT is managed by the tower's owner, the Woods Hole Oceanographic Institution (WHOI).

During initial validation of the lidar data, the unit's wind direction readings were found to be misaligned with regional observations. This issue was independently identified by one of the Initiative's Stakeholders and AWST. Uncertainty in the unit's orientation was noted in the commissioning form, but review of concurrent data from two long-term reference stations confirmed the presence of an offset. Similar analyses conducted by AWST also identified a misalignment in the direction readings collected by the station's new wind vane.

This memorandum summarizes the coordination and processes AWST employed to determine the physical orientations of both the lidar and the wind direction vane. Based upon these orientations, offsets for each of the sensors are recommended for post-processing of the data. The following sections present a brief overview of the station configuration and address each of the lidar and vane efforts individually.

2. LIDAR DIRECTION

2.1. Station Configuration Summary

The WLS7 436 lidar was deployed at the WHOI Air-Sea Interaction Tower (ASIT) station south of Martha's Vineyard on 8 October 2016 (Figure 1). The unit was positioned on an elevated work bench located along the south side of the station's "diving board", the narrow platform extending west-southwest from the main structure. To facilitate access to the lidar's interface hatch (located on its south side), and to ensure that the system' beams were not obstructed by the tower or appurtenances, the unit's north side was not oriented towards True North. General photos of the deployment are presented in Figure 1. Additional site photos have been added to the project FTP.

Figure 1.1: Windcube V2 profiling lidar (WLS7 436) installed on WHOI Air-sea Interaction Tower

During the lidar's commissioning several measurements were taken to help assess its orientation. System bearings were assessed through handheld compass measurements (taken by AWST and WHOI), as well as the lidar's internal compass. When integrated, those readings, along with the location's magnetic declination (14.6° W), resulted in an estimated system direction offset of 155.4°. Due to significant magnetic interference from the ASIT station's steel structure, as well as space constraints on the platform for siting the lidar chassis, the orientation was noted to be uncertain in the commissioning form. In addition to the compass readings, high-accuracy GPS measurements were taken at either end of the diving board to develop a better orientation of that structure.

2.2. Offset Identification

AWST and the Initiative Stakeholder both identified the lidar's offset during comparisons with local long-term reference stations. The two[2.1] stations evaluated by AWST were the Buzzards Bay offshore

[2.1] The ASIT station's 3D sonic anemometer mounted was also considered, but not included in the evaluation due to inadequate data coverage and confidence.

platform (BUZM3)[2.2] and the Martha's Vineyard airport (MVY)[2.3]. While the data averaging methods at those two reference stations vary from the lidar's, their observations are reliable and generally representative of the regional wind conditions.

Analyzing concurrent valid hourly wind direction values, AWST confirmed that the BUZM3 and MVY observations agreed well with each other (within expectations for distance and exposure). Using the same data, AWST also confirmed that the WLS7 436 data tracked well with both reference stations, but exhibited a distinct offset. The following figures illustrate the approaches employed to assess the measurement offset. Figure 2.1 presents a time series snapshot of the three stations over a two week period in October 2016. Figure 2.2 presents scatter plots of the lidar against the reference station values. Finally, Figure 2.3 presents a comparison of wind direction frequency distributions (wind roses). AWST also evaluated other metrics, such as the monthly means and average difference values between the lidar direction and the concurrent observation from a reference stations.

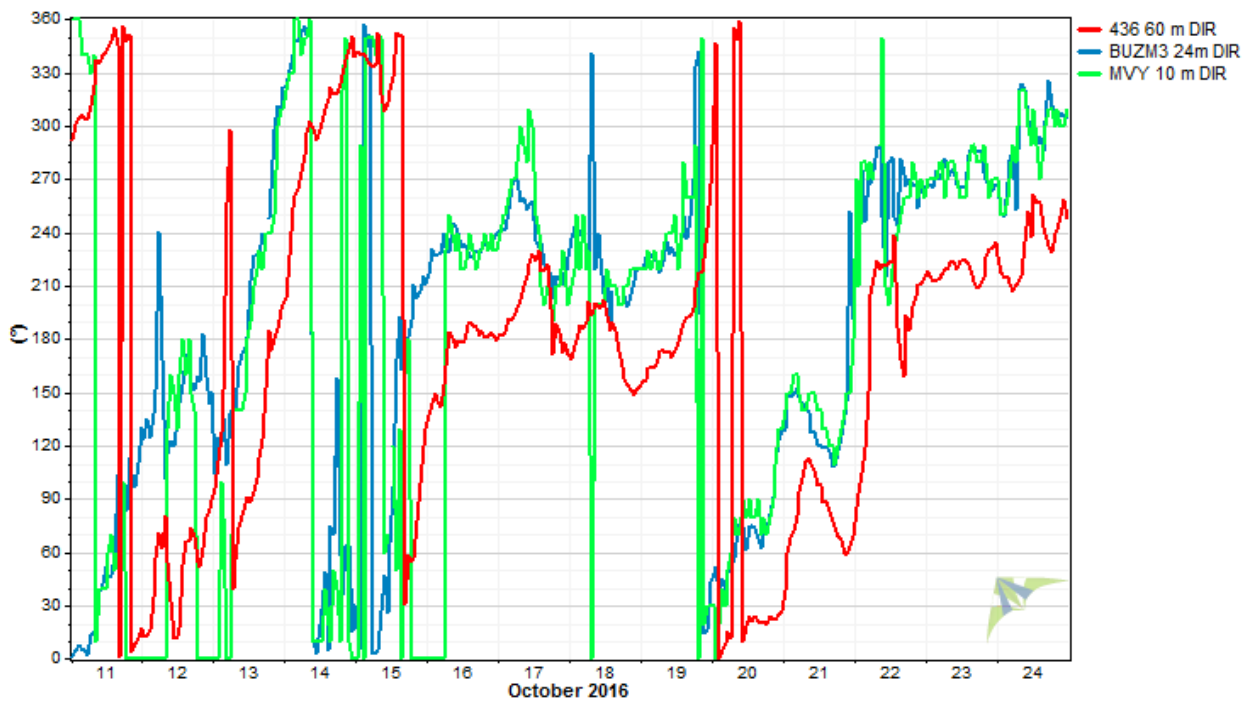

Figure 2.1: Snapshot of Time Series Comparison between WLS7 436 (Red), BUZM3 (Blue) and MVY (Green) Hourly Observations

[2.2] http://www.ndbc.noaa.gov/station_page.php?station=buzm3

[2.3] https://www.ncdc.noaa.gov/

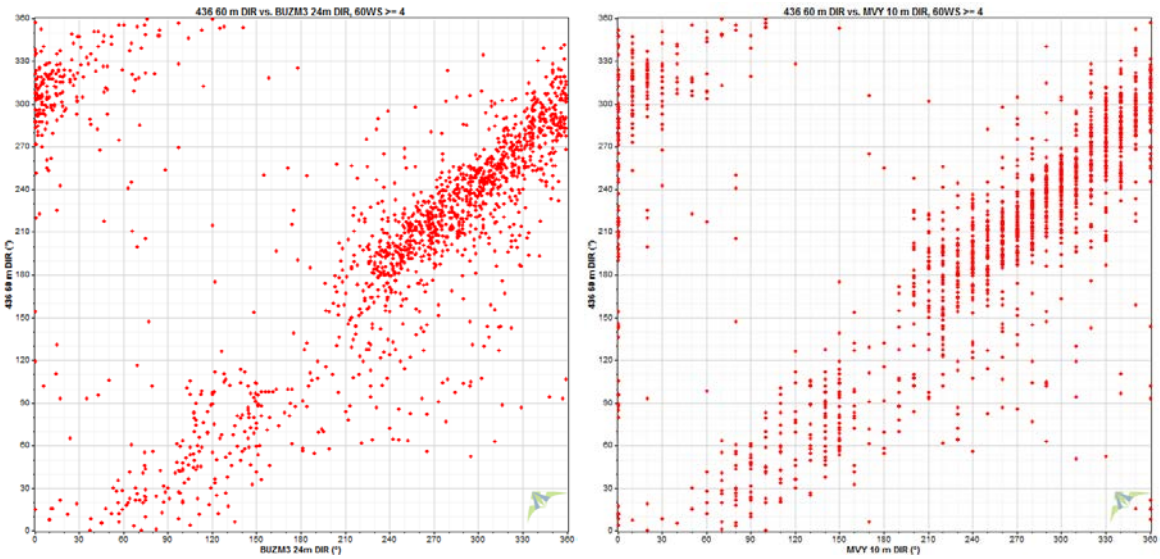

Figure 2.2: Scatter Plot of WLS7 436 Direction Readings versus BUZM3 (Left) and MVY (Right), both Screened for Speeds Greater than 4.0 m/s at the Lidar (60 m MSL monitoring level)

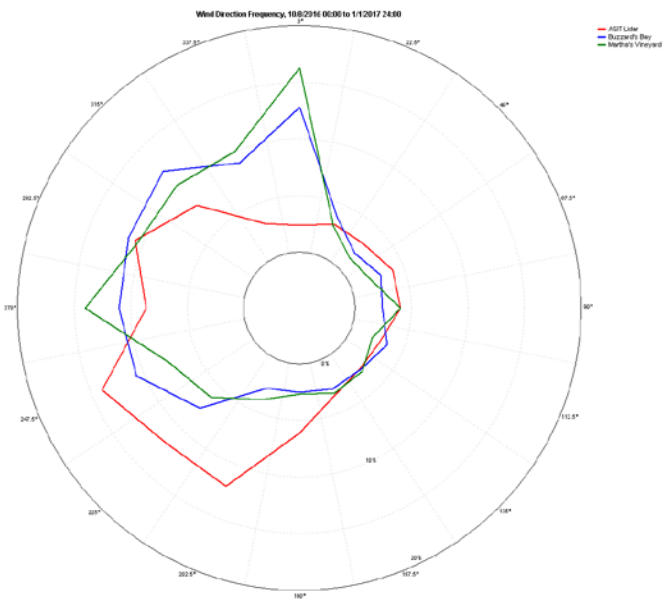

Figure 2.3: 16-sector Wind Rose Comparison Illustrating WLS7 436 (Red), BUZM3 (Blue) and MVY (Green) Observations for Speeds over Lidar 4.0 m/s (60 m MSL monitoring level)

2.3. Offset Measurement

AWST carried out additional physical and high-precision GPS measurements of the lidar's orientation during a field visit to ASIT. Specifically, physical measurements of the unit's angle relative to the diving board structure were collected. Additional GPS measurements of the lidar's chassis alignment, as well as the diving board's bearing were also collected. AWST's separate GPS measurements – from commissioning and from the subsequent site visit – indicated an orientation of approximately 255° True

for the diving board, which was independently confirmed by the WHOI team.[2.4] A simplified diagram of one set of physical and GPS measurements is presented in Figure 2.4 below.

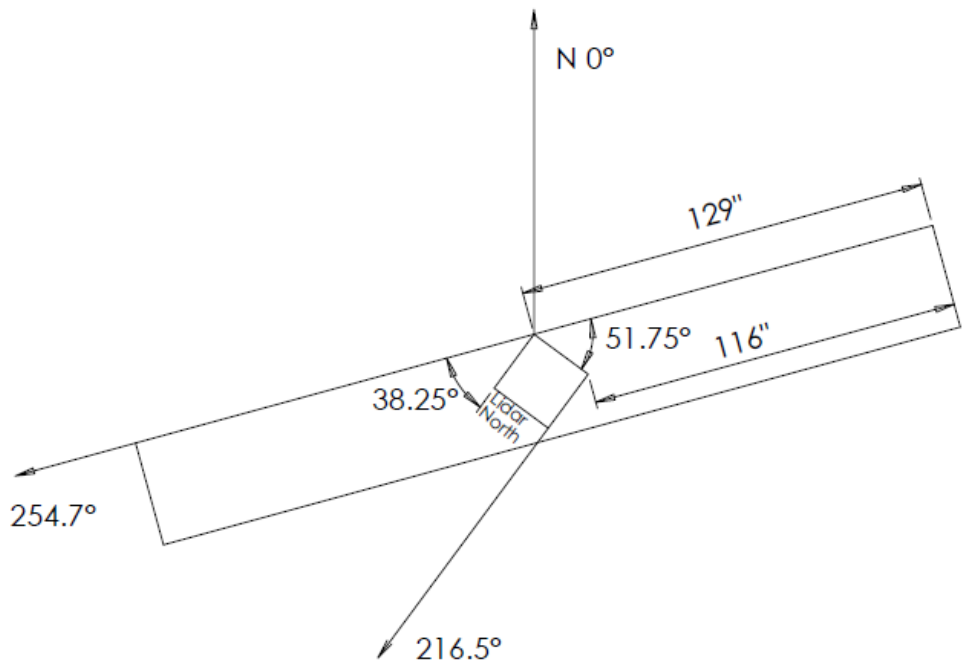

Figure 2.4: Example Set of AWST's Lidar Alignment Measurements – Physical Measurements of the Lidar's Position Relative to the Diving Board's GPS-derived Orientation

The measurements of the lidar position, the length of the lidar chassis (approximately 21 inches along the south side), and the orientation of the diving board were evaluated to determine the system's alignment relative to True North. These orientations were combined with the lidar's internal offset[2.5] to derive values for adjusting the lidar observations in post-processing. The average post-processing offset from the three sets of measurements was 60.5°. The results of these calculations are summarized in Table 2.1 below. AWST plans to re-verify these measurements during subsequent site visits.

Table 2.1: Summary of WLS7 436 Orientation and Offset Estimates

Method	Lidar Orientation (°TN)	Internal Offset* (°)	Post-Process Offset (°)
GPS + Measurements-1	216.5	155	61.5
GPS-only	214.0	155	59.0
GPS + Measurements-2	216.1	155	61.1
Average	**215.5**	**155**	**60.5**
*: Rounded value of lidar internal offset used in calculation due to variation in the offset; under investigation			

[2.4] WHOI is planning a detailed survey of the tower later in 2017

[2.5] Due to small variations noted in the lidar offset value (e.g. 155.4° at commissioning, 155.3° in March), a rounded value of 155° was used in the calculations. The cause of the offset variation is being investigated.

2.4. Offset Verification

AWST independently verified this average offset by comparing the adjusted lidar wind direction data to the two reference stations noted above. The adjustment significantly improves the agreement between the lidar observations and the concurrent regional measurements. Plots replicating information shown in Figures 2.1 through 2.3 are presented below in Figures 2.5 through 2.7 with lidar data offset by 60.5°.

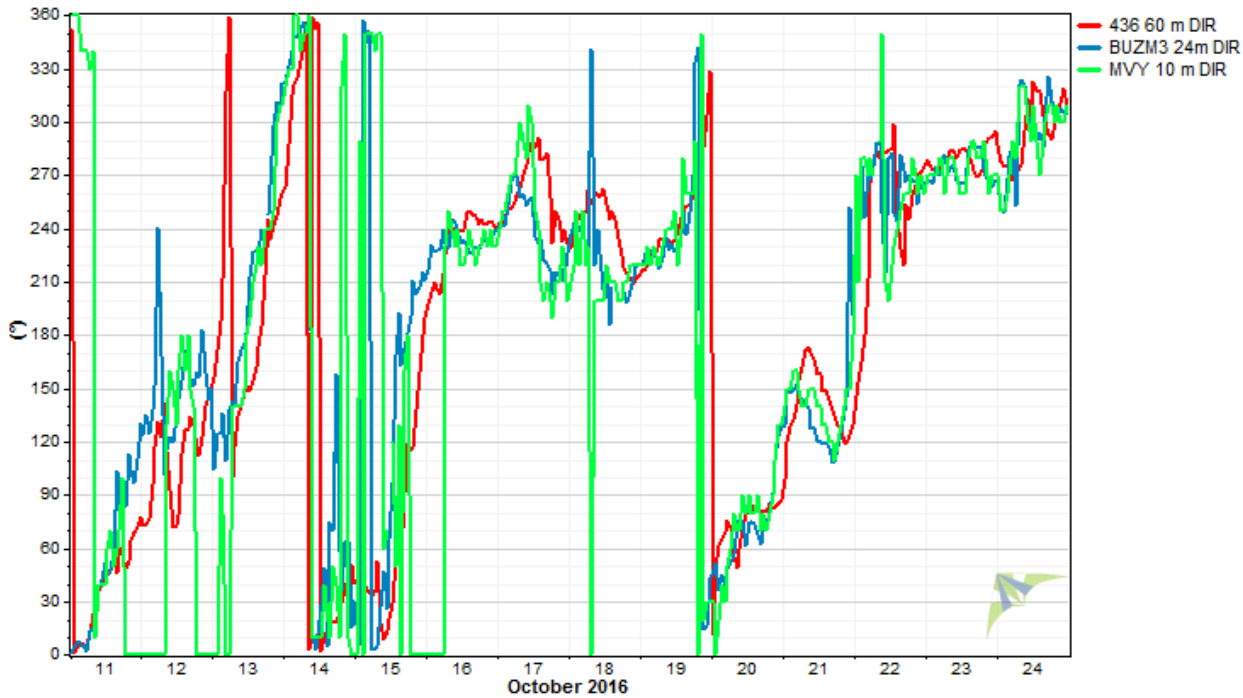

Figure 2.5: Snapshot of Time Series Comparison between Adjusted WLS7 436 (Red), BUZM3 (Blue) and MVY (Green) Hourly Observations

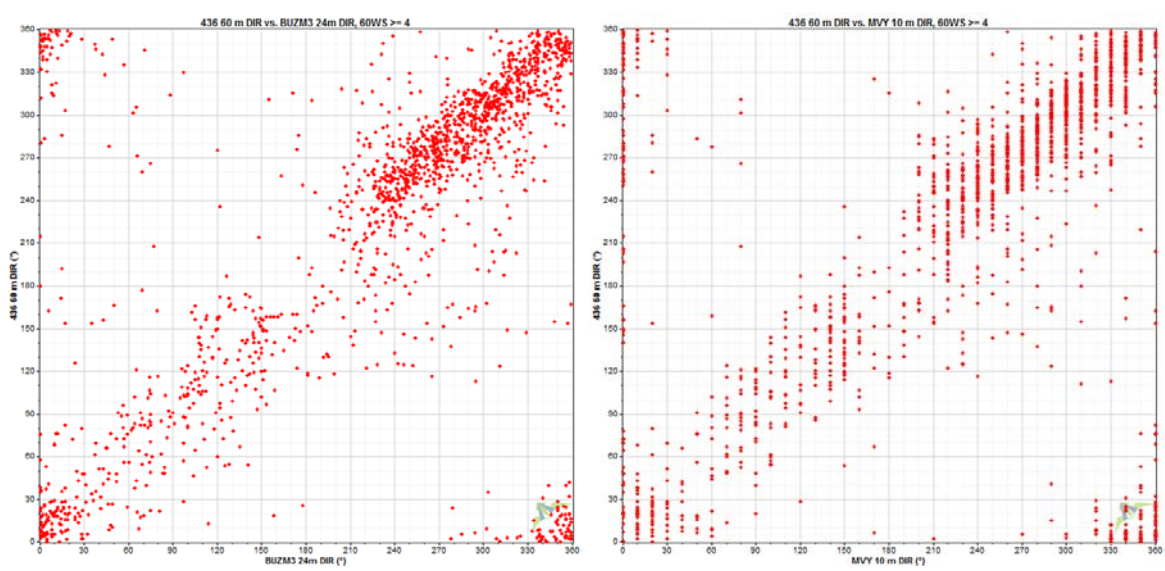

Figure 2.6: Scatter Plot of Adjusted WLS7 436 Direction Readings versus BUZM3 (Left) and MVY (Right), both Screened for Speeds Greater than 4.0 m/s at the Lidar (60 m MSL monitoring level)

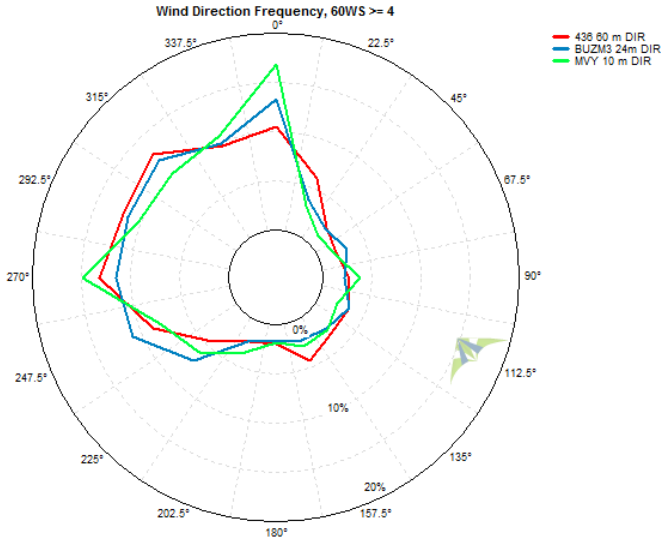

Figure 2.7: 16-sector Wind Rose Comparison Illustrating Adjusted WLS7 436 (Red), BUZM3 (Blue) and MVY (Green) Observations for all Speeds

Additionally, several quantitative metrics verified the offset, including alignment of monthly average wind direction values and minimized average hourly differences between the lidar and reference stations. Based upon these results and the available data on hand, the 60.5° offset will be applied in a post-processing mode to the raw lidar data. The internal offset of the unit will not be adjusted. AWST will re-verify these analyses as the data set grows and additional onsite physical and GPS measurements are collected. A diagram of the station and lidar orientations is presented in Figure 2.8.

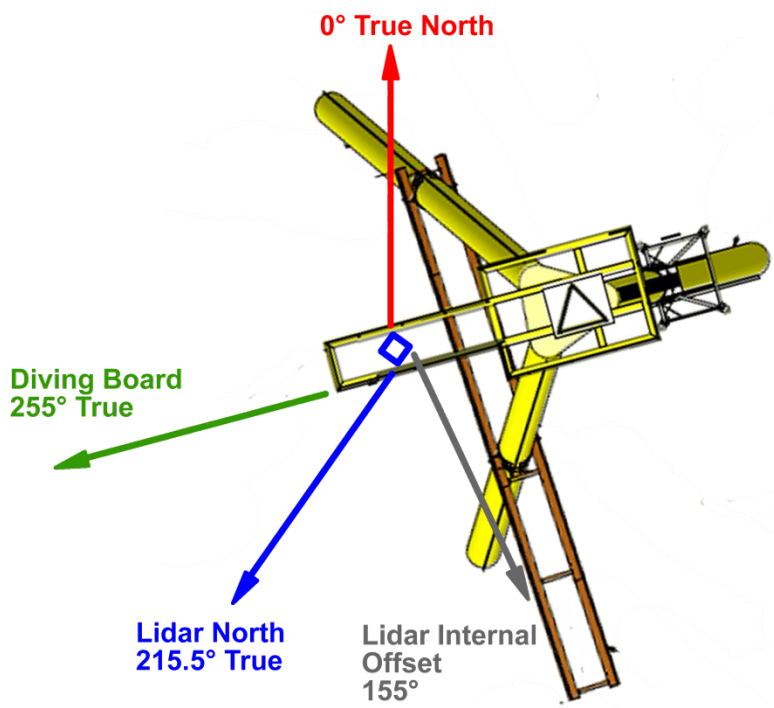

Figure 2.8: Diagram of Estimated WLS7 436 and ASIT Orientations

3. VANE DIRECTION

The ASIT station also has new, standard wind speed and directions measurement equipment mounted on the structure's lattice mast. The sensor package includes two anemometers and a wind vane mounted above the station's Rohn lattice tower on custom booms. AWST's standard data review identified a likely offset in this sensor's measurement when comparing it with the regional reference stations and the adjusted lidar measurements. This analysis suggested that the wind vane data required an offset of approximately 10° to bring it into alignment with these other data sources.

Several potential causes of offset were identified and examined, including processing within the data logger and/or the WHOI data system, errors in onsite alignments, or variations in actual ASIT orientation from station drawings. After consultation with WHOI personnel about the configuration of the ASIT mast, sensors and data logger, AWST determined that no offset was added to the vane data in the data logger or the downstream data system. Through that interaction, AWST also learned that the alignment of the wind vane's north indicator was originally set using the faulty assumption that the tower diving board orientation was 245° True. The diving board's actual orientation was independently assessed to be approximately 255° True. This difference, considered with the balance of the commissioning information for the station, identified the most likely source of the vane offset.

AWST tested the 10° offset in a similar fashion as the lidar measurements described above. This adjustment brought the vane measurements into alignment with regional observations and the collocated lidar measurements. It will be added as a post-processing adjustment, similar to the lidar's. This orientation will also be re-verified during subsequent site visits and data collection.

4. SUMMARY

AWST, the Metocean Initiative team members and Stakeholders identified offsets in the raw wind direction readings from the ASIT station's lidar (WLS7 436) and new 200 P wind vane. Additional physical measurements and GPS readings from the station supported estimation of the lidar's actual orientation of approximately 215.5° True. Integration of this bearing with the system's approximate internal offset of 155° yielded a necessary post-processing adjustment of approximately +60.5°. Analysis of ASIT documentation and the GPS-measured diving board orientation (approximately 255° True) resulted in a vane offset of approximately +10°. Both of these adjustments were verified with concurrent regional reference station observations. These estimated sensor orientations and offsets are summarized in Table 2.2 below. AWST recommends that the data streams are not altered. The station commissioning forms have been updated and all adjustments should be conducted in post-processing. These findings will be re-verified after additional data collection and site measurements.

Table 2.2: Summary of ASIT WLS7 436 and 200P Orientation and Offset Estimates

Sensor	Sensor Orientation (°TN)	Internal Offset* (°)	Post-Process Offset (°)
WLS7 436 Lidar	215.5	155	+60.5
200 P Wind Vane	10.0	0	+10.0

*: Rounded value of lidar internal offset used in calculation due to variation in the offset; under investigation