Correlation of SODAR and Meteorological Tower Measurements

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CORRELATION OF SODAR AND MET TOWER MEASUREMENTS

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Disclaimer:

Table of Contents

Table of Figures

Table of Tables

Table of Equations

CORRELATION OF SODAR AND MET TOWER MEASUREMENTS

Introduction

This data correlation project was undertaken as part of a larger assessment project that aims to further development of wind energy on former surface-mined land in West Virginia. The study area is located in the vicinity of historical surface mine operations in northeastern West Virginia.

The project utilized a Second Wind Triton Sonic Detection And Ranging (SODAR) unit to compare measured wind speed and direction data with the same data collected by a nearby meteorological (met) tower located in northeastern West Virginia. This report compares the correlation of wind speeds recorded by the SODAR unit and nearby met tower 1111 during a three week period from November 10, 2010 until December 1, 2010. For guidance in analyzing the data, two recent comparison reports were modeled (Scott, Elliott and Schwartz 2010, Walls 2010). Two main correlations will be calculated:

- Wind speed data
- Wind direction data.

Both the met tower and the SODAR unit recorded wind speed measurements at varying heights during this three week time frame. Three reading heights, at 40, 50 and 60 meters, were logged by both measurement units, while the SODAR unit measured wind speeds at additional taller heights. However, due to the layout of the site, the SODAR unit had to be placed slightly downhill from the met tower and was therefore was positioned about 14 meters lower than the ground level of the met tower.

The following measurement heights were paired to compensate for the 14 meter height difference and will be used for the correlations.

Table 1 Measurement Heights

SODAR Height	Met Tower Height	SODAR Difference
50m	40m	-4m
60m	50m	-4m
80m	60m	+6m

Met tower 1111 has both a Northwest and South anemometer reading at the 60 meter height. For the purpose of the correlation, the average of these two anemometers will be used after calibration, as described below.

Time Zone and Time Lag Configuration

Wind speed measurements documented by met tower 1111 were recorded in Eastern Standard Time (EST). In contrast, wind speed measurements documented by the SODAR unit were recorded in Universal Standard Time (UST). For this reason, the times provided in the original data set for the SODAR unit prior to the end of Daylight Savings Time (DST) were decreased by four hours. As DST ended at 2:00 AM EST on November 7, 2010, the SODAR unit time records needed to be decreased by an additional hour. Therefore, times provided in the original data set for the SODAR unit during the specified time period have been decreased by a total of five hours to be consistent with EST recordings.

Also, both the SODAR unit and the met tower record wind speed data at 10 minute intervals. However, a lag in time reporting exists. The timestamp for the SODAR unit records the time at the end of the 10 minute period while the met tower timestamp records the time at the beginning of the 10 minute period. Therefore an 11:00 AM EST reading for the SODAR corresponds to a 10:50 AM EST reading for the met tower.

The SODAR unit was located near met tower 1111 from 2:20 PM EST on November 10, 2010 until December 1, 2010 at 12:40 PM EST. Due to the lag in time reporting, the correlation will follow this time period with the met tower reading beginning at 2:10 PM EST on November 10, 2010.

Met Tower Configuration

Calibration calculations for slope and offsets for the Northwest and South anemometers at the 60 meter height on the met tower were made. The calibration calculation is illustrated in Equation 1.

Equation 1 Met Tower Calibration Calculation

$$vCal = \frac{v - 0.78}{1.711} \quad slopeCal \times 2.237 \quad + \; offsetCal \times 2.237$$

Where:

- $vCal$ represents the calibrated speed in MPH
- v represents the recorded wind speed in MPH
- $slopeCal$ represents the slope calibration value
- $offsetCal$ represents the offset calibration value.

The following table provides the slope and offset calibration values for each anemometer.

Table 2 Anemometer Calibration Values

Anemometer	Slope Calibration Value	Offset Calibration Value
Northwest	0.758	0.39
South	0.76	0.37

Wind speeds recorded by the met tower, measured in miles per hour (MPH), also had to be adjusted and converted to match the SODAR's wind speed reading of meters per second (m/s). After the calibrations were made, a conversion factor of 0.44704 m/s was applied to the met tower's MPH readings for consistency.

Site Layout and Typical Conditions

The SODAR was located 680 feet away from the met tower at an elevation 46 feet (14m) lower than the tower. The immediate site was an open field located within an immature wooded area. Scattered large and small trees surrounded the site. Several trees with heights of 60 to 65 feet were located between 57 and 92 feet away from the SODAR unit. Second Wind recommends siting a Triton no closer to trees than three times their height due to the potential for the trees to cause some wind speed averages to be echo-affected (Second Wind 2009). However, the density of the foliage in the area made tree removal impractical for this project.

Data Filtering

Filtering Wind Speed Data

Before measurements from the met tower were correlated with the SODAR data readings at the three measurement heights, both sets of data were filtered. The SODAR unit data was sorted to remove any observation in which a wind speed measurement was not taken or was equal to zero.[1] Similarly, the met tower data was sorted to remove observations in which a wind speed measurement was not taken or was equal to zero,[2] and was subjected to an additional filter to remove any observations which read less than 0.5 m/s. Because the calibration offset on a typical anemometer is approximately 0.35 m/s, the purpose of this additional filter is to ensure that the documented reading is greater than the value of the offset (Scott, Elliott and Schwartz 2010).

Filtering Wind Direction Data

Additional correlations were conducted to compare wind direction (in degrees) for the SODAR unit and the met tower. For these correlations, wind direction values recorded by the met tower were only available at the 50 and 60 meter heights and are compared to the 60 and 80 meter SODAR readings, respectively. Similar to the wind speed correlations discussed in the previous section, the wind direction correlations follow the same time reporting period. The same low wind speed observations removed from the wind speed correlations were removed from this data set to maintain consistency. Any observation in which a wind direction was not recorded for either the met tower or the SODAR unit was omitted.

Wind direction data was also adjusted to account for readings in the northern direction sector. A reading of 1° compared to a reading of 359° is, in actuality, only 2° different. However, comparing the base numbers of one and 359 will skew the reading in determining the correlation coefficient. Therefore, any observations limited to the northern direction sector where the difference between the SODAR and met tower readings is less than 45° were adjusted by 360°. The following equation was used to determine the 45° difference:

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[1] In any instance where one observation for either the met tower or SODAR unit was removed, the entire observation for that 10 minute interval was removed to maintain a consistent number of observations for each height and wind speed measurement.

[2] As a result of the calibration of the Northwest and South anemometers on the met tower, some values which were originally recorded as 0 MPH were converted to 0.3 m/s. These observations were also removed from the correlations.

Equation 2 Determining 45° Difference

$$Difference = 360 - S_A + MT_A$$

Where:

- S_A represents SODAR direction reading A
- MT_A represents met tower direction reading A.

This equation calculates the difference between a large SODAR unit observation and a small met tower observation. The same equation was used by replacing the S_A and MT_A variables to calculate the difference between a large met tower observation and a small SODAR unit observation.

The following example illustrates this adjustment in detail.

Assume that for Observation A the met tower direction was 13° and the SODAR unit direction was 340°. Inserting these values into the difference equation:

$$Difference = 360 - 340 + 13 = 33° < 45°$$

Because the difference is less than 45°, 360° will be added to the met tower direction reading so that the new observation value is 373°. The same method is also used to adjust small SODAR unit readings compared to large met tower readings.

Overall SODAR Performance

The operational uptime of the SODAR unit was 99.97 percent. This resulted in gross data recovery of 3,014 observations out of a possible 3,015 observations over the three week time period. The met tower did not record wind speeds for one continuous period of 6 hours and 20 minutes during the three weeks.

The percentage of valid data versus height available for correlation at the three heights of comparison is shown below, before and after filtering. The 90 percent quality level is shown, as that is the level chosen for this correlation.

Table 3 Percentage of Valid Data versus Height, at 90% Quality

Height	Data Count Unfiltered		Data Count Filtered	
	# Obs	%	# Obs	%
40 m	2,941	98	2,894	96
50 m	2,975	99	2,931	97
60 m	2,972	99	2,930	97

Correlation Results

The following subsections illustrate the relationship between the SODAR unit and met tower measurements on the basis of wind speed and wind direction.

Wind Speed Correlation Results

After configuring and filtering the wind speed data, the correlation coefficients and number of observations were calculated for each measurement height. The results of these calculations are provided in the following table.

Table 4 SODAR v. Met Tower Wind Speed Correlation Results

Height	Coefficient	Data Count
40m	0.9604	2928
50m	0.9632	2930
60m	0.9673	2861

The correlation coefficients calculated for all three measurement heights demonstrate that the SODAR unit and met tower wind speed readings are highly correlated.

Figures 1 through 3 illustrate a graphical representation of the data used for each correlation.

Figure 1 SODAR v. Met Tower 1111 Wind Speed at 40m

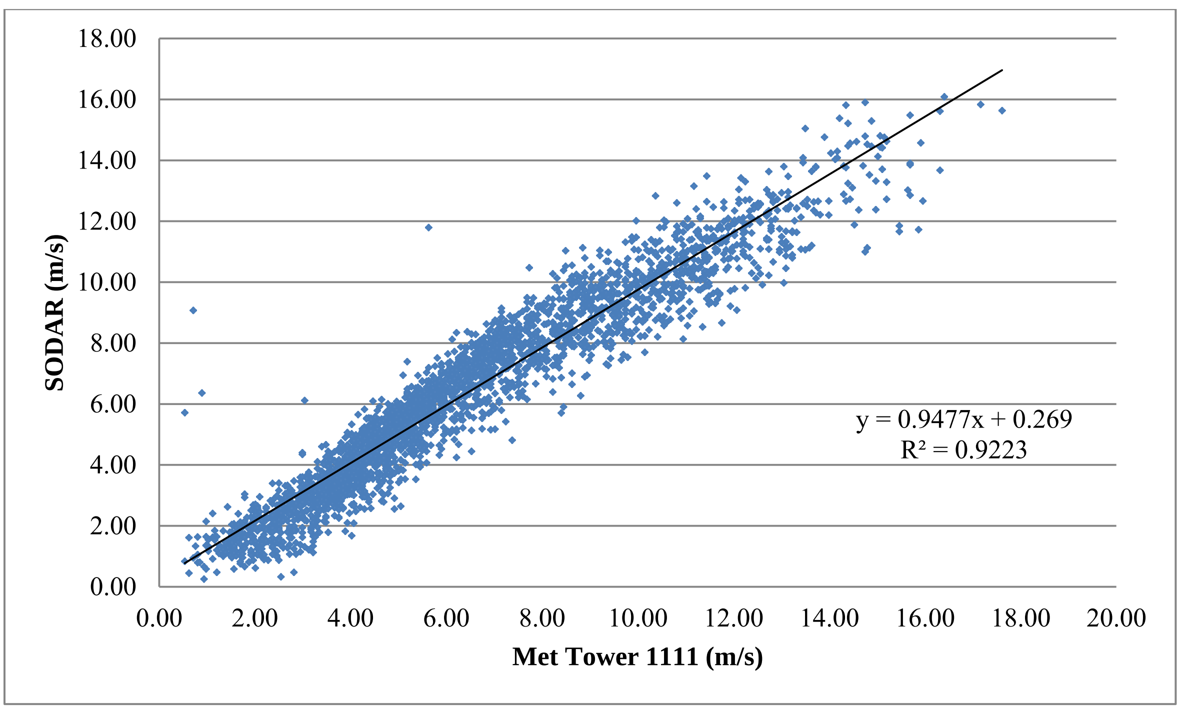


Figure 2 SODAR v. Met Tower 1111 Wind Speed at 50m

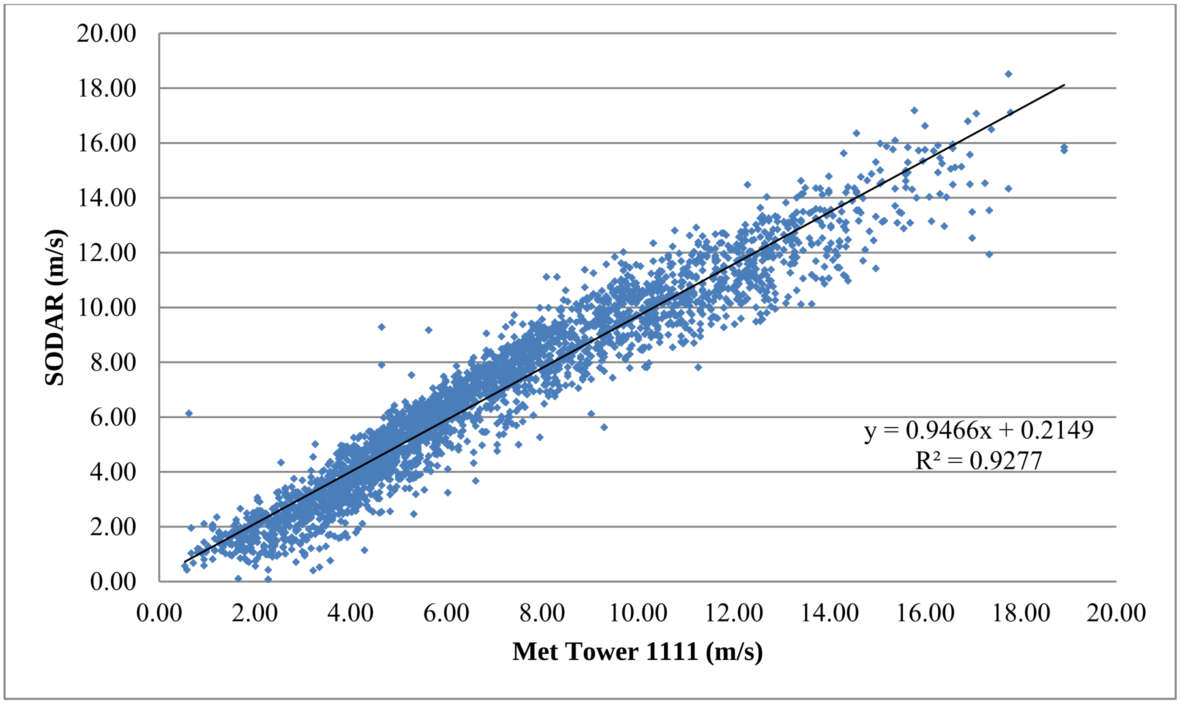
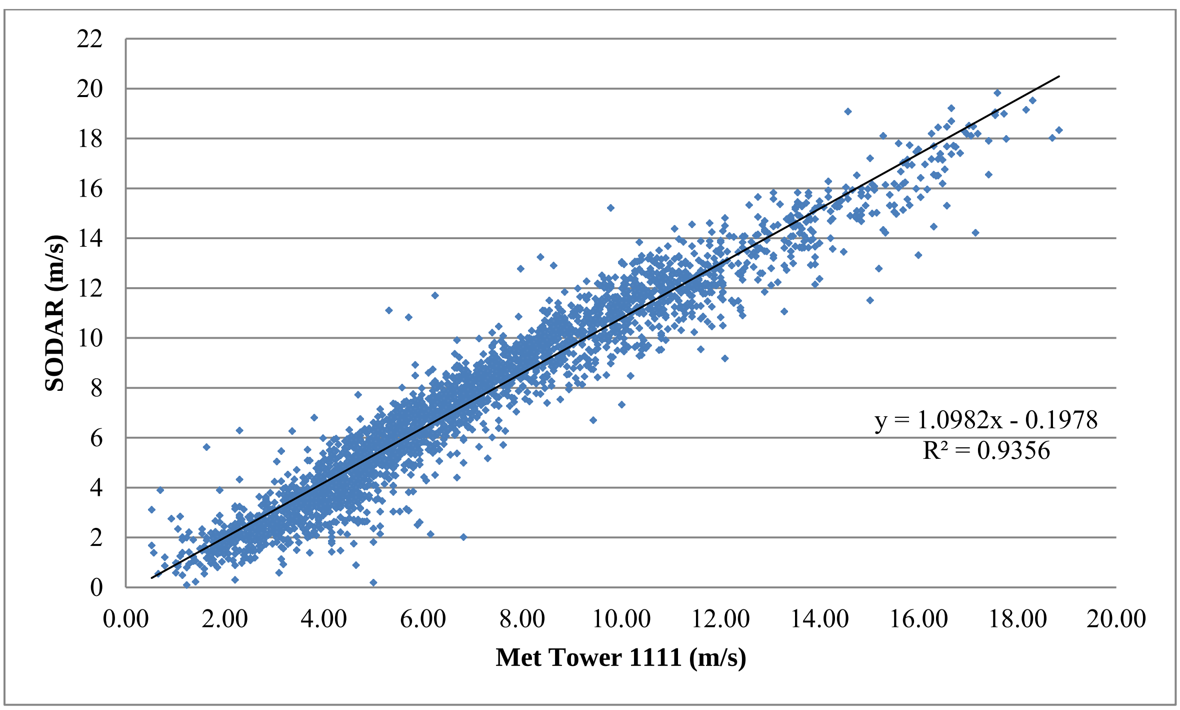


Figure 3 SODAR v. Met Tower 1111 Wind Speed at 60m



Wind Direction

After configuring and filtering the wind direction data, the correlation coefficients and number of observations were then calculated for each measurement height. The results of these calculations are provided in the following table.

Table 5 SODAR v. Met Tower Wind Direction Correlation Results

Height	Coefficient	Data Count
50 m	0.9719	2930
60 m	0.9519	2861

Both correlation coefficients at the 50 and 60 meter heights demonstrate that the SODAR unit and met tower wind direction readings are highly correlated. Wind direction data was not available from the met tower at 40 meters.

Figures 4 and 5 provide a graphical representation of the data used for each correlation.

Figure 4 SODAR v. Met Tower 1111 Wind Direction at 50m

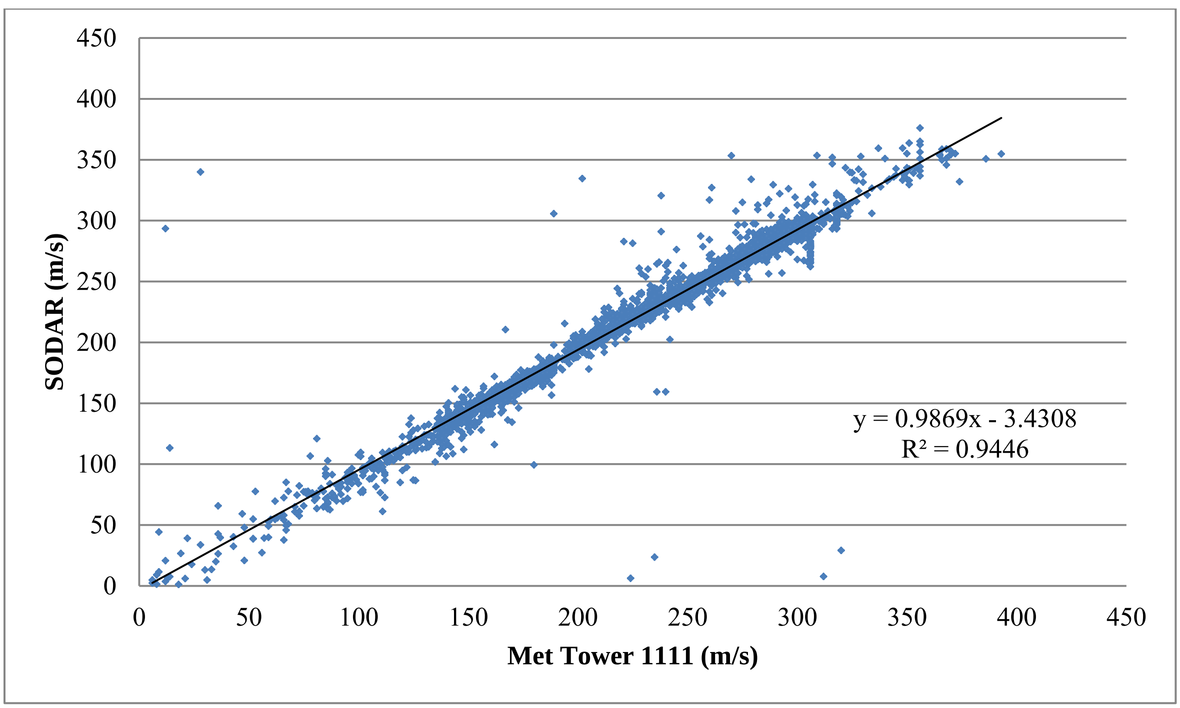
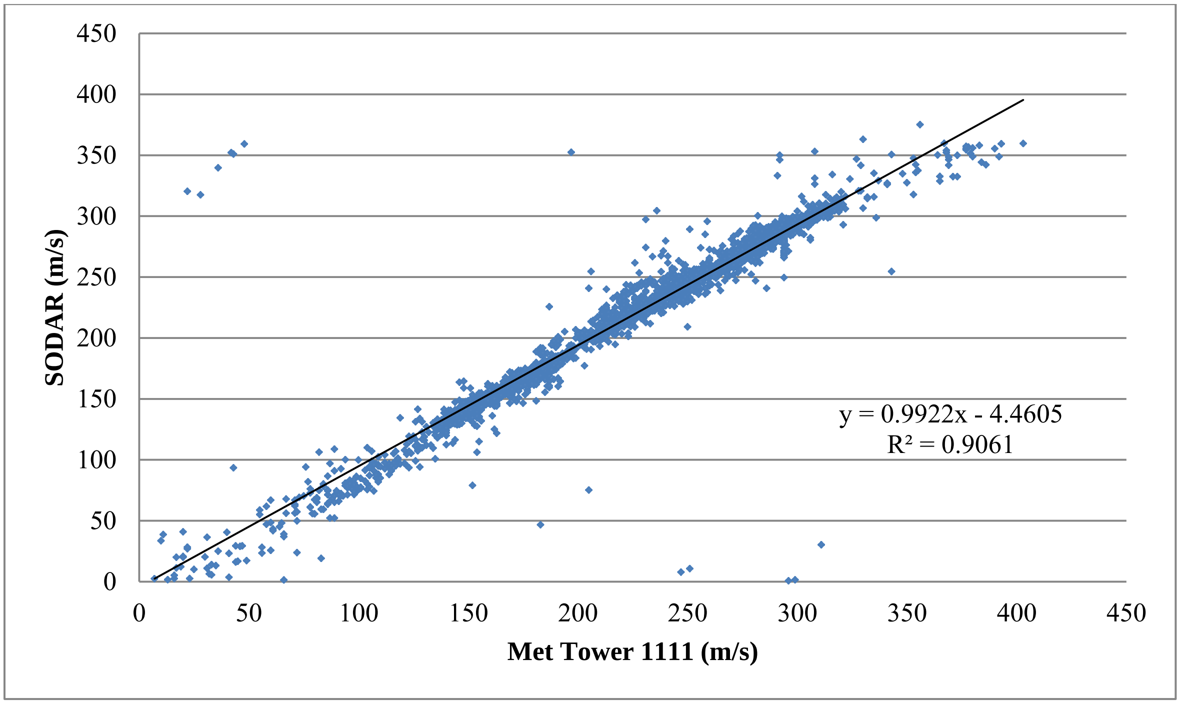


Figure 5 SODAR v. Met Tower 1111 Wind Direction at 60m



Wind Distribution

Wind rose charts were also created to illustrate wind direction distributions between the SODAR unit and met tower 1111. These distributions are provided in Figures 6 and 7.

Figure 6 Distribution of Wind Direction at 50m

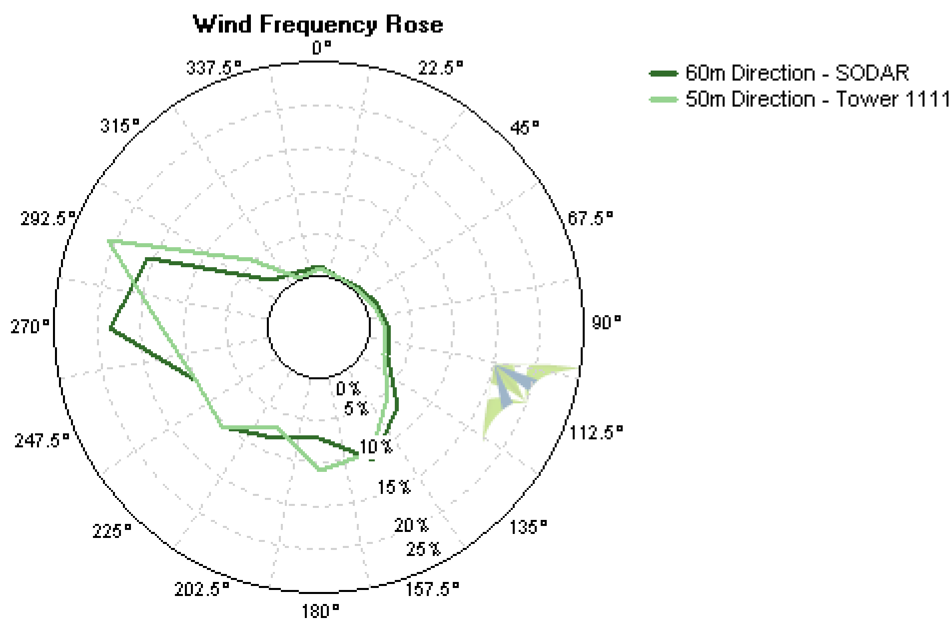
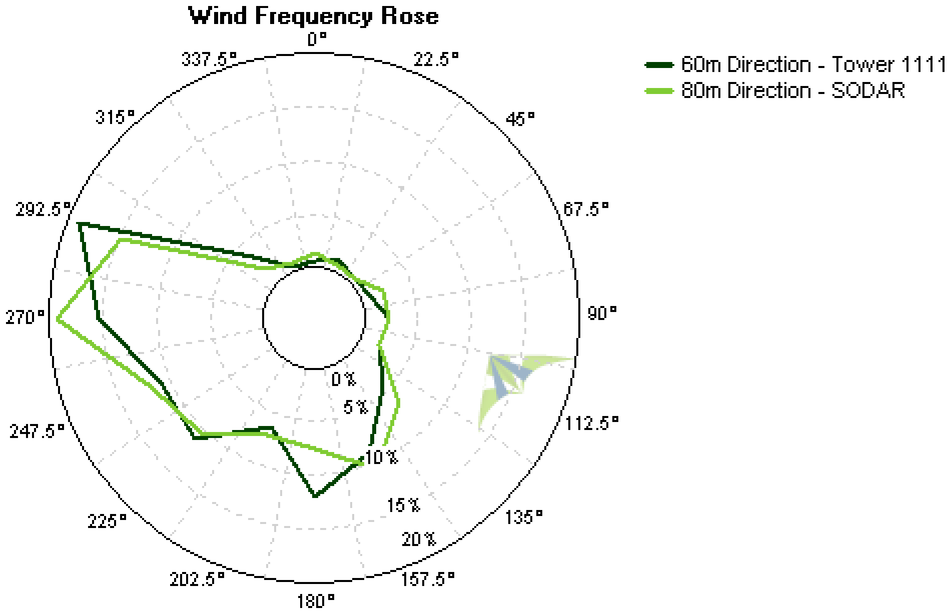


Figure 7 Distribution of Wind Direction at 60m



Average Wind Speed Comparison

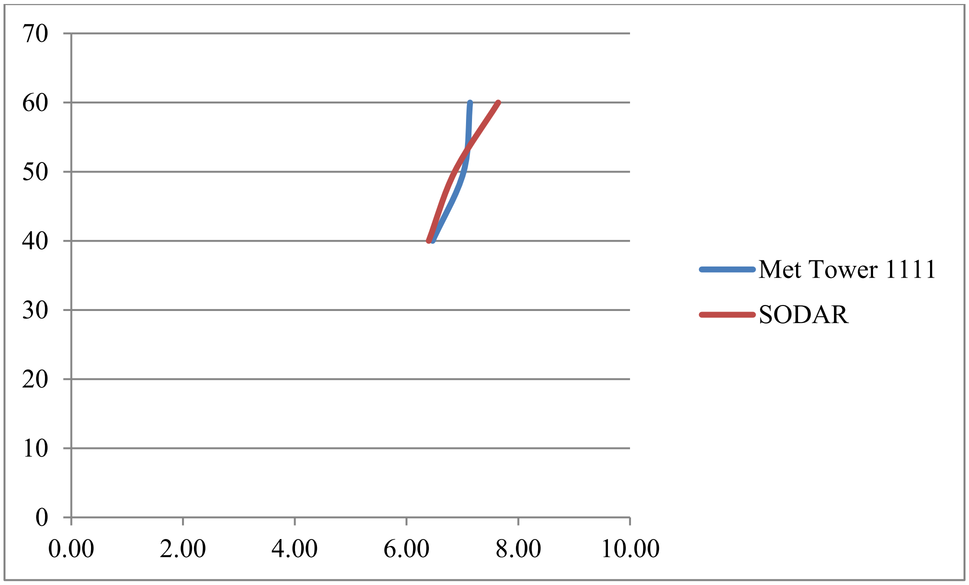
Average wind speeds were calculated for the three measurement heights to further examine the SODAR unit and met tower wind speed readings. The same time period and data set used for the correlation were studied. The following table provides the average wind speeds and differences by measurement height.

Table 6 Average Wind Speeds

Height	Met Tower	SODAR	Difference
40m	6.47	6.40	0.07
50m	7.02	6.86	0.16
60m	7.14	7.64	-0.50

Consistent with the wind speed correlations, the average wind speeds of the met tower and SODAR unit at each measurement height were very similar. The largest difference occurred with the 60 and 80 meter correlation where the SODAR unit recorded an average wind speed that was 0.5 m/s faster than the met tower. This difference could be explained by the larger height difference of 6 meters after taking into account the 14 meter base height difference. This data is also illustrated in Figure 8.

Figure 8 Average Wind Speeds for SODAR and Met Tower 1111 Readings



Conclusions

The results of the correlations demonstrate that the SODAR unit and met tower are highly correlated with respect to wind speed and direction measurements. Further illustration of the relationship between the SODAR unit and met tower wind direction distributions using wind roses also shows very consistent measurement readings.

References

Scott, G., D. Elliott, and M. Schwartz. *Comparison of Second Wind Triton Data with Meterological Tower Measurements.* Technical Report, Golden: National Renewable Energy Laboratory, 2010.

Second Wind. "Guidelines for Siting a Triton by Met Towers, Trees and in Complex Terrain." User Manual, 2009.

Walls, Liz. *Guidelines for Triton Data Analysis and Comparison to Nearby Met Tower Measurements, rev. 3.1.* Secondwind, 2010.