

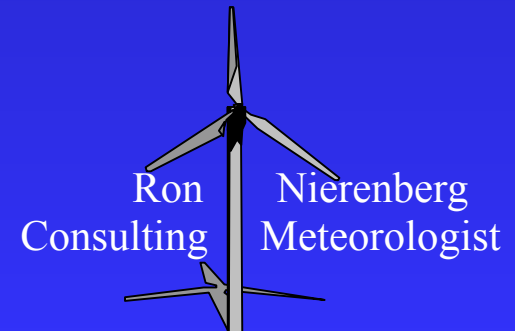
Testing and Validation of the Triton Sodar

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AWEA Resource Assessment Workshop

Ron Nierenberg, Consulting Meteorologist

Liz Walls, Second Wind Inc.



Sodar (Sonic Detection and Ranging) Background

- Sodar has been used for over 30 years.
- Sodars emit high frequency acoustic signals in (usually) three consecutive directions.
- After every chirp, some acoustic energy is backscattered due to changes in the refractive index of air => returned signal is measured.
- The spectral energy from each height of interest is analyzed.
- The shifted frequency is determined after every chirp and the wind speed is calculated.
- After ten minutes, the average wind speed is calculated in each beam direction and the vector wind speed can then be found.

Introduction

- Second Wind brought a new low power consumption sodar to the market at the end of 2007 called Triton.
- A validation study was set up at 7 locations with Tritons co-located with conventional meteorological towers.
- Results in this study are based on current configuration of Triton.
- Results reported here may be representative of the advanced Sodars on the market today.
- Correlation coefficients to met towers averaged 0.98.
- Data recovery at met tower heights was 99%.
- Data recovery at 120m (typical top of rotor height) was 87%.

Outline

- Description of Each Sodar Validation Site
- Operational Uptime
- Sodar Correlation to Anemometers
- Average Wind Speeds: Sodar vs Tower
- Valid Data vs Height
- Wind Shear Exponent and Wind Shear Profile Comparison
- Wind Direction Distribution Comparison
- Interim Results of BAO (Boulder Atmospheric Observatory) Tall Tower Study

SODAR Validation Sites

Site	Description	Tower Height, m	Start date	End date	Number of days
Tehachapi, CA	Complex, Hilly	58	30-May	1-Sep	94
Kansas	Flat field	60	28-May	1-Sep	96
Wareham, MA	Trees, in cranberry bog	60	15-May	31-Jul	77
Colorado	Flat field	58	25-Aug	2-Sep	8
NREL, CO	Flat field	80	27-May	13-Aug	78
Goodnoe, WA	Hilly, in wind farm	60	30-May	2-Aug	64
BAO, CO	Flat field	200	18-Aug	2-Sep	15

Percent of Operational Uptime

- Average % of uptime = 99 %
- Due to system reliability and low power consumption of ~7 Watts

Site	% Oper. Time
California	98.4%
Kansas	97.4%
Massachusetts	98.6%
Colorado	99.8%
BAO	99.4%
NREL	100.0%
Washington	97.0%

Correlation to Anemometers

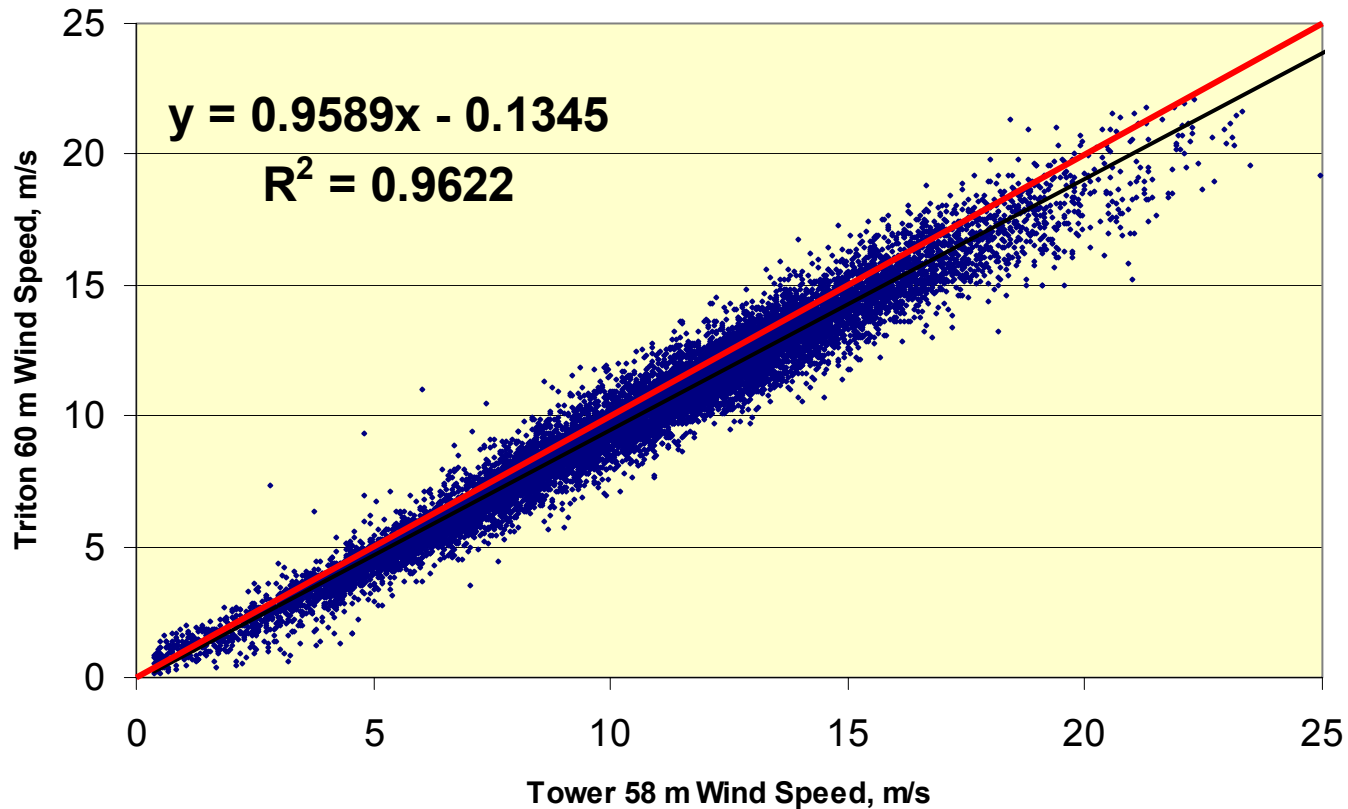
Site	Tower Height, m	Triton Height, m	Correlation Coefficient	Data Count
California	58	60	0.981	13406
Kansas	60	60	0.981	13830
Mass.	60	60	0.969	10527
Colorado	58	60	0.990	1496
BAO	100	100	0.980	1693
NREL	80	80	0.956	10756
Wash.	60	60	0.981	4326
Average:			0.977	

Data Count = # of 10-min averages

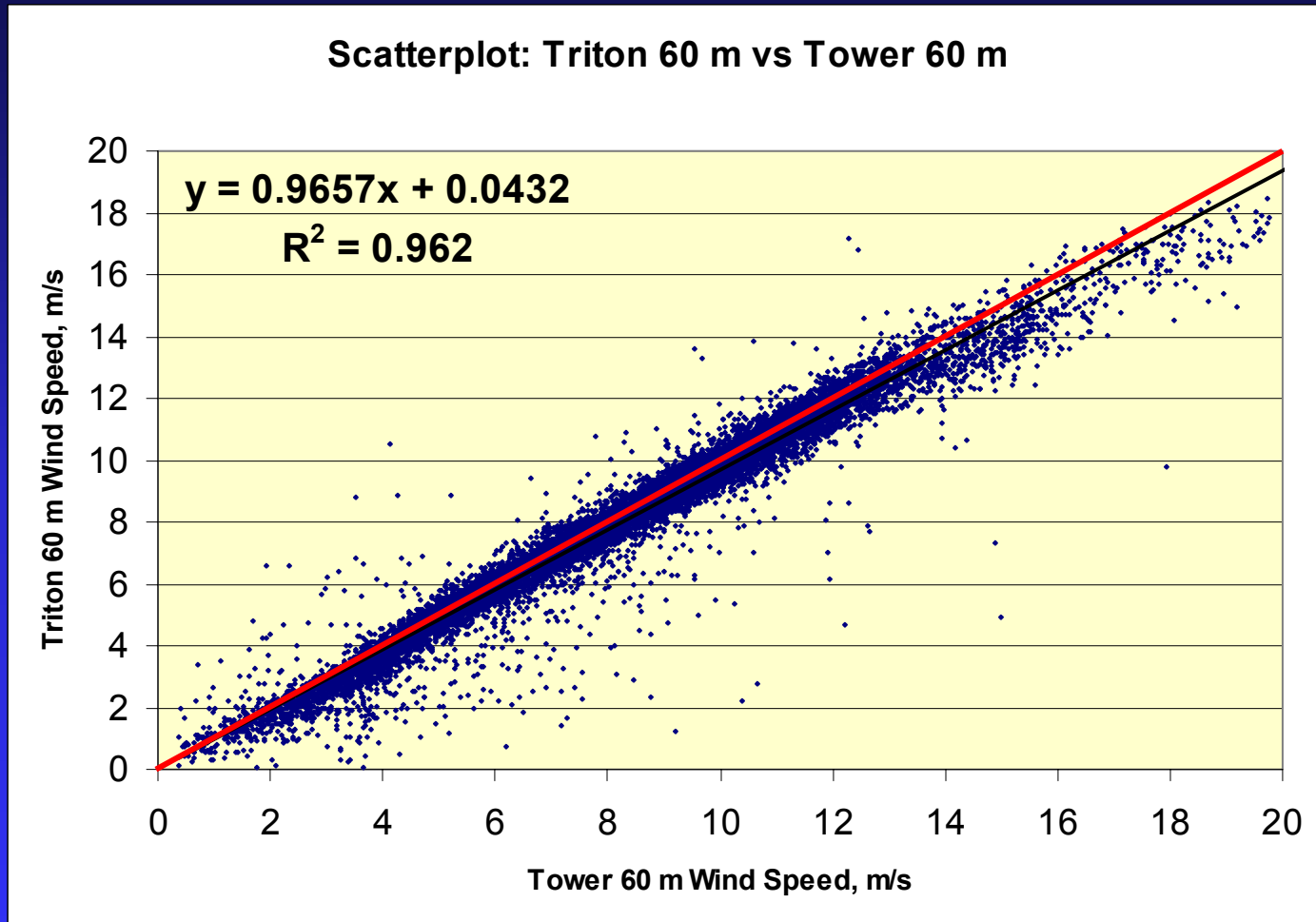
Correlation Coefficients based on 10-min averages

Sodar vs. Tower Data in California

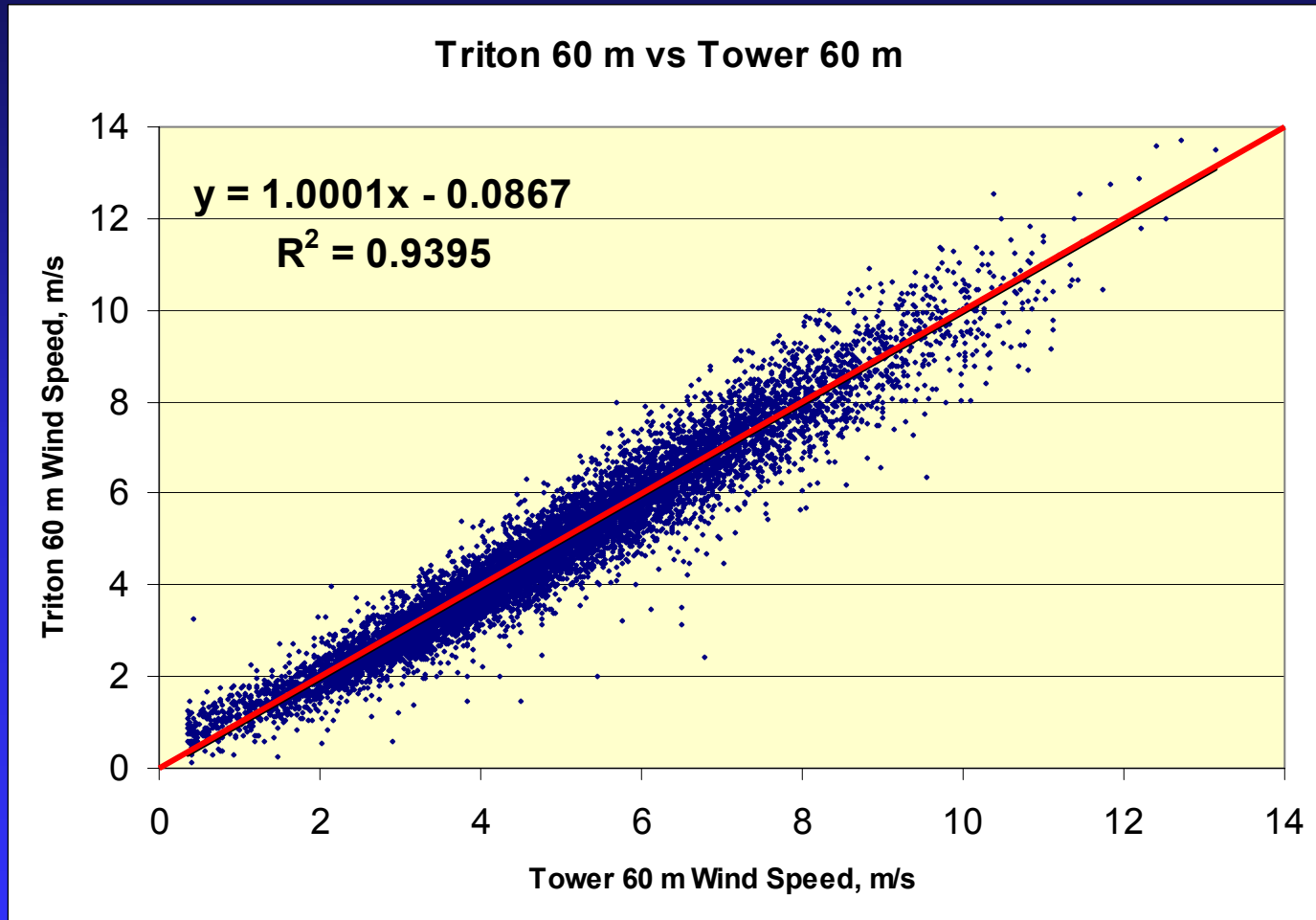
Scatterplot: Triton 60 m vs Tower 58 m



Sodar vs. Tower Data in Kansas



Sodar vs. Tower Data in Massachusetts



Average Wind Speed Comparison

- Differences may be attributed to:
 - ◆ Terrain/Spatial Difference
 - ◆ Vector/Scalar Averaging
 - ◆ Volume Averaging
 - ◆ Anemometer Over-Speeding
 - ◆ Anemometer Off-Horizontal Flow

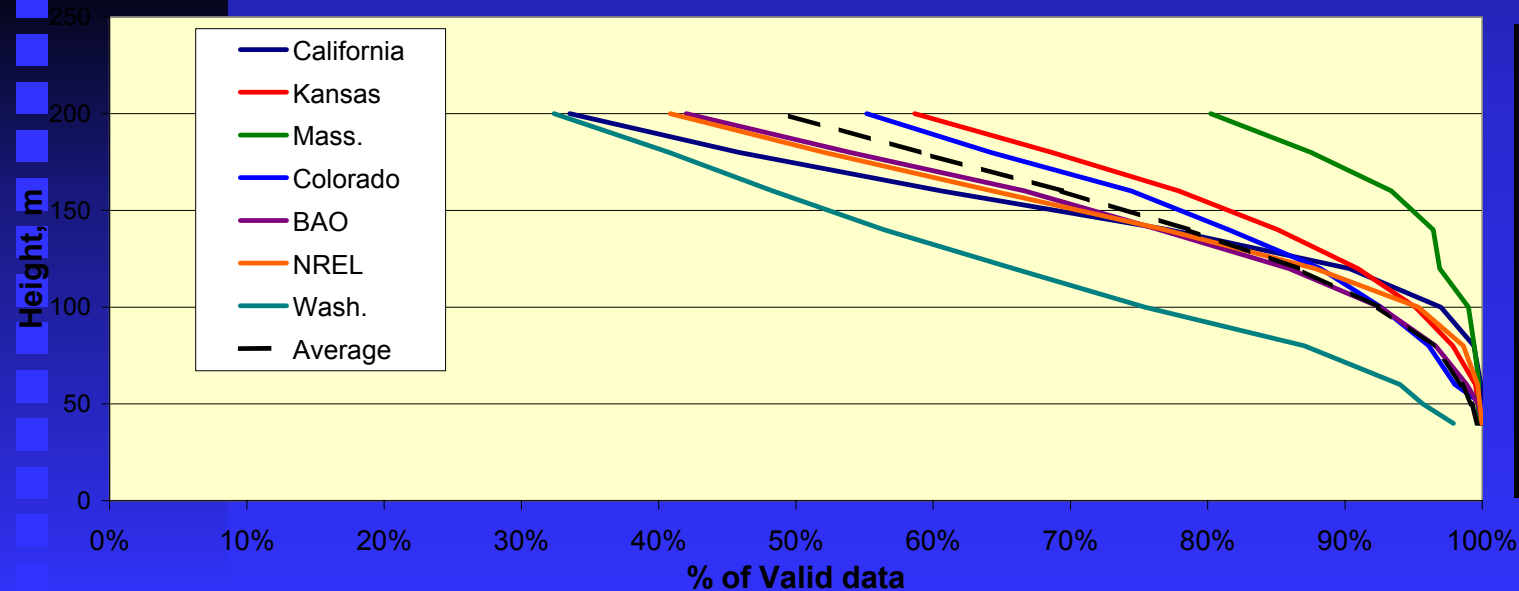
Site	Tower Height, m	Tower Mean Wind Speed, m/s	Triton Height, m	Triton Mean Wind Speed, m/s	% Difference	Data Count
California	58	10.63	60	10.06	-5.4%	13154
Kansas	60	8.21	60	7.97	-2.9%	13342
Mass.	60	4.79	60	4.71	-1.8%	10309
Colorado	58	9.92	60	9.62	-3.1%	1125
BAO	100	4.49	100	4.36	-2.9%	1659
NREL	80	4.56	80	4.24	-7.1%	10756
Wash.	60	6.33	60	5.98	-5.6%	4326
Average					-4.1%	

Triton measurements have NOT been adjusted/corrected

Percent Valid Data vs. Height

- Valid data is a function of a Signal-to-Noise Ratio and number of valid samples within average
- Amount of valid data may be reduced due to ambient noise, low humidity, stable atmospheric conditions (i.e. at night), etc.
- On average, data recovery at 100 m > 90 %

Percent of Valid Data vs. Height



Height	Average
40	99.7%
50	99.2%
60	98.5%
80	96.4%
100	92.4%
120	86.6%
140	78.6%
160	69.4%
180	59.0%
200	49.0%

Wind Shear Exponent Comparison

- Tower exponent found using data from two heights
- Triton exponent found using data from 50 m to 120 m:

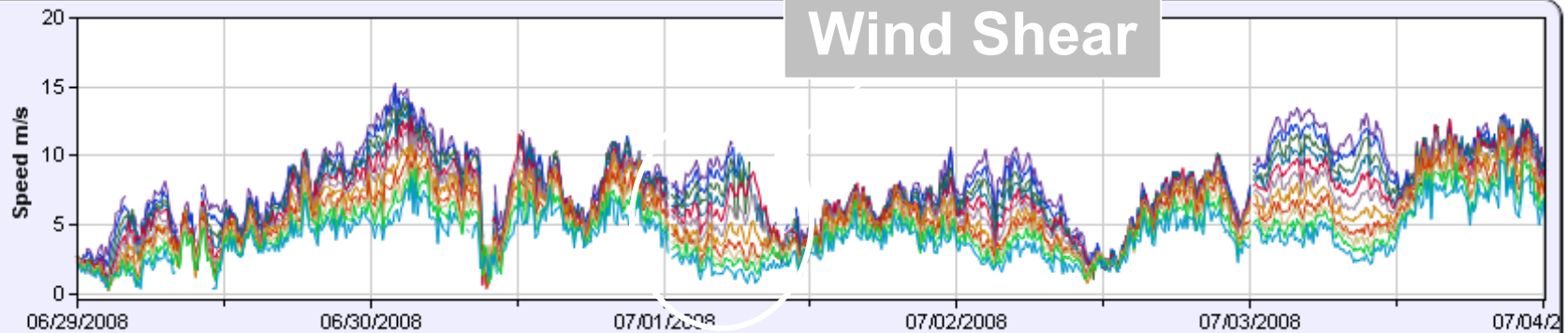
$$\frac{U_z}{U_{z_R}} = \left(\frac{z}{z_R} \right)^\alpha$$

◆ Plot: $\log(U_z/U_{z_r})$ vs $\log(z/z_r)$

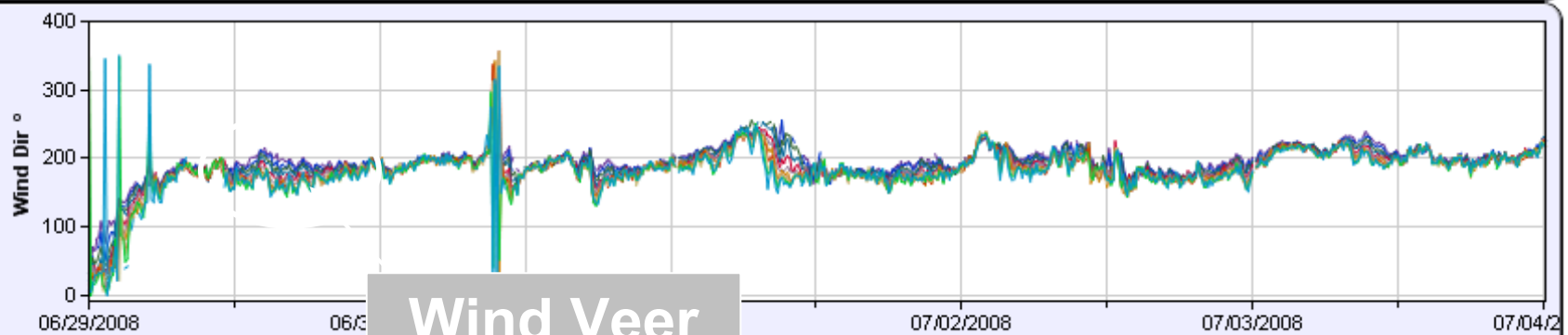
Site	Tower Heights	Triton Overall	Tower Overall	Triton DayTime	Tower DayTime	Triton NightTime	Tower NightTime
California	58 / 33	0.11	0.15	0.05	0.09	0.16	0.20
Kansas	60 / 45	0.20	0.13	0.08	0.01	0.32	0.24
Mass.	60 / 40	0.36	0.45	0.23	0.32	0.52	0.63
Colorado	58 / 40	0.19	0.15	0.05	0.06	0.25	0.24
BAO	100 / 50	0.13	0.16	0.09	0.11	0.17	0.20
NREL	80 / 50	0.06	0.09	0.04	0.06	0.09	0.12
Wash.	60 / 40	0.09	0.11	0.04	0.08	0.15	0.15
Average		0.16	0.17	0.08	0.10	0.24	0.25

Example of Wind Shear and Veer in Massachusetts

Wind Shear



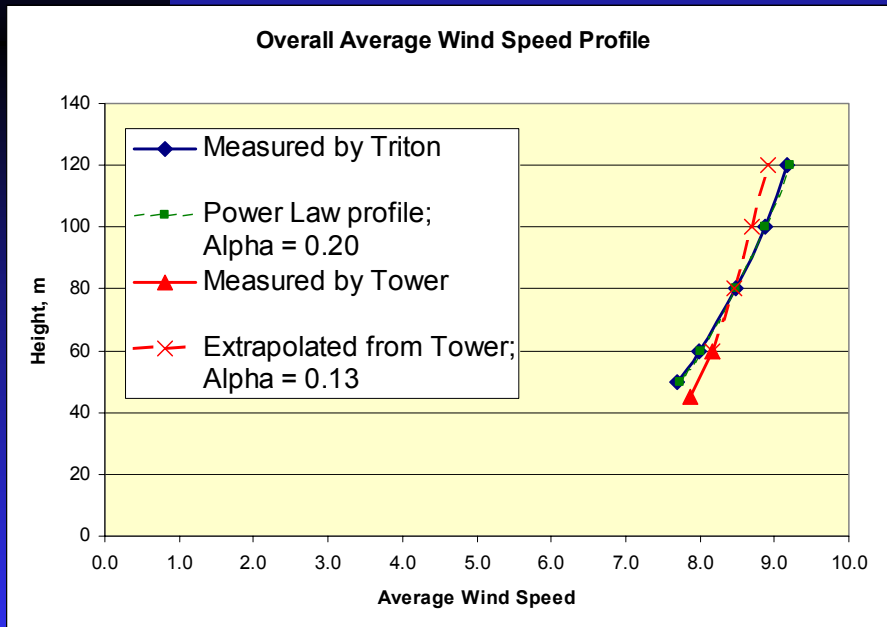
Wind Veer



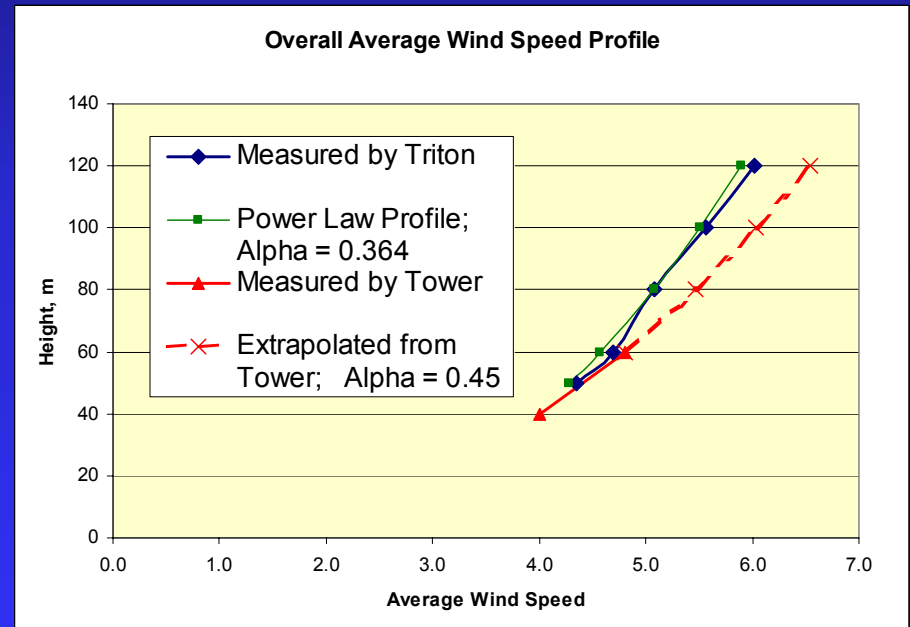
Wind Shear Profile Comparison

- Extrapolating from tower can lead to underestimation or overestimation at upper heights.

Kansas



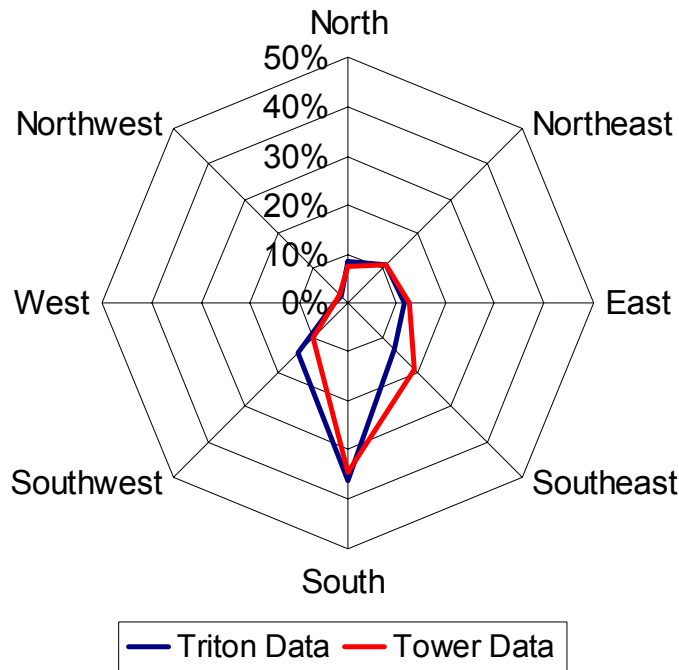
Massachusetts



Wind Direction Distribution Comparison

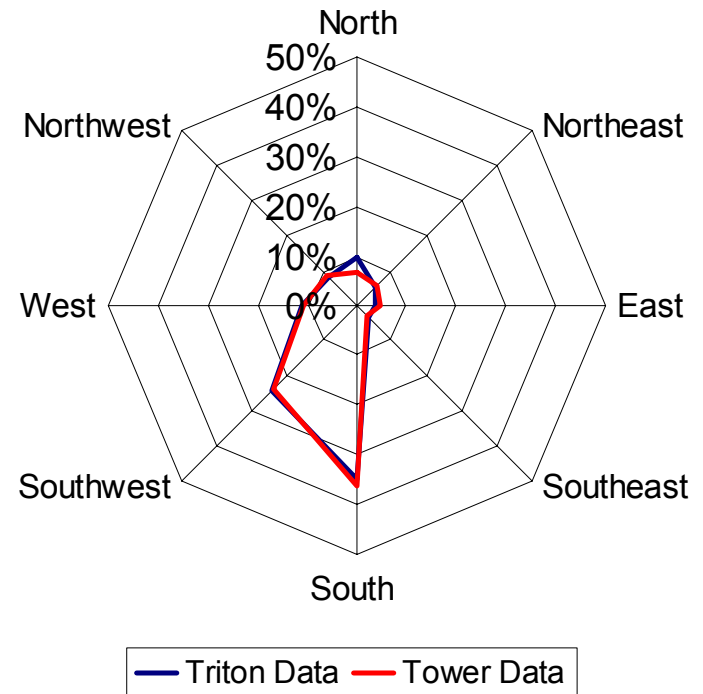
Kansas

Triton vs Tower Wind Rose



Massachusetts

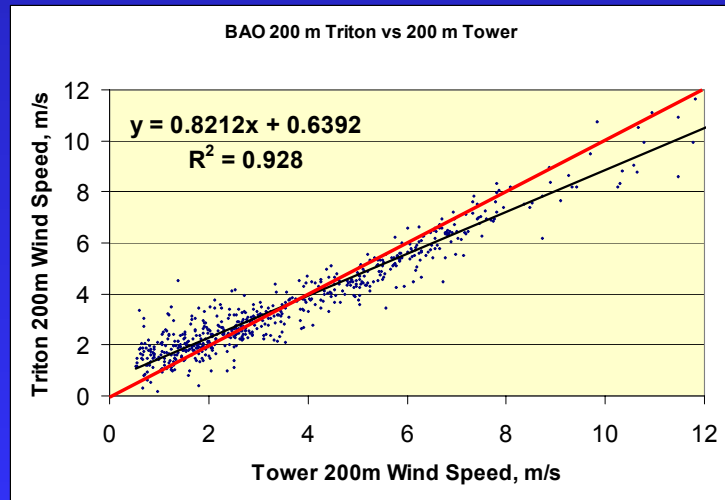
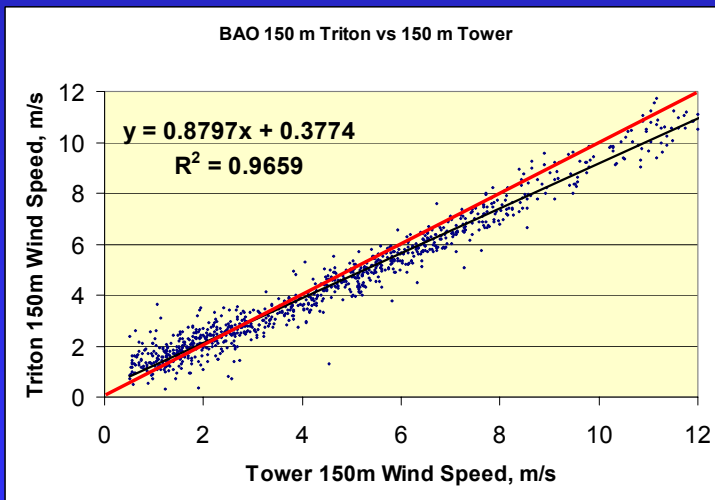
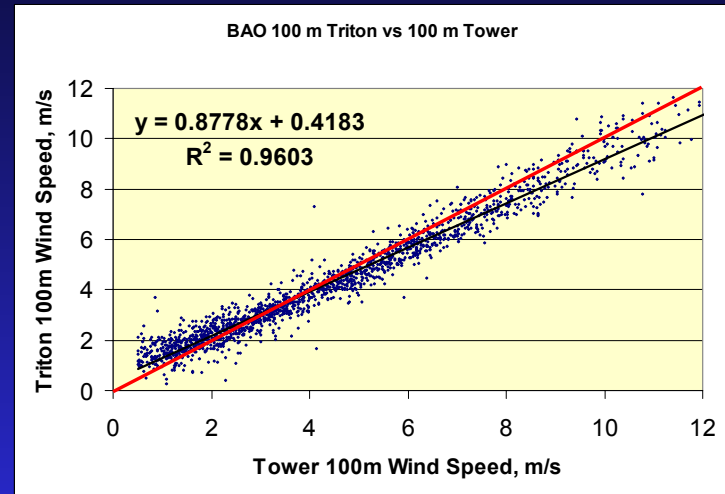
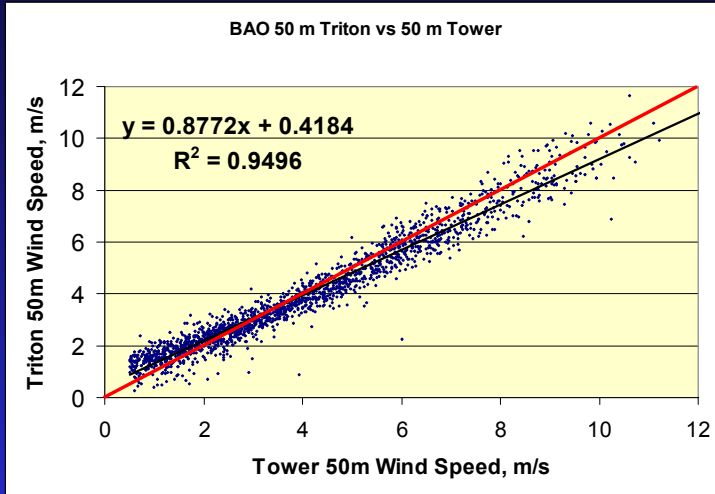
Triton vs Tower Wind Rose



BAO Tall Tower Study

- 300 m Tower at BAO near Boulder, CO
- Anemometers at 50, 100, 150 and 200 m
- Very wide lattice tower (~7 ft with 12 ft booms)
 - ◆ Tower effects on anemometers may be significant
- Data collection began on Aug. 18 and is on-going
- Objectives of study:
 - ◆ Validate sodar data at higher heights
 - ◆ Study the difference between sodar and anemometers at a range of heights

BAO Scatterplots



BAO Correlation

- At all heights, the correlation to the anemometers is very high (> 0.96)
- As more data is collected, we hope to learn more about how anemometer and sodar measurements compare at various heights, wind speeds, wind directions, etc.

Height, m	Correlation Coefficient	Wind Speed Bias	Data Count
50	0.974	-2.0%	1848
100	0.980	-2.9%	1693
150	0.983	-4.1%	958
200	0.963	-1.1%	642

Summary

- Seven validation sites were examined in detail where a Triton collected data adjacent to a met tower
- Average % of operational uptime was ~99%
- Average correlation coefficient to tower data was 0.98
- Average valid data recovery at 100 m > 90%

Summary 2

- Measured shear exponents by Triton and tower were comparable
- Extrapolating from tower data can lead to over- and underestimations at upper heights
- Triton wind direction distributions are consistent with vane data
- BAO tall tower study:
 - ◆ Very high correlation coefficients at all heights (50, 100, 150 and 200 m)
 - ◆ Bias between -4 and -1 %

Conclusions

- Sodar can reliably measure wind speed and direction.
- Sodar can provide data equivalent to met tower data.
- The use of sodar avoids the need for extrapolation thereby reducing uncertainty in wind resource assessment.