

Understanding and Quantifying the Uncertainty in Tower Extrapolation and AEP Estimations Using SODAR

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Abstract summary

As the wind industry continues to grow, larger wind turbines are being installed and higher hub heights are becoming the standard. Some traditional approaches in wind resource assessment have not evolved to take into account this trend. For example, it is common to measure the wind resource with a 60 m met tower, extrapolate to hub height, and then use this extrapolated wind speed distribution to estimate the AEP (Annual Energy Production). There are two sources of uncertainty in this approach: the extrapolation to hub height and the use of only hub height data in the AEP estimation, while ignoring effects such as wind shear. The purpose of this study is to quantify the uncertainty of this approach to AEP estimation with the use of SODAR data.

Objectives

1) To quantify the uncertainty in the AEP estimation when extrapolating from 40 - 60 m to 80 m hub height using the **power law** profile in various terrain types.

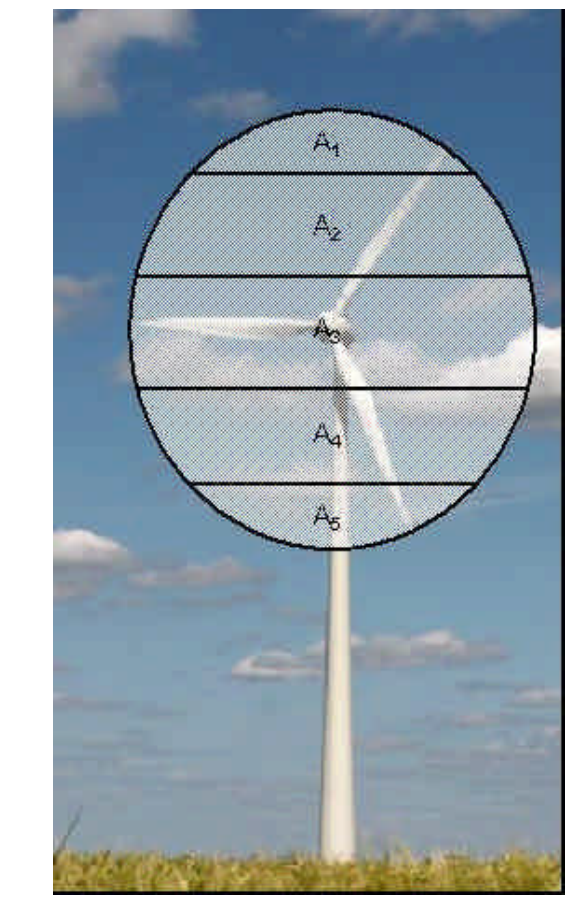
$$\text{Power Law Profile} \\ U(z) = \left(\frac{z}{z_r} \right)^a$$

2) To quantify the uncertainty in the AEP estimation when extrapolating from 40 - 60 m to 80 m hub height using the **log law** profile in various terrain types.

$$\text{Log Law Profile} \\ U(z) = \frac{U^*}{k} \ln \left(\frac{z}{z_0} \right)$$

3) To quantify the uncertainty in the AEP estimation when neglecting to take into account wind shear across the rotor.

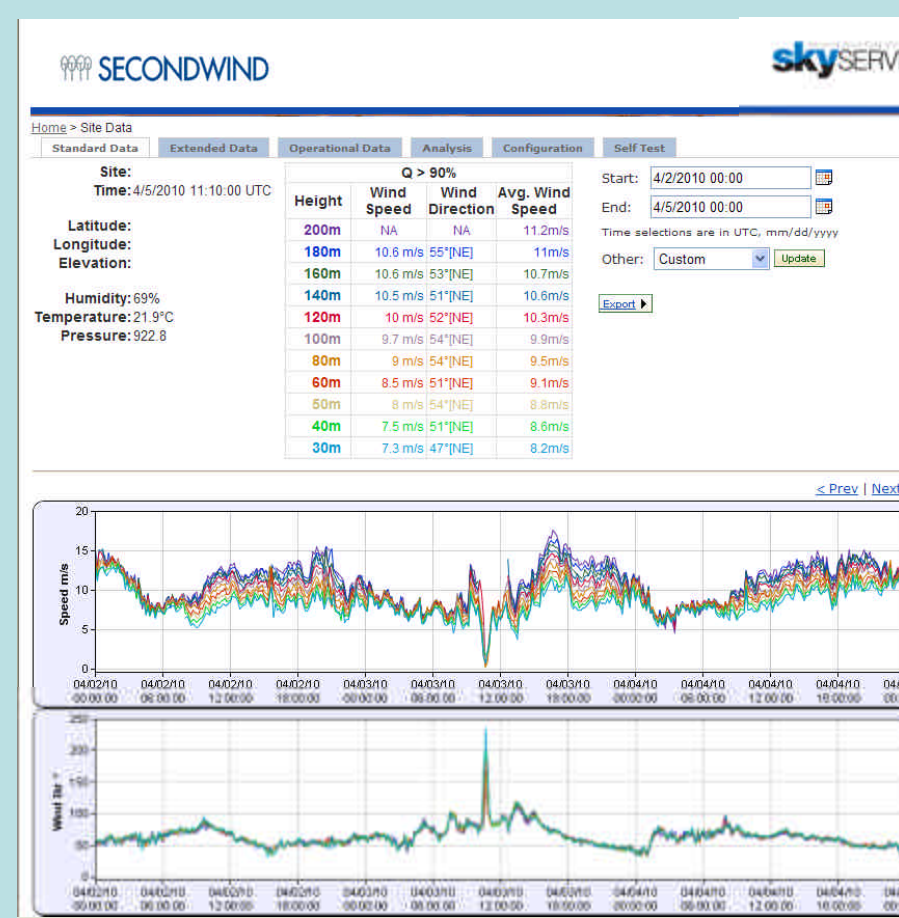
$$\text{Equivalent Hub Height Wind Speed} \\ U_{eq} = \frac{\sum U_i A_i}{A}$$



Methodology

1) Triton Data from 111 sites worldwide were downloaded from SkyServe™ and filtered based on:

- Min. Quality factor = 90 %
- Vertical wind speed = +/- 1.5 m/s



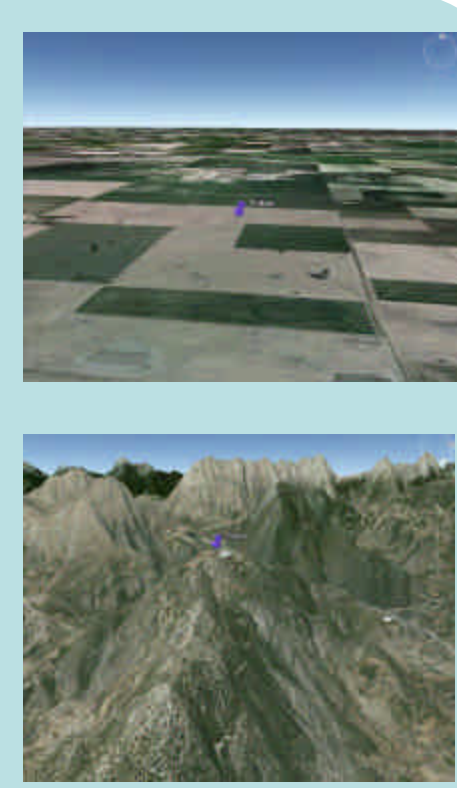
Description of 111 Triton Data Sets

Sites Across the Globe:

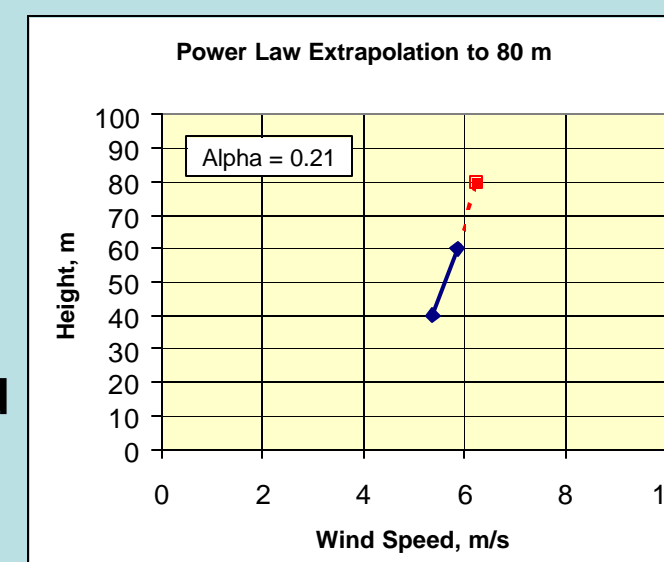
- 81 sites in North America
- 16 sites in Europe
- 14 sites in Australia and New Zealand

Variety of Terrain Types:

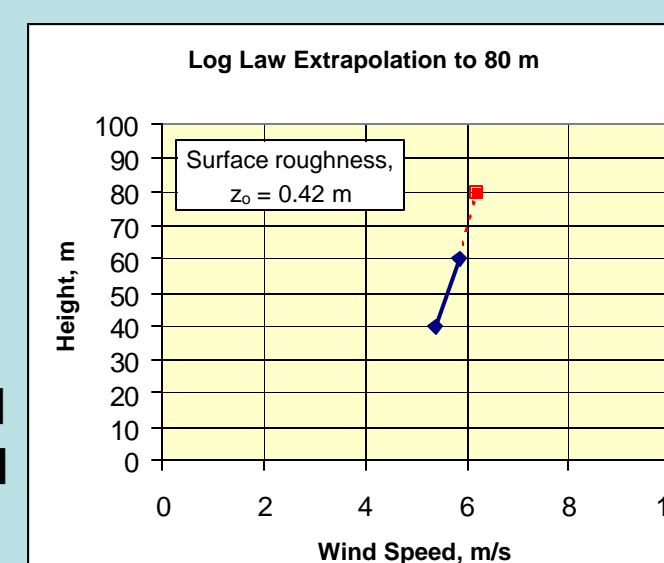
- 44 sites in flat terrain
- 17 sites in forested areas
- 48 sites in hilly terrain or on ridgelines
- 2 coastal sites



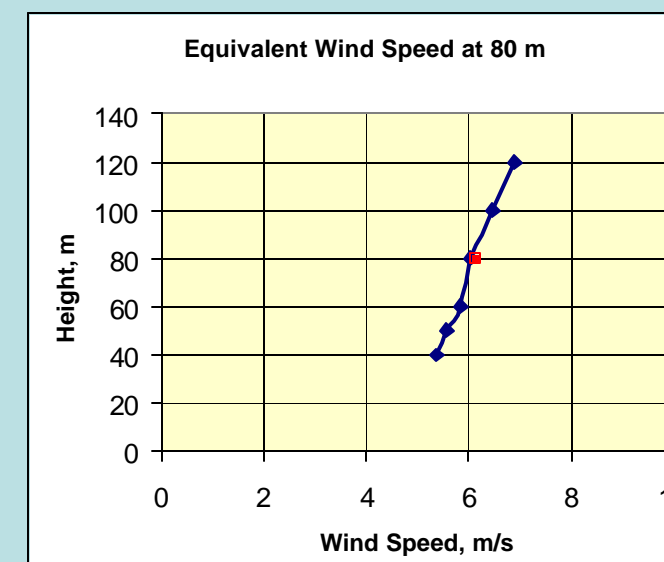
2a) Using 40 and 60 m Triton wind speeds, at every 10-minute interval, calculated power law exponent and extrapolated to find 80 m wind speed



2b) Using 40 and 60 m Triton wind speeds, at every 10-minute interval, calculated surface roughness length and extrapolated to find 80 m wind speed

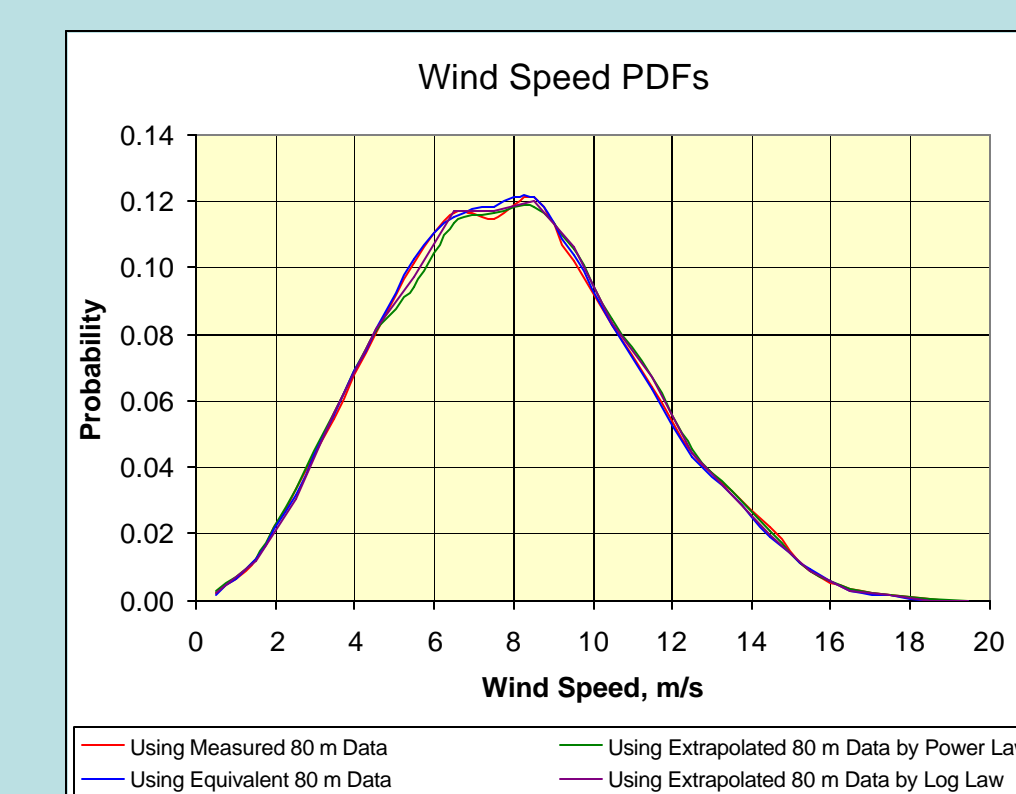


2c) Using Triton wind speeds from 40 to 120 m, at every 10-minute interval, calculated the equivalent hub height wind speed



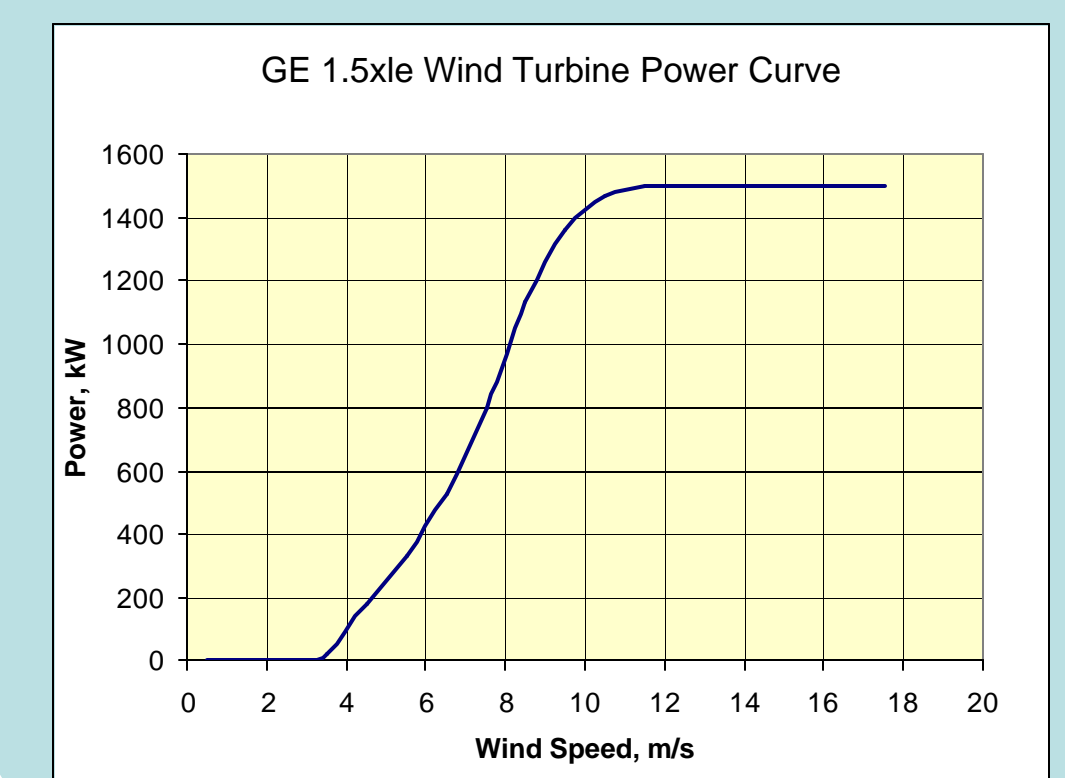
3) Compiled data and determined 80 m wind speed probability density functions (PDFs) based on:

- Measured 80 m wind speeds
- Extrapolated 80 m wind speeds (Power law)
- Extrapolated 80 m wind speeds (Log law)
- Equivalent 80 m wind speeds



4) With the four PDFs, calculated the annual energy production (AEP) using GE 1.5 xle power curve.

$$AEP = \left[\sum_{j=1}^{N_j} Prob(U_j) \times Power(U_j) \right] \times 8760 \text{ h}$$

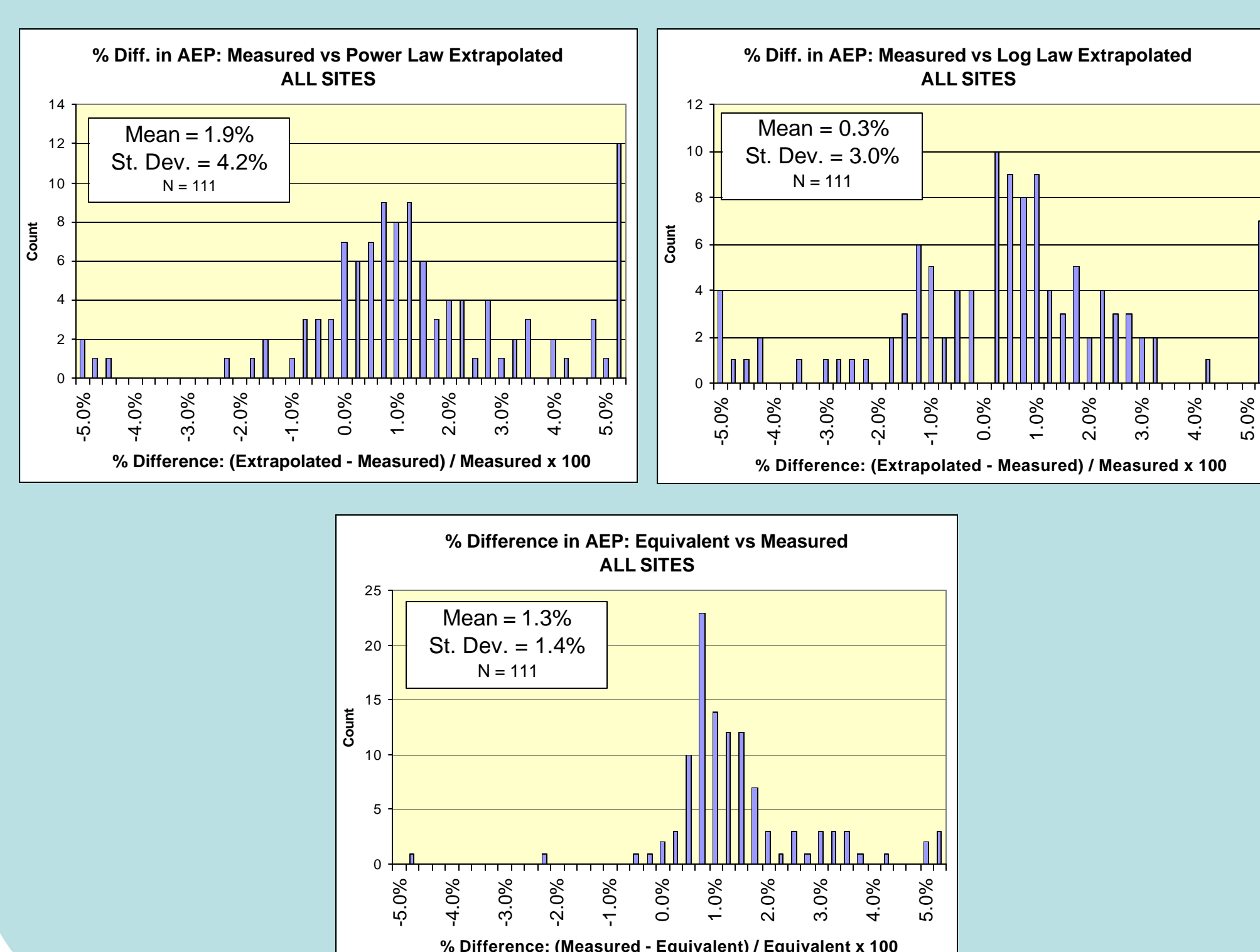


5) For 111 sites, compared the AEP difference:

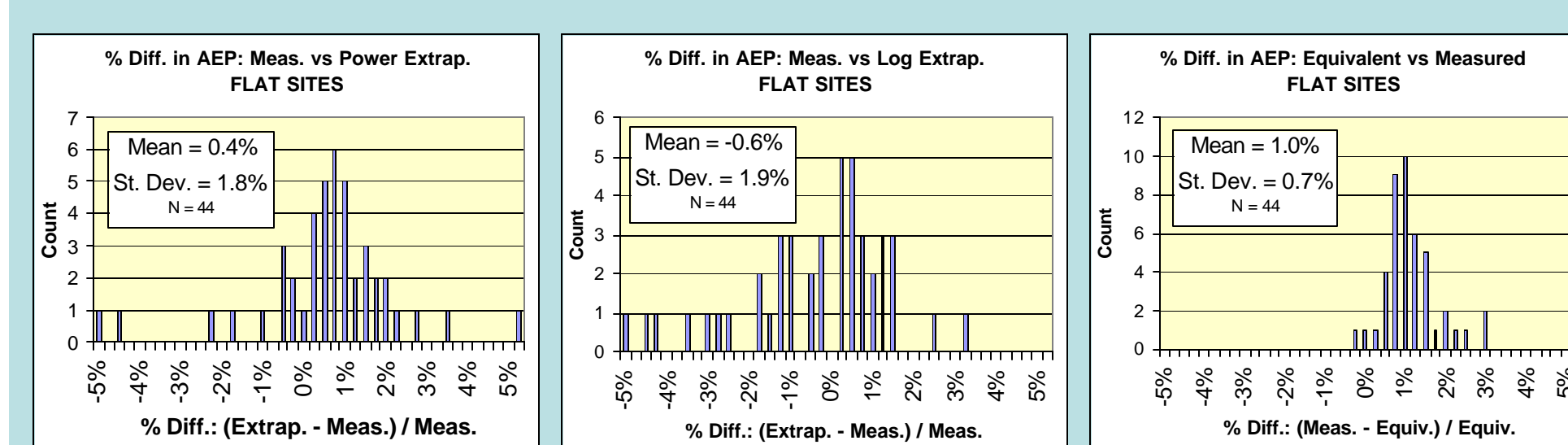
- Measured vs. Power Law Extrapolated
- Measured vs. Log Law Extrapolated
- Equivalent vs. Measured

Results

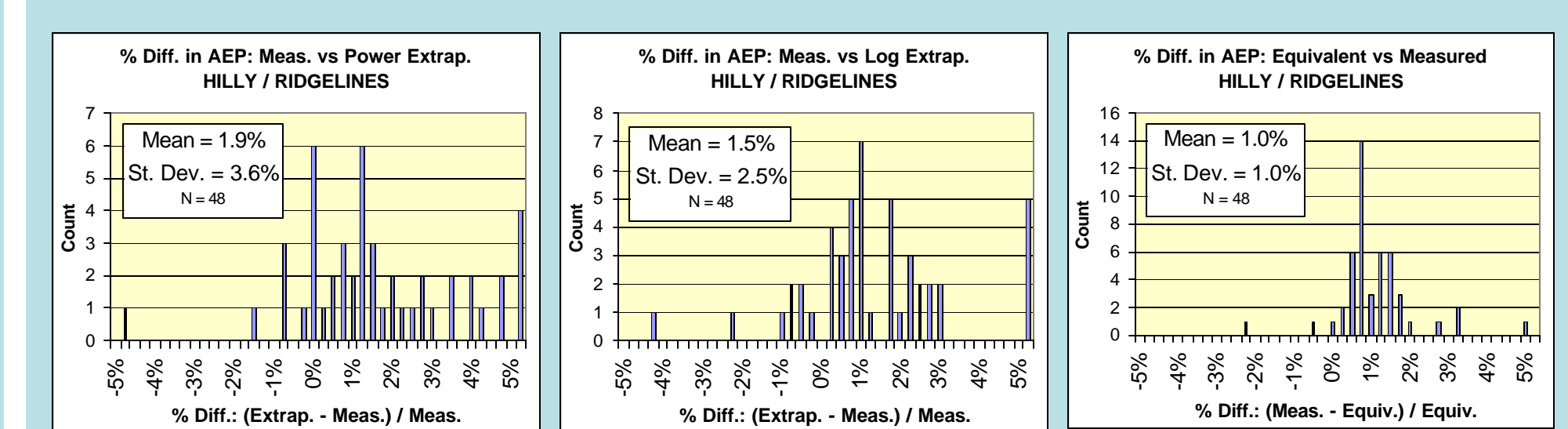
Results of AEP Comparison: ALL SITES



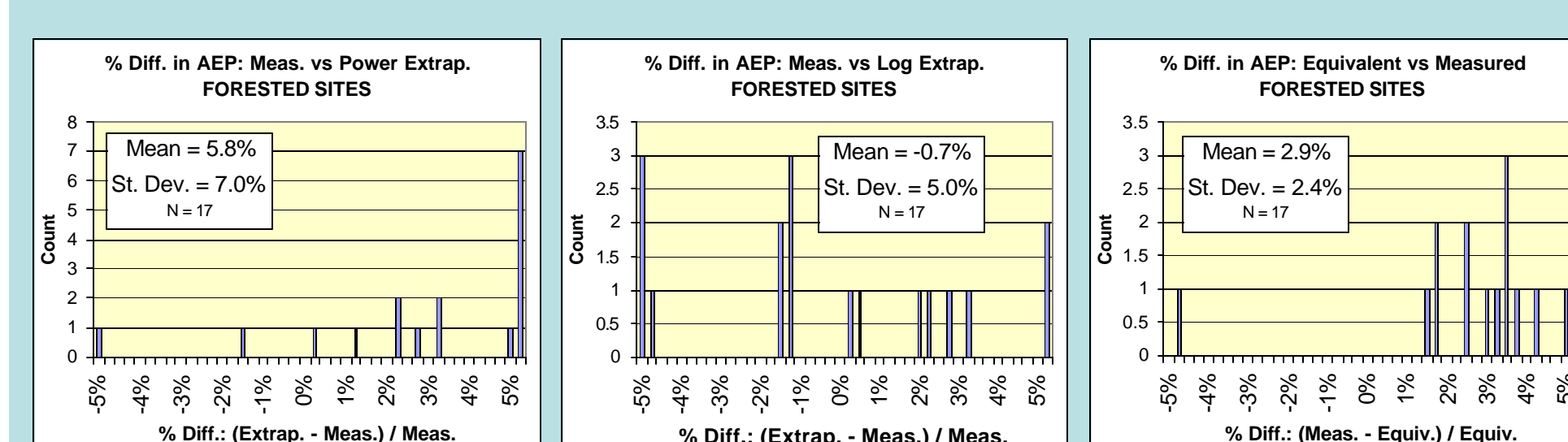
Results of AEP Comparison: FLAT SITES



Results of AEP Comparison: HILLY / RIDGELINES



Results of AEP Comparison: FORESTED SITES



SUMMARY OF AEP COMPARISONS

	Measured vs. Power Extrapolated		Measured vs. Log Extrapolated		Equivalent vs. Measured	
	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
All Sites	1.9%	4.2%	0.3%	3.0%	1.3%	1.4%
Flat Sites	0.4%	1.8%	-0.6%	1.9%	1.0%	0.7%
Forested Sites	5.8%	7.0%	-0.7%	5.0%	2.9%	2.4%
Hilly / Ridgelines	1.9%	3.6%	1.5%	2.5%	1.0%	1.0%

Observations / Conclusions

- 1) Overall, using the power law profile to extrapolate led to an overestimation of energy production. The log law extrapolation method did not demonstrate a bias.
- 2) At flat sites, when either the power or log law was used to extrapolate, the uncertainty in the energy estimate was found to be ~2%.
- 3) At forested sites, the power law largely overestimated the AEP with a mean percent difference of 5.8%. The log law extrapolation did not yield a bias however the uncertainty in the AEP estimation was large at 5.0%.

- 4) At hilly sites and on ridgelines, both the power and log law yielded energy estimates that were, on average, 1.9% and 1.5% high and with fairly high uncertainties of 3.6% and 2.5%, respectively.
- 5) Overall, when only the 80 m wind speed was used to determine the AEP (i.e. not the equivalent 80 m wind speed), the calculation led to an over-prediction.
- 6) At flat and hilly sites, using only the 80 m wind speed data led to a 1.0% overestimation of the AEP with an uncertainty of 0.7% and 1.0%, respectively.
- 7) At forested sites, if the equivalent wind speed was not used in the AEP calculation, the estimate was 2.9% high with a 2.4% uncertainty.

References

- 1) Antoniou et al., "Influence of wind characteristics on turbine performance", EWEC 2007 Conference Proceedings
- 2) Manwell, J.F., McGowan, J.G., Rogers, A.L., "Wind Energy Explained", John Wiley & Sons, 2003
- 3) Swift et. Al, "The Use of Tall Tower Field Data for Estimating Wind Turbine Power Performance", AWEA 2006 Conference Proceedings