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Extrapolation of Wind Speed Data for Wind Energy Applications

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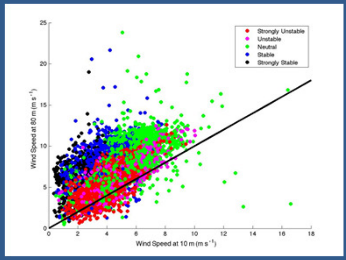
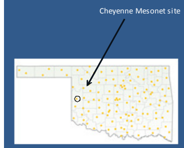
GOAL: Use 10-m Wind Speeds to Estimate Hub Height Wind Speed

- Standard meteorological observation sites were not designed with wind energy applications in mind.
- Standard observations are taken at 10 m above the ground, while turbine hub heights are typically 60–100 m above ground level.
- How accurate are extrapolation methods for different stability regimes?
- August 2011 was chosen for initial analysis. Oklahoma is under a persistent ridge during the summer, and most changes in wind speed profiles are likely related to stability.

DATA SOURCES: Oklahoma Mesonet Stations and OWPI Tall Towers

- Oklahoma Mesonet stations report 5-minute averages of temperature, wind speed, humidity, and other variables at approximately 2 m and 10 m.
- Tall towers report 10-min. averages of wind speed and direction at several heights up to 80 m.
- Cheyenne Mesonet site and tall tower ~25 km away were selected for analysis.
- Gradient Richardson number (calculated from Mesonet observations) was used to classify stability.





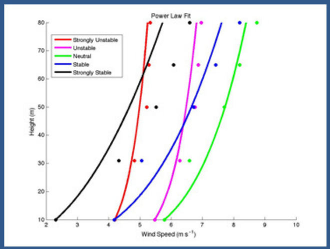
Scatter plot of 10 m wind speeds from the Cheyenne Mesonet site and 80 m wind speeds from a nearby tall tower for the month of August 2011. 1:1 line is shown for reference.

METHOD 1: Power Law Fit

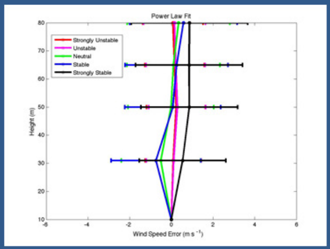
$$u(z) = u_{ref}\left(\frac{z}{z_{ref}}\right)^p$$

- p is the wind shear exponent → Controls how wind speed changes with height
- Linear regression was used to find a best-fit line of the form u(80m) = u(10m)* slope → Slope = $(z/z_{ref})^p$

Stability Classification	Shear Exponent	R^2
Strongly unstable	0.11	0.936
Unstable	0.11	0.959
Neutral	0.18	0.926
Stable	0.29	0.903
Strongly Stable	0.44	0.826



Mean wind speeds produced by power law fit. Average tall tower observations are shown with circles and power law fit is shown with lines.

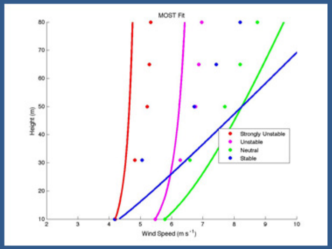


Mean wind speed errors produced by power law fit. Circles denote mean error values at each height and error bars indicate one standard deviation.

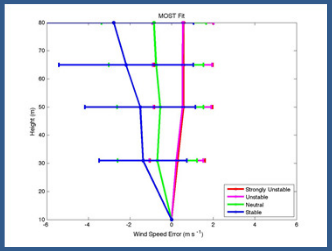
METHOD 2: Monin-Obukhov Similarity Theory (MOST)

$$\bar{u}(z) = \frac{u_*}{\kappa}\left(ln\frac{z}{z_o} - \Psi_m(\zeta)\right)$$

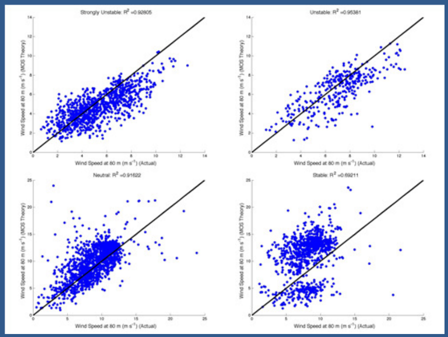
- Dimensionless wind speed gradients are related to similarity functions. Assumes heat and momentum fluxes are uniform with height in the surface layer.
- Modified log-law relates wind speed profile to friction velocity (u_*), roughness length (z_o), and stability correction parameter (Ψ_m).
- These parameters were estimated using 10-m wind speed and stability data from the Mesonet station (gradient method in Arya [2001]).



Mean wind speeds produced by MOST fit. Average tall tower observations are shown with circles and MOST fit is shown with lines.



Mean wind speed errors produced by MOST fit. Circles denote mean error values at each height and error bars indicate one standard deviation.

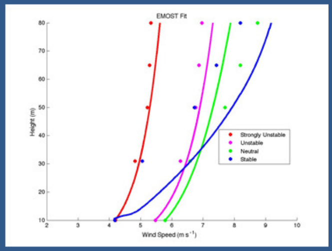


Scatter plots of 80 m tall tower wind speed vs. 80-m wind speeds estimated from Monin-Obukhov Similarity Theory. 1:1 line is shown for reference.

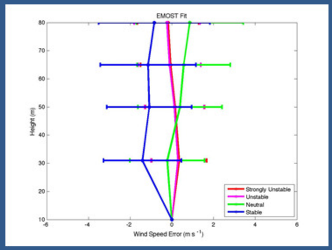
METHOD 3: Extended MOST (EMOST)

$$\bar{u}(z) = \frac{u_*}{\kappa}\left(\underbrace{ln\frac{z}{z_o} - \Psi_m(\zeta)}_{Stability} + \underbrace{\frac{z}{L_{MBL}}}_{MiddleBL} - \underbrace{\frac{z}{z_i}\frac{z}{2L_{MBL}}}_{UpperBL}\right)$$

- Follows work of Gryning et al. (2007).
- Uses different length scales for different parts of the boundary layer.
- Incorporates stability correction, similar to MOST.
- Requires estimation of boundary layer height, z_i.



Mean wind speeds produced by EMOST fit. Average tall tower observations are shown with circles and EMOST fit is shown with lines.



Mean wind speed errors produced by EMOST fit. Circles denote mean error values at each height and error bars indicate one standard deviation.

Conclusions

- Power law fit works well for nearly all stability regimes (strongly stable regimes are the exception). Important to develop different fits for different stability regimes.
- Errors are lowest for convective regimes.
- On average, MOST appears to overestimate wind speeds in stable regimes.
- EMOST fit is dependent on z_i, which is difficult to estimate.

Future Work

- Find correlation between 10-m wind speeds at the Mesonet site and at the tall tower site.
- Determine better way to estimate z_i (i.e., from remote sensing data, rather than through a basic parameterization).
- Develop a more sophisticated extrapolation method for stable regimes.

References

Arya, S. P., 2001: Introduction to Micrometeorology. Academic Press, 420 pp.

Gryning, S.-E., E. Batchvarova, B. Brümmer, H. Jørgensen, and S. Larsen, 2007: On the extension of the wind profile over homogeneous terrain beyond the surface boundary layer. *Boundary-Layer Meteorology*, **124**, 251–268.