Extrapolation of Wind Speed Data for Wind Energy Applications

Jennifer F. Newman and Petra M. Klein
School of Meteorology, University of Oklahoma

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 OWI 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.

METHOD 1: Power Law Fit

\[ u(z) = u(10m) \left( \frac{z}{10m} \right)^p \]

- \( p \) 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 \( u(80m) = u(10m) \cdot \text{slope} \)

METHOD 2: Monin-Obukhov Similarity Theory (MOST)

\[ u(z) = \frac{u_*}{\kappa} \left( \ln \left( \frac{z}{z_0} \right) - \frac{\Psi_m}{\kappa} \right) \]

- 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 \( z_0 \), and stability correction parameter \( \Psi_m \).
- These parameters were estimated using 10-m wind speed and stability data from the Mesonet station (gradient method in Arya [2001]).

METHOD 3: Extended MOST (EMOST)

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, \( z_i \).

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 \( z_i \) (e.g., from remote sensing data, rather than through a basic parameterization).
- Develop a more sophisticated extrapolation method for stable regimes.

References