Assessing Wind Representation in Reanalyses and Methods of Extrapolation to Hub-height for the Upper Midwest

Jacob Coburn (Cobur018@umn.edu)

Department of Geography, Environment and Society – University of Minnesota

A. Background

The recent societal drive toward renewable energy has caused a need for wind data at the hub-heights of wind turbines, which is severely lacking in observations and climate and reanalysis models. When data is needed for a specific location, a data collection campaign is often undertaken at the site with some form of measure-correlate-predict (MCP) being applied to obtain a longer record. Upcoming reanalysis datasets will output data around hub-height, with ERA5 sporting wind fields at 100 meters. In the meantime, however, many studies which use reanalysis or climate model data often apply a simple wind profile (1/7 power rule) to extrapolate wind speeds to hub-height based on 10-meter wind fields. The goal of this work was to assess several possible methods of extrapolation by how well they represent hub-height wind fields for the Upper Midwest (40-52N, 87-105W), a region important to wind energy developers.

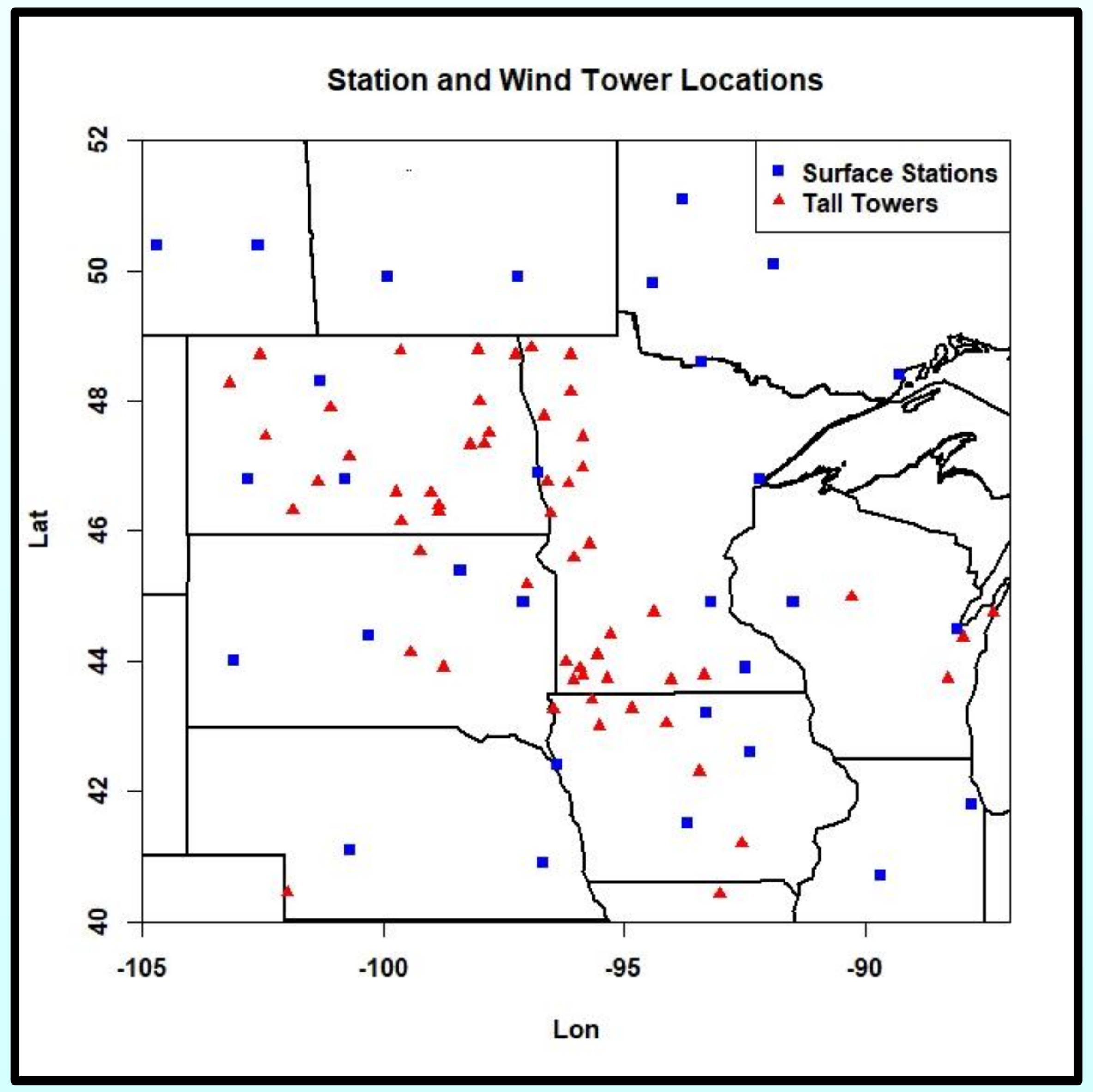

Figure 1 – Map of the Upper Midwest. Tower locations used for comparison to the reanalyses marked in red. Surface stations (marked in blue) were used to assess the skill of the reanalyses in capturing 10 meter winds.

B. Data

- ERA-Interim, CFSR and MERRA, 3 widely used reanalyses
  - ➢ Resolutions: ERA [0.71°], CFSR [0.5°], MERRA [0.625x0.5°]
  - ➢ Wind speeds are generally stronger than observed in MERRA, weaker in CFSR, mixed biases in ERA (weak in spring)
  - ➢ Wind speed spreads are larger than observed in all 3 datasets

- Tall Tower Wind Data (special thanks to Stephen Rose*)
  - ➢ Top heights range from 40 – 90 meters
  - ➢ 95 towers recorded over timespans in period 1995 – 2007
  - ➢ Towers with less than a year of data excluded

C. Methods

- Max heights for each tower (H) compared to 10-meter winds extrapolated to said height from the nearest grid cell
- Where grid cells overlaid more than one tower at same height, the towers were averaged (~55 timeseries for each comparison)
- Power Law and Log Law used in 4 methods:

Power Law: $U(H) = U(10) * (H / 10)^{\alpha}$

Log Law: $U(H) = U(10) * [\log(H / z) / \log(10 / z)]$

- *1/7 power rule* (α = 1/7), *log law* (using grid-cell roughness (z)) applied to all three reanalyses
- CFSR and MERRA were extrapolated using power law wherein the Hellmann exponent (α) was *derived* from winds at two heights in the models (hybrid height in CFSR, 50 meters in MERRA)
- CFSR and MERRA were also extrapolated using the power law wherein the Hellmann exponent was classified by *stability* using the gradient Richardson number between 2 & 10 m (MERRA) and 10 m and the hybrid-height (CFSR)
- Timeseries compared using measures shown in Table 1

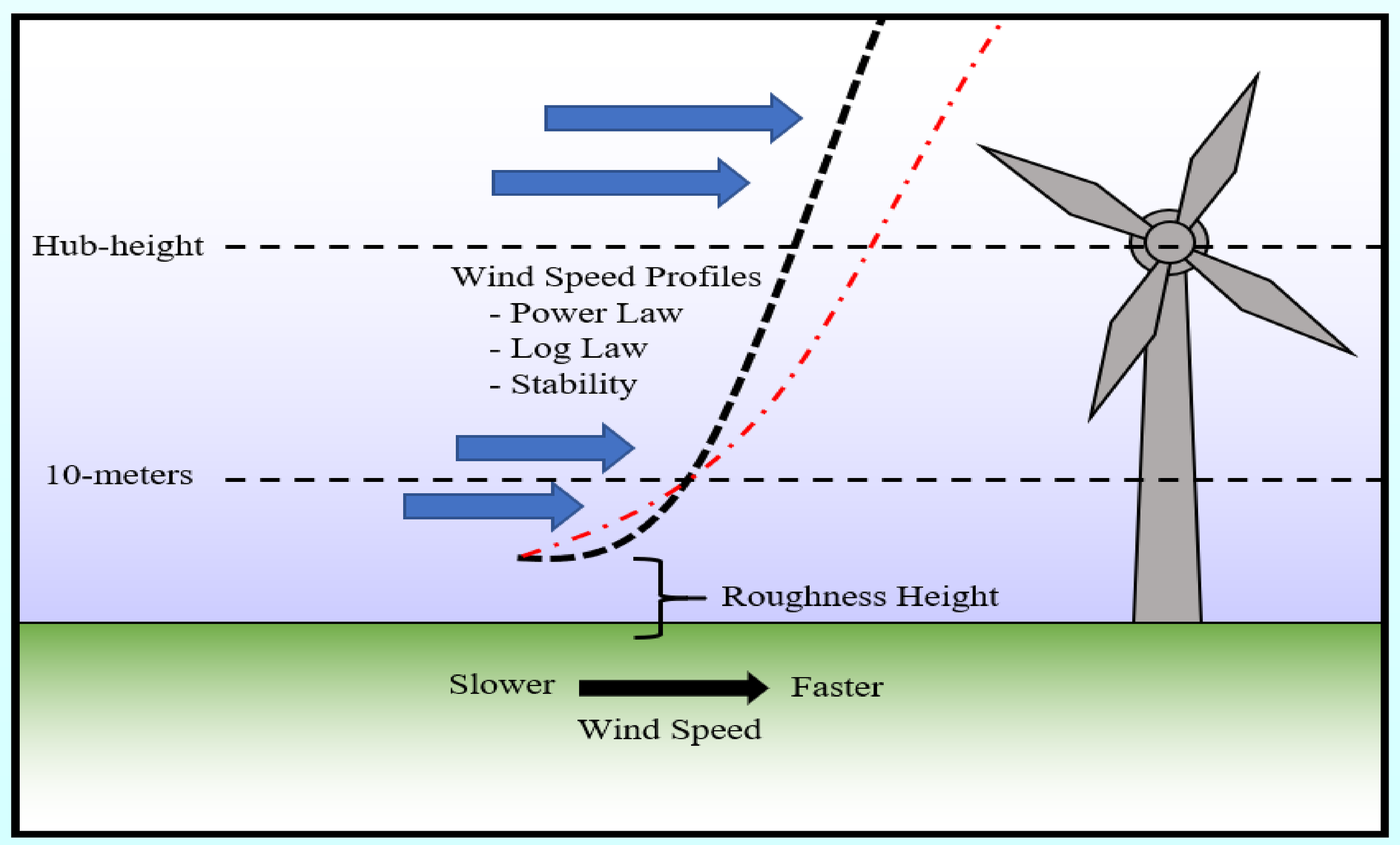

Figure 2 – diagram of the basic elements behind this project. I use the power and log laws to derive wind speed profiles with which to extrapolate 10 meter wind data from the reanalyses to hub-height. This is useful to wind energy applications.

D. Results and Conclusions

- Best results obtained using the MERRA derived power law (see Table 1)
- Interestingly, the same method used on CFSR showed the least skill
  - ➢ Possibly due to differences in roughness / boundary layer scheme
- Broadly, using the log law reduced the RMSE compared to the basic 1/7 power rule by 4 – 30%
- Hub-height winds tend to exhibit negative biases in shape and scale parameters
- Where possible, use of methods beyond the 1/7 power rule is preferred
- MERRA derived power law used to obtain wind fields at 80 meters for period 1980 – 2016 (see Fig. 3 and Fig. 4)

		Means	RMSE	COR	Weibull: Shape	Weibull: Scale
OBS	-	7.35	0	1	3.18	8.19
ERA	1/7 rule	5.96 (-19%)	2.01	0.83	2.66 (-16%)	6.71 (-18%)
ERA	log law	7.37 (0.5%)	1.85	0.83	2.66 (-16%)	8.3 (1%)
CFSR	1/7 rule	5.45 (-26%)	2.18	0.9	2.79 (-12%)	6.12 (-25%)
CFSR	log law	6.3 (-14%)	1.52	0.91	2.88 (-9%)	7.07 (-14%)
CFSR	derived	3.72 (-49%)	3.87	0.91	3.14 (-1%)	4.35 (-47%)
CFSR	stability	6.67 (-9%)	1.4	0.9	3.51 (10%)	7.39 (-10%)
MERRA	1/7 rule	6.52 (-12%)	1.43	0.9	2.8 (-12%)	7.33 (-11%)
MERRA	log law	6.67 (-9%)	1.37	0.9	2.84 (-11%)	7.49 (-9%)
MERRA	derived	7.3 (-0.7%)	1.18	0.92	3.19 (0.3%)	8.15 (-0.5%)
MERRA	stability	6.94 (-6%)	1.29	0.9	3.3 (4%)	7.73 (-6%)

Table 1 – Mean, RMSE, correlation and Weibull parameter values from comparing the tower data to the reanalyses according to the methods in column 2. Percentages are differences from the observed values. Means, RMSE and Weibull: Scale are in units of m/s.

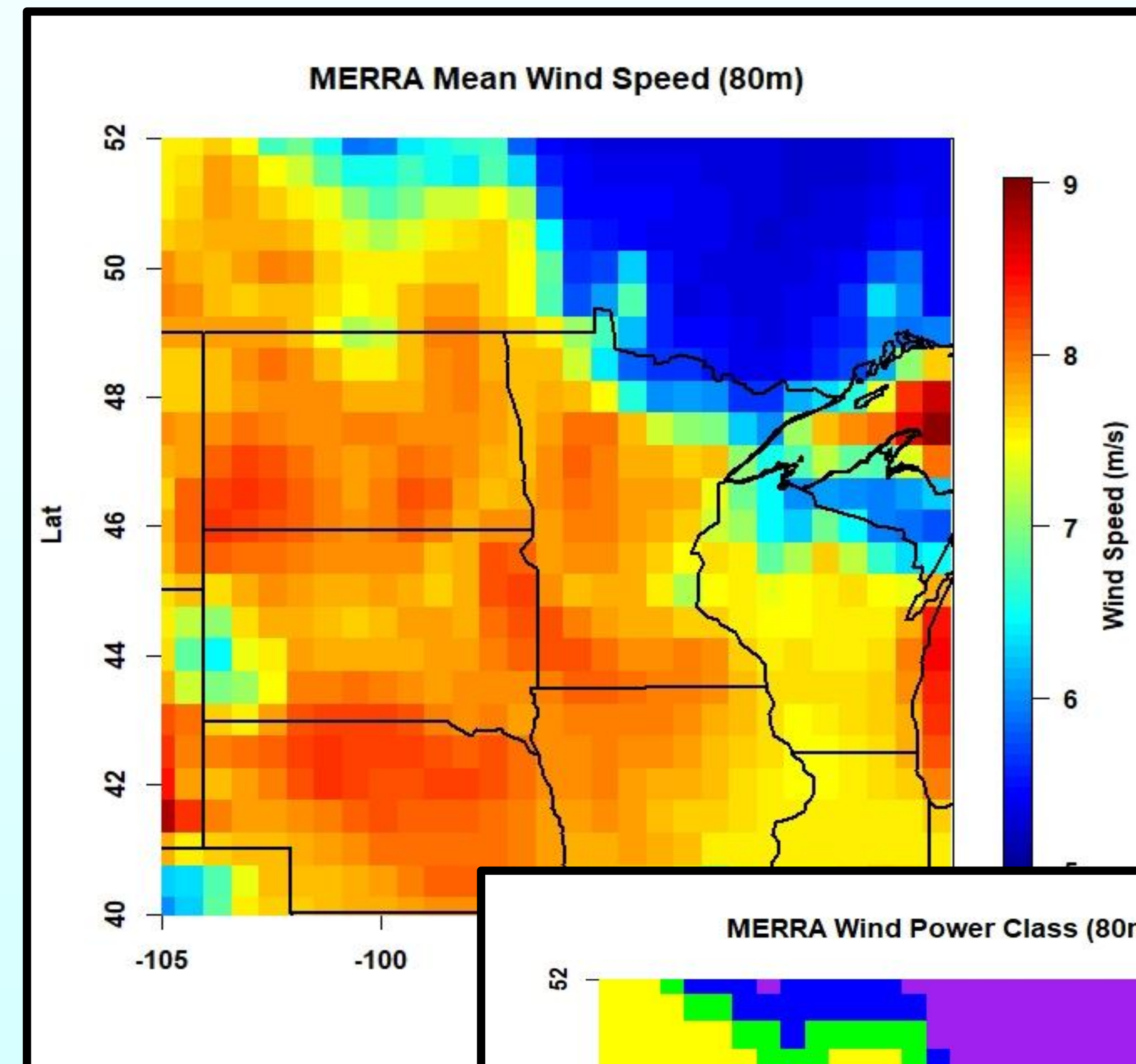

Figure 3 – Map of the mean wind speeds at 80 meters from the MERRA derived power law applied to the period 1989 – 2016. The speeds map reflect the types of landforms and surfaces present in the region.

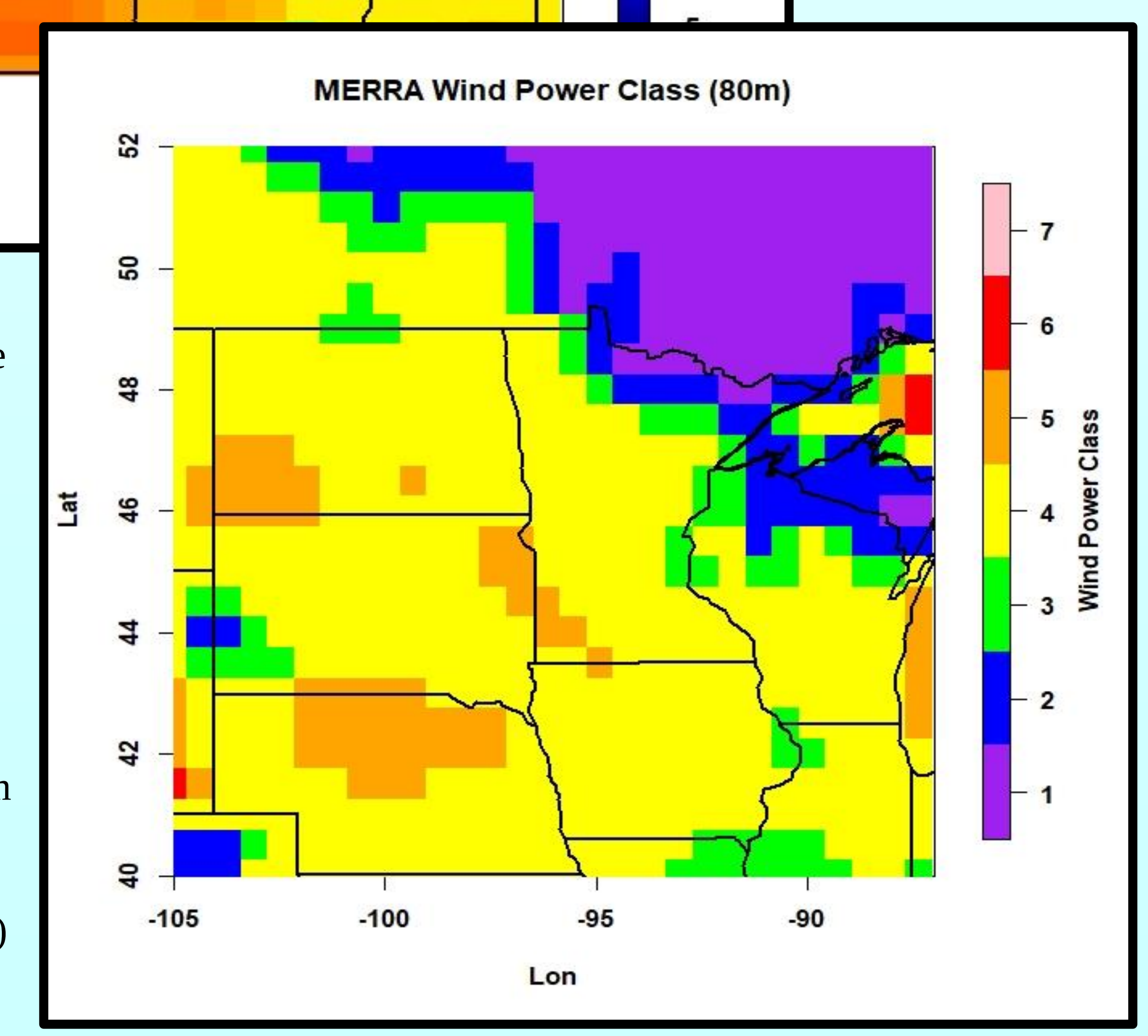

Figure 4 – Map of the mean wind classes using the wind speed data used to produce Fig 3. Wind development is most promising in areas with a Class 3 or higher. Class definitions taken from National Renewable Energy Lab (NREL: https://www.nrel.gov)

*See Rose, Stephen, and Jay Apt. 2015. "What Can Reanalysis Data Tell Us about Wind Power?" *Renewable Energy* 83. Elsevier Ltd: 963–69. doi:10.1016/j.renene.2015.05.027.