Could crop height impact the wind resource at agriculturally productive wind farms?

Brian Vanderwende, Julie K. Lundquist
Atmospheric and Oceanic Sciences
University of Colorado at Boulder

brian.vanderwende@colorado.edu
(303) 492-2654
julie.lundquist@colorado.edu
(303) 492-8932

1. Interaction between wind farms and the land surface

In the United States, the most productive onshore areas for wind power exist in the Great Plains and the Midwest. These areas feature extensive agriculture, so wind farms are often built over cropland. Potential interactions between the turbines and the managed cropland surface include:

- Turbulent mixing generated by the turbines can modify surface layer profiles of temperature and momentum as well as surface fluxes
- The roughness of the land surface can affect the wind resource aloft through frictional drag

The effect of roughness changes gradually propagate vertically, forming a growing internal boundary layer with a maximum height of around L/200, where L is the horizontal fetch over the roughness patch. In this study, we simulate the impact of crop roughness on winds at a location in central Iowa.

2. Typical characteristics of the two largest Iowa crops

Fully grown corn (maize)
Height = 2-3 m
Density = 8 plants/m^2
Roughness = 25 cm

Fully grown soybeans
Height = 1-1.5 m
Density = 25-40 plants/m^2
Roughness = 10 cm

* Roughness from Davenport[1] classification scheme

3. Model setup and physics/data configurations

We used the Weather Research and Forecasting model V3.4, which includes a wind farm parameterization[2] designed to simulate effects of wind farms on regional scale flow. To evaluate WRF performance, we compared 40-120 m winds from many input data and PBL configurations to lidar observations.

Common WRF settings
- Nested 1.25km domain
- 60 vertical levels
- RRTM/Dudhia radiation
- 6-class microphysics
- Noah land model

Input data: ERA-Interim, GFS-FNL, GEFSR2, NARR

PBL scheme: MYNN, MYJ, YSU, ACM2, QNSE

Roughness tests: Free-stream flow (FS) Corn vs. Soy; Wind farm present (WFP) Corn vs. Soy

4. Evaluation of WRF performance in the turbine rotor layer

The lidar observed rotor-layer wind speeds and vertical shears (from the 2011 CWEX study), as represented by the power-law shear exponent:

$$U_2 = U_1 \left(\frac{z_2}{z_1}\right)^{\alpha}$$

were compared to WRF output for a three day period spanning 1300 LST July 14th to 0100 LST July 17th.

- Use of the NARR data produced the largest error and highest bias in rotor-layer winds
- No one particular PBL scheme outperformed its peers

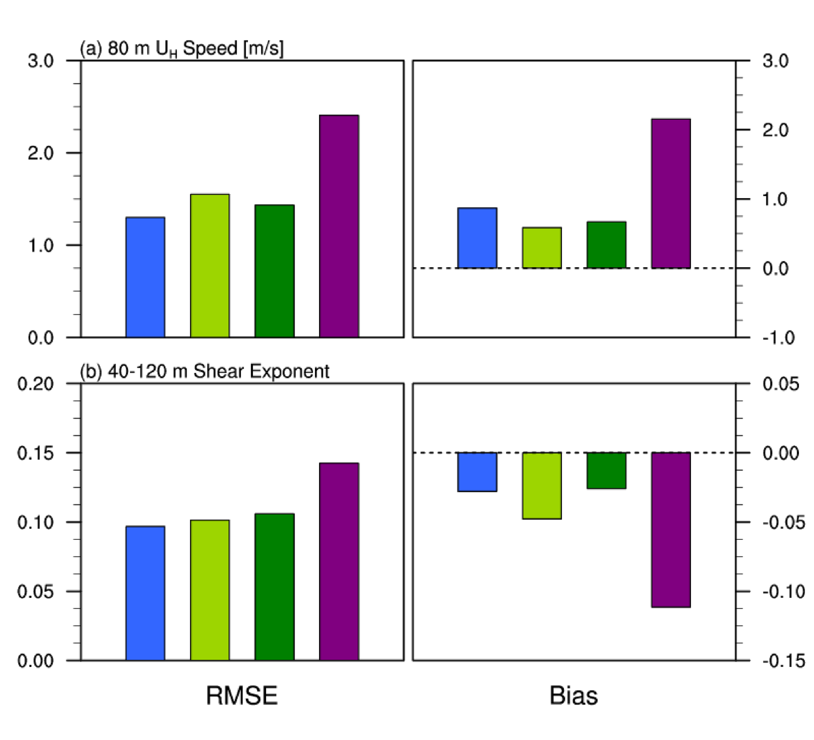

Figure 1: Comparison of RMSE and bias in (a) 80 m wind speeds and (b) rotor-layer shear produced by WRF while using the four input data sets.

The GFS-FNL input data were used as they produced the best qualitative representation of the wind field. The MYNN scheme, required by the wind farm parameterization, performed on par with other schemes.

5. Response of the wind resource to corn & soy crop roughness

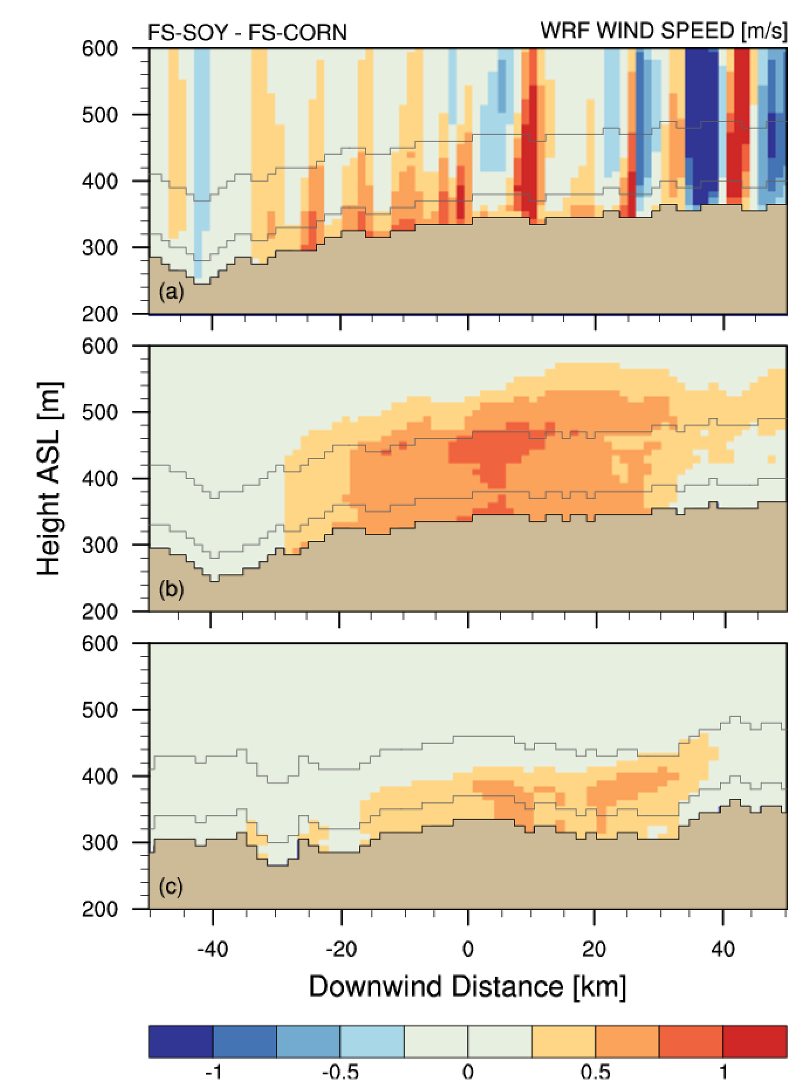

Figure 2: Soy - corn wind difference for (a) unstable, (b) weakly stable, and (c) strongly stable conditions.

Using the GFS/MYNN WRF configuration, we first varied the surface roughness across a 57 x 57 km patch without a wind farm to quantify what effect, if any, crop changes could have on the wind resource. Over a three day period, we found that:

- Median hub-height winds increased by 0.24 m/s with soy instead of corn
- Effects on rotor-layer shear were strongest in the bottom half of the disk, and were most apparent in the day
- The average impact of roughness changes on boundary layer winds depended on the surface layer stability:
  - Largest effect = weakly stable
  - Smallest effect = strongly stable
  - Convective plumes carried surface influence rapidly upward

6. Roughness impacts within a parameterized wind farm

To determine whether roughness effects on the wind resource persist in the presence of turbine-induced momentum reductions, we used the WRF wind farm parameterization to simulate an array of 121 Vestas V90 1.8MW turbines.

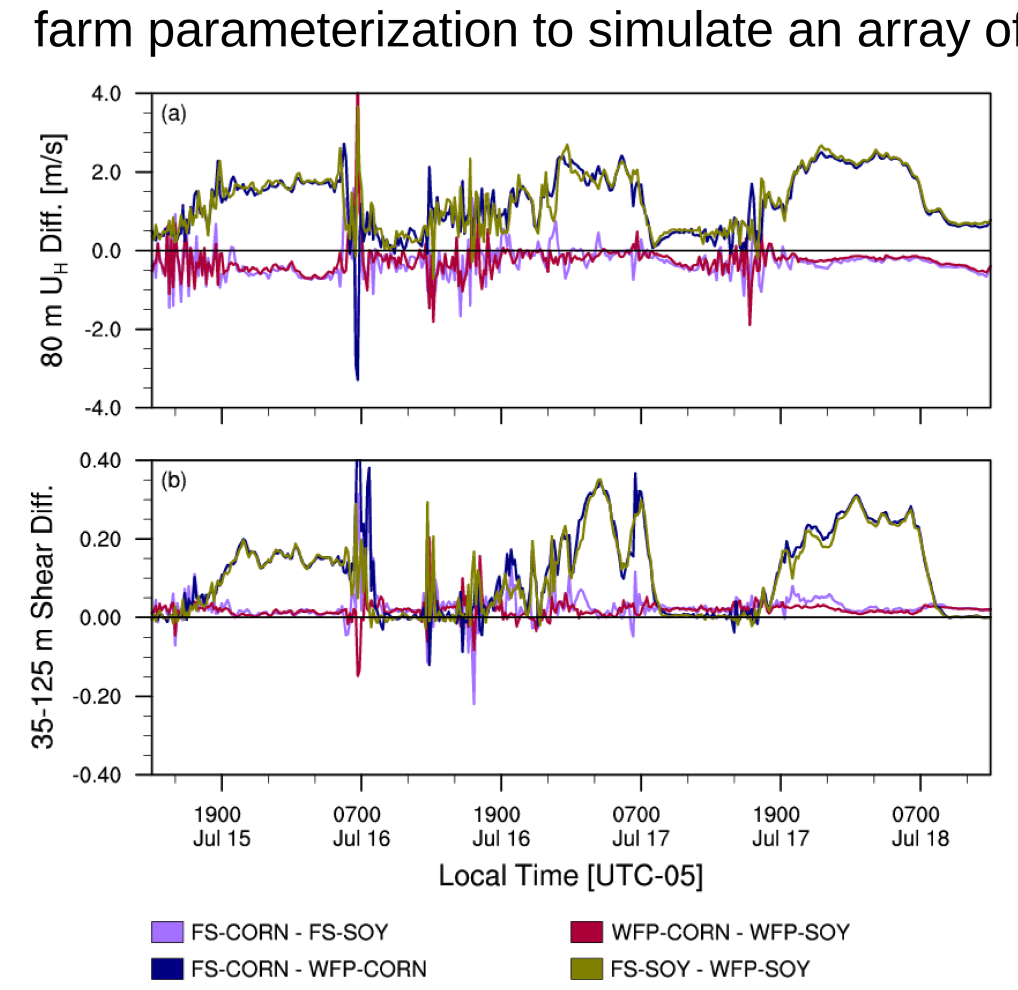

Figure 3: Differences in (a) 80 m speed and (b) rotor-layer shear between various farm states including: corn, soy, no wind farm (free stream), and wind farm present.

- Average hub-height wind speed increase from corn to soy was equal to 14% of turbine wake loss during the night; 32% during the day
- Turbulence (TKE) increase from wake dwarfed small rise from roughness change
- Both wake losses and roughness effects on hub-height winds are dependent on stability and time of day
  - In unstable conditions, roughness change can compensate for majority of small daytime wake loss

Conclusions

- **The mature corn crop reduces hub-height wind speeds and increases rotor-layer shear, even in the center of a large 121 wind turbine array**
- **The turbine array produced 13% more power when soy roughness was used instead of corn. Using modern rates of \$30-\$60 per MWh, we find that targeted crop management practices could increase the income from this wind farm by \$16,035 - \$32,069 during the three day period**
- **Still need to determine the smallest required patch to see speed effect**

References

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2. Fitch, A.C., J.B. Olson, J.K. Lundquist, J. Dudhia, A.K. Gupta, J. Michalakes, and I. Barstad (2012), Local and Mesoscale Impacts of Wind Farms as Parameterized in a Mesoscale NWP Model, Mon. Wea. Rev., 140, 3017-3038, doi:10.1175/MWR-D-11-00352.1.
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