Effect of wind turbine wakes on summer-time wind profiles in the US Great Plains

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Wind Energy & Agriculture

- Wind energy currently provides 3% of U.S. electricity and accounts for 35% of new generating capacity.
- Midwest US is one of the richest wind & agriculture resources (Figures 2 & 3)
- How do wind turbines affect local wind patterns?
- Do the changed wind patterns alter surface flows?
- Do changes in surface flows affect biological growth?
- What does this mean for the economic and technological futures of co-located wind energy & agriculture?

• Upwind & downwind 80m LIDAR wind direction for July 23, 2011. Turbine wake exists over the surface with a hub height of 80m.

Experiment Description

- From 2 Jul to 20 Aug 2011, teams from CU-Boulder, NREL, NCAR, & Iowa State University collected meteorological measurements from an operating wind farm in central Iowa.
- Surface station measurements and LIDAR wind and turbulence profiles were taken on opposite sides of a row of multi-MW wind turbines.
- Turbine rotors span from 40m to 120m above the surface with a hub height of 80m.
- The table below details the available measurements made at each location show in the map to the right.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Measurement</th>
<th>Height AGL (m)</th>
<th>Budget Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windcube LIDAR (CU-Boulder)</td>
<td>3 component wind speed and variance</td>
<td>50, 60, 80, 100, 120, 140, 160, 180, 200, 220 (adjustable)</td>
<td>2 min.</td>
</tr>
<tr>
<td>CSAT3 sonic Anemometer (NCAR)</td>
<td>3-D wind speed, temperature</td>
<td>4.5 m</td>
<td>20 Hz</td>
</tr>
<tr>
<td>Infrared Gas Analyzer (NCAR)</td>
<td>H2O, CO2 Concentration</td>
<td>4.5 m</td>
<td>20 Hz</td>
</tr>
<tr>
<td>Pressure Transducer (NCAR)</td>
<td>Pressure</td>
<td>2 m</td>
<td>1 Hz</td>
</tr>
</tbody>
</table>

> Windcube LIDAR (CU-Boulder)

Map of the experiment location (Figs. 4 & 5)

Comparison of two LIDARs

- LIDARs were deployed side-by-side for two days at the southern location to quantify measurement difference.
- Results (Figure 5) verify agreement between the LIDARs.
- Following this short verification period, CU2 LIDAR was moved to the northern location.

Conclusion

- Upwind and downwind LIDAR profiles enable characterization of turbine wake effects.
- A momentum deficit exists in turbine wake; for both stability conditions.
- Momentum deficit is larger in stable conditions although upwind wind speed is lower in stable conditions than in convective.
- The maximum deficit is found above hub height.
- Turbulence Kinetic Energy (TKE) increases in the wake for both stability conditions.
- Maximum TKE enhancement occurs during stable conditions.
- TKE differences are observed at the lowest altitude observable by LIDAR, suggesting wake enhancement of TKE may impact the surface.
- Ongoing analysis in conjunction with surface station data will explore wake impacts on surface.
- LIDAR profile dataset may be useful for testing large-eddy simulations of turbine wake dynamics.

Acknowledgements

This work would not be complete without help and support from Dr. Gene Tabba’s group at Iowa State University, the National Renewable Energy Laboratory (NREL), the National Center for Atmospheric Research (NCAR), NRG Systems Inc., and the cooperation of the property owners and wind farm owner/operator.