A Comparison of Remote Sensing and In Situ Boundary Layer Measurements
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1 Motivation

Temperature, moisture, and wind profiles are used to quantify atmospheric stability. Stability is important to quantify near wind farms as it is a critical meteorological factor that affects wind energy production (Garcia et al., 2012; Wiersma and Bruintjes, 2012). In-situ measurements, such as meteorological towers (bottom) are generally used to obtain these profiles. However, they are expensive and the measurements have an inherent uncertainty. Remote sensing instruments, such as microwave radiometers (right) and LIDARs, are portable and can make measurements well above typical tower heights (height~150m). In our analysis, we compare temperature, moisture, and stability profiles observed from the tower and radiometer in order to explore the use of remotely sensed profiles in the boundary layer.

Why is stability important?

- Stability causes variability on the profile of mean wind speed, wind direction, and turbulence intensity across a wind turbine's rotor disk (Wharton and Lundquist 2012a).
- Research has shown that generated power depends on stability, although the sign of power change depends on whether or not wind is present during stable conditions (Wharton and Lundquist 2012b).
- Accurate stability forecasts can help wind farms ensure more power output will be generated (Wharton and Lundquist 2012b).

2 Goals of the Project

- Explore the pros and cons of taking in situ vs. remote sensing measurements at wind sites.
- Compare the temperature and moisture profiles from the M5 tower data to those measured from the MP-3000A radiometer and vertically-profiling wind LIDAR data.
- Use wind and turbulence profiles from the LI-7500 A and MP-3000A to determine the Richardson number and compare to the tower-derived Richardson number.
- Determine if the radiometer and LIDAR combination is a viable option for determining stability at wind farms.

3 Data

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Start/End Date</th>
<th>Height Range</th>
<th>Time Resolution</th>
<th>Measured Quantities</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>M5 Tower</td>
<td>August 2012-present</td>
<td>3m-152m</td>
<td>20Hz</td>
<td>T, T, wind speed, wind direction</td>
<td>Finer height resolution, includes wind speed and direction</td>
<td>Limited vertical extent, affected by prevailing wind direction, no humidity profiles</td>
</tr>
<tr>
<td>Radiometer</td>
<td>June 2012-present</td>
<td>0-150m</td>
<td>~ every 3 minutes</td>
<td>T, RH, liquid water content</td>
<td>Measure up to 150m, includes vertical humidity profiles</td>
<td>Does not measure wind speed or direction</td>
</tr>
<tr>
<td>Windcube LIDAR</td>
<td>August 2012-present</td>
<td>0-150m</td>
<td>2 minute averages</td>
<td>Wind speed, turbulence intensity</td>
<td>Measures wind speed and direction and turbulence intensity</td>
<td>Does not measure temperature or humidity profiles</td>
</tr>
</tbody>
</table>

4 Quantifying Temperature & Moisture Structures

<table>
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<tr>
<th>Instrument Locations</th>
<th>Radiometer</th>
<th>M5 Tower</th>
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5 Tower and Radiometer Comparison

- The potential temperature (Θ) for the tower is derived from temperature at a specific level and the pressure at that level, whereas the Θ for the radiometer is measured directly over a 5m deep volume.
- The radiometer and tower are well-correlated at the lowest and middle heights and moderately correlated at the highest height.
- The range of Θ values derived from the tower are generally smaller than the other instruments, but the radiometer does not provide average values over discrete measurements like the tower.

6 Conclusions

- Radiometers can be used to quantify stability well above the vertical extent of a meteorological tower.
- Potential temperature and virtual potential temperature from the radiometer are well-correlated with that of the tower at lowest and middle heights and moderately correlated at the highest height.
- Specific humidity from the radiometer and tower are moderately correlated, but do not have good agreement perhaps due to the calculations required to estimate specific humidity from dew point temperature measured at the tower.
- Remote sensing instruments at wind farms could aid in more accurate and complete calculations of stability and estimated production.

7 Future Work

- Carry out cross comparisons between remote sensing instruments and the tower for the entire season to ensure reliable statistics.
- Compare wind profiles from a vertically-profiling wind LIDAR to those from the tower.
- Calculate the shear and buoyancy terms of the gradient Richardson number to determine stability and correlation between the remote sensing and in-situ measurements.
- Determine if the radiometer and LIDAR combination offers advantages in measuring atmospheric stability over the tower.

8 References


9 Acknowledgements

This work would not be possible without Andy Clifton from the National Renewable Energy Laboratory (NREL), who provided MS Tower data.