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 stability and turbulence affect wind energy production (Friedrich et al. 2012; Vanderwende and Lundquist 2012). In situ measurements, such as meteorological towers (bottom) are generally used to obtain these profiles. In situ instruments can be calibrated within a wind tunnel to reduce the uncertainty of the measurements and towers have established international standards . However, towers are expensive, fixed, and cannot collect data above the tower. On the other hand, remote sensing instruments, such as microwave radiometers (right) and LIDARs, are portable and can make measurements well above typical tower heights (60m-135m). 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.

Above: 135-m M5 meteorological tower (left of photo) which measures the inflow into the DOE/ GE 1.5 MW turbine (right of the photo) located at The National Renewable Energy Laboratory's NWTC. Photo courtesy of Department of Energy and the National Renewable Energy Laboratory.

Above:MP-3000A Radiometrics Corporation microwave radiometer located at the National Wind Technology Center (NWTC). Photo courtesy of Evan Kalina.

Why is stability important?

- **Stability causes variability in the profiles 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 veer is present during stable conditions (Wharton and Lundquist 2012b).**
- **Accurate stability forecasts can help wind farms assess how much 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 LIDAR to determine the Richardson number and compare to the tower-derived Richardson number**
- **Determine if a radiometer and LIDAR combination is a viable option for determining stability at wind farms**

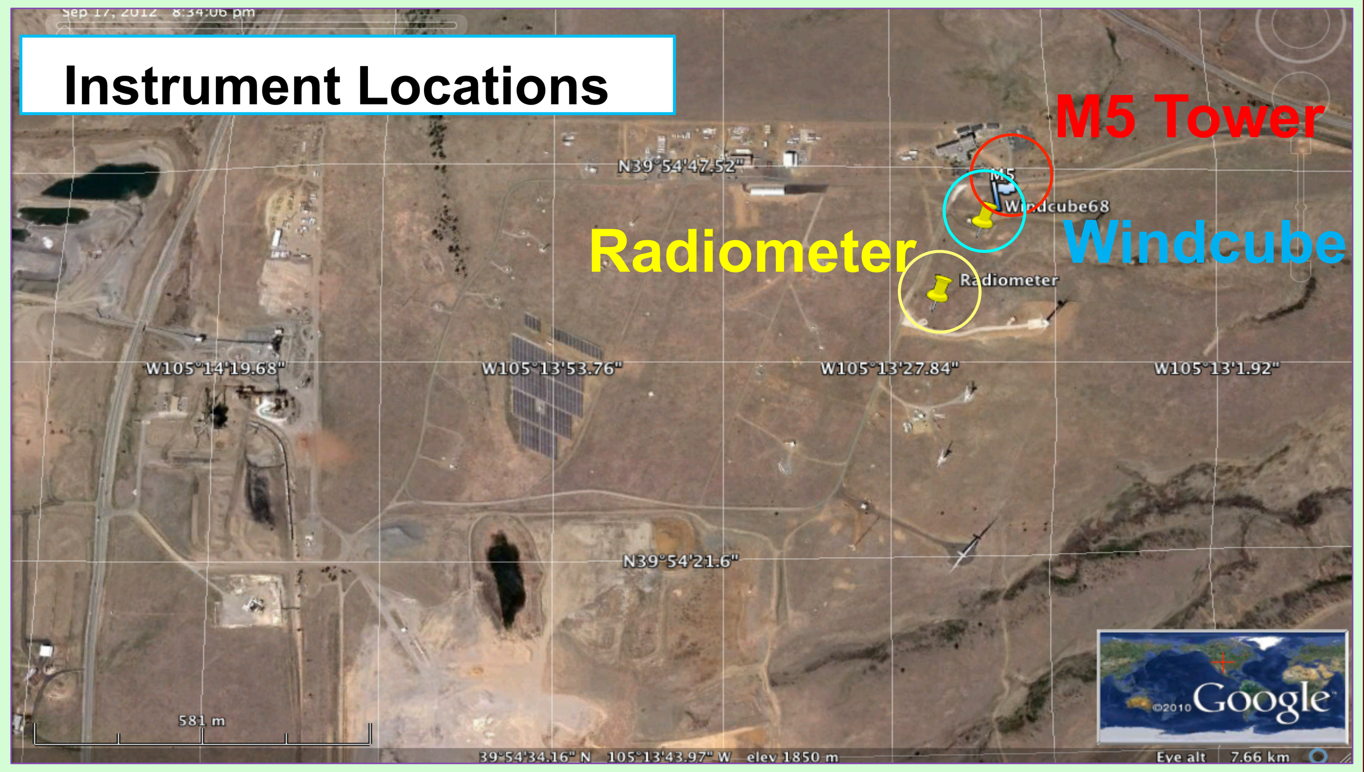
Note: Not all goals have been completed for this project yet. Refer to 'future work' to see the next steps for the project.

Methodology

- **Choose a case study with the following conditions: westerly winds, relatively moist boundary layer, strong vertical shear, and conditionally unstable atmosphere**
- **Plot and compare potential temperature, virtual potential temperature, and specific humidity for both the tower and radiometer to show that the radiometer provides additional details about the structure of the atmosphere**
- **Determine if the radiometer and tower measurements are well correlated and if they have good agreement.**

3 Data

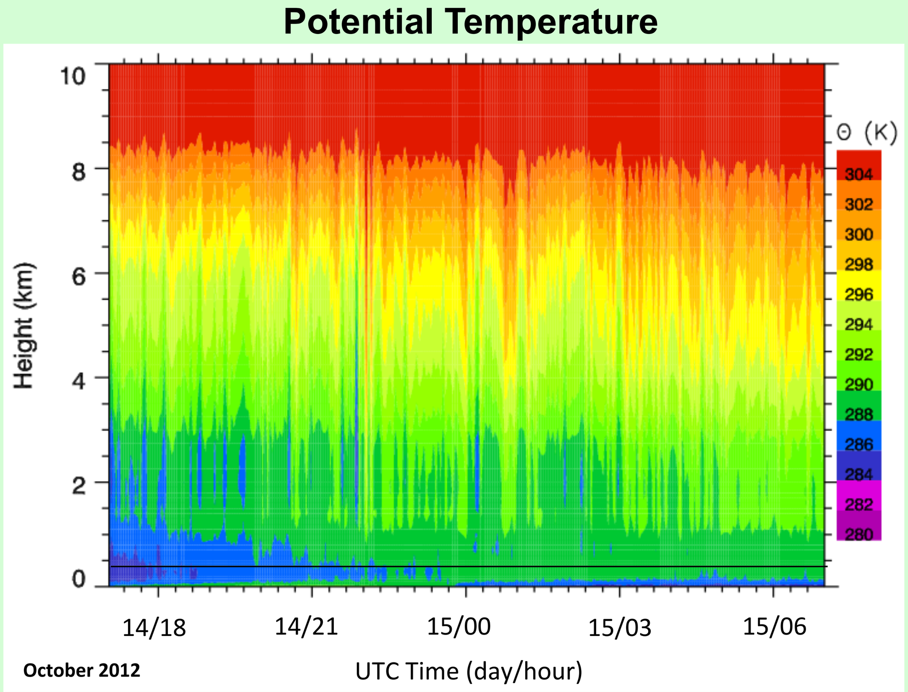
Instrument	Start/End date	Height Range	Time Resolution	Measured Quantities	Pros	Cons
M5 Tower	August 2012-present	3m-122m	20Hz	T, T_d, wind speed, wind direction	Finer height resolution, includes wind speed and direction	Limited vertical extent, affected by prevailing wind direction, no humidity profiles
Radiometer	June 2012-present	0-10km	~ every 3 minutes	T, RH, liquid water content	Measure up to 10km, includes vertical humidity profiles	Does not measure wind speed or direction
Windcube LIDAR	August 2012-present	40m-220 m	2 minute averages	Wind speed, wind direction, turbulence intensity	Measures wind speed and direction and turbulence intensity	Does not measure temperature or humidity profiles



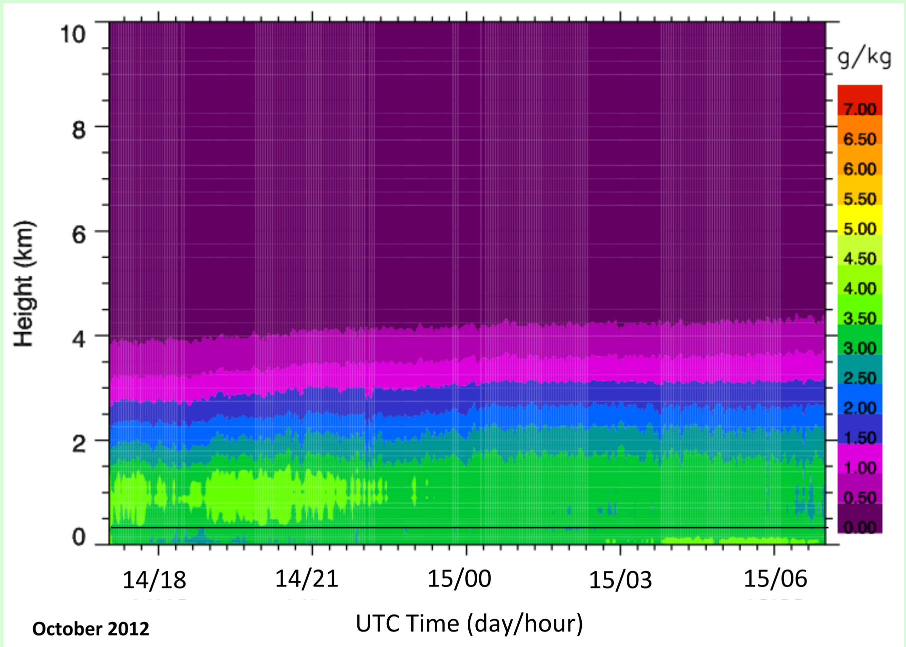
4 Quantifying Temperature & Moisture Structures

Radiometer

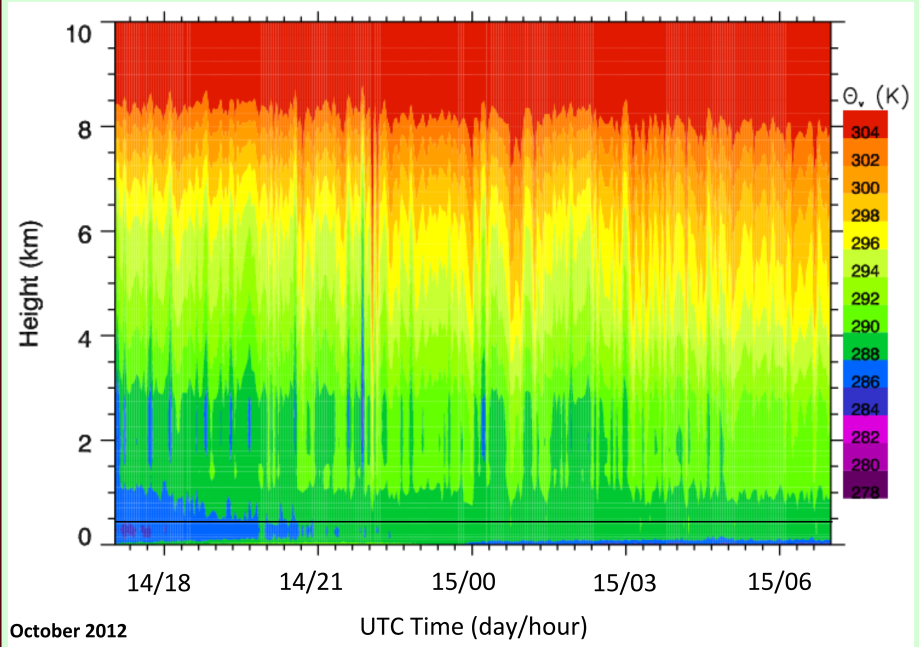
Potential Temperature



Specific Humidity

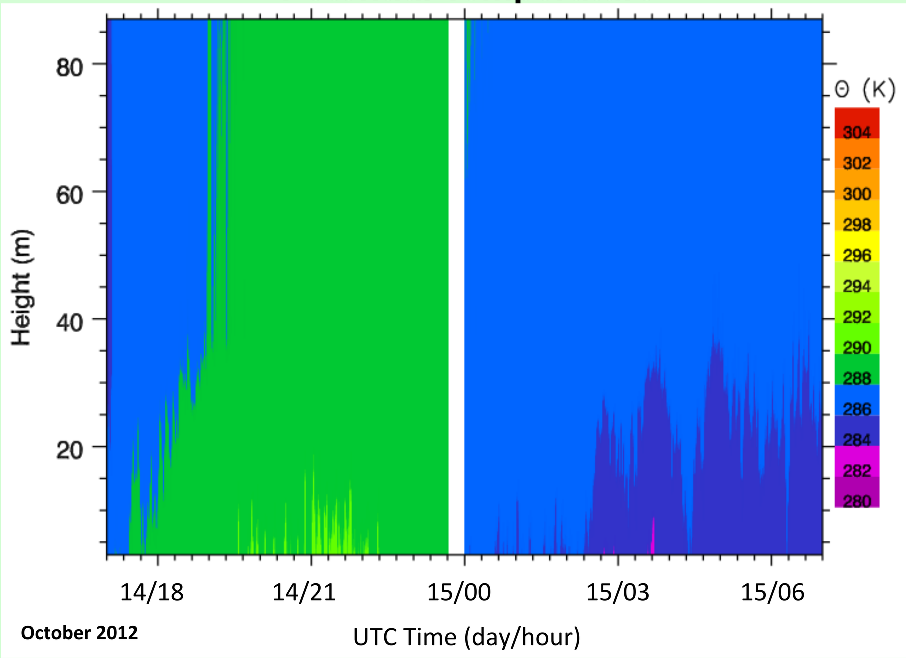


Virtual Potential Temperature

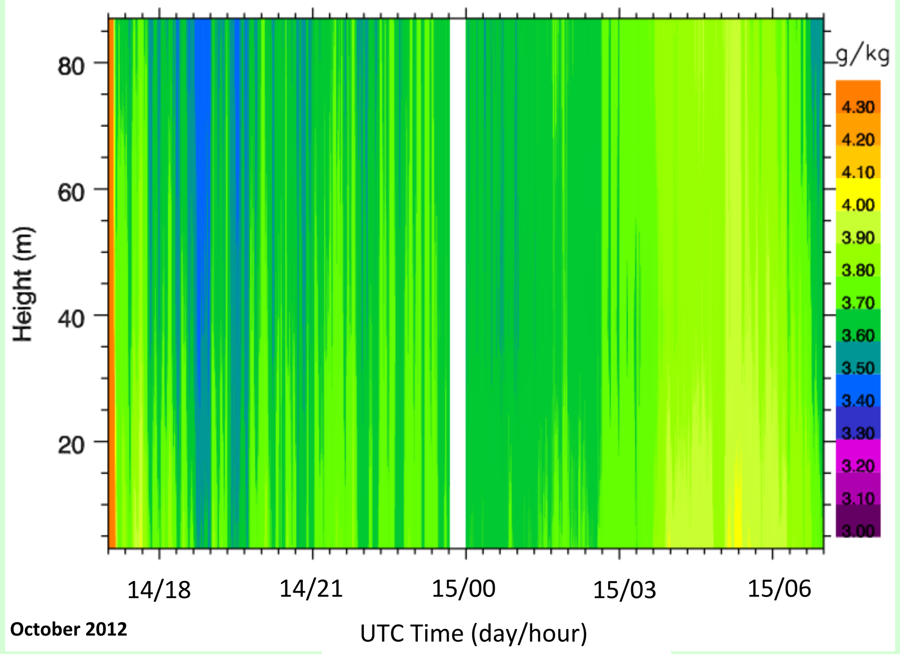


M5 Tower

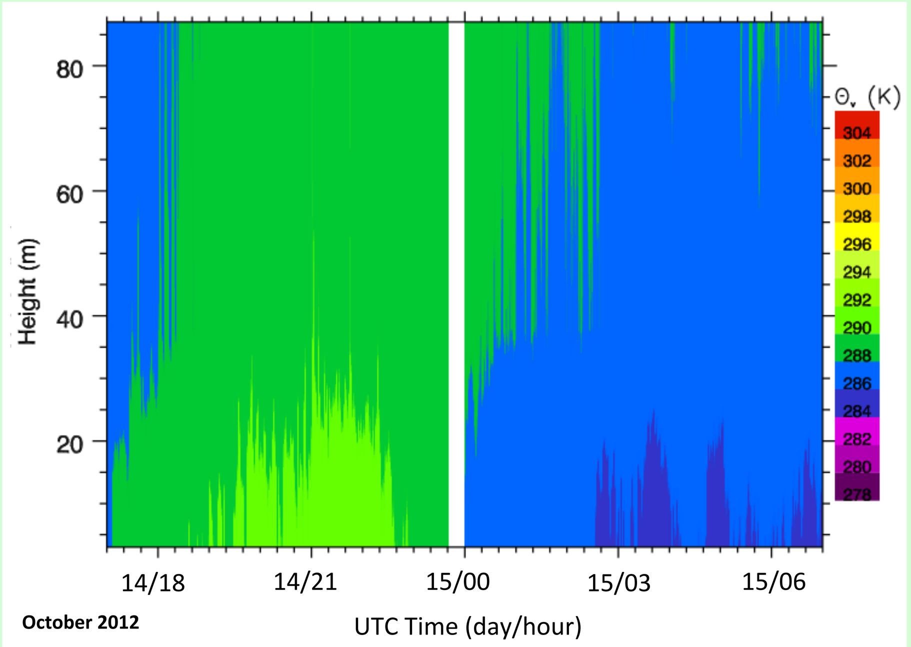
Potential Temperature



Specific Humidity

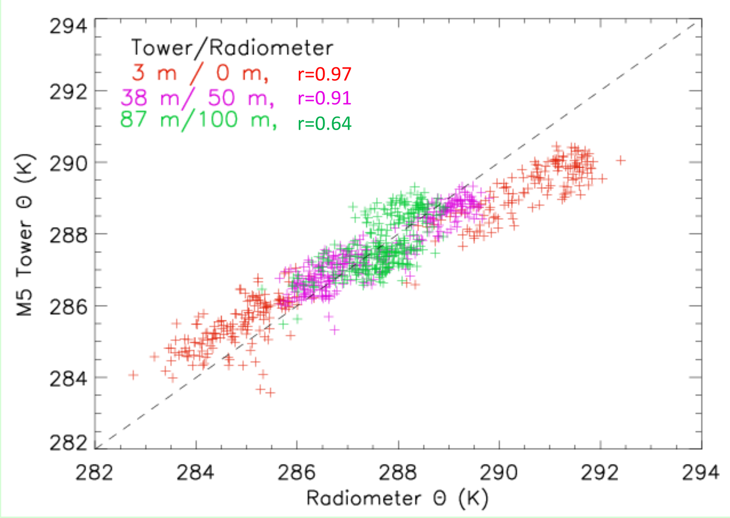


Virtual Potential Temperature



5 Tower and Radiometer Comparison

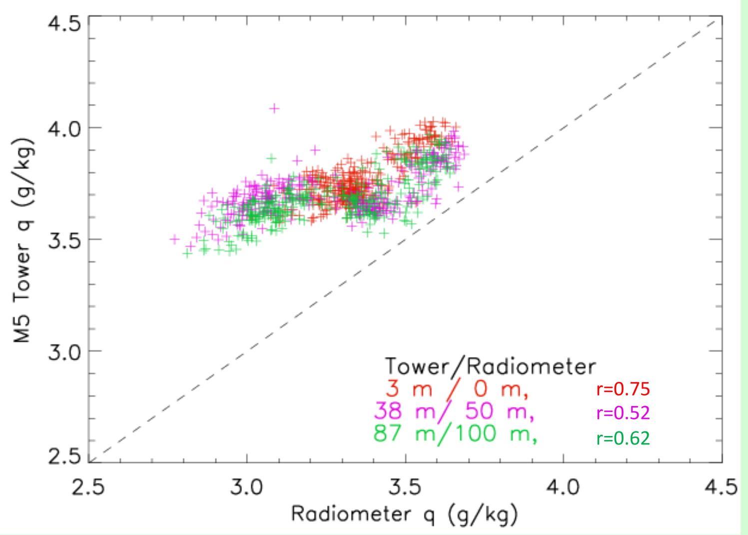
Correlation



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 50m 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 smaller than that observed from the radiometer at the same level. The difference may be because the radiometer takes vertical averages opposed to discrete measurements like the tower.

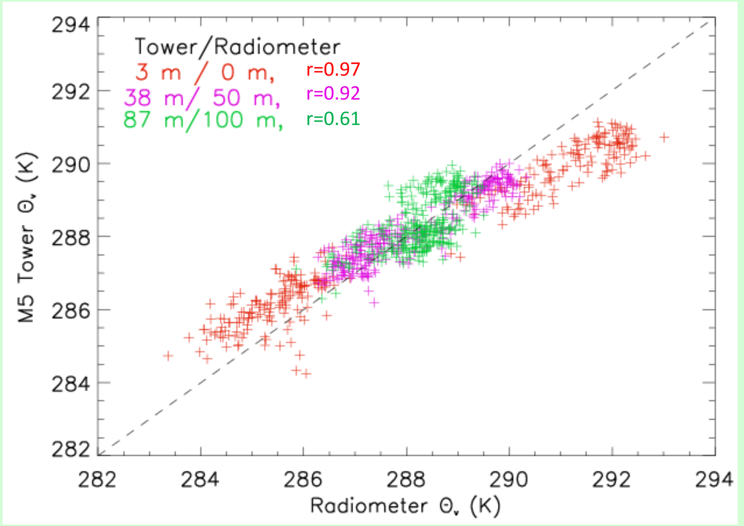


The specific humidity (q) for the tower was derived by converting dew point temperature to relative humidity, relative humidity to mixing ratio, and then mixing ratio to specific humidity.

$w= (M_w/M_d)*(RH/100)*(esat(T)/(p-U*esat(T)))*1000$
$q=w/(1+w)$

M_w: mass of moist air T: air temperature
M_d: mass of dry air esat: saturation vapor pressure
RH: relative humidity w: mixing ratio
q: specific humidity

The specific humidity profiles are moderately correlated at all heights, but they are not in good agreement; the tower consistently measures higher values than the radiometer. This difference may be a result of the tower humidity profile being a derived quantity and the radiometer humidity profile being a measured quantity.



Virtual potential temperature is used in buoyancy measurements as a surrogate to density. Buoyancy also indicates stability in the atmosphere.

$Θ_v = Θ(1+(0.61*w/1000))$
Θ: potential temperature w: mixing ratio

The radiometer is well correlated at the lowest and middle height and in agreement with the values derived from the tower. Like the potential temperature, the range of virtual potential temperature values for the tower is smaller than that of the radiometer.

As with the potential temperature, the virtual potential temperature plots show a distinct shift from an unstable atmosphere to a stable atmosphere as the sun sets (~ 24z on the 15th) .

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 power production.**

7 Future Work

Carry out comparisons between remote sensing instruments and the tower for an 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

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9 Acknowledgements

This work would not be possible without Andy Clifton from the National Renewable Energy Laboratory (NREL), who provided M5 Tower data.