Wind lidar performance in the region of turbine rotor disks

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1. Introduction

With the continued growth of the wind energy industry, reliable vertical wind profiles are needed for:

- resource assessment
- diagnosis of turbine performance
- validation of forecasting models

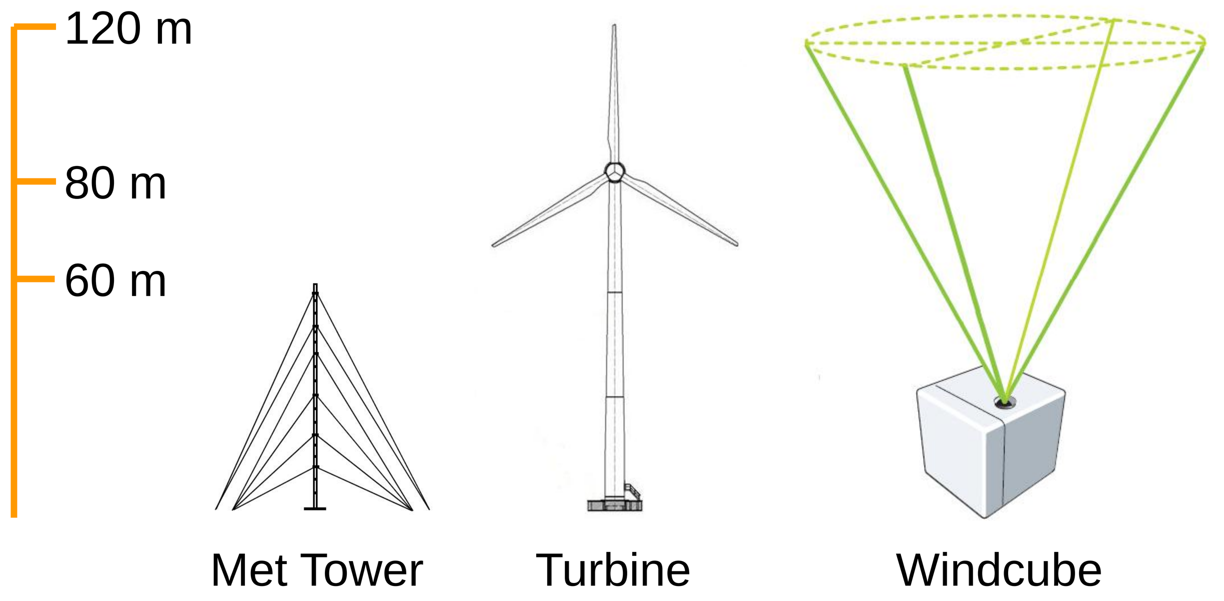


FIG. 1. *In situ* instrumentation on standard 60-m met towers can rarely probe the atmosphere across the full span of modern turbine rotor disks. Conversely, the Leosphere Windcube lidar is capable of measuring wind speeds at 10 different altitudes up to 200 m above ground level (AGL).

The availability of Windcube measurements is defined by the carrier-to-noise ratio (CNR) of the laser signal, which depends on atmospheric conditions, such as:

- **aerosol backscatter (β)**
- **atmospheric refractive turbulence**
- **relative humidity (RH)**
- **precipitation**

The Windcube disregards all measurements for which CNR < -22 dB.

Goal: To determine situations of suitable data availability for future field deployments by quantifying Windcube performance with respect to the parameters above.

2. Two Windcube datasets

(a) A Windcube was deployed in late summer 2010 as part of the Skywatch Observatory, a set of meteorological instruments on the roof of the Duane Physics building at the University of Colorado. Backscatter was measured using a Vaisala CL31 ceilometer, located approximately 5 m from the Windcube.

(b) A second Windcube dataset was collected at a wind farm in central Iowa in late June and early July 2010. Additionally, the following measurements were taken at a nearby flux station (located 142 m due west of the Windcube):

Instrument	Measurement	Height AGL
RM Young 03002 cup anemometer	wind speed	9 m
Vaisala HMP45 probe	temperature & relative humidity	9 m
Campbell Scientific TE525 tipping bucket	precipitation	6 m

3. Influence of aerosol backscatter on CNR

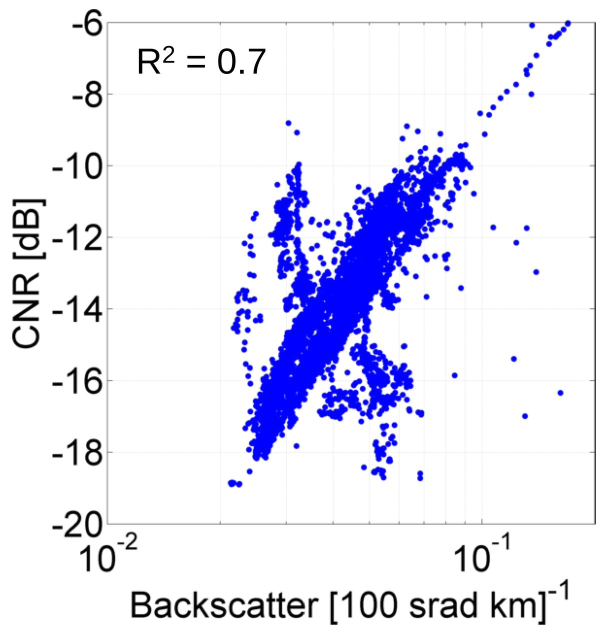


FIG. 2. Scatter plot of CNR vs. β at 80 m AGL for the week 29 Aug. 2010 to 5 Sept. 2010 in Boulder. The correlation coefficient is 0.7, suggesting a nearly linear relationship. Outliers are likely due to variations in atmospheric conditions, such as turbulence and humidity.

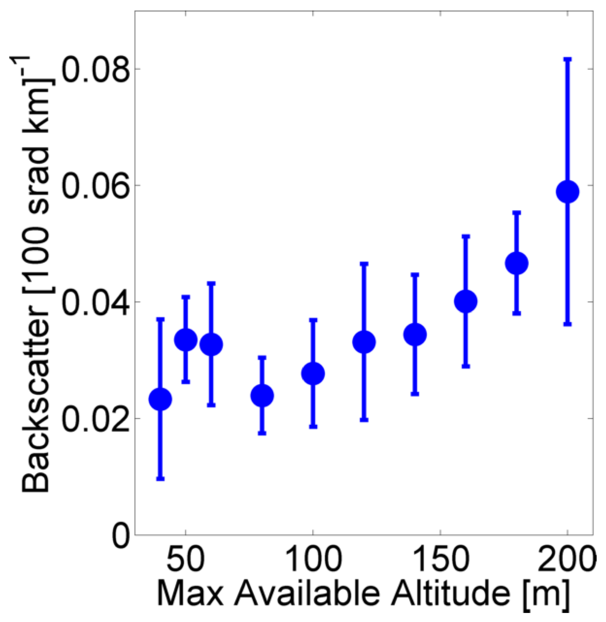
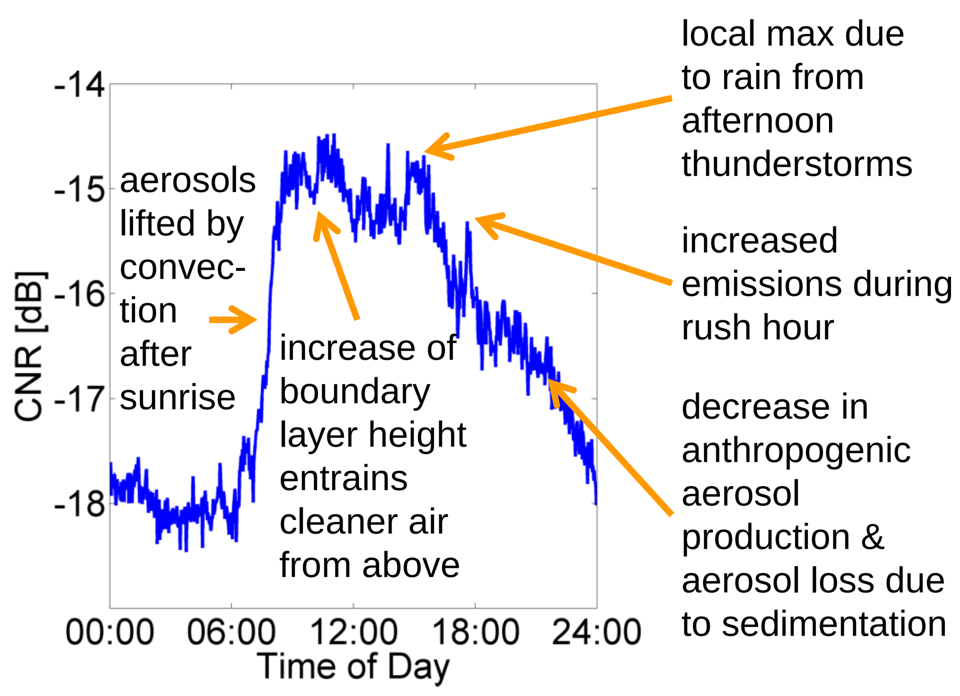


FIG. 3. Average and standard deviation of backscatter corresponding to each maximum available altitude (highest altitude for which CNR > -22 dB) for August 2010 in Boulder. In general, more backscatter is necessary for Windcube measurements at higher altitudes.

FIG. 4. Average CNR diurnal cycle at 40 m AGL for the month of August 2010 in Boulder.



4. No CNR loss due to turbulence in Iowa

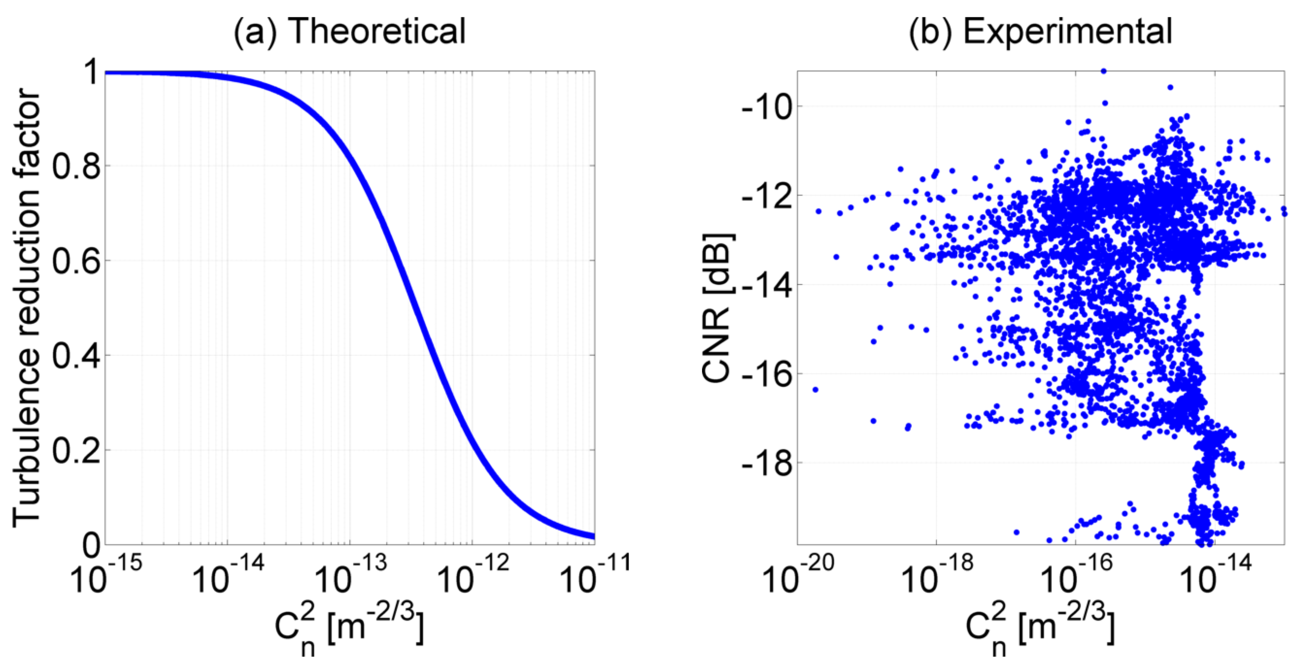


FIG. 5(a). The turbulence reduction factor is defined as the ratio of CNR in the presence of turbulence to CNR in the absence of turbulence and is a function of the refractive index structure parameter, C_n^2. High values of C_n^2 on the order of 10^{-13} m$^{-2/3}$ and greater are indicative of strong turbulence.

FIG. 5(b). Turbulence levels were most often weak or moderate in Iowa; thus, there is no discernible relationship between CNR and turbulence. CNR should only noticeably decrease in strongly turbulent conditions, say $C_n^2 > 5\times10^{-14}$ m$^{-2/3}$, a situation that occurred less than one percent of the time in Iowa.

5. Humidity affects CNR only near saturation

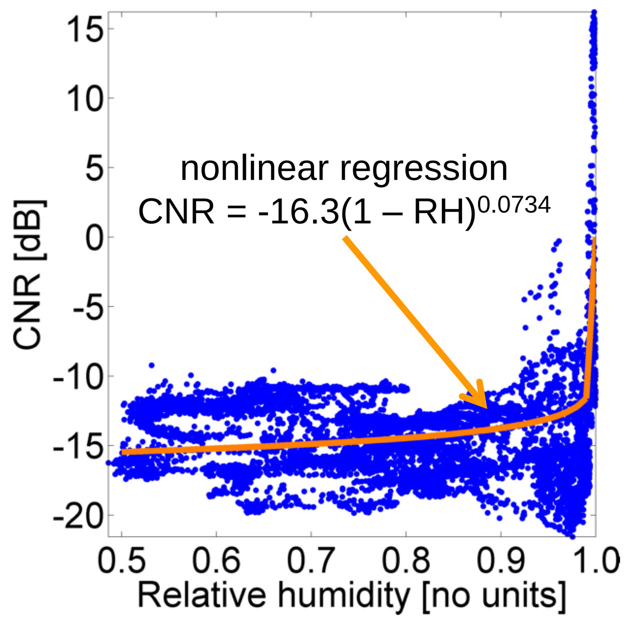


FIG. 6. Scatter plot of CNR at 40 m AGL vs. RH at 9 m AGL from 28 June 2010 to 9 July 2010 in Iowa. The plot includes only periods without measurable precipitation.

Aerosol scattering is a complex function of refractive index and particle size, both of which depend on relative humidity. Although the refractive index tends to decrease with increasing humidity, this effect is small and is dominated by the swelling of hygroscopic particles near the saturation point. It is also possible for the lidar signal to scatter from water droplets, thus enhancing CNR during precipitation events. Previous studies indicate that scattering remains nearly constant for low to moderate levels of humidity and increases rapidly for RH > 0.8.

6. Erroneous measurements during rainfall

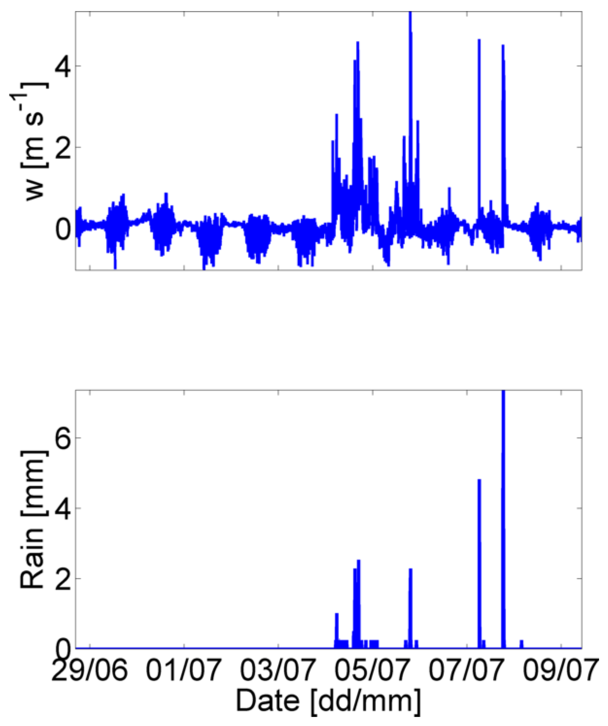


FIG. 7. During precipitation events in Iowa, vertical wind speed (w) ranges between 1 to 5 m s^{-1} (positive vertical axis points toward the ground), which is of the same order as the terminal velocity of a raindrop and almost certainly too large to be actual wind speed. Thus, measurements during rain should be treated with caution.

7. Conclusion

- CNR is linearly proportional to **aerosol backscatter** and tends to be higher during the day than at night.
- Because CNR ~ $1/R^2$, more backscatter is necessary at higher altitudes for suitable data return.
- The lack of data in strongly turbulent conditions precluded the discernment of CNR loss due to **turbulence**.
- While **humidity** does not influence CNR for RH < 0.8, CNR increases sharply near saturation due to swelling of hygroscopic particles.
- The Windcube is adversely affected by **precipitation**, as rainfall is measured instead of vertical wind speed.

Acknowledgments

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