Supplement

S1 Lidar variability

Lidar measurements of wind speed and direction exhibit larger variability than those from the met tower; the average median absolute deviation (MAD) over all relevant wind speed bins using the lidar measurements was 0.83 m s^{-1}; the average MAD using the met tower measurements was 0.33 m s^{-1}. This variability may be due to the lidar's operating assumption of homogeneity across the measurement volume: the WINDCUBE v1 measures volumetric-averaged wind speeds and directions over a 20 m thick layer with an effective diameter on the order of the height of the measurement (30° beam angle) and assumes homogeneous flow within that layer. This assumption may not be reliable at this site: observations from scanning lidar of flow at the U.S. Department of Energy (DOE) National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL) indicate that flow can be very inhomogeneous (Smalikho et al., 2013; Aitken et al., 2014).

Despite this potential for variability at the NWTC, the lidar and tower measurements are generally well-correlated (R = 0.969 and bias of 0.21 m s^{-1}, with the lidar recording higher values than the anemometer for this time period; Fig. 7). Note that the bias is likely significantly influenced by the accuracies of the instrument compared (see Sect. 2.2.1 and Sect. 2.2.2). Previous work by Smith et al. (2006), Sathe et al. (2011) and Sanz Rodrigo et al. (2013) saw strong correlations between lidars and anemometers in flat terrain. Smith et al. (2006) found a correlation coefficient of 0.9843 between a ZephIR lidar and a cup anemometer at 80 m for 10min wind speed averages for 1 day, Sathe et al. (2011) found correlation coefficients greater than 0.98 between WINDCUBE and ZephIR lidars and sonic anemometers at 100 m for 10-min wind speed averages for 4–5 months, and Sanz Rodrigo et al. (2013) found correlation coefficients greater than 0.99 between WINDCUBE and ZephIR lidars and cup anemometers at 89 m for 10min wind speed averages for 10 days. Sanz Rodrigo et al. (2013) also performed lidar–tower comparisons in complex terrain in the Alaiz mountain range in Navarra, Spain, and found correlation coefficients greater than 0.98 between WINDCUBE and ZephIR lidars and cup anemometers at 78 m for 10min wind speed averages for approximately 5 months. Our correlations between a lidar and an anemometer, based on 2.5 months of collecting wind speed and direction-filtered data in complex terrain in an atmosphere with relatively few aerosols for backscatter, resulted in a relatively high correlation coefficient of 0.969. Our correlation in an inhomogeneous flow is only slightly lower than other correlation coefficients previously found between lidars and towers in flat terrain.

S2 Rotor equivalent wind speed

Quantifying the wind profile across the entire swept rotor area (SRA) has been shown to improve correlations between wind inflow and power output (Wagner et al., 2009). Here, we calculate rotor equivalent wind speeds (REWS) following Wagner et al. (2009):

$$U_{eq} = \left(\sum_i U_i{}^3 \ \frac{A_i}{A_{tot}}\right)^{1/3} \ , \qquad \text{(S1)}$$

where i represents the index of the level, U is the horizontal wind speed, A_i is the area of the turbine rotor disk of the level with the corresponding data point (the area of the sector defined by chord/arc relative to 360°, minus the area of the triangle), and A_{tot} is the SRA. When calculating the REWS from the lidar profiles, five levels (40, 60, 80,100, 120 m) are available; when calculating the REWS from the tower cup anemometer data, three levels (55, 80, 105 m) are available, all of which use Thies anemometers. Cup anemometer data available at 38, 87, and 122 m were not used in these REWS calculations for consistency because these were different instruments than those at 55, 80, and 105 m, which were used to calculate the REWS.

Despite the variability in the shear exponent as calculated from the tower measurements (Sect. 3.7), the high correlations between the 80m wind speeds and REWS shown in Fig. S1 suggest that power curves for 80 m will be very similar to power curves for REWS for this data set. The high turbulence at the NWTC may have prevented the occurrence of larger wind shear across the rotor disk. This might lead to significant differences in REWS from 80m wind speeds, which may manifest in the power curves at other sites.

S3 Yaw error and veer

Additionally, we explore the effects of yaw error and wind veer and distributions of these variables as shown in Fig. S2. To calculate yaw error, we subtracted the wind direction as measured by the met tower near hub height from the nacelle position as given by the supervisory control and data acquisition (SCADA) system. The resulting yaw error, however, was centered around 90° instead of 0°, which means the orientation of the turbine position is around 90° off of North. To correct for this, we assume that the yaw error should be 0° at rated power, so we took the average yaw error when the turbine was producing rated power (94.21°) and subtracted this from the yaw error to get the correct values of yaw error. After correcting for the turbine yaw orientation offset, we determined that it was not appropriate to split the yaw error distribution into regimes as 78% of the data lie within ± 5° yaw error and 95% of the data lie within ± 10° yaw error.

We found no impact of yaw error or wind veer on the power curves at this site. However, based on other locations (Vanderwende and Lundquist, 2012; Rhodes and Lundquist, 2013; Walton et al., 2014) where significant veer does occur, it may affect power production, but this site does not regularly experience that phenomena.

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Supplementary Figures

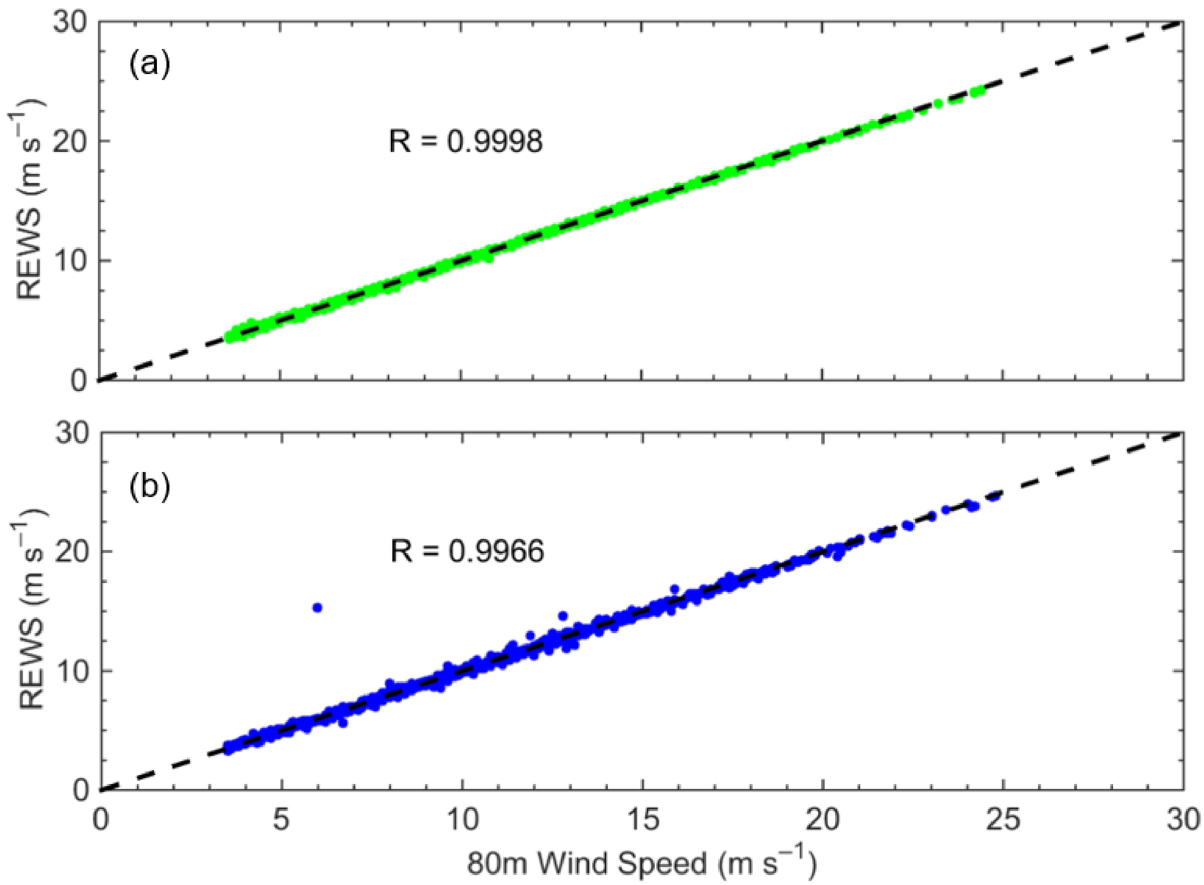

Figure S1. REWS as a function of 80m wind speed from (a) the tower and from (b) lidar. Black dotted line represents a 1:1 relationship. Includes data filtered for tower 80m wind speeds between 3.5 and 25.0 m s^{-1}, 87m wind directions between 235° and 315°, and blade pitch angle within $\pm$ 3 MAD.

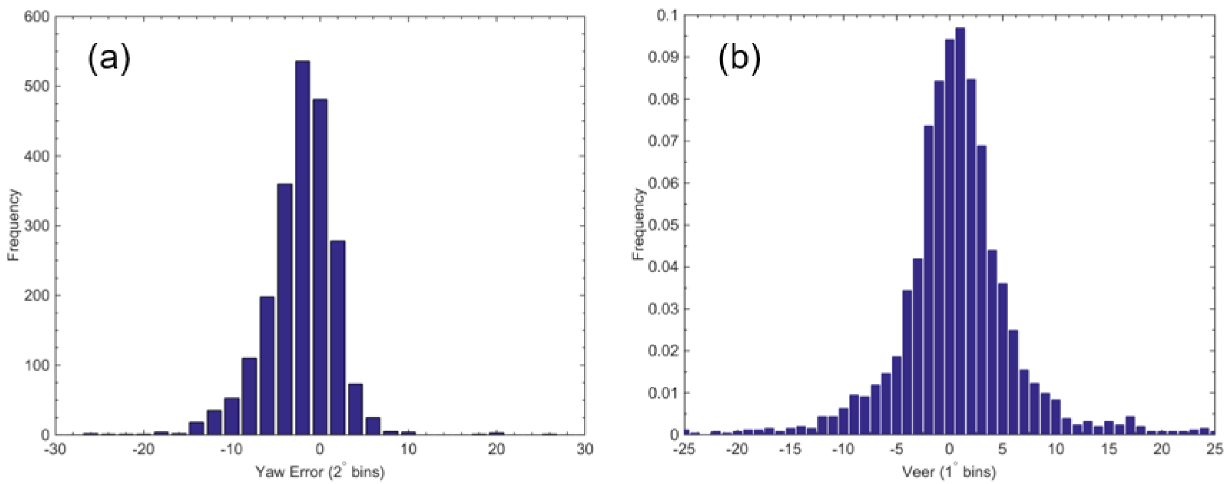

Figure S2. (a) Yaw error histogram and (b) wind veer histogram. Includes data filtered for tower 80m wind speeds between 3.5 and 25.0 m s^{-1}, 87m wind directions between 235° and 315°, and blade pitch angle within $\pm$ 3 MAD.