Response to RC1 of wes-2016-21, "Wind turbine power production and annual energy production depend on atmospheric stability and turbulence" by C. M. St. Martin, J. K. Lundquist, A. Clifton, G. S. Poulos, and S. J. Schreck.

This manuscript uses nacelle-based and upwind met tower measured data to calculate power curves (PC) and annual energy production for a specific wind turbine. This work thoroughly investigates the sensitivity of the PC and AEP to atmospheric parameters such as turbulence intensity (TI), Turbulence Kinetic Energy (TKE) and Bulk Richardson Number (RB) which would be of value to manufacturers in power performance testing. As indicated by the authors, the existing literature do not agree on the effects that these atmospheric parameters have on the PC and AEP.

Although the present work provides significant observations about the effect of TI, TKE and RB on power performance, it does not elaborate on the underlying physics of the obtained results. Also, this work does not provide any insights towards the factors that can contribute to the variability in the results reported in the existing literature.

We thank the reviewer for this comment, and we agree. We have added the following passage to Section 4.1 (Results – Power curves) to explain the underlying physics behind the results of this work:

> "The large variability reported in the literature (and herein) regarding power production can be understood by recognizing the interactions between a pitch-controlled turbine and the atmosphere, as well as recognizing that the control algorithms generally operate differently in different wind speed regimes. Depending on the ambient turbulence, this effect can be different.
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> At low wind speeds, around and above cut-in wind speed, the turbine generator speed or revolutions per minute (RPM) increases as well as the generator torque, the blades will often pitch backward to generate more thrust, and the power produced ramps up. At low wind speeds and higher turbulence, the turbine is reacting to the higher variation in wind speed. The turbine is able to capitalize on the variation seen in the wind flow because of the thrust resulting from the blade pitch. At low wind speeds and lower turbulence, and therefore the variation in wind speed is lower, the turbine sees a more consistent wind than in highly turbulent conditions and therefore produces less power.
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> At higher wind speeds, closer or just below rated speed, the turbine needs to maintain rated generator speed rather than continuing to increase its generator speed, and the blades will pitch forward to essentially be feathered, allowing the power production to flatten out to rated power. This process effectively decreases the amount of thrust generated by a non-feathered blade. At these wind speeds during periods of high TI, a turbine reacts to the high variation in wind speed with subtle changes in blade pitch. For example, if the turbine detects a drop in wind speed, the blades may pitch back to generate more thrust, but then if the wind speed increases quickly after, the blades will pitch forward again. If the blade

> pitch is not consistent when the average wind speed is higher, then power losses occur, in contrast to a case when the blade pitch is consistent. At these higher wind speeds, lower turbulence allows the turbine to capture more power: the lower the turbulence, the longer the wind speed and blade pitch stays consistent and the more energy the turbine can capture.
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> It is also important to mention the strong connection between turbulence and shear: high shear will eventually erode turbulence (Wharton and Lundquist 2012). Periods of high shear generally coincide with periods of low turbulence and vice versa. With low shear, the mean wind speed is more consistent over the height of the rotor disk. However, since we did not see significant differences in power curves for different shear regimes here, we cannot speculate further on this in this analysis. Finally, if veer occurs in the wind profile (as in Vanderwende and Lundquist 2012 and Dörenkamper et al. 2015), which usually occurs only in stable or low turbulence atmospheric conditions, that veer will generally undermine power production as the turbine blades are not oriented perpendicular to the flow at all vertical levels."

Specific comments:

Power curve measurements using hub height winds result in high uncertainties and are not a good representative of the energy contents of the flow. How does this known fact play role in the current study?

If the reviewer is referring to the use of nacelle-based wind measurements, then the reviewer brings up an important and relevant issue. We have added a short paragraph in Section 3.4 (Power curves) further explaining the issues resulting from the interference of the rotor disk on the ambient wind:

> "The nacelle-mounted anemometer does not observe the ambient wind speed that the rotor disk experiences because the wind that flows through the rotor disk and along the nacelle during operation is modified by the blades and nacelle (Antoniou and Pedersen 1997; Smith et al. 2002; Frandsen et al. 2009; Zahle and Sørensen 2011). However, power curves calculated using nacelle wind speeds are shown here along with power curves calculated using upwind measurements in order to compare the different methods. In many cases, operators calculate these nacelle-based power curves due to lack of other data."
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> Citations to be added:

> Antoniou, I., and Pedersen, T.F.: Nacelle Anemometry on a 1MW Wind Turbine, Risø National Laboratory, Roskilde, Denmark, 37 pp., 1997.
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> Frandsen, S., Sørensen, J.N., Mikkelsen, R., Pederesen, T.F., Antoniou, I., and Hansen, K.: The generics of wind turbine nacelle anemometry, Proceedings of European Wind Energy Conference, Marseille, France, 2009.

Smith, B., Link, H., Randall, G., and McCoy, T.: Applicability of Nacelle Anemometer Measurements for Use in Turbine Power Performance Tests, AWEA Windpower, Portland, OR, 2002.

Zahle, F., and Sørensen, N.N.: Characterization of the unsteady flow in the nacelle region of a modern wind turbine, Wind Energy, 13, 271-283, doi: 10.1002/we.418, 2011.

P5: Did you perform any data quality control on the 3D sonic measured values? If yes, what is the total number of data points remained for 3D sonic and why resulted in less number of data points for this instrument compared to the other met tower instruments?

Yes, data quality control filters presented in Section 3.1.2 (Analysis methods – Data quality control – Meteorological tower) were also applied to the sonic anemometers. In addition, several spikes in the sonics were filtered, which resulted in fewer data points in the analysis. The following sentence will be added to Section 3.1.2 describing the de-spiking methodology used:

> "Several spikes in wind speed are detected in the sonic anemometer data. Therefore, a de-spiking filter is applied: the change in wind speed from each data point to the next is calculated. Data points are removed if they are preceded and followed by changes in the top 1% of all changes."

P8: It is not clear how the authors came up with a different classification for RB. This needs to be explained in more detail.

To expand upon the discussion in Section 3.5 (Atmospheric stability regimes), that R_B regimes were based on similar work performed at the NREL-NWTC (Aitken et al. 2014), we will add the following passage to the text in Section 3.5 to make the classification methodology more clear:

> "Similar to the approach used in Aitken et al. (2014), the R_B distribution is split roughly into thirds to allow for less overlap between stable and unstable regimes. The uncertainty in R_B for these instruments over the measurement period is about 0.01, therefore the R_B classifications used are larger than the uncertainty."

P9: It appears that L values are calculated using 80m measurement data. Since at 80m only cup anemometers are installed, how is w' obtained?

The reviewer comments on an important detail that will be added to the text in Section 3.5 (Atmospheric stability regimes). The L values were calculated using sonic measurements at 15 m. The reviewer also asks about w'. The authors will make it more clear here that sonic measurements are used to calculate L. The following sentence will be added to the text:

> "L calculations are based on sonic anemometer measurements at 15 m and temperature measurements interpolated to 15 m to ensure L is calculated using measurements still within the surface layer."

P12: Observations are made regarding the differences between nacelle power curves and tower curves and their dependency on the wind speed range (Lines266-276). However, no discussion is provided as to what are the possible explanations for such observations/ behavior.

We will expand on the existing discussion to add the underlined to Section 4.1 (Results – Power curves):

> "Statistically distinct wind speed bins in power curves calculated from nacelle winds tended to be similar to those in power curves calculated from tower winds near rated speed. At lower wind speeds, however, between about 5 and 9 m s^{-1}, many more statistically distinct differences emerged between nacelle power curves than between tower power curves, most notably in the power curves segregated by TI regimes. Turbine operations were especially variable in this region of rapid increase in power with wind speed. The turbine reacted directly to the conditions as measured by instruments on the turbine. <u>The nacelle-mounted anemometer observed winds that flowed through the rotor disk and along the nacelle during turbine operation, and therefore was likely measuring different wind speeds than the upwind met tower. The nacelle anemometer observes complex flows behind the rotor disk that are strongly influenced by ambient turbulence, leading to more statistically significant differences in the nacelle power curves for TI regimes."</u>

P13: Authors have used power curves calculated using upwind tower data to obtain AEP. Given the variability observed between the tower data and the nacelle data, it would be interesting to look at the AEP values calculated using power curves obtained using nacelle measurements.

The authors agree it would be interesting to calculate AEP based on the nacelle measurements, and in their revision will include these results.

P14: Given the lack of statistically significant impact of wind shear on the power curves and the AEP values provided in Table 5 for shear filter, one cannot make a conclusive statement about the effect of shear on AEP.

We will remove those AEP results in the revision.

P15: the authors suggest calculating different power curves for different conditions. Now the questions is with the practicality of this approach.

The reviewer brings up an interesting point of discussion, and the authors will add the following passage to Section 5 (Conclusions):

> "As a small percent difference in AEP leads to a large deviation in cost for both operators and manufacturers, calculating different power curves for different atmospheric conditions may not only be a practical approach, but may lower the financial risks for both parties."

Technical corrections:

Fig 1: this figure is not providing the required information. I suggest that you replace this with a schematic drawing which marks and labels the turbine, the lidar and the met tower. Also include prevailing wind direction.

We will include a new, clearer Figure 1 that includes labels for each instrument as well as the prevailing wind direction.

Fig 6: "Grey line represents.." It should read "black line..."

We thank the reviewer for catching this. We will make this change.

Fig 17: mark rated wind speed on the graphs

We will add a small vertical line marking rated speed on all figures showing the power curve.

The vertical axis on all distribution plots is not representing frequency but rather the number of points. This needs to be corrected.

We will replace the number of points with frequency.