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Interactive comment

Interactive comment on "Wind Turbine Wake Measurements with Automatically Adjusting Scanning Trajectories in a Multi-Doppler Lidar Setup" *by* Norman Wildmann et al.

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1 Author response

We want to thank the two anonymous reviewers for their valuable feedback and valid points of criticism to our manuscript describing automatically adjusting scanning trajectories in a multi-Doppler lidar setup. In the presented study, we wanted to focus on the atmospheric measurement technology, showing the possibilities with state-of-the-art scanning Doppler lidar systems in a large experimental setup and especially focussing on wind turbine wake measurements. A main point of criticism of both reviewers is

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that the behaviour of the wake has not been analysed in all details with regard to atmospheric stability, turbulence in the wake, lateral wind speeds in the wake, etc. We are aware that all these topics are highly relevant and we also believe that the presented technology will help to study these processes in the future, but in the presented manuscript we want to emphasize the measurement technology and measurement strategy and decided to limit the scope of this paper to the most basic analysis of mean wind speed deficit for two reasons. First, the database is comparatively small, because the technique to adapt the scanning trajectories has been implemented for the first time and a much longer time during the Perdigão experiment was used for continuous RHI scans at a fixed angle. The results of these scans are presented in a different publication. Second, during the Perdigão experiment, the DLR WindScanners were suffering from a software bug, as described in the manuscript and could only be operated comparatively slowly, which limits the possibility to analyse turbulence to only the large scales. In the direct responses to the reviewer comments we will elaborate in detail on the mentioned issues and suggest to add some additional analysis to the revised manuscript, always highlighting the constraints of the dataset. Despite the constraints and limitations of the dataset, we still believe that the technique of measurements, the proof-of-concept and the results of the mean wind speed deficit is of high value for the scientific community and suitable for publication in AMT. It will hopefully foster future long-term campaigns with similar scanning strategies and smart layouts of experiments.

1.1 RC2, General Comments

- *I do not fully understand why two lidars have been sited close to each other and the third one further away. I would expect the greatest flexibility in measuring fluctuating wakes when having the lidars in a sort of an equally-sided triangle around the expected measurement volume.*
  As described in Sect. 2.2 of the manuscript, a primary scanning strategy that

was pursued for the experiment was RHI scans with all three systems. The advantage of these measurements over the experimental strategy described in the manuscript is that these are well-established methods with little risk of problems with software or hardware of the lidars. Another advantage is that these RHI scans were of great benefit for other research goals of the experiment, namely the characterisation of the flow in the valley and above. For wake characterization, unique two-dimensional flow visualizations of the wake could be captured for main wind direction as presented in Wildmann et al. (2018). For those coplanar measurements it was important to have one lidar (#2) in the valley measuring radial wind speeds at a higher elevation angle compared to the lidar on the North-East ridge (#1). The siting of the lidars is always subject to logistical constraints, especially in a complex terrain as in Perdigão (see Vasiljević et al., 2017). In best case, lidar #2 would have been placed closer to the wind turbine and at a lower elevation, but the topography and availability of electrical power did not allow it.
In a revised manuscript we will elaborate more on the siting of the lidars in Sect. 2.2.

- *I do not fully understand why the results have been discussed in terms of the Jensen Park model. This model has been developed for flat terrain and essentially neutral thermal stratification.*
  We are aware that the Jensen-Park model has not been developed for complex situations as found in Perdigão and have mentioned it in the text. We still believe that there is a value of showing the prediction of this model in comparison to the measurement results to give the reader some reference. We are not aware of any engineering models that could take complex terrain, flow and atmospheric conditions as they are found in Perdigão into account.

- *The formula given for kw essentially says that kw is equal to turbulence intensity. Thus, turbulence measurements could be used to test the validity of the calculation of kw.*

Assuming that friction velocity u_* is proportional to σ_u, it is true that $k_w \approx 0.4I$ (Peña et al., 2016). Again, theoretically this relation only holds for flat and homogeneous terrain such as we do not have in Perdigão. Nevertheless we can derive the theoretical wake decay for the wind turbine in flat terrain as a comparison to our measurements. As can be seen from Fig. 1, background turbulence intensity is 16% for 17 May and 13% for 2 June, which translates to a value 0.062 and 0.052 for k_w respectively. This is considerably smaller than using the parametrization of the logarithmic wind profile ($k_w = 0.11$) and thus also lifts the model curve to almost the same level as the measurements (see Figs. 3-4). Section 4.3.1 is adapted accordingly in the revised manuscript.

- *For the assessment of the samples shown, it would be really interesting to learn something about thermal stability and overall turbulence intensity during these measurement periods. Maybe, this would be the clue to the overestimation or underestimation of the wake.*

  For a proper study of wake behaviour in different stability conditions, not enough measurements have been done with the described method, so that no statistics could be derived. A first attempt to classify the wake behaviour in Perdigão for different stability is described in Menke et al. (2018) and Wildmann et al. (2018). We will add some analysis on turbulence intensity from the lidar scans in the revised manuscript as Sect. 4.3.2. Figures 1-2 shows the result. On both days that are analysed, background turbulence intensity is of the same magnitude. On 17 May, it varies more, because measurements are carried out from late afternoon throughout the night until early morning. It is seen that in all cases I in the wake is significantly higher and decays towards 8 D downstream where it reaches the background value.

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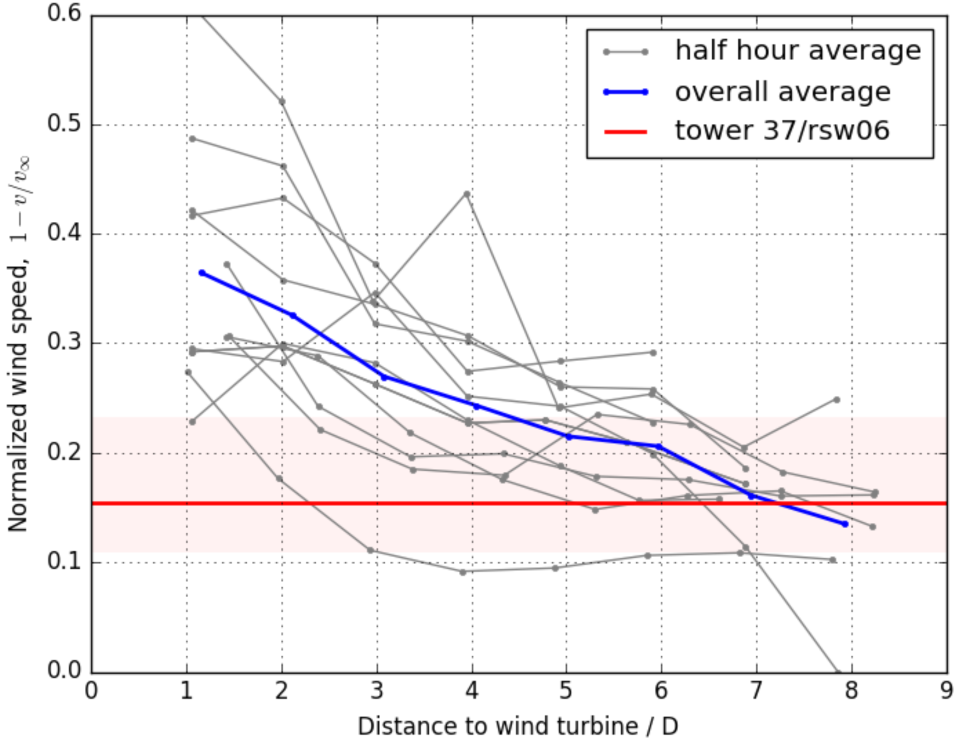

Fig. 1. Turbulence intensity in dependency of distance to the wind turbine for half hour periods (grey lines) and overall average (blue line) on 17 May.

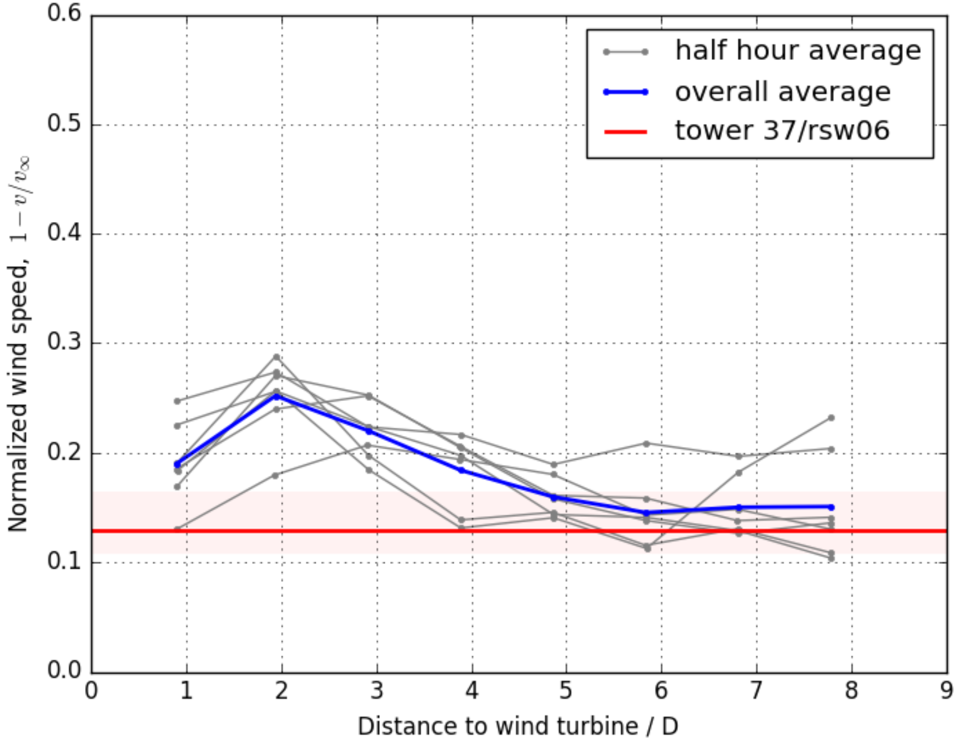

Fig. 2. Turbulence intensity in dependency of distance to the wind turbine for half hour periods (grey lines) and overall average (blue line) on 2 June.

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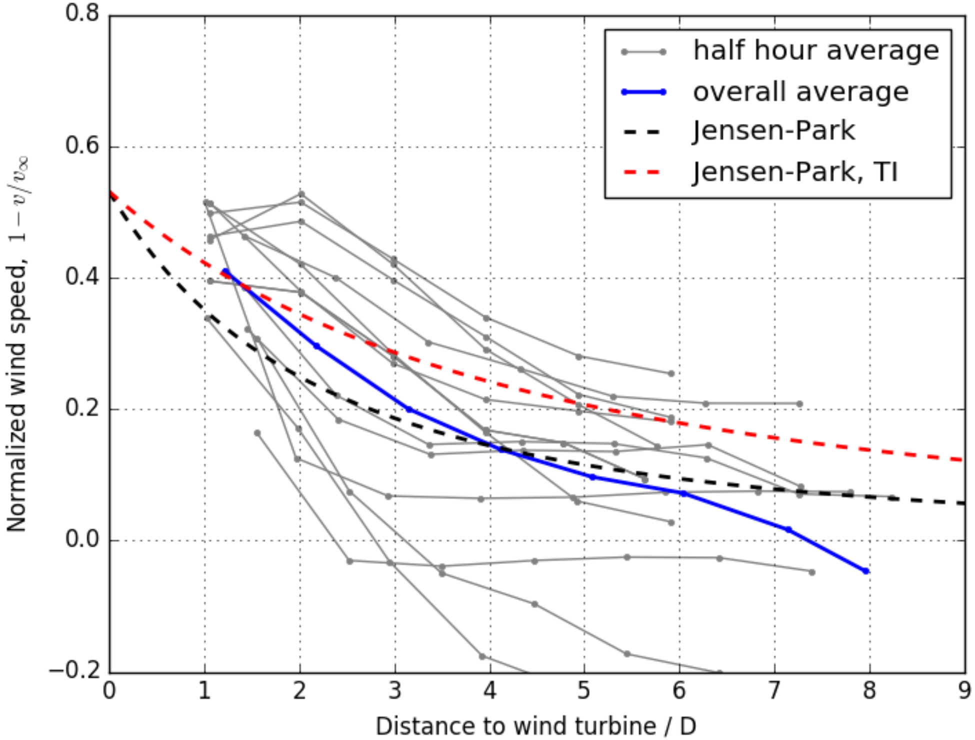

Fig. 3. Wind speed deficit in the wake of the wind turbine over distance for 17 May.

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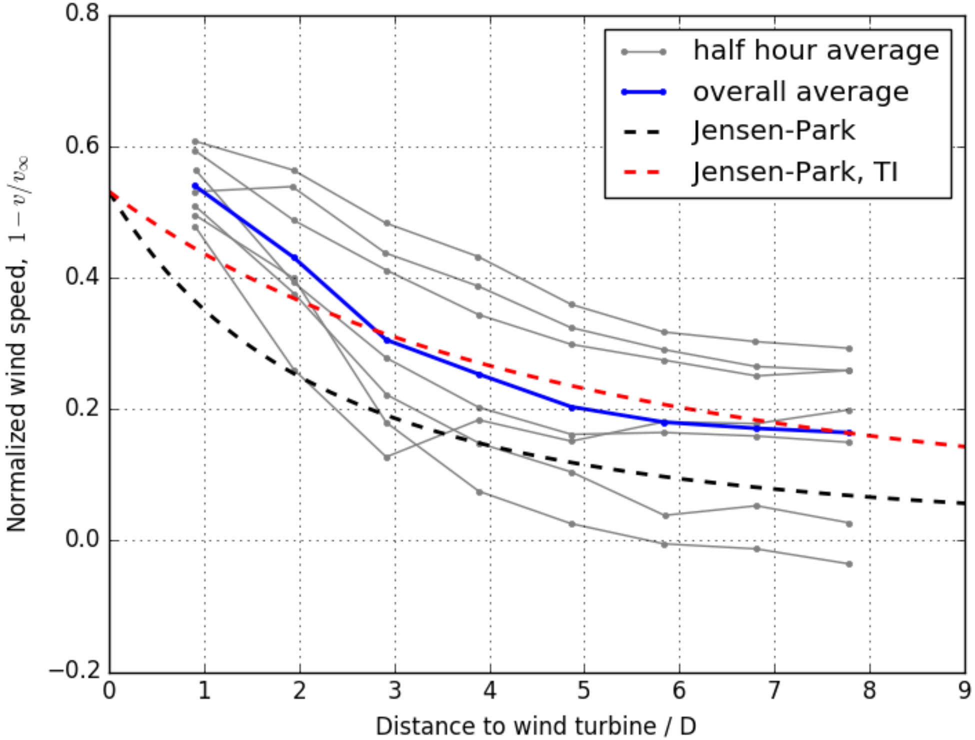

Fig. 4. Wind speed deficit in the wake of the wind turbine over distance for 2 June.