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Comment

Interactive comment on “A quantitative analysis of the impact of wind turbines on operational Doppler weather radar data” by L. Norin

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Response to Anonymous Referee #2

Let me start by thanking the referee for his/her constructive comments and suggestions that have led to clear improvements in the manuscript. Below, please find a point-by-point reply to the comments (reproduced in part in italics).

General Comments

The author examines a large data set comprised of the three meteorological radar variables for a Swedish radar site located near a wind farm. The data exist both before and after the construction of the wind farm, allowing for a comparison between the two

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time periods. The impact of the wind farm is apparent and analyses are performed. Spatial and temporal impacts are explored through a variety of figures and statistics. While the methodologies are not extremely novel, the data itself and the capability to perform such an analysis is quite unique and contributes to the understanding of the impacts of wind turbines on weather radar systems. Significant consideration for prior work was apparent. Methodologies were simple, but scientifically sound, with assumptions clearly defined and convincingly explained. The discussion of ground clutter filtering is brief, and the impact of the filter will need some further explanation in the final revision; however, the overall quality of the paper is good. Some of the language regarding the potential mitigation/recovery technique should be softened. Overall, the figures and charts were well presented and relevant to the analysis.

The description of the clutter filter in Section 2 has been extended and the impact of the filter is discussed in a new section. See also the response below to a specific comment regarding the clutter filter.

Specific Comments

Abstract

1. (Line 17) The author should soften the language regarding the impact of the wind turbines. The data do not show definitively that the impact ‘disappears’, but it is greatly reduced.

The text has been modified accordingly.

Section 2

1. (Paragraphs at lines 81 and 85) The minimum detectable signal is -30 dBZ: what is the equivalent SNR? Please include the SNR censoring level during the dBZ censoring discussion. Minimum SNR information gives the reader more details about the level of censoring, as well as the expected performance of the estimators used in the analysis.

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I have been unable to find the SNR censoring level from the existing radar documentation. However, the dBZ censoring discussion in Section 2 has been extended and now includes information about the minimum detectable signal.

2. (Line 96) Please give some examples of what constitutes invalid data for each variable.

Invalid data for all spectral moments are produced whenever the radar fails. This could for example be due to the radar not finding the specified azimuth or elevation angle or if the transmitter is not ready in time. This information has been added to the manuscript.

3. (Paragraph at line 97) More information about the clutter filter is needed. The implications of the filter on the evaluation presented later in the paper are substantial. The discrepancies between the lower elevation grouping and the higher grouping are attributed to the change in range gate size, but the clutter filter is also omitted in the higher scans and should be accounted for in the discussion.

When double checking with the company charged with radar maintenance I learned that the clutter filter is actually on for all scans. I am very sorry about this. This has been corrected in the manuscript.

The clutter filter works by removing the three frequency channels (out of 32) of the frequency spectrum that are closest to zero (0, 1, 31). No compensation for these frequency channels is made when summing to obtain the reflectivity. Section 2 has been extended to include this information.

4. (Section 2) Please provide some information/details about the radar sidelobes in this section. The analysis performed later (line 211) should reflect the locations of the radar sidelobes. A plot/image of the antenna pattern would be useful in this section.

A description of the antenna pattern has been included in Section 2. In a new section

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the antenna pattern is shown together with the increase in reflectivity for all tilt angles.

Section 4.1

1. *(Figure 2) Suggestion: It would be useful to include a difference plot ($Z-Z_0$) as in Figures 4 and 5, and would make comparisons with said figures easier.*

Difference plots are now included in Figure 2.

2. *(Paragraph at line 147) Here, and as the discussion of the impact of the wind farm progresses through the meteorological variables, an acknowledgement of the impact of the clutter filter is necessary. Please include a discussion addressing the impact that the clutter filter may have on the presented results, i.e., is the contribution solely due to the blades, or does the clutter residue play a role?*

It is possible that clutter residue can persist even after the clutter filter has been applied. If the stationary clutter is strong enough spectral leakage in the frequency spectrum can lead to clutter residue which can affect all spectral moments. This is discussed in an added section of the manuscript.

3. *(Paragraph at line 162) Similarly, the absolute velocity bias toward zero could be due to the clutter residue, or to the blades imposing both positive and negative velocity values (aliasing) on the spectrum. Please discuss what might cause the velocity to be biased toward zero.*

The absolute velocity bias toward zero could, as the referee points out, be caused by clutter residue. It is interesting to note that the bias toward zero occurs in radar cells behind the wind turbines whereas the radar cells in which the wind turbines are located show an increase in absolute velocity. It is possible that the bias toward zero occurs when the main contribution to the scattered signal originates from the stationary parts of the wind turbine (i.e., tower and hub) whereas the increase in absolute velocity

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occurs when the moving parts (i.e., blades) dominate the scattered signal. This is discussed in an added section in the manuscript.

4. (Paragraph at line 171) Similar to the previous two comments, please include a discussion addressing the reasons for the decrease in spectrum width in the wake of the wind farm.

A possible explanation for the decrease in spectrum width in the wake of the wind farm is that this main contribution to the scattered signal comes from the stationary parts of the wind turbine (i.e., tower and hub). This is discussed in an added section in the manuscript.

Section 4.2

1. (Line 217, 228, 236) The fifth elevation tilt is also where the clutter filter is no longer applied. Please include this fact in the discussion for each of the variables.

As mentioned above, the clutter filter is actually on for all tilt angles. Again, sorry for this.

2. (Line 236) The decrease in range resolution at the higher elevation tilts is cited as a possible cause for discrepancies. Please expand and explain the reasoning.

Yes, an extended explanation is needed. Also, a more detailed description of the radar measurement technique is required.

The spectral moments for a radar cell are calculated from the average value of 12 frequency spectra. The range resolution within a radar cell is 166.7 m for the lower tilt angles and 83.3 m for the higher tilt angles. Furthermore, the actual resolution in azimuth is not the same for the lower and the higher tilt angles. The lower tilt angles use a set of lower PRFs compared to the higher group which leads to a lower resolution

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in azimuth for the lower tilt angles ($\approx 1.49^\circ$) compared to that of the higher group ($\approx 0.75^\circ$). Section 2 has been extended to include this information.

The radar cell range resolution is, as described above, 2 km for the lower tilt angles and 1 km for the higher tilt angles. Not all frequency spectra within a radar cell are necessarily affected by the wind turbine. For example, a wind turbine located in the centre of a 2 km-wide radar cell would have an impact on the last 6 spectra of that cell. However, all 12 spectra from a 1 km-wide radar cell would be affected and that radar cell would register a higher average value in reflectivity compared to that of the lower group.

The changes to the azimuthal resolution can also contribute to the observed change. A lower resolution in azimuth (used by the lower tilt angles) means that fewer measurements in a frequency spectrum will be impacted by the wind turbine, leading to a smaller impact compared to measurements from the higher tilt angles which use a higher azimuthal resolution.

A discussion of the effect of the changes in radar cell resolution has been added to the manuscript.

3. (Line 283) It would be useful at this location in the paper to evaluate a potential inversion situation, and show the effect on the beam propagation. For instance, calculate the height of the beam at the standard tilt angles for normal propagation, and compare that to the heights of the beams during a moderate to extreme ducting scenario. A brief presentation would validate the author's argument.

An extended investigation of anomalous propagation has been performed for the period April 2010–December 2013 (after the construction of the wind farm). Beam propagation using ray tracing was calculated every hour using vertical profiles of refractivity (constructed using data from Sweden's operational NWP model). The results of the investigation show that anomalous propagation is unlikely to be the reason for the im-

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pact observed on scans with higher tilt angles. A new section has been added to the manuscript that discusses anomalous propagation, increased turbulence, and radar sidelobes.

Section 4.3

1. (Line 356) *Suggestion: It would be useful to show some climate data, such as a wind rose, for the time period in question to show the dominate wind direction relative to the radar radial. Such a presentation would validate the observed velocities.*

A wind rose has been included showing the distribution of the wind direction and wind speed for the period of study (Jan 2008–Dec 2013). The data for the wind rose come from a weather station located approximately 21 km to the West of the weather radar.

2. (Line 376) *The author should soften the language from ‘recover’ to ‘approach’ or ‘resemble’ the values before the construction of the wind farm.*

Done.

Section 4.4

1. (Section 4.4) *Throughout this section, the author should soften the language regarding the recovery of estimates. The impact of the wind farm approaches that of the clean reference gate, but the data do not show that the impact is completely eliminated.*

The text has been modified accordingly.

2. (Correlation Coefficient, Figure 9, and Figure 10) *It is not apparent what the correlation coefficient values are intended to provide. The high degree of variability between the parameters and the elevation tilts makes it difficult to draw meaningful conclusions, i.e., a conditional threshold as mentioned in the conclusion. Please include a dis-*

cussion of how the data presented in Figures 9 and 10 could be used/combined to determine a valid threshold for meteorological data recovery.

Figures 8 and 9 show in detail how the spectral moments from the lowest scan are affected by the wind farm as a function of reflectivity from a reference cell. The correlation coefficients in Figure 10 are intended to indicate, in a condensed way, what happens at higher tilt angles. I agree that it is difficult to draw any hard conclusions from Figure 10 but the figure does show that the correlation coefficient values increase for increased tilt angles as well as for increased reflectivity of the weather. To quantitatively determine the impact of the radar cells from the higher tilt angles a more detailed analysis should be performed, such as the one shown in Figure 8 and 9.

This discussion has been added to the manuscript.

Section 5

1. (Line 472) The mitigation scheme presented here seems premature as a definitive threshold determination is not presented in the paper. The author should refrain from suggesting a threshold, i.e., larger than the average wind turbine value, without a more detailed analysis and justification.

The text has been modified accordingly.

Interactive comment on Atmos. Meas. Tech. Discuss., 7, 8743, 2014.

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